Smart Turbine Blades for Wind Energy Efficiency

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College of Engineering

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Mission/SOW

Our faculty mentors requested the research and design of smart turbine blades equipped with sensors to adapt to their environment.

Criteria for this Project:

- Research existing smart blade technologies
- Investigate different wind speed sensors
- Create code script for sensors and motors
- Build/wire components
- Create SolidWorks models
- Conduct simulations
  - QBlade and SolidWorks were used to design wind turbine blades.
- Develop a mechanism for blade adjustment
- Prototype a smaller scale product using 3D printed material and purchased components.
- **Prototype bench scale testing:**
  - Measure power output produced by the turbine to verify the functionality of the system.

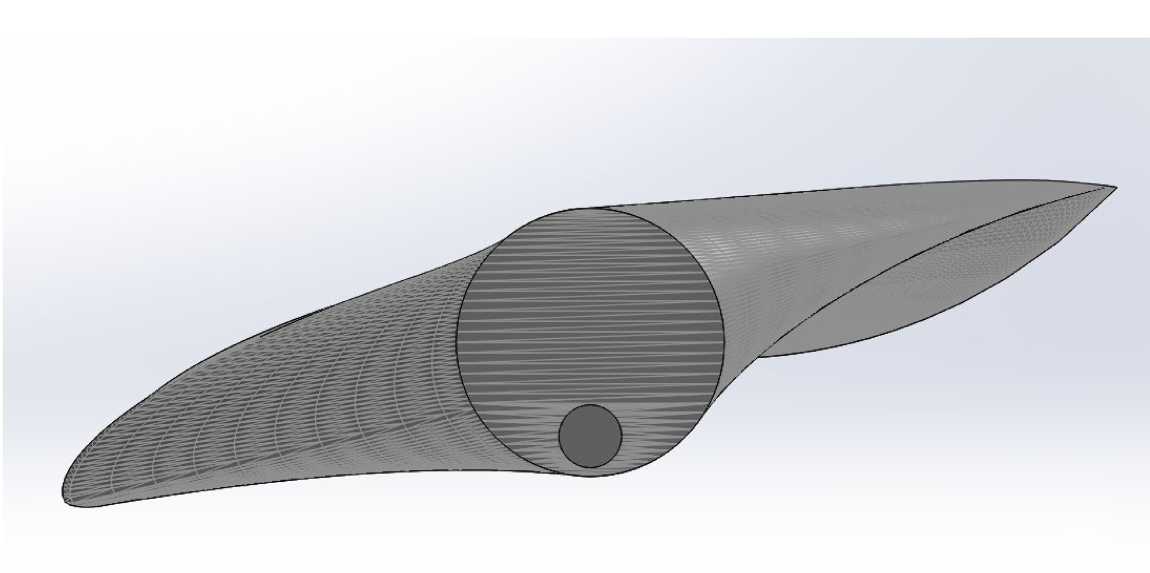
Research

Challenges in Wind Energy Production

- Wind energy is a growing source of sustainable energy; however, efficiency varies based on location and the region's wind speed.
- Research shows improved efficiency by accessing stronger winds at higher altitudes using taller towers and longer blades.
- Wake steering can enhance energy production by 1-2% annually [8].

