Innovation With Purpose

Composite Aircraft Structures Certification and Progressive Damage Analysis

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Introduction

- Asked to discuss Composite Progressive Damage Analysis and inclusion/maturing in aircraft certification process
- In the next few charts I will briefly describe the Airframe Certification process
- Followed by current Composites PDA research

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Airframe Certification Process and Certification by Analysis Today

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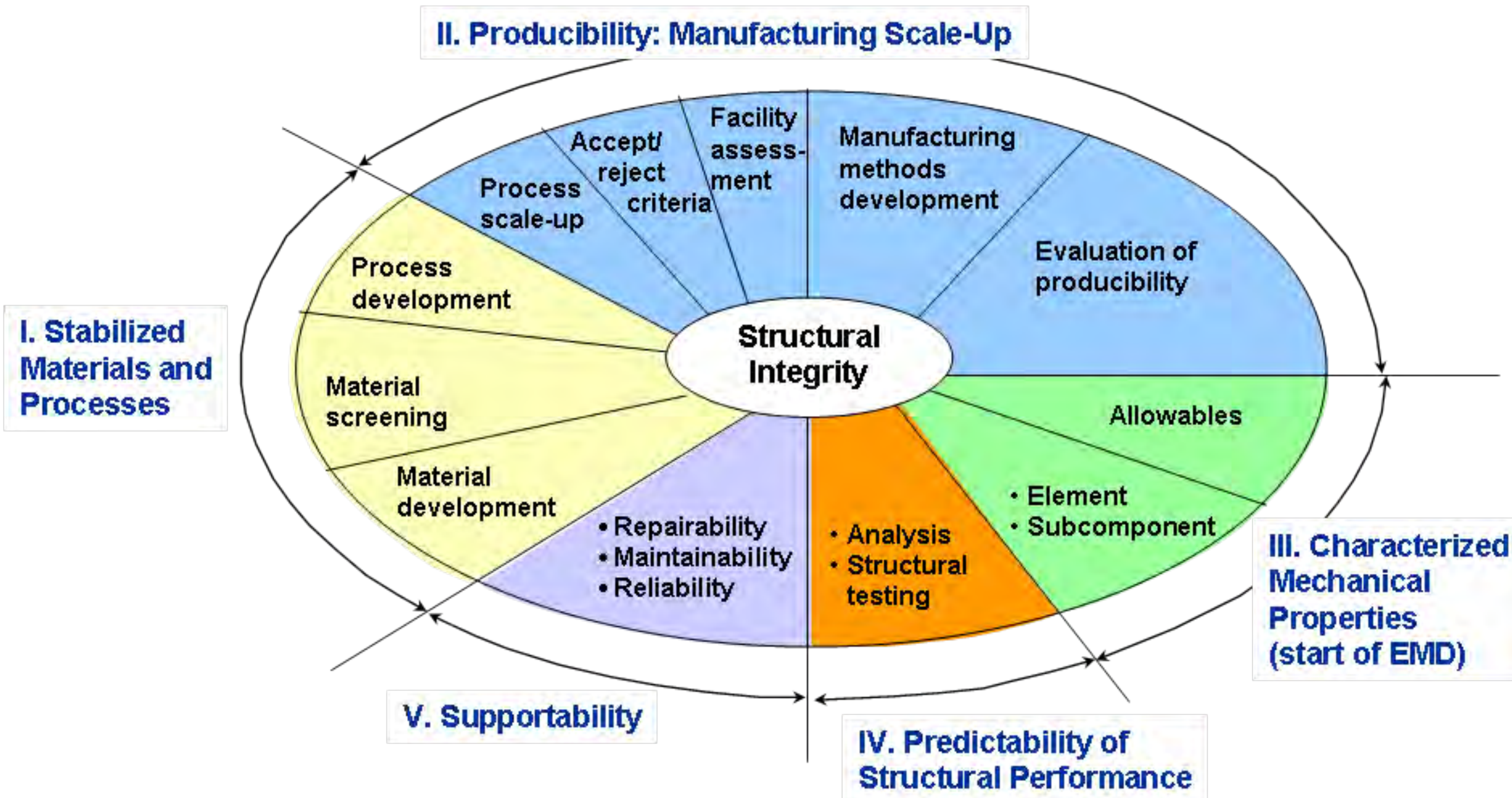
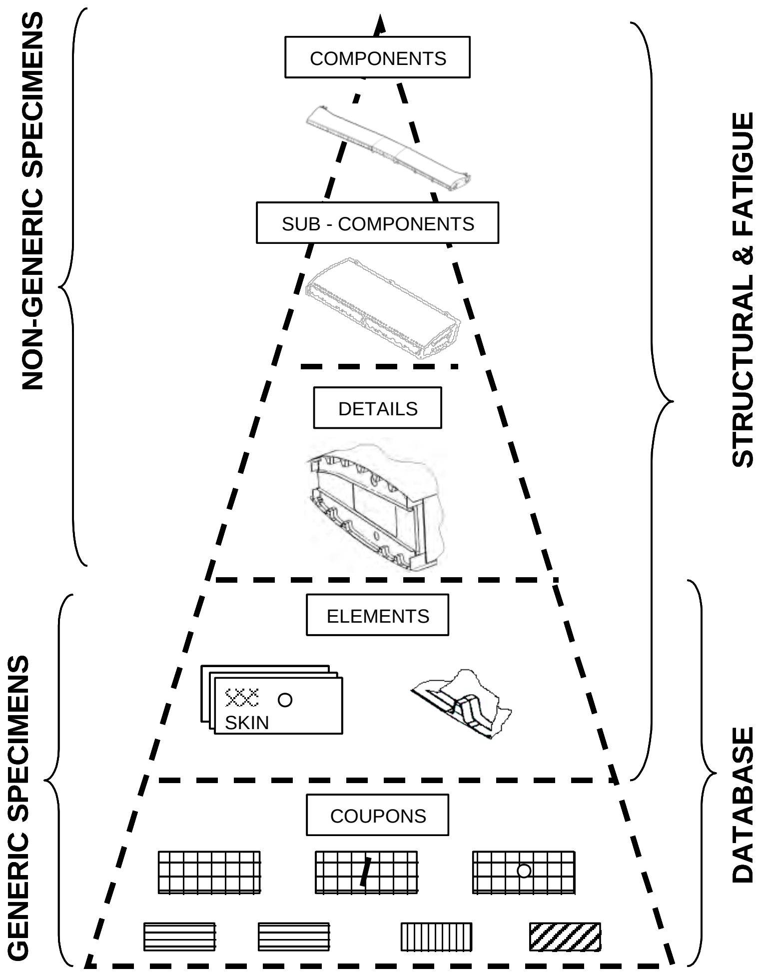
Five Factors for Technology Transition



