Research Proposal Submitted to the Harvey Mudd College Center for Environmental Studies

Improving Wind Turbine Efficiency through Whales-inspired Blade Design

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Abstract

Due to the rapid depletion of hydrocarbon-based energy resources and their harmful effects on the environment, there is an urgent need to seek alternative and sustainable energy sources. Wind power is among the potential alternatives to fossil fuels; however, the efficiency to convert wind energy into a useful form such as electricity using wind turbines still requires some engineering design innovation. Energy efficiency in traditional horizontal-axis wind turbine (HAWT) is largely determined by the aerodynamics of the turbine blades and the characteristics of the turbulent fluid flow. The objective of this proposed project is thus to investigate improvement of HAWT blade design by incorporating the bumps on humpback whales' fins into blades. This application is thought to produce more aerodynamic blades by creating turbulence in the airflow behind each groove. This project would focus on designing, prototyping, and testing a HAWT with whale-inspired blades to determine the differences in the associated turbulent flow field and energy efficiency compared to traditional HAWTs using an engineering approach of computational and experimental studies. The expected outcome, if successful, is that the whale-inspired HAWT prototype will offer a better energy conversion than traditionally designed prototypes.

Starting date, duration and location of proposed research

The proposed starting date for this project is May 25th. Research would take place primarily in Professor Ng's laboratory in the Department of Mechanical and Industrial Engineering at Concordia University in Montreal, Quebec, Canada. The duration of this research project would be for ten weeks. Professor Ng's laboratory provides access to useful CAD/CFD software such as SolidWorks, CATIA, Pro/ENGINEER, Fluent, and CFDesign; this software is useful for alternative energy system and wind turbine blade design. A home-made wind tunnel is installed in the lab to test small small-scale wind turbine prototypes. Advanced fluid dynamic measurement diagnostics such as Particle Image Velocimetry (PIV) and high-speed photography are also available in the department. These resources have already been used successfully in Concordia University undergraduate turbine design projects and a wind energy project is currently undertaken by one graduate student using these facilities. Concordia University is continuously committed to leadership in sustainable development in Canada. The student will therefore work in an environment with a culture of sustainability.

Proposed research

This project investigates improving horizontal-axis wind turbine (HAWT) blade design by mimicking the serrated edges of the Humpback Whale's fins. These bumps defy traditional blade design, which is to make the leading edge of the blade as smooth as possible. However, evolution of the bumps in Humpback Whale's fins suggests that there is an aerodynamic advantage to them. WhalePower, a Canadian whale-inspired blade company, has altered fan blade design to make them more like the whale fins and has found a 20% decrease in energy consumption [1]. While the initial explanation for this efficiency improvement is that the blades can be used for a higher angle of attack while avoiding flow separation by creating turbulence behind the blades, no detailed studies into this explanation have yet to be done.

Therefore, the objective of this research study is to investigate the turbulent flow field and aerodynamics of these new blades to improve efficiency of wind turbine energy conversion. This project would involve designing, prototyping, testing, and refinement of whale-inspired blades for application in wind turbines using both experimental and computational fluid dynamics methods. The student, Alex Krause, would be working on a team alongside a Concordia University graduate student, with faculty advising from Professor Ng of Concordia University's mechanical and industrial engineering department. Engineering Professor Bassman would be the HMC faculty liaison.

In the weeks leading up to the project, the student would study traditional blade design, HAWT design, and fluid dynamics over blade surfaces. During this time period, the student would likely consult Professor Ng, Professor Bassman, Professor Steinberg, and the Concordia University graduate student. The project would begin with one week of practice using SolidWorks and CFDesign software packages to model traditional blades. CFDesign uses numerical methods to model airflow over surfaces that can be imported from SolidWorks. During this first week, the student would also become acquainted with the test setup and Professor Ng's wind tunnel.

Two weeks of new blade designing would be done using SolidWorks and CFDesign. During this time period, the fins of the Humpback Whale would be researched to inspire prototype designs. SolidWorks would be used to make 3D designs of whale-inspired blades. The designs would focus on carving grooves into the surface of the blade, perpendicular to the blade's leading edge. The size, spacing, quantity, and depth of the grooves will be varied to produce different design options. Then, CFDesign would be used to numerically determine which blade produces the best airflow. Airflow over the new whale-inspired designs would be compared to the airflow over standard turbine blade designs to determine the differences. The student would select the most promising design based on computational flow quality and then begin the first prototype.

