SMART Wind Consortium

Subgroup Leads

SMART Wind Launch
October 16, 2014

DWEA
DISTRIBUTED WIND ENERGY ASSOCIATION

eFormative options LLC | Wind Advisor Team | WINDYGLICK | SUMMERVILLE WIND & SUN

OUR WIND OUR POWER OUR FUTURE

Composite subgroup lead

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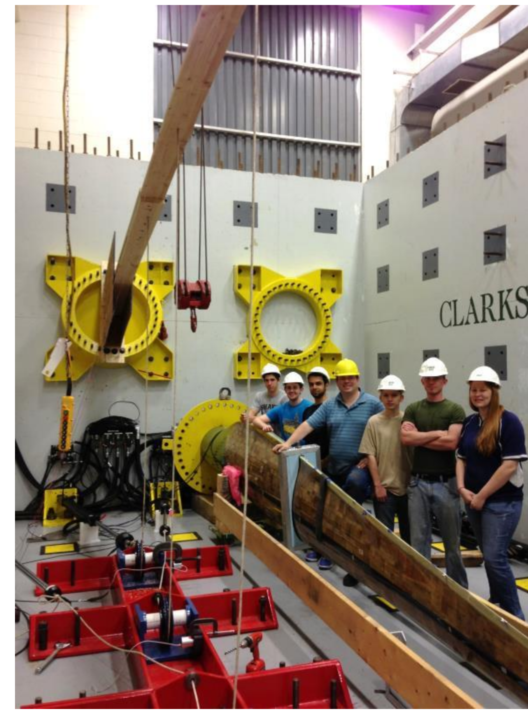

Blade Test Facility BTF Clarkson - Intertek

Clarkson UNIVERSITY defy convention™

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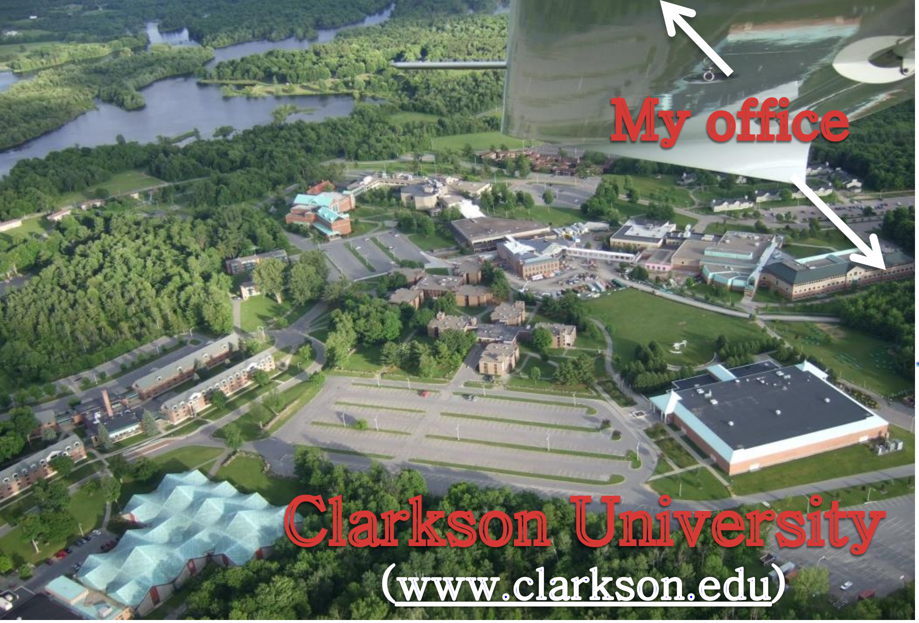


Signature Areas of Excellence

- **Advanced Materials and Structures**
- **Energy and Environment**
- Biotechnology
- Entrepreneurship
- Global Supply Chain Management

BTF Research and Testing Activities

WT Blades FSI and Damage Progression

- Composite Blade Design
- Thin-walled Composite Modeling
- Aeroelasticity of WT Blades
- Aeroelastic and Aerodynamic Control
- Damage Progression
- System Identification
- 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

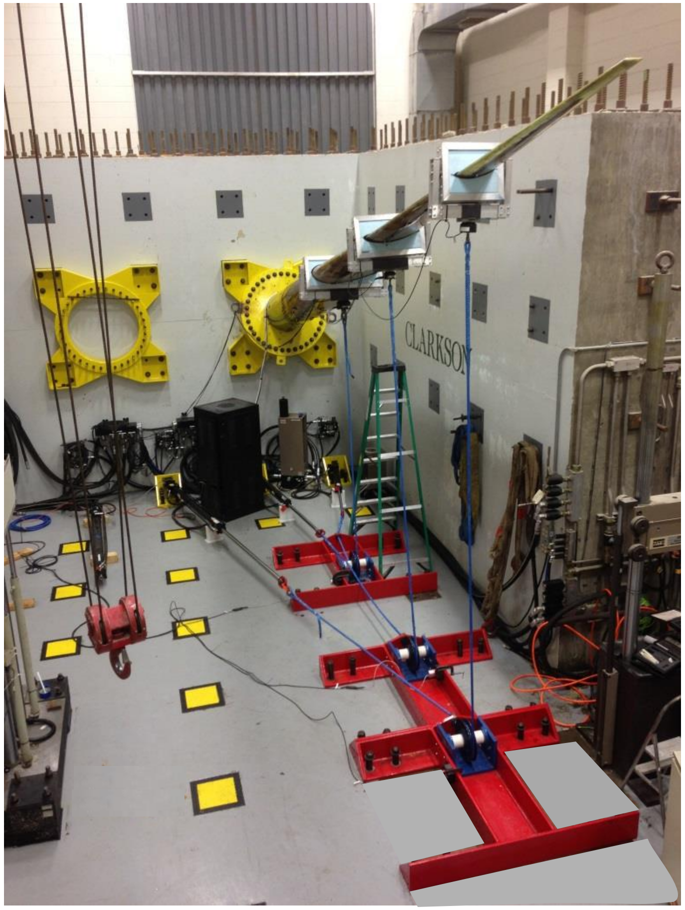
Blade Test Facility – Center for Evaluation of Clean Energy Technologies

