WindSTAR

Wind-Energy Science, Technology, and Research
Industry/University Cooperative Research Center

2019 ANNUAL REPORT

UMass Lowell ✦ UT Dallas

MESSAGE FROM OUR CENTER DIRECTORS

Center Director
Christopher Niezrecki, Ph.D.
University of Massachusetts Lowell

Site Director
Mario Rotea, Ph.D.
University of Texas at Dallas

Dear IAB Members,

On behalf of the WindSTAR I/UCRC Directors and Faculty members, we would like to thank you for your continued support and membership. The Center has completed its fifth year (Phase I) and we're proud of what we've accomplished having faculty and students work side by side with company members. During Phase I, the Center completed dozens of projects, published numerous papers, had multiple M.S. and Ph.D. students graduate, filed a patent, and implemented several software and hardware systems that are in use by the WindSTAR company members. For every dollar coming from a Full IAB member, ~16 dollars are invested in the Center from another source. For small business IAB members, the leveraging is approximately 48:1. Without operating through the National Science Foundation's I/UCRC program, this level of commitment and value to industry would not be possible.

Awareness of WindSTAR continues to grow and more people in the wind industry are learning that the Center is a platform that enables universities, industrial partners, and government to collaborate on developing novel solutions to wind energy problems. As we progress through our sixth year of operation (Phase II), we will continue to grow the Center, strengthen existing collaborations, and increase awareness of WindSTAR within the wind industry. In 2020, we will launch a new "**WindSTAR Webinar Series**" that will provide its members the opportunity to provide outreach to a broad wind energy audience.

The WindSTAR Center is working to improve the performance and availability of wind energy conversion systems. The Center's efforts will help drive down the cost of wind-generated electricity and make the use of wind energy more widespread within the United States and globally. Results from projects have provided valuable data to Center members who have acquired several multi-million dollar grants augmenting their R&D capacity. Through continued advancements in technology we believe that wind power will be a major player in improving the sustainability of the Nation's electricity portfolio. We are happy you are participating in the WindSTAR I/UCRC and look forward to working with you in the years to come.

Sincerely,

Christopher Niezrecki, Ph.D.
Professor and Chair, Department of Mechanical Engineering
Co-Director, Structural Dynamics and Acoustics Systems Laboratory
Director, WindSTAR I/UCRC
University of Massachusetts Lowell

Mario Rotea, Ph.D.
Erik Jonsson Chair in Engineering and Computer Science
Professor and Head, Department of Mechanical Engineering
Site Director, WindSTAR I/UCRC
University of Texas Dallas

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A NATIONAL SCIENCE FOUNDATION SUPPORTED INDUSTRY-UNIVERSITY COLLABORATION DRIVING DOWN THE COST OF WIND POWER

MISSION STATEMENT

The mission of WindSTAR is to bring together university and industry researchers to conduct basic and applied research on topics important to wind industry members. The Center combines capabilities, facilities, and knowledge to execute projects of interest to industry partners, train students in advanced technologies, and foster a community for industry/university networking and collaboration.

WindSTAR is an NSF-funded Industry/University Cooperative Research Center for Wind Energy, Science, Technology and Research, established in 2014. A collaboration between UMass Lowell, the University of Texas at Dallas, and its members, the Center aims to solve the pressing needs of the wind industry.

The University of Massachusetts Lowell is the lead WindSTAR site and focuses on projects that advance the materials, manufacturing, reliability, testing, modeling, and monitoring of turbines as well as energy storage and transmission. The University of Massachusetts Lowell is a public national research university in Lowell, Massachusetts.

The University of Texas at Dallas is a WindSTAR site with foci on high-fidelity simulation of wind power systems and components, LiDAR measurements and analysis of wind fields for diagnostics and model validation, Boundary layer and subsonic wind tunnel testing, control system design for wind turbines and wind farms, large rotor design, grid integration and energy storage. The University of Texas at Dallas is a public research university in Richardson, Texas.

IAB MEMBER COMPANIES

WindSTAR's industry membership is diverse across the wind energy supply chain, including wind farm owner and operators; turbine, blade and tower manufacturers; material suppliers; condition monitoring & control electronics manufacturers; actuator technology developers; and other organizations with a stake in the growth of the wind energy market.

2019-2020 IAB Chair
Neal Fine
CEO
Aquanis, Inc

2019-2020 IAB Vice Chair
Nathan Bruno
Regional Segment Leader - Composites
Hexion

2018-2019 IAB Chair
Nicholas Althoff
Sr. Advanced Manufacturing Engineer
GE Renewable Energy

2018-2019 IAB Vice Chair
Neal Fine
CEO
Aquanis, Inc

Past IAB Chairs:
2017-2018: Ben Rice, Pattern Energy
2016-2017: Steve Johnson, GE Renewable Energy
2015-2016: Justin Johnson, EDP Renewables
2014-2015: Steve Nolet, TPI Composites, Inc

AQUANIS
bachmann.
edp renewables
EPRI ELECTRIC POWER RESEARCH INSTITUTE
GE Renewable Energy
HEXION™
HUNTSMAN Enriching lives through innovation
LEEWARD Renewable Energy, LLC
LM WIND POWER a GE Renewable Energy business
MASSACHUSETTS CLEAN ENERGY CENTER
Olin™ EPOXY
Pattern
Shell
TWT Texas Wind Tower
tpi COMPOSITES

Previous Members include:
Keuka Energy
Maine Composites Alliance
National Instruments
NRG Renew

FINANCIAL OVERVIEW: RETURN ON INVESTMENT

MEMBERSHIP LEVELS 2018-2019

Full Mebership
$42,400 Annually

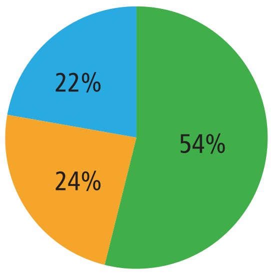
Small Business Associate
$15,900 Annually

REVENUE FOR 2018-2019

NSF Award
$178,950

IAB Contributions
$429,300

University Contribution (Cost Share)
$192,019



ANNUAL REVENUE: $800,269

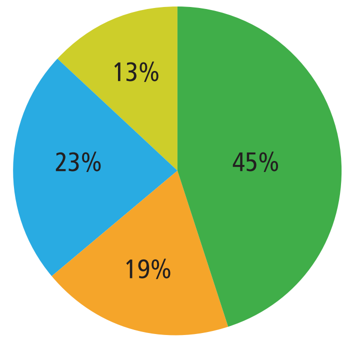
CUMULATIVE INVESTMENT

NSF Award
$874,643

IAB Contributions
$1,736,650

University Contribution (Cost Share)
$754,180

In-Kind
$527,508



TOTAL INVESTMENT: $3,892,981

5-YEAR REVIEW

PROJECTS COMPLETED	34	SOFTWARE DEVELOPED	05	HARDWARE BUILT	03
PATENT FILED	01	JOURNAL ARTICLES	11	CONFERENCE PAPERS	24

2018-2019 PROJECTS

- Mechanical Properties Enhancement Prediction for Matrix Material
  Project ID: A1-18
- Engineered Sandwich Core Construction: Experiment and Evaluation
  Project ID: A2-18
- Structural Wind Blade Repair Optimization
  Project ID: A3-18
- Residual Stresses in Thick Paste Adhesive Bondlines
  Project ID: A4-18
- Monitoring of Wind Turbine-Foundation and Technology Assessment
  Project ID: B1-18
- System integration of a Wind Turbine Blade Acoustic Monitoring System
  Project ID: B2-18
- Proactive monitoring of Wind Farm Performance through Wind LiDAR Data and a Reduced Order Model
  Project ID: C1-18
- Advanced Control System for Evaluation of on-Blade Load Mitigation Technologies
  Project ID: D1-18
- NREL FAST Modeling for Blade Load Control with Plasma Actuators
  Project ID: D2-17
- Mechanical Properties, Micro-structure Property Relationship and Manufacturing/Construction Methods for UHPFRC for Both the Foundation and Towers
  Project ID: F1-18
- Development of a Unique Fiber-Optic Resin Cure Sensor
  Project ID: U1-19
- Wind Turbine Characterization and Design of High-Efficiency DC Motors
  Project ID: U2-19

Mechanical Property Enhancement Predictions for Matrix Material

Principal Investigator:
Marianna Maiaru (University of Massachusetts Lowell)

Co-Principal Investigators:
Alireza Amirkhizi (University of Massachusetts Lowell)
Christopher Hansen (University of Massachusetts Lowell)

Student Researchers:
Sagar Shah, Joshua Morris & Willoughby Chen (University of Massachusetts Lowell)

IAB Mentors:
Bruce Burton & Marc Chouinard (Huntsman)
Steve Nolet & Amir Salimi (TPI Composites)
Nicholas Althoff (GE Renewable Energy)
Nathan Bruno, Mirna Robles & Paul Ubrich (Hexion)

Curing results in spatial variability of mechanical properties of composites and uneven cure consolidation when large structures are manufactured. Different properties can be obtained as a function of different processing conditions. During curing residual stress build-up due to mismatch in thermo-mechanical properties of fiber and matrix. Inhomogeneous thermo-mechanical property distribution within the part, along with manufacturing defects such as local variations in volume fraction, voids, porosity and wrinkles may affect composites behavior. All these aspects of manufacturing make the correlation between resin properties and its in-situ behavior at the composite level very difficult to establish. As a result, the trade-off between resin properties and composite performance becomes difficult to achieve in design phase. In order to accurately predict transverse composite properties, we proposed a three-step approach involving 1) material characterization (cure kinetics, stiffness and strength measurement), 2) numerical studies using the Finite Element Method (FEM) of composite microstructures and 3) experimental validation (see Figure 1). Accurate material characterization is fundamental to study curing. Through this study we are creating a material database of thermo-mechanical property evolution as a function of cure. This data can be implemented in FE modeling to predict transverse composite strength and stiffness at the micro-scale while accounting for random fiber distribution and fiber volume fraction variations (see Figure 2). Transverse tensile testing of thin unidirectional laminates is used to establish boundaries of applicability for theory of micromechanics and provide experimental validation for numeric predictions. CT-scans are used to quantify void content within tows in defective specimens and to assess defect morphology. Improved prediction of transverse elastic modulus was used at the blade level to quantify resin benefits in terms of resistance to bending, torsion and buckling loads.