Building Block Process

Normally see figures like this for the building blocks



Meaning to Steps of the Building Block

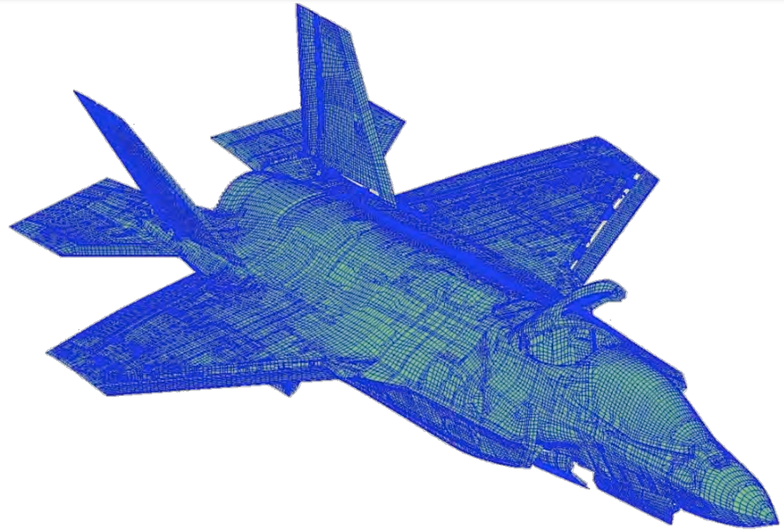
Potential PDA Opportunities: Areas where Reduction in Testing is Occurring Over Time

