Design and Testing of Composite Wind Turbine Technologies

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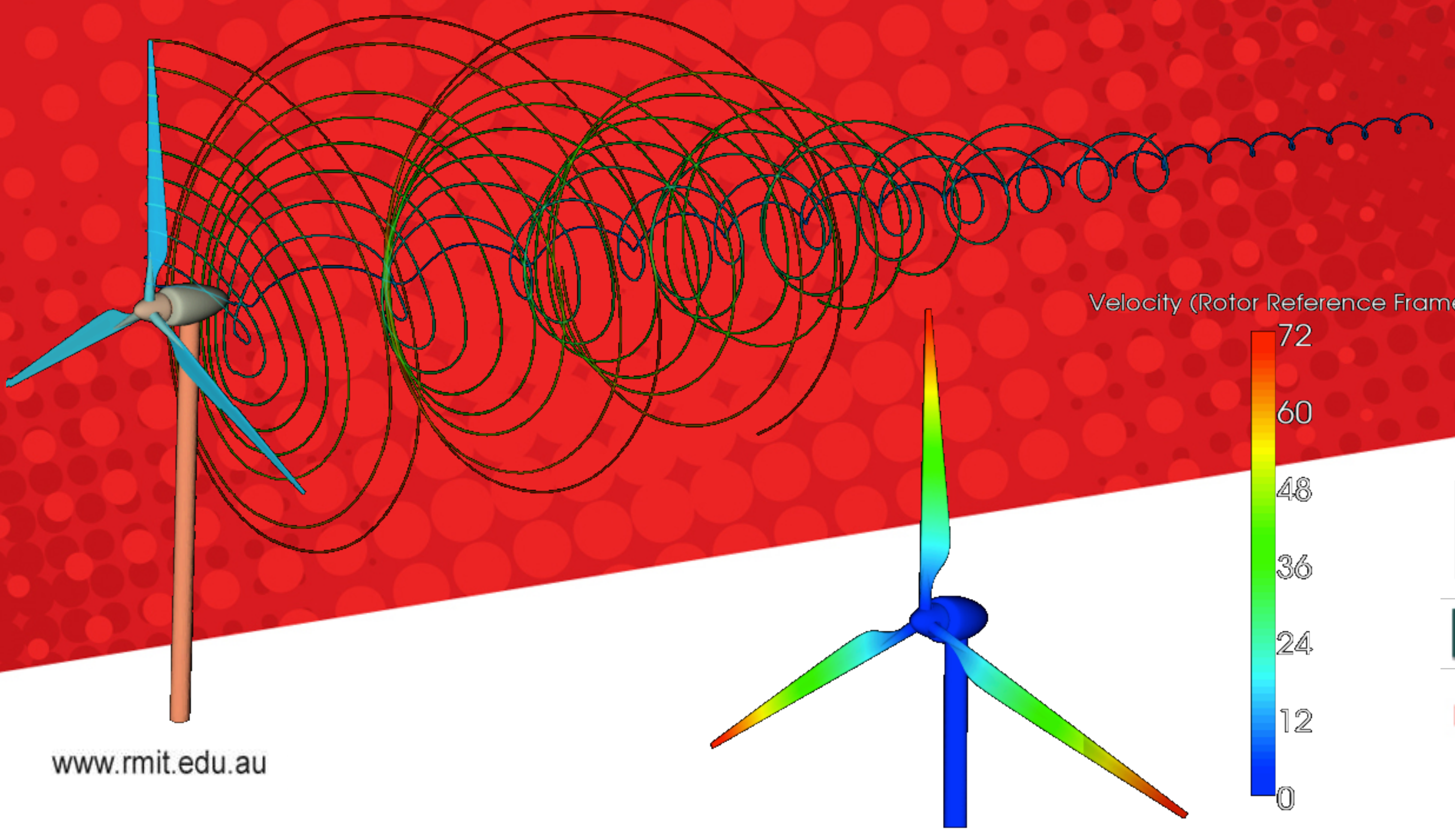

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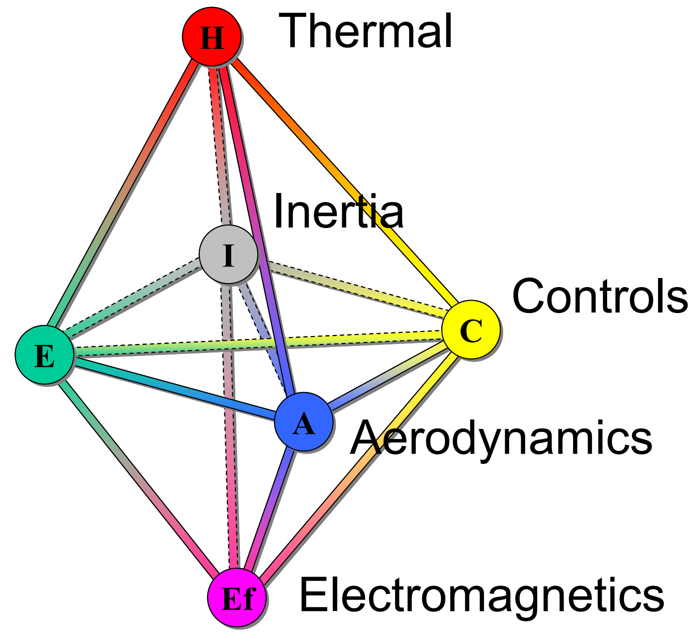
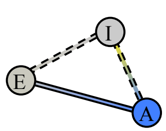
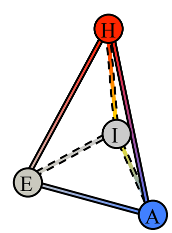
Applied Aerodynamics & Aeroelasticity Lab
Clarkson/CECET Blade Test Facility (BTF)



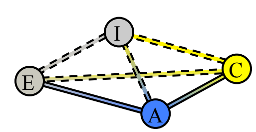
- Aero-elasticity



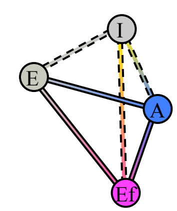
- Aero-thermo-elasticity



- Aero-servo-elasticity



- Aero-magneto-elasticity



Wind Energy Research Activities

WT Blades FSI and Damage Progression

- Composite Blade Design
- Composite Thin-walled-Beam Modeling
- Aeroelastic and Aerodynamic Control
- Aeroelasticity of WT Blades
- System Identification
- Damage Progression
- Structural Health Monitoring
- Load Monitoring

Small Wind Turbine Technologies

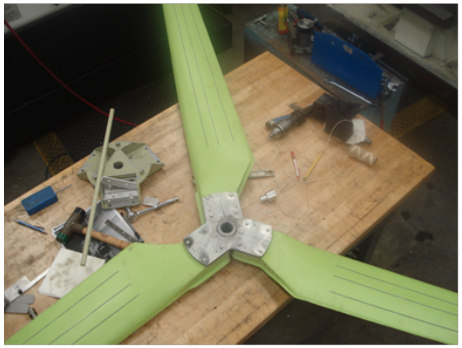
- Wind Tunnel and Field Testing
- Blade/Components Structural Testing
- Active/Passive Flow Control
- Power Performance Evaluation

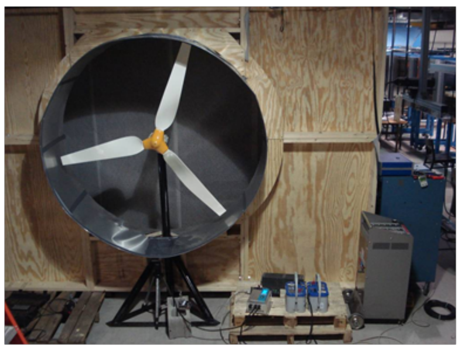
Wind Resource Assessment

- UAS Flight Measurements
- Computational Fluid Dynamics

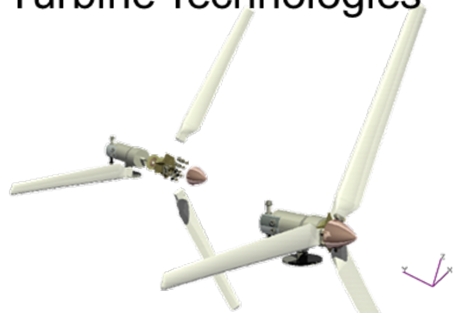
Design and Performance Analysis of WT
Active and Passive Control of WT

