JAMS

Joint Center of Excellence for
Advanced Materials & Structures

Established December 2003

Center of Excellence for Advanced Materials in Transport Aircraft Structures (AMTAS)
University of Washington – Co-Lead
Washington State University
Oregon State University
Edmonds Community College
University of Utah
Florida International University

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: 18: see "Faculty" section
Students: 37**:** 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).

The original AMTAS academic members include the UW, Washington State University, Oregon State University, and Edmonds Community College. The University of Utah and Florida International University became academic members in 2008. 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, averaging about 1,500 visits per month.

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 1,000 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 16 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; 70 attendees
15. AMTAS Spring 2008 Semiannual Meeting, 3/20/08, Seattle, Washington; 81 attendees
16. JAMS 4th Technical Review meeting, 6/17–19/08, Everett, Washington; 104 attendees (with CECAM)

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; 13 attendees
4. 3/24–28/08, Seattle, Washington; 8 attendees

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 newly developed design methodology has been implemented as the Virtual Testing Laboratory (VTL) software package consisting of two parts: 1). Reliability-based Lifecycle Analysis of Composite Structures (RELACS) for the time-dependent reliability simulations, and 2). Virtual Strength Test Module (VSTM) for the stochastic FEA-based virtual testing. This design methodology can be used to evaluate the reliability of composite aircraft structures in real-world service environments, and to minimize the lifecycle costs by optimizing the inspection/repair program.

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

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

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

Collaborations
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, Mr. Gerald Mabson, Dr. Lyle Deobald, Dr. Razi Hamid from the Structures Technology Group, and Mr. Randy Coggeshall from the 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 the Phase I period (2004–2008), 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.

Ongoing Research
In Phase II of this research, the developed methodology described above will be enhanced and applied to study interlaminar fracture in aircraft composite structures. The following tasks are being conducted:

1. **Extension of Current Capabilities - RELACS**
   RELACS is being extended to evaluate the lifecycle reliability of co-cured structures and other structures susceptible to interlaminar fracture. The risk associated with interlaminar fracture is of particular interests because these damages are mostly caused by discrete impact events, which is random in nature. Also, the potential for damage growth is also random. In addition, the choice of inspection/repair program (methods, frequencies, BVID limit, etc) has great influence over the final reliability of damage tolerant structures. RELACS provides a comprehensive platform for the evaluation of reliability and cost-optimization of maintenance program, where traditional quasi-deterministic approaches may have difficulties in making an accurate assessment, resulting in an over conservative design and maintenance guidelines.

   RELACS will be completely integrated into the process of establishing the maintenance scope and schedule dictated by MSG-3 criteria. Currently, MSG-3 procedures do not consider the probability of structural failure associated with the selected maintenance plan, which is an important criterion. RELACS is capable of providing such information. The MSG-3 procedure may be automated by including RELACS into software that creates the MSG-3 maintenance routine. This routine may be developed as RELACS add-in as well.

2. **Extension of Current Capabilities - VSTM**
   One of the inherent difficulties when designing and testing for interlaminar fracture is the large scatter observed in test results. Moreover, these uncertainties are often not well understood, thus reducing our confidence in the analysis methods as well as the testing methods. The large scatter may be due to random variations in material properties, dimensions and test conditions. The stochastic FEA capabilities provided by VSTM allows for the parametric study of the effects of various input uncertainties on the distribution of the final structural response. Results from sensitivity study can provide valuable insights into sources of uncertainties and potential ways for improvements and optimizations. The ability to systemically recreate and understand uncertainties by virtual testing can greatly support the development, verification and application of analysis methods. Currently, the VSTM random input is limited to thickness and material properties. In order to study the interlaminar fracture, new random inputs specific to this fracture process will be comprehensively studied and integrated into VSTM.

3. **Development of Deterministic Methods for Interlaminar Fracture**
   The accuracy of any structural reliability analysis relies on the accuracy of the underlying deterministic analysis model. A common method for the interlaminar fracture analysis is the FEA-based virtual crack closure technique (VCCT). However, VCCT has limited computational efficiency, making in-depth sensitivity study and optimization impractical. This is because the number of variables in this type of problem is large, e.g. delamination location, ply thicknesses and orientations, material properties, damage geometry, load

cases. The aircraft industry is interested in the development of a more efficient and versatile analysis tool for analyzing 3-D interlaminar fracture problems.

