Modular Lab-Scale Wind-Turbine Prototype For Aerodynamic Research

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Abstract

- The goal of this capstone project is to design and construct a lab-scale wind-turbine prototype to be used in 1m x 1m open-jet wind tunnel. Modularity is emphasized in this project, to allow for testing of a variety of blade profile designs and the data acquisition of sectional blade forces. In the overall design, the wind turbine includes the blades, nose, nacelle, and the tower with the integration of electrical components for data acquisition and transmission.
- Through the completion of this project, this experimental platform will be supporting future aerodynamic research in the Laboratory for Turbulence Research in Aerodynamics and Flow Control (LTRAC) under the supervision of the project sponsor, Dr. Eric Limacher.

Introduction

- In today's pursuit of sustainability, the global focus on reducing carbon emissions and transitioning away from fossil fuels underscores the significance of renewable energy sources like wind power. Wind energy stands as a vital contributor, offering clean electricity generation instead of greenhouse gas emissions.
- Essential to maximizing the efficiency and performance of wind turbines is an understanding and improvement of aerodynamics. This capstone project aligns with the research on unsteady wind-turbine aerodynamics, aiming to fill the gap in the limited existing literature concerning sectional blade forces and their correlation with local airflow patterns.
- The objective of the project is to develop a versatile lab-scale wind turbine prototype for a 1m x 1m wind tunnel, requiring precise wireless sensor integration for blade force measurements, while ensuring ease of assembly and accurate data acquisition through mechanical and electromechanical design, concluding with experimental validation.
- Dr. Limacher and his research for the LTRAC laboratory are looking to test the relationship between sectional blade forces and the local air flow around the blades.
- While the project primarily focuses on designing an experimental apparatus, its significance lies in creating a functional platform to fulfill future research needs. The outcome of our capstone project will serve as a cornerstone for upcoming graduate students within the LTRAC lab, facilitating innovative aerodynamic research.

Design Specifications

- The culmination of the work completed through this project resulted in the following design specifications being achieved:
  - Modular wind turbine design that allows multiple blade profiles to be tested with various pitch angles.
  - Implemented 2 strain gauges to read the forces experienced internally.
  - Achieved a design of 65cm in diameter of the full turbine assembly.
  - Can run up to a wind speed of 20 m/s, with an upper limit for torque being 7.91 Nm.
  - Wireless data acquisition was accomplished, and batteries are swappable to allow for quick turnaround time.

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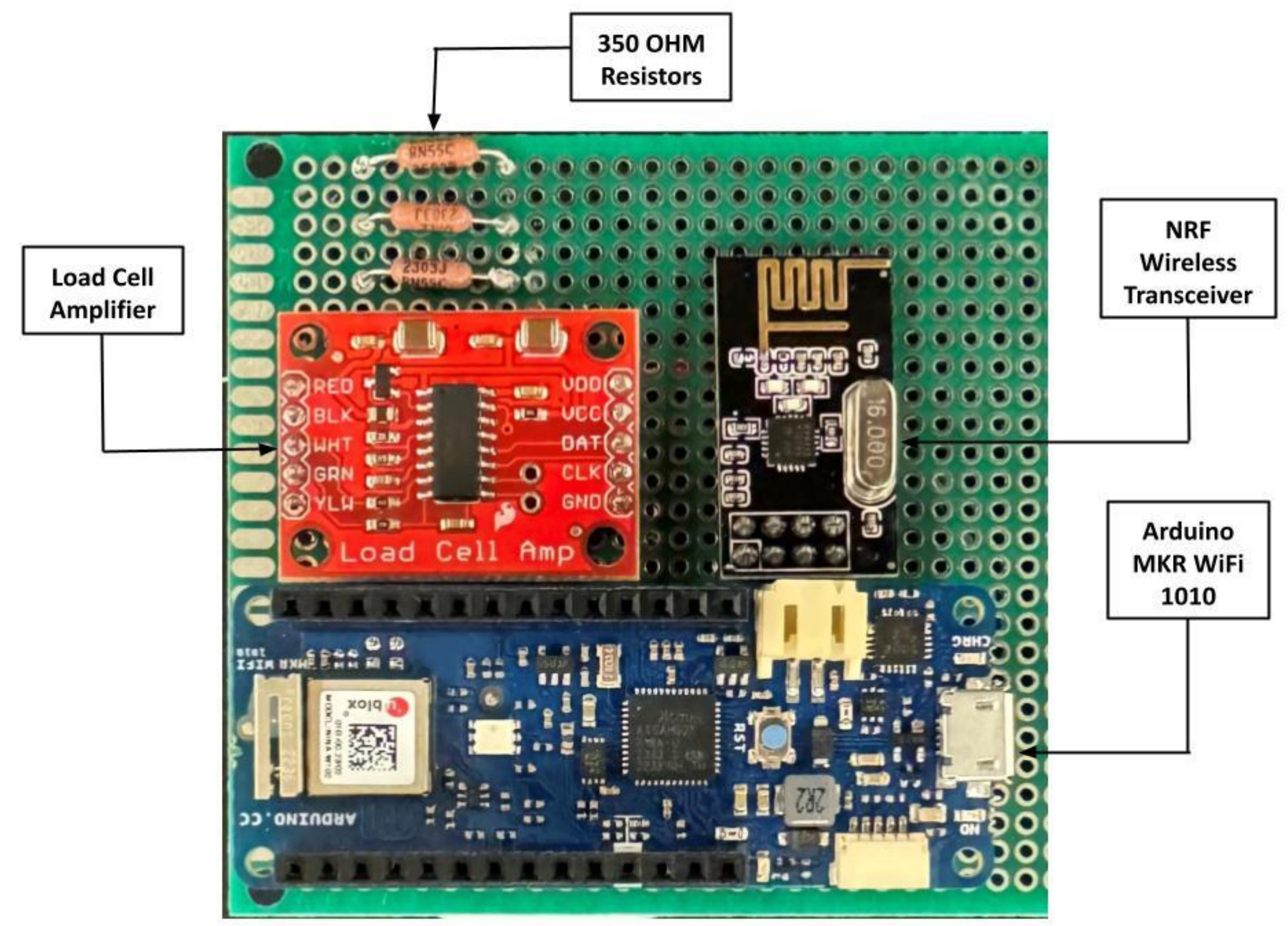

