The Effects of Damage and Uncertainty on the Aeroelastic / Aeroservoelastic Behavior and Safety of Composite Aircraft

Presented by

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and

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Contributors

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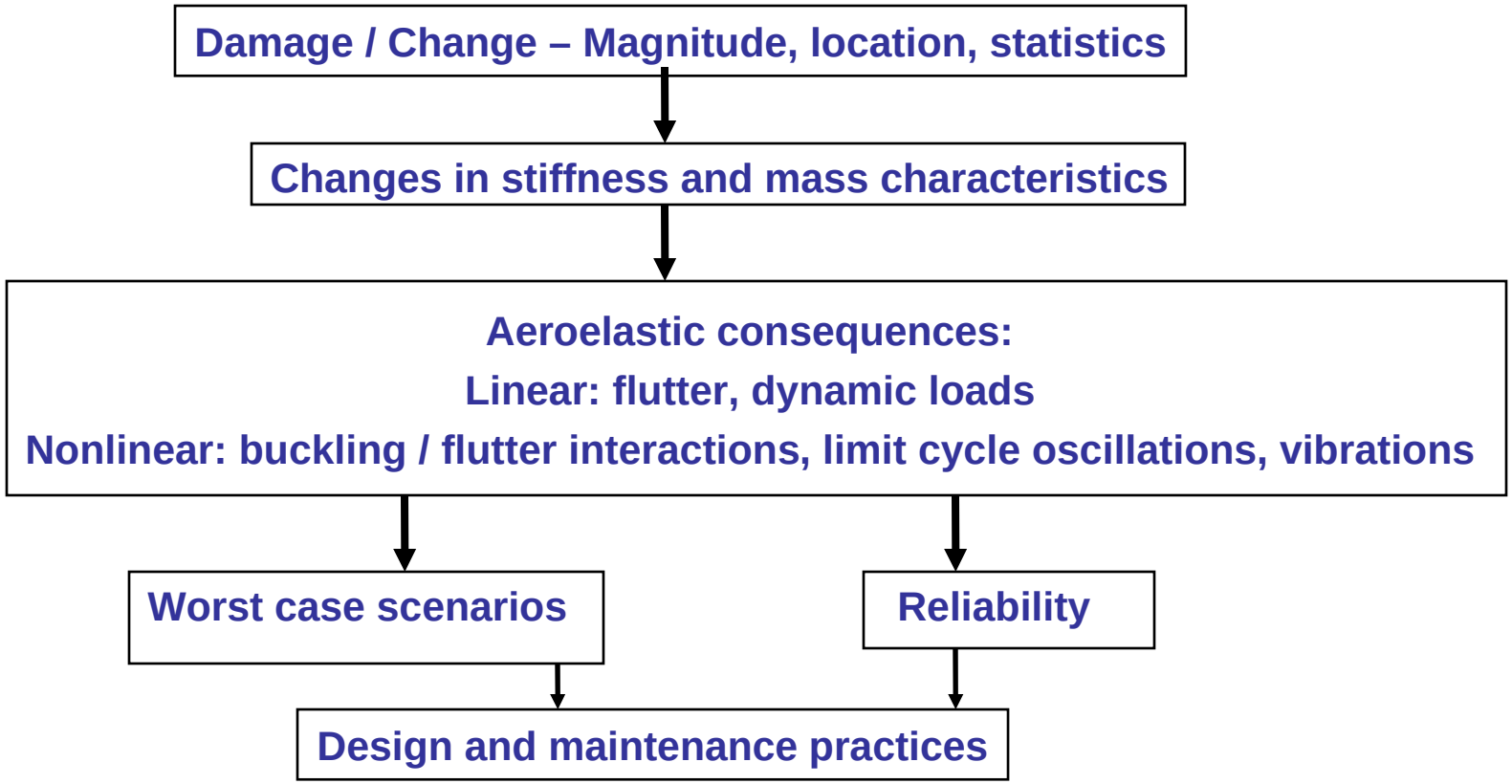
  - Andrey Styuart, research scientist, assistant professor temp.
  - Eli Livne – PI, Professor
- Department of Mechanical Engineering
  - Francesca Paltera, graduate student
  - Bill Kuykendall, Lab engineer
  - Mark Tuttle, professor
- Boeing Commercial, Seattle
  - James Gordon, Associate Technical Fellow, Flutter Methods Development
  - Carl Niedermeyer, Manager, 787/747 Flutter Engineering & Methods Development
  - Kumar Bhatia, Senior Technical Fellow, Aeroelasticity and Multidisciplinary Optimization
- FAA Technical Monitor
  - Curtis Davies, Program Manager of JAMS, FAA/Materials & Structures
- Other FAA Personnel Involved
  - Larry Ilcewicz, Chief Scientific and Technical Advisor for Advanced Composite Materials

The Problem

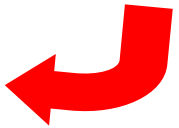

Damage / Change – Magnitude, location, statistics
Changes in stiffness and mass characteristics
Aeroelastic consequences:
Linear: flutter, dynamic loads
Nonlinear: buckling / flutter interactions, limit cycle oscillations, vibrations
Worst case scenarios
Reliability
Design and maintenance practices

Recent Major Progress Reports

- JAMS meeting in July 2007
- 3 papers at the SDM Conference in April 2007
- 2 papers submitted for publication

The Main Components of This Research

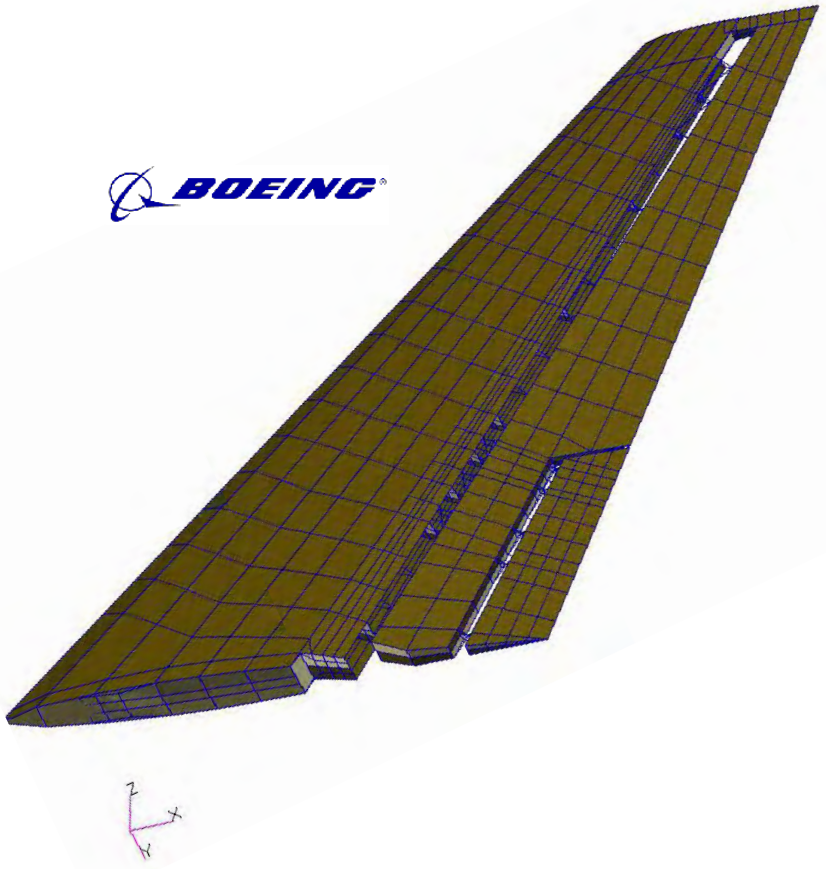
- **Automated linear flutter analysis of uncertain composite airframes with damage**
- **Flutter analysis with structural nonlinearities (damage in composites)**
- **Probabilistics / reliability**
- **Experiments: validation of analysis & benchmark results for industry**