Past developments in semi-analytical approaches, which combine load conditions from a global finite element analysis, the crack tip strain energy release rate (SERR) from analytic modeling and fracture mode decomposition from decomposition parameters, promises drastic computational savings and allows optimization analysis. However, these approaches need to be further improved in order to study delamination growth in a large structure. Fundamental understating of the crack tip stress/strain fields and the associated SERR is crucial to the accurate prediction of delamination/disbond growth under tensile and compressive loads. Additionally, fatigue, moisture effects as well as nonlinear viscoelastic behavior of matrix need to be further explored. The ultimate goal is to develop an efficient and accurate method for the analysis of 3-D interlaminar fracture problems. The developed method will be used to study delamination growth and arrest in co-cured and co-bond structural components.

Student Thesis Completed:

Chi Ho Eric Cheung, "Reliability of Composite Structures with Damage Growth Consideration," MS Degree, Department of Aeronautics and Astronautics, June 2008.

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

Abstract
Develop analytical, computational and experimental capabilities to address aeroservoelastic stability and dynamic response of composite airplanes due to damage and other sources of structural uncertainty. Of particular interest are aeroelastic consequences of damage mechanisms in wing / control surface and tail / rudder systems. 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 for uncertain composite structures and associated probabilistic / reliability methods and capabilities. 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, Ph.D. student, ME Department (has just completed her master's thesis)

The Research Team and Its Progress
To date our team has made significant progress in all areas of the project. A rapid modeling / analysis aeroelastic capability for composite airframes based on industry-standard commercial codes (FEMAP, PATRAN, NASTRAN, ZAERO, Matlab) has been developed alongside a reliability / probabilistics analysis capability. This allows studies of aeroelastic reliability of existing composite airframes as well as effects of design and maintenance practices on such reliability. Exploratory results for a test delta wing and a realistic vertical tail / rudder assembly of a passenger airplane have been completed and reported in conference publications and journal papers.

Simultaneously, we have developed techniques for aeroelastic stability analysis of composite airframes with geometric nonlinearities. These techniques allow aeroelastic stability evaluation of optimized, highly flexible, composite airframes as well as airframes subject to nonlinear structural effects of localized damage. Finally, major progress has been made in the experimental part of our project as described below. We now have at the University of Washington the capability to design, build, and test aeroelastic models of composite airframes or airframe components.

People and their contributions:
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. Demasi is now an assistant professor of Aerospace Engineering at San Diego State University. He will continue supporting our effort as needed.

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. Dr. Styuart now works for Stirling Dynamics, Inc. in Kirkland, WA, and will continue to support our effort as needed.

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 Fellow): 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. Recently Carl Niedermeyer retired from Boeing and will be working for the FAA. We hope to continue our fruitful collaboration with him at the FAA.

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.

Ms. Francesca Paltera completed her MS degree in mechanical engineering in August 2008. Her thesis was entitled "Flutter Response To Damage Of Composite Aircraft Control Surfaces". Her study involved both analytic and experimental studies of a 3 degree-of-freedom airfoil section. The experimental portion of her work was based on a laboratory-scale airfoil section that was designed and built on the UW campus. The model is designed such that a composite rudder can be easily removed and replaced. The flutter response of this system with both pristine and with damaged composite rudders were measured during wind tunnel tests and compared with analytical predictions. Measurements show that various forms of damage can change flutter speeds and frequencies. Generally speaking, damage tends to reduce flutter speeds.

In general, our experimental capability development is part of a long-term plan to build a center of excellence for the aeroelasticity of composite airframes at the University of Washington that will include state of the art computational as well as experimental capabilities. The idea is to have a rapid model construction, structural dynamic testing, and wind tunnel testing to allow quick response to industry and government needs.

