Predicting Aeroelastic Loads and Response of Healthy and Damaged HAWT Blades

Heather Sauder

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Personal Background

- Education:
  - Ph.D. in progress in Engineering Mechanics and Wind Energy Science, Engineering and Policy
  - M.S. in Mechanical Engineering from the University of Wyoming Dec 2012
    - DOE Workforce Training Fellowship in Wind Energy
  - B.S. in Physics and Spanish from Furman University 2011
- Research:
  - Project sponsored by the Iowa Energy Center – Smart Sensory Membrane for Wind Turbine Blades
  - Developing a cost-effective Structural Health Monitoring (SHM) solution
  - Project PI – Simon Laflamme (Assistant Professor CCEE)
  - Interdepartmental project between CCEE, AerE, and ECpE

Objective

- The primary objective of this research is to develop a better understanding of the aeroelastic loads and response of healthy and damaged wind turbine blades in varying wind conditions (i.e. smooth flow, turbulent flow, gusty winds, boundary layer, and yaw misalignment).

Dynamic Wind Loads

- Self-excited
- Buffeting
- Vortex-Shedding Induced

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Self-excited Wind Loads

- Motions of structures perturb the flow
    - Modified flow patterns produce additional aerodynamic stiffness and damping
    - Transfer energy from wind to motion of structure or help is dissipating kinetic energy of the structure.
- Flutter speed
    - Above a certain wind speed the kinetic energy of the structure will no longer be dissipated and it will become dynamically unstable. This wind speed is known as the flutter speed.

Equations for Flutter

$$L_{se} = \frac{1}{2}\rho U^2 B \left[K H_1^* \frac{\dot{h}}{U} + K H_2^* \frac{B\dot{\alpha}}{U} + K^2 H_3^* \alpha + K^2 H_4^* \frac{h}{B} \right]$$

$$D_{se} = \frac{1}{2}\rho U^2 B \left[K P_5^* \frac{\dot{h}}{U} + K P_1^* \frac{B\dot{p}}{U} + K^2 P_4^* p + K^2 P_6^* \frac{h}{B} \right]$$

$$M_{se} = \frac{1}{2}\rho U^2 B^2 \left[K A_1^* \frac{\dot{h}}{U} + K A_2^* \frac{B\dot{\alpha}}{U} + K^2 A_3^* \alpha + K^2 A_4^* \frac{h}{B} \right]$$

Equations for Flutter

$$L_{se} = \frac{1}{2}\rho U^2 B \left[K \quad K \quad + K^2 H_3^* \alpha + K^2 H_4^* \frac{h}{B} \right]$$

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Equations for Flutter

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$$M_{se} = \frac{1}{2}\rho U^2 B^2\left[K\boxed{A_1^*}\frac{\dot{h}}{U} + K\boxed{A_2^*}\frac{B\dot{\alpha}}{U} + K^2\boxed{A_3^*}\alpha + K^2\boxed{A_4^*}\frac{h}{B}\right]$$