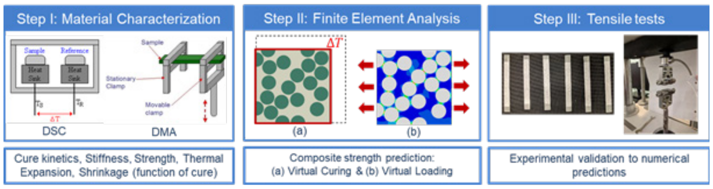
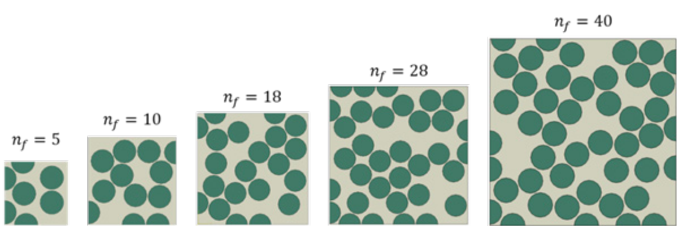
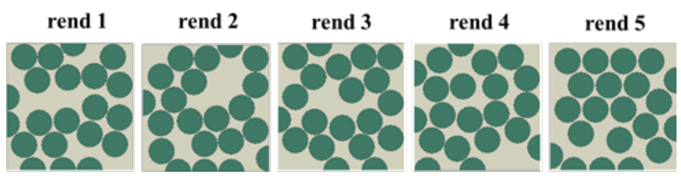


Figure 1:
Three-step approach adopted for enhanced matrix property predictions

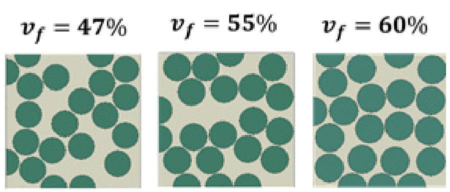
Output of this project will enable resin and composite manufacturers to assess various resin formulations in design phase using minimum testing. Relying on FE models for accurate transverse property predictions will reduce testing in design phase, thus reducing the head cost of the blade.
This study will provide better understanding of the most relevant resin thermo-chemical properties to optimize to achieve enhanced performance across the composite characteristic length scales up to the blade level.



(a) RVE size variation



(b) Different renditions to account for random fiber distribution



(c) Fiber volume fraction variation

Figure 2:
FE modeling of composite microstructure accounting for (a) Representative Volume Element (RVE) size variation, (b) random fiber distribution within an RVE and (c) variation in fiber volume fraction.

PROJECT ID: A1-18

Engineered Sandwich Core Construction: Experiment & Evaluation

Principal Investigator:
Hongbing Lu (University of Texas at Dallas)

Student Researcher:s
Cheng Feng, Dongyang Cao, Vijay Kulkarni & Yao Ren (University of Texas at Dallas)

IAB Mentors:
Nicholas Althoff, Eric Shain & Xu Chen (GE Renewable Energy)
Paul Ubrich and Nathan Bruno (Hexion)

Sandwich-structured composites dominate the blade manufacturing due to its high stiffness and light weight along the shift of wind power industry to pursue long turbine blades to extract more power economically. Core material used as the middle supporting component of a sandwich structure serves to decrease weight and enhance structural performance. Wet lay-up and resin transfer molding (RTM) processes are typical manufacturing processes for turbine blade construction, in which resin is introduced to the core-face system and then cured. The mechanical properties of sandwich components, processing characteristics, and property changes due to processing conditions are critical for the design and optimization of blade structures. However, during these processes, there is a lack of understanding of the amount of resin uptake, mechanical property changes following resin uptake, and the property spatial variation in the resin/foam or composite face skin/resin interphase region. Also, the mechanical property and the failure criteria of foam core and sandwich structures have not been investigated thoroughly. This project addresses these issues. In the project, an experimental investigation was carried out on the core foams under tension, compressive, and flexural tests. Digital image correlation technique was incorporated in these tests to provide an accurate deformation measurement to characterize the stress-strain response and failure behavior on two types of PVC foam. Then, wet lay-up and vacuum assisted resin transfer molding (VARTM) processes were used to manufacture core composite sandwich specimens consisting of PVC foam sandwiched by glass fiber face skins. The amount of weight gain due to the resin uptake in different processes was measured and its impact on the mechanical properties, specifically compressive modulus and strength, was studied. It is determined that higher resin uptake tends to increase the compressive modulus but decrease the compressive strength. However, higher resin uptake increases the specific compressive modulus but barely affects specific compressive strength. To understand the property variation at the interface between glass skin and foam core where resin is partially penetrates to fill foam pores, nanoindentation experiments were performed in the resin/foam transition zone. The spatial variation of Young's modulus in the transition zone was determined. The experimental results provide a quantitative understanding of how the material properties of sandwich cores are affected by the resin uptake in the RTM process and how the core sandwich composites fail under loads. The results also form a guideline for the design and optimization of manufacturing sandwich cores for turbine blades to lower levelized cost of energy (LCOE). All these data can also be fed into a FEM model to further optimize the design and to investigate the failure of core composite sandwich structures under service conditions.

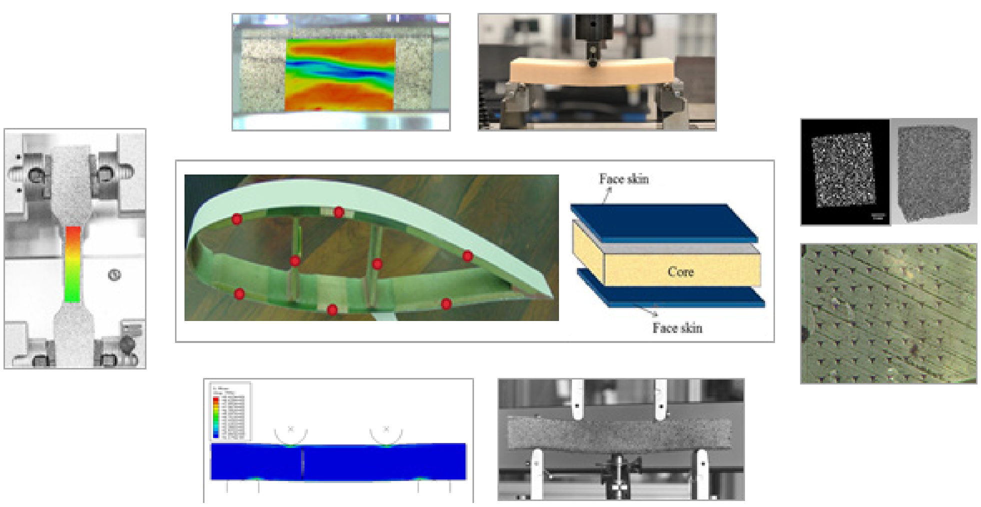


Figure 1. Experimental characterization of core foam, nanoindentation of resin/foam interface, and FEM simulation of sandwich under loading to facilitate the design and optimization of wind turbine blades.

PROJECT ID: A2-18

Structural Wind Blade Repair Optimization

Principal Investigator:
Marianna Maiaru (University of Massachusetts Lowell)

Co-Principal Investigators:
Scott Stapleton (University of Massachusetts Lowell)
Christopher Hansen (University of Massachusetts Lowell)

Student Researchers:
Sagar Shah & Freddy Santiago (University of Massachusetts Lowell)

IAB Mentors:
Steve Nolet & Amir Salimi (TPI Composites)
Nathan Bruno, Mirna Robles & Paul Ubrich (Hexion)
Marc Chouinard & Bruce Burton (Huntsman)
Ben Rice (Pattern Energy)
Jian Lahir (EDP Renewables)

Wind turbine blades can undergo in-service damage including lightning strikes, impact and erosion. Depending on the extent of the damage, the repair process can take more than 24 hours to be performed resulting in long and costly turbine downtime. Environmental conditions, such as temperature and humidity, play a key role in the repair process as they could affect the cure kinetics of the resin, affect the adhesion capability of the substrate and degrade composites mechanical performance. Time- and cost-effective repair procedures are fundamental to reduce the turbine downtime and successfully restore the aerodynamic efficiency and structural integrity of the blade. The state-of-the-art curing cycle for repair is not fully optimized which adds to the turbine downtime. The repair process is highly variable, and it depends on several requirements.

The goal of this study is to determine the shortest cure cycle to perform structural repairs understanding the effect of various curing cycle parameters such as, heating rate, hold temperature, hold time and cooling rate for each given configuration. This study will also provide information on the optimum environmental conditions to perform repairs efficiently. First, the cure kinetic of a baseline infusion resin system is determined accounting for different humidity levels and external temperatures. The moisture absorbed by the resin and the curing agent under various environmental conditions and their effect on the curing behavior are investigated performing Differential Scanning Calorimetry (DSC). Then, the repair geometry is modeled within the Finite Element software Abaqus to predict the cure evolution and temperature distribution during repair (See Figure 1). An optimization study for the proposed FE model is performed where all the cure cycle parameters are varied, one at a time, to analyze their effect on degree of cure and temperature distribution within the part (see Figure 2). The optimization study is performed implementing Python scripts. The optimized cure cycle is determined as a result of the FE simulations which account eventual constrains based on the manufacturer's recommendation. Lastly, to learn the state-of-the art of complex repair procedures pristine laminate panels are damaged and repaired in collaboration with TPI Composites. More repairs will be performed in the lab at UML to assess the quality of the part cured using the temperature cycle from the optimization study. Next, specimens will be cut from repaired panels and tested under various loading conditions to compare their strength with that of pristine specimens.