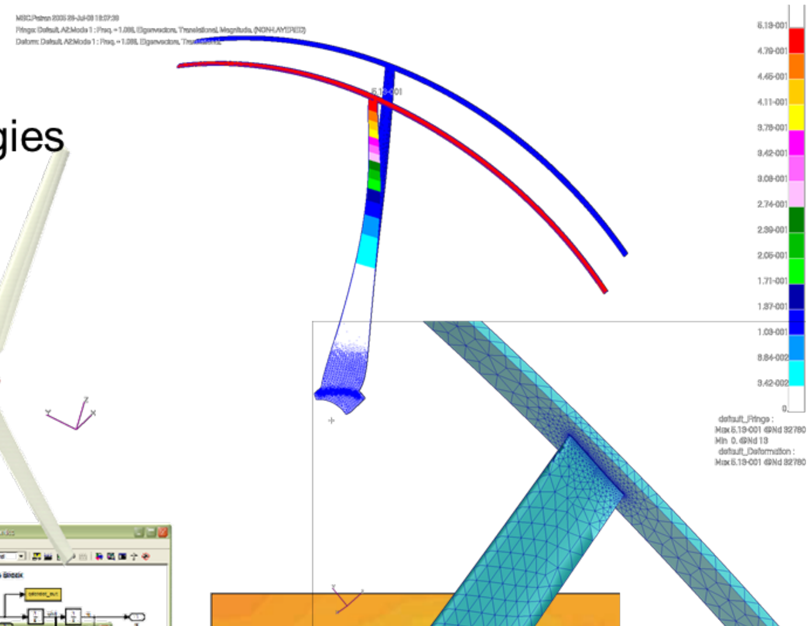
- Active Control
- Passive Control

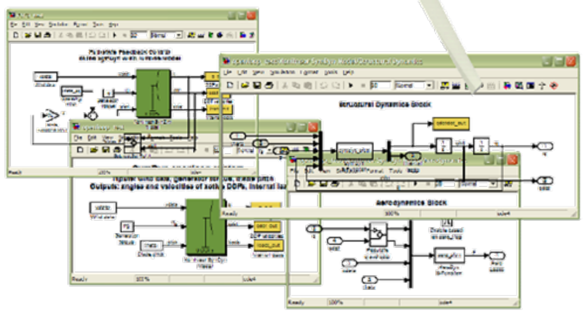


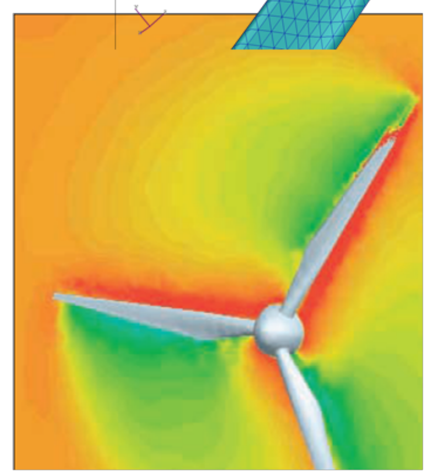


Active/Passive Control for Wind Turbine Technologies



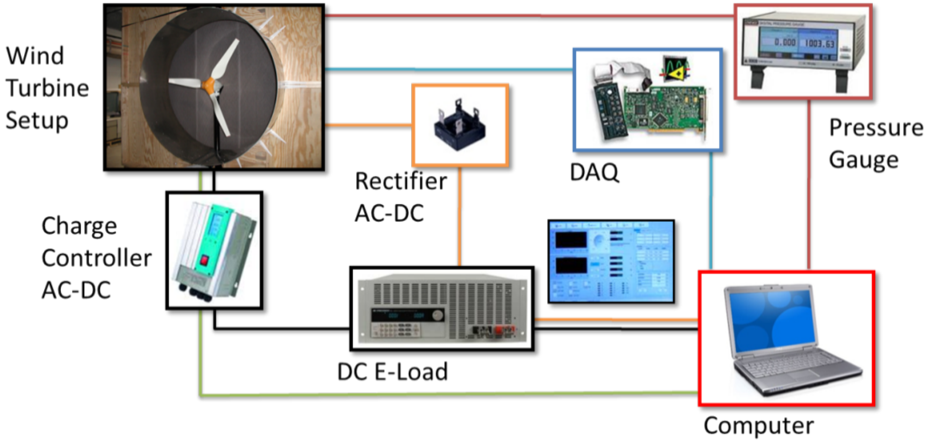


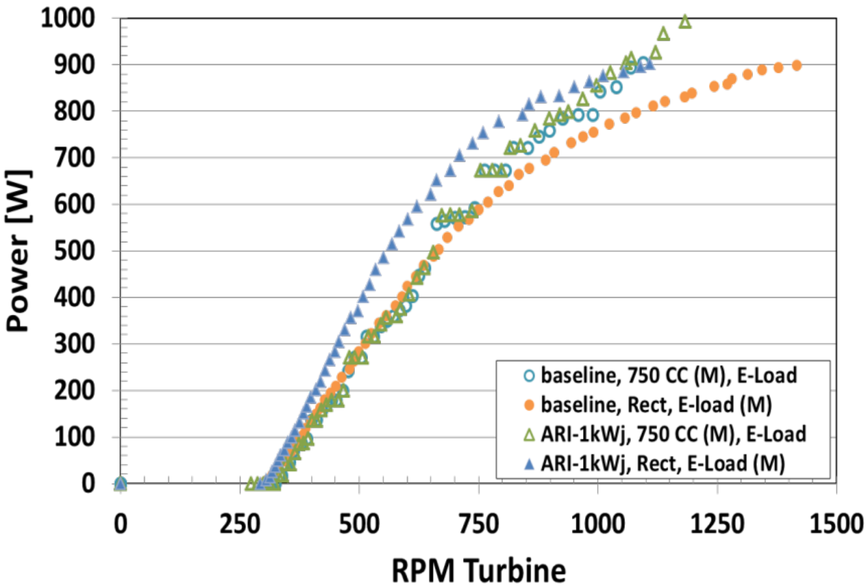




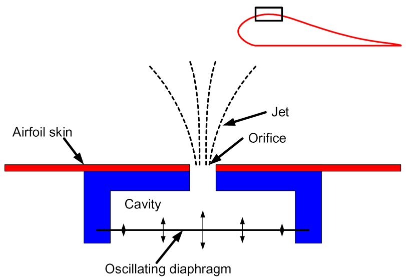
Design and Performance Analysis of WT Active and Passive Control of WT

- Wind Turbine Test in the Open-Jet Wind Tunnel Facility
- Power performance
- Comparison blade testing



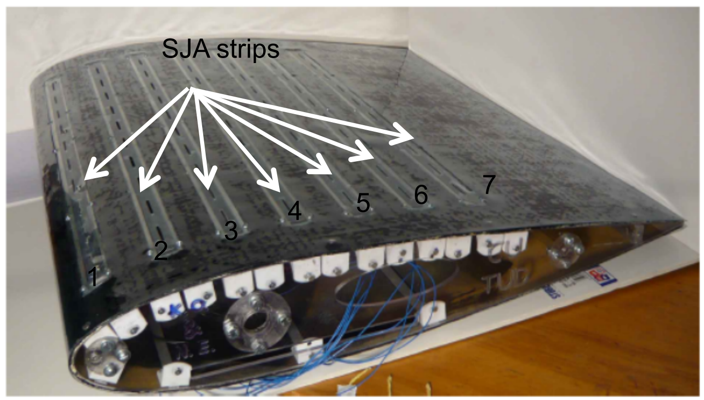


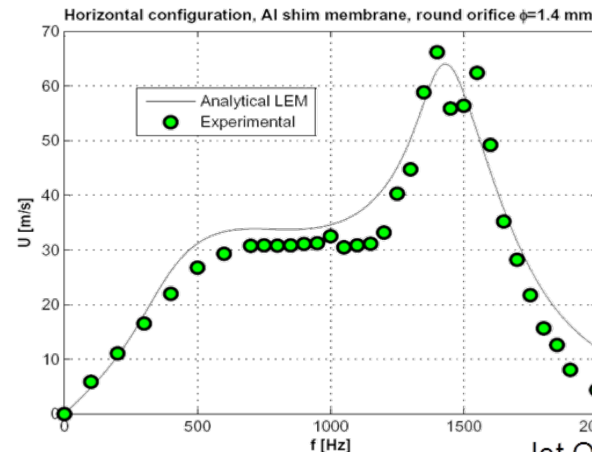
WT Active Aeroelastic Control with Synthetic Jet Actuators



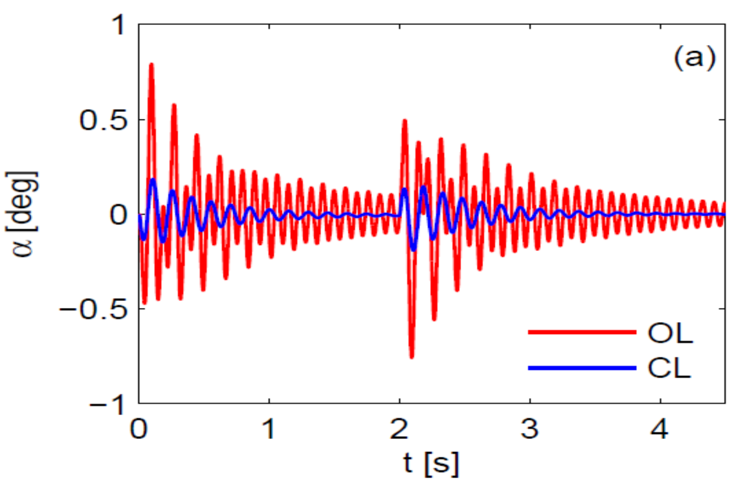
ZNMF

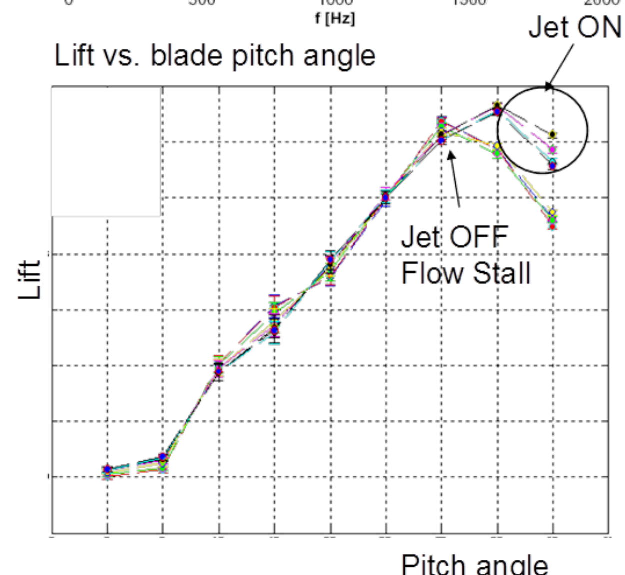
- 300kW WT

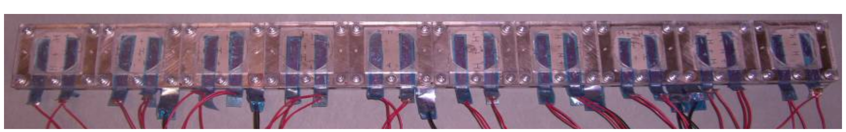




- Aerodynamic ROMS
- Aeroelastic Control
- Flutter suppression
- Gust/Load alleviation