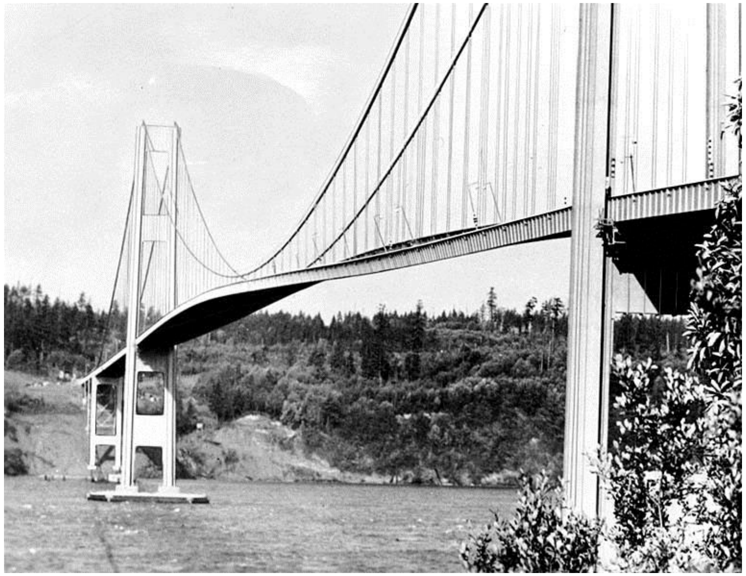
Flutter Derivatives

Flutter Derivatives

CASE	DOF COMBINATION	FLUTTER-DERIVATIVES EXTRACTED
1	1-DOF Vertical	H_1^*, H_4^*
2	1-DOF Torsional	A_2^*, A_3^*
3	1-DOF Lateral	P_1^*, P_4^*
4	2-DOF Vertical+Torsional	$H_1^*, H_2^*, H_3^*, H_4^*, A_1^*, A_2^* , A_3^*, A_4^*$
5	2-DOF Vertical+Lateral	$H_1^*, H_4^*, H_5^*, H_6^*, P_1^*, P_4^* , P_5^*, P_6^*$
6	2-DOF Lateral+Torsional	$P_1^*, P_2^*, P_3^*, P_4^*, A_2^*, A_3^* , A_5^*, A_6^*$
7	3-DOF	All 18 Flutter Derivatives

Examples of Flutter

- A traffic light moving up and down in the wind
- Stop sign
- The Tacoma Narrows Bridge (1940)

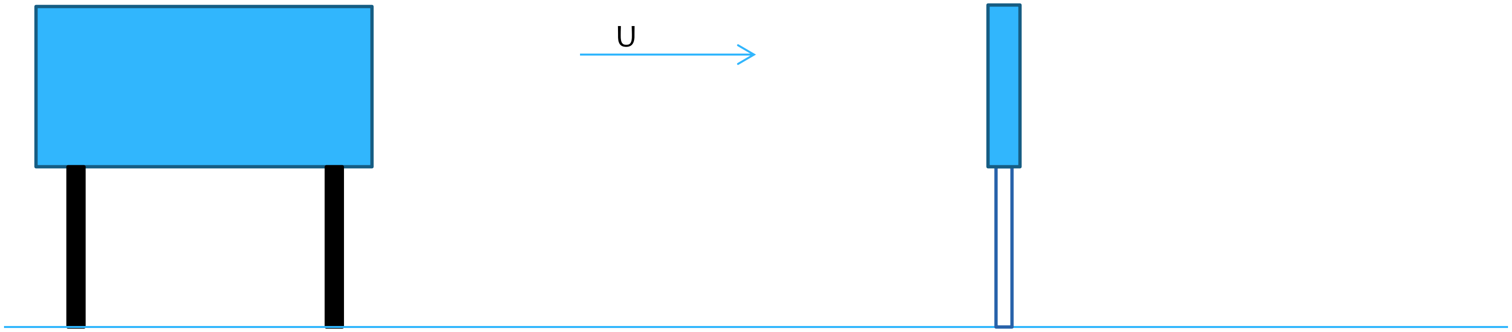


Flutter Video

- http://www.youtube.com/watch?v=_oIYiFyyGC4

Buffeting

- Caused by turbulence
- Occurs in the along wind direction
- Billboard



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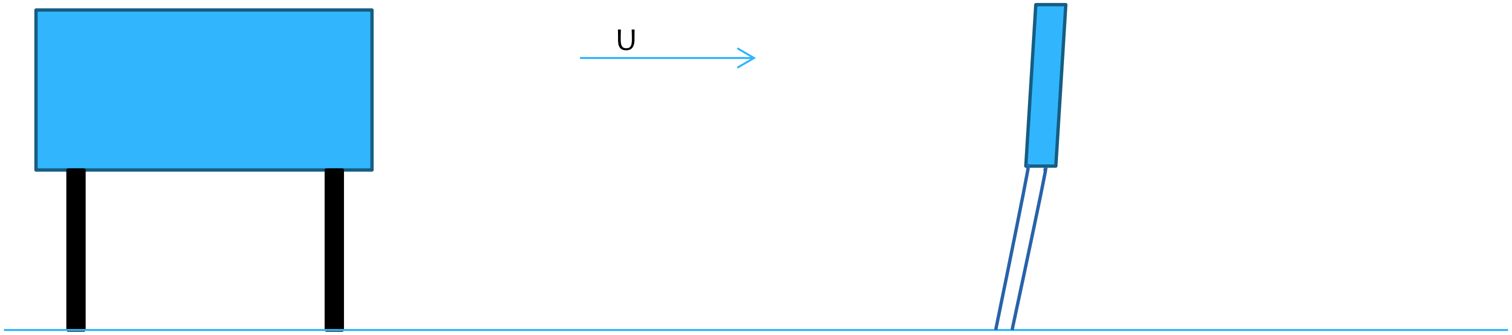


Why is this important?