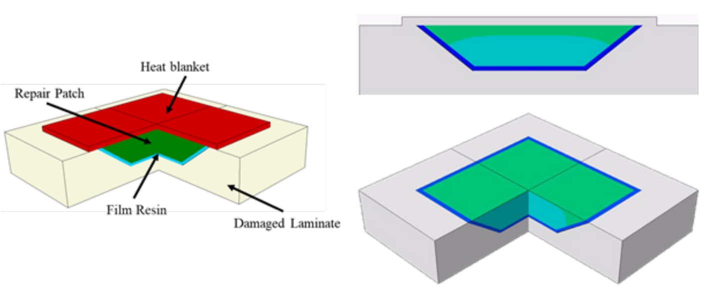


Figure 1: FE modeling of single side scarf geometry to predict degree of cure and temperature (different colors represent different temperatures within the patch and the adhesive).

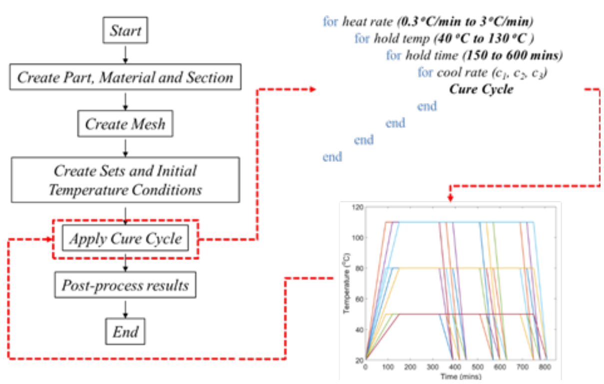


Figure 2: Flowchart showing the automated model generation, pre-processing and post-processing procedure developed in Abaqus, Python and MATLAB.

Reducing the blade downtime, while restoring the structural integrity and aerodynamic efficiency means longer blade life, higher revenues and lower cost of energy. This study benefits owners and operators as well as repair & manufacturing and resin companies. High fidelity FE modeling will provide guidelines to define optimized repair processes under various environmental conditions. Results from this project will be used to establish better practices for specific kinds of repairs. Additionally, this study is setting the basis for an onsite tool that can be used to provide the shortest cure cycle to evenly cured laminates for specific repair configurations.

PROJECT ID: A3-18

Residual Stresses in Thick Paste Adhesive Bondlines

Principal Investigator:
Scott Stapleton (University of Massachusetts Lowell)

Co-Principal Investigator:
Marianna Maiaru (University of Massachusetts Lowell)

Student Researchers:
Alessandro Cassano & Sara Najafian (University of Massachusetts Lowell)

IAB Mentors:
Paul Ubrich (Hexion)
Amir Salimi (TPI Composites)
Nicholas Althoff, Amir Raihi & Christopher Savio (GE Renewable Energy)

Bondline failure is a key critical failure mode in wind turbine blades. Substantial variation in bondline thickness can result in different thermal histories for the adhesive layer due to the exothermic curing of common adhesives. Predictive guidance regarding the impact of this variability in adhesive cure temperature cycles is extremely limited. Without guidelines of acceptable variability, excess resources may be placed into avoiding damage by processing at excessively low temperatures and longer processing cycles, which produce no discernible benefits. This project focuses on the characterization of adhesive bonded joints as a function of the curing temperature and adhesive thickness. In order to take into account the thickness influence, a series of experiments are conducted in a bonded joint configuration. Two sets of specimens for each thickness (10/20/30 mm) have been manufactured using recommended cure cycles and an elevated temperature cure cycle. A series of tensile tests is performed on the joint specimens to determine the mechanical properties and the thickness-temperature influence on the bonded joint performance. Moreover, due to the exothermic nature of the cure of most adhesives, thicker regions result in elevated temperatures during curing which can lead to higher residual stresses in the bondline. Little research has been conducted to characterize the effect of temperatures and exothermic reaction levels on adhesive quality for thick joints. Additionally, the effect of bondline thickness on curing temperatures is also poorly understood, and predictive capabilities in this field are presently unavailable. Therefore, a finite element model capable of tracing the thermal, conversion and residual stress histories in thick adhesive bondlines is presented. The cure kinetics of the bonding paste has been successfully characterized using non-isothermal DSC analysis and validated with temperature readings from the curing process of an adhesive bead of variable thickness from 5mm to 30mm. Residual stress predictions were compared with experimental results from tensile test on bonded specimens. Finally, cure cycle optimization strategies for a representative section of a wind turbine blade were proposed using active heating and active cooling and compared with a baseline cure cycle.

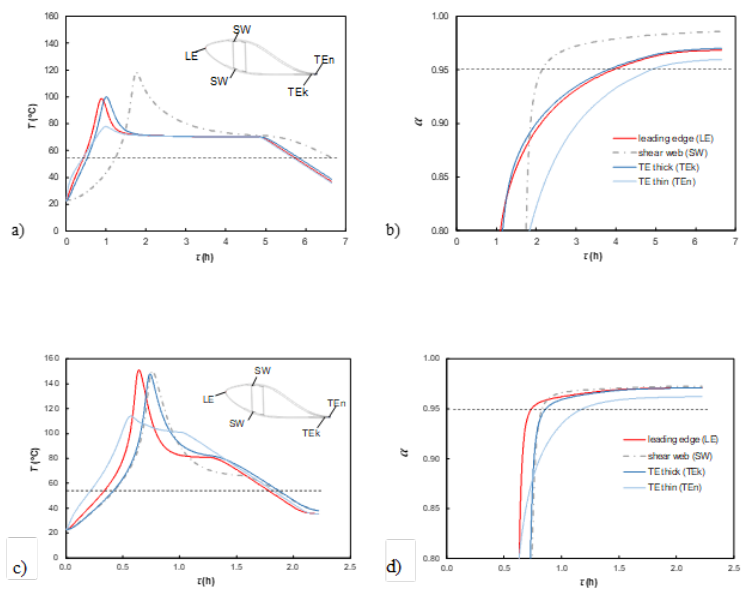


Figure 1. Simulated curing cycles for the baseline model: a) Adhesive temperature vs time b) Degree of cure α vs. time and Improved Spar Cap Heating: c) Adhesive temperature vs. time d) Degree of cure α vs. time.

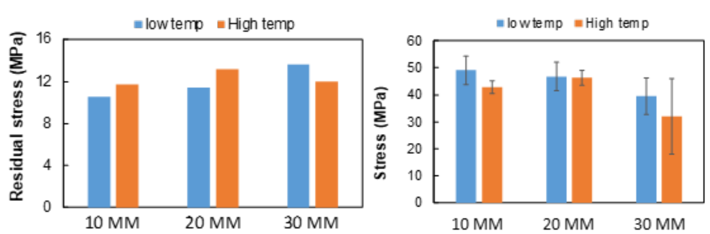


Figure 2. Comparison of a) residual stresses predicted by FE model and b) stress to failure from tensile testing on thick adhesive bondlines (10, 20 and 30 mm).

PROJECT ID: A4-18

Monitoring of Wind Turbine-Foundation and Technology

Principal Investigator:
Pradepp Kurup (University of Massachusetts Lowell)

Co-Principal Investigators:
Christopher Niezrecki (University of Massachusetts Lowell)
Raj Gondle (University of Massachusetts Lowell)

Student Researchers:
Husham Osman & SreeSnigdha Kolachana (University of Massachusetts Lowell)

IAB Mentors:
Ron Grife (Leeward Renewable Energy)
Adam Johs (EDP Renewables)

The dynamic forces combined with high fatigue loading on a wind turbine may result in foundation failures and affect the expected design life. Excessive tower displacements, tilt of a tower, or foundation cracks are some of the common foundation concerns. When the displacement worsens, it could lead to progressive failure due to fatigue and in some cases can even result in a cone pullout or overturning of the tower. The current practice of structural health monitoring of the foundation includes visually inspection of a turbine on a periodic basis. When surface cracks or water ingress into the foundation is reported, high-precision sensors are adopted for foundation monitoring, which can be time-consuming and very expensive. The project propose a novel, low-cost mechanical indicator to continuously monitor the wind turbine tower movement relative to the foundation. Some of the constraints placed on the mechanical indicator include: low cost, no electronics, readily discernable motion indication, and insensitivity to moisture. The mechanical device includes a spring-loaded rotary cam with a dial indicator that measures the displacement at the interface of the tower and the foundation. The device was field tested on several utility-scale wind turbine towers. The project report presents the results of field tests.

The displacement-monitoring indicator can be replaced as an effective tool for structural health monitoring of wind turbine foundations by significantly reducing the inspection costs per turbine. It is envisioned that these sensors will be deployed at large-scale to secure our energy infrastructure without compromising the lifetime of the asset.

Performance of the displacement-monitoring indicator operating at the base of a wind turbine tower's harsh environment.

PROJECT ID: B1-18

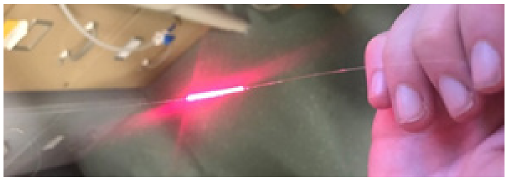
Development of a Unique Fiber-Optic Resin Cure Sensor

Project Instructors:
Christopher Niezrecki, Xingwei Wang (University of Massachusetts Lowell)

Student Researchers:
Joshua Bourke, Kaitlyn Chretien, Ashley Smits (University of Massachusetts Lowell)

IAB Mentor:
Steve Nolet (TPI Composites)

In this capstone project, a fiber optic sensor was designed to monitor the curing of epoxy resin in the manufacturing of wind turbine blades in order to determine when the resin has reached full cure. The sensor acts as a waveguide that light travels through. As the resin cures less light transmits through until the resin reaches full cure. Research was done on the manufacture of the optical fiber sensor comparing glass and polymer fibers in order to determine the materials which should be used in the sensor. Different methods for creating the sensor were researched. Prototypes were made using acrylic (PMMA) and glass optical fibers. The final sensor design is currently being validated through laboratory testing.