Figure 1: Wireless Force Data Acquistion Setup

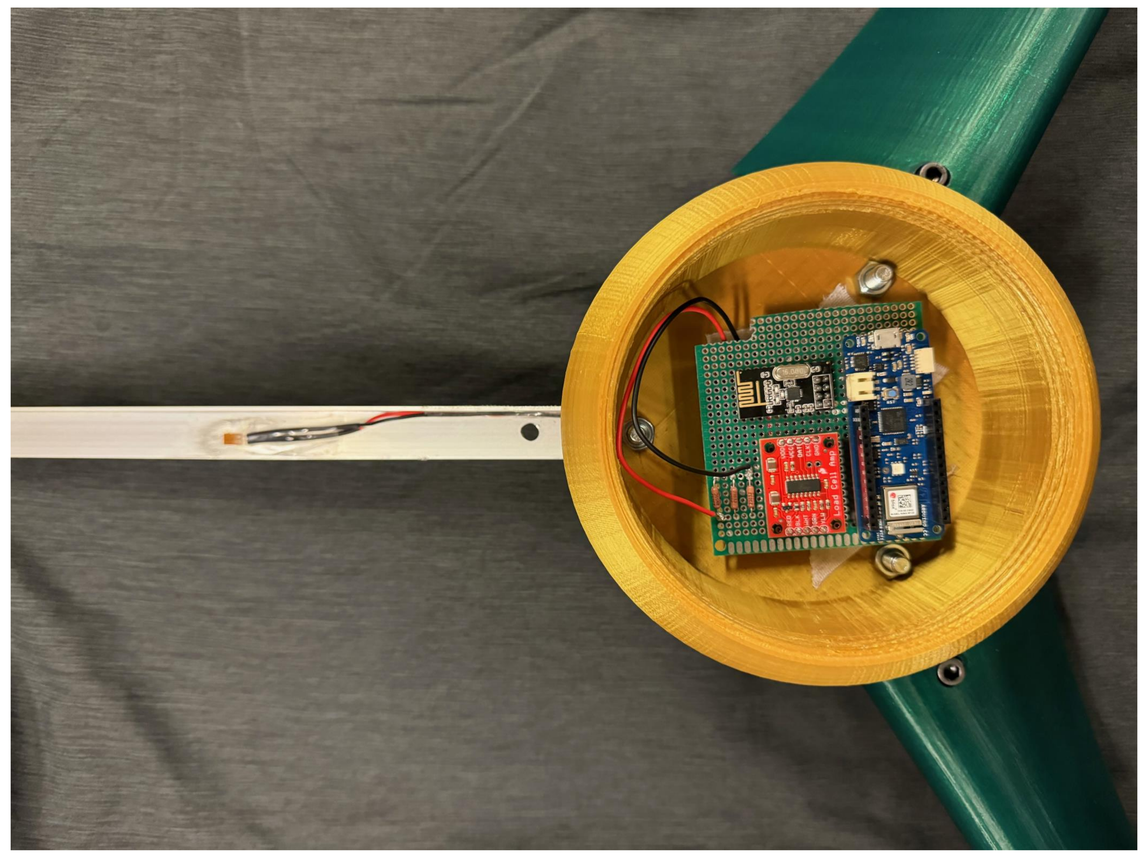

Figure 2: Wireless Force Data Collection: Hub-Spar Strain Gauge Setup

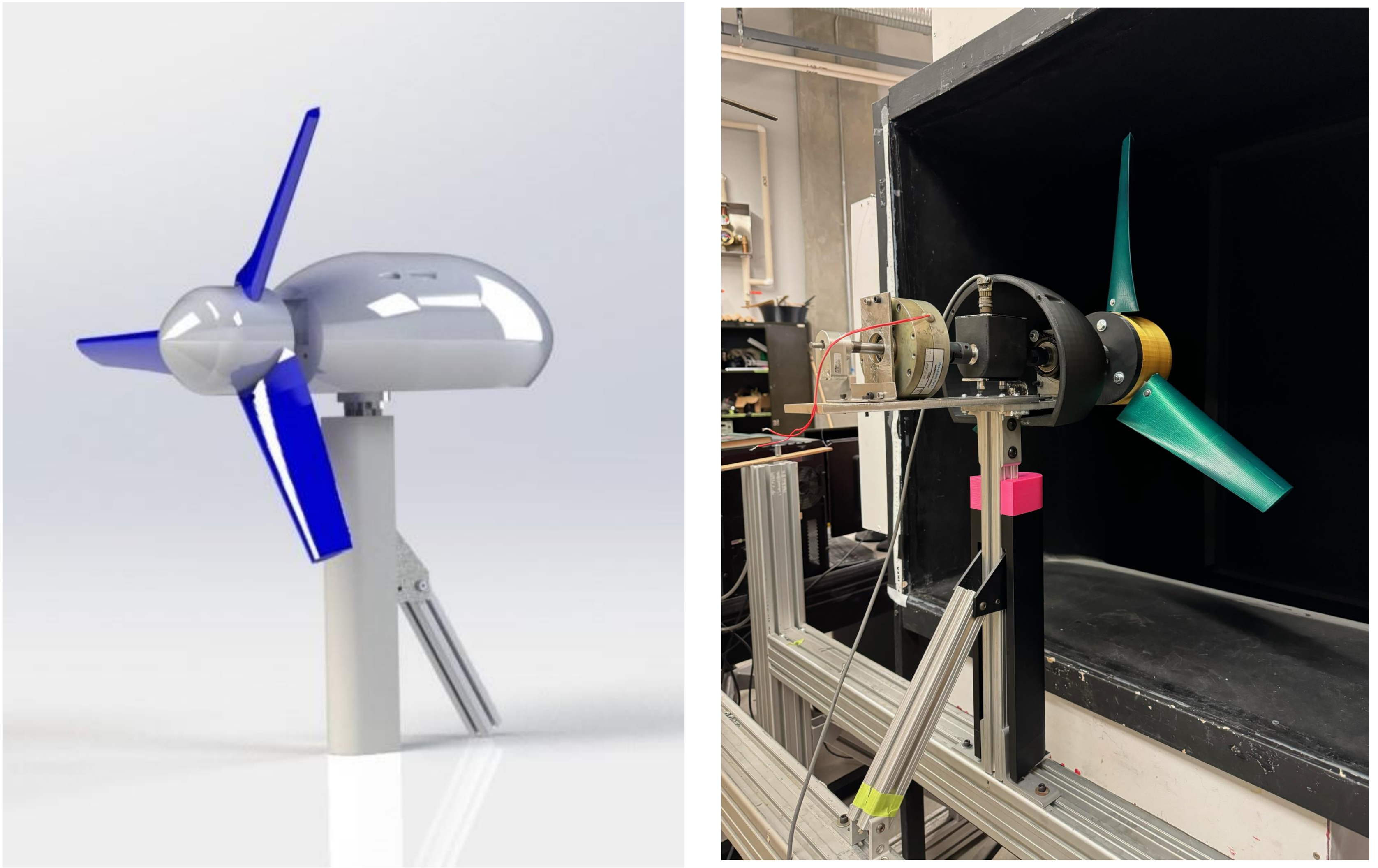

Figure 3: CAD and Physical Assembly of Wind Turbine

Methods and Materials

- The conceptual design of this project began with developing a working document of major requirements and constraints in the project. From here, background research was conducted on standard wind turbines, analyzing the aerodynamic profile, lift and drag forces.
- Within the early design development, a multitude of designs were drawn up and assessed, resulting in a final conceptual design. The main factors driving our early development were related to the sensors, their placement, and the internal spar design. From here, the electrical design and physical design were delved into, with the main goal being to achieve a smooth and accurate data acquisition process.
