Boeing Perspective on Future Research Requirements

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Outline

- **AMTAS Charter**
- **AMTAS Current Projects**
- **Alignment with Boeing**
- **Simulation Trend at Boeing**
- **Multi-Physics/ Multi-Scale Analyses at Boeing**
- **Technical Challenges**
- **Proposed new Topics**
- **Move Forward Plan**

AMTAS Charter

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 advanced materials for large transport commercial aircraft.

Approach

AMTAS projects are grouped into 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.**

Deliverables

Benefits to Boeing include:

- **Access to training opportunities/short courses on composites.**
- **Knowledge transfer through access to technical reports, seminars, workshops, presentations, and conferences.**
- **Access to AMTAS recommended experimental and analytical practices through Spring and Fall AMTAS review meetings.**
- **Increased visibility and enhanced working relationships with other universities and the FAA.**

AMTAS Active Projects

1. ***Improving Adhesive Bonding of Composites through Surface Characterization*** **– Brian Flinn (UW, Mat Sci) #3 –Van Voast. Shelly, Bossi, Gleason, George-6yrs (9/30)**
2. ***Identification and Validation of Analytical Chemistry Methods for Detecting Composite Surface Contamination and Moisture*** **– Dwayne McDaniel (FIU,ARC) #6 –Van Voast, Grace - 3yrs (9/14)**
3. ***Analysis of Disbond and Delamination Arrest Features in Composite Structures*** **– Kuen Lin (UW,AA) #9 –Piehl, Mabson, Cregger -1yr**
4. ***Standardization of Analytical and Experimental Methods for Crashworthiness Energy Absorption of Composite*** **– Paolo Feraboli (UW,AA) #4 –Rassaian, 3yrs (9/30)**
5. ***Combined Global/Local Variability and Uncertainty in Integrated Aeroservoelasticity of Composite Aircraft*** **– Eli Livne (UW,AA) #2 – Gordon, Kumar (Boeing) -6yrs –(8/31)**
6. ***Certification of Discontinuous Composite Material Forms for Aircraft Structures*** **– Paolo Feraboli (UW,AA) #7 –Avery -2yrs (8/31)**
7. ***Failure of Notched Laminates Under Out-of-plane Bending*** **– John Parmigiani (OSU, ME) #5 – Mabson -3yrs (9/30)**
8. ***Inverse/Optimal Thermal Repair of Composites*** **– Ashley Emery (UW,ME) #8 –Cregger, Blohowiak, Bossi -2yrs (5/31)**
9. ***Development of Reliability-Based Damage Tolerant Structural Design Methodology*** **- Kuen Lin (UW,AA) #1 -- Mabson -6yrs (8/31)**
10. ***Development and Evaluation of Fracture Mechanics Test Methods for Sandwich Composites*** **- #7 – Dan Adams (Utah) – 3yrs**

Alignment with Boeing

Development of Reliability-Based Damage Tolerant Structural Design Methodology → **Reliability-Based Methods**

Combined Global/Local Variability and Uncertainty in Integrated Aeroservoelasticity of Composite Aircraft → **Multidisciplinary Aeroelasticity Optimization**

- **Improving Adhesive Bonding of Composites through Surface Characterization**
- **Identification and Validation of Analytical Chemistry Methods for Detecting Composite Surface …**
- **Analysis of Disbond and Delamination Arrest …**

} → **Bonding Key Initiative**

- **Standardization of Numerical and Experimental Methods for Crashworthiness**
- **Development and Evaluation of Fracture Mechanics..**

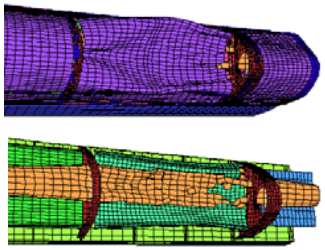
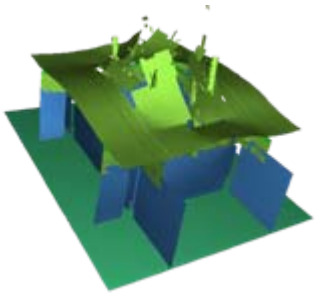
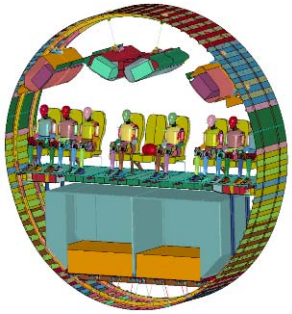
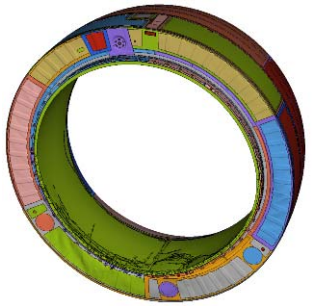
→ **Virtual Testing & Simulation**