PROJECT ID: U1-19

System Integration of a Wind Turbine Blade Acoustic Monitoring System

Principal Investigator:
Murat Inalpolat (University of Massachusetts Lowell)

Co-Principal Investigator:
Christopher Niezrecki (University of Massachusetts Lowell)
Yan Luo (University of Massachusetts Lowell)

Student Researchers:
Christopher Beale & Ioannis Smanis (University of Massachusetts Lowell)

IAB Mentors:
Ron Grife (Leeward Renewable Energy)
Adam Johs (EDP Renewables)
Ben Rice (Pattern Energy)
Nicholas Althoff (GE Renewable Energy)

High operational loads cause significant bending and shear and thus are detrimental to wind turbine blades. Currently available condition monitoring systems are not capable of detecting different types and severity levels of damage and defects such as leading and trailing edge splits, holes and cracks. A comprehensive damage detection system that can monitor the blades for leading and trailing edge splits, delaminations, cracks and holes is currently not available. Consequently, it is vital to provide a low cost yet highly capable condition monitoring solution that will reduce the need for unscheduled maintenance. Deployment of a previously developed wind turbine blade acoustic monitoring system requires complete understanding and mitigation of the mechanical, electrical and structural problems associated with the installation and operation of the system. The project team will continue the efforts from our previous project, which has successfully shown the feasibility of the proposed technique in the laboratory environment as well as in the field (at the WTTC). This year's project entails integration of this novel acoustic monitoring system on a full scale operational turbine blade and mitigating the potential problems with the system and the blade interface. Lessons learned will be leveraged in order to improve the current system design and its integration. In this project, acoustic sensing will be used to detect cracks, holes, delaminations and trailing edge splits. Acoustic speakers will be used to excite the blade's cavity from internally and aerodynamic noise due to wind from externally. Wireless microphones will be used for the cavity-internal passive detection and a single microphone located underneath the nacelle will be used for the external active detection of damage. Performance of the new approach to identify structural damage will be validated on a full-scale wind turbine blade. The team will focus on the field tests on a full-scale turbine as well as improving and implementing the developed signal processing and machine learning algorithms to enable this technology in the near future.

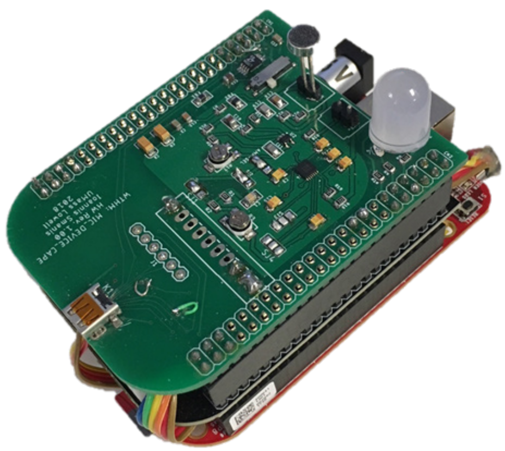


Figure 1: Acoustic sensing node circuitry.

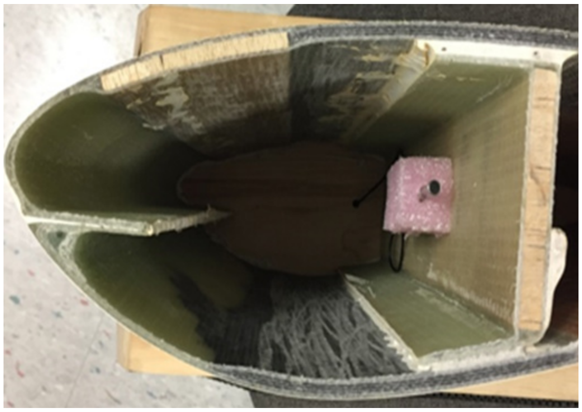


Figure 2. A close-up view of the blade-internal acoustic

PROJECT ID: B2-18

2018-2019 PROJECT HIGHLIGHTS

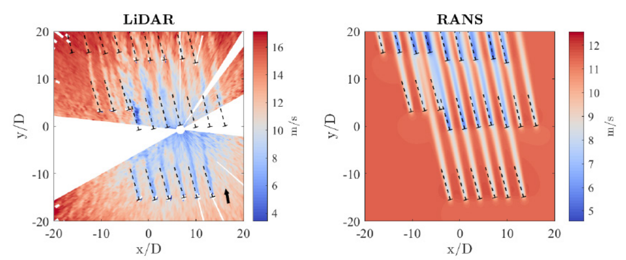
Proactive monitoring of Wind Farm Performance through Wind LiDAR Data and a Reduced Order Model

Principal Investigator:
G. Valerio Iungo (University of Texas at Dallas)

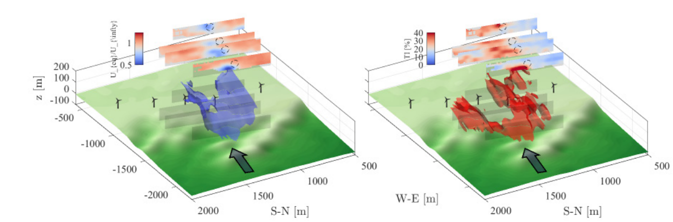
Student Researcher:
Stefano Letizia (University of Texas at Dallas)

IAB Mentors:
Ron Grife (Leeward Renewable Energy)
Bernard Landa (GE Renewable Energy)
Patrick Pyle (Pattern Energy)
Neal Fine (Aquanis)
Adam Johs (EDP Renewables)

This project aims to develop a CFD tool for accurate predictions of wind turbine wakes and power capture at the turbine level by reproducing the typical variability during the daily cycle of the atmospheric stability. This CFD tool is based on the Reynolds-averaged Navier-Stokes (RANS) equations, which are solved parabolically in order to reduce the computational costs. The model has been validated against real data of a flat terrain farm with 10-minute time resolution. The latest upgrade of the CFD tool showed an accuracy of 12% with a confidence level of 90% for estimates of power capture from individual turbines. Among different features, the CFD tool provides a data-driven calibration of the turbulence closure in order to mimic variability in wake recovery due to different regimes of the atmospheric stability. Furthermore, the thrust force over the turbine blades is experimentally estimated by coupling LiDAR data and RANS simulations.



LiDAR data compared to the 2D RANS numeric field in the Panhandle Phase II wind farm.



3D reconstruction of the velocity field induced by the topographic wake impacting a Mitsubishi turbine at the Cedar Creek wind farm.

In order to extend the range of applicability of this CFD tool to wind farms on complex terrain, a new LiDAR field campaign was carried out for the Cedar Creek wind farm in Colorado. Massive topography-induced wakes were detected by our LiDAR station and their effect on the power or the nearby turbines was quantified. Losses in power up to 33% were observed in particularly unfavorable conditions, along with enhanced power fluctuations increased by 115% compared to the baseline case. Statistical analysis of 3 years of SCADA data allowed to quantify the yearly energy losses due to this kind of phenomena that amounts to 4% for the turbines installed by the escarpment. Furthermore, the LiDAR capability for resource assessment in complex terrain were explored ad reveal an outstanding accuracy. Finally, the 2D RANS model has been adapted for the Cedar Creek I wind farm. The large inhomogeneity in the flow induced by the complex orography has been taken into account by adding a data driven pressure field able to mimic the action of topography no the wind speed.

PROJECT ID: C1-18

Wind Turbine Characterization and Design of High-Efficiency DC Motors

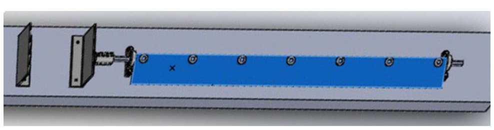
Project Instructors:
Christopher Niezrecki, Siavash Pakdelian (University of Massachusetts Lowell)

Student Researchers:
Chloe Andrews, Alex Antonitis, Martin Ssenyonjo (University of Massachusetts Lowell)

IAB Mentors:
Neal Fine, John Cooney, Chris Szlatenyi (Aquanis)

This Capstone Design project designed a movable gurney flap for a wind turbine. The flap needed to be capable of being actuated in 0.25s or less. Maintenance of wind turbines is difficult because of their height and accessibility. For this reason, one project constraint was that there be little to no additional mechanical parts to create the flap. It was determined that the gurney flap needed to be driven directly by a DC motor. The project team selected an LRPX 32 motor from Electrocraft. The wind load on the flap opening to 90° was simulated to achieve a motor a moment arm of 20 in-lb. When the flap was in the 0° position the torque on the motor would be close to zero.

Several systems of attaching the flap to the motor shaft were compared. It was ultimately decided that the system involving bolting a steel shaft to one side of the flap, coupling it to the motor shaft, and mounting the steel shaft on both ends in bearings was the simplest and most cost effective to perform. The final flap design was assembled and able to rotate under direct DC power.



PROJECT ID: U2-19

Advanced Control System for Evaluation of On-Blade Load Mitigation Technologies

Principal Investigator:
Mario Rotea (University of Texas at Dallas)

Co-Principal Investigator:
Yaoyu Li (University of Texas at Dallas)

Student Researcher:
Chang Liu (University of Texas at Dallas)

IAB Mentors:
Steve Nolet (TPI Composites)
Nicholas Althoff (GE Renewable Energy)
Neal Fine (Aquanis)

Rotor load mitigation technologies have the potential to allow new larger rotors with the same load envelope of smaller rotors, or extend the operational life of components in existing assets. In project D2-17, the team developed a simulation tool to aid in the analysis and design of on-blade active load control systems. The tool allows for control algorithms to command virtual on-blade actuators that modify the local sectional lift and drag coefficients over a partial-span of each blade. Then the impact of closed loop flow control on reduction in fatigue or extreme loads caused by turbulence, wind shear or gusts can be evaluated. While the work was originally motivated by plasma actuator devices, this computer tool is applicable to other on-blade devices for flow control, such as micro tabs and trailing edge flaps. In project D1-18, we proposed to develop advanced multivariable control algorithms, where all sectional actuator elements are allowed to vary independently (but coordinated). This controller is universally applicable to any actuation technology used to command changes in sectional lift.