- The engineering analysis examined moment, stress, and strain calculations by using constant and triangular loading. These analytical results were compared with experimental values to finalize the project results.
- Prototyping resulted in multiple renditions of the electrical system, with each version building upon the functionality and final goal of achieving wireless data acquisition. In conjunction, the physical system was being developed, with many versions and finalization developed using SolidWorks. Finally, testing of the final prototype was completed, with comparisons to the analytical results.
- The stand of the turbine is assembled using an aluminum T-slot and steel interconnects. It is bolted to a larger aluminum frame. For the attachment system, the different components of the turbine were attached using steel screws.
- Electrical components for the experimental setup of the turbine are situated on the blades and housed in the turbine. These include strain gauges, resistors in a Wheatstone bridge formation, load cell amplifier (model HX711), Arduino ESP, radio frequency, and lithium polymer (LiPo battery).

Results

- From the engineering analysis, the moment, stress and strain were calculated through constant and triangular loading. At a location of 0.132 m from the base of the blade, roughly halfway up the entire length, the following results were obtained:
  - Constant Loading: Moment= 0.71 Nm, Stress= 944410.22 N/m, Strain= 1.37e-05
  - Triangular Loading: Moment= 0.91 Nm, Stress= 1205585.42 N/m^2, Strain= 1.75e-05

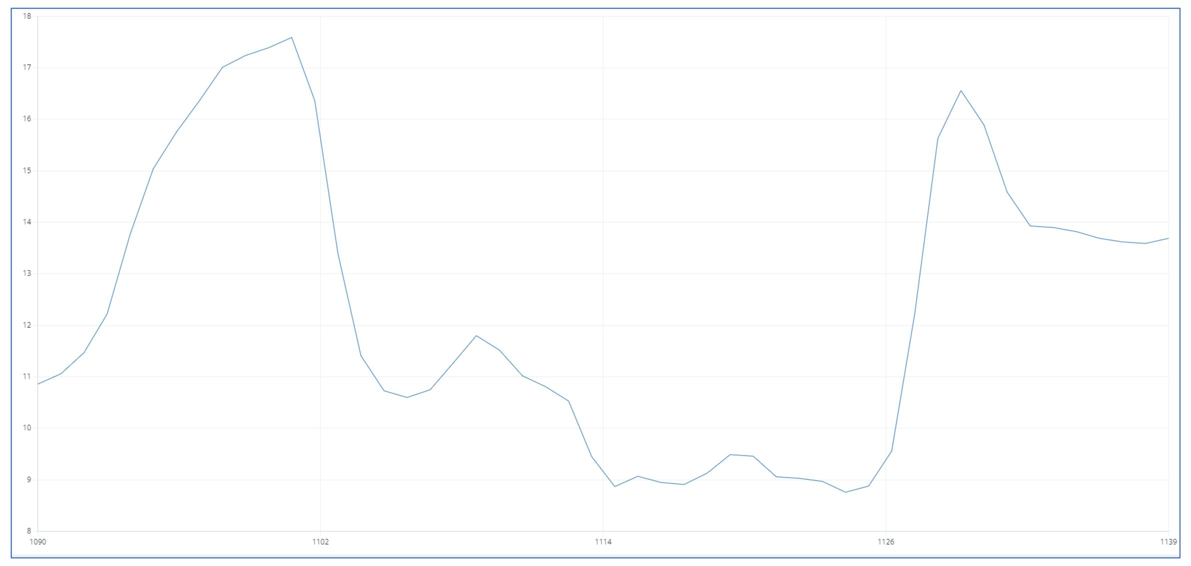

Figure 4: Proportional Force Vs Time Graph of Turbine Blade

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