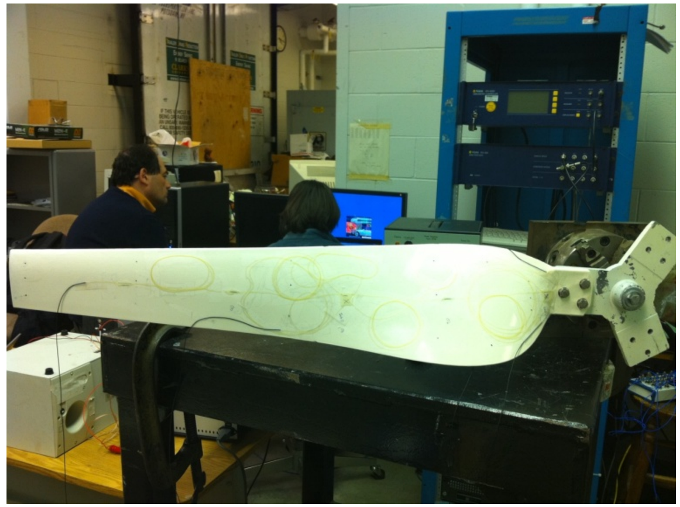


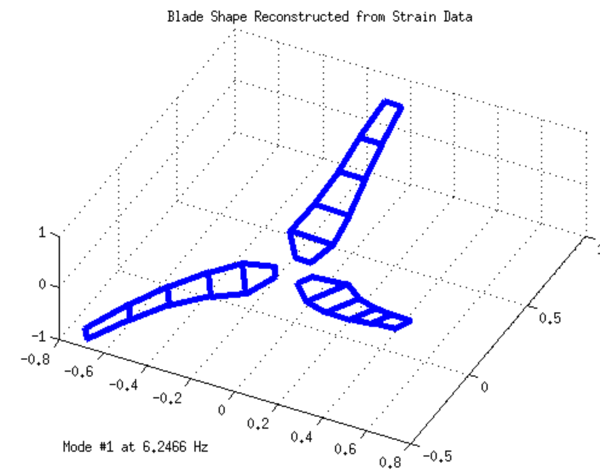




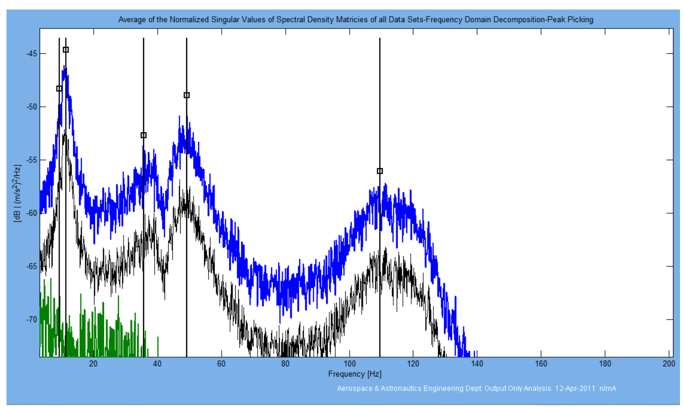
Synthetic Jet Actuators Strip

Blade Structural Characterization and System ID – SHM and Load Monitoring

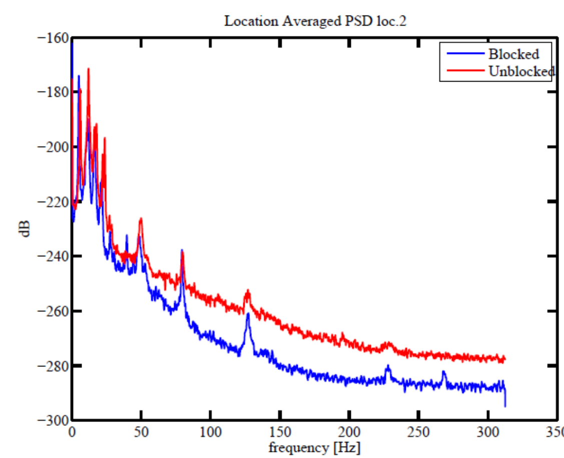




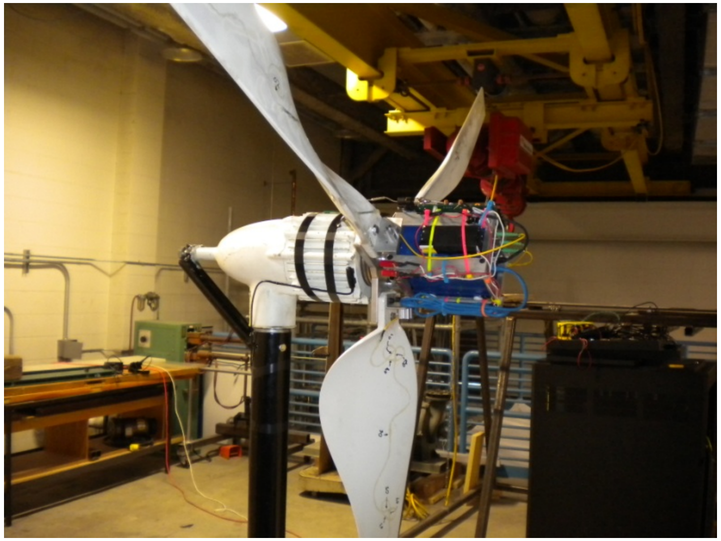
- FBG strain sensor
- Operational Modal Analysis

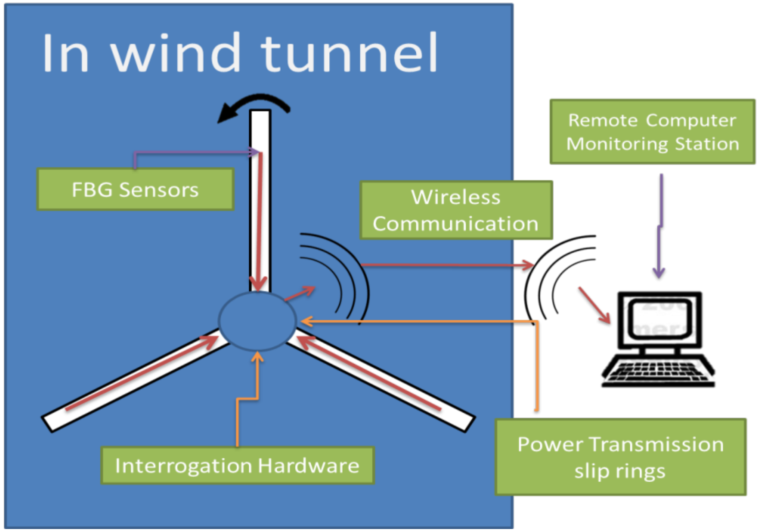


- Modal properties reconstruction



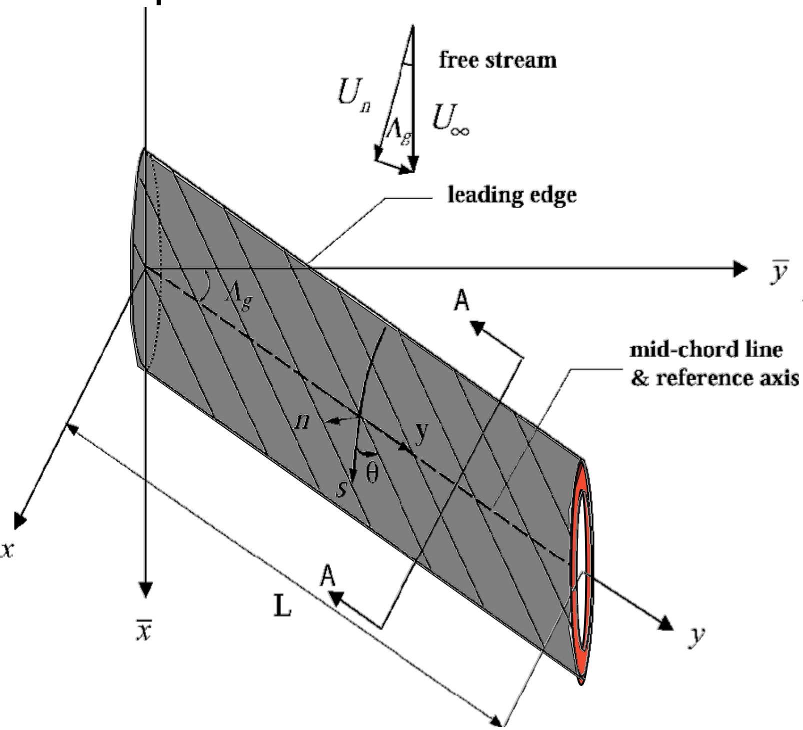
Blade Structural Characterization and System ID – SHM and Load Monitoring

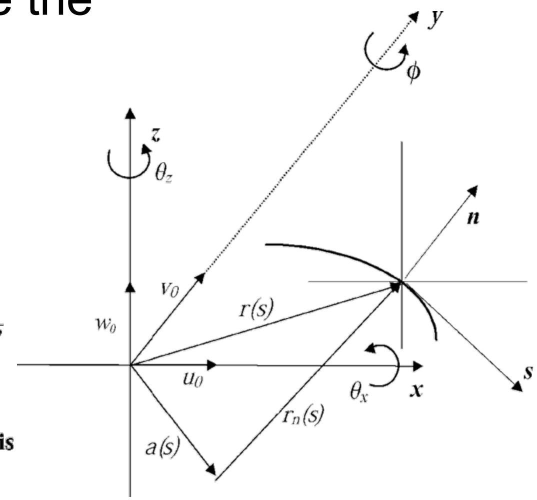


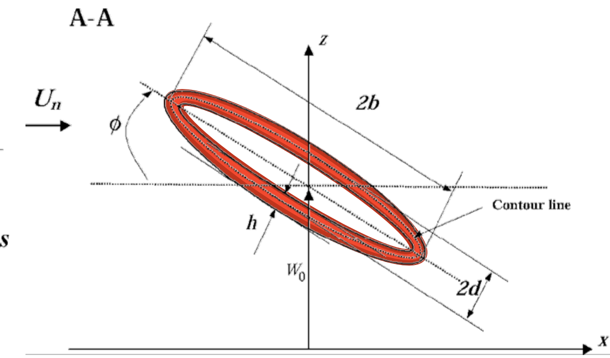


Aeroelasticity of Thin-Walled Composite Wing and Rotating FGM Blades

- **Aeroelastic Tailoring:** What are the important effects to consider?



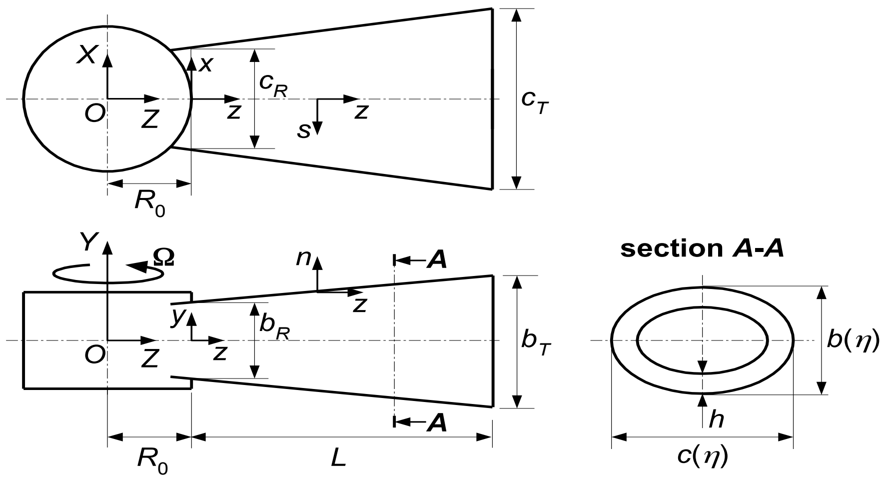




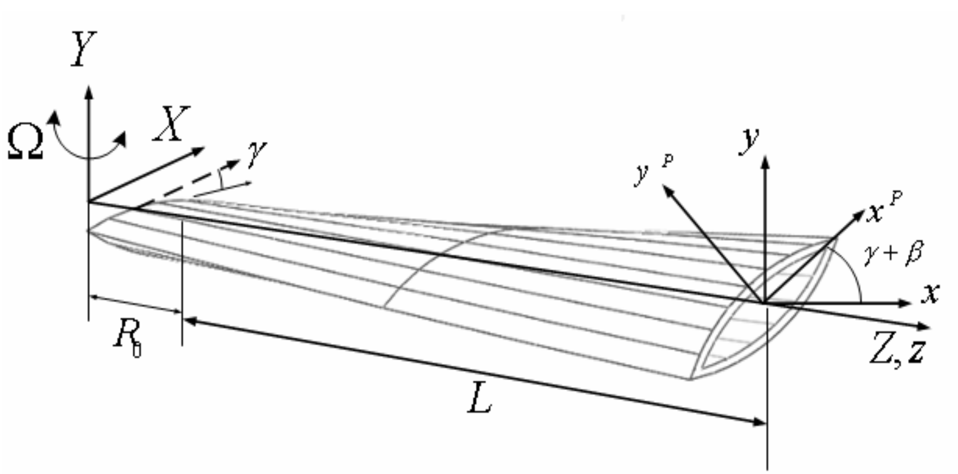
- Transverse shear, warping restraint, non-uniformity of shear stiffness, and three-dimensional strain effects

