Utilizing Biological Airfoils to Reduce the Acoustic Noise Produced by Wind Turbine Blades

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Background

Climate Change

- The large-scale emission of fossil fuels as a source of energy is the driving force behind climate change, as well as various health-related issues (Perera, 2017).
- According to the Intergovernmental Panel on Climate Change, the average temperature of Earth's atmosphere could increase by up to 1.5 °C by 2040 (Masson-Delmotte et al., 2021).
- The continued release of greenhouse gasses will only continue to worsen global warming, and the overall air quality.
- Wind turbines are a growing source of renewable energy to aid in the conversion to clean energy (Friedlander, 2021).

Wind Turbine Acoustics

- While wind turbines may be environmentally friendly, they do produce noise as a byproduct.
- Increasing in size, they cause an increase in tip speed resulting in greater sound power levels.
- As a result, wind turbines have regulations based on sound power levels at nearby residencies, limiting the energy produced by wind turbines (Hoen et al., 2023).
- The main noise created by wind turbines is from the blades moving through the air, creating a whooshing sound (Wind Turbine, n.d.).

Biological Airfoils

- Biological airfoils have inspired countless numbers of airfoils, including wind turbine blades.
- Seagull wings have been tested because of their high lift to drag ratio (Hua et al., 2019).
- Owl wings have been studied the most because of their near silent flight. Owls have evolved to possess three main features that enable their quiet flight: trailing edge fringes, leading edge serrations, and velvety feathers. These adaptations aid in regulating the streamlines, therefore reducing the turbulence that creates sound (Wang et al., 2019).

Methods

CAD Design
Each wing/blade was located, imported, and attached to the hub that was designed.

Apparatus Construction
The 3D blades connected to the hub were printed, and connected to the stand that was built.

Testing
Each blade was tested under three different power levels of the fan. RPM was measured using a photogate.

Decision Matrix to Determine Biological Airfoils, Scale 1-4

Decision Matrix for Models	Owl Wing (general)	Bat Wing (general)	Pterodac-tyl wing	Seagull Wing (general)	Penguin Wing (general)
Noise Reduction (4)	4*4	4*4	1*4	2*4	2*4
Lift/Power generation (3)	2*3	3*3	3*3	3*3	3*3
Availability of Model (3)	1*3	2*3	3*3	2*3	3*3
Ingenuity (4)	0*4	2*4	4*4	2*4	4*4
Score	25/50	39/50	38/50	31/50	40/50

Problem

Wind turbine blades generate enough noise to be disruptive to local residencies and environments, resulting in restrictions and regulations being placed.

Goal

Take scaled biological airfoils and use them as wind turbine blades to lower the sound produced while maintaining efficiency. Then, determine what windepeed each wing performs optimally at in terms of power and acoustics.

