Environment and Natural Resources Trust Fund
2017 Request for Proposals (RFP)

Project Title: **ENRTF ID: 143-E**

Active Wind Turbine Skin for Wind Energy Harvesting

Category: E. Air Quality, Climate Change, and Renewable Energy

Total Project Budget: $ 302,621

Proposed Project Time Period for the Funding Requested: 3 years, July 2017 - June 2020

Summary:

This project will develop and test an actuation technology to actively change the shape of a wind turbine blade to produce maximum power over a range of atmospheric conditions.

Name: Julianna Abel

Sponsoring Organization: U of MN

Address: 111 Church St SE
Minneapolis MN 55455

Telephone Number: (612) 301-7065

Email jabel@umn.edu

Web Address

Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

The visual shows the corrugated Active Knit actuation structure, a representation of the Active Skin, and a graphic of how the wind turbine may change shape.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: Active Wind Turbine Skins for Enhanced Wind Energy Harvesting

I. PROJECT STATEMENT

The State of Minnesota has made significant strides toward attaining its Renewable Energy Standard of 25% by 2025. In 2014, wind energy generation accounted for 15.94% of all in-state electricity production in Minnesota.[1] The 2,257 turbines installed in Minnesota have the capacity to generate 3,235 megawatts of electric power.[1] However, the wind does not blow consistently all the time, and this power capacity can only be reached during a narrow band of wind speeds. The ability to actively change the shape of wind turbine blades in response to changing wind speeds would increase the amount of power a wind turbine actually produces.

The goal of this project is to develop and test an actuation technology to actively change the shape of a wind turbine blade to produce a maximum amount of power over a broad range of atmospheric conditions. The shape of wind turbine blades is optimized to harvest the energy under specific wind speeds. If the wind speed falls above or below the ideal wind speed, the ability of the turbine to harvest energy is reduced because the air flow over the wind turbine blade is not ideal. The air flow over the wind turbine blade could be controlled by adapting and optimizing the shape of the wind turbine blade for the wind speed at any given time, resulting in increased energy harvesting. The ability to tailor the shape of the wind turbine blade is very promising. However, no surface actuators currently exist to create the desired shape change in wind turbine blades.

This project will establish the foundation for a novel surface actuator technology, Active Knits. Traditional textile manufacturing processes are utilized to create Active Knits from smart material wires. Active Knits transform from nearly planar textiles to corrugated structures with a series of raised and lowered ridges when actuated. Active Knit surface actuators will be designed, characterized, and modeled. The actuators will be embedded in a flexible composite to form an Active Skin that can be used to control flow. Though a combination of modeling and experiments, we will develop a novel active wind turbine skin that provides the large forces and complex shape changes required to enhance wind energy harvesting.

II. PROJECT ACTIVITIES AND OUTCOMES

Surface actuators for the shape change of wind turbine blades must be lightweight, load carrying, and shape adaptable. These actuator characteristics are achieved with Active Skins by integrating a strong metallic smart material fiber into a textile structure that is inherently flexible, and embedding the textile into a flexible composite to create a smooth surface. The integration of the different materials and manufacturing processes will be systematically addressed through three activities – Surface Actuator Design, Characterization, and Modeling; Active Skin Design, Manufacturing, and Modeling; and Active Skin Optimization and Control.

Activity 1: *Surface Actuator Design, Characterization, and Modeling* **Budget: $96,277**

Surface actuators transform flat surfaces into textured surfaces that can support significant applied forces. The performance of Active Knit surface actuators depends on the mechanical properties of the smart material wire, and the geometric (wire diameter, loop size, etc.) and architectural (pattern characteristics) properties of the textile structure. Prototypes with different material, geometric, and architectural properties will be manufactured by Professor Julianna Abel's custom-built three-dimensional knitting machine for high stiffness wire. The mechanical performance of the prototypes will be experimentally characterized. The experimental

[1] State Wind Energy Statistics: Minnesota by the American Wind Energy Association: http://awea.files.cms-plus.com/FileDownloads/pdfs/Minnesota.pdf

results will be used to develop a model and design tool that will identify the material, geometric, and architectural properties necessary to application specifications of actuator force and shape change.