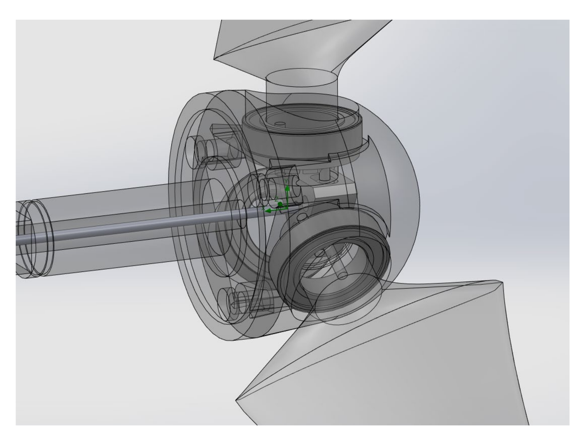
Technology Advancements

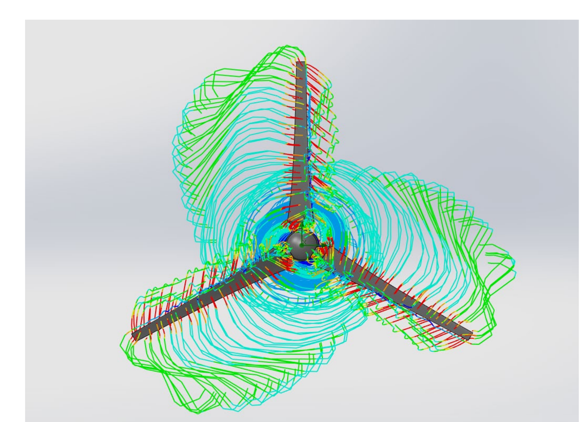
- Modern turbines utilize pitch angle control to optimize efficiency.
- Blades adjust to wind speeds to maximize energy capture and minimize wear.
- Smart blade systems can enhance power generation, reduce costs, and improve turbines' lifespan.