Just a few words about:

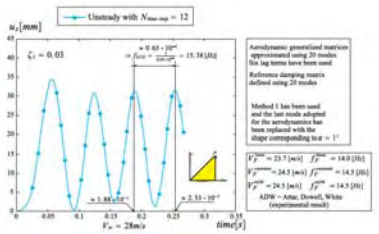
Damage Scenarios and Reliability of Composite Airframes – Classical Flutter / Linear Behavior

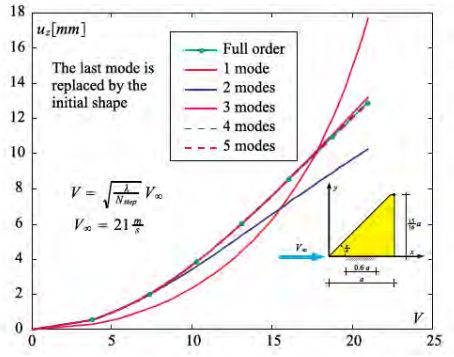
- Computational array of industry standard tools – ready and tested
- Already used for flutter damage-sensitivity and flutter-failure reliability studies of fighter wing / flaperon system
- Boeing NASTRAN vertical tail / rudder model will be provided soon and used in flutter sensitivity-to-damage and reliability studies.



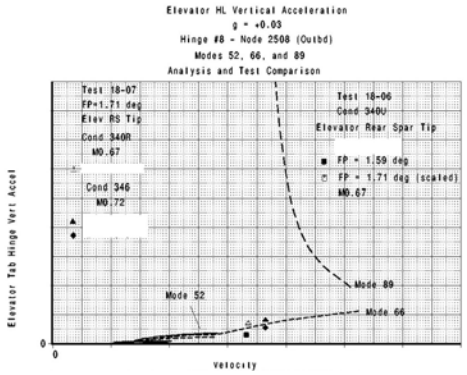
A typical passenger airplane Boeing vertical tail / rudder NASTRAN model

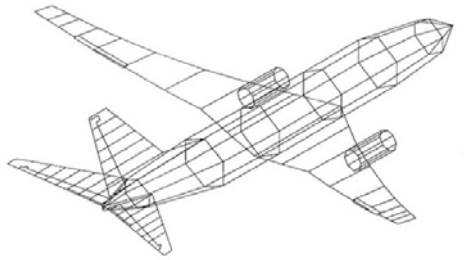
Progress in methods development for nonlinear aeroelasticity of damaged nonlinear composite structures





Progress in control surface limit cycle oscillation analysis for composite airframes





Experiments and experimental capabilities development

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

Goals:

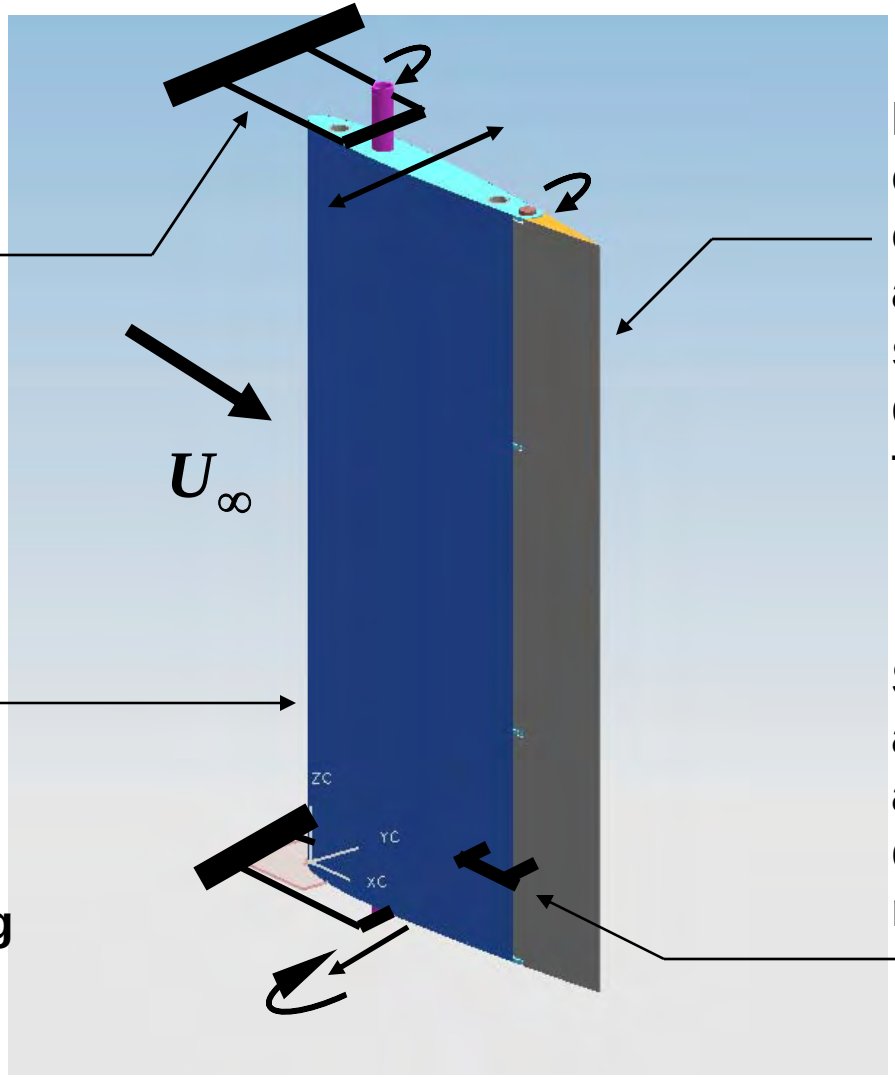
- **Develop a low-cost rapid aeroelastic testing capability at the UW for studies of aeroelastic problems of interest, with special emphasis on**
  - **Composites**
  - **damaged airframes**

  and
  - **nonlinear aeroelastic behavior**

- **Use tests to validate and calibrate numerical models**

- **Use tests to support FAA / NTSB work**

UW Flutter Test Wing / Control Surface Design mounted vertically in the UW A&A 3 x 3 wind tunnel



Wing - wind tunnel mount Providing linear Plunge And torsional pitch stiffnesses

Rudder – composite construction allowing for simulations of damage and hinge failure