Flight Test	Validate/Calibrate External Loads Distributions & Magnitudes; Validate Systems Ops & ECD
Full Scale (Static & Fatigue)	Analytical Method Validation; Validate Internal Loads Distribution; Validate Strength & Deformation Capabilities; Validate Durability Requirements are Achieved
Component (Static & Fatigue)	Analysis & Modeling Validation & Correlation; Complex Loading; Scale-up Effects; Failure Criteria Validation; Inspection Criteria & Scale-up; Load Distribution Validation
Subcomponents (Static & Fatigue)	Analysis & Modeling Validation & Tuning; Combined Load Effects; Certification Approach Validation; Scale-up Effects; Failure Modes & Criteria Correlation; Inspection Criteria & Scale-up; Damage Tolerance
Element Tests	Joint Strength Allowables; Combined Load Effects; Environment Knockdowns; Process Spec Compliance; Joint Failure Modes; Inspection Criteria Development; Damage Tolerance
Coupons	Elastic Properties; Mat'lStrength & Variability; Environment Knockdowns; Process Stability & Qualification; Failure Modes; Inspection Technique Selection & Development; Effects of Defects

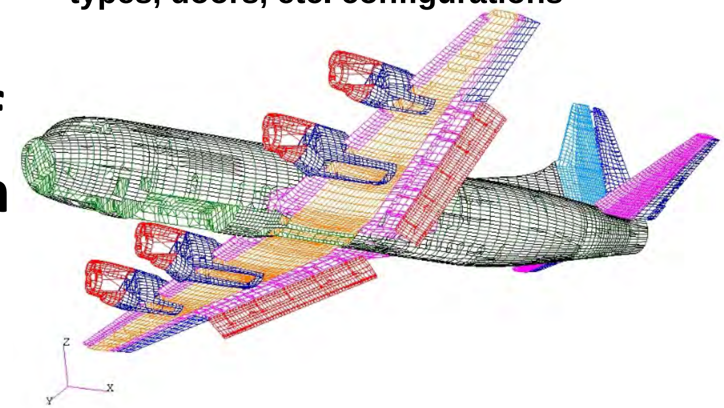
Much of coupon allowables development <u>requires testing</u> – effects of defects, variability, environment, process stability, NDI

We do Certification by Analysis Today

- **Test validation**
  - Full scale ground test used to validate internal loads predictions
  - Flight test validates external loads predictions
  - Subcomponents and components validate analysis
  - Coupon and element tests generate allowables for critical environments, failure modes, effects of defects, etc.
- **Based on this foundation, the aircraft is certified for <u>thousands</u> of load cases based on analysis, which is truly <u>"Certification by Analysis Supported by Test</u>**



AVFEMs – Internal Loads Models
Validated by Full Scale Static Test
Cost/span = approximately 18 man-years over 9 months (industry average)
Run in numerous control surface, engine types, doors, etc. configurations



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How to Maximize ROI for Future Certification by Analysis Activities?

- **Examination of Heritage Fighter and Transport Aircraft Development Cost Data Reveals That on Average (Relative to Total Program Costs):**
  - Engr costs accounted for 40 to 50%
  - Development test costs accounted for 25 to 30%
- **Structures Related Ground & Flight Tests Account for Over 75% of Test Costs**
  - Major cost centers are component and full-scale aircraft testing
  - Materials property development testing (coupons & elements) account for small fraction of program costs

Sacrosanct!