- Wind Turbine blades are susceptible to these vibrations
  - Actual Flutter speed is 2x operating wind speed
- Blade life is determined by fatigue tests
- Natural frequency changes when damage is present

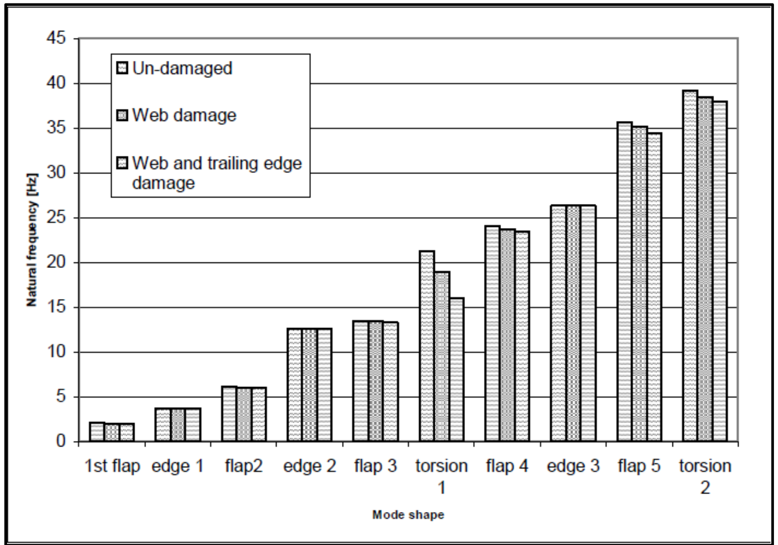
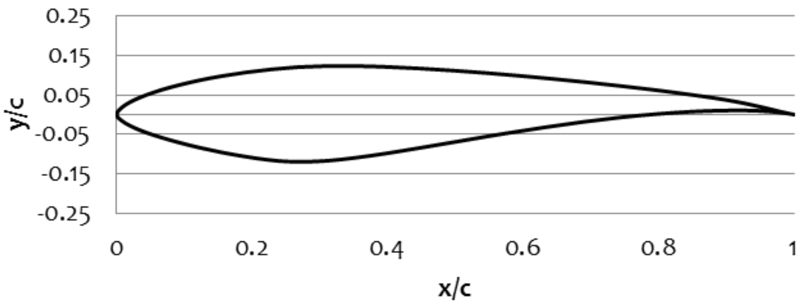


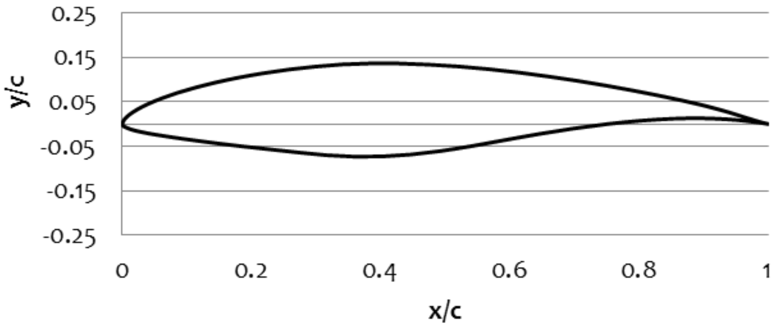
Image from Identification of Damage to Wind Turbine Blades by Modal Parameter Estimation

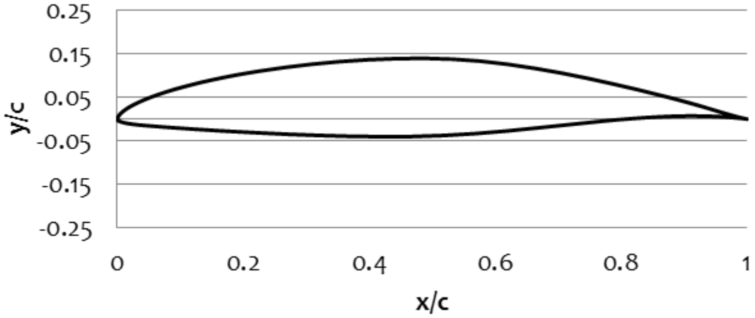
My Research Plan

- Task 1 – Develop Wind Turbine Blade
- Task 2 – Section Model Testing
- Task 3 – Finite Element Model
- Task 4 – Wind Tunnel Tests