Certification of Discontinuous Composite Material Forms for Aircraft Structures → **Computational Allowables**

Inverse/Optimal Thermal Repair of Composites → **Composite Repair**

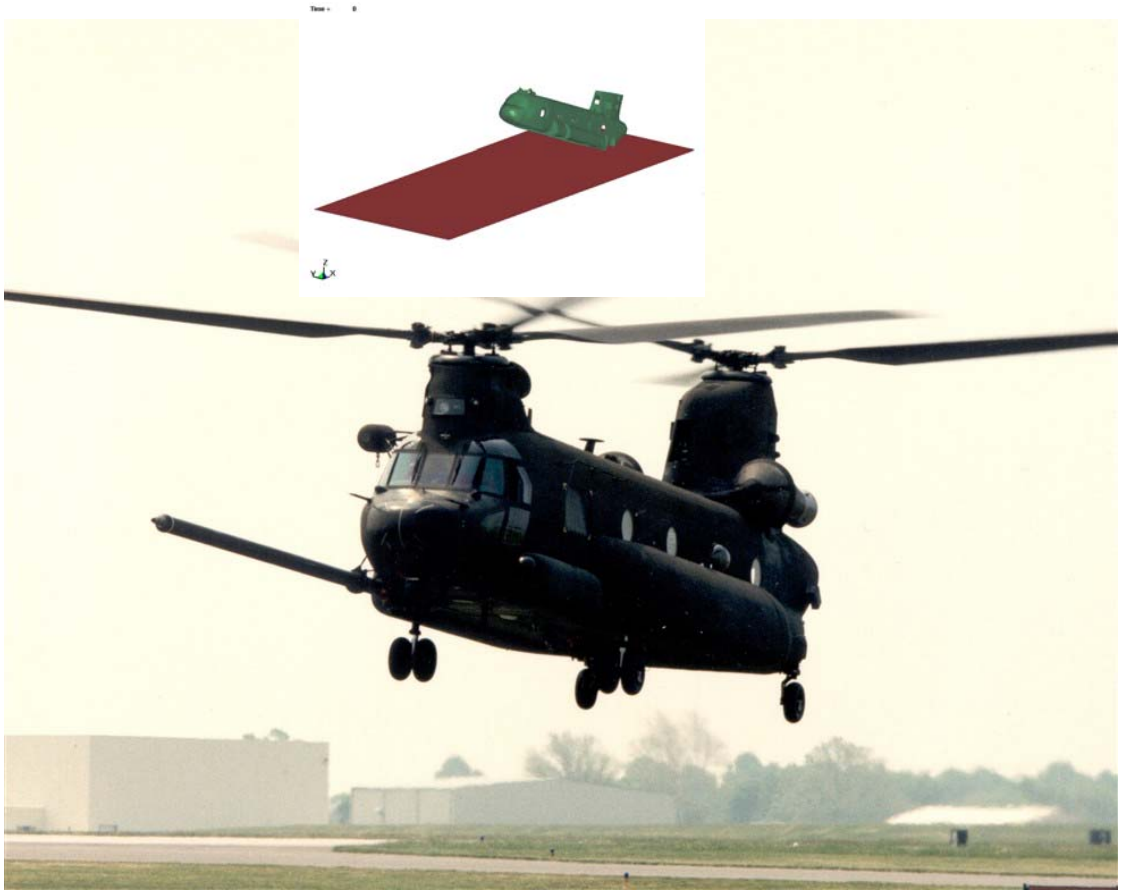
Failure of Notched Laminates Under Out-of-plane Bending

Simulation's Trend More Complexity

Circa	1995-1999	1999-2003	2003-2007	2007-Present
Simulation	 *Bird Strike*	 *Live Fire*	 *Crashworthiness*	 *Fan Blade Out*
Size	*100k*	*300k*	*700k*	*2.5 M*
Run Time	*1 cpu x 1 Day*	*8 cpus x 4 Days*	*8 cpus x 5 Days*	*62 cpus x 2 Days*
HPC				
Model	*HP C180 Workstation*	*SGI Origin*	*IBM P655*	*SGI Altix 3700 BX2*
Speed Index	*1x*	*5x*	*25x*	*100x-200x*
No. CPU's	*1*	*16 cpus*	*16 cpus*	*64 CPU's*

