A Thesis Presented to

The Faculty of Alfred University

Bio-Inspired Wind Turbine Blade Profile Design

by

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In Partial Fulfillment of
the Requirements for
The Alfred University Honors Program

December 14, 2017

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Bio-inspired Wind Turbine Blade Profile Design

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December 14, 2017
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Abstract

The wind energy industry needs technological advancements in cost-efficiency if it is to compete with fossil fuels for large-scale energy production. In addition, many communities refuse to allow wind turbines to be erected nearby due to noise complaints. To solve issues of cost-effectiveness and noise reduction, this proposal suggests that nature may have viable designs which can be implemented. Of particular note are nearly-silent owl feathers and the tubercles of humpback whale fins, known for improving efficiency. The design project proposed here will investigate the creation of a hybrid blade profile which seeks to capitalize on both designs, improving efficiency and reducing noise in one profile. After research and testing on the hybrid profile, it was determined that while the noise reduction aspect of the design was sound, the placement of the tubercles on the trailing edge was incorrect due to faulty research, leading to a drop in overall efficiency. Further development is necessary to refine this design, though the basic principles behind the design remain sound.

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Introduction

Wind energy is one of the most potent renewable energy sources available, second only to hydroelectric plants. It suffers, however, in the field of cost-efficiency when compared to fossil fuels, even when considering the lack of a fuel requirement for a wind turbine. The upfront costs for building a wind turbine vary between the price of a small car to the construction of a large house, while our current energy production systems only require a fraction of the cost per year to provide fuel. In order to persuade the power industry to further develop wind energy applications, improvements in wind energy technology must be made to improve the feasibility of utility-scale wind power.

Another challenge facing wind energy development comes from a municipal viewpoint. Many cities do not allow wind turbines to be erected near city limits regardless of favorable winds, primarily due to complaints about the visual annoyance and aerodynamic noise. While designing aesthetically pleasing wind turbines will not be discussed in this proposal, reducing aerodynamic noise is a purely mechanical design challenge, and can be a focus of the project. Aerodynamic noise reduction will serve to open up more areas for wind resource exploitation, further improving cost-efficiency.

This senior capstone project focuses on the development of a wind turbine blade profile which will improve aerodynamic efficiency and reduce aerodynamic noise, through the use of biomimicry. Biomimicry is a field of study that suggests that engineers and scientists can take advantage of nature's superior sample size and "development time", resulting in bio-inspired designs with various improvements. I have chosen to look into owls, well known for their near-silent flight capability, in order to combat aerodynamic noise in wind turbine blade profiles. For aerodynamic efficiency, I have chosen to investigate the benefits of tubercles on humpback whale fins, known to improve hydrodynamics and facilitate easy maneuvering.

Previous research has already been done on bio-inspired airfoils, and yet it seems that transferring the designs to wind turbines has been comparatively slow going. Owl feathers get their silent-flight properties primarily through the use of serrations on the leading edge of the blade profile and a "canopied" surface (see Figure 1).