True Measured ROI for Future CBA Activities May Realistically be Small if Coupon/Element Test Replacement is the Goal

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Current Aerostructures PDA Research

1. AFRL/RQ: Benchmarking of PDA Tools

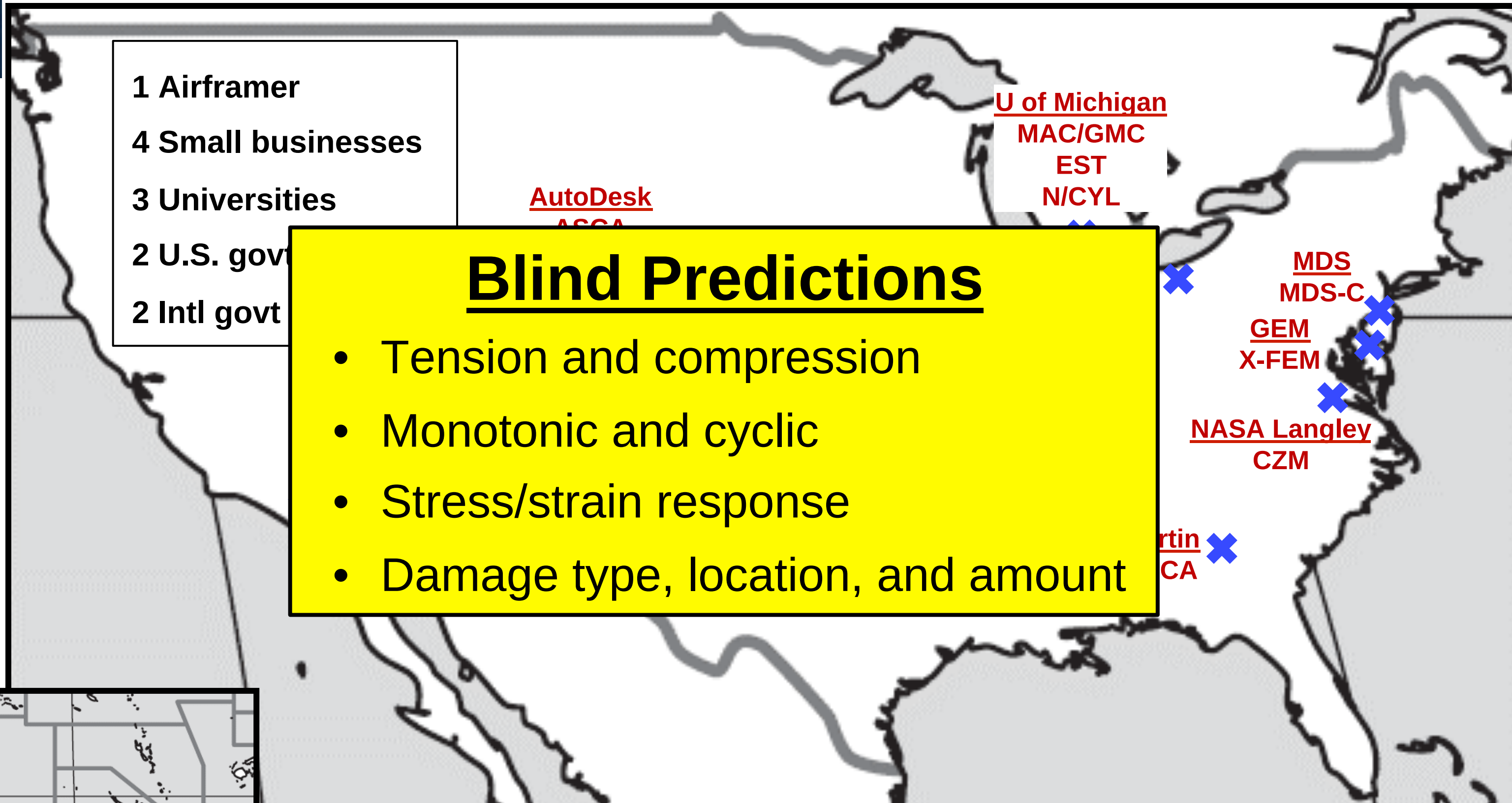
2. NASA: Advanced Composites Project

3. AFRL/RX: Integrated Computational Methods for Composite Materials (ICM2)

AFRL/RQ: Benchmarking PD Tools Goal

- AFRL/RQ and LM Aero research program to characterize the readiness of progressive damage analysis codes for application to aerospace vehicle structural design