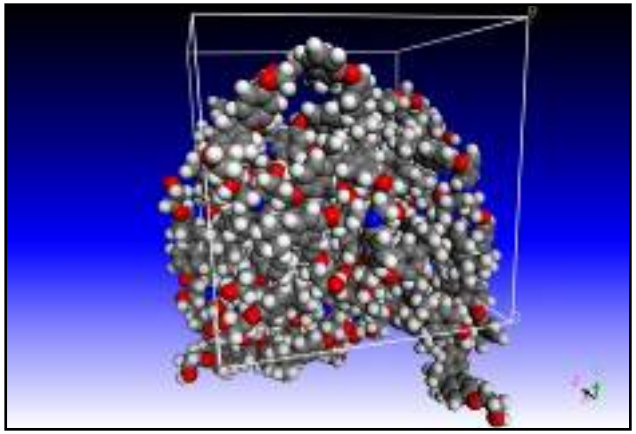
Software, Hardware and Ability to Validate Pace Our Simulations

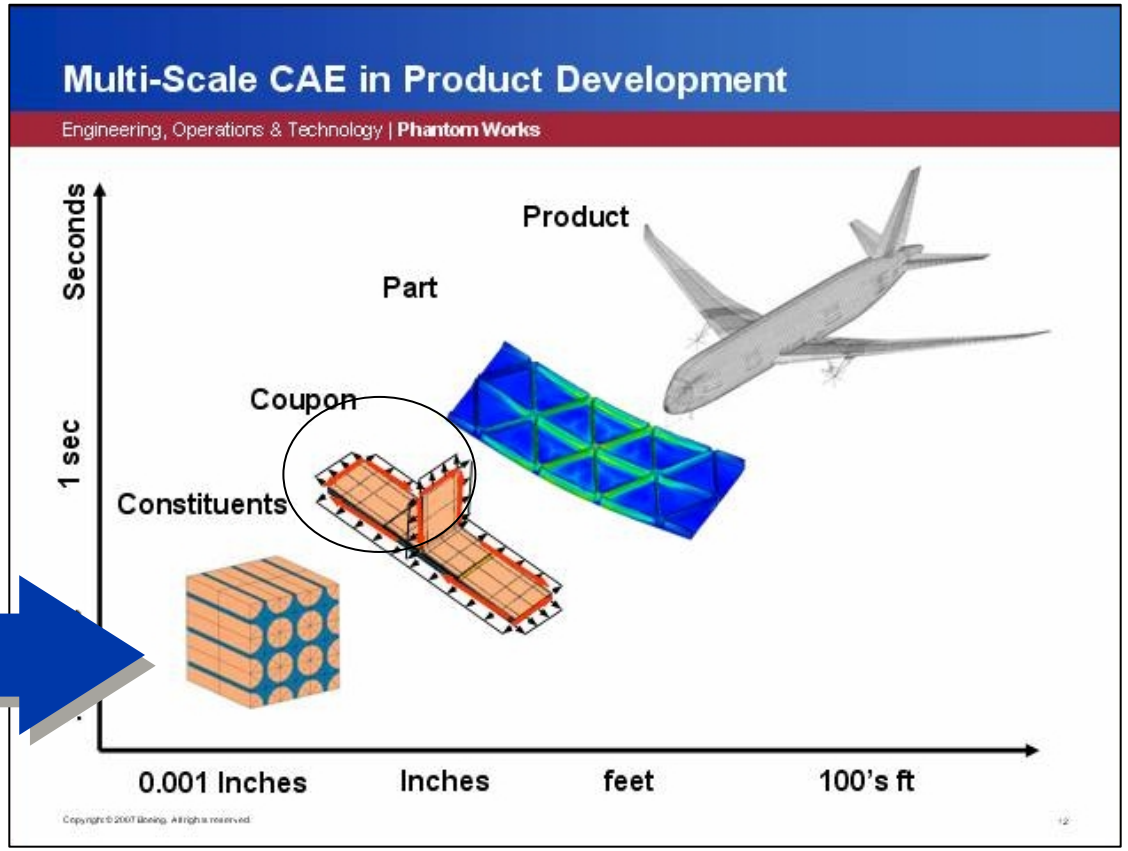
Multi-Physics Simulation - Water Ditching



Multi-physic Simulation Is Used to Understand Complex Interactions

Multi-Scale Extension to Molecular Scale





Linked scales include fundamental material behavior "atoms to airplanes"