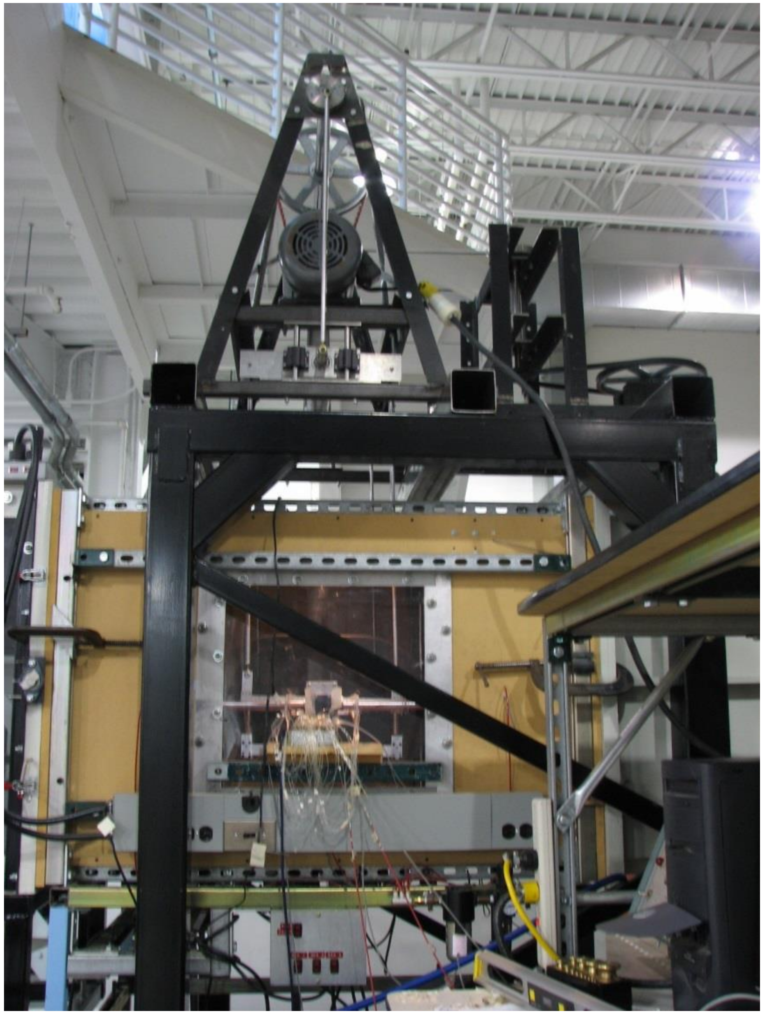
Task 1 – Develop Wind Turbine Blade


S818 Airfoil

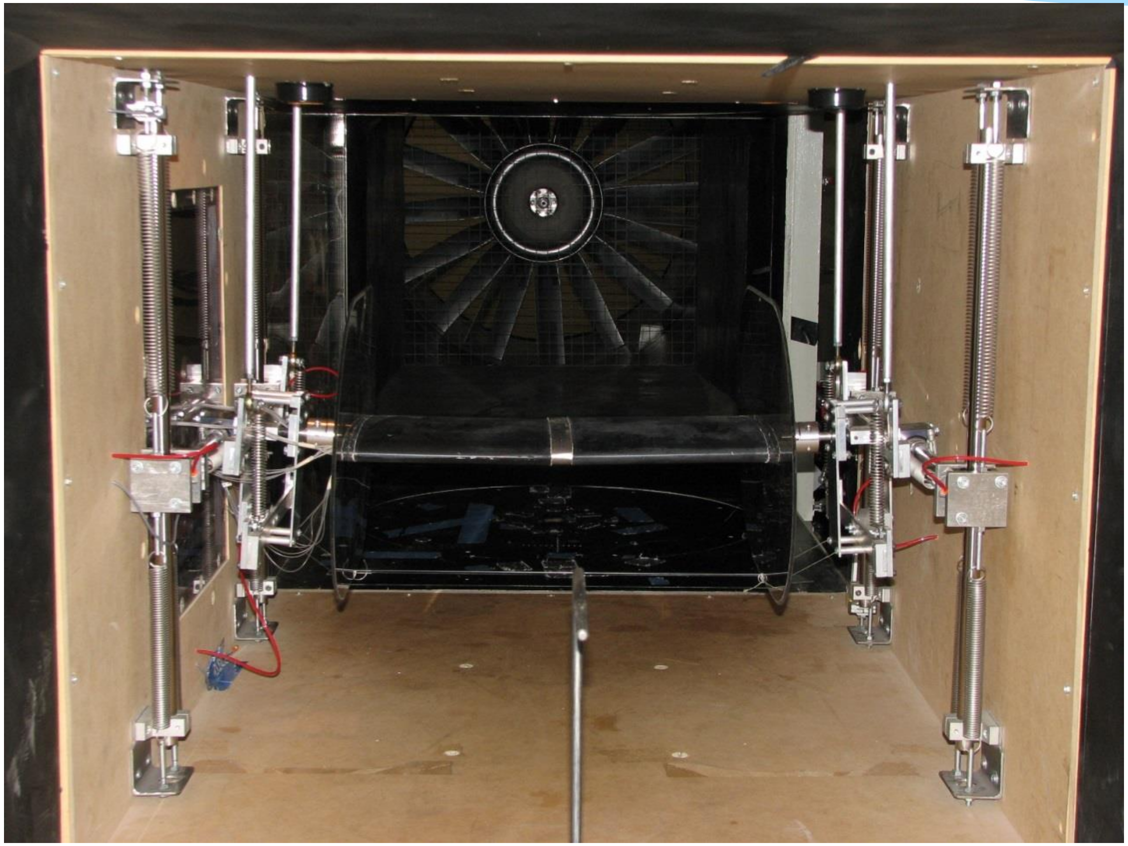

S830 Airfoil


S831 Airfoil