Outcome	Completion Date
1. Characterize Surface Actuators	*Dec 31, 2017*
2. Develop Predictive Model and Inverse Design Tool	*June 30, 2018*

Budget: $103,126

Activity 2: *Active Skin Design, Manufacturing, and Modeling*

The Active Knit surface actuators from Activity 1 will be integrated into a flexible composite to form an Active Skin with a smooth aerodynamic surface. The flexible composite material will be experimentally evaluated to determine its mechanical properties. The manufacturing process will be optimized to enable the Active Skin to undergo a significant shape change. Mechanical characterization tests of the Active Skin will be conducted to determine the impact of the flexible material on the surface actuator performance. The results of the mechanical characterization tests will be used to produce predictive capabilities of the Active Skin.

Outcome	Completion Date
1. Establish Active Skin Manufacturing Process	*Dec 31, 2018*
2. Evaluate Active Skin Mechanical Performance and Enhance Model	*June 30, 2019*

Budget: $103,218

Activity 3: *Active Skin Optimization and Control*

To produce wind turbine blade shapes that are optimized for a range wind speeds, the Active Skin must be able to provide controlled local surface actuation. The placement of Active Knit surface actuators in the flexible composite will be optimized. A control algorithm will be developed that will determine which Active Knit surface actuators will be actuated to enable the Active Skin to achieve the desired shape change.

Outcome	Completion Date
1. Optimize Location of Surface Actuators	*Dec 31, 2019*
2. Develop Control Algorithm	*June 30, 2020*

III. PROJECT STRATEGY

A. Project Team/Partners

Professor Julianna Abel is an expert in the design of smart materials and structures to generate shape change. As a junior faculty member, she has published seven journal articles in the area of smart materials and structures. Her research in active textiles have applications including energy, aerospace structures, medical and rehabilitative devices, and consumer products. Professor Abel will manage a team of two mechanical engineering graduate students to establish the experimental and theoretical framework of this technology.

B. Project Impact and Long-Term Strategy

This proposed work develops technology that will enhance our ability to harvest wind energy, reducing the need for energy from nonrenewable sources. It leverages research conducted in the Design of Active Materials and Structures Laboratory (directed by Julianna Abel). The outcomes of this project will expand the scientific knowledge base, possibly affecting diverse applications that could benefit from surface actuation for flow control. If successful, the technology developed holds significant potential for commercialization. Findings will be disseminated through scientific presentations and papers.

C. Timeline Requirements

The project will be completed in 36 months. All milestones are explained above.

2017 Detailed Project Budget

Project Title: *Active Wind Turbine Skins for Enhanced Wind Energy Harvesting*

IV. TOTAL ENRTF REQUEST BUDGET 3 years

BUDGET ITEM *(See "Guidance on Allowable Expenses", p. 13)*	**AMOUNT**
Personnel:	
Julianna Abel, Project Manager, 1.5 months summer salary per year (plus fringe) for three years. Supervise graduate students, evaluate data, design experiments.	$ 63,228
Graduate Student 1, 50% appointment (plus fringe) for three years. Develop models, design tools, and control algorithms.	$ 140,262
Graduate Student 2, 25% appointment (plus fringe) for three years. Manufacture and characterize prototypes.	$ 70,131
Equipment/Tools/Supplies:	
Smart materials (shape memory alloys and polymers)	$ 5,000
Composite materials and molds	$ 5,000
Load cells	$ 2,500
Displacement sensors	$ 2,000
Microcontrollers and electronics	$ 1,500
Raw materials for experimental test setup construction	$ 3,000
Lab supplies: chemicals, gloves, etc.	$ 1,000
User fees for instrumentation (differential scanning calorimetry, rheology) at the University of Minnesota - College of Science and Engineering Characterization Facilty	$ 9,000
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 302,621

V. OTHER FUNDS

SOURCE OF FUNDS	**AMOUNT**	**Status**
Other Non-State $ To Be Applied To Project During Project Period:	$ -	*Indicate: Secured or Pending*
Other State $ To Be Applied To Project During Project Period:	$ -	*Indicate: Secured or Pending*
In-kind Services To Be Applied To Project During Project Period:	$ -	*Indicate: Secured or Pending*
Funding History:	$ -	
Remaining $ From Current ENRTF Appropriation:	$ -	*Indicate: Unspent? Legally Obligated? Other?*