Figure 2: Wind Tunnel Experiment

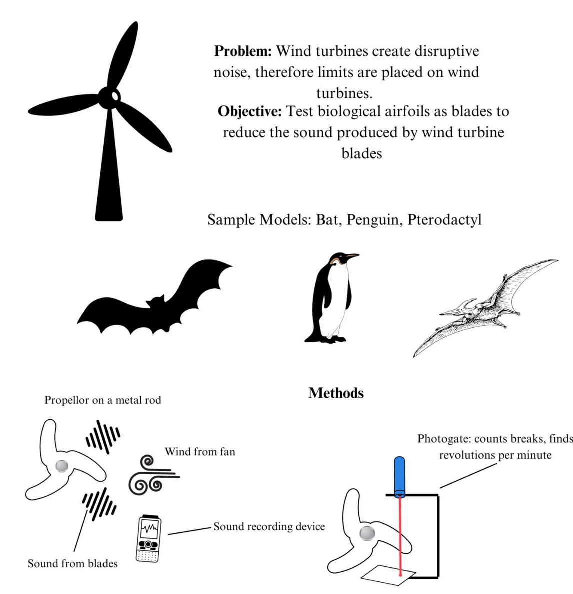

Figure 3: Graphical Abstract

Figure 4: Final Prototype

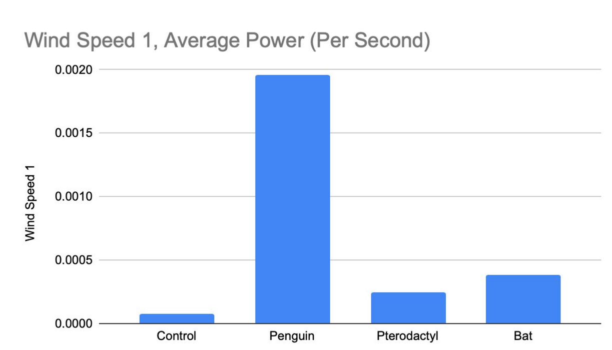

Figure 5: Wind Speed 1, average power generation

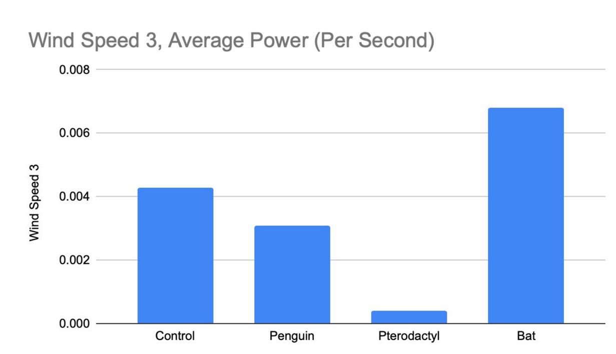

Figure 6: Wind Speed 3, average power generation

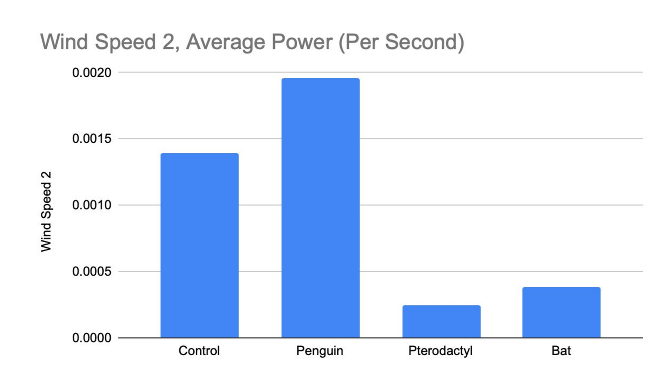

Figure 7: Wind Speed 2, average power generation

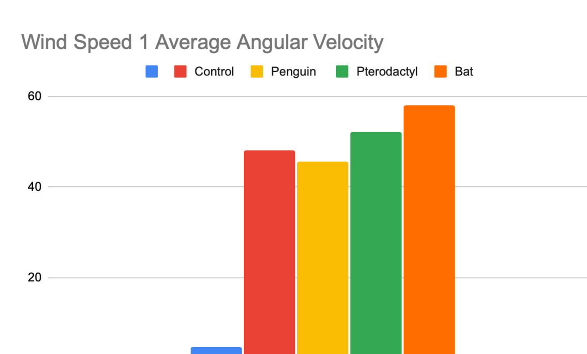

Figure 8: Wind Speed 1, average angular velocity

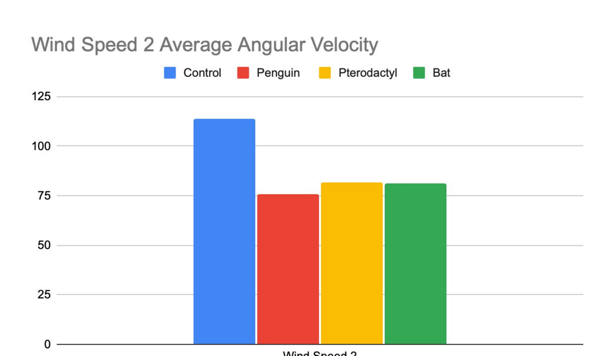

Figure 9: Wind Speed 2, average angular velocity

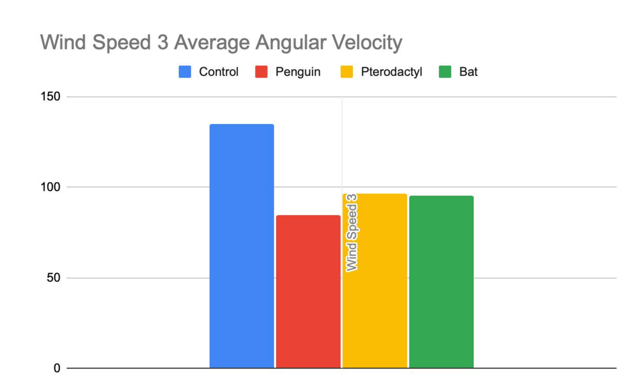

Figure 10: Wind Speed 3, average angular velocity

Sound Power Levels Tests

- The sound measurements were considered "lost in noise", and were insiginfigant compared to the noise fo the fan and mechanical components of the wind turbine.

