Dear IAB Members,

On behalf of the WindSTAR I/UCRC Directors and Faculty members we would like to thank you for your sustained support and Membership. The Center has now completed its fourth year with 9 research projects currently being executed. As the awareness and engagement of WindSTAR continues to grow, more people in the wind industry are learning that the Center is a platform that allows universities, industrial partners, and government to collaborate on developing novel solutions to wind energy problems. We are working toward the goal of lowering the LCOE and helping to make the use of wind energy more widespread within the United States and globally. Without leveraging the infrastructure of a National Science Foundation I/UCRC, this level of commitment and value to industry would not be possible. For every dollar coming from a Full IAB member, 15 dollars are invested in the Center from another source. For small business IAB members the leveraging is approximately 40:1.

As we enter our fifth year of operation, we hope to grow the Center, strengthen existing collaborations, and increase awareness of WindSTAR in the wind industry community. The WindSTAR Center is working to meet the challenge of improving performance and reliability of wind energy conversion systems to help drive down the cost of wind-generated electricity. For example, Center members are utilizing research results and custom software to improve blade materials and increase turbine power production, and newly developed monitoring systems for blades and foundations are expected to be field tested in 2019. Results from projects have provided valuable data to Center members who developed large proposals for federal funding; thus, augmenting their R&D capacity. Through continued advancements in technology we believe that wind power will be a major player in the future of the Nation’s electricity portfolio. In the ever changing energy business climate, we will look for creative solutions to help grow and expand the Center. 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.
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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'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.

CURRENT 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.

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

2017-2018 IAB Chair
Ben Rice
Senior Manager, Operations Engineering
Pattern Energy

Past IAB Chairs:
2015-2016: Justin Johnson, EDP Renewables
2014-2015: Steve Nolet, TPI Composites, Inc

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

2017-2018 IAB Vice Chair
Nicholas Althoff
Sr. Advanced Manufacturing Engineer
GE Renewable Energy

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

AQUANIS  bachmann.  edp renewables
GE Renewable Energy  Hexion  Huntsman
Enriching lives through innovation

AEEWARD  Pattern  TWT

Renewable Energy, LLC
UT Dallas invested approximately $5 million to build the Boundary Layer and Subsonic Tunnel (BLAST) which opened this year. The tunnel features two test sections: the boundary layer test section (up to 76 mph with 100 feet of optical access) and the subsonic test section (up to 112 mph). Image shows visualization of air flow past a wind turbine with smoke generator inside BLAST.
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 and fatigue 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, beyond a critical threshold, lead to a degradation of adhesive properties. These regions with degraded properties are often visibly indiscernible from adhesive cured at recommended temperatures. 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 and conversion histories in thick adhesive bondlines is presented. The cure kinetics of the bonding paste has been successfully characterized using isothermal DSC analysis. The finite element model is validated with experimental results from temperature sensors embedded in the adhesive centerline of 10, 20 and 30 mm specimens. Finally, an example of curing cycle optimization on a geometry representative of the trailing edge of a wind turbine blade is proposed.
Uniform curing of matrix material during wind turbine blade manufacturing is a challenge as the thermal field is spatially dependent and non-uniform. The potential for localized, non-uniform cure states could affect blade performance and result in premature failure. Resin material is primarily responsible for the transverse response of the composite materials used in blade manufacturing. The blade can undergo high transverse and shear stresses which can cause delamination or trailing edge splitting. Micromechanical analysis to predict the transverse response of the composite as a function of degree of cure of the resin material was the focus of this project.

Previous WindSTAR work determined the effective composite stiffness dependence on the resin properties by employing the Continuous Periodic Fiber Model (CPFM). A MATLAB tool was created that performed modulus prediction and applied layup adjustments to accurately determine the effective composite properties using several micromechanical models, including CPM. This was followed by a numerical study to predict the effect on stiffness response of the composite due to the change in stiffness of the resin material. It showed that for a 20% increase in the matrix Young’s modulus, the transverse stiffness rose by 16%. This approach, although valuable, can be employed only to estimate the stiffness of the composite based on component properties. To predict failure in the blade as a function of curing, a more sophisticated approach is required, and this has been completed in this project.

A combined experimental-micromechanical analysis approach was employed to characterize the matrix material in-house and use the experimental results for matrix material as an input to the micromechanical model. The characterization began with cure kinetic study to accurately predict the cure of the matrix material when subjected to a thermal cycle. This characterization task was followed by stiffness measurement using a Dynamic Mechanical Analyzer (DMA). Combining the cure kinetics with the DMA, the stiffness of the matrix material as a function of cure was obtained. Finally, the strength of the matrix material was measured by tensile testing specimens subjected to different thermal cycles which eventually yielded strength measurements as a function of cure state. The mechanical response (strength and stiffness) of the neat matrix material for different degrees of cure were used as inputs to the micromechanical model to predict failure of the composite material.