- Single/multi-cell closed cross-section, fiber-reinforced composite thin-walled beam
  - E-B: E/G = 0, transverse shear stiffness is infinite.
  - For anisotropic composite material E/G=O(100).
  - The classical St. Venant twist model not applicable
  - Restrained twist model
  - The non-uniformity of shear stiffness has a significant influence on warping and twist

Aeroelasticity of Thin-Walled Composite Wing and Rotating FGM Blades

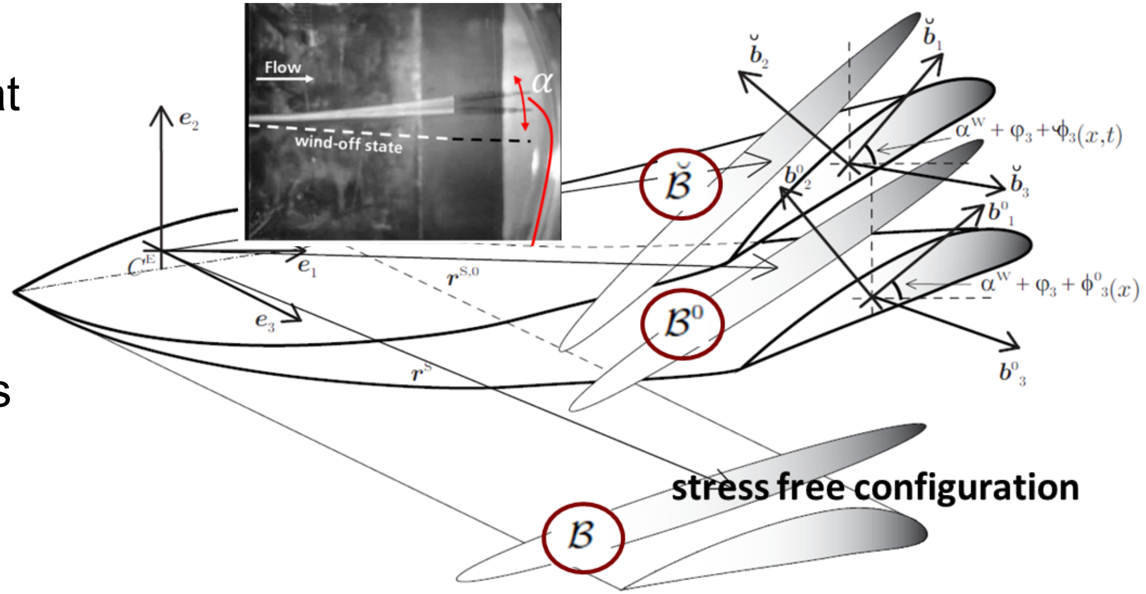


- Coriolis effect, and centrifugal acceleration
- Functionally Graded Material properties, constituent material of the structure features thermo-mechanical properties.
- In-plane strains are assumed to be negligibly small when compared with the axial strain.



Nonlinear Aeroelasticity with Fully Nonlinear Wing Models

- 1D Parametric Cosserat Continuum
- Geometrically exact semi-intrinsic theory
- EOM in Updated and Total Lagrangian Forms



finite 3D kinematics: finite displacements and rotations

Kinematic descriptors

Static

$$u^0(x) = u_1^0(x)e_1 + u_2^0(x)e_2 + u_3^0(x)e_3$$
$$\phi_i^0(x) \ \forall \ i = 1,2,3$$

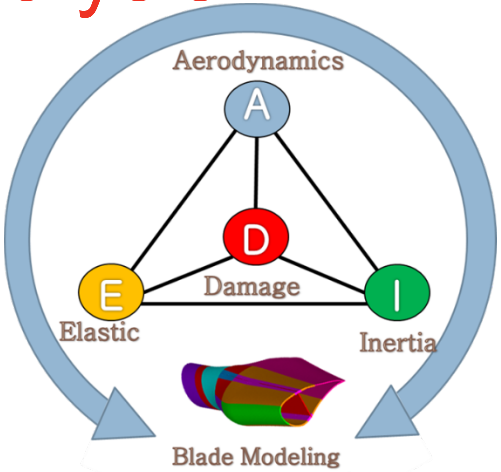
Dynamic (ULF)

$$u(x,t) = u_1(x,t)e_1 + u_2(x,t)e_2 + u_3(x,t)e_3$$
$$\phi_i(x,t) \ \forall \ i = 1,2,3$$

- **Geometrical exact formulation:** Shear strains and the stretch configuration in their fully nonlinear form (warping effects neglected)

Aeroelasticity of Damaged Rotor TWB & Progressive Failure Analysis

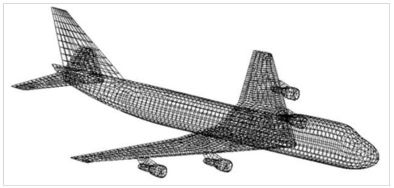
- **Progressive Failure Analysis (PFA) into a Thin-Walled Beam (TWB) FE model**
- Semi-Analytical Representation of Finite Element Models via Progressive Polynomial and B-Splines Reduction of Modal Data (Poly-SAFE, B-SAFE)



Based on FEM Model

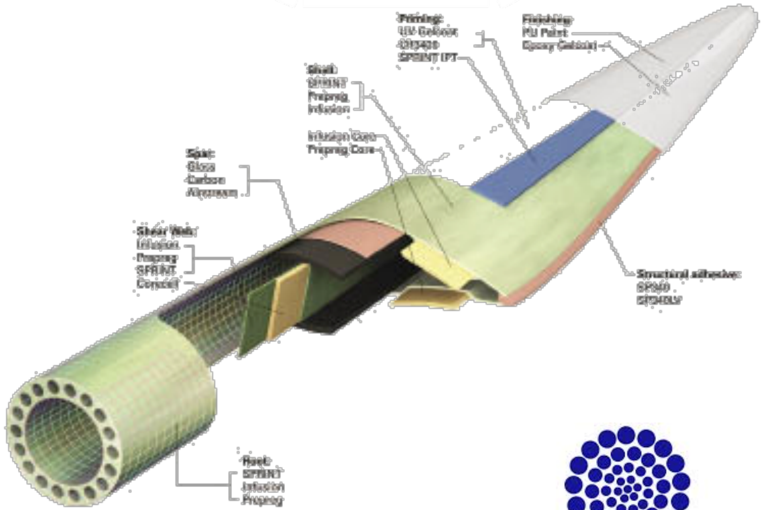
SIMULIA

ANSYS



AlphaSTAR

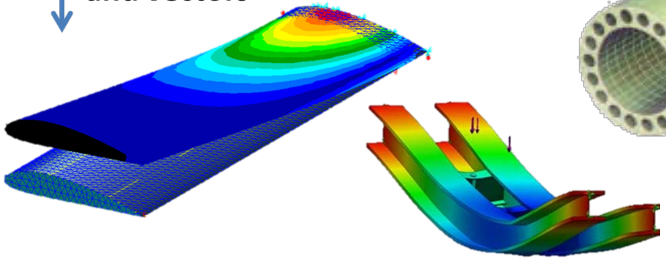
MSC Software



Use Simple Modal Analysis

To extract eigenvalues and vectors

Simple approach to obtain Displacement, strain and stress analytical function to evaluate static, dynamic, aeroelastic behavior of structural systems



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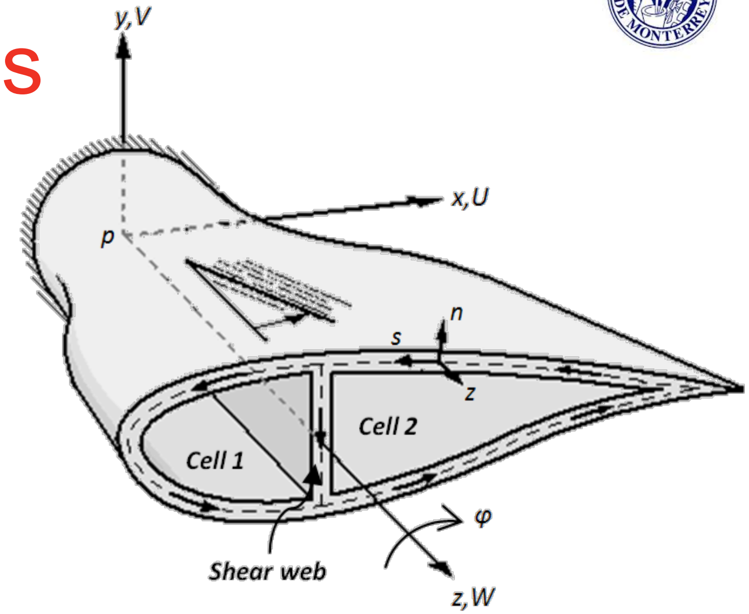
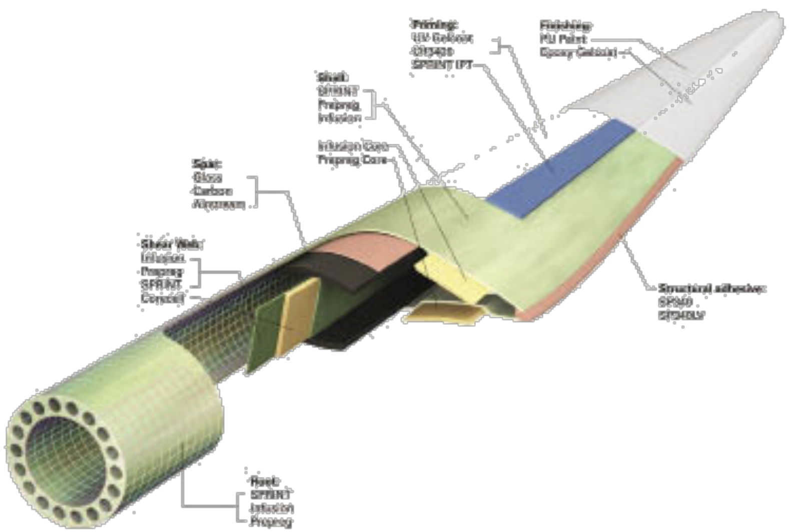
Composite Thin-Walled & Progressive Failure Analysis