Task 2 – Section Model Testing



Task 2 – Section Model Testing



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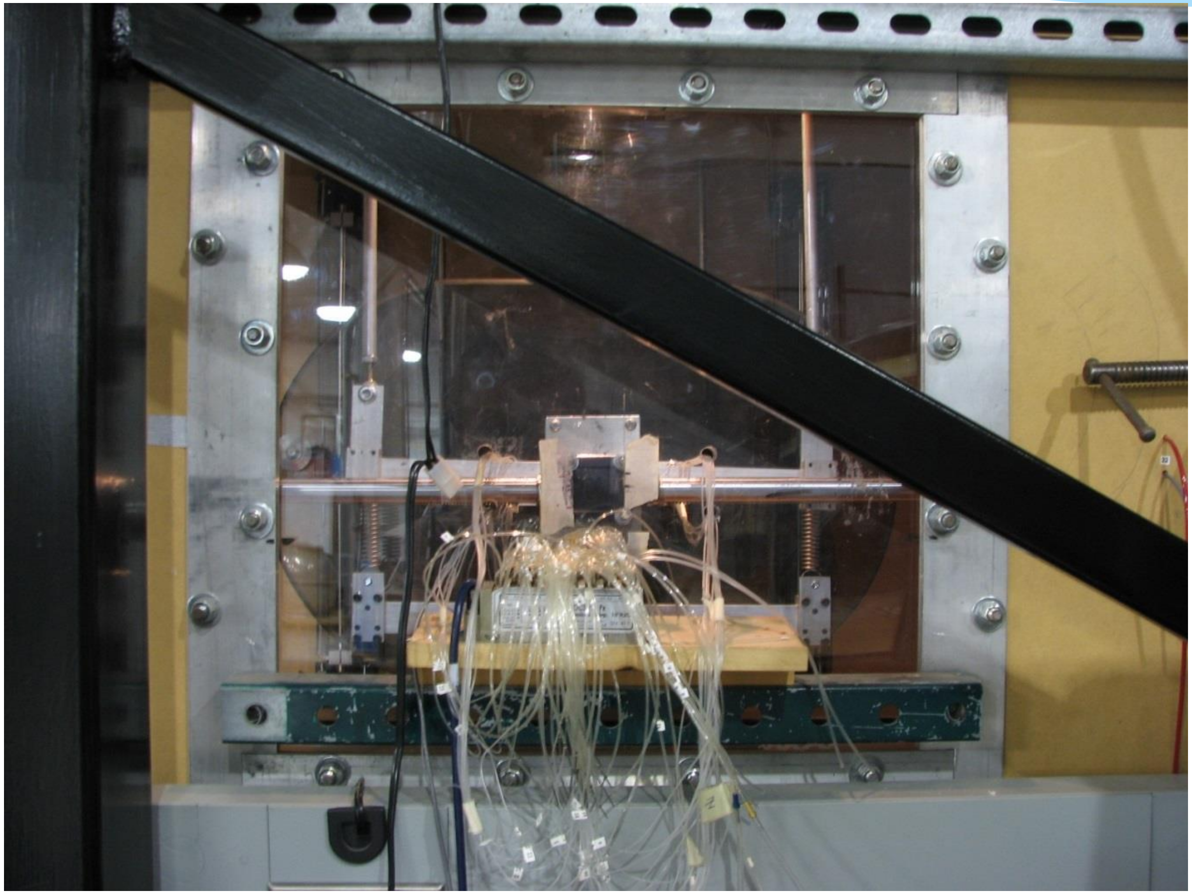