Figure 1 shows a conceptual diagram of sectional lift control using plasma actuation. Figure 2 shows preliminary load reduction results for the DTU 10-MW Reference Wind Turbine. The load reduction is obtained using a feedback controller to command sectional lift in response to measured changes in the three blade-root flapwise bending moments.

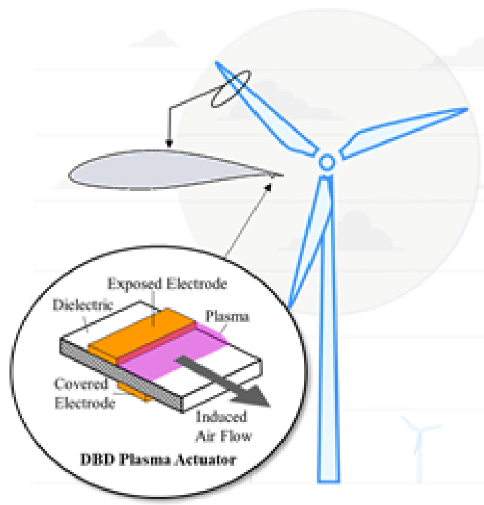


Figure 1: Conceptual diagram of a flow control device (DBD plasma actuator) to modulate the lift force along the blade span. Blade and rotor loads may be reduced by controlling the lift at various sections of the blade span. Diagram by Courtesy of Aquanis, Inc.

DTU 10-MW Reference Wind Turbine

Parameter	Value
Rated power	10 MW
Rotor Diameter	178.3 m
Hub Height	119.0 m
Cut-in, Rated, Cut-out Wind speed	4 m/s, 11.4 m/s, 25 m/s
Cut-in, Rated Rotor Speed	6 RPM, 9.6 RPM
Turbine Control	Variable speed, Collective pitch

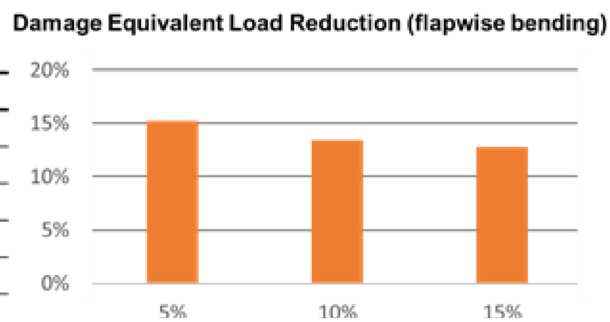


Figure 2: (Left) Parameters of the 10 MW Reference Turbine model developed at the Wind Energy Department in the Technical University of Denmark[i]. (Right) Percentage reduction in damage equivalent loads resulting from sectional lift control in the outer span of the blades. The wind conditions are 18 m/s hub-height wind with 0.2 shear exponent and three values of turbulence intensity.

[i]Bak, C., Zahle, F., Bitsche, R., Kim, T., Yde, A., Henriksen, L.C., Hansen, M.H., Blasques, J.P.A.A., Gaunaa, M. and Natarajan, A. (2013). The DTU 10-MW reference wind turbine. In Danish Wind Power Research 2013.

PROJECT ID: D1-18

NREL FAST Modeling for Blade Load Control with Plasma Actuators

Principal Investigator:
Mario Rotea (University of Texas at Dallas)

Co-Principal Investigator:
Yaoyu Li (University of Texas at Dallas)

Student Researcher:
Chang Liu (University of Texas at Dallas)

IAB Mentors:
Nicholas Althoff (GE Renewable Energy)
Neal Fine (Aquanis)
Steve Nolet (TPI Composites)

Reducing extreme and fatigue loads on the rotor blades of a wind turbine lowers the Levelized Cost of Energy (LCOE), which is particularly critical for future wind turbines equipped with longer and more flexible blades. With larger rotors, the span-wise variability of the wind challenges the capabilities of the blade load control strategies of current operational systems. Active flow control (AFC) has emerged as an appealing solution to fast and localized rotor control for load mitigation and energy capture enhancement. Among the existing AFC devices, plasma actuators have drawn attention due to their mechanical simplicity (no moving parts), fast response time and low cost. This project developed a simulation tool for design of plasma-based AFC systems for blade load reduction. The tool is based on the NREL FAST code. The FAST module with integrated plasma actuation is demonstrated using the NREL 5-MW reference turbine. With the feedback of blade-root flapwise bending moments, a Multi-Blade Coordinate (MBC) transformation based controller is used to drive the voltage commands to the plasma actuators. Load reduction is demonstrated without noticeable penalty in turbine performance as measured by rotor speed and power errors in Region 3. Further details in C. Liu, Y. Li, J.A. Cooney, N.E. Fine and M.A. Rotea, "NREL Fast Modeling for Blade Load Control with Plasma Actuators," 2018 IEEE Conference on Control Technology and Applications (CCTA), Copenhagen, 2018, p. 1644.

Figure 1 shows a segmented blade form plan where the aerodynamics of each segment is simulated using FAST. The plasma actuators are modeled as changes in local lift coefficient ΔC_L in the outer span of the blade (sections 12 to 17 in the segmented blade). The controllable lift coefficients are modulated by voltage signals (one per blade) generated by a feedback controller that measures selected blade loads to calculate the voltage commands for each blade (IBVC). Figure 2 demonstrates the reduction of blade loads at the rotor angular frequency when both vertical shear (non-uniform flow) and turbulence (unsteady flow) are present.

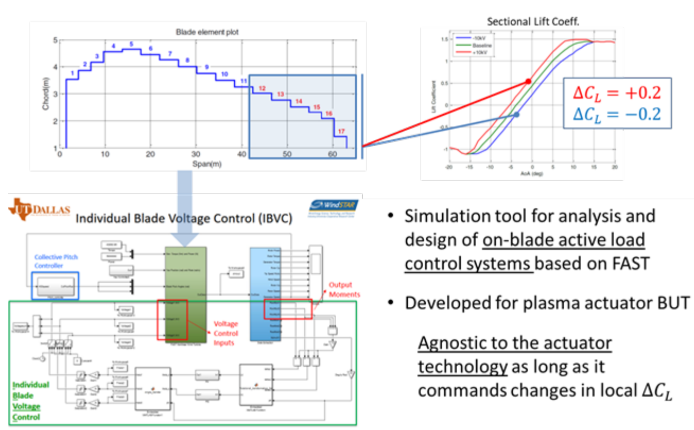


Figure 1: 5MW NREL ref turbine blade showing controllable local lift coefficients (Top). Simulink diagram of NREL FAST tool with controllable sectional lift coefficients (bottom left).

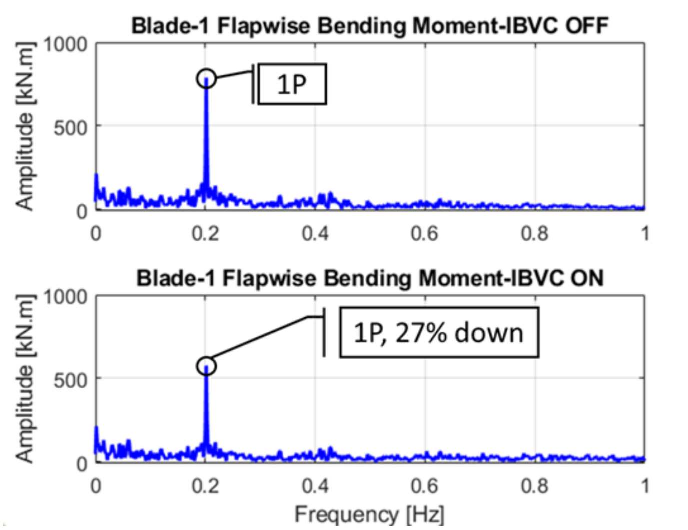


Figure 2: Frequency response of load signal with IBVC OFF (top) and IBVC ON (bottom) for the 5 MW NREL reference turbine at 18 m/s wind speed, vertical wind shear and 15% turbulence intensity. The "one-per-rotor-revolution" frequency (1P = 0.2Hz) dominates the spectrum of the blade root moment. The 1P mode amplitude is reduced from 788 kNm to 576 kNm, which represents a 27% reduction of the 1P amplitude.

PROJECT ID: D2-17

Mechanical Properties, Micro-structure Property Relationship and Manufacturing/ Construction Methods for Ultra-High Performance Fiber Reinforced Concrete for Wind Towers

Principal Investigator:
Dong Qian (University of Texas at Dallas)

Co-Principal Investigator:
Hongbing Lu (University of Texas at Dallas)

Student Researchers:
Ning Bian & Yingjian Liu (University of Texas at Dallas)

IAB Mentor:
John Buttles (Texas Wind Tower)

Ultra-High Performance Fiber Reinforced Concrete (UHPC) is a relatively new construction material that is mainly composed of high-performance concrete and fiber materials. The combination of higher binder and fiber dosage with low water to binder ratio provides UHPC with exceptionally mechanical properties such as high strength, outstanding ductility and durability, and energy absorption capability. Motivated by its remarkable material properties, a combined experimental/modeling approach has been established in this project to investigate the application of UHPC as a material solution for wind tower. The experimental studies were focused on identifying key mechanical properties such as stiffness, flexural, tensile and compressive strengths, and resistance to crack imitation and propagation. In addition, microstructures of UHPC were characterized by micro-CT. The experimental results have been incorporated into a multiscale model to capture the critical link between the microstructural constituents of UHPC and the macroscopic mechanical properties. In this multiscale model, a micromechanical modeling approach employing representative volume element (RVE) was first established. This approach accounts for the key effects such as size, shape, distribution and orientation of the constituents that were obtained from the experiments. Based on the RVE studies, a macroscopic constitutive model featuring coupled plasticity and damage effects was developed and implemented in the finite element method (FEM). Extensive design analysis employing a commercial FEM code were performed on UHPC wind towers of three different heights of 100 m, 150 m and 200 m. Key design parameters were obtained by performing both static and dynamic analysis to ensure that the requirements on stress and deflection were met. Topological optimizations were further performed on the initial designs to reduce material consumption. Based on the optimized UHPC wind tower design, levelized cost of energy (LCOE) analysis were carried out and compared to the cases of all-concrete and all-steel towers. The comparison demonstrated significant advantage of UHPC solution for tall wind towers. Such an advantage can be further enhanced by the outstanding durability and longer service life of UHPC, which requires more study.