Simulated actuator attachment allowing for different nonlinearities

Aluminum wing allowing for variable inertia / cg properties

Model Design and Construction

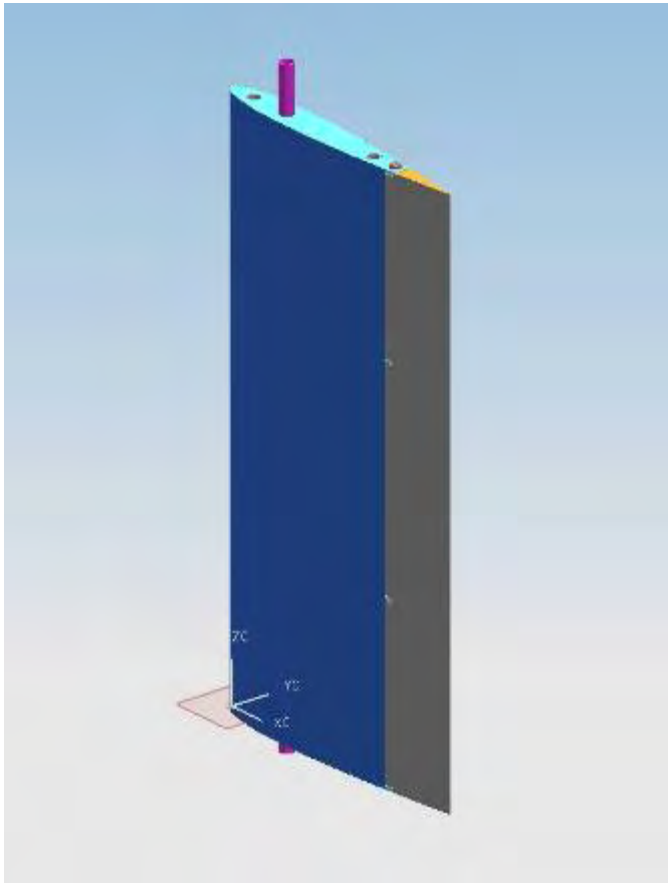
- Francesca Paltera
- Prof. Mark Tuttle
- Bill Kuykendall

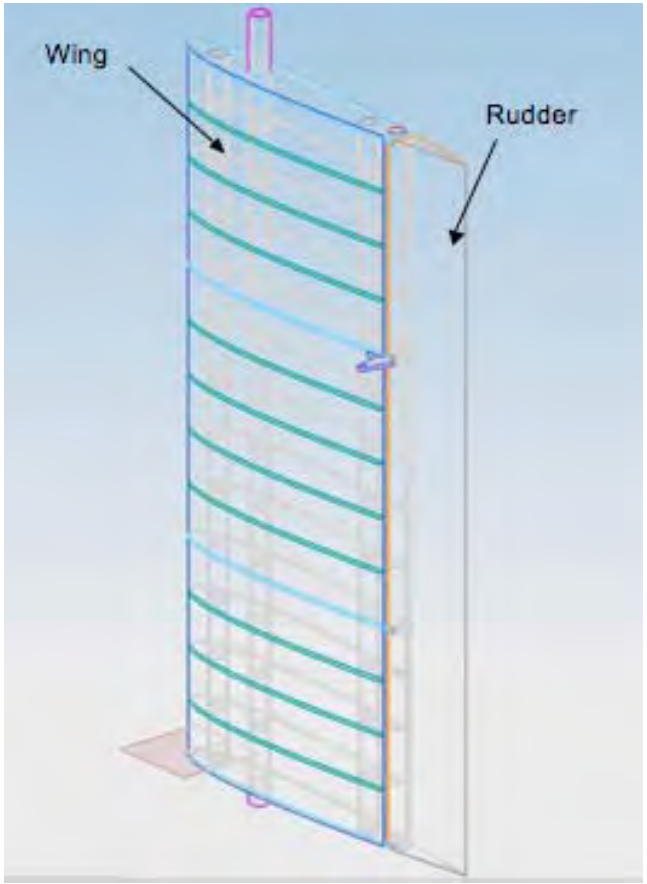
Outline

- Design
- Materials
- Manufacturing
- Assembly
- Curing
- Issues and Solutions
- Future Work