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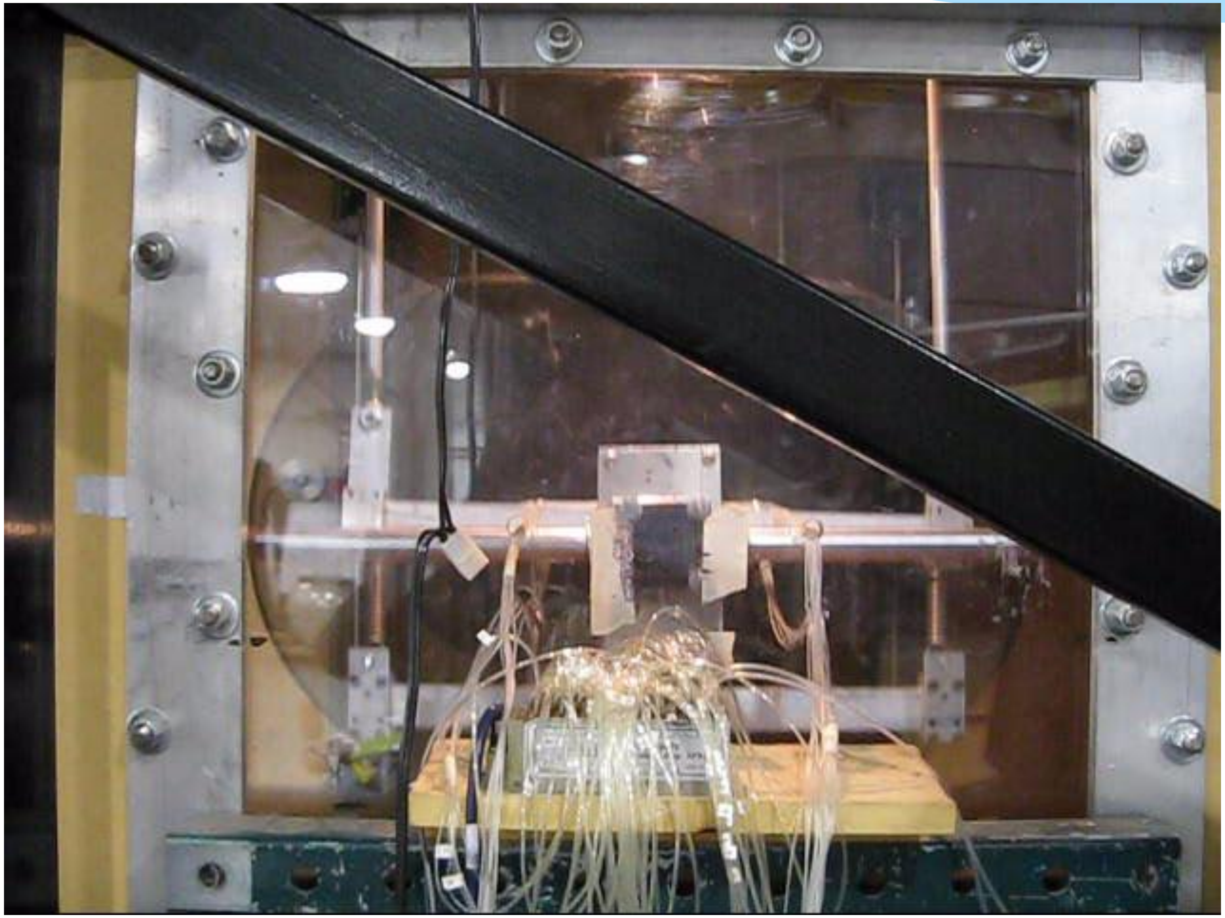