Active Wind Turbine Skins for Enhanced Wind Energy Harvesting

PI: Julianna Abel, University of Minnesota

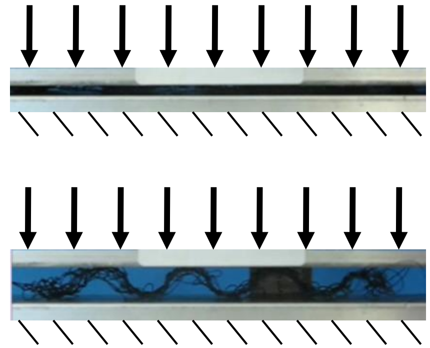
Goal: Develop technology to actively change the shape of a wind turbine blade to maximize energy harvesting over a broad range of atmospheric conditions

Requirements: Large Motions, Complex Shape Change, Distributed Actuation, Large Force

Approach:

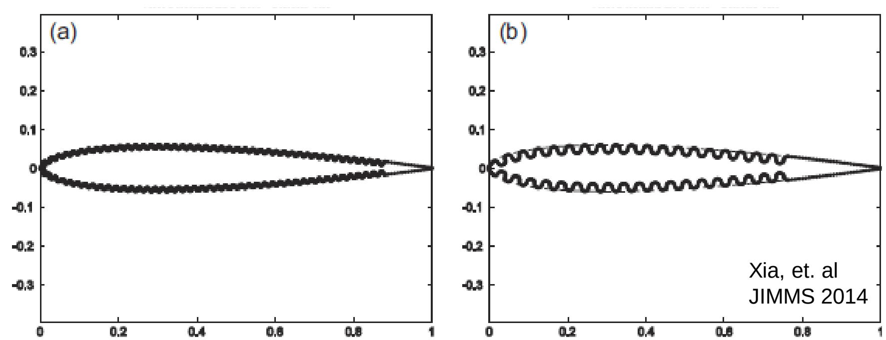
1. Design, Characterize, and Model Active Knit Surface Actuators
2. Design, Manufacture, and Model Active Skin Composites
3. Optimize and Control Active Skin

Impact: Enhance ability to harvest wind energy, reducing need for energy from nonrenewable sources.



Active Knits Actuate to Corrugated Structure

Composite Active Skin Supports Aerodyamic Loads



Potential Shape Change of Wind Turbine Blades

Julianna Abel
Assistant Professor, Department of Mechanical Engineering
jabel@umn.edu

University of Minnesota
Driven to Discover℠

Dr. Julianna Abel is a Benjamin Mayhugh Assistant Professor in the Department of Mechanical Engineering at the University of Minnesota. Dr. Abel earned her Ph.D. and M.S. in Mechanical Engineering from the University of Michigan (2014 and 2011, respectively) and her B.S. in Mechanical Engineering from the University of Cincinnati in 2005. During her undergraduate studies, she conducted research on high-temperature superconductors at the Air Force Research Laboratory at Wright-Patterson Air Force Base. Dr. Abel discovered her passion for smart materials and structures research during her graduate studies. Her current research focuses on the model-based design of smart material technologies. Her research combines analytical modeling and experimental characterization to establish frameworks for the design and synthesis of smart material technologies for innovative robotic systems. She leads the Design of Active Materials and Structures Laboratory, which endeavors to develop technologies that enable new energy, aerospace, and medical devices applications. Julianna Abel received the ASME Adaptive Structures and Material Systems Best Paper Award in Structural Dynamics and Control in 2013 and was featured in the Smart Materials and Structures Highlights of 2013.

Julianna Abel is the PI of this proposed work, and she will be responsible for the management of the project. Her primary responsibilities are to supervise graduate students, design experiments, and evaluate data. Julianna will provide technical guidance to experimentally develop and characterize the Active Skin and to theoretically explore and validate the relationship between design parameters and Active Skin performance.