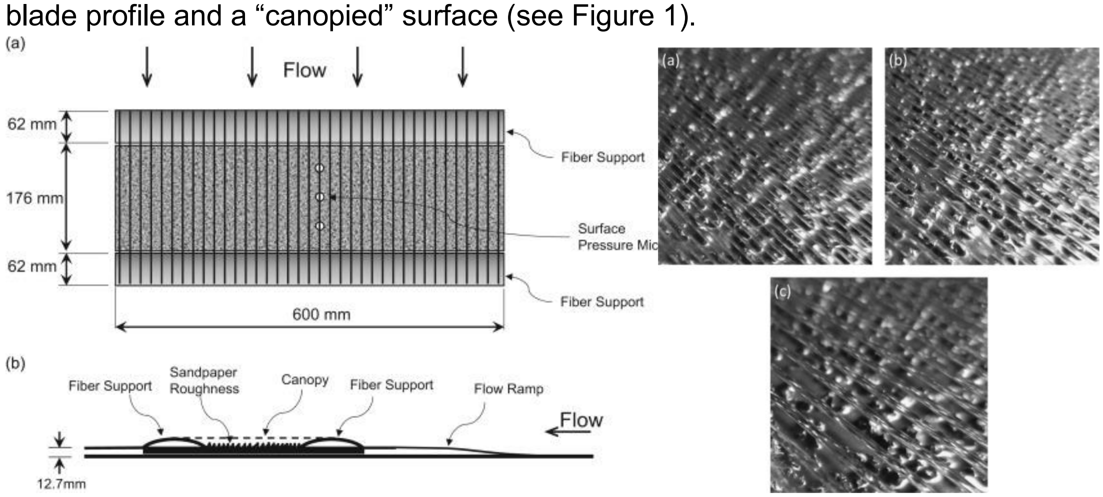

Figure 1: The canopied airfoil design.
Left: Illustration of a unidirectional canopied surface similar to owl feathers.
Right: Test surfaces using a canopied support structure above a sandpaper surface.

The overall wind turbine blade profile has remained mostly unchanged in terms of efficiency since the inception of large-scale wind turbines. Adjusting the material components of the blades has been the primary concern of rotor efficiency development, looking to adjust blade weight or composition to improve the performance of the blade without changing its shape. However, while the hydrodynamic benefits of tubercles on humpback whale fins have been observed, such a modification has also not been tested in the context of wind energy.

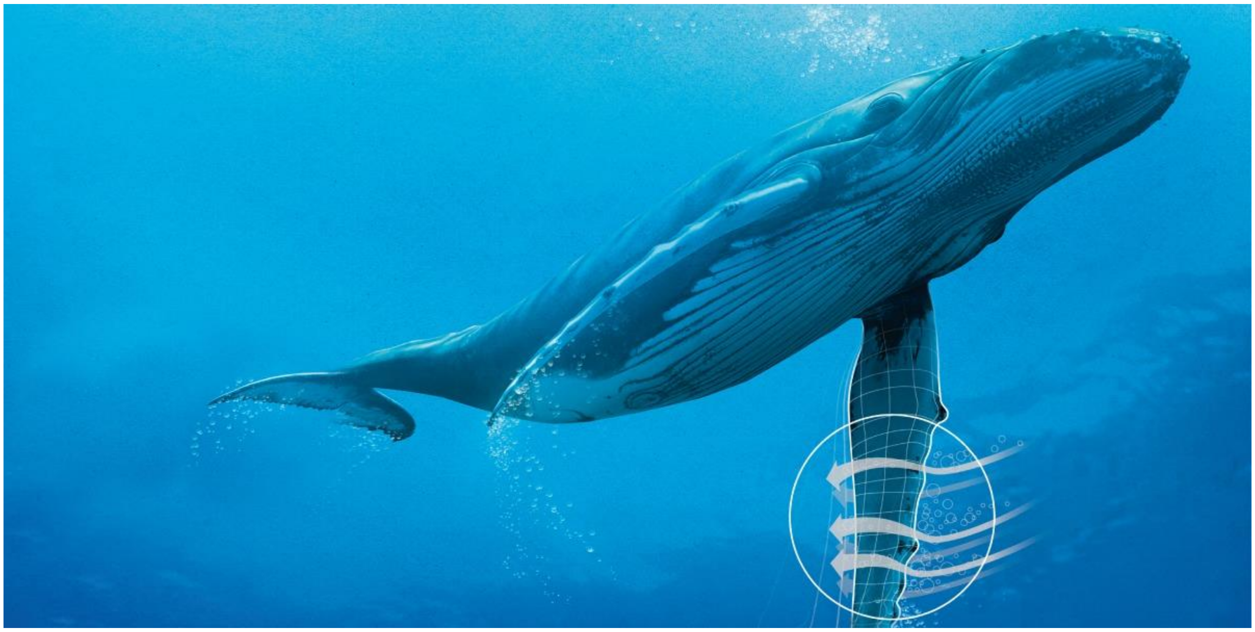

Figure 2: A humpback whale illustrating the hydrodynamic advantage of its tubercles.

