Background

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

Wind turbines and especially wind farms produce enough sound to be damaging to the local environment, including residencies. Usually, these sounds are not very strong, they are enough to cause disruptions to local ecosystems and most prominently, residencies. Therefore, some restrictions are placed on wind turbines based on the number of decibels produced in the nearest residency. Restrictions placed on wind turbines limit many factors, overall hindering the total amount of energy that can be harnessed from wind turbines. The reduced amount of energy harnessed from wind turbines makes them less desirable compared to less environmentally friendly alternatives.

Climate Change and Pollution

Climate change and pollution are two of the greatest problems experienced globally. Driven by the large-scale emission of carbon dioxide and other greenhouse gasses, the burning of fossil fuels continues to be the prominent factor behind these two issues. Fossil fuel emissions have also been linked to various health complications, prominently in children and the elderly. Some developmental issues in children include both behavioral and cognitive issues, respiratory-related illnesses, and other terminal illnesses (Perera, 2017). Over 1.7 million deaths have been recorded in children below the age of 5 as a result of environmental pollution. It is projected that over 50% of deaths in children will be caused by outdoor air pollution by 2050 (Perera, 2017). Based on Working Group I's Sixth Assessment Report from the Intergovernmental Panel on Climate Change, Earth's average atmospheric temperature may increase by 1.5 °C by 2040. Some results of such drastic increases in global temperatures are sea levels rising, increasing intensity of hurricanes and wildfires, and sustained periods of drought. (Masson-Delmotte et al., 2021). Global warming can be connected to many different problems across the world, and the longer it remains unaddressed, the more difficult it becomes to solve. Part of the solution to combat the use of fossil fuels and therefore global warming is clean, renewable energy. Wind turbines are a growing source of renewable energy, and as they continue to grow in popularity, the efficiency and overall energy produced by wind turbines must increase (Friedlander, 2021).

Wind Turbine Acoustics

While wind turbines are better for the environment than fossil fuels, they also produce sound that can harm nearby ecosystems and residencies. As wind turbines grow, the wing tip speed of the blades also increases, thereby generating stronger sound power levels. Consequently, regulations have been placed on wind turbines based on the sound power levels in decibels of the closest residencies. Based on the sound power levels, limits are placed on where these turbines can be, how many there can be, and how large they can be, greatly hindering the potential energy that could be acquired (Hoen et al., 2023). Wind turbines emit two different types of frequencies: tonal and broadband. Tonal noise created from the mechanical components emitting low frequencies is more dangerous, however, this problem has been solved with modern-day wind turbines. Therefore, broadband noise is the dominant contributor to the sound produced by wind turbines. Broadband noise is a range of frequencies that are combined. This type of noise is generated by the blades moving through the air and can be described as a “whooshing” noise (Wind Turbine Sound, n.d.).

Biomimicry

Biological airfoils have been the inspiration for countless numbers of airfoils throughout history. An airfoil is an object that generates lift and drag while moving through a fluid (Britannica, 2023). One example of animal wings that have been modeled is seagull wings—because of their high lift-to-drag ratio, explaining their optimal aerodynamic performance (Hua et al., 2019). Owl wings are the most used biological airfoils to reduce airfoil noise emission. Owls have evolved to fly silently enough to locate their prey and prevent detection from their prey. Owls’ leading-edge serrations, trailing-edge fringes, and smooth velvety feathers enable them to fly near silently (Wang et al., 2019). The trailing edge fringes force the airstream above and below the wing to converge, resulting in the absence of noise-producing vortices. The velvety feathers aid in reducing trailing edge sound by lowering the streamline speed along the trailing edge. Leading edge serrations are the most prominent element that contributes to silent flight, by helping to eliminate turbulent boundary layer noise by causing the streamline to stay steady along the wing. An owl's typical leading-edge serrations consist of sinusoidal serrations and sawtooth serrations. These four qualities that owls possess have been integrated into different types of airfoils as methods of noise reduction (Wang et al., 2019). However, because there is already extensive research on owl wings, this project examines penguin wings, pterodactyl wings, and bat wings.

Penguin Wings

Penguin wings perform optimally in water, a denser fluid than air. While penguins are flightless, their wings are highly specialized for swimming. Penguins have undergone different adaptations from typical bird wings, converting them to better suit their given environment underwater. Some of these adaptations include reduced feather sizes, and barbules that have an increase in thickness. Overall size adaptations have made these wings shorter and firmer, converting the purpose to propulsion in water, and making the wing like a paddle (Louw, 1992). Penguins wings perform optimally, generating a lot of power in water. They were chosen to determine whether the same can be said in air: producing more power without increasing sound output.

Pterodactyl Wings

Pterodactyls were a subgroup of the family pterosaurs. Therefore, pterodactyls were related to the largest animals to have ever flown. These include the Quetzalcoatl and Montanazhdarcho, the two largest animals to have ever flown (Britannica, 2023). Although the acoustic performance and other characteristics of these animals' wings can never be exactly known, data from archeologists' 3D models can provide insight into knowledge that was gained from other fields. Pterodactyls' wingspan ranged from 20 inches to 3.3 feet, making them smaller relative to these other pterosaurs. However, the wing characteristics of these different species were similar, including their use of skin as a membrane for the wings instead of feathers. Boonman et al., in 2020 found that the feather noise contributed roughly 1/16th to 1/18th of the total amplitude of the sound created by the wingbeat of a Little Burn. Their study finds that feathers contribute to the overall noise created by birds flying. Recent evidence of soft tissue in pterodactyl wings was found, suggesting they had wing root fairings, which would aid in overall force generated upon each wing stroke (Pittman et al., 2021). Due to the availability of 3D models, scaling factors, pterodactyl wings, and the optimal gliding performance possessed by pterosaurs, pterodactyls were the best option, representing these larger pterosaurs at a scaled-down size (Britannica, 2023).

Species	Weight (g)	Wing length (mm)	Surface area (cm2)	dB SPL @1 m rec > 50 cm	Furthest rec distance (cm)	AcousticWingbeat (Hz)	Real wingbeat (Hz)
Pigeon	**232**	**250**	**220**	**67.6**	**126**	**9.6**	**9.4**
Myna	**112**	**160**	**117**	**60.8**	**116**	**11.4**	**12.1**
Bulbul	**41**	**125**	**85**	**57.1**	**81**	**17.4**	**12.3**

House sparrow	**28.5**	**76**	**80**	**58.2**	**107**	**22.0**	**22.6**
Eptesicus	**18.6**	**130**	**49**	**44.2**	**61**	**17.0**	**14.8**
Rhinopoma	**28.4**	**160**	**78.5**	**50.7**	**66**	**10.5**	**10.8**
Rousettus	**168.5**	**220**	**167**	**59.5**	**142**	**8.2**	**8.3**

Table 1: Sound Pressure Levels (SPL) in birds and bats at low flight speeds. (Boonman et al., 2020).

Bat Wings

Bat wings are like pterodactyl wings in that they don't have feathers but rather the skin that makes a membrane. The table above shows data for low flight speeds of 3 different bird species and 3 different bat species. The data shows that, on average, bats were quieter than birds whose wings were of similar size (area and length) (Boonman et al., 2020). Their silent, yet effective wings could provide another alternative turbine for the third set of wind turbine blades.