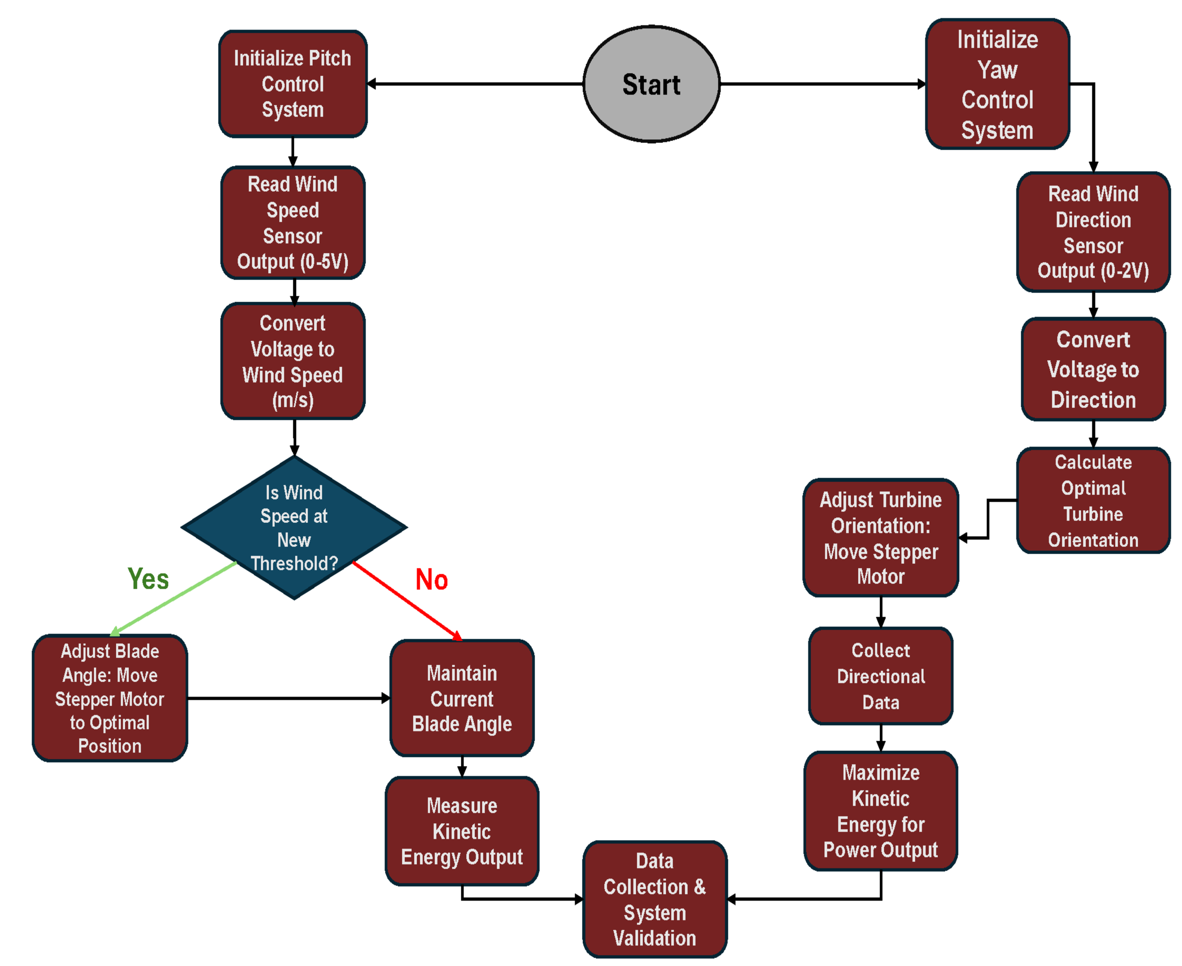


Final Design

- To operate the pitch angles of our blades, we integrated a central mechanism within the rotor hub that connects to each blade.
- The movement of this mechanism is a horizontal motorized pitch system. With each lateral movement, the mechanism is causing the blades to rotate, allowing for a more efficient pitch angle.
- There are bearings and c-clips keeping the blades in place, allowing them to move efficiently to adjust as required by the pitch control system.
- The central mechanism is connected to a rod that is driven by a stepper motor which is the origin of movement.
- A wind speed anemometer and wind vane direction sensor are used along with Arduino components and proper code to properly get readings from the environment.
- Blades utilize the SG6043 airfoil, optimized for efficient performance at low Reynolds numbers