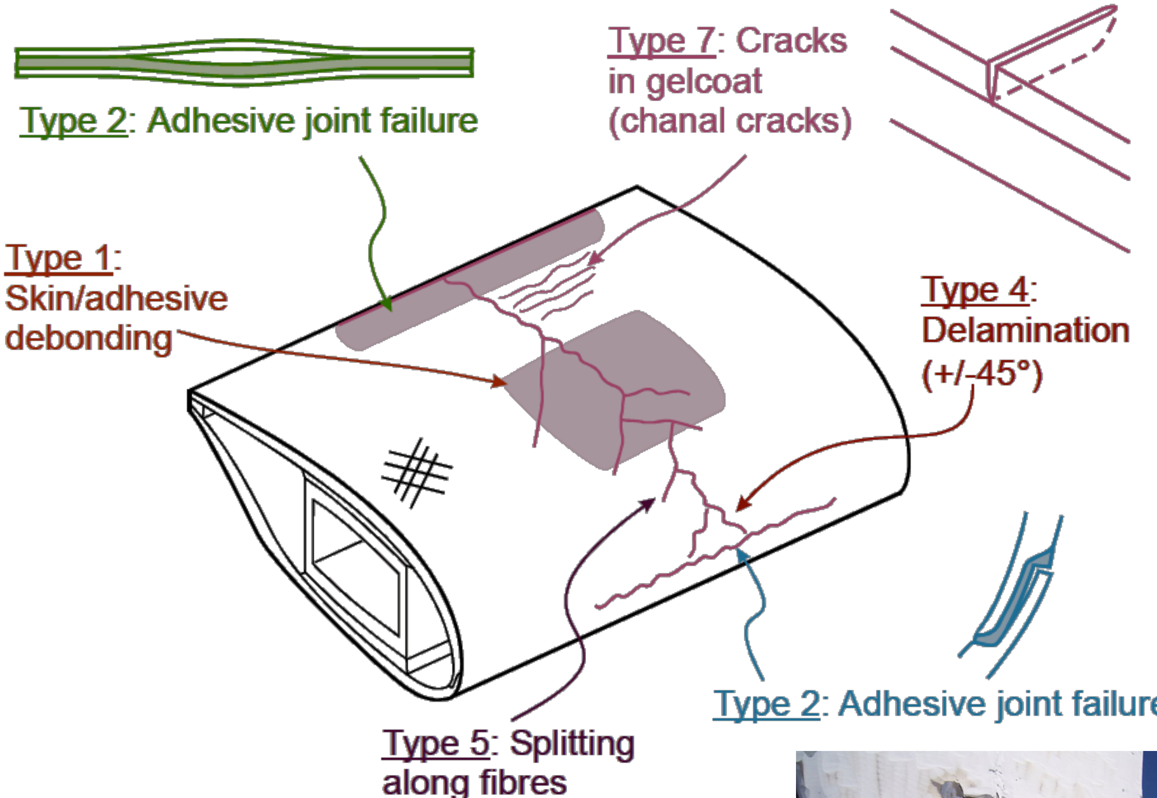
- Progressive Failure Analysis (PFA) into a Thin-Walled Beam (TWB) FE model
- TWB, a 1D model used to reproduce the structural behavior of a more complex 3D shells or solid FEM elements
- TWB with shell capabilities, retains beam composite lamination information to recover stresses/strain and deformations
- Composite failure criteria can be applied
- TWB and GENOA® share same PFA algorithm





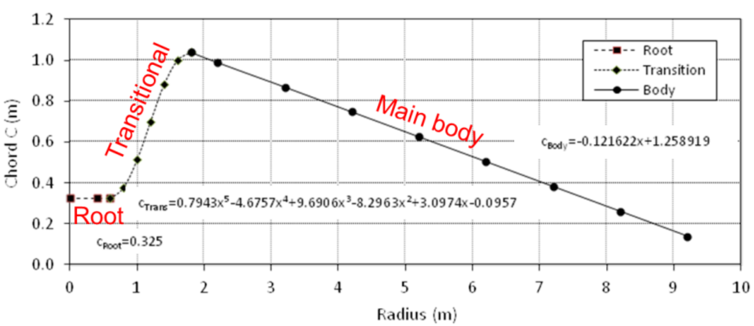
Composite Damage & Failure Models

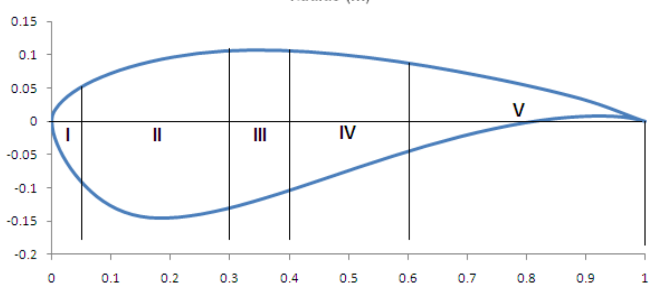
- Type of load
  - Monotonic
  - Cyclic
- Damage and fracture behaviour models
  - Parametric
  - Phenomenological
  - Micromechanical
  - Probabilistic
- Modes of failure
  - Fiber (tension, compression, shear)
  - Matrix (transverse tension/compression, shear or combination)
  - Lamina vs. constituents (matrix and fiber) properties

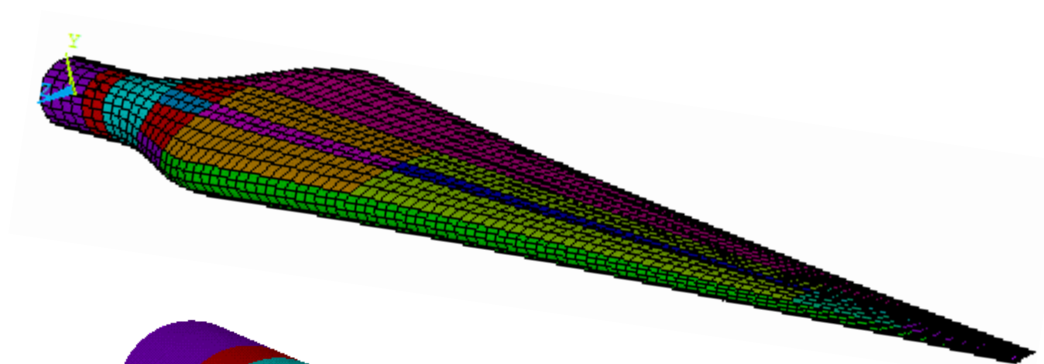


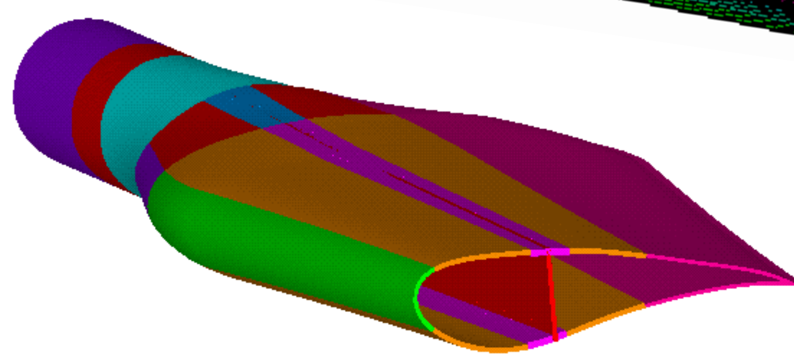
PFA Validation of TWB

- Validation using detailed numerical model of a 9.2m wind turbine blade (NPS-100) from SANDIA (SNL) / TPI Composites
  - ANSYS® 3D-shell99 quadratic 8-nodes elements conformed by **55,356 DOF**
  - Timoshenko-TWB element in MATLAB® conformed by **217 DOF (~0.4%)**
- Same b.c. for both models (fixed at the root end) and loading (flapwise force @ each 0.6 m and starting at 0.8 m from the root)



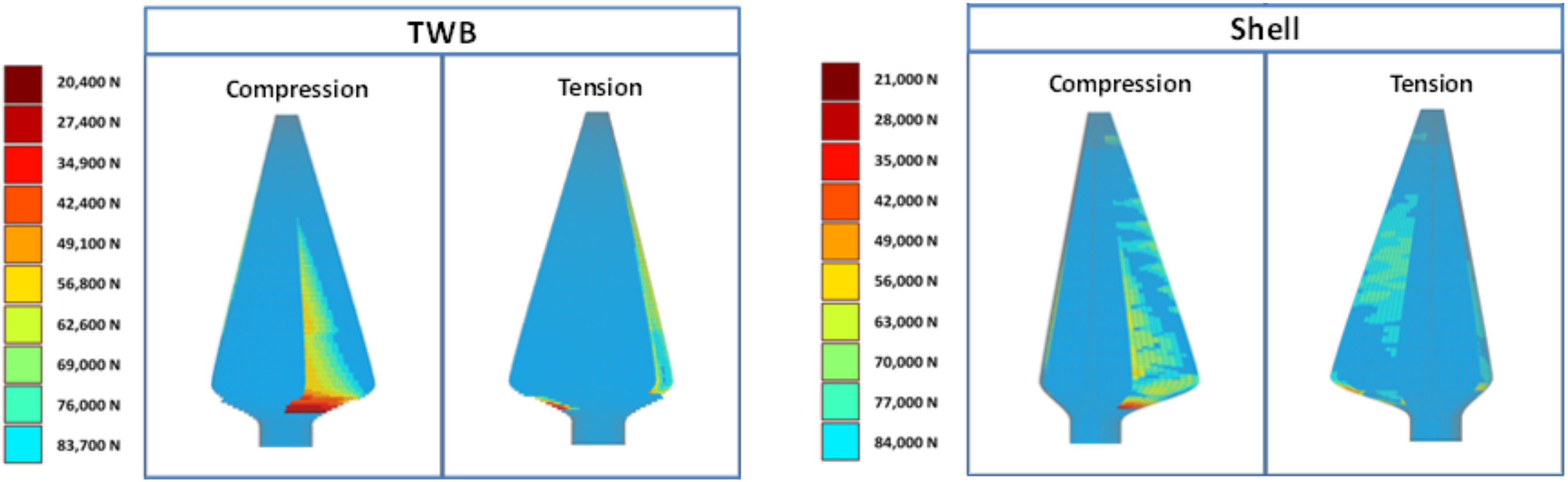






Results and Discussion
PFA Static Simulations

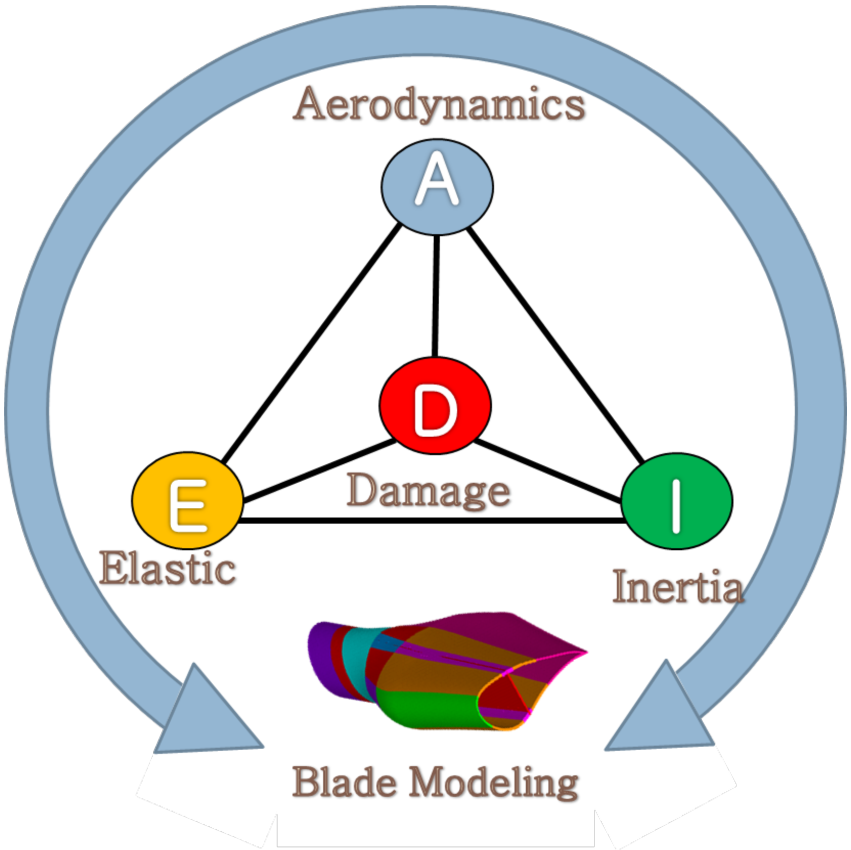
Progressive Failure for layer 6 (Balsa).