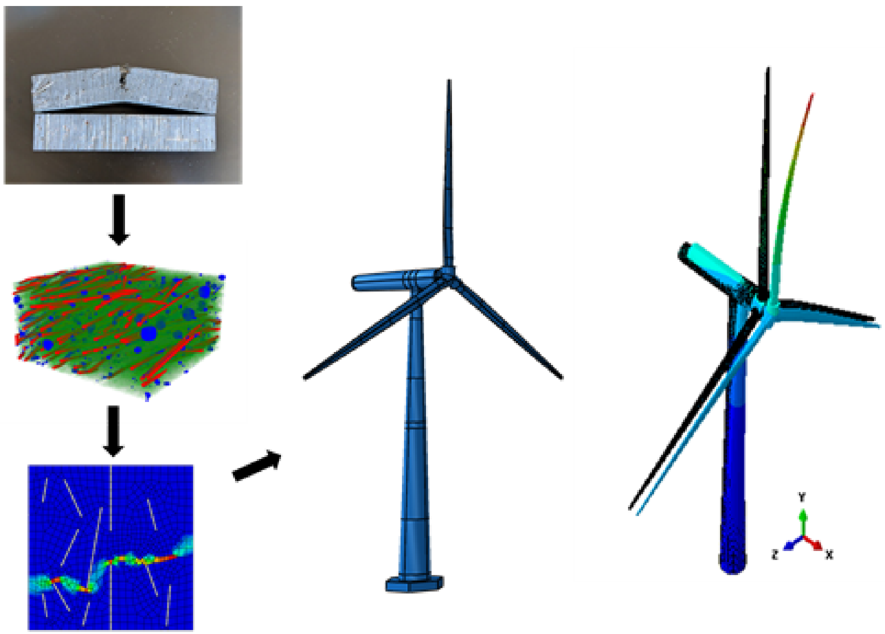


Figure 1: A combined experimental/model approach to the design of wind tower based on Ultra-High Performance Fiber Reinforced Concrete (UHPC).

PROJECT ID: F1-18

2014-2019 OUTCOMES

Through August 31, 2019

Deliverables:

1. Software: A user-based subroutine written in Fortran for use in the finite-element software Abaqus, to calculate the degree of cure and temperature of an adhesive under exothermic curing reaction.
2. Software: A tool to simulate blade active load control systems using NREL FAST and any actuation system (plasma actuators in particular) that can command changes in the local lift coefficient along the blade span.
3. Software: A Matlab-based GUI that can predict the axial, transverse, and shear properties of composite laminates used in wind turbine blades based on CPFM advanced micromechanics model
4. Software: A Matlab based GUI for prediction of power production and wind turbine wakes for the Panhandle Phase II wind farm.
5. Software: Simulink code for Extremum Seeking Control of NREL CART3 (Controls Advanced Research Turbine, 3-bladed).
6. Patent Filing: Wind Turbine Foundation Motion and Crack Indicator, May 2019
7. Hardware: Fiber Optic Interrogator for Strain Monitoring
8. Hardware: Passive Acoustic Damage Detection System for Blades
9. Hardware: Active Acoustic Damage Detection System for Blades

Journal Papers:

1. Beale, C., Willis, D. J., Niezrecki, C., & Inalpolat, M. "Passive acoustic damage detection of structural cavities using flow-induced acoustic excitations." Structural Health Monitoring. https://doi.org/10.1177/1475921719860389, 2019.
2. Beale, C., Inalpolat, M., & Niezrecki, C. Active acoustic damage detection of structural cavities using internal acoustic excitations. Structural Health Monitoring. https://doi.org/10.1177/1475921719835761, 2019.
3. Morris J., Hansen C. J., Amirkhizi, A. V. "Improved approximation of transverse and shear stiffness for high volume fraction uniaxial composites," Mechanics of Materials, Vol. 129, 230-235, 2019.
4. Xiao, Y., Li, Y. and Rotea, M.A. "CART3 Field Tests for Wind Turbine Region-2 Operation with Extremum Seeking Controllers," IEEE Transactions on Control Systems Technology, Vol. 27, No. 4, pp. 1744 - 1752, July 2019.
5. Ciri U., M.A. Rotea, and S. Leonardi, "Effect of the turbine scale on yaw control," Wind Energy, 2018, Vol. 21 (12), pp. 1395-1405.
6. Iungo G. V., Santhanagopalan V., Ciri U., Viola F., Zhan L., Rotea M. A. and Leonardi S., "Parabolic RANS solver for low-computational-cost simulations of wind turbine wakes," Wind Energy, Vol. 21, No. 3, March 2018, pp. 184-197.
7. Santhanagopalan V., M.A. Rotea, G.V. Iungo, "Performance optimization of a wind turbine column for different incoming wind turbulence," Renewable Energy, Vol. 116, February 2018, pp. 232-24.
8. Willis, D. J., Niezrecki C., Kuchma, D., Hines, E., Arwade, S., Barthelmie, R. J., DiPaola, M., Drane, P. J., Hansen, C. J., Inalpolat, M., Mack, J. H., Meyers, A. T., and Rotea, M., "Wind Energy Research: State-of-the-Art and Future Research Directions," Renewable Energy, Elsevier, vol. 125(C), pages 133-154, 2018.
9. Ciri U., Rotea M.A., Santoni C., Leonardi S., "Large-Eddy Simulation with Extremum Seeking Control for wind turbine array power optimization," Wind Energy, Vol. 20 , No. 9, September 2017, pp. 1617-1634.
10. Ciri U., Rotea M.A. and Leonardi S. "Model-free Control of Wind Farms. A comparative study between individual and coordinated extremum seeking," Renewable Energy, Vol. 113, December 2017, pp. 1033-45.
11. El-Asha S., Zhan L., Iungo G.V., "Quantification of power losses due to wind turbine wake interactions through SCADA, meteorological and wind LiDAR data," Wind Energy, Vol. 20, No. 11, November 2017, pp. 1823-1839.

Conference Papers:

1. Beale, C., Inalpolat, M., and Niezrecki, N., "An Experimental Investigation into the Interactions between Acoustic Modes and Structural Damage on a Cavity Structure," International Modal Analysis Conference (IMAC XXXVI), Orlando, Florida, February 2018.
2. Cassano A, Hansen C, Stapleton S, Maiaru M, "Prediction of Cure Overheating in Thick Adhesive Bondlines for Wind Energy Applications", 2018 Simulia Global User Meeting, Boston, MA, June 18-21, 2018
3. Fickenwirth, P., Inalpolat, M., "Feature Extraction for Vibration Based Damage Detection Using Spatio-temporal Structural Patterns," International Modal Analysis Conference (IMAC XXXVI), Orlando, Florida, February 2018.
4. Iungo G.V., S. Letizia and L. Zhan, "Quantification of the axial induction exerted by utility-scale wind turbines by coupling LiDAR measurements and RANS simulations", TORQUE 2018, Milano, Italy, June 20-22 2018, J. Phys.: Conf. Ser. 1037 (7), 072023.
5. Liu C., Yaoyu Li, John A. Cooney, Neal E. Fine, and Mario A. Rotea, "NREL FAST Modeling for Blade Load Control with Plasma Actuators," 2018 IEEE Conference on Control Technology and Applications, pp. 1644-1649, Copenhagen, Denmark, August 21-24, 2018.
6. Nanos, E.M., Robke, J., Heckmeier, F.M., Cerny, M., Bottasso, C.L., Jones, K.L., Iungo, G.V., "Wake characterization of a multipurpose scaled wind turbine model" (2019) AIAA Scitech 2019 Forum, San Diego; United States; 7 January 2019 through 11 January 2018
7. Santhanagopalan V., Letizia S., Zhan L., Al-Hamidi L.Y., Iungo G.V. "2018 Profitability optimization of a wind power plant performed through different optimization algorithms and a data-driven RANS solver." 2018 Wind Energy Symp., AIAA Scitech Forum AIAA 2018-2018.
8. Santoni C., Garcia-Cartagena E.J., Ciri U., Iungo G .V. and Leonardi S., "Coupling of mesoscale Weather Research and Forecasting model to a high fidelity Large Eddy Simulation", TORQUE 2018, Milano, Italy, June 20-22 2018, J. Phys.: Conf. Ser. 1037 (6), 062010.
9. Su, J., Johnson, S., Stapleton, S., Sherwood, J., Nolet, S., Althoff, N., "Effects of Localized Manufacturing-Induced Defects in Wind Turbine Blades, Proceedings of the American Society for Composites: Thirty-Third Technical Conference, Seattle, WA, 2018.
10. Ciri U., Rotea M.A. and Leonardi S., "Nested Extremum Seeking Control for Wind Farm Power Optimization," 2017 American Control Conference, Seattle, WA, May 24-26 2017, pp. 25-30.
11. Polcari M, Sherwood J. "Automation for Wind Blade Manufacturing." 3rd International Symposium on Automated Composites Manufacturing. Montreal, 2017.
12. Ashuri T, M.A. Rotea, C.V. Ponnurangam and Y. Xiao, "Impact of airfoil performance degradation on annual energy production and its mitigation via extremum seeking controls," 34th Wind Energy Symposium, AIAA SciTech, AIAA 2016-1738, San Diego, CA, 4-8 Jan 2016.
13. Ciri U., Rotea M.A., Santoni C., Leonardi S. Large-Eddy Simulation for an array of turbines with extremum seeking control. In: Proceedings of the American Control Conference, Boston, MA, USA, 6–8 July, 2016; pp. 531–536.
14. DiPaola M., D. J. Willis, S. Leonardi, "A Fast Differential Deficit Control Volume Approach for Modeling Turbine-Turbine Interactions," 46th AIAA Fluid Dynamics Conference, 2016, (AIAA 2016-3962), Washington, DC, June 13-17, 2016.
15. Iungo G.V., F. Viola; U. Ciri; S. Leonardi and M.A. Rotea, "Reduced order model for optimization of power production from a wind farm," 34th Wind Energy Symposium, AIAA SciTech, AIAA 2016-2200, San Diego, CA, 4-8 Jan 2016.