Closely packed fibers act as stress rises which could lead to crack initiation in the composite. Thus, a random fiber distribution was modeled to investigate the effect of fiber packing on the strength and failure of the composite. In order to ensure convergence, the number of fibers were increased from 5 fibers in a repeating unit cell (RUC) to 50 fiber RUC, while keeping the fiber volume fraction constant. Convergence was achieved for the 50 fiber RUC, which could accurately predict the strength and stiffness of the composite material based on individual components. This approach was employed for two different resin formulation, RIMR 135/RIMH 137 and RIMR 135/RIMH 1366, prior being the baseline system for the analysis.
2017-2018 PROJECT HIGHLIGHTS

Intelligent Damage Detection from Wind Turbine Blades Using Acoustic Excitation

In this project, a novel acoustic sensing technique was used to detect cracks, holes, delaminations and trailing edge splits from wind turbine blades. Acoustic speakers were used to excite the blade’s cavity from internally and aerodynamic noise due to wind from externally. Wireless microphones were used for the cavity-internal passive detection and a single microphone located underneath the nacelle was used for the external active detection of damage. The main focus of this project was on the field tests on a full-scale turbine blade as well as signal processing and machine learning algorithm development to enable this technology.

This project enabled the team further develop a state of the art acoustics-based structural sensing and health monitoring technique, which requires efficient algorithms for operational damage detection from wind turbine blades. The team initially focused on the passive acoustic detection aspect of the project. A renewed passive damage detection test campaign was initiated on a fullscale blade undergoing flapwise fatigue testing at the Wind Technology Testing Center (WTTC) in Charlestown, MA. This approach leverages the energy caused by the wind/flow-induced noise, exterior to the cavity. It is inexpensive, in-situ, and effective to detect holes, cracks and leading/trailing edge splits in bonded surfaces. The blade can be continuously monitored and when damage is originated, the internal acoustic signature should change due to the changes in the transmission loss (caused by the hole or crack) and/or the distorted acoustic pressure field. The sound field inside the blade should be significantly different when the blade cavity is no longer sealed to the fluid passing over the exterior of the blade. A single microphone inside the blade cavity can be used to track the differential noise component caused by the damage, which essentially couples the blade cavity to the exterior airflow.

The team has also worked on the active detection part of the project. For this part of the project, a utility scale turbine blade that exists at the WTTC has been utilized. The blade-internal cavity has been ensonified by acoustic speakers and blade-external microphones have been used to detect any changes in the acoustic transmission loss due to damage. After the aforementioned tests, the team has been developing a suite of preliminary damage detection algorithms that will be used to detect damage under operation.

Wind Turbine Aerodynamics Modified Gurney Flaps

This Capstone Design project examined different designs of Gurney flaps for wind turbine blades using computation fluid dynamics and wind tunnel experiments. Gurney Flaps have been demonstrated as a viable solution to increasing the efficiency of aircraft wings, race car spoilers and wind turbine blades. However, previous research has only examined the Gurney Flap height, length and installation location. This work examined different Gurney Flap shapes to determine increases in both efficiency and lift force. In much of the previous Gurney Flap research, a simple ninety-degree tab is used as the aerodynamic actuator; however, in this project different Gurney Flap profile shapes are examined, including convex and concave designs. Initial results indicate that convex curves yield improved aerodynamics efficiency and performance.
Sensing and control improvements in the blades of wind turbines plays a vital role in improving their power production efficiency and reliability. However, the blades suffer from exposure to harsh environments and continuous dynamic loads. It is important to utilize structural health monitoring sensors for operation monitoring and condition based maintenance and repair. Fiber Bragg grating (FBG) technology has the potential to be being widely used in wind turbine structural health monitoring. It has several advantages compared to other incumbent technologies, due to its small size, distributed sensing properties over long distances (20-120 km), immunity to electromagnetic interference, resilience to harsh environments, and capability of monitoring structural behavior of new composite materials in bending loads. To perform demodulation of FBG sensors, optical fiber sensor interrogator technology has been used for many years. In this project, a low-cost self-powered interrogation system that can be simultaneously operated by multiple optical fiber strain sensing elements is proposed. The interrogator dimensions are smaller than conventional systems (i.e., ~6" by 6" in size). The interrogation system being developed includes a low power-consumption tunable laser, photodiodes, controller and integrated data storage. The Field Programmable Gate Array (FPGA) technique is applied to conduct the high-speed scanning for the FBG wavelength. Vertical Cavity Surface Emitting Laser (VCSEL) is utilized for reducing power consumption. The 24 channels are divided from a laser source using a 1-24 optical splitter. 24 FBGs were mounted on three fiberglass panels to test the performance of the interrogator in the detection of strain and temperature. The electrical strain gauges were used as a reference during testing in operation. The results indicate the successful validation of interrogator in the laboratory and this optical fiber strain sensor methodology is found to be promising for detecting dynamic strain and temperature on utility-scale turbine blades.
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. Calibration and assessment of this code has been performed by leveraging LiDAR measurements of wind turbine wakes, SCADA and meteorological data collected for a wind farm in North Texas deployed over a relatively flat terrain. For this test case, the CFD tool showed an accuracy of 7% 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. The current challenge for this project consists in extending the range of applicability of this CFD tool to wind farms on complex terrain. To this aim, a new LiDAR field campaign is under execution for a wind farm in Colorado. This new experimental dataset will allow us to single out potential weaknesses of the CFD tool in presence of topographic effects and, hopefully, to overcome those through further developments of the tool. Mesoscale simulations with ad-hoc wind farm modeling have been executed for the wind farm in North Texas, showing a good accuracy in predicting the wind field around and within the wind farm, while estimating power capture at the turbine level as well.