Technical Challenges

- **Demand for Analysis of Composite Structure**
  - **Numerous design options**
  - **Complexity of design/ analysis poses high risks**
- **Management of Analysis Data**
  - **Statistical tools**
  - **Optimization**
- **Risk Quantification (robustness, design efficiency)**
  - **Engineering education**
- **Multi-scale - atoms to airplanes (Computational Materials)**
- **Increasing Complexity & Model Size**

AMTAS Boeing New Proposed Research Topics

- **Analysis Methods, Processes & Tools**
  - **Development of bonded repair – VCCT implementation in Explicit LS-Dyna**
  - **Fracture analysis techniques for determining crack propagation direction and origin in failed composite bonded joints**
  - **More robust progressive damage algorithms in explicit FE codes**
  - **Rapid PD methods for sizing/optimizing bird-strike-designed structure**
  - **Non-FEA for design optimization of disbond arrest features**
- **Standardized test methods for composites and allowables**
- **Performance of Recycled Fiber**
- **Active Aeroelastic wing**
  - **Composite stiffness tailoring to affect the flying qualities of aircraft**
  - **Combined use of actively actuated control of stiffness tailored aircraft**
  - **Flutter suppression or gust/maneuver loads alleviation**
- **Material & Processes**
  - **Peel ply effects on bonding for large transport aircraft materials**
  - **In-line QC methods for adhesive bonding processes**
  - **Moisture detection and removal from composites**
  - **Detection and analysis of heat damaged composites**

AMTAS Boeing New Proposed Research Topics (Cont'd)

Nonlinear Aeroelasticity – Extension of Tasks
AMTAS Wind Tunnel Aeroelastic Testing

- **Current**
  - **Wing/control surface (tail & rudder) 2D 3dof system with rudder stiffness freeplay**
- **Near-to-medium term**
  - **Wing/control surface (tail & rudder) 2D 3dof system with no rudder hinge stiffness and a nonlinear hinge damper**
  - **Composite rudder (aeroelastically scaled) with broken hinge that will require 3D aeroelastic modeling due to rudder rotation about the intact hinges plus out-of-plane bending near the broken hinge**
- **Longer term**
  - **Investigate more complex systems simulating empennage systems (stabilizers - elevators - tail – rudders) with**
    - **Single nonlinearity**
    - **Multiple nonlinearities**

AMTAS Boeing New Proposed Research Topics (Cont'd)

Potential NDE topics:

- **Material property measurement (local stiffness/modulus measurement)**
- **Rapid non-destructive inspection methods for damage and repair**
- **Bondline strain and damage measurement**
- **Non-destructive method for fiber waviness quantification**
- **Thermally controlled cures in high temperature repairs using magnetic induction**
- **Validate laser bond inspection bond strength testing on various bond configurations**

JAMS – FAA Needs

Priority 1: Damage Tolerance of Composite Structures:

- ✓ **Study critical defects (e.g., disbonding and other defects) and service damage threats (e.g., impact damage, fluid ingression) to understand the damage tolerance of airframe structures (e.g., sandwich and laminated)**
- **Support large-scale structural substantiation by establishing structural test protocol, load enhancement factors to cover reliability, analysis limits and test/analysis methods to simulate damage**
- **Address safety concerns from expanding composite applications such as transport wing and fuselage structure**
- ✓ **Understand damage threats (damage detectability, residual strength, and growth potential) from high energy blunt impact**
- ✓ **Determine the probability of critical damage threats (e.g. in-flight hail, bird strike) and realistic analysis & test simulations along with deterministic engineering assessment to create practical design criteria**
- **Identify laminated skin design parameters that affect large notch/penetration residual strength**
- **Develop a fatigue and damage tolerance module for the structural safety awareness course**

JAMS – FAA Needs (Cont'd)

Priority 2: Structural Integrity of Adhesive Joints:

- ✓ **Evaluate the effects of adhesive joint design, process and tooling issues on the integrity of bonded structure (e.g., static strength, fatigue, environmental resistance, aging, and damage tolerance)**
- ✓ **Ensure reliable bonded structure by documenting engineering guidelines and process acceptance criteria; establishing environmental durability testing of metal-bonded aircraft structures and composite bonded joints**
- ✓ **Study bonded stiffening attachments to ensure sufficient process control, certification test and analysis protocol**
- **Consider combined load conditions, environmental and aviation fluid resistance, long-term aging and damage to support structural joint substantiation protocol**
- ✓ **Develop a bonding module for structural safety awareness course**