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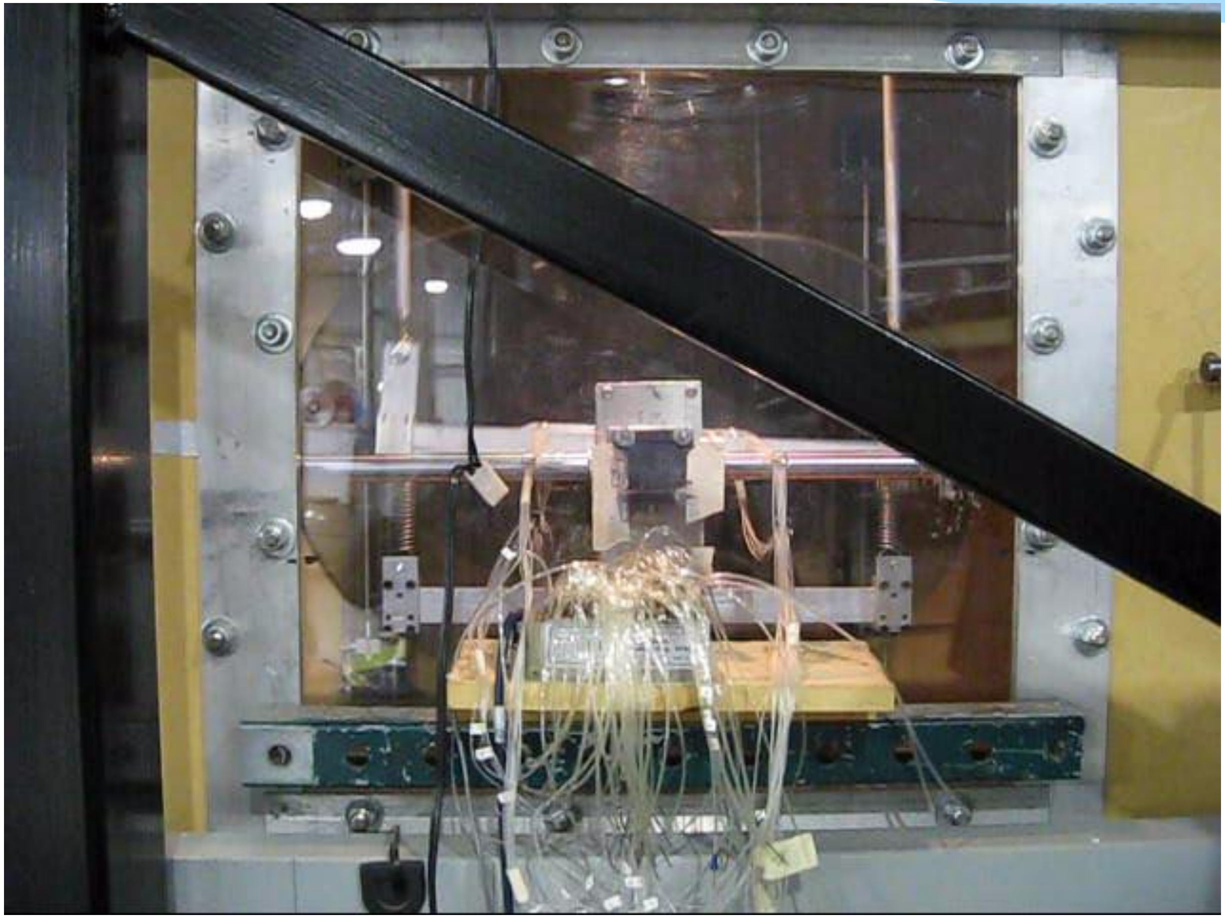