Blade Test Facility
BTF
Clarkson - Intertek

Blade Test Facility – Center for Evaluation of Clean Energy Technologies

- Full-scale/scaled wind turbine blade structural testing up to 15 meters
- New rotor blade designs with cost effective testing capabilities
- Certification Testing to AWEA, IEC 61400-2 and -23 Standards (Intertek)
- New testing methodologies in support of DOE NREL and SANDIA Laboratories

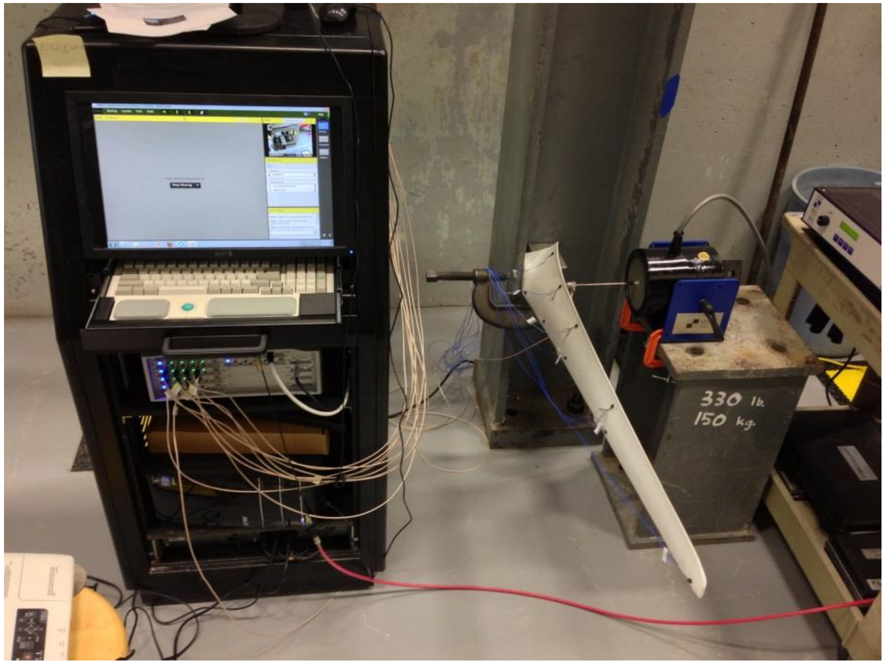
Blade Test Facility

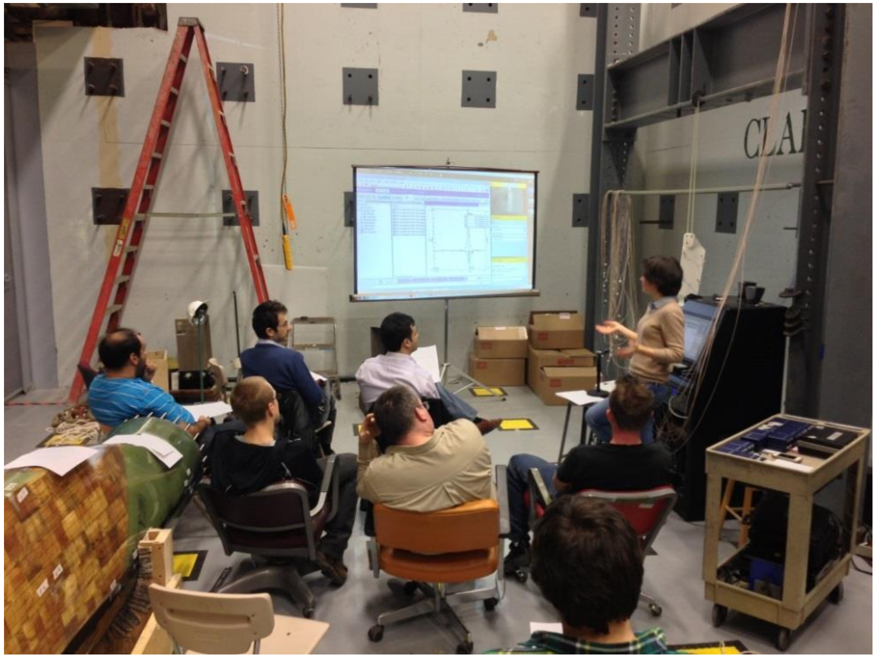


- Static test stand

- Fatigue test stand

Blade Test Facility

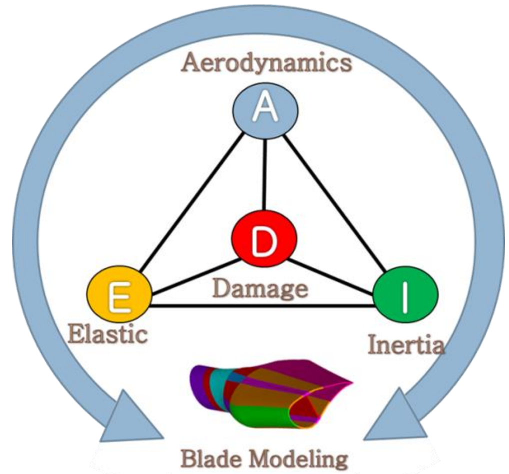




- Workforce development and training courses including webinars
- Life assessment / strength of materials under extreme environmental conditions
- Experimental studies on material behavior
- Determination of the aging properties of materials

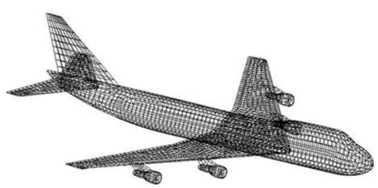
Aeroelasticity of Damaged Rotor
TWB & Progressive Failure Analysis

- Progressive Failure Analysis (PFA) into a Composite Thin-Walled Beam (TWB) FE model
- Semi-Analytical Representation of Finite Element Models via Progressive Polynomial Reduction of Modal Data