General Plans

Experiments and Experimental Capability Building

- Design and build (in collaboration with Boeing) aeroelastic models of composite airframe components of interest and carry out modal and wind tunnel tests of such models. Correlate with computations. Use to validate computational / design capabilities.
- Continue development of the University of Washington's experimental aeroelastic capabilities by improving the test and data acquisition / analysis equipment and preparation for aeroelastic tests in both the small 3' x 3' and large 12' x 8' wind tunnels.

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 (Limit Cycle Oscillations)

- 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). Surfaces 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. Year Three research investigated two additional prepreg materials (Hexcel 7714A and Cytec 9714A) and included paste adhesives. Additional work included development of an instrumented Rapid Adhesion Test (i-RAT) to assess bond quality and an investigation of contamination of bond surfaces from protective gloves.

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
John Aubin, MSE Master candidate, Research Assistant
Jeffery Saterwhite, MSE Masters candidate, Research Assistant
Curtis Hickmott, MSE Senior

Past Students, degree and current positions

Bjorn Ballien, BSc	Henkel
Brian Clark, MSc	Integrated Technology (INTEC)
Tucker Howie, BSc	Graduate student, Univ. of Washington
Rockey Aye, BSc	Graduate student,
Connor Keenan, BSc	Graduate student, Univ. of Delaware

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, 2008). Five different students (Molly Pharris, Brian Clark, Jeff Saterwhite, Conor Keenan and John Aubin have been finalists at the SAMPE student symposiums and finished in the top three. Research findings and best practices have been incorporated in two composite related classes (MSE 475 Introduction to Composites and MSE 599 Repair of Aircraft composite structures) at the University of Washington.

Our current research has focused on bond quality of fiber reinforced, epoxy matrix composite surfaces prepared using peel plies and bond with epoxy based adhesives. We have studied systems composed of 8 different carbon and fiberglass prepregs, 10 different peel plies, 8 different film adhesives and 1 paste adhesive. 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. The potential applications and limitations of various surface characterization techniques to determine the suitability of composite surfaces for bonding and the potential for contamination of composites surfaces from protective gloves has also been 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. Surface characterization techniques also identified features that may have contributed to strong or weak bonds. The combination of testing and characterization has contributed to the fundamental understanding of composite bonding.

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 envelops 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
10) Care must be taken in selection of protective gloves used for handling of composite surfaces that have been prepared for bonded. Certain brands of gloves have been shown to contaminate the bond surface and lead to weak bonding.
11) Contact angle measurements on composite surfaces with multiple fluids and subsequent data analysis to plot wettability envelopes can illustrate variation in surface chemistry from different surface preparation techniques and /or contamination.

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).
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.

Expected Outcomes

The research findings from this program will provide a better understanding of the role of 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, 2004 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 that describes how the curriculum was developed.

The final phase of the development adapted the course content into an on-line class format. Twenty-seven students from a broad spectrum of industry, academia and regulatory organizations attended the 6-week on-line class, followed by an optional 3-day laboratory, which was attended by 9 students. A generic structural repair manual, referred to as a training repair manual, was developed 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 by their originators and will not allow public use of their materials. The SRM is an essential source document for performing qualified repairs of composite materials.

During 2008, the FAA is adapting the awareness course described above for training inspectors. A workshop was held with FAA inspection practitioners in order to focus on essential topics needed by FAA inspectors. A prototype class will be conducted in September 2008, over a six-day period, which will be a hybrid classroom and laboratory experience. Preceding this course, the students will be completing a prerequisite course that has the objective of bringing all students to a common level of fundamental understanding of composite materials technology.

Publications
A final report was provided during 2007 to the FAA Technical Center for final review and posting. Additional reports were published for the training repair manual, with feedback on the online course, which was conducted in 2007 and described above.

Information Dissemination
Materials and development progress have been presented through a variety of workshops and conferences, such as CMH-17, SAE and CACRC committees. Publications are available through the FAA Technical Reference and Research Library: **http://actlibrary.tc.faa.gov**.

