Structural Health Monitoring – Mechanical and impact damage detection via fluorescent coatings

**OBJECTIVE:**
Improve inspection capability by developing a fluorescent coating to visually detect impact events and mechanical damage.

**RESULTS:**
Aerospace-compatible fluorescent coatings activated by mechanical force

Contact:
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PARTNERS:
Flinn & Jen Research Groups,
UW MSE
The Boeing Company

Consistent with barely visible impact damage (BVID) force levels

Increasing impact energy→

Off→

Coatings are activated by compression, indentation, impact events

Off

On→

Force→
Experimental and Numerical Study on Low-Velocity Impact on Composite Laminate Structures

OBJECTIVE:
Develop numerical models to predict low velocity impact of composite laminate structures
• Impact response & damage
• Compressive strength after impact

PARTNERS:
Boeing Company, Research and Technology, Seattle & St. Louis

RESULTS:
Low-velocity impact experiments were done with face-on and edge-on impact. Finite elements models using Enhanced Schapery Theory (EST) and Discrete Cohesive Zone Method (DCZM) elements for in-plane and out-of-plane damage and failure, respectfully. Results agree well with experiments.

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Face-on impact, experiments (left) and simulations (right)
Structural Health Monitoring – Thermal monitoring & damage detection via fluorescent coatings

OBJECTIVE:
Improve inspection capability by developing a fluorescent coating to quantify thermal exposures and identify damaged areas.

RESULTS:
Fluorescent coatings activated by thermal exposure developed
ON
Wide temp range (175-450F)
Capable of quantifying exposure times

PARTNERS:
Flinn & Jen Research Groups, UW MSE
The Boeing Company

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Applications: fire/ exhaust/ lightning damage, repair/cure monitoring
Braid Your Airplane: Rapid Manufacturing and Insertion of Composites in Flying Vehicles

**OBJECTIVE:**
Develop braided large scale unitized primary structures for air & space vehicles

**RESULTS:**
- Manufactured from constituent materials in one piece
- Minimal post-manufacturing processing
- Out of autoclave capable
- Unitized stiffened panel unable to delaminate under compressive loads
- Best void volume fractions in the industry at $V_{vf} < 1\%$

**PARTNERS:**
National Aeronautics and Space Administration
University of Michigan

**Contact:**
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Design and fabrication of self-sensing composites with embedded nanofibers

**OBJECTIVE:**

Use direct-printing technique to develop self-sensing composites with embedded multifunctional nanofiber network

**RESULTS:**

**PARTNER:**

Samsung Research America

**Contact:**

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Acoustic emission beamforming for detecting and characterizing damage in composite materials

**OBJECTIVE:**

Develop a non-invasive, non-contact method for real-time monitoring of composite materials for detecting and localizing damage

**RESULTS:**

- Capable of detecting early failure of composites in real time

**PARTNERS:**

SMI, Inc.  Toray for material support

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Identification of weak bond damage in composites using acoustic solitons

OBJECTIVE:
To detect the presence of weak bond in composites in two steps:
- Introduce delamination in weakly bonded composites using solitons
- Study the reflected solitons’ characteristics for identifying debond

RESULTS:
The soliton-based diagnostic technique shows promising results in terms detecting weak bonds.

PARTNERS:
JCATI

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Application of shallow-angle, thin-ply laminates to composite wings

**OBJECTIVE:**
Investigate the effect of shallow-angle, thin-ply laminates on the structural performance of wings

**RESULTS:**
64% improvement in bending stiffness-to-weight when using shallow-angle, thin-ply laminates compared to regular laminates.

**PARTNERS:**
Stanford University  
Chomarat  
JCATI

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**OBJECTIVE:**
Understand relationship between material microstructure and highly nonlinear material properties

Applications: shock mitigation, low-density materials, acoustics/structural vibration

**PARTNERS:**
Related wave propagation in designed materials projects (ARO/NSF):

**Contact:**
Dr. Nicholas Boechler
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**Web:** [http://faculty.washington.edu/boechler/](http://faculty.washington.edu/boechler/)
Crashworthiness Analysis of Textile Composites

OBJECTIVE:
1) to formulate *multiscale models* for effective crashworthiness *design of textile composite structures*;
2) to develop *new experiments* for material characterization and *scaling from lab to structure*

RESULTS:
1) Effective *multiscale model* based on *microplane decomposition* (b) with excellent agreement with experimental data (d);
2) *mesostructural optimization* enabled by the proposed multiscale framework

PARTNERS:
Dept. of Energy, GM, Ford, Chrysler

Contact:
Dr. Marco Salviato
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Durability of Textile Composite Structures: Experimental and Computational Analysis

OBJECTIVE:
1) To provide experimental and computational tools to assess the durability of large textile (2D and 3D) composite structures; 2) To provide tools for mesostructural optimization for durability;

RESULTS (ongoing):
1) A general computational framework is under development to account for (a) fatigue, (b) matrix degradation, (c) randomness of material properties; 2) A new set of experimental protocols is under study to characterize material degradation from lab to large structures.