Based on FEM Model

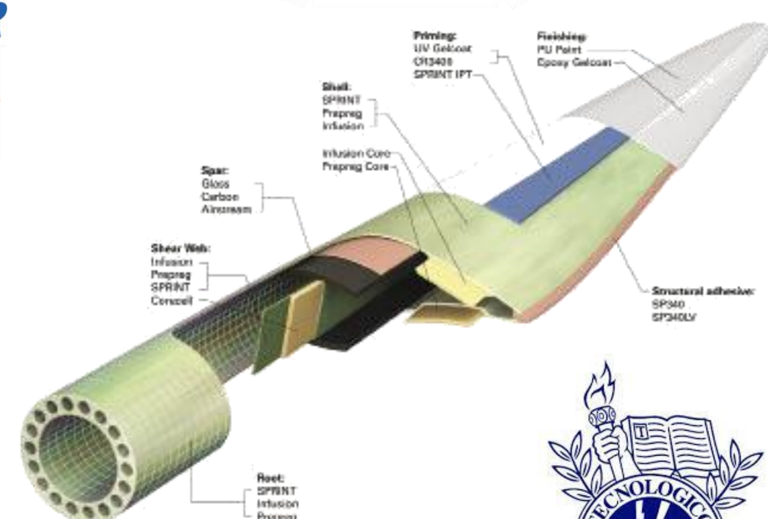
SIMULIA
ANSYS



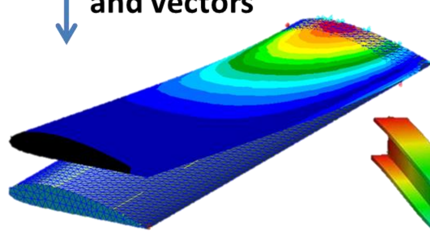
AlphaSTAR
MSC Software

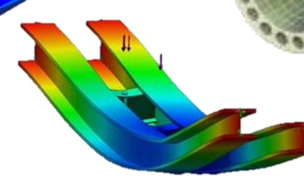
Use Simple Modal Analysis

To extract eigenvalues and vectors



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

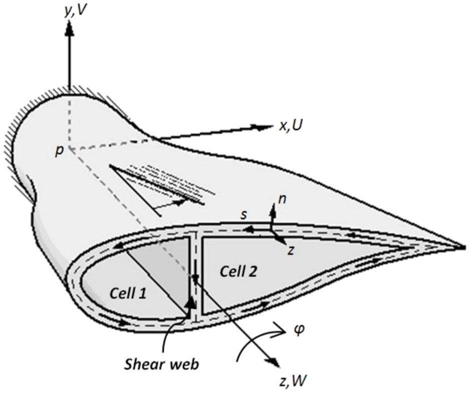


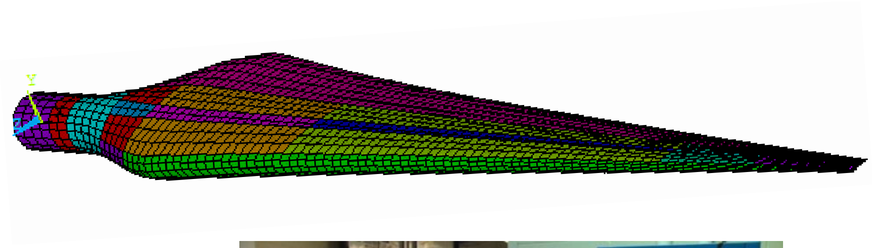


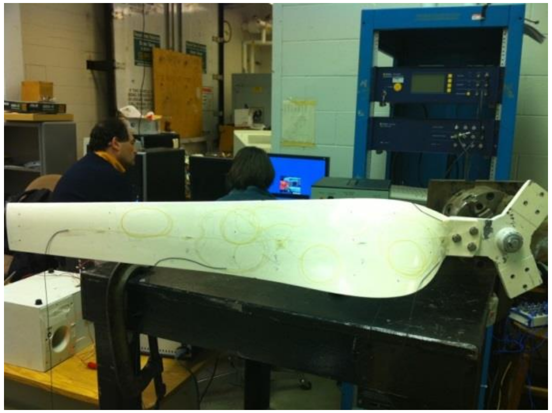
Distributed Wind Activities

Identify short term challenges

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



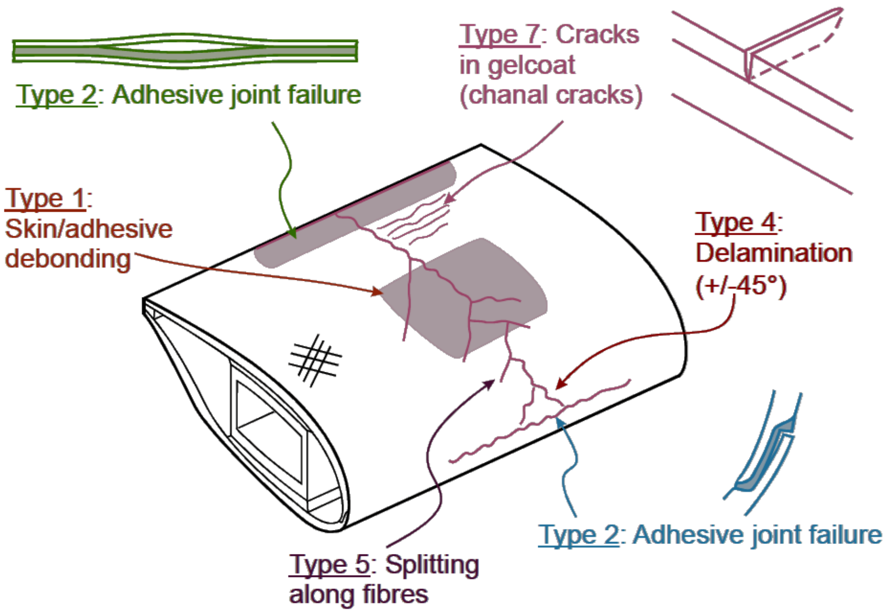




Distributed Wind Activities

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
- Improved fatigue life prediction
- Manufacturing process evaluation and control
- Carbon fiber reinforcements introduced into blades to improve stiffness/tensile strength in the fiber direction, however compressive strength are low



Distributed Wind Activities

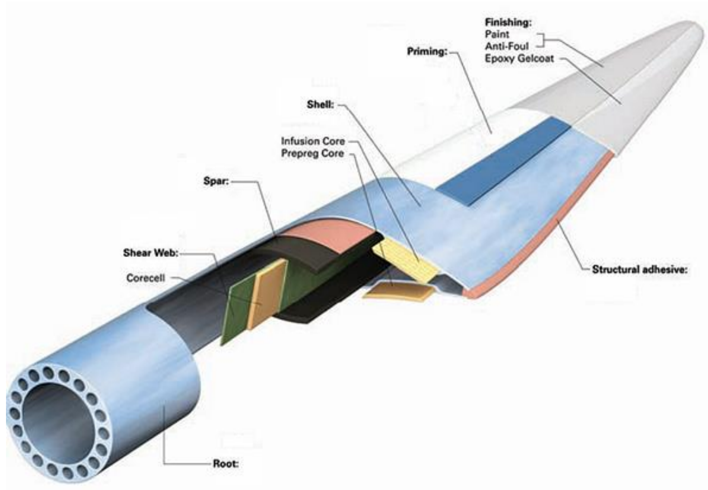
Identify short term challenges: new materials