Students

2007 Online Class

Thim Wai Ng	Wichita State University
Lamia Salah	Wichita State University
Genevieve Vallieres	Canadian Forces
Aric Repp	Canadian Forces
Andrew Davidson	Canadian Forces
Tim Lebaron	NTSB
Kristi Dunks	NTSB
Mark Kistner	USAF
NOVA DUBOVIK, MSgt	USAF
Brian Julian	Boeing
Anna Kolachalama	Cessna
Albert Park	GE
Kent Hearn	Hawker Beechcraft
Andrea Kanaya	Lockheed Martin
Ryan McCoy	Lockheed Martin
Mary K. Langlais	Boeing
Lynn Pham	FAA
TBD	FAA
Rusty Jones	FAA
Bill Scott	FAA
Mike Hendricks	FAA
Charlie Ruggiero	FAA
Alain Douchant	Transport Canada
Marco Mariotti	Transport Canada

2007 Laboratory (3-day)

Nova Dubovik	USAF
Brian Julian	Boeing
Mark Kistner	USAF
Anna Kolachalama	Cessna
Mary Langlais	Boeing
Tim Lebaron	NTSB
Ryan McCoy	Lockheed Martin
Genevieve Vallieres	Canadian Forces
Allen Rauschendorfer	FAA

2008 Class (All FAA)

Onofrio Savino
Harold J. Jones
Steven Sandmann
Lee R. Koegel
Tony Alfaya
Larry Penland
Lewis D. Johnson
Jose D. Salazar
Roger Wasserman
Kathleen Arrigotti

PROJECT TITLE 6
Failure of Notched Laminates Under Out-of-Plane Bending

Abstract
The overall goal of this research is to develop analysis techniques that are useful for the design of composite aircraft structure subjected to general out-of-plane loading. This particular project is limited to the case of out-of-plane bending, with a focus on some very basic experiments and modeling efforts involving simple structures (center-notched, unstiffened laminates) under pure bending. We will determine the modes of failure of the laminates and evaluate the capability of some currently existing analysis techniques for predicting these failures.

PI
Timothy C. Kennedy, Ph.D., Oregon State University School of Mechanical, Industrial, and Manufacturing Engineering

Student(s)
Sergio Gonzalez, PhD Candidate and Graduate Research Assistant

Technical Advisers
Gerald Mabson, Boeing
Tom Walker, NSE Composites
Larry Ilcewicz, FAA

Progress
Accomplishing our objective requires both experimental and computational efforts. The project can be divided into three main tasks. The first task involves performing 4-point bending tests on laminates with center notches in the form of elongated ellipses. The second task involves using the general purpose finite element analysis program ABAQUS to construct models of each of the laminates tested under 4-point bending so that bending moment concentration factors can being calculated. For task 3 we focus on progressive damage modeling using the damage model for composites in ABAQUS. As in task 2, we will perform calculations for the cases studied in the notch experiments. We will simulate the growth of the notch up to laminate failure. Failure modes predicted by the model will be compared to those observed in the experiments. This will allow us to evaluate the validity of this model for simulating notch growth under out-of-plane bending. This project began on July 15, 2007. Progress to date on each of these tasks is described below.

Task1: Twenty-four of the planned forty-eight experiments involving four-point bending of notched laminates have been completed. There are twelve different specimen types depending on the laminate type, laminate thickness, and notch length. Each specimen type has been tested twice. During the test the thin laminates exhibited negligible visible damage before failure, which was sudden and usually resulted in the laminate being broken into two pieces. The thick laminates exhibited a gradual progression of damage, which usually began with wrinkling of the outer ply on the compression side. This was followed by delamination at the outermost 0-degree ply and fracture of the plies between the outermost 0-degree ply and the surface. The tension side of the laminate generally exhibited little visible damage.

Task 2: The primary objective of Task 2 is to determine the effects of transverse shear on the moment concentration around a notch in a plate under bending. Finite element models of plates with a 0.25-in circular hole, a 1-in long ovaloid hole, and a 4-in wide ovaloid hole were constructed using two types of shell elements – one with transverse shear effects and one without. The moment concentration factor at the edge of the notch was calculated for each case. For 20-ply thick laminates, the moment concentration factors were on average 27 percent higher in the models with transverse shear effects than the models without transverse shear effects. For 40-ply thick laminates, the moment concentration factors were on average 41 percent higher in the models with transverse shear effects than the models without transverse shear effects.