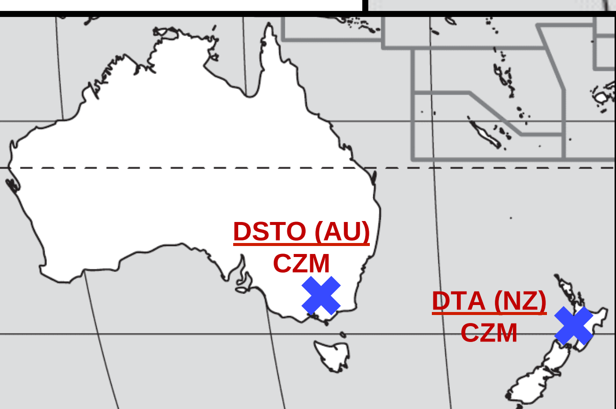
AFRL/RQ: Benchmarking PD Tools
Team



- 1 Airframer
- 4 Small businesses
- 3 Universities
- 2 U.S. govt
- 2 Intl govt

Blind Predictions

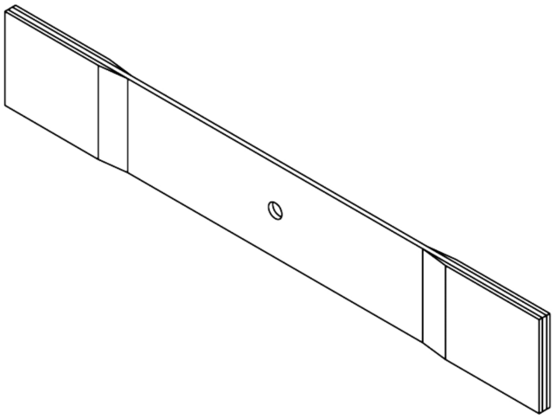
- Tension and compression
- Monotonic and cyclic
- Stress/strain response
- Damage type, location, and amount