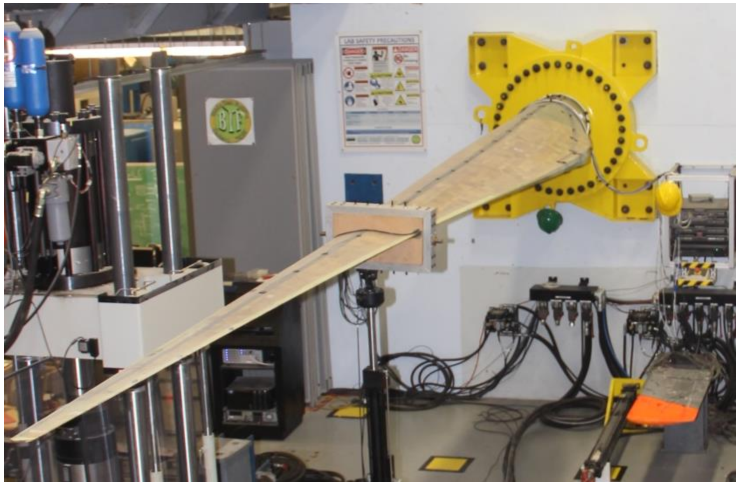
- New high-strength and high-stiffness reinforcement fibers, glass-carbon mixture
- Develop WT with increased combination of strength, stiffness, and toughness, and adhesion
- Needs for strong, stiff, and low weight. Increased tensile and shear strength in the out-of-plane direction including compressive strength
- 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

Distributed Wind Activities

Identify short term challenges: structural design & testing

- Weight reductions with fiber composite blades, through improved structural design
- Optimized thinner/smaller root diameters, lighter reducing hubs' cost
- 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"?

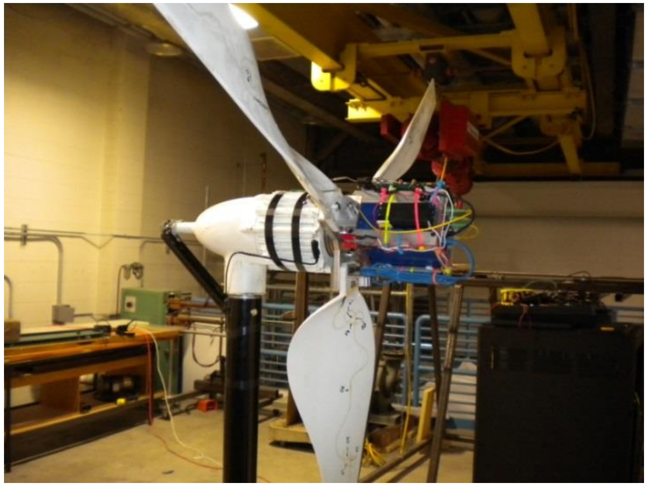




Distributed Wind Activities

Identify short term challenges: NDI and 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



Distributed Wind Activities

Support the development of DWEA Roadmap

- A 3 to 5 year industry plan for distributed wind turbine technology
- Focus on composites materials, manufacturing and technology issues. Develop strategies for low-volume and cost reliable products

- Identify critical challenges in the short (3-5) and long term (5-10). What did we learned from the past ? What does it work and what doesn't?
- Identify key DW stakeholders that can contribute to address critical challenges
- Gauge constituents interest in supporting activities
    - **Identify technology barriers and gaps**
    - **Identify technology needs and actions**
    - **Identify research and other priorities**

Distributed Wind Activities

Support the development of DWEA Roadmap

- **Market**
  - Support DW market penetration, importance of lessening the perceived danger of using wind turbines in urban areas and municipalities

- **Reliability**
  - Importance of testing technologies to evaluate reliability and life assessment. Durability and Damage Tolerance. Structural and safety testing are *as important as* performance testing. Outlook into standards and guidelines, what is current and what is at the horizon

- **Materials and Manufacturing Processes**
  - Lower quality w.r.t. aerospace composites. Barriers and specific challenges ahead. How we can move rapidly toward cost-effective, environmentally friendly, and reliable productions and products

Distributed Wind Activities

Support the development of DWEA Roadmap

Develop a solid plan within the DWEA Composite Subgroup to:

- Engage stakeholders to identify technology barriers to market penetration
  - Market requirements
  - Wind turbines cost and COE
  - Product reliability
  - Technology tools (design, production, inspection, testing, operation)

- Composite materials and manufacturing technologies. Lesson learned and outlook on future technologies.

- **Help plan and guide future R&D activities and support decisions by industry, utilities, state and federal agencies, insurance companies, policy makers, and other interested parties**

Additional slides

Distributed Wind Activities

Lesson learned and actions from SWT RDMP specific to materials and manufacturing

- **Reduced cost of energy resulting from turbines that operate in low-wind regimes**
  - Develop U.S. technology for low-cost, robust rotors optimized for low wind speed regimes.
  - Develop low-cost, very tall towers

- **Improved turbine reliability**
  - Develop test methods for reliability issues like "extreme events.“
  - Gather multi-year data on turbine performance, reliability, operation, and maintenance.
  - Develop structural safety standards for the small turbine industry.

