Wind Turbine Blades: Modifications to Reduce Aerodynamic Noise
(Technical Topic)

Analyzing the Politics of Wind Farm Development
(STS Topic)

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Author
Justin Smith
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Technical Project Team Members:
Levi Otis
Caleb Owen
Megan Anderson
Nathan Jacobson

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed: ____

Approved: _____________________________________ Date _______________________
Rider Foley, Department of Engineering and Society

Approved: _____________________________________ Date _______________________
Michael Momot, Department of Mechanical and Aerospace Engineering

Background

Numerous self-reported mental and physical health problems are attributed to the constant hum of wind turbines in a nearby location. One example comes from Massachusetts, where a woman named Sue Hobart, "couldn't understand why she suddenly developed headaches, ringing in her ears, insomnia and dizziness to the point of falling 'flat on my face' in the driveway" (James, 2013). Reports like this bring attention to the potential health risks caused by living adjacent to a wind turbine or wind farm. Currently, an average of 3000 wind turbines are installed in the United States of America each year, and the rate of installation is increasing proportionally to the size and power output of the turbines. Wind energy has become the primary method utilized for renewable energy generation in the US (Brower, 2020). The expansion in the wind energy market has provided the cleanest energy in the nation's history, but perhaps at the cost of local communities' well-being. The prolonged exposure to the turbine noise has been argued to negatively impact human health in addition to being a source of constant annoyance.

There are two main sources of noise produced by wind turbines: mechanical and aerodynamic. Mechanical noise is generated by contact between moving parts like gears and rotaries. Aerodynamic noise is caused primarily by wind blowing across the turbine blades, especially toward the tips, and this creates noise-producing vibrations in the blade. The mechanical noise is insignificant in comparison to the aerodynamic, so the noise discussed for the remainder of the paper will be referring to aerodynamic noise. A modern wind turbine will produce sounds at over 100 decibels (dB) in typical conditions (Noise, 2020). For comparison purposes, this level of noise is about the same as a power lawn mower or a jackhammer (Noise, 2000). A modern wind turbine, for the purposes of this article, will be defined as a utility scale turbine rated between 2-3 megawatts (MW) of power. This type of wind turbine, operating full capacity, could power approximately 1500 homes. The technical portion of the thesis involves the discussion of several modifications a turbine blade in order to reduce the amount of aerodynamic noise produced. Each technique is evaluated with the criteria of added cost, noise reduction, and efficiency. The Science, Technology, and Society (STS) section of the thesis deals with the process of selection for the location of wind turbines, and the impact of wind turbines on local communities' health.

Designing a Turbine Blade to Reduce Aerodynamic Noise

The technical portion of the capstone project involves altering the turbine blade in a way that reduces the aerodynamic noise created by the turbine blade. As air flows over turbine blades, it can become turbulent and vortices are generated. The vortices crossing over the trailing edge of the blade cause the blade to vibrate. Those vibrations propagate through the air as pressure waves and, depending on the frequency and intensity, can be identified by the ear as sounds. The two different types of aerodynamic noise that will be discussed in this paper are broadband and low frequency noise. Broadband noise means that there is a large range of frequencies involved, typically above 10 Hertz (Hz), which are created from the interaction between the turbine blades and atmospheric turbulence. Low frequency noise can be attributed to turbulence in airflow on wind turbines caused by towers or blades from turbines up wind (Saavedra & Samanta, 2015). Turbines also produce sounds below the human hearing capacity at 20 Hz called infrasound (Bolin, Bluhm, Eriksson & Nilsson, 2011). Infrasound is only audible when the amplitude is near 90 dB, and the infrasound from turbines has been proven to be well below that threshold at neighboring communities, so this type of noise will not be analyzed in this thesis (Turunen et. al., 2020). For a control, a standard blade will be used, and this has an airfoil shape, similar to that of an airplane wing. The airfoil is facing the wind so a lift force is created under the airfoil that drives the motion of the turbine. There are three modifications to be made to a standard wind turbine blade, all to be tested.

The first modification involves adding serrations to the trailing edge of the blade. Previous work has demonstrated that serrations in a triangular shape, such as the example shown in Figure 1, would be successful in significantly decreasing the noise produced by the blade. Field testing showed a maximum reduction of noise of 15 dB (Cao, Zhang, & Cai, 2020). Our research group will follow this general idea, but shape the trailing edge serrations in a sinusoidal pattern to avoid sharp changes in the geometry of the blade. Furthermore, the testing demonstrated the lift-to-drag coefficient remained relatively constant with these additions. This behavior of the ratio of lift and drag forces is a good indication that the efficiency of the turbine with our group's modifications should not significantly decrease.