The student would spend two weeks building a small wood prototype. It is expected that grooves could be easily carved in wood blades using the engineering department's machine shops. The prototype would be tested using the wind tunnel during this time period. Angular speed of the turbine could be measured using an optical probe or a high speed digital camera (1000fps), both of which Professor Ng has available in his laboratory. Angular speed would provide preliminary feedback on the performance of the prototype.

The final three weeks of the project would be spent building an electrical grid, performing final testing, and investigating topology effects with any leftover time. An electromechanical system will be setup to determine the power output of the prototype. The new prototype could be incorporated with previously-existing prototypes in Professor Ng's lab in an electrical grid. Different configurations of the turbines can be compared to see which produces the optimum power generation. Additional time leftover would be spent investigating the following topology topics: height of turbine, tilt of turbine, and rotation of turbine away from perpendicular to the flow.

Educational value

The student, Alex Krause, is planning on becoming a mechanical engineer and is interested in alterative energies. The student had an engineering internship last summer in blade design and hopes to work in industry on HWAT projects after graduation. This project would expose the student to multiple phases of professional turbine design in an engineering approach similar to HMC's clinic program. The student would get the opportunity to carry a design all the way to prototype testing, which would be great preparation for next year's clinic and future professional endeavors. The proposed project's different phases apply many facets of the engineering program's multi-disciplinary education. Intellectually, the student would gain knowledge in wind turbine design, blade design, fluid dynamics, and electromechanical systems to supplement the HMC engineering curriculum.

Significance of research for environmental quality

Power generated from wind energy currently contributes 9% of the total power generated from renewable energies [2]. In the midst of an energy crisis and unstable energy costs, there have been numerous proposals to substantially increase the number of wind farms. The areas along the Western and Eastern seaboards of the United States, as well as the Great Plains, have high enough wind power densities to make HWATs economically feasible. A vast majority of current energy comes from fossil fuels, which harm natural environmental habitats when harvested and produce pollution and greenhouses gases when consumed. Improving turbine energy efficiency of existing wind turbines makes large-scale wind farms more economically feasible, promoting an increase in wind farm prevalence. An increase in wind energy conversion efficiency can lead to a greater decrease in the amount of fossil fuels consumed and fossil fuels' total impact on the environment. By using humpback whales (an endangered species) as an inspiration for refining existing engineering techniques, a greater appreciation for the importance of studying and protecting all species is encouraged.

Feasibility

Professor Ng's laboratory has the necessary equipment for testing wind turbines, including a wind tunnel, optical probes, high speed camera, and already-existing wooden turbine prototypes. Concordia University's Mechanical and Industrial Engineering Department has housed undergraduate turbine prototyping design projects in a program that is similar to HMC's clinic program [3]. Furthermore, the lab has computers with SolidWorks, Pro/ENGINEER, CATIA, Fluent, and CFDesign installed. The mechanical and industrial engineering department has a machine shop that the student would be permitted to use to build the bumped HWAT prototypes. The student would be working in close proximity to Professor Ng and the student would be on a team with a mechanical engineering graduate student from Concordia University. The student has lived in Montreal on multiple occasions and has already established housing for this summer.

The student has taken necessary courses to establish a strong background for all phases of the project. E4 (Introduction to Engineering Design) and E8 (Design Representation and Realization) are directly applicable to the design and prototyping of the HWAT. E171 (Dynamics of Elastic Systems) provides a strong mechanical engineering background for the prototyping phase of the project. The optical sensors would be similar to those used in Physics 28 (Physics Laboratory) and the student has experience with wind tunnels from E80 (Experimental Engineering). The student is currently taking E84 (Electronic and Magnetic Circuits and Devices), which is sufficient to set up the turbine's power grid. Additionally, the student has had real-world blade design experience via an engineering internship last summer at a leading blade-producing company.

Budget

Item	Cost	Total
Student Stipend	$400 per week	$4000
Airfare from LAX to Montreal	$550	$550
Food Expenses	$100 per week	$1000
Equipment Expenses	$400	$400
Total		**$5950**

References

[1] Lane, Patti. "Whales inspire better blade designs." Christian Science Monitor 15 May 2008.

[2] Energy Information Administration. "Electricity Net Generation From Renewable Energy by Energy Use Sector and Energy Source." May 2008. http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/table3.html.

[3] Hong H., Hoa S.V., Bhuiyan N., Siddiqui K., and Pugh M. "Capstone Design Projects at the Department of Mechanical and Industrial Engineering at Concordia University." *Proceedings of the Second CDEN International Conference*, 2005.