ANSYS: 3353 elements, 9926 nodes, **55,356 DOF**
TWB: 30 beam elements, 31 nodes, **217 DOFs**

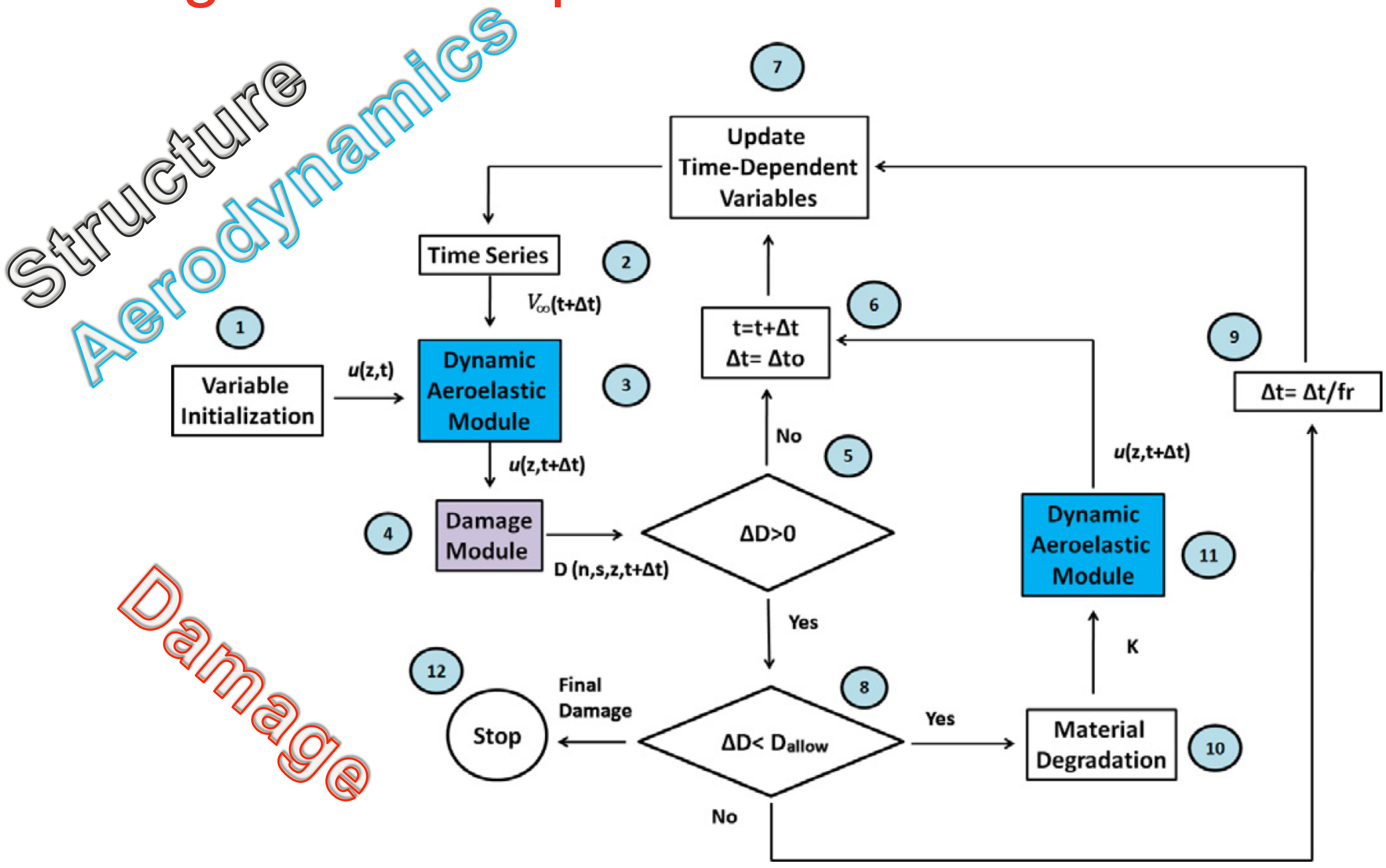
~0.4% DOF

Flow Structure Interaction and PFA



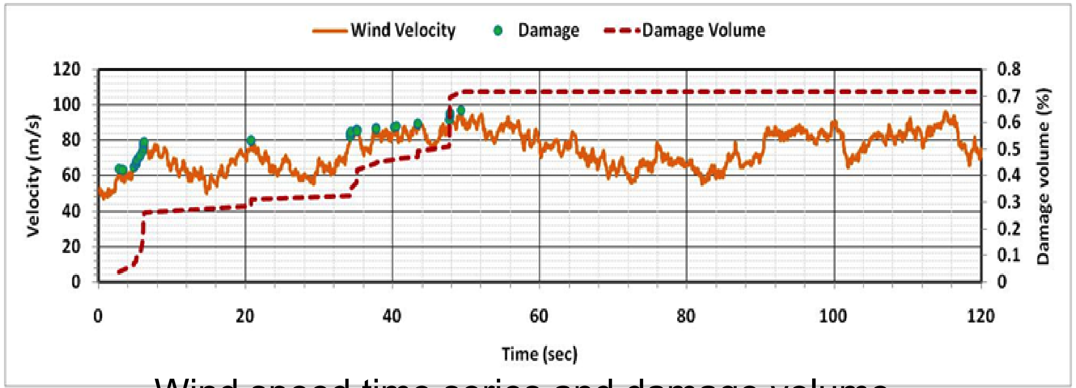
- Develop a PFA onto a computationally-attractive composite TWB FE model
- Gravitational, centrifugal, and aerodynamic loads included in dynamic aeroelastic simulation
- Aerodynamic loads based on Blade Element Momentum (BEM) theory

Aeroelastic Code with Damage Progression Capabilities

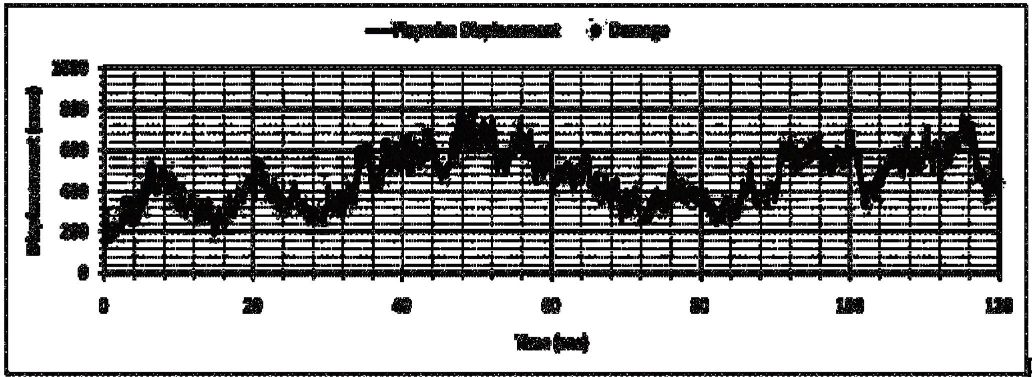


Results and Discussion

Case 1: Parked rotor facing class 5 hurricane

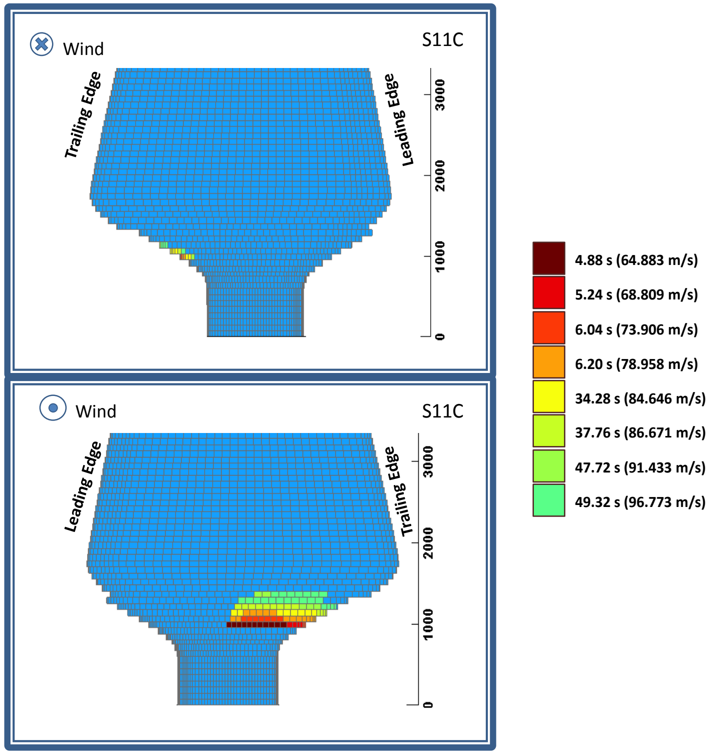


Wind speed time series and damage volume



Flapwise displacement

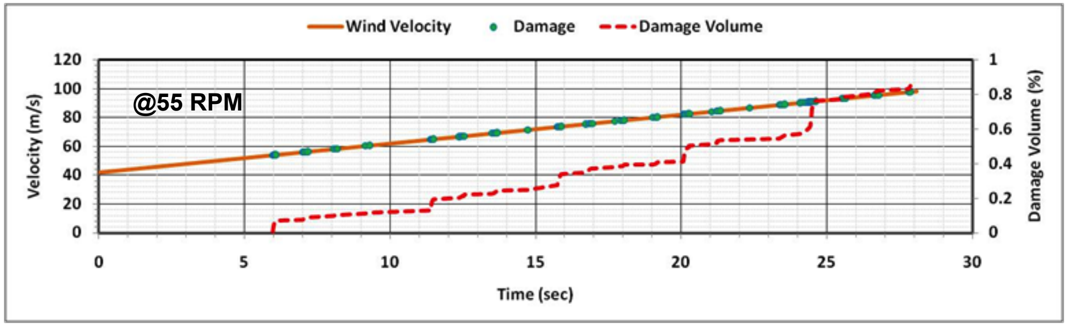
PFA Layer 6 (Balsa)