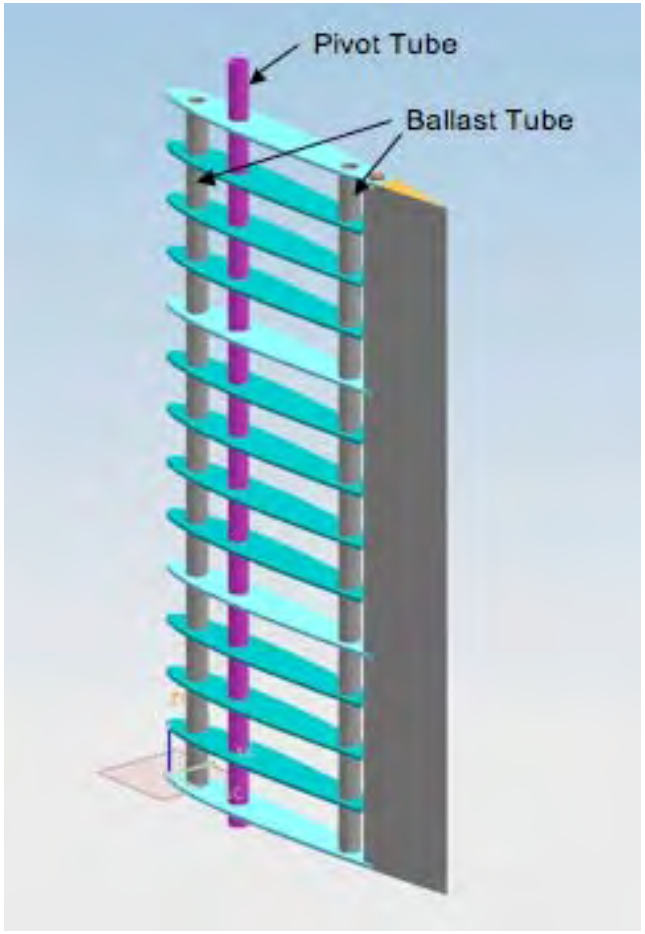
Wing Design

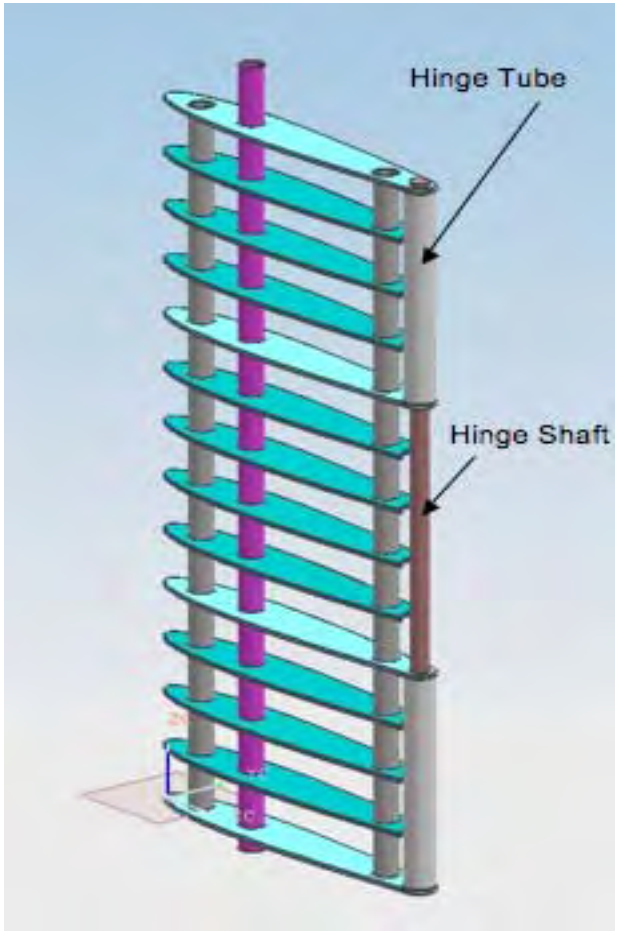
- UGS Unigraphics



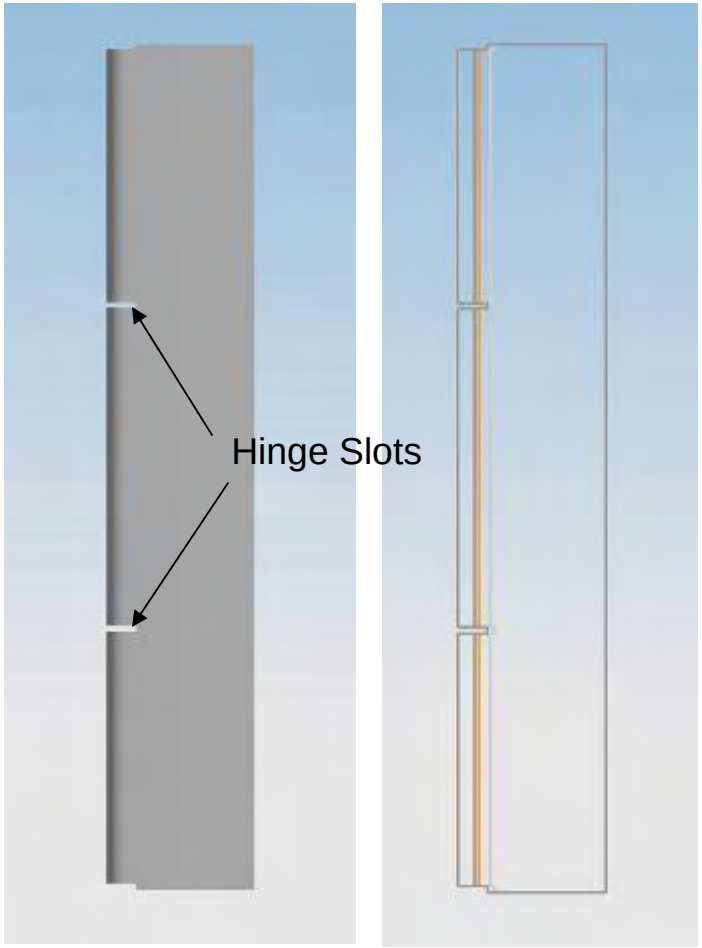


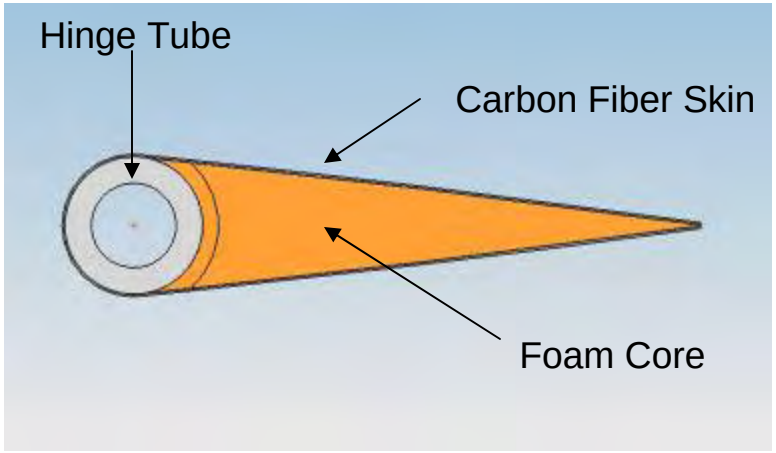
Wing Design

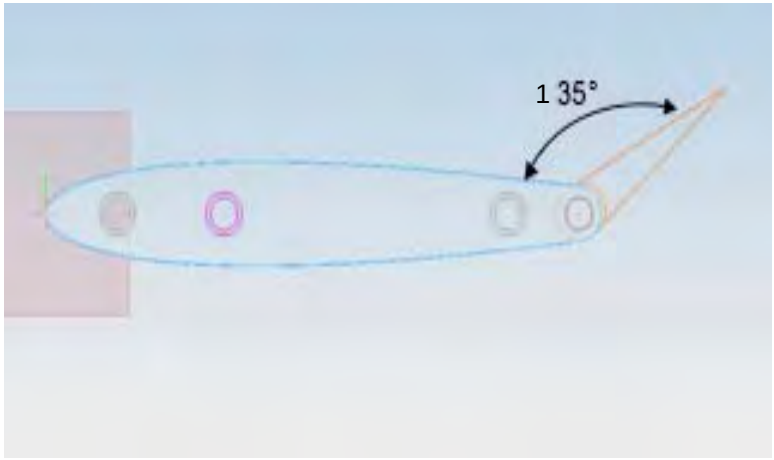




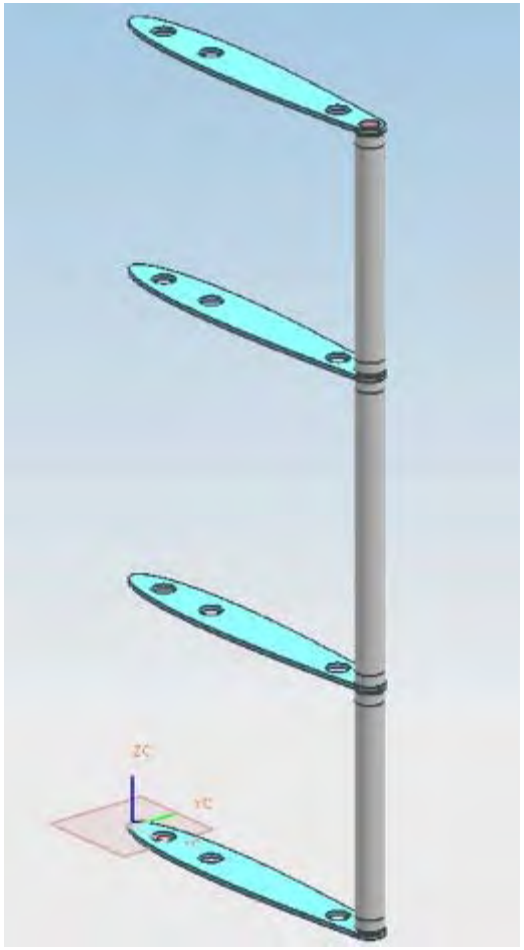
Wing Design

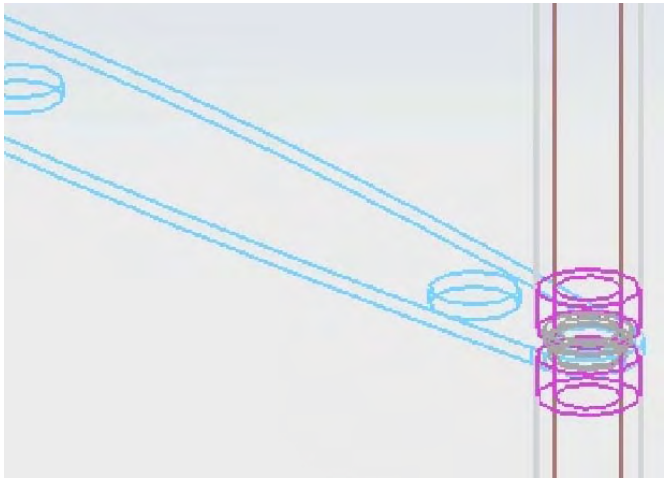


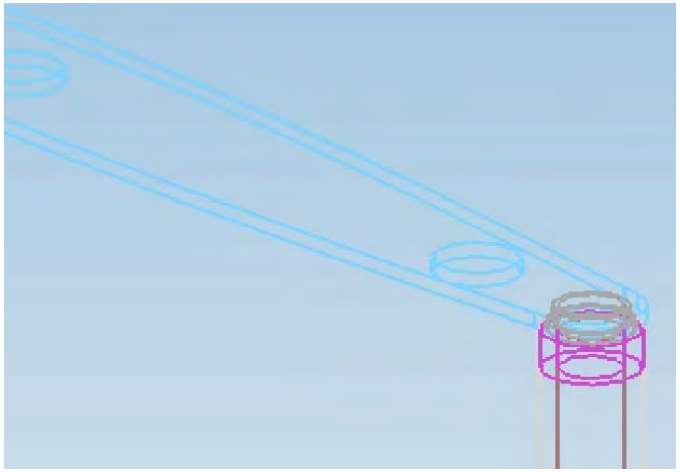




Wing Design







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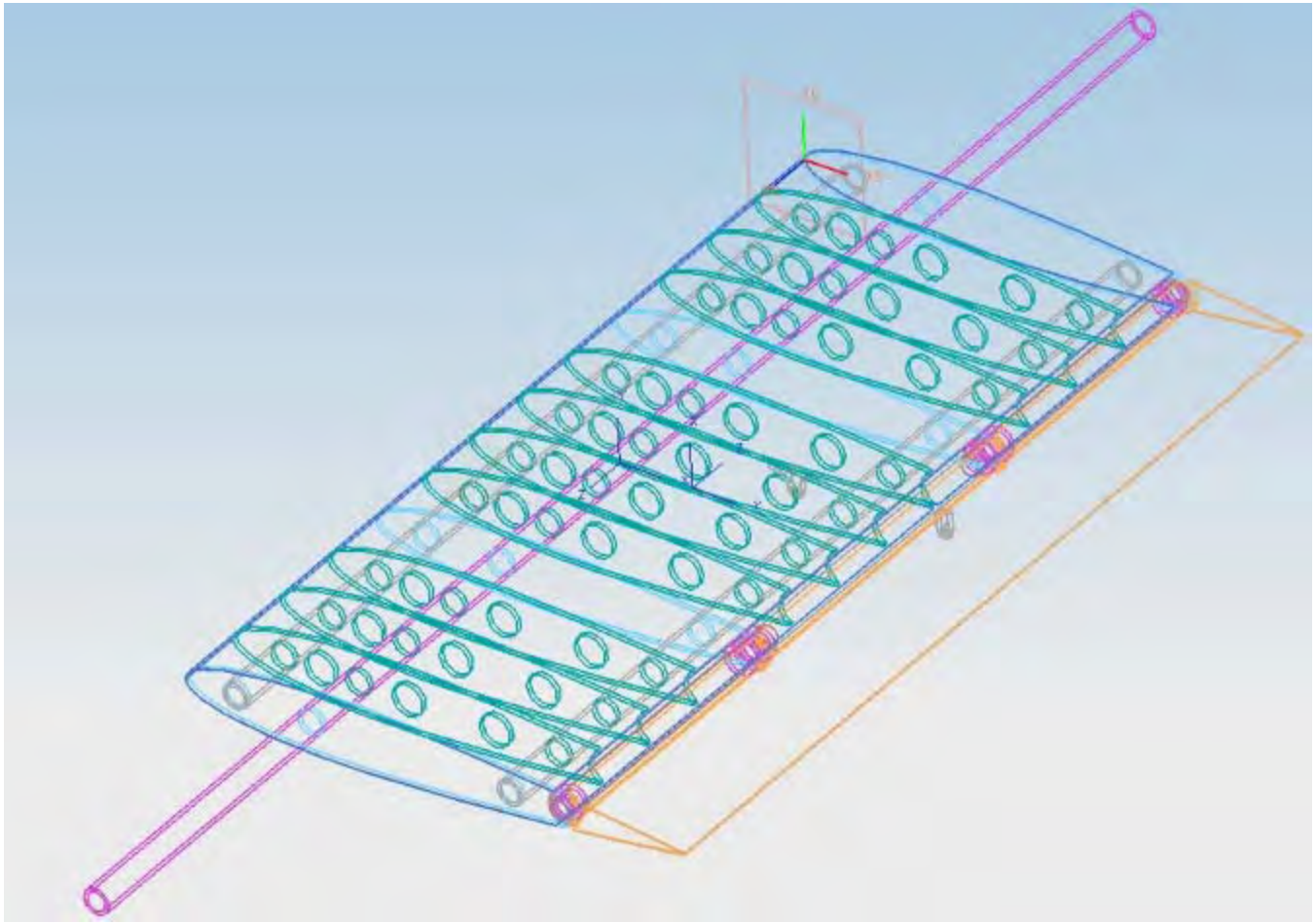