Task 3: Finite element models of the laminates were constructed using conventional shell elements. In the progressive damage model for composites contained in ABAQUS, damage is accounted for in each individual ply, but there is assumed to be perfect bonding at the ply interfaces. Comparing the test results and model predictions, we observed fair to good agreement for all of the thin (20 ply) laminates. The agreement was not as good for the thick (40 ply) laminates. The poor agreement between tests and theory in this case may be the result of the model not having the capability of simulating delamination.

PROJECT TITLE 7
Standardization of Numerical and Experimental Methods for Crashworthiness Energy Absorption of Composite Materials

Abstract

The project is aimed at developing test standard, currently non-existing, to determine the energy absorption capability of composite materials, and assessing the validity of current finite element analysis tools to model the post-failure behavior.

PI

Professor Paolo Feraboli, University of Washington, Aeronautics and Astronautics

Program Monitor

Allan Abramowitz, FAA

Student(s)

Francesco Deleo, MS student (graduating) but continuing as PhD student
Barbara Wade, Undergraduate Research Assistant

Technical Advisers

Mostafa Rassaian, PhD – Boeing Phantom Works, 787 Crashworthiness Advanced Analysis
Larry Ilcewicz, FAA

Progress

The project has been closely tied with the CMH-17 Crashworthiness Working Group activities. These include the development of a corrugated self-stabilizing test specimen for standardization, and the evaluation through an industry-wide round robin of all state-of-the-art modeling techniques.

PROJECT TITLE 8
Identification and Validation of Analytical Chemistry Methods for Detecting Composite Surface Contamination and Moisture

Abstract
Adhesive bonding has been used in the manufacture and repair of primary aircraft structures for over 50 years and is still in use on current aircraft projects as a direct competitor to riveting. Adherend surface preparation is a critical issue to structural integrity of bonded structures. Inadequate surface roughening, possible chemical contamination on peel ply, release fabric and release film, and surface moisture may result in poor adhesion, i.e. a weak bond between the adhesive and adherend, and reduced long-term durability. The problems with chemical contaminations from peel ply, release fabric and release film that prevent adhesion of the adhesive to the substrate are now fairly well known. What is far less understood is the adverse influence of pre-bond water moisture that is unavoidable during manufacture, repair, and service. Thus, current adhesive bonding quality assurance practice relies on tightened surface preparation process control, mechanical testing on bonded specimens and non-destructive inspection (NDI) after bonding. In the absence of a definitive, in-field surface quality control method, laborious and sometimes inadequate measures are used to ensure the quality of adhesive bonding, thereby creating an undue expense on an otherwise economic manufacturing process. The objectives of the proposed research are: 1) identify surface quality assurance methods that are currently being used by aircraft manufacturers and repair service providers and determine whether the current quality assurance tests including the wedge test are sufficient to ensure the contaminated peel plies are detected and not used, and 2) to identify and evaluate definitive analytical chemistry methods to provide sufficient in-field quality assurance. Technologies that this research has been focusing on are: 1) solid-state electrochemical sensors; 2) carbon nanotube based humidity sensors, and 3) atomic force microscopy (AFM) and chemical force microscopy (CFM). Since 2004, the following results have been obtained. First, literature review shows that current surface pretreatments may be insufficient for assurance of a high long-term durability of the adhesive bonds. Activation of the pre-bonding surfaces is more important than achieving a high cleanliness of those surfaces. Second, a carbon nanotube based moisture sensor has been devised and evaluated. Third, a series of solid-state electrochemical sensors have been devised and evaluated. The sensors are very sensitive to the changes of surface chemical conditions and suitable for in-field inspection of the pre-bonding surfaces. Finally, evaluation of the AFM and CFM is in progress. The initial results show that AFM and CFM are able to detect the surface chemical properties.