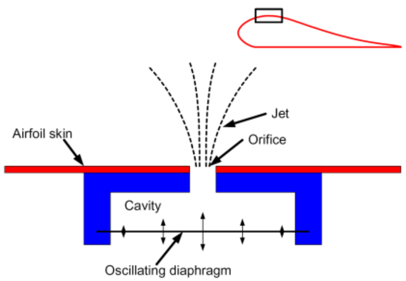
Distributed Wind Activities

Lesson learned and actions from SWT RDMP specific to materials and manufacturing

- **Reduced manufacturing costs by increasing the volume of production**
  - Engage manufacturing consultants to advise individual manufacturers on improved manufacturing techniques, improved throughput time, and development of a manufacturing plan
  - Encourage small turbine manufacturers to explore state incentives for building manufacturing businesses

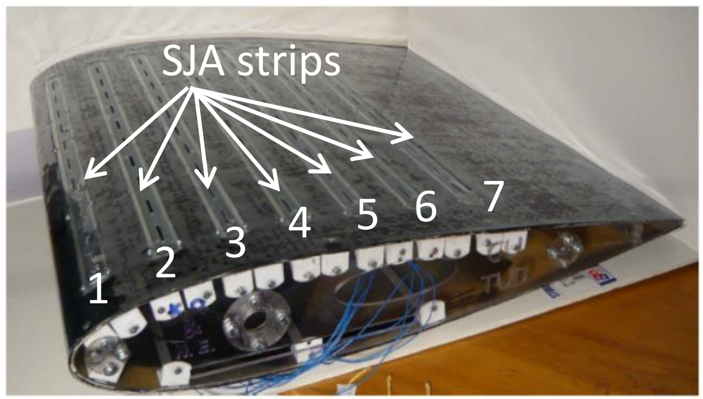
- **Improvement in the reliability and durability of small wind turbines**
  - Develop improved life-cycle testing protocols and analytical methods for small wind turbines
  - Develop better understanding of design load characterization for enhanced reliability, durability, and longevity
  - Identify design elements necessary to achieve 50-year operating life
  - Perform durability and reliability testing for environmental extremes
  - Support company-specific, in-house reliability enhancement projects

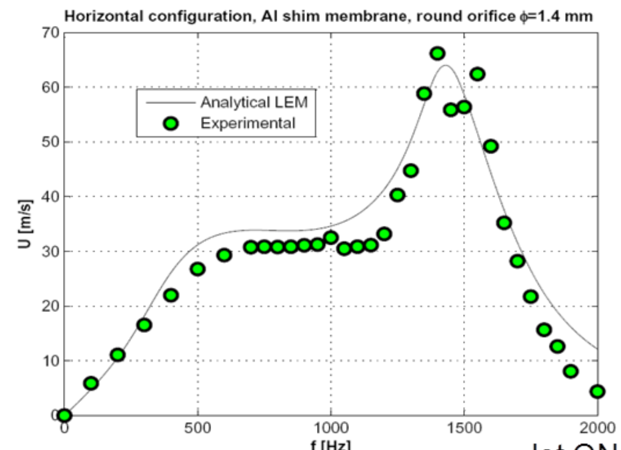
WT Active Aeroelastic Control with Synthetic Jet Actuators



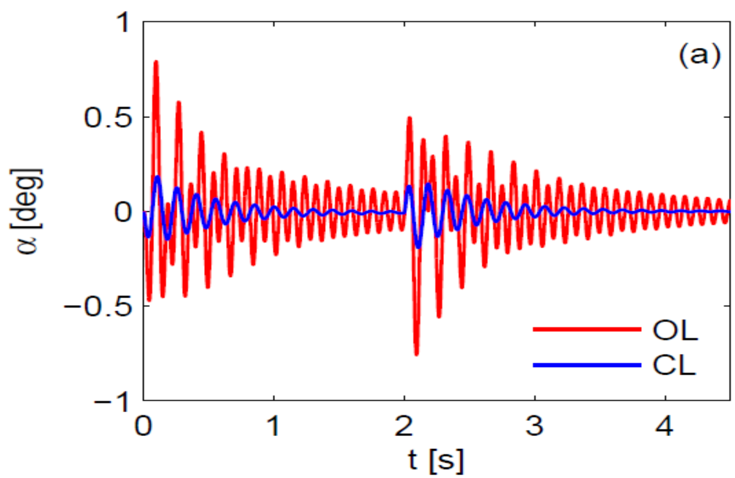
ZNMF

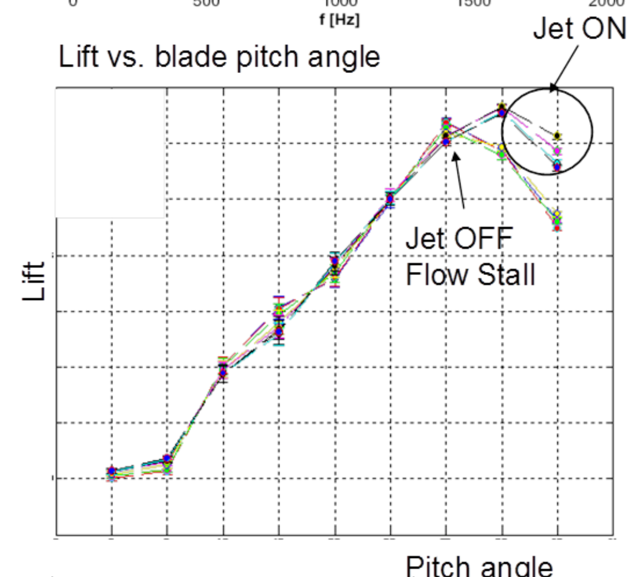
- 300kW WT

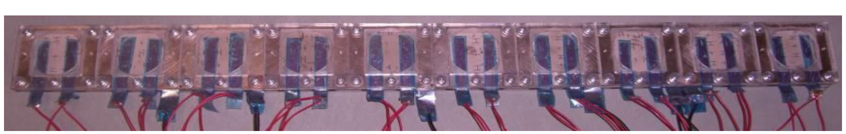




- Aerodynamic ROMS
- Aeroelastic Control
- Flutter suppression
- Gust/Load alleviation