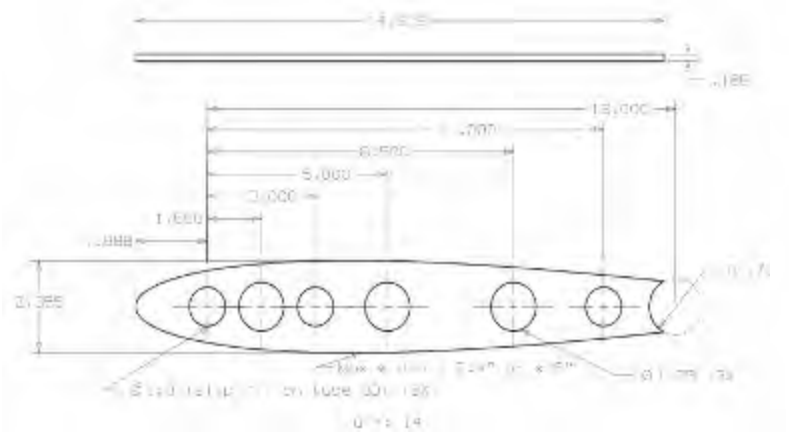
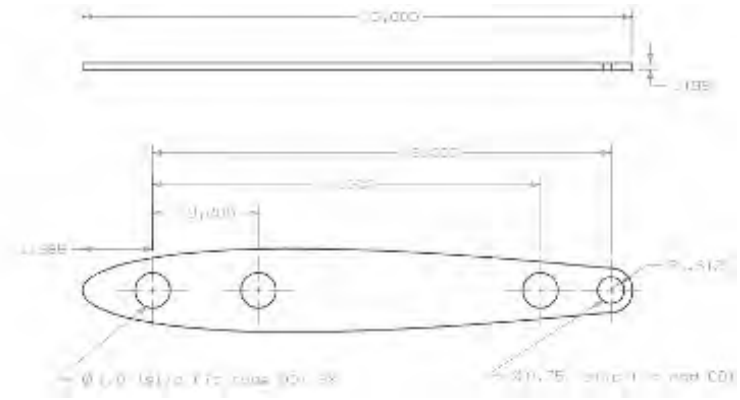


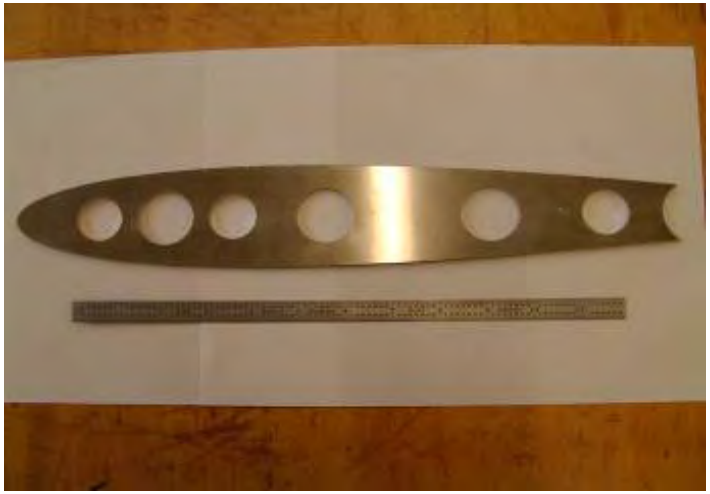
Materials

- Skin: Al 5052-H32
- Ribs, Pivot Tube, Ballast Tube and Inserts : Al 6061-T6
- Hinge Tube: Al 3003 -H14
- Shaft Tube: Al 2024
- Epoxy Adhesive: 3M DP460
- Epoxy Adhesive Film: 3M CY1-421081
- Foam: General Plastic FR10118 (density: 18lb/ft^3); General Plastic FR10518 (density: 20lb/ft^3)
- Prepreg: HEXCEL M47JB/M71
- Strain Gages: Vishay Micro-Measurements CEA-06-125UW-120