Task 3 – Finite Element Model

- Used for a stress/response analysis of the prototype blade
- Used to predict loads which can then be validated through pressure data taken

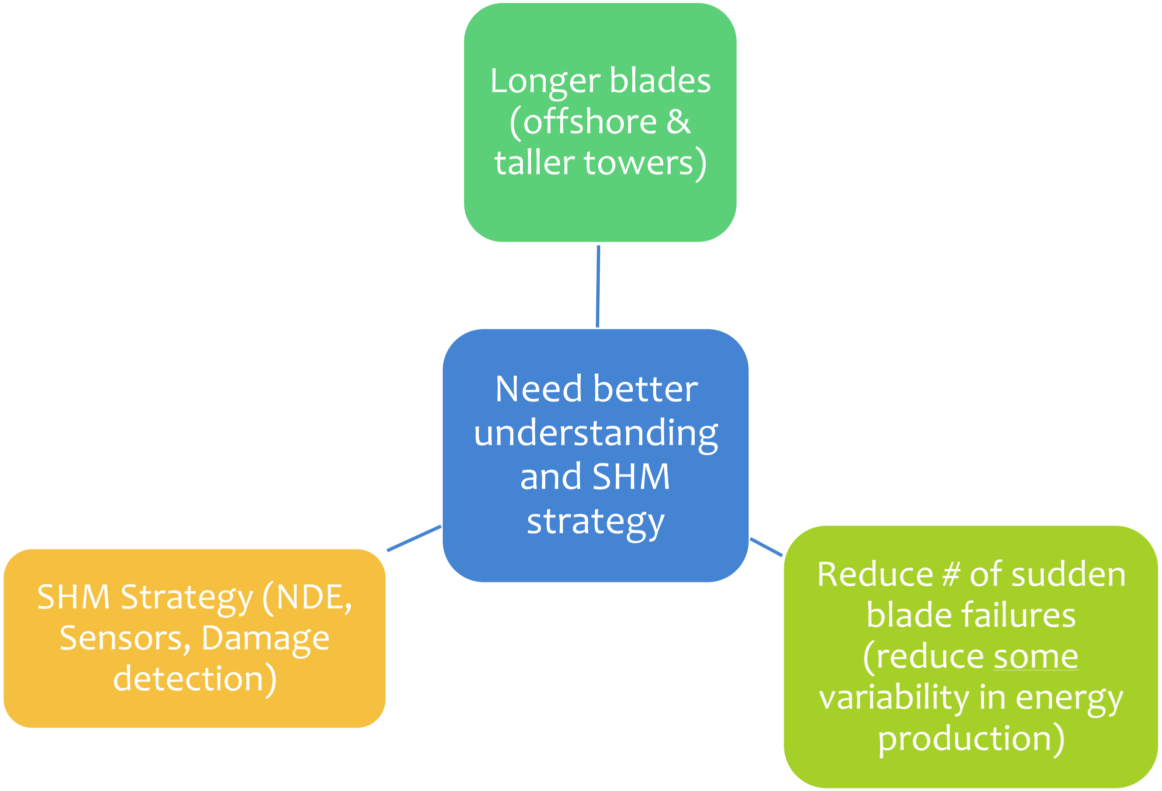
Task 4 – Wind Tunnel Tests

- AABL Wind Tunnel (8ft x 6ft test section)
- 4ft long blade
  - Fixed at one end
  - Free to vibrate on other end
  - 1 Healthy & 4 damaged
- Instrumented with:
  - 1 Zoc33/ERAD Pressure Transducer
  - 2 Accelerometers
  - Conventional Strain Gauges
  - Sensor Membrane
  - Force/Torque sensor

Additional Work

- Difference in loads and response from:
    - Gusts
    - Turbulence
    - Boundary Layer
    - Yaw Misalignment

Relation to Other WESEP Students



Longer blades (offshore & taller towers)

Need better understanding and SHM strategy

SHM Strategy (NDE, Sensors, Damage detection)

Reduce # of sudden blade failures (reduce some variability in energy production)

Questions?

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