16. Martin, R., Baird, C., Giles, R., Niezrecki, C., "Terahertz ISAR and x-ray imaging of wind turbine blade structures," Proceedings of the SPIE Symposium on Smart Structures & Materials/NDE, Las Vegas, NV, March 20-24, 2016.
17. Polcari M., and Sherwood J. 2016. "Simulation of the Automation of Composite Wind Turbine Blade Manufacture", Proceedings of the American Society for Composites 31st Technical Conference and ASTM Committee D30 Meeting. September 19-12, Williamsburg, VA.
18. Xiao Y., Y. Li and M.A. Rotea, "Experimental Evaluation of Extremum Seeking Based Region-2 Controller for CART3 Wind Turbine," 34th Wind Energy Symposium, AIAA SciTech, AIAA 2016-1737, San Diego, CA, 4-8 Jan 2016.
19. Xiao Y., Y. Li and M.A. Rotea, "Multi-objective Extremum Seeking Control for Enhancement of Wind Power Capture with Load Reduction," TORQUE 2016, Munich, Germany, 5-7 October 2016. J. Phys.: Conf. Ser. 753 052025.
20. Dev S. and Hansen C., "Screening Barrier Properties for Robust Double Shell Walled Microcapsules," Fifth International Conference on Self-Healing Materials, Durham, North Carolina, NC, USA, June 2015.
21. Dev S. and Hansen C., "Evaluation of self-healing performance in epoxy/glass fiber composites manufactured using VARTM. 20th International Conference on Composite Materials, July 19-24 2015, Copenhagen Denmark.
22. Iungo G.V., Santoni C., Abkar M., Porté-Agel F., Rotea M.A. and Leonardi S. (2015), Data-driven Reduced Order Model for prediction of wind turbine wakes. J. Phys.: Conf. Ser., 625 012009.
23. Iungo G.V., Viola F., Ciri U., Rotea M.A. and Leonardi S. (2015) Data-driven RANS for simulations of large wind farms. J. Phys.: Conf. Ser., 625 012025.
24. Antoni C., Ciri U., Rotea M., and Leonardi S. (2015) Development of a high fidelity CFD code for wind farm control. American Control Conference, American Control Conference, 1715-1720.

Selected Presentations:

1. Rotea M.A., "Control of Wind Energy Systems," J. Mike Walker '66 Seminar Series, Texas A&M University, February 20, 2019.
2. Letizia S., Zhan L., Iungo G.V., "Effects of topographic wakes on wind turbine performance," Wind Energy Science Conference, June 17-20 2019, Cork, Ireland.
3. Nanos E.M., Letizia S. , Zhan L., Rotea M.A., Bottasso C. and Iungo G.V., "An experimental study of lateral wake interactions within a wind farm," Wind Energy Science Conference, June 17-20 2019, Cork, Ireland.
4. Iungo G.V., "Data-driven modeling of wind farm performance and wakes based on LiDAR and SCADA data," Presentation at the Sandia Wind Turbine Blade Workshop, August 29, 2018, Lubbock, TX.
5. Letizia S, Lu Zhan and G. Valerio Iungo, "LiDAR data-driven modeling of onshore wind farms on flat and complex terrains," 71st Annual meeting of the American Physical society, Division of Fluid Dynamics, November 18-20, 2018, Atlanta, GA.
6. Niezrecki, C., Keynote Address: "Recent Developments in Wind Turbine Sensing for Structural Health Monitoring," World Energy Congress, Boston, MA, August 27-28, 2018.
7. Niezrecki, C., Keynote Address: "Recent Developments in Wind Turbine Sensing for Structural Health Monitoring," International Conference On Renewable & Non-Renewable Energy, Las Vegas, NV, July 16-17, 2018.
8. Rotea M.A., Extremum Seeking Control of Wind Energy Systems, AWEA Wind Project O&M and Safety Conference 2018 (largest North American gathering of wind energy O&M industry professionals), San Diego, CA, February 27-28, 2018.
9. Rocchio B., U Ciri, S Leonardi, M Salvetti, "Stochastic calibration of the actuator line model parameters," Bulletin of the American Physical Society, November 2018.
10. Santoni C., E García-Cartagena, U Ciri, GV Iungo, S Leonardi, "Turbulence generation in a large eddy simulation of a wind farm coupling meso-and micro scale," Bulletin of the American Physical Society, November 2018.
11. Ciri, U., Rotea M.A., and Leonardi S., "Evaluation of active wake steering using large-eddy simulations," North American Wind Energy Academy Symposium, Ames, Iowa, September 26-29, 2017.
12. Rotea, M.A., Optimization & Control of Wind Energy Systems, CREST 4th JST-NSF-RCN Workshop on Distributed Energy Management Systems, June 12-14, 2017, Tokyo.
13. Rotea M.A., S. Leonardi and Y. Li, "Extremum Seeking Control of Wind Turbines and Wind Farms," Invited presentation at the Mini Symposia "WindFarm2017," Wind Energy Science Conference 2017, June 26-29, 2017, Technical University of Denmark, Lyngby, Denmark.
14. 1Santoni C., Garcia-Cartagena E.J., Zhan L., Iungo G.V., Leonardi S., 2017 Weather research forecasting model simulation of an onshore wind farm: assessment against LiDAR and SCADA data. 70th Annual Meeting APD DFD, Denver, CO.
15. El-Asha S., Zhan L. and Iungo G. V., "Quantification through SCADA, Meteorological, and Wind LiDAR Data of Power Losses due to Wake Interactions", Windfarms 2016, Richardson, TX, 2016.
16. Li. Y., "Maximizing Wind Power Output with Extremum Seeking," SWiFT Facility, Sandia National Laboratory, Lubbock, TX, July 28, 2016.
17. Niezrecki, C., Offshore Wind Leaders Conference; Panel on Positive Impacts of Basic and Applied Research of an Emerging Offshore Wind Sector: U.S. Higher Education, March 1, 2016 (invited).
18. Rotea Mario A., "Modeling and Control of Wind Energy," Plenary, IEEE Multi-Conference on Systems and Control 2016, Buenos Aires, Argentina, September 19-22, 2016.
19. Niezrecki, C., National Renewable Energy Laboratory – National Wind Technology Center, "Digital Image Correlation Applied to Structural Dynamics, Structural Health Monitoring, and Wind Energy," January 20, 2015, (invited).

Master of Science Thesis:

1. Behzad Najafi, "Characterization of uniform momentum zones in the atmospheric boundary layer," M.S. in Mechanical Engineering, University of Texas at Dallas, July 2019 (Chair: G.V. Iungo). Now with IAB member Leeward Renewable Energy, LLC.
2. Joshua Morris, "Improving Wind Turbine Blade Transverse and Shear Response Using Advanced Resins," Master of Science Thesis, University of Massachusetts Lowell, 2018. (Advisor: Alireza Amirkhizi).
3. El-Asha, Said, "Performance Analysis of an Onshore Wind Farm Through LiDAR, SCADA and Meteorological Data," M.S. in Mechanical Engineering, University of Texas at Dallas, December 2017 (Chair: G. Valerio Iungo).
4. Martin, R. W., "Analysis of polarimetric terahertz imaging for non-destructive detection of subsurface defects in wind turbine blades," Master of Science Thesis, University of Massachusetts Lowell, 2016. (Advisor: Christopher Niezrecki).

PhD Dissertations:

1. Christopher Beale, "System Integration of a Wind Turbine Blade Acoustic Monitoring System," PhD in Mechanical Engineering, University of Massachusetts Lowell, 2019. (Advisor: Murat Inalpolat).
2. Umberto Ciri, "Analysis of Model-Free Control of Wind Farms using Large-Eddy Simulations," Ph.D. in Mechanical Engineering, University of Texas at Dallas, July 2019. Now postdoctoral associate at UT Dallas. (Chair: Stefano Leonardi).
3. Zhan Lu, "LiDAR measurements for the characterization of wind turbine wakes, wake interactions and their effects on wind farm performance," Ph.D. in Mechanical Engineering, University of Texas at Dallas, December 2019 (Chair: G. Valerio Iungo).
4. Siddharth Dev, "Novel Microcapsule Chemistries for Self-Healing Applications in Polymeric Materials," Ph.D. in Mechanical Engineering, Dissertation, University of Massachusetts Lowell, 2018. (Advisor: Christopher Hansen).
5. Cristian Santoni, "Wind Farm Modeling: From the Meso-Scale to the Micro-Scale," Ph.D. in Mechanical Engineering, University of Texas at Dallas, 2018. Now postdoctoral associate at UT Dallas. (Chair: Stefano Leonardi).
6. Yan Xiao, "Control of Wind Power Systems for Energy Efficiency and Reliability," Ph.D. in Electrical Engineering, University of Texas at Dallas, 2018. Now with Danfoss, Rockford, IL. (Chair: Mario Rotea, Co-Chairs: Yaoyu Li, Babak Fahimi).