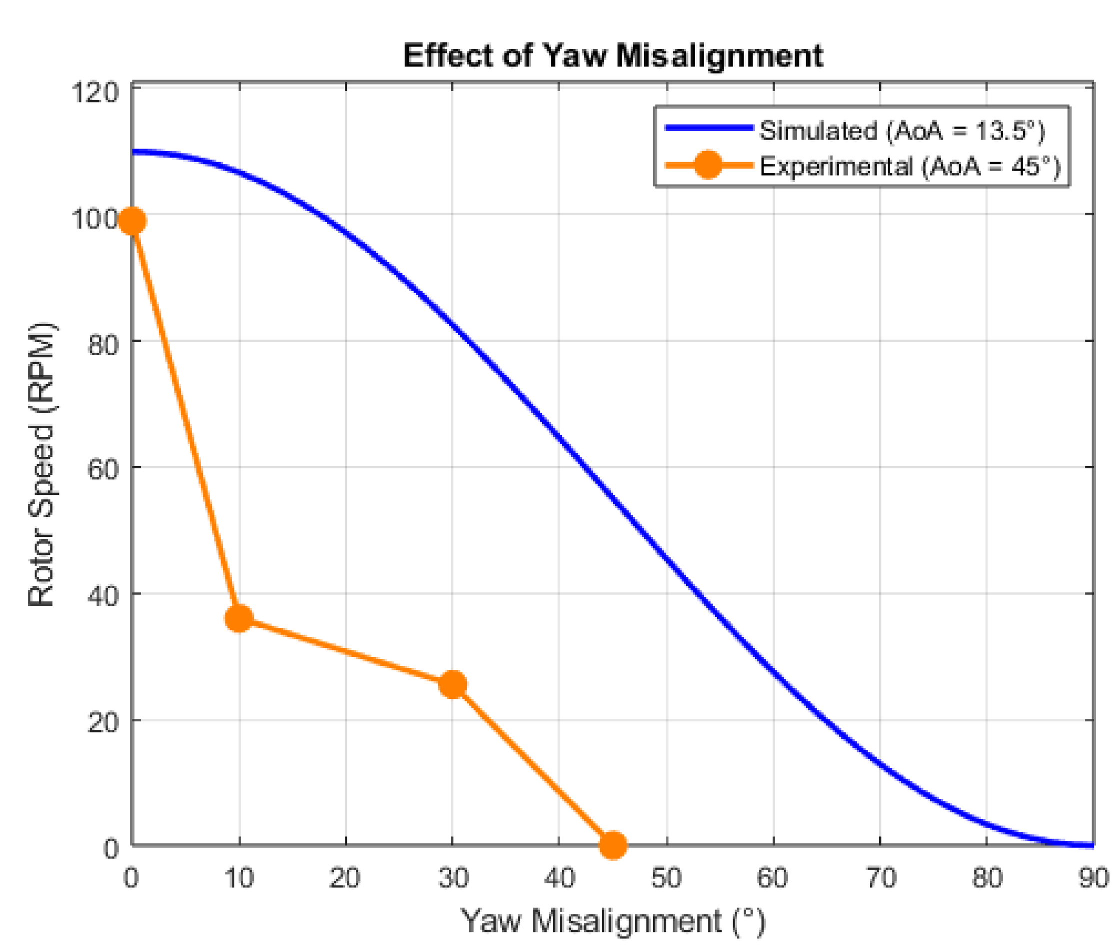






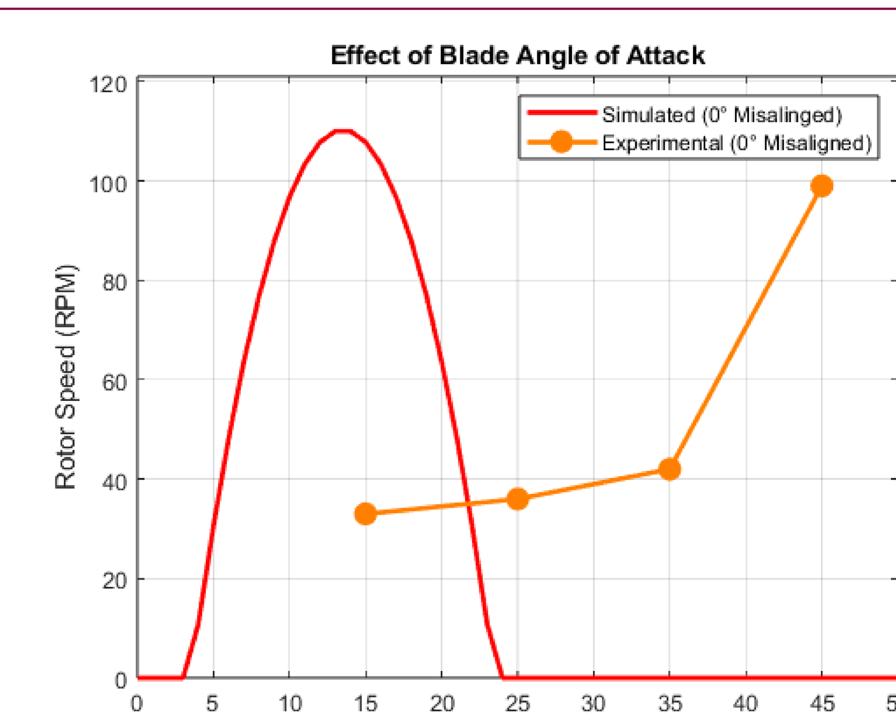
Results

- Conducted sensor verification with a voltmeter to ensure voltage outputs were correct.
- Circuit wiring connecting the Arduino, sensors, drivers, and motors are functional.
- Sensor outputs worked with code to initiate the motors to adjust accordingly.
- Pitch mechanism worked correctly through testing and troubleshooting.
- Validated Arduino code through correct motor steps.