PI
Dwayne McDaniel, Ph.D., P.E., Florida International University, Applied Research Center,
Co-PI: Xiangyang Zhou, Ph.D., University of Miami, Department of Mechanical and Aerospace Engineering

Current Student(s)
- Yijin Yin, Ph.D. candidate, Research Assistant
- Zhedong Wang, Ph.D. candidate, Research Assistant
- Tomas Pribanic, MS candidate
- Kevin LaMott, BS Junior

Progress
Several in depth technical interactions have taken place with engineers from Bombardier, Embraer, AeroMatrix, Exponent and Infiniti who have provided technical discussions that have helped direct the detailed research plans for this project. The results have been presented in five JAMS and AMTAS technical review meetings.

Summary of Findings

1) Literature review and analysis

   Analyses on conflicting results of surface pretreatments lead to conclusions as follows:

   a) Strong initial bond strength does not ensure the durability of an adhesive bond. In other words, additional mechanical tests including the Boeing wedge test are not sufficient for certifying environmentally durable adhesive bonds.
   b) Variations in bond strength and durability with the same pretreatment-bonding method implies that an effective quality control procedure is needed to control and reduce the variations. Adhesively bonded joints fabricated under quality control procedures will have predictable in-service performance.
   c) Bond quality is affected by the nature and timing of surface hydrocarbon contamination during pretreatment peel ply or tear ply procedures, while pre-bond moisture on the adherends is the most detrimental to bond integrity.
   d) A contaminate-free adherend surface is a pre-requisite but not a sufficient condition for forming a strong and durable adhesive bond. A chemically activated adherend surface can enable covalent bonds between the adherend and adhesive; these covalent bonds can effectively reduce bond displacement, which might otherwise occur due to contamination and the ingress of water during service.
   e) Certification of pre-bond surface preparation quality requires implementation of effective surface chemistry inspection technologies for each and every step of the surface preparation procedure to ensure the strength and durability of the bonded aviation structure.

2) Carbon-nanotube based moisture sensor

   Single wall carbon nanotubes (SWCNTs) and Y-junction single wall nanotube were synthesized by using Mo doped Fe catalyst particles with similar temperature conditions. Moisture on the carbon-nanotubes can be evaluated using an electrochemical impedance method.

3) All solid-state electrochemical sensors

   The solid-state electrochemical sensor can detect surface contaminates on the surfaces of peel ply prepared laminates. The sensitivity of the electrochemical sensor to the surface contamination level is very high. The sensitivity of the sensors can be further enhanced by varying the mediators in the solid-state electrolyte. With the Mn(II)/Mn(III) mediators, the sensitivity could be increased by 3 orders of magnitude. Two electrochemical measurement methods, i.e. cyclic voltametry and electrochemical impedance spectroscopy have been used for the measurements. The results from both methods are generally consistent but the electrochemical impedance spectroscopy method shows a better repeatability than the cyclic voltametry method. Incorporation of the sensors into a portable device is underway. The solid-state electrochemical sensor is a very promising to enable a low-cost, portable, online, and in-field technology for surface quality assurance of pretreated laminate surfaces.

4) AFM and CFM

AFM studies were conducted on laminate surfaces prepared with polyesther (PE), super release blue (SRB), and nylon peel plies. A new atomic force microscope with a higher resolution (5 nm) from FIU's Advanced Materials Research Institute is available. The new capabilities include an optical microscope and a tapping mode. We have been focused on force spectroscopy studies on laminate surfaces prepared with polyester, nylon, and SRB peel plies. Hundreds of readings of the maximum attractive force were obtained. The statistical analysis of the data indicate that the attractive force on the SRB prepared laminate surfaces are lower than those for the surfaces prepared with polyester and nylon peel plies. Functional groups have been attached to the AFM tips to conduct chemical force microscopy (CFM) studies of the laminate surfaces. These studies will help to detect the chemical composition of the laminate surface. In addition, first principle quantum mechanics modeling methods were established for evaluating the interaction between an AFM tip and laminate surface. The model will help to interpret AFM and CFM force spectroscopy results.