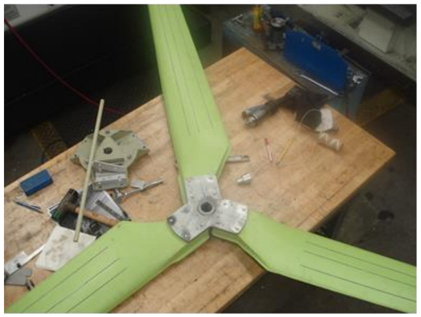


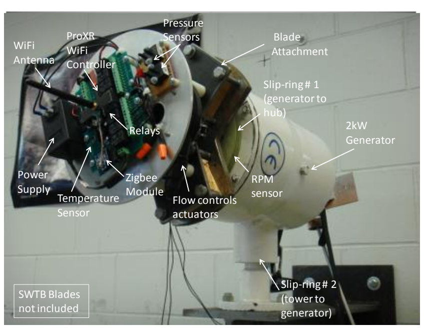


Synthetic Jet Actuators Strip

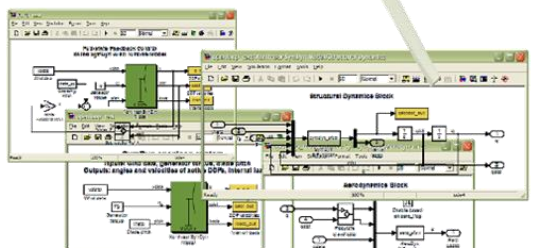
TU Delft
Delft University of Technology

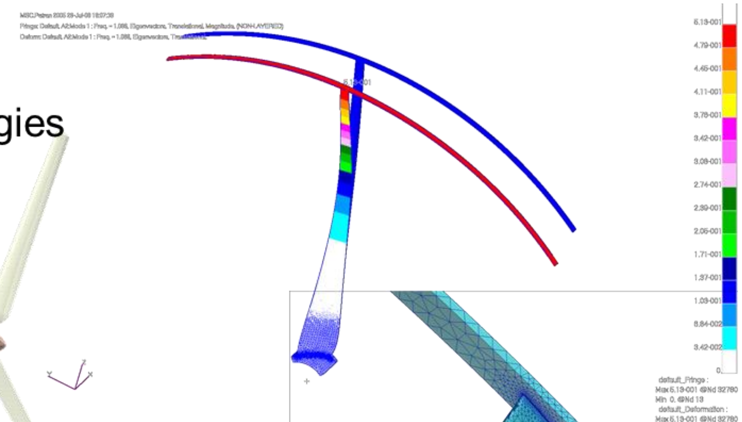
Design and Performance Analysis Active and Passive Control of WT

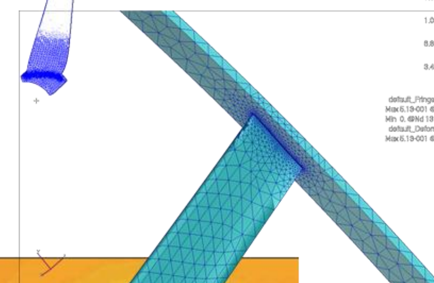


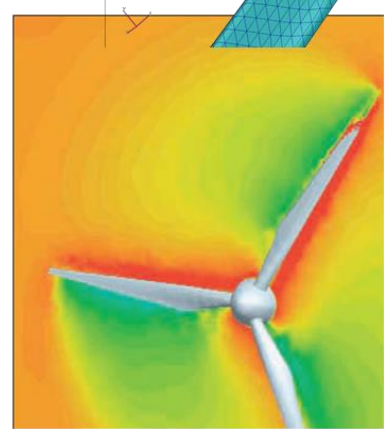


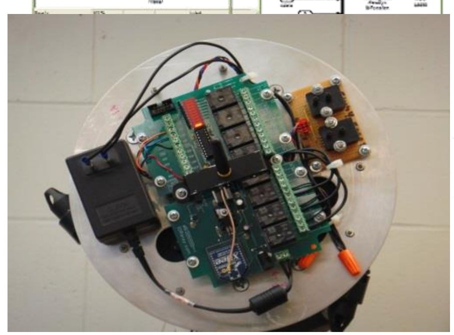
Active/Passive Control for Wind Turbine Technologies