Interns at Member Companies:

1. Said El-Asha, recipient of WindSTAR NSF REU at UT Dallas, Engineering Intern at Leeward Renewable Energy, LLC.

PAST PROJECTS

1. Curing of Thick Adhesive Joints
   Project ID: A1-17
   PI: Scott Stapleton (University of Massachusetts Lowell)
   IAB Mentors: Amir Riahi (GE Renewable Energy), Chris Savio (GE Renewable Energy), Nicholas Althoff (GE Renewable Energy), Paul Ubrich (Hexion)
2. Mechanical Properties Enhancement Prediction for Matrix Materials
   Project ID: A2-17
   PI: Marianna Maiaru (University of Massachusetts Lowell)
   IAB Mentors: Stephen Nolet (TPI Composites), Hui Zhou (Huntsman)
3. Intelligent Damage Detection from Wind Turbine Blades Using Acoustic Excitation
   Project ID: B1-17
   PI: Murat Inalpolat (University of Massachusetts Lowell)
   IAB Mentors: Adam Johs (EDP Renewables), Ben Rice (Pattern), Kathi Bentzel (GE Renewable Energy)
4. Low Cost Optical Fiber Strain Sensor Interrogator for Wind Turbine Blades
   Project ID: B3-17
   PI: Xingwei Wang (University of Massachusetts Lowell)
   IAB Mentor: Bernard Landa (GE Renewable Energy)
5. Proactive Monitoring of Wind Farm Performance Through Wind LiDAR Data and a Reduced Order Model
   Project ID: C1-17
   PI: G. Valerio Iungo (University of Texas at Dallas)
   IAB Mentors: Adam Johs (EDP Renewables), Bernard Landa (GE Renewable Energy), Ron Grife (Leeward Renewable Energy)
6. Uncertainty quantification of wind farm performance through high fidelity simulations and wind LiDAR measurements
   Project ID: C2-17
   PI: Mario Rotea (University of Texas at Dallas)
   IAB Mentors: Neal Fine (Aquanis), Nicholas Althoff (GE Renewable Energy), Steve Nolet (TPI Composites)
7. NREL FAST Modeling for Blade Load Control with Plasma Actuators
   Project ID: D2-17
   PI: Mario Rotea (University of Texas at Dallas)
   IAB Mentors: Stephen Nolet (TPI Composites), Neal Fine (Aquanis), Nicholas Althoff (GE Renewable Energy)
8. Wind Turbine Aerodynamics Modified Gurney Flaps
   Project ID: U1-17
   PI: David Willis (University of Massachusetts Lowell)
   IAB Mentor: Neal Fine (Aquanis)
9. Wind Turbine Foundation Monitoring Sensor Development
   Project ID: U2-17
   PI: Christopher Niezrecki (University of Massachusetts Lowell)
   IAB Mentors: Ron Grife (Leeward Renewable Energy), Adam Johs (EDP Renewables), Diogo Silva (EDP Renewables)
10. Automation for Blade Manufacturing
    Project ID: A3-16
    PI: James Sherwood (University of Massachusetts Lowell)
    IAB Mentors: Steve Nolet (TPI Composites), Nick Althoff (GE Renewable Energy)
11. Effects of Manufacturing Induced Defects
    Project ID: A4-16
    PI: James Sherwood (University of Massachusetts Lowell)
    IAB Mentors: Nick Althoff (GE Renewable Energy), Joyee Zhu (GE Renewable Energy), Amir Riahi (GE Renewable Energy), Steve Nolet (TPI Composites)
12. Mechanical Property Enhancement Prediction for Matrix Materials
    Project ID: A5-16
    PI: Alireza V. Amirkhiz (University of Massachusetts Lowell)
    IAB Mentors: Stephen Nolet (TPI Composites), Hui Zhou (Huntsman), Marc Chouhinard (Huntsman)
13. Performance Effects of Adhesive Bond Defects
    Project ID: A6-16
    PI: Scott Stapleton (University of Massachusetts Lowell)
    IAB Mentors: Nick Althoff (GE Renewable Energy), Paul Ubrich (Hexion)
14. Low-Cost Wind Turbine Blade Structural Health Monitoring
    Project ID: B1-15
    PI: Murat Inalpolat (University of Massachusetts Lowell)
    IAB Mentors: Adam Johs (EDP Renewables), Dushyant Tank (Pattern Energy)
15. Diagnosis of Electrical Faults of Wind Turbine DFIGs
    Project ID: B1-16
    PI: Siavash Pakdelian (University of Massachusetts Lowell)
    IAB Mentors: Veronica Hernandez (Bachmann Electronic Corp), Paul Haberlein (Pattern Energy)
16. Proactive Detection of Under-Performing Wind Turbines Combining Numerical Models, LiDAR and SCADA Data
    Project ID: C1-16
    PI: Giacomo Valerio Iungo (University of Texas at Dallas)
    IAB Mentors: Patrick Pyle (Pattern Energy), Neha Marathe (EDP Renewables), Hector Figueroa (Leeward Renewable Energy)
17. Evaluation of Nested Extremum Seeking Wind Farm Control with SWiFT Facility
    Project ID: D1-16
    PI: Yaoyu Li (University of Texas at Dallas)
    IAB Mentors: Veronica Hernandez (Bachmann), Ron Grife (Leeward Renewable Energy)
18. Design for Composite Wind Turbine Blade Manufacturing
    Project ID: A1-14
    PI: James Sherwood (University of Massachusetts Lowell)
    IAB Mentor: Stephen Nolet (TPI Composites)
19. Self-Healing Materials for Wind Turbine Blades
    Project ID: A3-14
    PI: Chris Hansen (University of Massachusetts Lowell)
    IAB Mentors: Hui Zhou (Huntsman), Chris Savio (GE Renewable Energy), Amir Riahi (GE Renewable Energy)
20. Large Area Turbine Blade Inspection
    Project ID: D1-14
    PI: Christopher Niezrecki (University of Massachusetts Lowell)
    IAB Mentor: Rahul Yarala (Massachusetts Clean Energy Center)
21. Extremum Seeking Control for Wind Turbine Power Maximization
    Project ID: E2-14
    PI: Yaoyu Li (University of Texas at Dallas)
    IAB Mentor: Paul Haberlein (Pattern Energy)
22. Two-layer Optimization for Maximizing Wind Farm, Power Output
    Project ID: E3-14
    PIs: Mario Rotea (University of Texas at Dallas) and David Willis (University of Massachusetts Lowell)
    IAB Mentor: Jaimeet Gulati (EDP Renewables)

WindSTAR members hike at Mt. Washington

WindSTAR members during Summer 2019 IAB Meeting

CENTER EVENTS

IAB Meetings:

- University of Massachusetts Lowell, June 5-6, 2019
- University of Texas at Dallas, January 30-31, 2019

Invited Keynote Speakers for Center Banquets:

- Daniel Shreve, Wood Mackenzie Power & Renewables, June 5, 2019
- Dr. Daniel Laird, NREL, January 30, 2019
- Dr. Danielle Merfeld, GE Renewable Energy, June 6, 2018
- Walt Musial, NREL, January, 31, 2018
- John Douglas McDonald, GE Grid Solutions, January 18, 2017
- Dr. Rebecca Barthelmie, Cornell University, February 3, 2016
- Dr. Mike Robinson, NREL/DOE, January 28, 2015
- Daniel Shreve, MAKE Consulting, July 10, 2014

Events:

- Dinner with John Lavelle, GE Renewable Energy, CEO Offshore Wind, June 5, 2018
- Mt. Major Hike, June 5, 2018
- Mts. Lafayette, Lincoln, & Little Haystack Hike, June 13, 2017
- Mt. Washington Hike, June 24, 2016
- Mt. Katahdin Hike, June 23, 2015

ACTIVE PROJECTS: 2019-2020

- Mechanical Properties Enhancement Prediction for Matrix Materials
  Project ID: A1-19
  PI: Marianna Maiaru (University of Massachusetts Lowell)
  Co PIs: Alireza Amirkhizi (University of Massachusetts Lowell), Todd Griffith (University of Texas at Dallas)
  Mentors: Hexion, TPI Composites, GE Renewable Energy, LM Wind Power
- Cure Cycle Optimization of Wind Turbine Blades Adhesive Bondlines
  Project ID: A2-19
  PI: Scott Stapleton (University of Massachusetts Lowell)
  Co PI: Marianna Maiaru (University of Massachusetts Lowell)
  Mentors: Hexion, TPI Composites, GE Renewable Energy
- Structural Wind Blade Repair Optimization
  Project ID: A3-19
  PI: Marianna Maiaru (University of Massachusetts Lowell)
  Co PIs: Scott Stapleton & Christopher Hansen (University of Massachusetts Lowell)
  Mentors: Hexion, TPI Composites, Pattern Energy, EDP Renewables
- Long-duration Testing of the Acoustic Blade Monitoring System in a Wind Farm
  Project ID: B1-19
  PI: Murat Inalpolat (University of Massachusetts Lowell)
  Co PIs: Christopher Niezrecki & Yan Luo (University of Massachusetts Lowell)
  Mentors: GE Renewable Energy, EDP Renewables, Pattern Energy, Bachmann, Leward Renewable Energy
- Data-driven Reduced Order Model Based on LiDAR Measurements for Predictions of Wind-Farm Annual Energy Production
  Project ID: C1-19
  PI: Giacomo Valerio Iungo (University of Texas at Dallas)
  Mentors: GE Renewable Energy, EDP Renewables, Pattern Energy, Aquanis, Leward Renewable Energy, EPRI
- Decision Support Using FAST Aero-elastic Models of Operating Wind Turbines
  Project ID: C2-19
  PI: Todd Griffith (University of Texas at Dallas)
  Co PI: Mario Rotea (University of Texas at Dallas)
  Mentors: Aquanis, EDP Renewables, Pattern Energy, Leeward Reneable Energy, EPRI
- Modeling of Power Losses due to Leading Edge Erosion
  Project ID: C3-19
  PI: Giacomo Valerio Iungo (University of Texas at Dallas)
  Co PI: N/A
  Mentors: LM Wind Power, Leeward Energy, EDP Renewables, GE Renewable Energy
- Development of a Computational Tool to Maximize Wind Farm AEP by Yaw Angle Optimization
  Project ID: D1-19
  PI: Stefano Leonardi (University of Texas at Dallas)
  Co PIs: Mario Rotea (University of Texas at Dallas)
  Mentors: EDP Renewables, Bachmann, Pattern Energy, Aquanis, Leeward Renewable Energy
- Wind Turbine Foundation Monitoring Sensor Development
  Project ID: U3-19
  PI: Christopher Niezrecki (University of Massachusetts Lowell)
  Mentors: Leeward Energy, EDP Renewables
- Adhesion Test Device for Evaluating Adhesive/Sealant for Lap Joints in Wind Turbine Blades
  Project ID: U1-20
  PI: Scott Stapleton (University of Massachusetts Lowell)
  Mentors: LM Wind Power

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