PARTNERS:
NSF (pending), Albany Composites

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Nanocomposites for Large Lightweight Structures: Experiments and Modeling

OBJECTIVE:
1) To develop *new nanocomposites* with *enhanced quasi-static and fatigue behavior*;
2) To formulate models for *material and structural optimization*

RESULTS (ongoing):
1) *Strength* and *fatigue threshold enhanced by more than 50%* compared to epoxy specimens;
2) Ongoing work focuses on translating these results to 3D textile composites;
3) a *multiscale modeling* framework is under development to describe *fatigue damage*

PARTNERS:
Royalty Research Funds (pending)

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Reliability-Based Damage Tolerant Structural Design

**Objective:** Develop probabilistic methods for evaluating structural component reliabilities suitable for aircraft design, inspection, and regulatory compliance

**Sponsors:**

![Boeing Logo](image)

- Various failure modes
- Strength vs. temperature
- Moisture content vs. time
- Residual strength vs. damage size & damage type
- Probability of detection vs. damage size & damage type
- Maximum load vs. time of damage existence
- Damage size & damage type spectra
- Flight temperature spectra
- Strength degradation due to environmental exposure

**Probability of failure**

- Inspection intervals, Repair philosophy, Structural risk

**Contact:** Prof. Kuen Lin
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Delamination Arrest Features in Bonded Structures

Objective: To analytically predict crack arrest capability in bonded-bolted composite structures and to verify analysis by experiments

Sponsors: 'TORAY'
Enhanced Schapery Theory for Progressive Failure Analysis and High Fidelity Testing for Validation

OBJECTIVE:

Develop and validate high fidelity, computationally efficient models for the progressive failure analysis of polymer matrix composites and make virtual testing possible.

RESULTS:

- Mesh objective predictions
- Unified approach for modeling in-plane and flexural problems
- Excellent agreement with experiments
- Digital Image Correlation and Acoustic Emission measurements

PARTNERS:

Boeing Research & Technology

Contact:

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Development of New Material Systems for Binder Jetting AM (Powder Bed Printing)

**OBJECTIVE:**
To develop new powdered material systems for Binder Jet AM such as ceramics, glasses, bio-printable, cements, etc.

**RESULTS:**
To date: we have successfully tested and released more than 20 different materials systems for Powder Bed Printing.

**PARTNERS:**
University of Washington (Solheim Additive Manufacturing Lab), Open3DP, Seattle Pottery, Olympic Color Rod

**Contact:**
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Development of Vat Photo-Polymerization Systems – devices & materials (DLP systems)

**OBJECTIVE:**
To aid in the development and adoption of vat photo-polymerization systems and materials.

**PARTNERS:**
University of Washington, LittleRP, LLC

**RESULTS:**
Autumn 2015 ME480 class fabricated, tested and printed with 10 new systems.

Tested several new photopolymers for photoelastic engineering uses.

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Development of Mechanochromic Materials for Multi-Material AM.

OBJECTIVE:
To deploy recently developed mechanochromic materials into the 3D Printing world via Filament Printing.

PARTNERS:
UW Chemistry Department, Research Corporation for Science Advancement (RCSA)

RESULTS:
New materials were successfully deployed in a multi-material AM system to create force sensors.

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Development of Multi-Material & Graded Property Materials via Vat Photo-Polymerization AM.

**OBJECTIVE:**
To modify existing Photo-polymerization system, models and materials to allow for the creation of multi-material and graded property materials.

**RESULTS:**
Successfully demonstrated graded property objects using vat photo-polymerization AM via DLP.

**PARTNERS:**
UW Chemistry Department, Research Corporation for Science Advancement (RCSA).

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Virtual manufacturing of advanced textile composite aerostructures

OBJECTIVE:
- To numerically study the effect of processing on strength/shape of cured composite aerostructures
- To identify key processing parameters that dictate performance

PARTNERS:
GE Global Research, GE Aviation, Air Force Research Lab

RESULTS:
- Processing induces residual stresses in the cured structure
- If stresses during curing exceed a certain limit, microcracks can form in the matrix which can lead to reduction in stiffness and strength
- Simulations are performed with Epon 862 data on curing (i) at microscale for unidirectional laminates (ii) for textile composites such as satin weave

Contact:
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Certification of Discontinuous Fiber Composites in Aircraft Structures: Stiffness and Strength Predictions

OBJECTIVE:
Develop statistical methods to predict stiffness & strength of chopped fiber composites such as HexMC™, leading to certification based on analysis w/modest experimental database

RESULTS:
Predicted

PARTNERS:
Ctr for Adv Materials in Transport Aircraft Structures (AMTAS), The Boeing Company, and Hexcel

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Predicted

Measured

Contour Plots of Major Principal Strain in a HexMC Intercostal

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Effects of Moisture Diffusion in Sandwich Composites

OBJECTIVE:
Evaluate the impact of moisture and thermal cycling (room temps to -55°F) over long times on stiffness and fracture toughness of honeycomb core sandwich composite structures

RESULTS:

PARTNERS:
Ctr for Adv Matl’s in Trans Aircraft Str (AMTAS), Boeing, Bell Helicopters, 3M Company

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Single Cantilever Beam (SCB) sandwich specimen used to measure Mode I Fracture Toughness