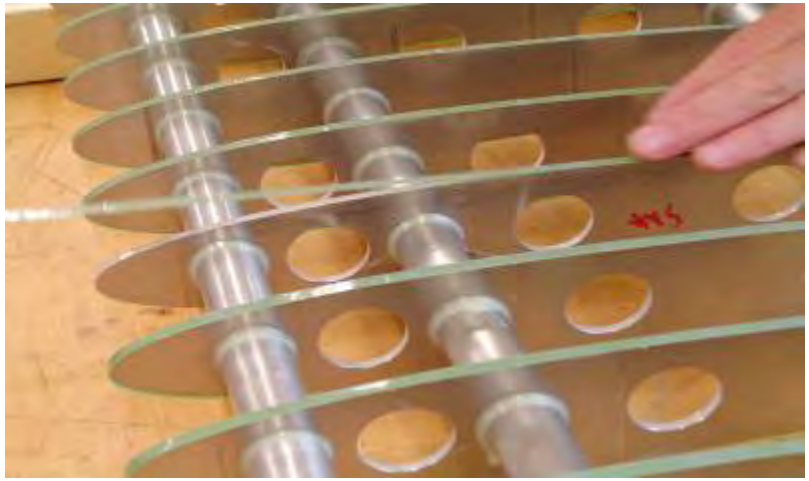
Ribs Manufacturing

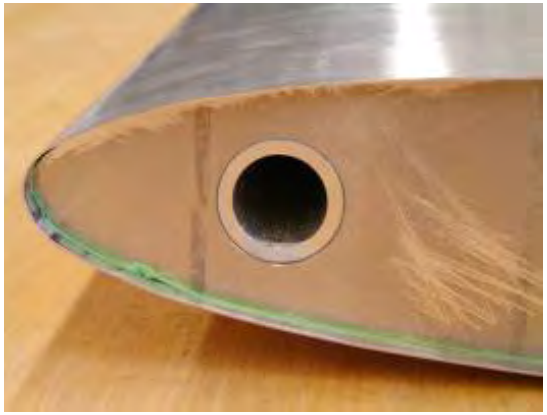




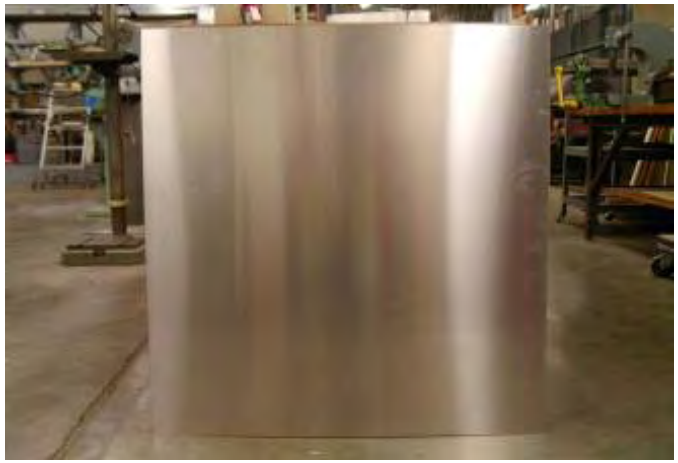


Wing Assembly

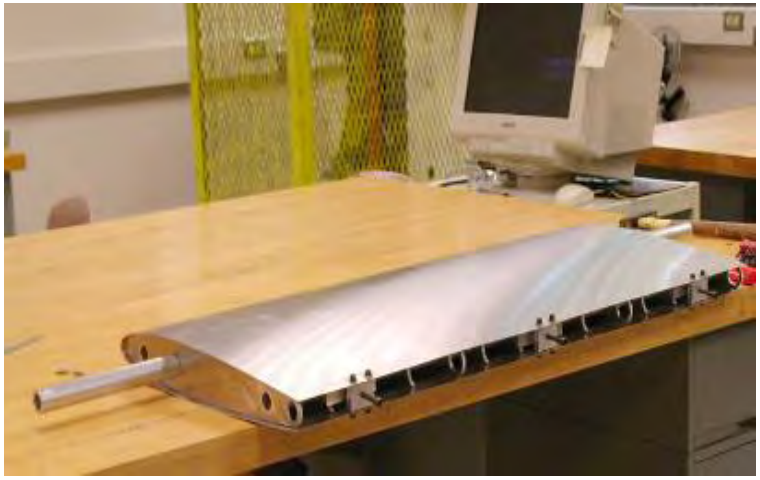




Skin Manufacturing



Tension System



Wing Curing

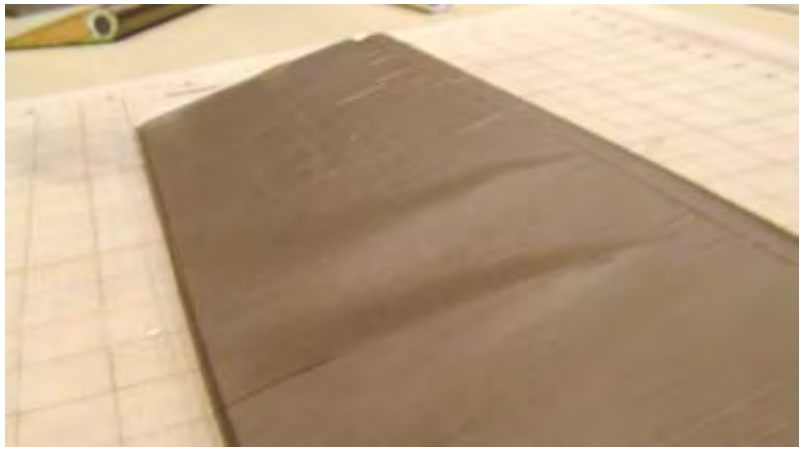
Foam Machining

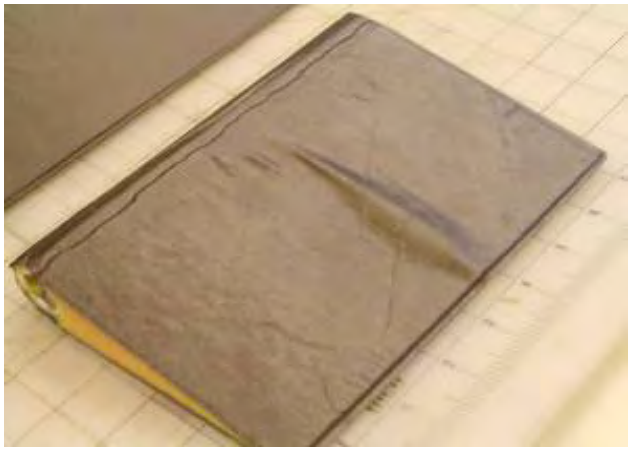
Rudder Assembly

Rudder Curing

- Initial process utilized General Plastic Foam FR10118 (density: 18lb/ft^3) and vacuum pressure only;
- Substantial delamination encountered between prepreg adhesive film and foam core;
- Several attempts using different cure temperatures, times and cooling rates were unsuccessfull;