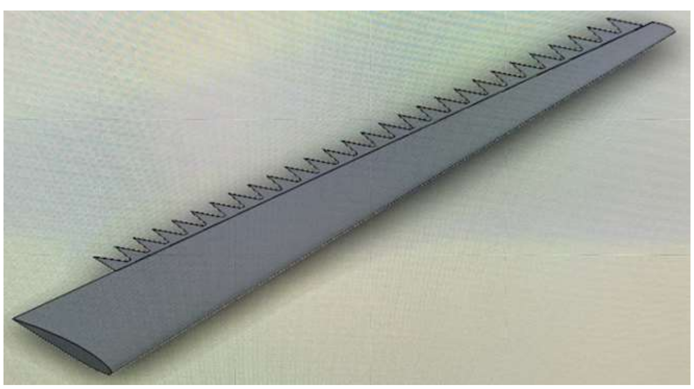

Figure 1. trailing edge serration blade modification (Jacobson, 2020)

The second modification under consideration is creating small nodes on the leading edges of the blade. The nodes will be relatively small and evenly spaced out along the leading edge of the blade, as seen in Figure 2. The nodes in this modification serve two purposes. First, they aid in straightening the airflow across the top of the turbine blade (Paruchuri, Joseph & Ayton, 2018). Although this particular modification has not been thoroughly tested in the past, our group believes the airflow will be less turbulent at the trailing edge of the blade with the nodes compared to the standard model. Second, the nodes should produce a more uniform flow across the length of the blade. A uniform flow would decrease the uneven vortices and limit their effect on the vibrations of the blade.

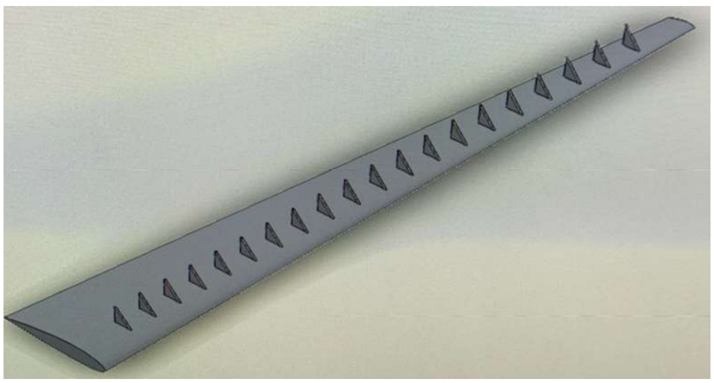

Figure 2. Thin nodes attached to leading edge (Jacobson, 2020)

The third modification the research group will be testing is folding the tip of the blade at a 90-degree angle, as displayed in Figure 3. This tactic is meant to reduce the large vortices and turbulence that are created from the airflow over the tip of the blade. A turbine blade tip has the highest velocity of any part of the turbine, and thus has the capability of producing the most broadband noise (Maizi, Mohamed, Dizene & Mihoubi, 2018). Adding the fold at the tip of the blade reduces the strength of the vortices that are generated, which reduces the noise. Since the maximum power produced from a wind turbine can be represented as a function of the blade's coverage area, the imaginary circle that the blades spinning creates, folding material at the end of the blade would reduce the overall efficiency of the wind turbine. Although a costly tradeoff, the research group believes it is worth testing as it could result in the greatest reduction of noise among the three modifications.

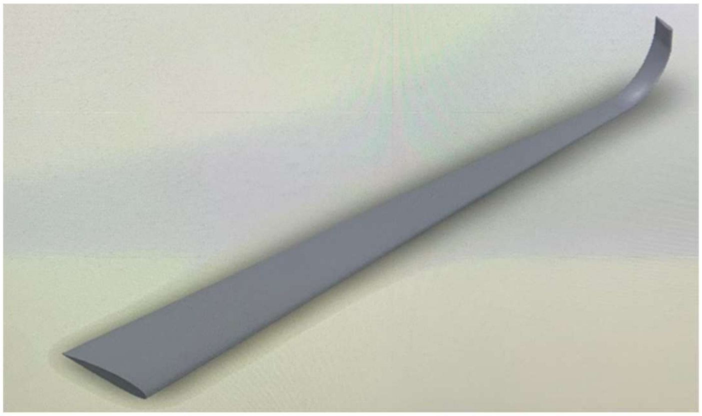

Figure 3. 90-degree folded blade tip (Jacobson, 2020)

Analyzing the Impacts of Wind Turbine Farm Installation

While wind turbine and other sustainable energy system manufacturers attempt to maintain a green and good reputation in relation to other types of power plants, many times they can be found just as guilty by targeting the locations of the wind farms near lower-income areas (Ottinger, 2013). Utility scale wind turbines are typically over 100m in total height (blade length included). Wind farms vastly vary in number of turbines from as few as 5 to as many as 150 (Onshore, 2020). These statistics demonstrate the widespread impact that the installation of a wind turbine or farm can have on many neighboring communities. It also justifies looking further into the risks and benefits among stakeholders that accompany the installation of wind turbines.