The primary benefit of this design project is in the combination of both bio-inspired designs into one airfoil, for optimal effectiveness. While research has been done on the theoretical applications of owl feather serrations and humpback whale tubercles, it appears that combining the two to create a profile with both reduced noise and improved efficiency may as well have not been approached. My study investigates the merits of a hybrid design, seeking to incorporate the benefits of both noise reduction and aerodynamic efficiency, without sacrificing either criterion to implement the design. Above all, the project evaluates the final profile in an attempt to determine its overall feasibility in the wind energy industry, based on projected ease of manufacturing, material costs, and potential benefits to mitigate the former two.

Procedure:

The project focuses on the design and testing of wind turbine blade profiles, comparing them with a control case of a “standard” turbine airfoil. In order to do this, simulations in SolidWorks, in addition to wind and water tunnel testing of prototypes based on the same SolidWorks models, are used to develop a profile design with clear advantages over the control if possible.

The project fell under two phases after research was completed:

Initial Design (August to mid-November, 2017)

- Development of prototype airfoils in SolidWorks, based on bio-inspired designs.
- Virtual testing of prototype airfoils in SolidWorks Simulation.
- Revision of profile if necessary.

Rapid Prototyping and Testing (November to December, 2017)

- 3D printing of approved design and control profile.
- Wind tunnel testing and validation of designs.

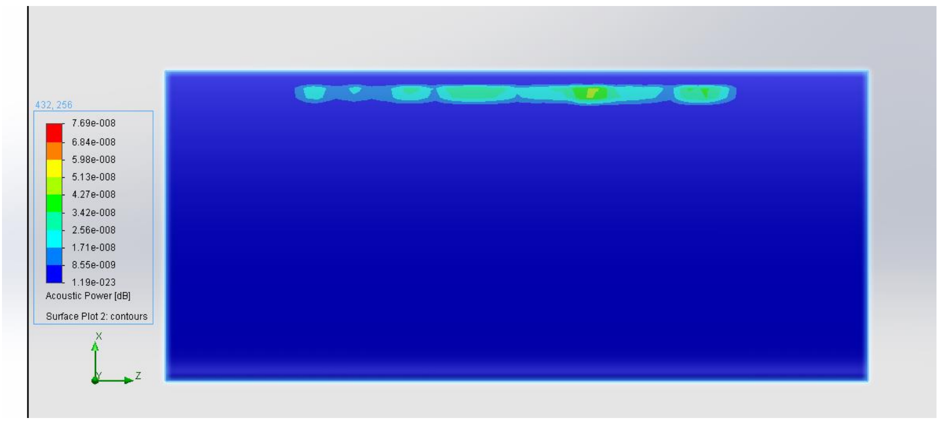

Figure 3: Solidworks Simulation of the control profile, testing for noise generated.

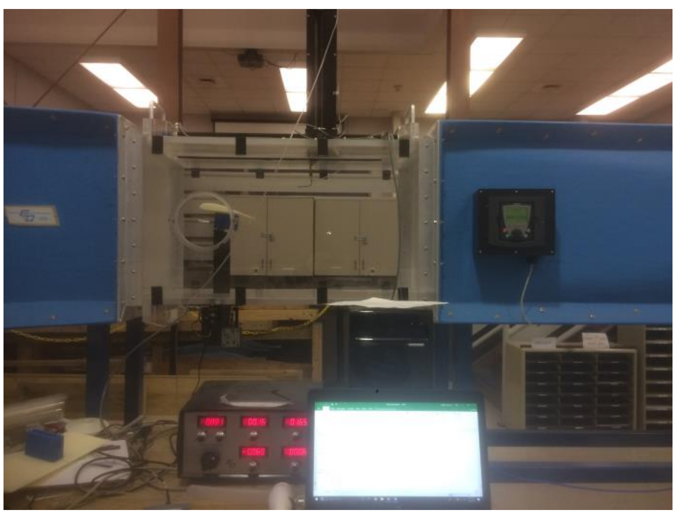

Figure 4: Wind tunnel testing equipment, with the control profile loaded at a 10° angle.

Results:

The equipment available at Alfred University was suited for testing acoustic power using Solidworks and lift/drag values using the wind tunnel, but not both at once. As such, the hybrid profile was tested in both in order to verify the effectiveness of the design.