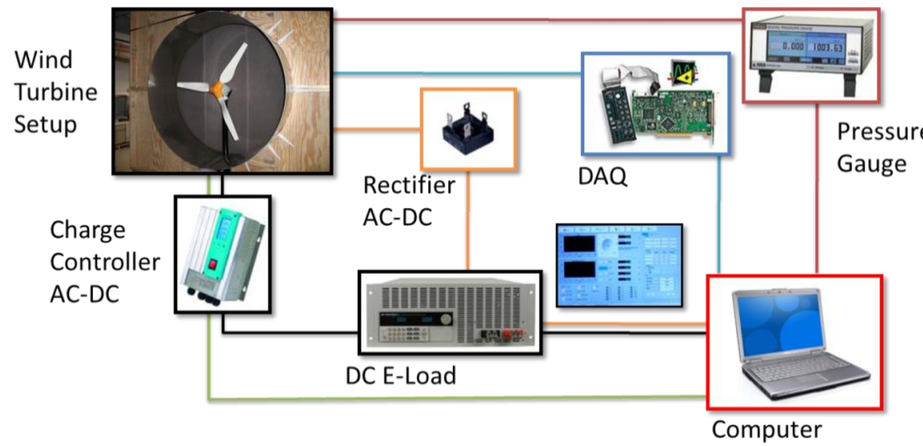


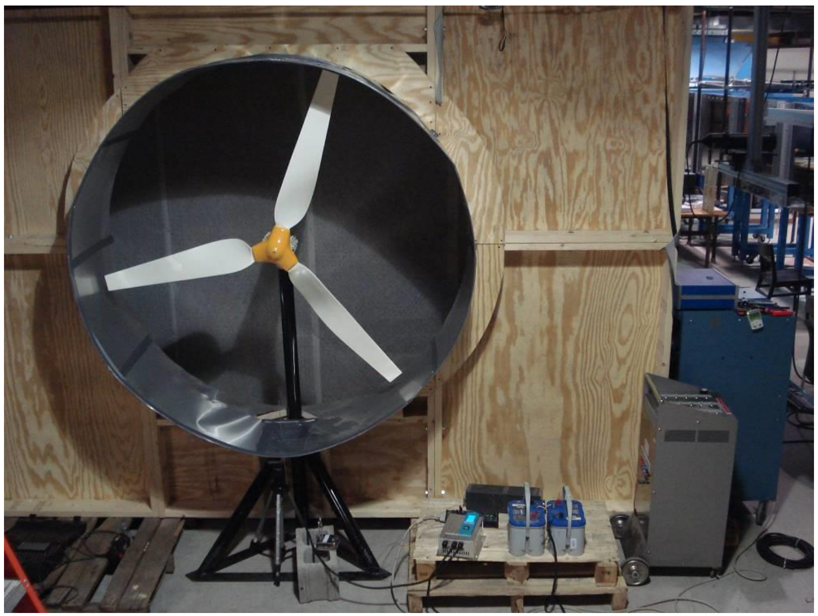


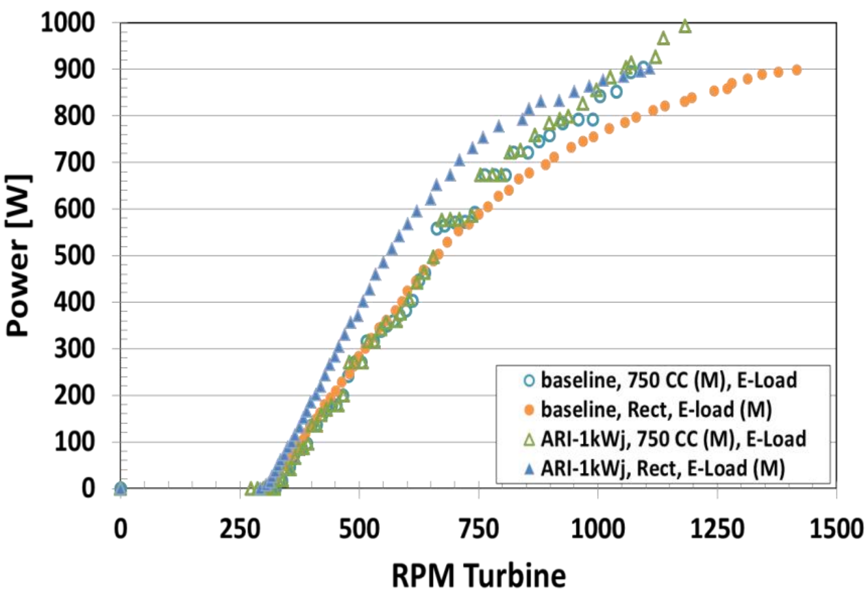


Design and Performance Analysis Active and Passive Control of WT

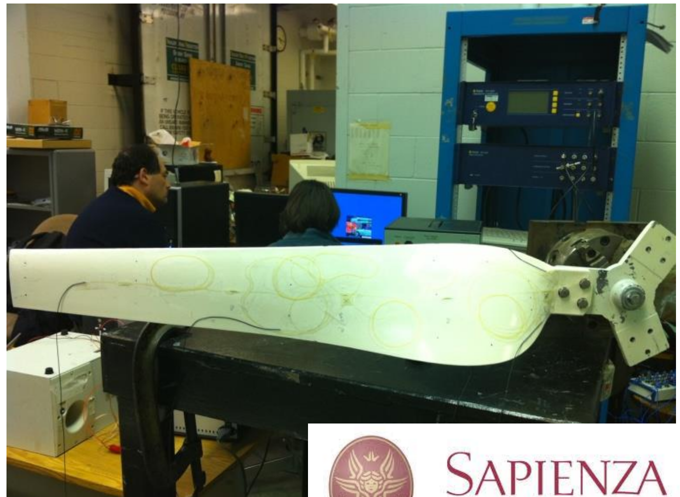
- Wind Turbine Test in the Open-Jet Wind Tunnel Facility
- Power performance
- Comparison blade testing