In his paper *Do Artifacts have Politics*, Winner (2009) discusses two ways in which technologies possess political properties. The first concerns a creation or implementation of technology. A technology that is designed or arranged in order to influence power or decision making in a community has political qualities. The second case involves a technology that requires certain power relationships to maintain and could be considered inherently political. The injustices occurring with the wind farms support Winner's latter argument. In general, renewable energy systems, relative to their fossil fuel counterparts, are thought to be more decentralizing and democratic. The large-scale wind turbine technologies are proving to be an exception here as they have developed to be compatible with a relationship that favors urban residents at the expense of lower-income residents further away from the population center. In her article, Ottinger (2013) explains that the benefits, in this case power, are distributed mainly among a population unaffected by the noise, aesthetics, or optical effects from the wind farms. The risks and benefits are not equally shared among stakeholders, therefore, painting the utility scale wind farms as environmentally unjust.

Looking at a case scenario, in Ohio, there is a bill proposed that would allow township voters to vote on wind farm projects through a referendum (Chow, 2019). Currently, if a landholder agrees to lease land to a company to construct a wind farm on their land, they are paid royalties from the company while neighboring residents are not given compensation. The environmental justice argument here is that neighboring residents are still accruing risk with the installation of the turbines while not receiving any benefits from the project. Advocates in favor of the wind farms argue that a referendum would unfairly hinder future wind projects in the state. In Colorado, however, where a dual-authority approach is taken and community members are enabled to have a say in wind farm construction, building wind infrastructure has not decreased and Colorado remains in the top 10 states of wind energy production (Khan, 2020).

There is controversy surrounding the adverse health effects potentially caused by wind turbine noise. From three surveys conducted in Sweden and the Netherlands with residents exposed to between 40-45 dB of consistent turbine noise, between 25 and 30% reported the noises as annoying. In two of the three studies, there was a statistically significant association between noise level and self-reported sleep disturbance (Bolin, Bluhm, Eriksson & Nilsson, 2011). The authors mentioned that a causal relationship between the noise and the reported sleep disturbance could not be established. In a book titled, *Wind Turbine Syndrome, A Report on a Natural Experiment,* Dr. Nina Pierpont asserts these symptoms and others can be attributed to low frequency noise and termed the disorder, Wind Turbine Syndrome (WTS). It is worth noting that Pierpont's work is in the midst of debate as there is still no concrete study showing the link between these reported symptoms and low frequency noise. Some critics cite her work as containing too small of a sample size and sample bias (Taylor & Klenk, 2019). It is evident that more research still needs to be completed in this area.

Research Design

I plan to continue conducting research to best answer the question: How has the shift toward wind turbines as a primary renewable energy source affected the distribution of risks, benefits, and authority among stakeholders? As wind energy technology is improving, and there is more pressure to utilize renewable energy, many energy companies are turning to wind energy to diversify and expand their energy portfolio. It is essential that the risks and benefits of wind are more equally shared among stakeholders. Energy companies, state and local governments, and community members must ensure the environmental injustices that occurred with fossil fuel and nuclear power plant sites are avoided as much as possible during the shift toward renewable energy.

In order to fully grasp and answer this question, I plan to gather data from policy documents, court cases, and prior literature. Policy documents will contain necessary information regarding siting regulations for wind turbines and farms. I expect that these will vary within, and between states as the authority for creating these regulations is handled on state and/or local level. I will cite prior court cases when discussing disputes over wind turbine complaints. Energy and Policy Institute (2019) found eight court cases in the US dealing with the issue of wind energy, noise, and health. Of these eight cases, there was only one ruling against wind farms coming from Friends of Maine Mountains vs Board of Environmental Protection. Lastly, the prior literature will be used as evidence for both the health effects and social impacts of wind turbine siting.

I will utilize case comparisons to describe the differences in survey responses from prior literature regarding favorability of wind energy either in a national or community scope. The same tactic can be used in the analysis of health impacts from wind turbine noise. Using the environmental justice ideology, I will be able to evaluate how different instances of wind turbine and wind farm installations impact stakeholders. I can then compare the impacts on the various stakeholders.

Over the course of the next month, I will revise and finalize my prospectus. During the following month, I plan on researching court cases that relate to wind turbine regulations. I will also use that time to gather more evidence on health effects from wind turbines from prior literature. Starting in the 2021, I will begin descriptive and evaluative analysis of the evidence that I collect. I plan to begin drafting my thesis by the end of January.

Conclusion

Unrelenting aerodynamic noise produced by wind turbines causes annoyance and potential health problems to residents of neighboring communities. By May, 2021, my research group will have designed, tested, and manufactured a series of modified turbine blades. One blade design will have added nodes on the leading edge, another will contain serrations on the trailing edge, and the last will have a folded tip at the blade end. Each modified blade will hypothetically reduce the aerodynamic noise of a wind turbine in use by reducing the turbulence of the airflow over the blade or minimizing the vortices being generated at the trailing edge. A quieter blade will help to alleviate the siting issues and adverse health effects of current wind turbines. Admittedly, aerodynamic noise is only one contributing factor of the negative view of wind turbines. A quieter blade should, however, prove to decrease controversies and injustices surrounding wind turbine siting.

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