Bonded Variability of the wake velocity field for different incoming wind speed and regime of the atmospheric stability.

Deployment of the UTD mobile LiDAR station at a wind farm on complex terrain in Colorado.
Reducing extreme and fatigue loads on the rotor blades of a wind turbine lowers the Levelized Cost of Energy, which is 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. 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 industry standard NREL FAST code. The FAST module with integrated plasma actuation is demonstrated using the NREL 5-MW reference turbine model. With the feedback of blade-root flapwise bending moments, a Coleman 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.

Figure 1 shows a segmented blade planform where the aerodynamics of each segment is simulated using FAST. The plasma actuators are modeled as changes in local lift coefficient $\Delta CL$ 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, referred as Individual Blade Voltage Control (IBVC) in the figure. Figure 2 demonstrates the reduction of the measured loads (blade-root flap-wise bending moments) for the case with vertical shear and no turbulence. Figure 3 demonstrates the reduction of blade loads at the rotor angular frequency when both vertical shear (non-uniform flow) and turbulence (unsteady flow) are present. Damage equivalent loads (DEL) under vertical shear can be reduced from 30% (no turbulence) to 10%-15%, approximately, when turbulence intensity is increased to 15%.

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: Time series of voltage commands to plasma actuators (one command per blade) and response of measured loads for the 5 MW NREL reference turbine at 18 m/s wind speed and with vertical wind shear.

Figure 3: Frequency response of load signal with IBVC off (left) and IBVC on (right) for the 5 MW NREL reference turbine at 18 m/s wind speed, vertical wind shear and 15% turbulence intensity. Rated rotor angular speed is 12.1 rpm (1P).
A novel method has been developed to derive a surrogate model for wind farm control. The procedure is based on a stochastic approach using generalized polynomial chaos (PC) and high-fidelity simulations. The turbine control law and the incoming wind conditions, such as speed and directions, are treated as uncertain variables. Wind farm power production is then viewed as the random process depending on these uncertain variables. Thus, polynomial chaos expansion can be used to obtain a response function that provides the wind farm power production as a function of the turbine control parameters and the wind speed and direction. The response function is obtained by using a finite set of deterministic realizations, which consist in high-fidelity simulations for certain values of wind speed, direction and control parameters, interpolated by polynomials. In PC, the interpolating polynomial basis and the set of realizations are selected according to the probability density function of the uncertain parameters. This allows using a limited number of realizations to obtain an accurate response function and provides uncertainty bounds on the model. Thus, a mapping of the optimal control settings is obtained for any wind speed and direction to be employed for real-time wind farm operations. In this work, the procedure is validated against field measurements in a real wind farm in north Texas. The surrogate model (Fig. 1) is obtained by performing 64 simulations with our in-house code interpolated by 7th-order Hermite polynomials. The average power production predicted by the model for six days of operation under stable atmospheric conditions is within 2% accuracy of experimental data. Additionally, other statistical metrics, such as the P50 or P90, are predicted correctly within a 5-10% bound (Fig. 2). The results emphasize the importance of the underlying high-fidelity solver used for the development of the model. When the same procedure is applied using an engineering wake model, the error of the surrogate model prediction respect to SCADA data increases of an order of magnitude.
Manufacturing-induced defects such as local regions of porosity are commonly formed during the resin-infusion step of composite wind blade manufacture, and this porosity is a consequence of air trapped during resin mixing or by nucleation from volatiles. These local regions of porosity can have an adverse impact on the resulting fatigue life of the blade. Due to the absence of any theoretical or empirical models to predict how these local regions of porosity will decrease the nominal fatigue life of a composite wind blade in service, the wind industry is forced to make subjective decisions on the disposition of composite wind turbine blades with regions of high porosity. The current research sought to fill this need for an empirical model to relate state of porosity to the associated fatigue life. A methodology for making composite plates with the various degrees of porosity that can result from the wind blade manufacturing process was developed. These plates were subsequently cut into flexure, compression and fatigue specimens using a water jet saw for large cuts and a wet saw for small cuts. The degree of porosity was investigated using three optical techniques, i.e. optical microscopy, SEM (scanning electron microscope), and micro-CT scanning. Future work in this research will include fatigue testing and the subsequent development of the empirical model(s). These model(s) will enable improved decision making on blade disposition, OEMs and wind farm operators to potentially negotiate reduced price based on the state of porosity, and insurers to tailor the insurance premium to the state of porosity.