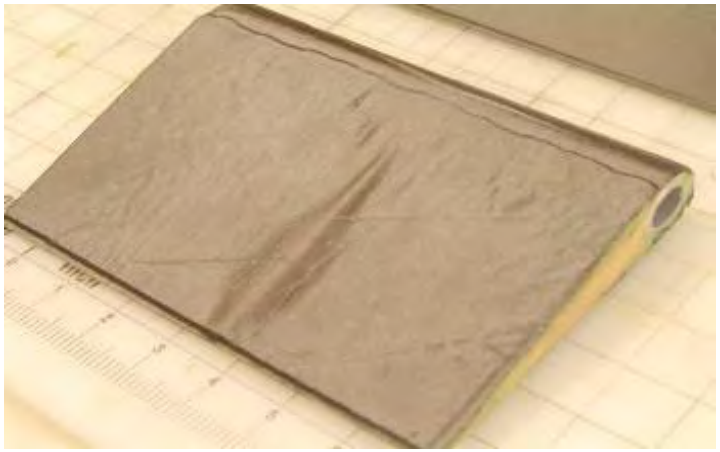
Delamination





Solutions

- Autoclave Process: 2hrs curing, 80 psi, 350 °F;
- Vacuum and pressure maintained throughout the curing process until cool down reached 70°F;
- Cool down rate: 2.5 °F/min;
- General Plastic Foam FR10518 (density: 20lb/ft^3) utilized.

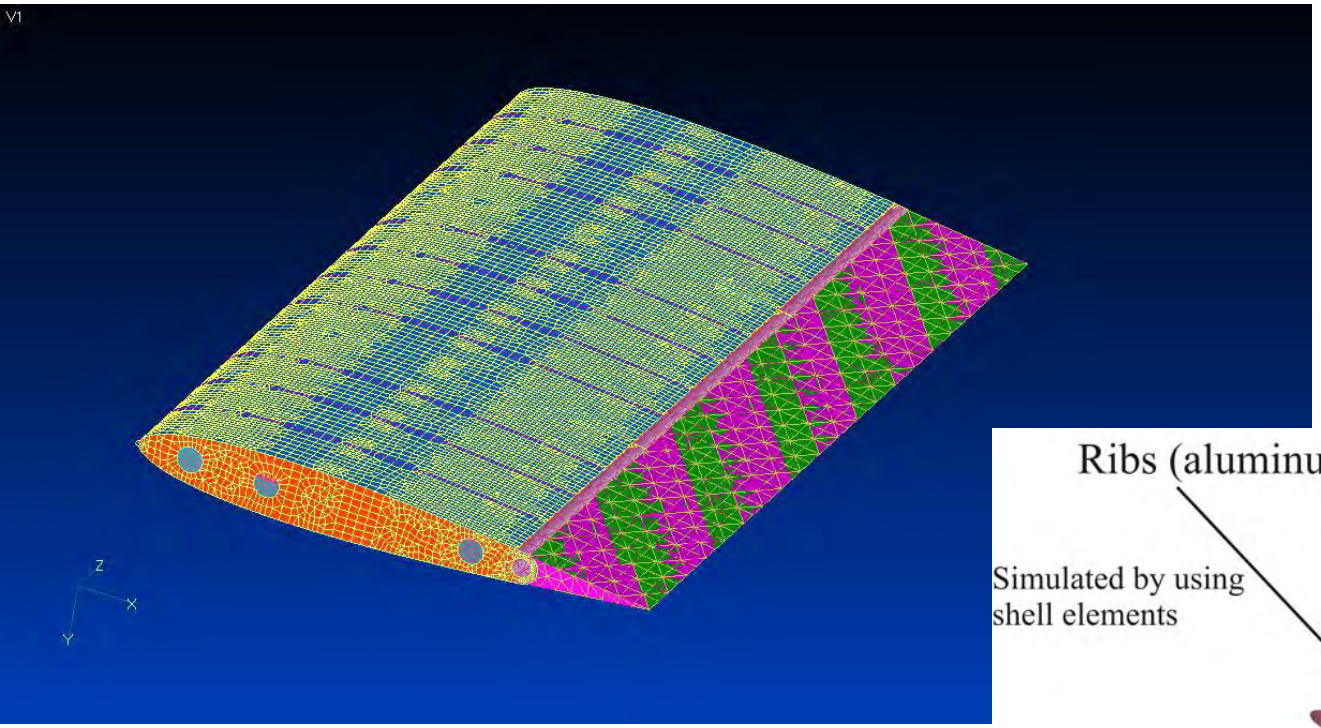


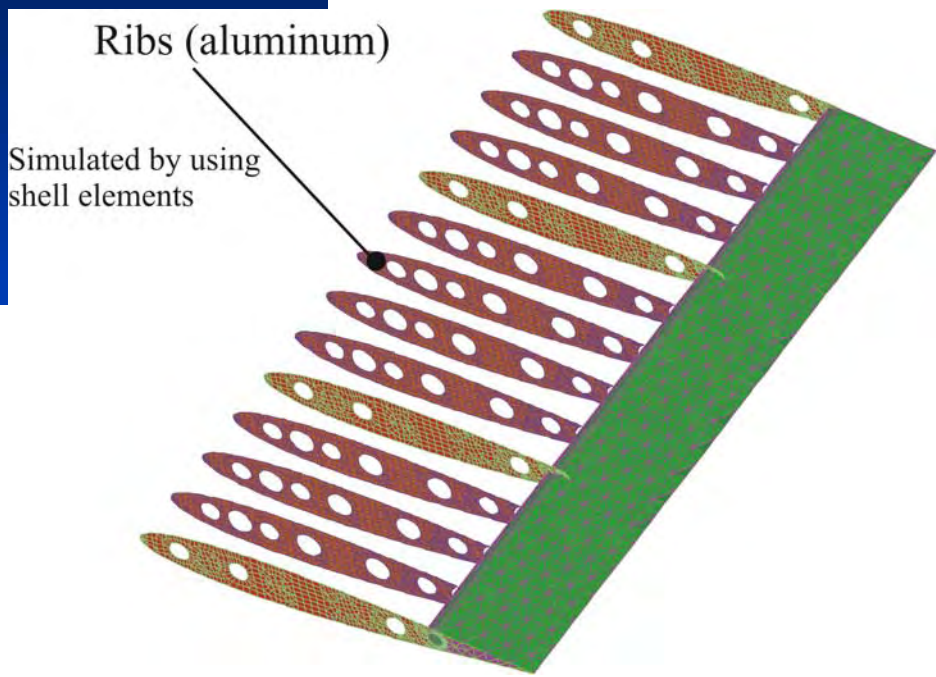
Future Work

- UW Autoclave too small for a 36 inch rudder;
- INTEC will be hired for large capacity autoclave use, in order to produce a defect free rudder in the week of October 29th 2007;
- Wind tunnel experiments scheduled throughout November and December 2007, to obtain empirical results in order to calculate flutter speed;
- Subsequently, additional rudders (3 to 5) with intentionally induced damage will be produced (delamination will be induced by using release mold and Teflon between the composite plies, between the foam and the composite, and between the shaft tube and the composites).