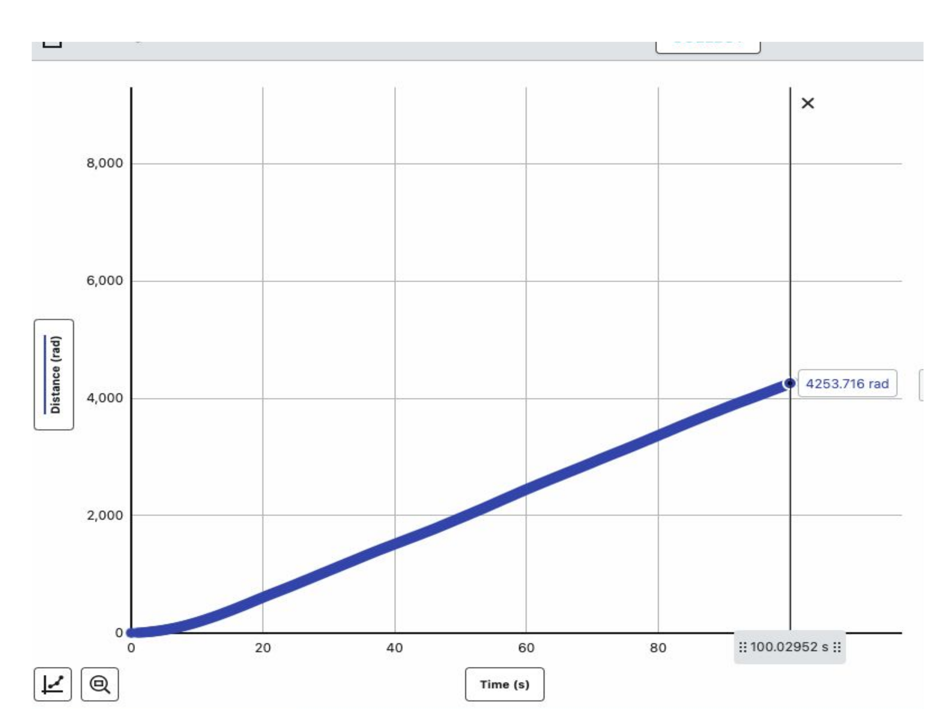

Figure 11: Wind Speed 1, 100 second penguin wing RPM measurements

Analysis

Faults with Design and Testing

- The photogate needed to be calibrated, resulting in large differences in data.
- Periods of unsteady movement where the hub hit the stand.
- The broadband noise being frowned out by the mechanical noise of the apparatus, and noise of the fan.
- The assumption that torque would remain the same throughout testing for each blade.

Analysis

- The penguin wing rotated the slowest on average.
- Due to its greater mass, for the first two wind speeds the penguin wing prototype generated the most power.
- The control rotated the fastest for the second two wind speeds, also correlating to a higher overall sound production.
- The pterodactyl wing generated the least amount of power due to its low mass/moment of inertia.

Conclusion

Summary

- Wind turbines generate noise that overall limits the potential energy that could be harvested from wind turbines. This project sought to look at three different animal wings, being the pterodactyl, penguin, and bat to determine whether certain characteristics of these wings could be used to make wind turbine blades quieter whale maintaining efficiency. 3D designs of the wing type were imported, and connected to a hub to make the propeller section of a wind turbine. The 3D prints were connected to the stand, and tested under three different wind speeds. The sound data was insignificant, however a greater mass and surface area may be better in areas with lower wind speeds. Future research should continue to test different features of each of these wings, and conduct the sound experiments using a physics software.

Future Research

Future Steps

- Run the sound tests of ANSYS Fluent software, to accurately gage the sound generated by each wing, and exact power measurements.
- Connect the 3D prints to a RC motor and record the average voltage produced.

Implications

- If successful, different characteristics that promoted silent operation and optimal efficiency can be taken and applied to actual wind turbine blades. This can increase the energy obtained by wind turbines by allowing more to be installed, and bigger turbines ot be installed, further aiding in the conversion to clean renewable energy.

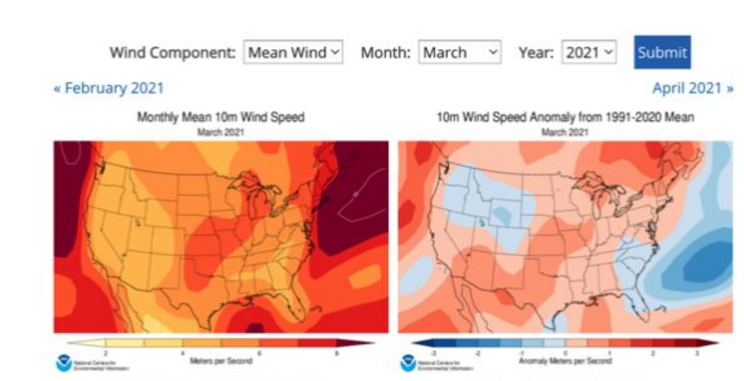

Figure 14: Maps of the average wind speeds in the United States (Average Wind Speeds, n.d).