Plots

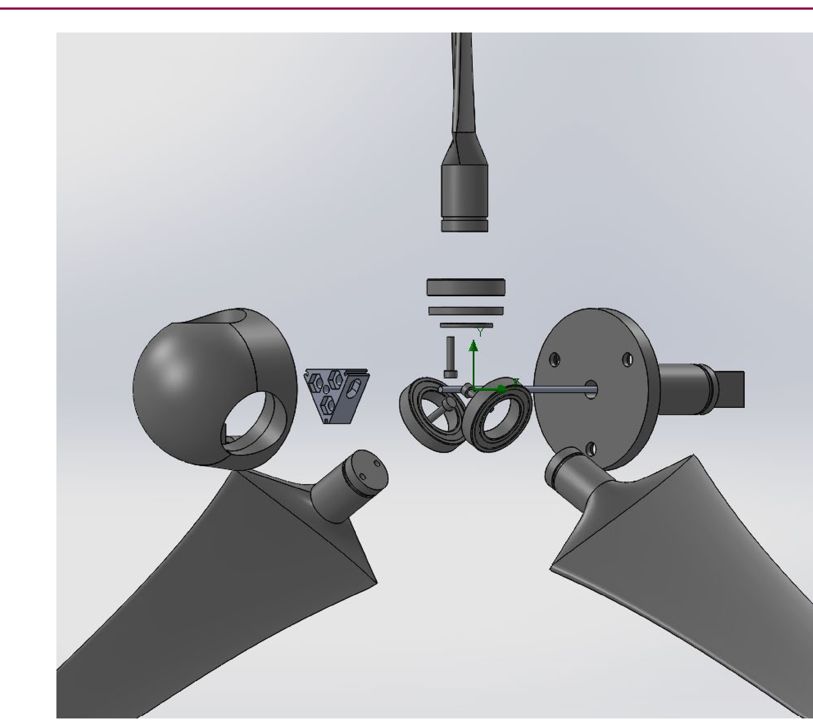
- Monte Carlo simulation predicted peak power output at lower angles of attack, aligning with aerodynamic theory at low Reynolds numbers.
- Experimental blade pitch testing showed higher RPM output at larger pitch angles.
- Yaw angle testing demonstrated that deviating from optimal wind alignment reduces power output.



Concept Development

Our concept development consisted of selecting optimal blade profiles, control mechanisms, and sensor integrations to enhance performance. The team systematically approached the design by defining key parameters, conducting simulations, and refining the prototype.

- **Airfoil Selection:** Various airfoils, including SG6043, FX 63-137, and S934 were evaluated for their aerodynamic performance. SG6043 was ultimately chosen due to its high lift-to-drag ratio and efficiency at a lower Reynold's number.
- Through our research our team decided to incorporate a **Pitch Control System:** The blades incorporated an active pitch adjustment mechanism that responds to wind velocity, optimizing power output while reducing mechanical stress.
- **Yaw Control System:** A wind vane driven orientation system ensured the turbine always faces the wind to maximize kinetic energy output.
- **Smart Sensor Integration:** Anemometer and wind vane provided real-time data, allowing for automated adjustments to the blade pitch and turbine orientation.



References

[1]https://doi.org/10.3390/app13031721
[2]https://doi.org/10.1088/1755-1315/161/1/012028
[3]https://doi.org/10.1016/j.esd.2019.02.003
[4]https://doi.org/10.1109/ACCESS.2019.2892728
[5]https://www.nationalgrid.com/stories/energy-explained/history-wind-energy
[6]https://www.youtube.com/watch?v=Hf875eOVrVI
[7]https://doi.org/10.1088/1755-1315/161/1/012028
[8]https://www.nrel.gov/news/program/2023/technology-advancements-could-unlock-80-more-wind-energy-potential-during-this-decade.html#:~:text=These%20innovations%20include%3A%201%20Longer%20blades.%20Significantly%20longer,5%20Climbing%20cranes.%20...%206%20Wake%20steering.%20
[9]https://doi.org/10.3390/ma14051124
[10]https://doi.org/10.3390/sym12010018
[11]https://www.sciencedirect.com/science/article/pii/S2214785321004508
[12]https://doi.org/10.1002/we.1974