The Solidworks testing showed that the initial design for the hybrid profile actually increased noise generation, as the 'hot spots', shown in Figure 3 on the control profile, were an order of magnitude louder. To counter this, the curved ridges forming the canopied surface were made narrow and more numerous, closing the gaps and effectively eliminating noise generation altogether, as shown in Figure 5.

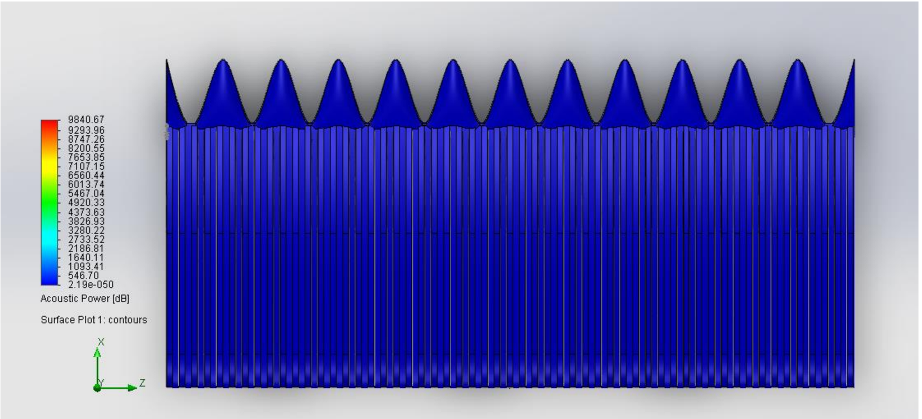

Figure 5: Solidworks Simulation of the modified profile, showing noise generation.

With the acoustic half of the design confirmed, the control and modified profiles were printed using the rapid prototyping tools at Alfred University. They were then placed in the wind tunnel to determine their lift and drag, from which their aerodynamic efficiency can be determined. The results of this testing are shown in Table 1 in Appendix A.

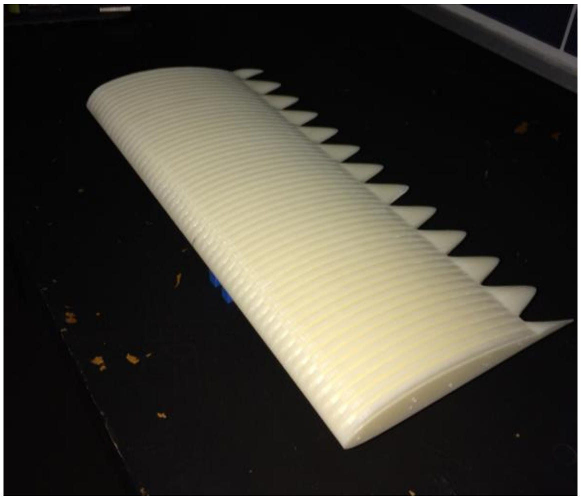
Figure 6: The completed hybrid blade profile after printing.

From these results, it is clear that the hybrid profile as it stands currently represents a decrease in efficiency as opposed to an improvement. The hybrid is slightly longer and heavier than the control model, as it was designed for manufacturers to simply add prefabricated additions (the canopied surface and tubercle edge) to their existing designs to reduce manufacturing costs. However, after additional research after finding this issue it became clear that my previous research was in error. While it is well known that the tubercles on humpback whales are on the leading edge of the flippers, previous research had suggested that wind turbine blades should add them to the trailing edge instead. This has been definitively proven false with this test result, and further iterations of this design will implement the tubercles on the leading edge instead to determine if the weight and length additions are not outweighed by the efficiency benefit.