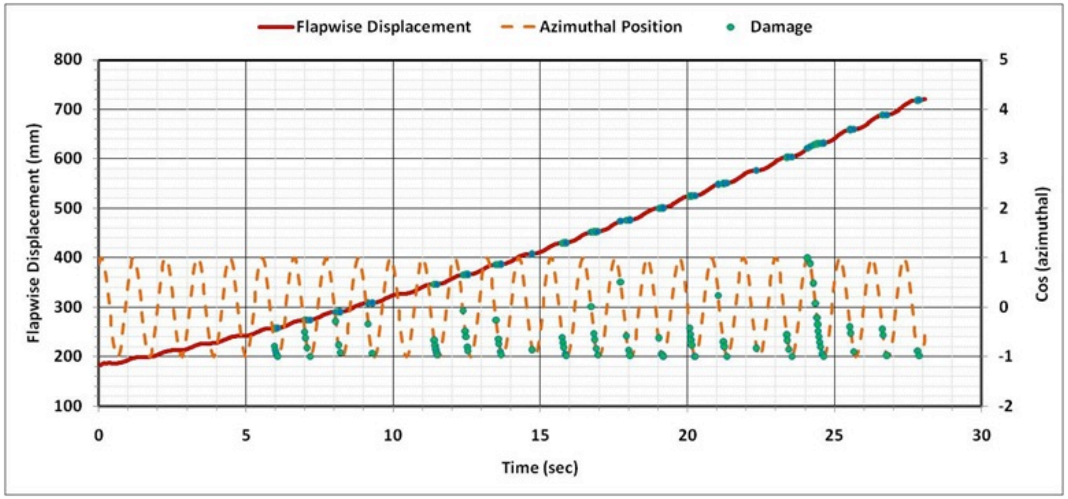
Progressive Failure Analysis of layer 6 (Balsa)

Results and Discussion

Case2: Wind speed ramp at constant rotor shaft frequency (55RPM)

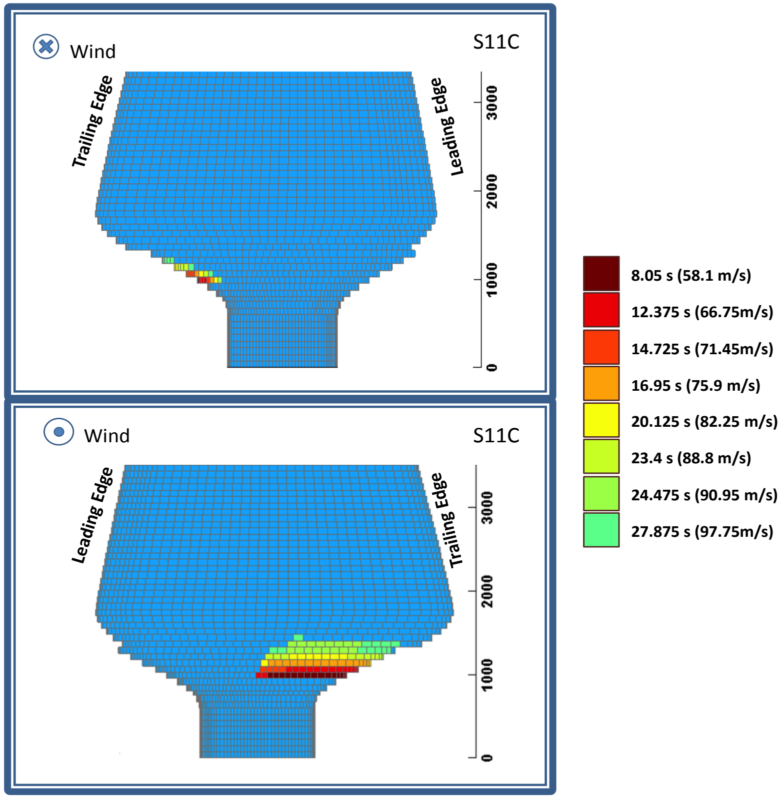


Wind speed time series and damage volume



Flapwise displacement and azimuth position of the blade

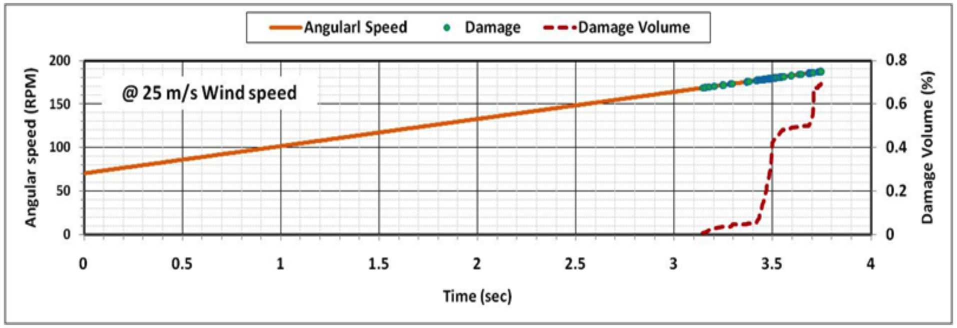
PFA Layer 6 (Balsa)



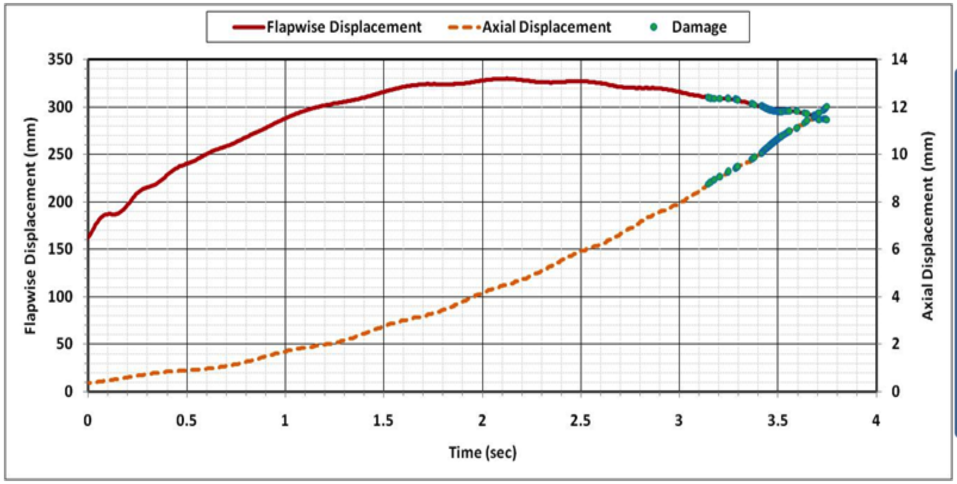
Progressive Failure Analysis of layer 6 (Balsa)

Results and Discussion

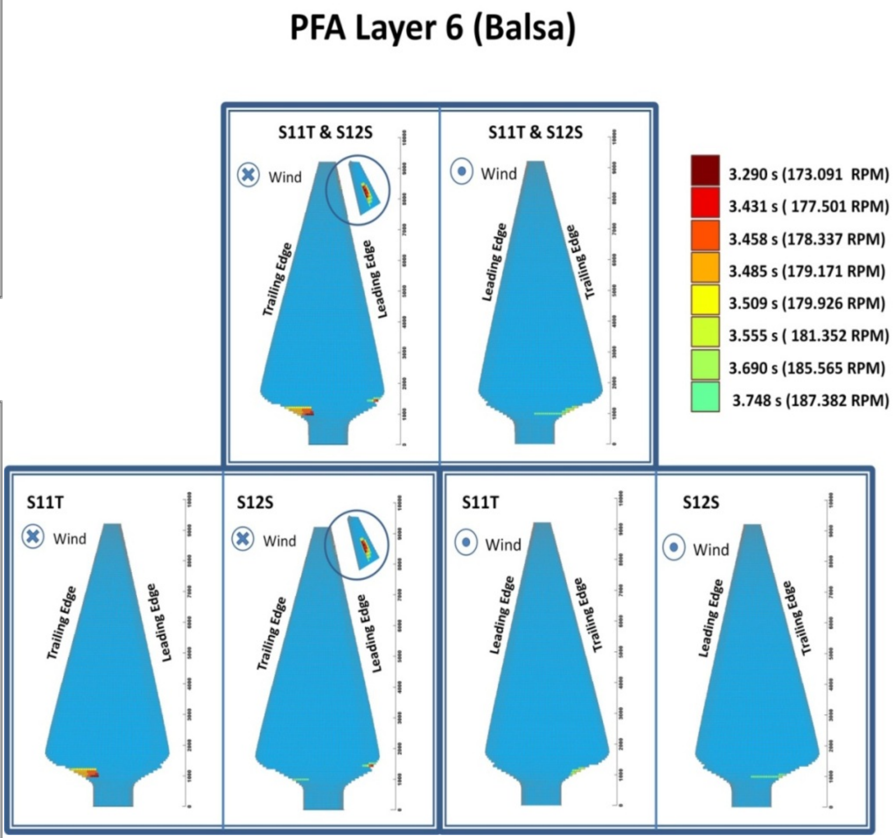
Case 3: Constant Wind Speed (25 m/s)



Wind speed time series and damage volume



Flapwise and Spanwise displacement of the blade



Progressive Failure Analysis of layer 6 (Balsa)