Principle Investigator:
James Sherwood, University of Massachusetts Lowell
Co-Principal Investigator:
Scott Stapleton, University of Massachusetts Lowell

Student Researcher:
Juan Su, University of Massachusetts Lowell
Stephen Johnson, University of Massachusetts Lowell

IAB Mentors:
Stephen Nolet, TPI Composites
Nicholas Althoff, GE Renewable Energy

IAB Meetings:
University of Massachusetts Lowell, June 6-7, 2018
University of Texas at Dallas, January 31 - February 1, 2018

Invited Keynote Speakers for Center Banquets:
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

WindSTAR members hike at Mt. Major.
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 CFPI advanced micromechanics model.
5. Software: Simulink code for Extremum Seeking Control of NREL CART3 (Controls Advanced Research Turbine, 3-bladed).

Journal Papers:


Master of Science Thesis:


PhD Dissertations:


Interns at Member Companies:

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

Conference Papers:

Selected Presentations:


ACTIVE PROJECTS: 2018-2019

- Mechanical Properties Enhancement Prediction for Matrix Material
  Project ID: A1-18
  PI: Marianna Malaru (University of Massachusetts Lowell)
  Co PIs: Ali Reza Amirkhiz, Christopher Hansen
  Mentors: Bruce Burton (Huntsman), Steve Nolet (TPI), Nicholas Althoff (GE), Nathan Bruno (Hexion), Paul Ubrich (Hexion)

- Engineered Sandwich Core Construction: Experiment and Evaluation
  Project ID: A2-18
  PI: Hongbing Lu (University of Texas at Dallas)
  Mentor: Nicholas Althoff (GE)

- Structural Wind Blade Repair Optimization
  Project ID: A3-18
  PI: Marianna Malaru (University of Massachusetts Lowell)
  Co PIs: Scott Stapleton, Christopher Hansen
  Mentors: Jian Lahir (EDPR), Nathan Bruno (Hexion), Paul Ubrich (Hexion), Nicholas Althoff (GE), Ben Rice (Pattern), Steve Nolet (TPI)

- Residual Stresses in Thick paste Adhesive Bondlines
  Project ID: A4-18
  PI: Scott Stapleton (University of Massachusetts Lowell)
  Co PI: Marianna Malaru
  Mentors: Steve Nolet (TPI), Nathan Bruno (Hexion), Paul Ubrich (Hexion), Nicholas Althoff (GE)

- Monitoring of Wind Turbine-Foundation and Technology Assessment Survey to Improve Expected Service Life predictions
  Project ID: B1-18
  PI: Pradeep Kurup (University of Massachusetts Lowell)
  Co PIs: Christopher Niezrecki, Raj Gondle
  Mentors: Ron Grife (Leeward), Adam Johns (EDPR), Ben Rice (Pattern), Nicholas Althoff (GE)

- System integration of a Wind Turbine Blade Acoustic Monitoring System
  Project ID: B2-18
  PI: Murat Inalpolat (University of Massachusetts Lowell)
  Co PIs: Christopher Niezrecki, Yan Luo
  Mentors: Ben Rice (Pattern), Ron Grife (Leeward), Adam Johns (EDPR), Jian Lahir (EDPR), GE

- Reduced Order Model developed through LiDAR measurements for Predictions of Wind Turbine Wakes and Power Capture
  Project ID: C1-18
  PI: G. Valerio Iungo (University of Texas at Dallas)
  Mentors: Ron Grife (Leeward), Ben Rice (Pattern), Nicholas Althoff (GE), Neal Fine (Aquanis), Neha Marathe (EDPR)

- Advanced Control System for Evaluation of on-Blade Load Mitigation Technologies
  Project ID: D1-18
  PI: Mario Rotea (University of Texas at Dallas)
  Mentors: John Cooney (Aquanis), Ben Rice (Pattern), Nicholas Althoff (GE)

- Mechanical Properties, Micro-structure Property Relationship and Manufacturing/Construction Methods for UHFPFRC for Both the Foundation and Towers
  Project ID: F1-18
  PI: Dong Qian (University of Texas at Dallas)
  Co PI: Hongbing Lu
  Mentors: John Buttes (Texas Wind Tower), Nicholas Althoff (GE)