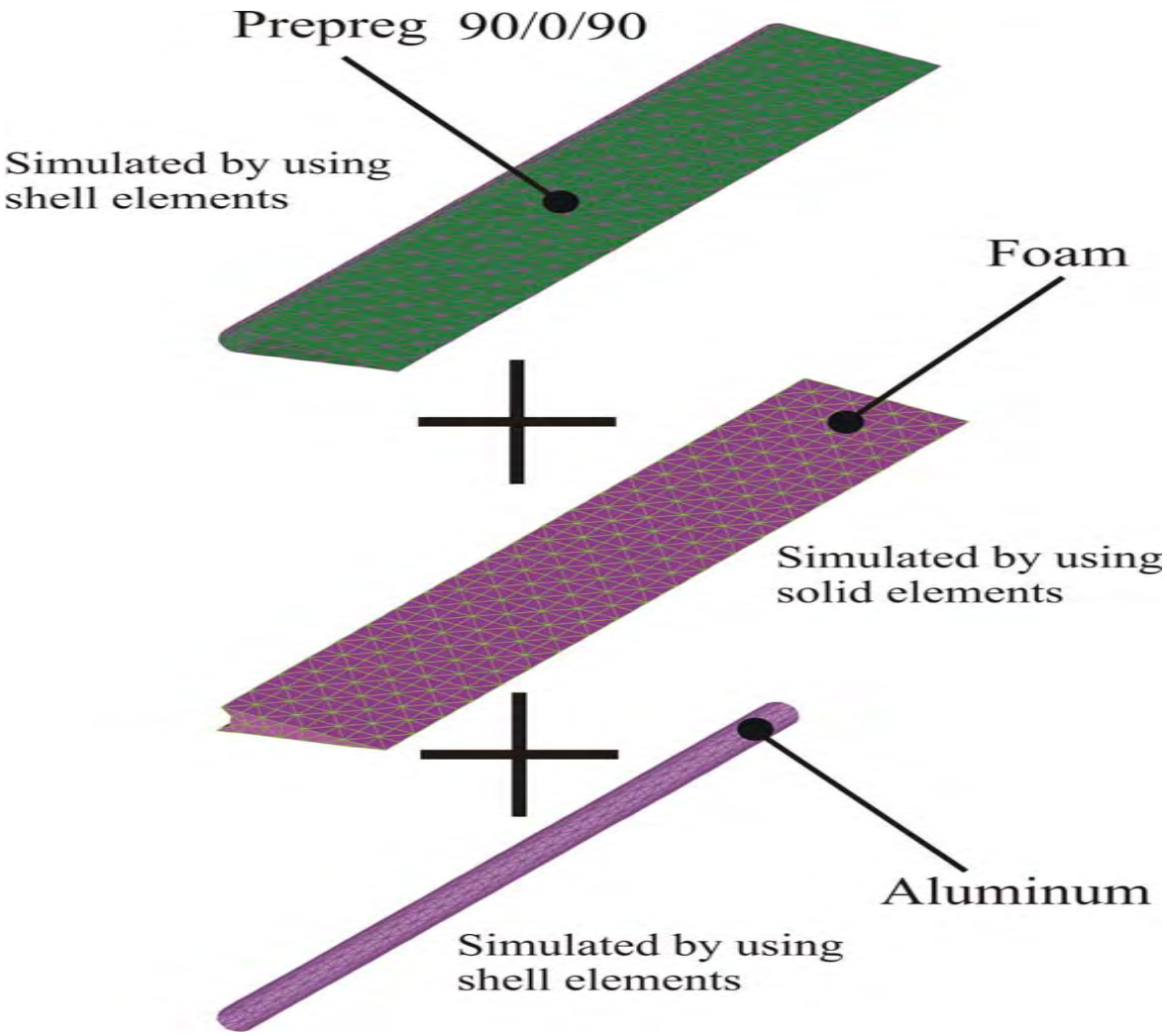
Model CAD and FE Modeling

Model FE Model

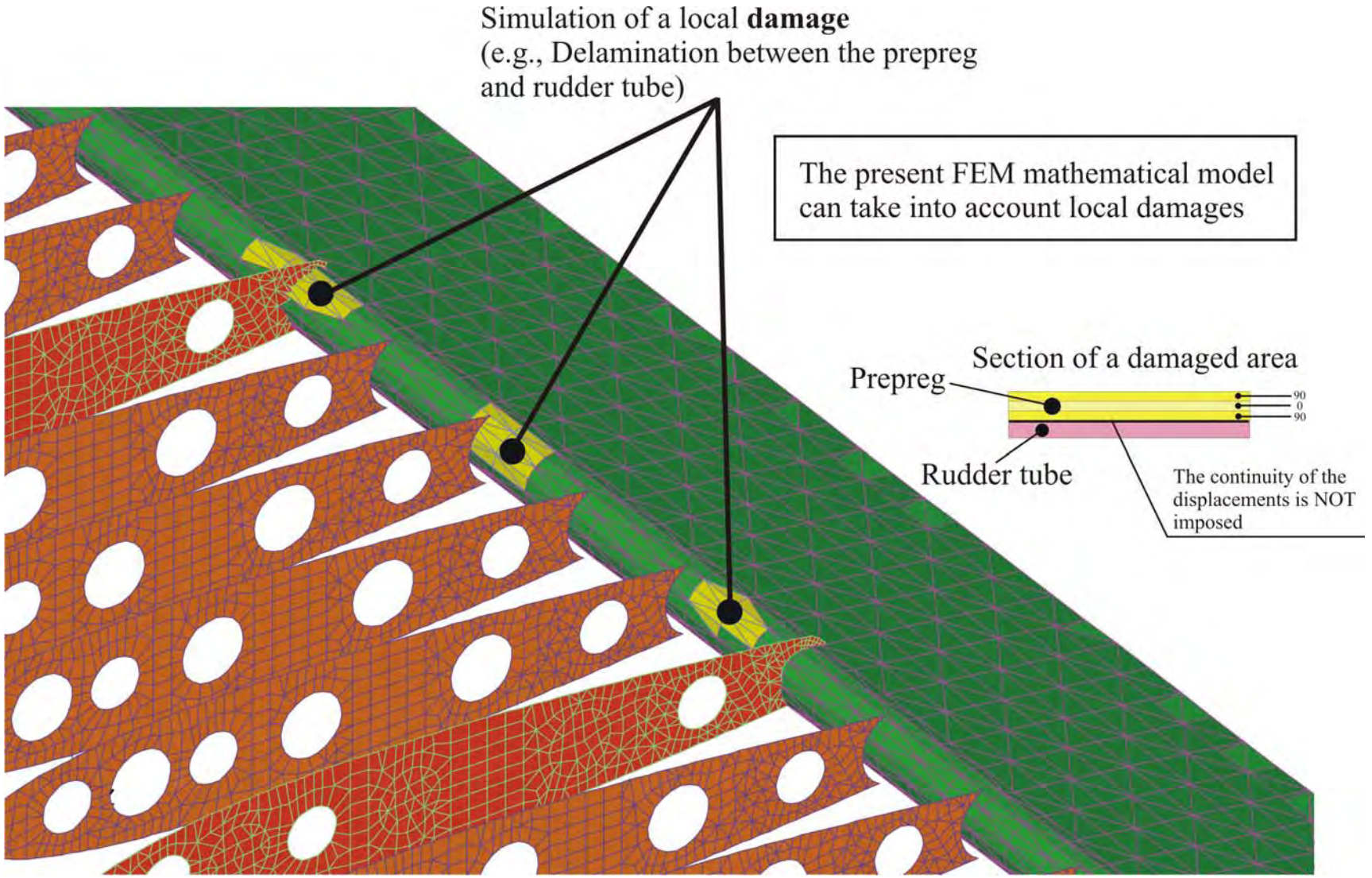




W.T. Model Rudder FE Model



W.T. Model – Debonding Effects Example



Conclusions

- Progress made in all areas of the project
- Major progress is expected in the next few months:
  - Aeroelastic tests
  - Worst case scenarios identification and reliability studies of the representative composite vertical tail / rudder system