JAMS – FAA Needs (Cont'd)

Priority 3: Composite Maintenance Practices

- ✓ **Study process variables and human factors contributing to repair process variability in both bonded and bolted repairs**
- ✓ **Resolve the effects of surface moisture exposure and drying of bonded repairs**
- **Identify inconsistencies and problems in other maintenance practices as well as control key process parameters and characteristics**
- **Focus on repair processing and proof of structure to reduce poorly performed major repairs with insufficient structural substantiation**
- **Consider repairs performed on pressurized shell structure to ensure structural integrity**
- ✓ **Evaluate the potential of new technology in health monitoring to support maintenance and mitigate safety risks**
- **Develop training standards including distance learning**

JAMS – FAA Needs (Cont'd)

Priority 4: Environmental and Aging Effects for Composite Structures

- ✓ **Identify environmental and aging factors affecting the performance and airworthiness of composite materials (e.g., study sensitivities to service environments and aircraft fluids including real-time interactions with loads)**
- **Support maintenance practices and establish criteria for structural retirement**
- ✓ **Conduct tear down inspection and laboratory tests on retired aircraft structures.**
- **Evaluate control surfaces in sandwich and metal-bonded sandwich structures.**
- **Determine realistic structural temperature exposures and moisture contents in comparison to current worst-case assumptions.**
- **Evaluate the composite materials in high temperature locations to investigate the effects of exposure to possible heat damage and establish field inspection procedures to detect the level and extent of damage**

JAMS – FAA Needs (Cont'd)

Priority 5: Cabin Safety Issues Unique to Composite Materials

- ✓ **Investigate composites in airframe structures crucial to cabin safety under crash conditions which must not reduce the level of safety**
- ✓ **Study composite materials and associated airframe structural details that may lead to changes in aircraft crashworthiness**
- ✓ **Perform both analysis and test evaluations to seek in substantiating crashworthiness for new composite airframe designs.**
- ✓ **Assess crashworthiness effect of structural scale and boundary conditions for building block tests, including assessment of strain rate sensitivity for typical composite material properties and their resulting structural behavior**
- ✓ **Evaluate existing analysis methods used to predict the crashworthiness of composite structures and develop test standards to measure the energy absorption of composite details. (In Work - CMH-17 Crashworthiness WG)**

JAMS – FAA Needs (Cont'd)

Priority 6: Specifications for Material Control and Test Standards for Advanced Materials

- ✓ **Establish information critical to composite material and process control such as specification requirements and reliable test standards.**
- ✓ **Focus on quality controls for material constituents and effectiveness of statistical process control procedures**
- ✓ **Evaluate material and process control for chopped fiber composites and possible TSO applications to achieve in more efficient structural substantiation procedures**
- **Develop a material and process control module for structural safety awareness course**

JAMS – FAA Needs (Cont'd)

Priority 7: Fatigue & Damage Tolerance for Dynamic Composite Structure Applications

- ✓ **Address fatigue and damage tolerance in dynamic service environments, damage conditions and loads.**
- ✓ **Identify damage growth mechanism for metal-bonded and composite rotorcraft parts and investigate control through damage tolerant design and maintenance practices.**
- ✓ **Define test and engineering protocol for damage growth and arrestment options**
- **Conduct impact surveys to better understand the potential threat to dynamic rotorcraft parts.**

JAMS – FAA Needs (Cont'd)

Priority 8: Advanced Materials and Processes

- ✓ **Study new structural materials (e.g. textile material forms, nano-particle enhanced resins, chopped fiber composites) and processes (e.g. resin-molding processes, stir friction welding, automated ply lay-up and machining processes) to identify the necessary quality controls and structural substantiation protocol**
- **Study high temperature applications (e.g., ceramic matrix composites)**
- **Develop an advanced material and processes module for structural safety awareness course.**

Move Forward Plan

- Strategy to infuse more funding for composite technologies through working with our congressional offices.
- Need to point out all the technology gaps we are facing, and how partnering with Universities, and programs like AMTAS is a win-win for education, jobs, and technology.
- Need to identify very high level gaps, and point out where AMTAS falls short due to resources.

AMTAS Boeing New Proposed Research Topics (Cont'd)

Potential NDE topics:

- **Laser ultrasound for material property measurement (local stiffness/modulus measurement)**
- **Rapid non-destructive inspection methods for damage and repair**
- **Bondline strain and damage measurement using embedded nanoparticles**
- **Non-destructive method for fiber waviness quantification**
- **Thermally controlled cures in high temperature repairs using magnetic induction**

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