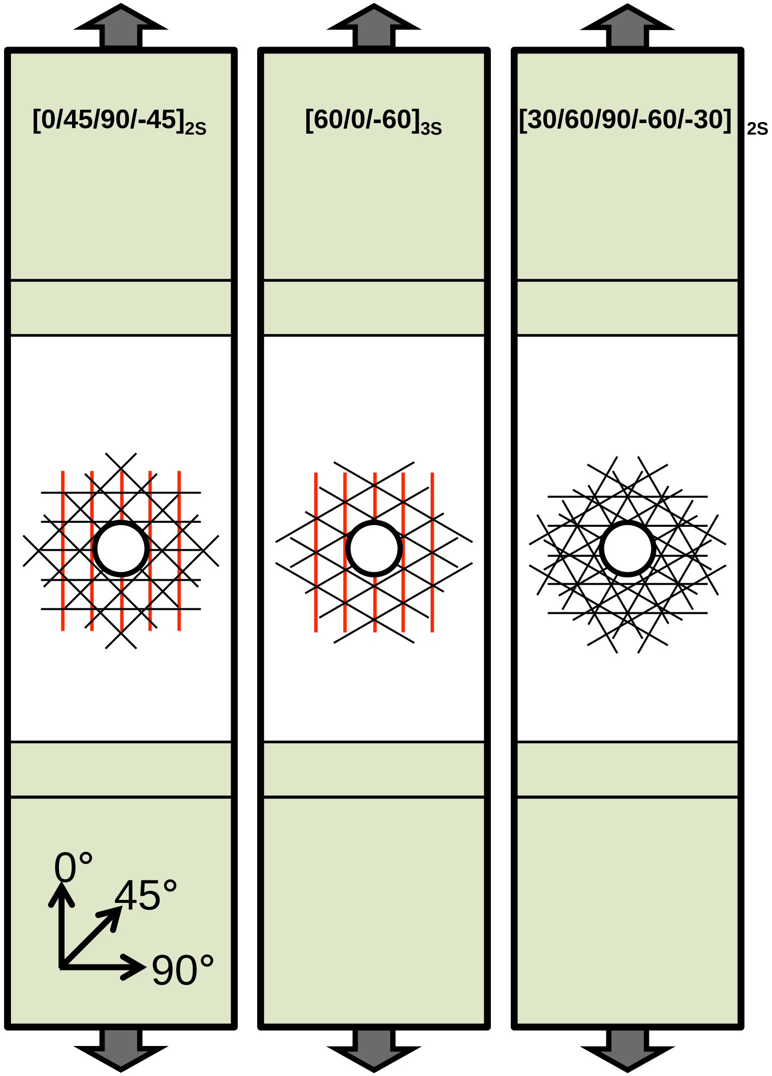
AFRL/RQ: Benchmarking PD Tools

Experimental Details

- **Geometry:** flat coupon with hole

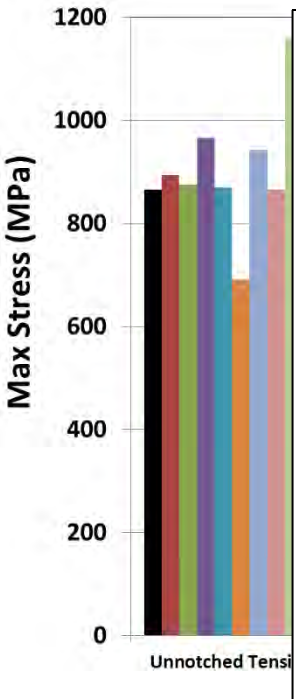


- **Material:** autoclave cured IM7/977-3
- **Monotonic loading:** constant displacement rate
- **Fatigue loading:** constant load amplitude
    - o R-ratio: 0.1
    - o Frequency: 10 Hz



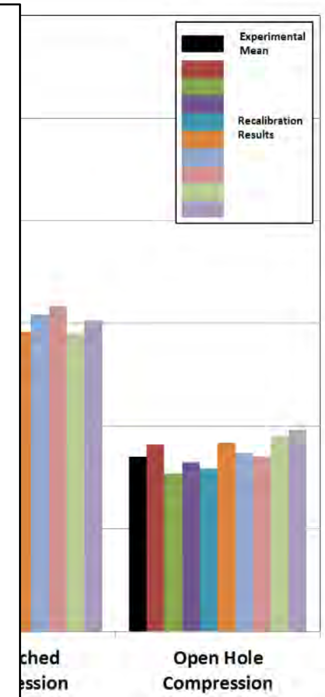
AFRL/RQ: Simulation Results

$[0/45/90/-45]_{2S}$



Discussion and Conclusions for all 3 layups

1. In general, tension better than compression
   - Some soft layup strength predictions were off due to lack of discrete delaminations in models
2. Compression stiffness and strength predictions were inaccurate due to:
   - 0° experimental calibration specimens buckling
   - Some analysts had never attempted compression
   - Some analysts used only the tension modulus



Bl ... ictions

Current Aerostructures PDA Research

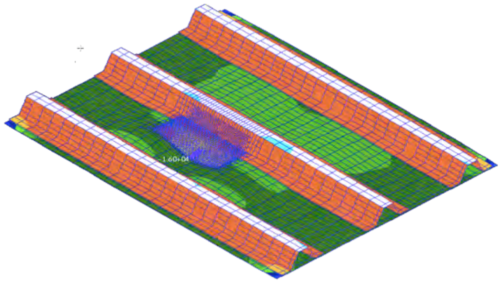
1. AFRL/RQ: Benchmarking of PDA Tools

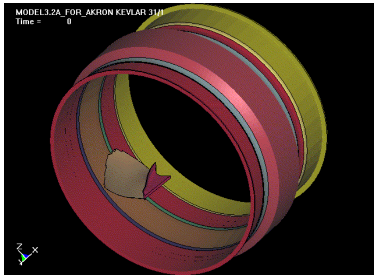
2. **NASA: Advanced Composites Project**

3. AFRL/RX: Integrated Computational Methods for Composite Materials (ICM2)

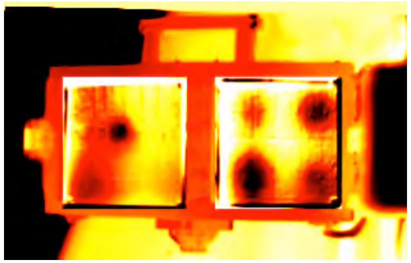
NASA Advanced Composites Project: Technical Challenges