PROJECT TITLE 9
Development and Evaluation of Fracture Mechanics Test Methods for Sandwich Composites

Abstract
Whereas the development of test methods for fracture mechanics of composite laminates has reached a high level of maturity in recent years, relatively little attention has been given to the development of fracture mechanics test methods for sandwich composites. Of the limited number of investigations performed to date, a majority have emphasized a particular sandwich material or the effects of specific environmental conditions. In general, the test methods proposed for fracture mechanics of sandwich composites have been found to be problematic due to problems in testing, crack propagation, and the analysis of test data.

Emphasis in this research project grant will be focused on the development of fracture mechanics test methods for sandwich composites. The ultimate goal of the proposed research is to establish draft ASTM standards for both Mode I and Mode II fracture toughness of sandwich composite materials.

PI

Daniel O. Adams, Ph.D., University of Utah, Department of Mechanical Engineering

Progress
Utah was not a member of AMTAS until this year and the project did not have funding during this report period.

Completed Projects

Project Title 10
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. Van Voast, 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 11
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.

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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
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Oregon State University

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Edmonds Community College

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University of Utah

Name	Univ./Dept.	Expertise	E-mail/Phone
Dan Adams Associate Professor	UoU Department of Mechanical Engineering	Mechanics of composite materials, damage mechanics, micromechanics	adams@mech.utah.edu 801-585-9807

Florida International University

Name	Univ./Dept.	Expertise	E-mail/Phone
Richard Burton Program Manager	FIU Applied Research Center	Aging aircraft maintenance, binary-material processing, systems engineering	Richard.Burton@arc.fiu.edu; 305-348-1677
Dwayne McDaniel Research Engineer	FIU Applied Research Center	Structural mechanics, structural analysis and composites	Dwayne.McDaniel@arc.fiu.edu; 305-348-6554

University of Miami-Coral Gables (works with Florida International University)

Name	Univ./Dept.	Expertise	E-mail/Phone
Xiangyang Zhou Assistant Professor	UM-CG Dept. of Mechanical & Aerospace Engineering	Materials science, Dynamics, Mechanical behaviors of materials	xzhou@miami.edu; 305-284-3287

COE STUDENTS & RESEARCH ASSOCIATES

University of Washington

Current COE-supported students:

- John Aubin, MSE Master candidate, Research Assistant
- 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, Senior
- Tucker Howie, Dept. of Materials Science & Engineering, Ph.D. candidate, Research Assistant
- Francesca Paltera, Dept. of Mechanical Engineering, 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
- Francesco Deleo, Dept. of Aeronautics and Astronautics, MS student (graduating) but continuing as PhD student
- Barbara Wade, Dept. of Aeronautics and Astronautics, Undergraduate Research Assistant

COE-supported students who have graduated as of July 2008:

- Rockey Aye, BSc; Graduate Student
- Bjorn Ballien, MSE, BSc., June 2005; currently works at Henkel
- Eric Brutke, MSE, BSc, graduated December 2006
- Brian Clark, MSE, Master of Science, graduated June 2006; currently works at Integrated Technology (INTEC)
- Levent Coskuner, Dept. of Aeronautics and Astronautics
- Tucker Howie, Double major: MSE BSc, ME, BSc.
- Cary Huang, Dept. of Aeronautics and Astronautics
- Connor Keenan, BSc, Graduate student, Univ. of Delaware
- 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
- Francesca Paltera, MSME, Dept. of Mechanical Engineering August 2008 (Ms. Paltera plans to pursue a Ph.D. at the UW, beginning Autumn 2008)

Washington State University

Current COE-supported students:

- None; projects ended

COE-supported students who have graduated as of Aug 2008:

- 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

Current COE-supported students:

- Sergio Gonzalez, PhD Candidate and Graduate Research Assistant

COE-supported students who have graduated as of Aug 2008:

- None

Edmonds Community College

- None

Florida International University

Current COE-supported students:

Yijin Yin, Ph.D. candidate, Research Assistant
Zhedong Wang, Ph.D. candidate, Research Assistant
Tomas Pribanic, MS candidate
Kevin LaMott, BS Junior

COE-supported students who have graduated as of Aug 2008:

Shijie Tang, MS
Yao Ge, MS
Sam Hill, BS
Francisco Delgado, BS
Sandeep Kosuri, MS