It is difficult to recommend this design without further testing; however if this efficiency issue resolves itself by moving the tubercles to the leading edge, it is possible that the design could be implemented as an addition to existing blade designs. An additional material cost would be incurred, but this could be countered by the simplified manufacturing process and shorter work cycles. Depending on blade material, it could also be possible to mold the additions directly into the existing blade design without incurring additional time and material costs, though the increased complexity of the design could make this difficult and new tooling would have to be formed for this process

Conclusion:

The overall goal of the senior design project was to determine if a hybrid design using a canopied surface and edge tubercles could reduce aerodynamic noise and improve performance without sacrificing either. The design developed currently only resolves aerodynamic noise while decreasing performance, leading to the conclusion that more design work is required before the hybrid profile can be considered a success. Therefore, it is the recommendation of this study that further development is done to fix the efficiency issue with the current design and maximize its potential.

References:

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Appendix A:

Control (flat)

Speed (Hz)	Lift	Drag
20	0.02	-0.006
30	0.055	-0.014
40	0.15	-0.024
50	0.15	-0.037

Hybrid

Speed (Hz)	Lift	Drag
20	0.015	-0.0085
30	0.045	-0.0175
40	0.095	-0.029
50	0.09	-0.045

10° pitch

Speed (Hz)	Lift	Drag
20	0.05	-0.009
30	0.11	-0.021
40	0.245	-0.038
50	0.32	-0.058

Speed	Lift	Drag
20	0.02	-0.015
30	0.065	-0.025
40	0.16	-0.04
50	0.17	-0.06

Table 1: Wind Tunnel Testing Results for both Flat and 10° pitch.

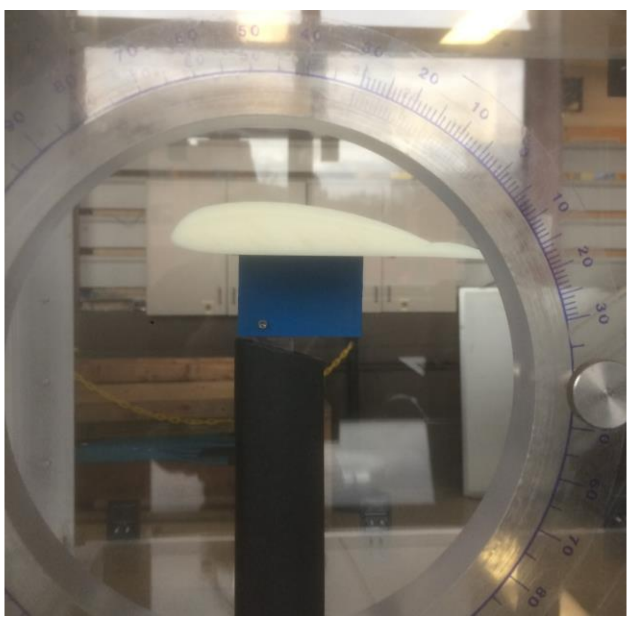

Figure 7: Detail of the hybrid profile in the wind tunnel.

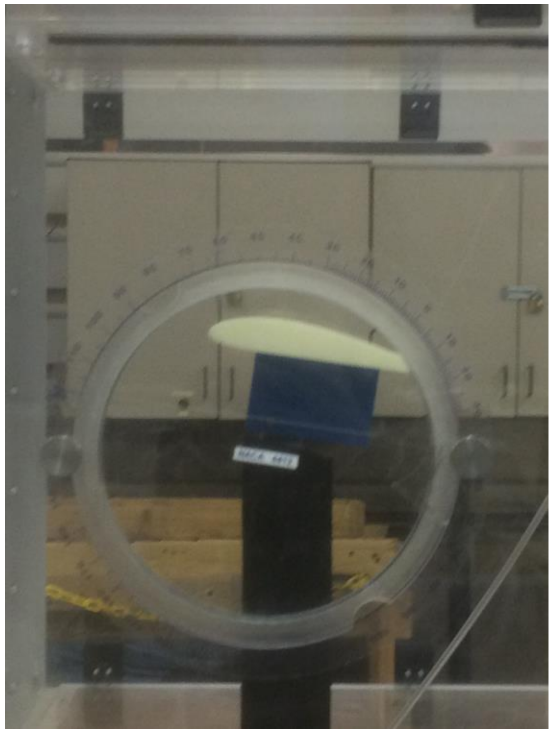
Figure 8: Detail of the control profile at a 10° pitch.