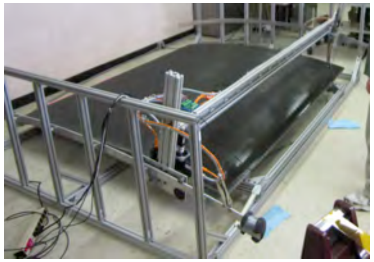
Accurate Strength & Life Prediction
- Reduce design and testing effort / time
- Robust high-fidelity analysis for damage
- Better prelim design, fewer redesigns



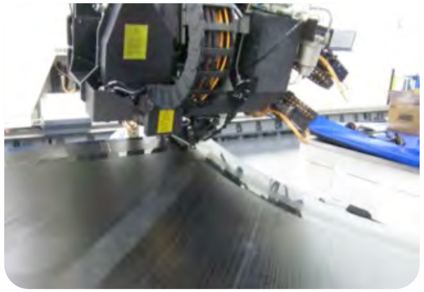


Rapid Inspection & Characterization
- Increase inspection throughput by 30%
- Quantitative characterization of defects
- Automated inspection





Efficient Manufacturing Process Development
- Reduce manufacture development time
- Fiber placement and cure process models to predict defects
- Improve quality control



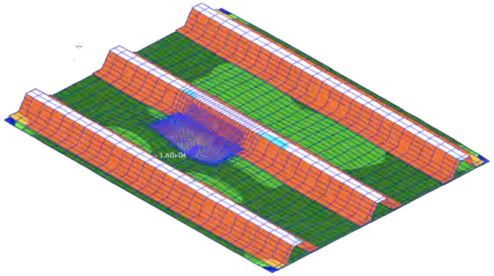
NASA public charts provided by Dr. Rick Young of NASA LARC

TC1: Accurate Strength & Life Prediction

Description:
Develop computational tools to reliably predict strength and life of composite structures

Benefit:
Reduce design cycle time and testing effort for development and certification; Reduce risk

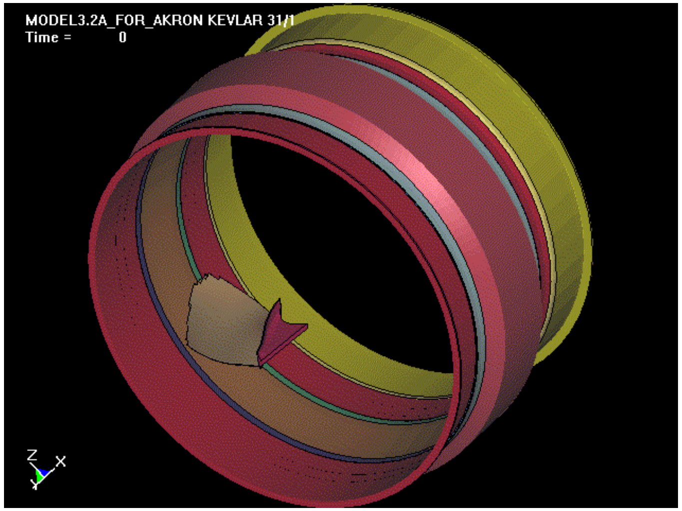
Experiments document damage progression



Validate new improved predictive models

Phase 1 Deliverables:

1. Ranking of modeling approaches & identify key gaps based on 1st Level BB Testing
   a. Post Buckled Panel with BVID, Strength and Life
   b. Engine Fan Containment
   c. Open Rotor Shields
   d. Rotor Blade Spar Fatigue
2. Ranking of proposed design tools to improve integrated design