DWEA Composite Subgroup: Identify short term challenges

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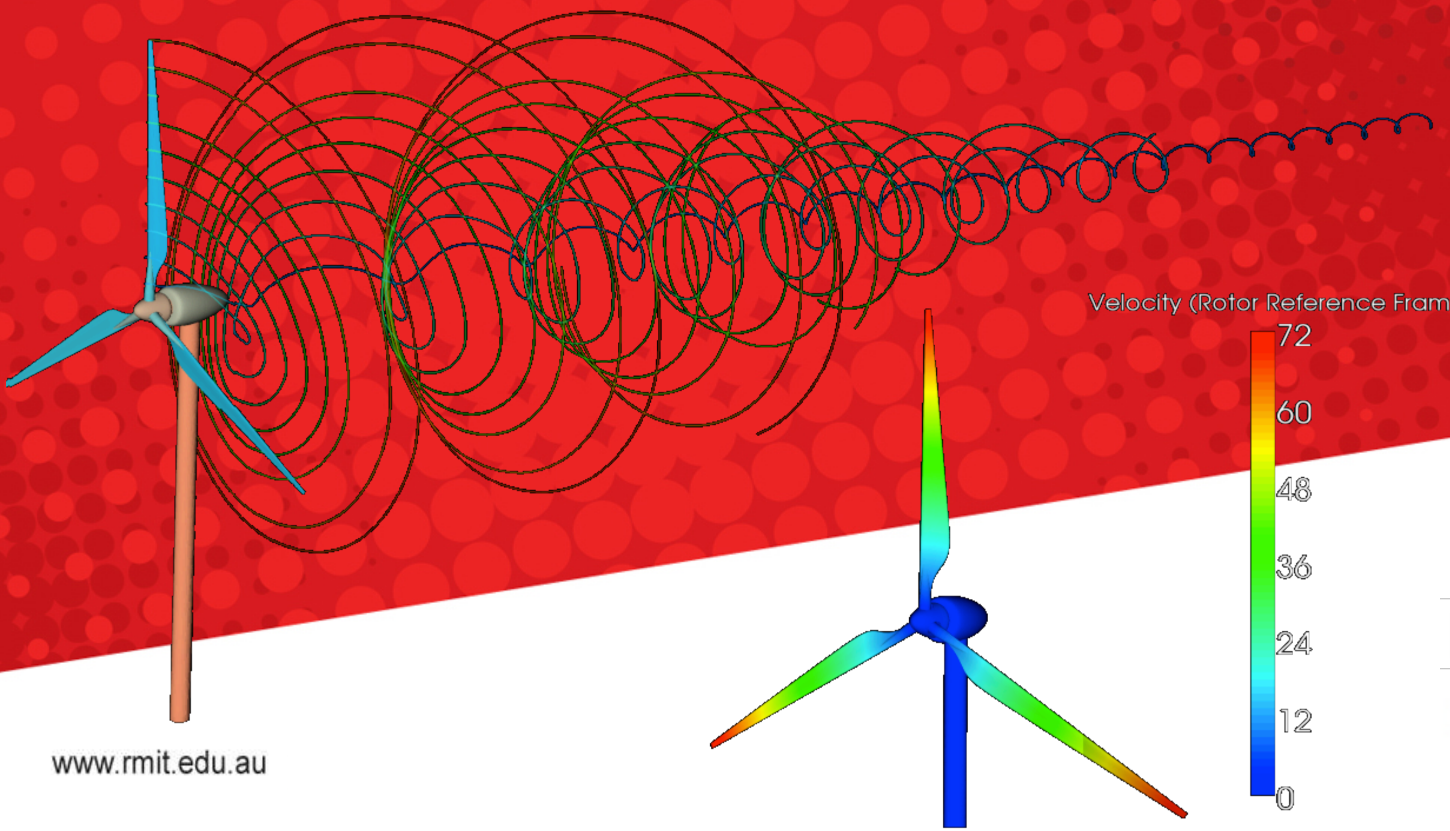
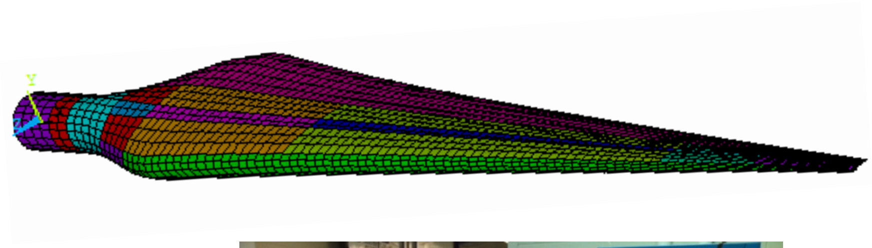
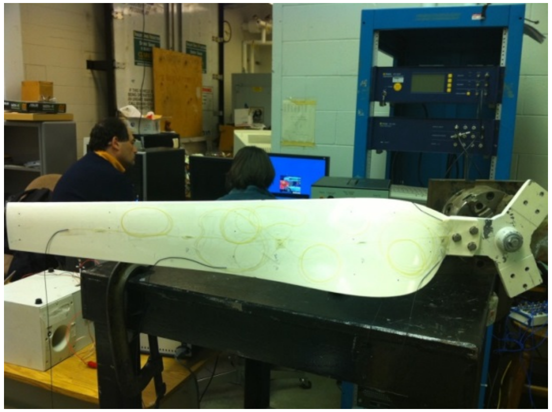


DWEA Composite Subgroup: Identify short term challenges

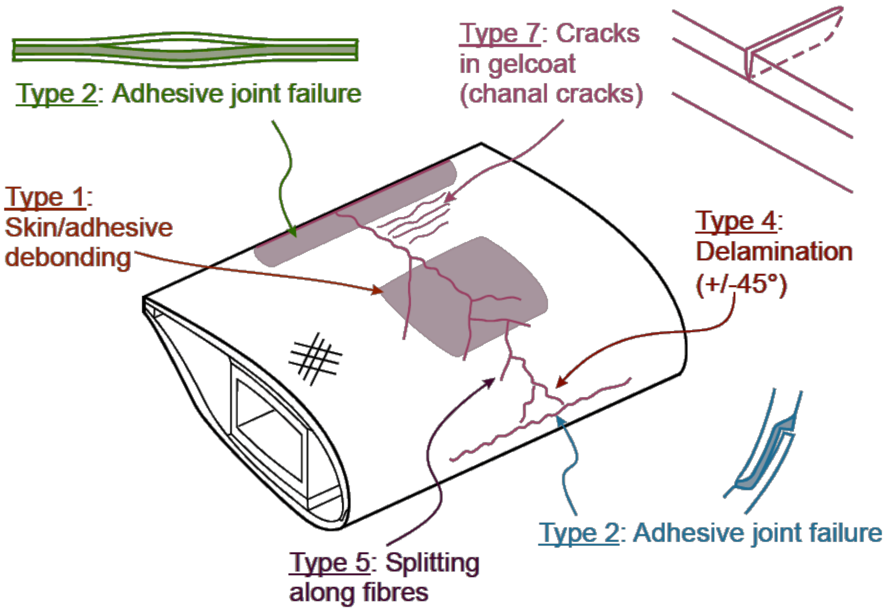
- Materials. Currently used vs. new materials including NFRP. Recyclability
- Manufacturing processes. including autoclave vs. out-of-autoclave, microwave bonding and joining, Energy and environment
- Aero-structural design and testing. Emphasis on robust design, durability and damage tolerance and structural testing
- Aerodynamic design. Loading and environmental conditions. Uncertainties qualification
- Non-Destructive Inspection and Structural Health Monitoring. At all levels from production to operation





Identify short term challenges: current materials

- Methods and models describing production defects effects
- Methods to evaluate imperfections and damage progression on the strength and lifetime of a wind turbine blade
- Methods to improved fatigue life prediction
- Manufacturing process evaluation and control
- Methods to improve stiffness / tensile strength in the fiber direction as well as compressive strength

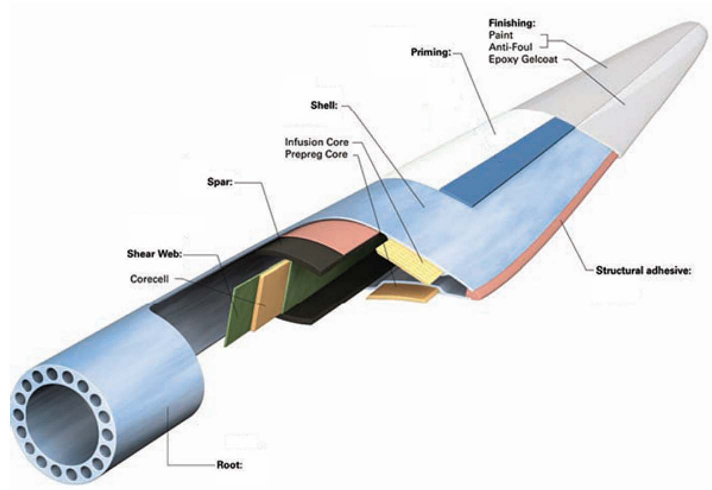


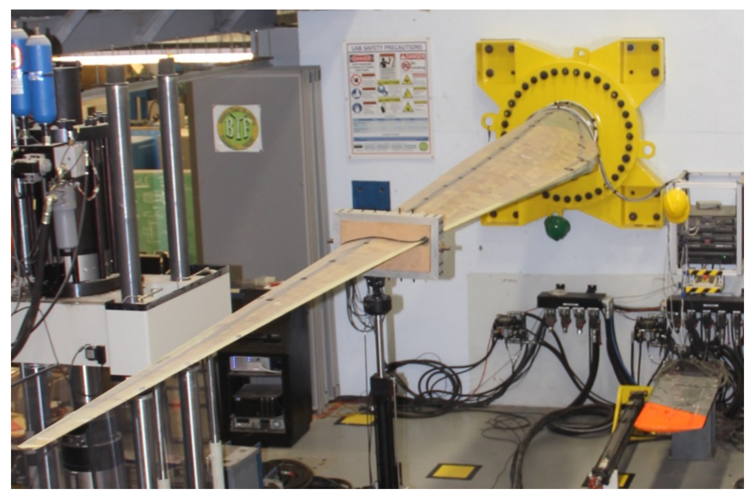
Identify short term challenges: new materials

- New high-strength and high-stiffness reinforcement fibers, glass-carbon mixture
- Develop WT with increased combination of strength, stiffness, and toughness, and adhesion
- Needs for strong, stiff, and low weight. Increased tensile and shear strength in the out-of-plane direction including compressive strength
- New manufacturing processes for new materials
- Recyclability: thermosetting resins cannot be recycled. Thermoplastic resins have high toughness and a higher degree of recyclability, however require intensive high temperatures production processes
- Environment considerations: renewable materials (natural cellulose fibers) for reinforcement and bio-based resins, rather than polymer materials based on oil
- Natural fibre-reinforced polymer (NFRP) composites vs. GFRP and CFRP. Importance of fiber treatment and coating technologies to minimize hydrophobic matrix/hydrophilic fiber issues and contact with environmental agents.

Identify short term challenges: aero-structural design & testing

- Weight reductions with fiber composite blades, through improved structural design
- Optimized thinner / smaller root diameters, lighter, optimized blades to avoid instabilities and dynamic loading / fatigue failures
- Develop practical approaches for achieving damage tolerant design
- Exploit anisotropic nonsymmetrical laminates, composites used to their best (bending and twist coupling)
- Aerodynamic profile optimization
- Pitch control mechanism is generally slow to respond to gusts. Solution: “smart blades”?
- Building integrated wind turbine concepts potentials





Identify short term challenges: NDI & SHM

- Early stage defect detection. visual inspection vs. advanced techniques. Cost-effectiveness and reliability
- Thick sandwich and laminated composites present challenges for NDI
- Uncertainties in the prediction of degradation due to fatigue and undetected production defects
- Monitor degradation of a blade while in service (lightning strikes, ice, and hailstorms)
- SHM systems, including acoustic emission, optical fibers, and advanced sensor technology, used to predict remaining lifetime (aid of damage models)
- Condition-based vs. scheduled-based maintenance