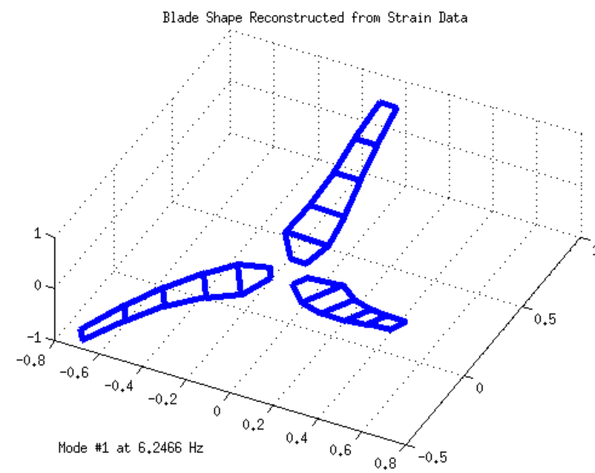




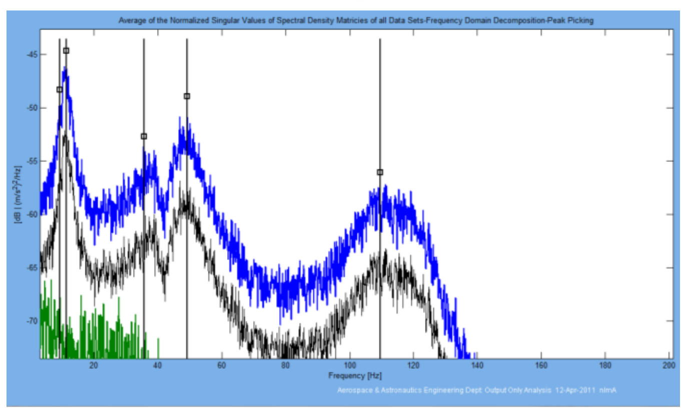


Blade Structural Characterization and SHM and Load Monitoring

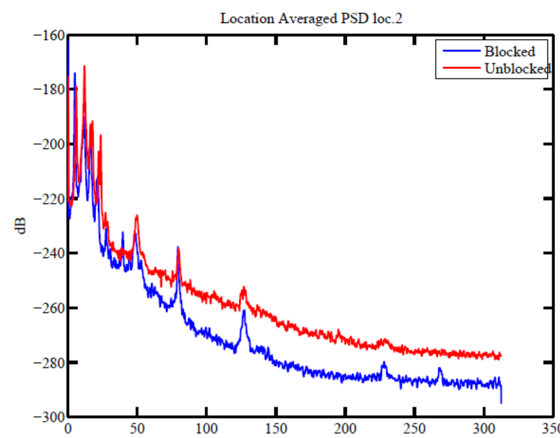




- FBG strain sensor
- Operational Modal Analysis



- Modal properties reconstruction



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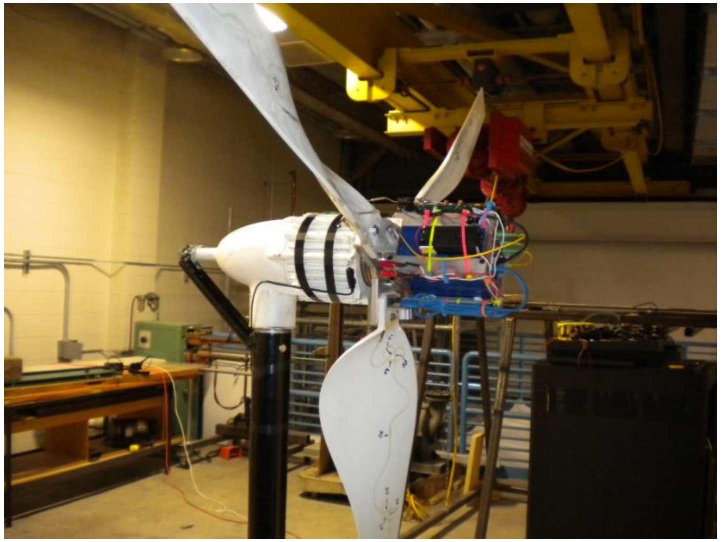
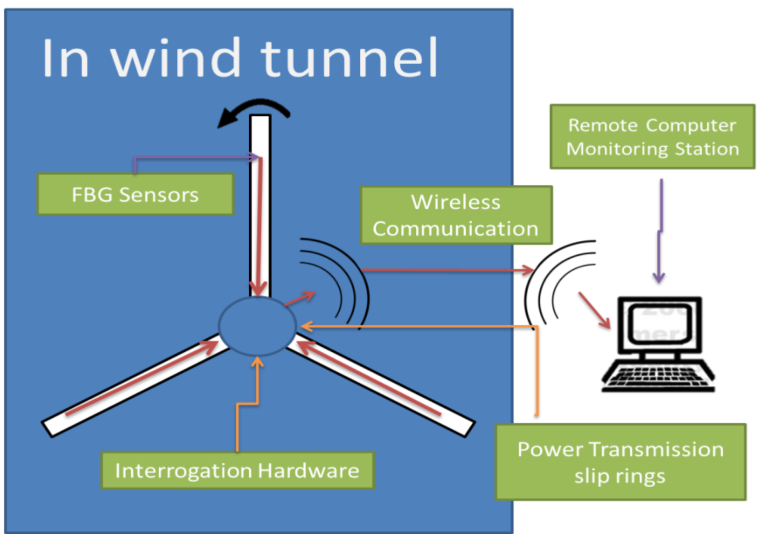
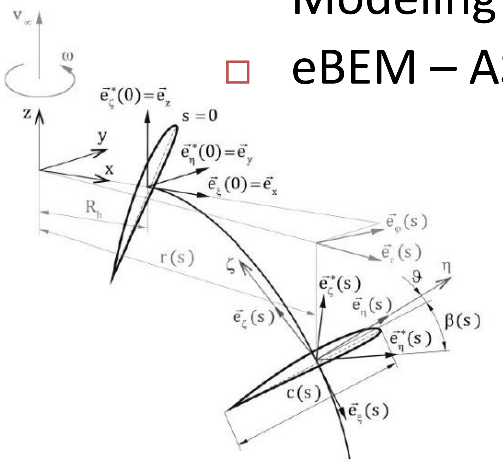
Blade Structural Characterization and SHM and Load Monitoring





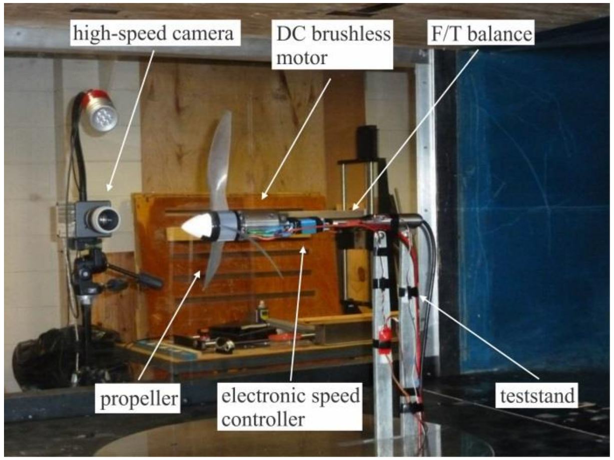
Aeroelastic Design of Blades with Optimized Load-Distribution

- Aeroelastic Modeling
- eBEM – AS FSI

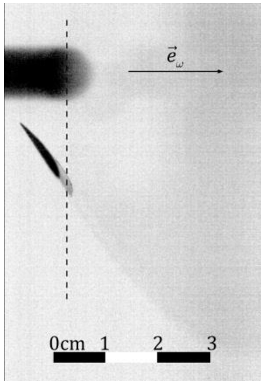


a.)

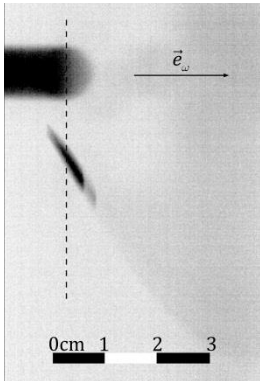
b.)



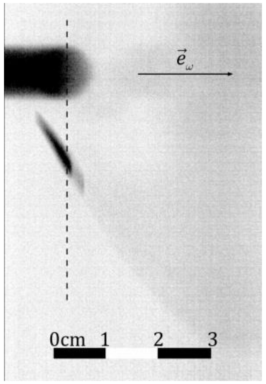
c.)



d.)



e.)



a.) Manufactured blades, b.) experimental setup and tip deflections c.) at rest, d.) at J = 1.1 and e.) at J = 1.8

From Design .... to ....
Prototype Field Testing

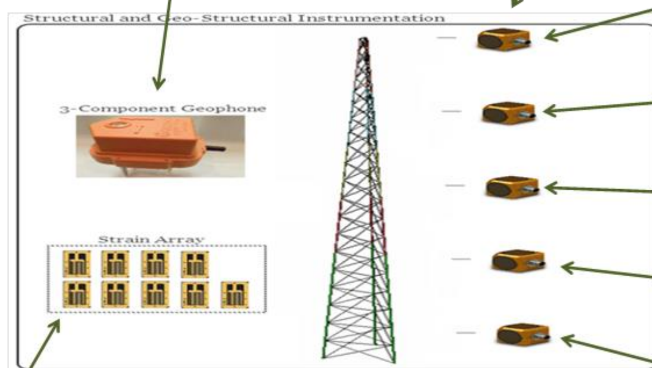
OPTIWIND

Tower-Rotor Interaction - Characterization and Coupled System ID – SHM

Sensing Platform

3 component geophone to record ground velocity at the foundation of each leg of the tower

Triaxial Accelerometers



120 Feet

95 Feet

70 Feet

40 Feet

13.33 Feet

Biaxial strain gauges on the legs and lower diagonals to capture interaction of the tower with the foundation and soil