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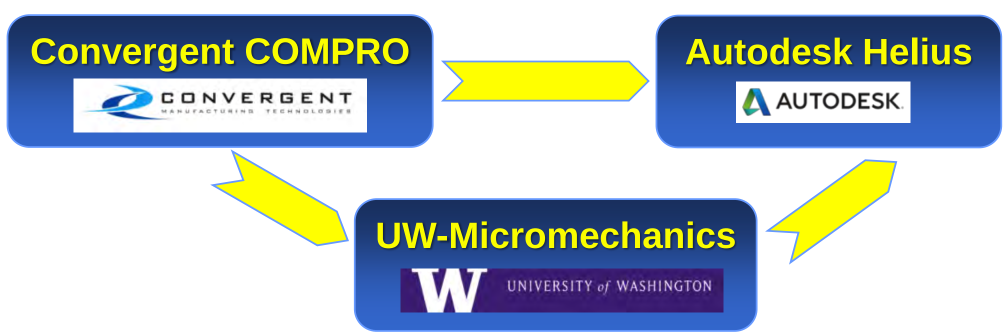
Integrated Computational Methods for Composite Materials (ICM2) Program

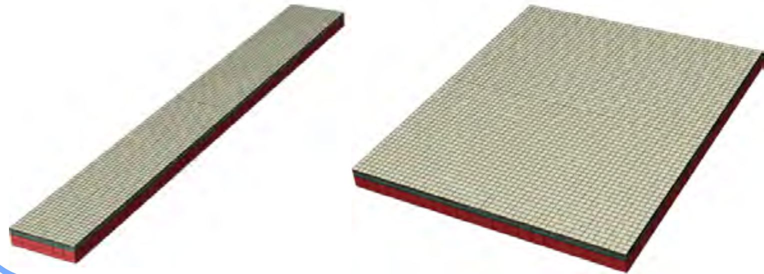
- **Integrated Computational Methods for Composite Materials (ICM2) is an AFRL/RX, GE, and LM Aero composites ICME program**
  - **GE studying engine applications**
  - **LM Aero studying airframe applications**
- **Airframe goal to amplify the weight advantage of IM7/M65 BMI**
  - **Studying autoclave cure cycle effects on design allowables**
- **Utilizing digital framework (ModelCenter®) to integrate**
  - **Cure Process Effects: <u>Convergent Manufacturing Technologies' COMPRO</u>**
  - **Multi-scale progressive damage: <u>Autodesk Helius</u> software**
  - **Ply level strength effects of cure: <u>University of Washington</u>**



ICM2: Roles of Each Analysis Tool

COMPRO Analysis

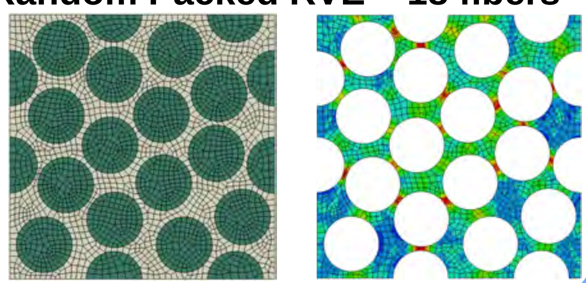
OHC/FHC Laminate   CSAI Laminate



- COMPRO Model of OHC/FHC and CSAI Laminates
- Provide cure cycle data to both UW and Helius

UW-Micro Analysis

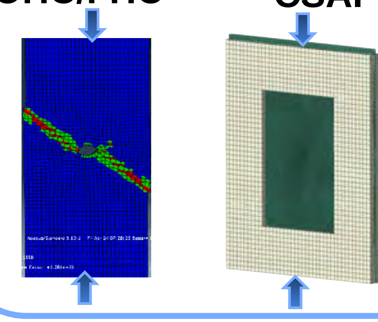
Random Packed RVE – 18 fibers



- UW Model of Lamina level strengths as function of cure
- Provide lamina strength data to Helius

Helius Analysis

OHC/FHC   CSAI



- Helius models of OHC, FHC, and CSAI laminate properties
- Predict notched laminate strengths as function of cure

Summary

- Research ongoing with Air Force, NASA, Navy, OEMs
- Confidence in PDA analysis is a requirement for transition
- Areas of opportunity for new PDA tools
  - Middle of the building block tree
  - Future composite SLEP activities
  - Bonding Certification
  - ICME