Design and Construction of a Tabletop Wind Tunnel for Aerodynamics Experiments

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Abstract

This project sought to develop a modular wind tunnel capable of simple in class experiments to demonstrate aerodynamics. Built from accessible and cost effective materials, the tunnel features real-time wind speed and lift-force measurement using Arduino-compatible sensors. A server fan controls wind speed and a smoke machine helps visualize air flow. A load cell measures lift. The final setup offers a robust educational platform for hands-on aerodynamics projects.

Objectives

- Construct a compact, affordable wind tunnel using simple materials and 3D printing.
- Achieve and visualize laminar airflow
- Measure lift forces using a load cell
- Display wind speed as a function of PWM control
- Apply findings to test models

Mechanical Design

Materials Used:

- ¼ inch plywood for the structure
- Plexiglass for viewport
- 3D-printed funnels and laminar flow filter
- Drinking straws for enhanced laminar flow
- Wood stand for elevation and stability
- Silicone sealant for airtight construction
- Smoke machine for visualizing airflow

Design Overview:

The wind tunnel uses a suction-type airflow system with a fan mounted at the outlet. Air enters through the honeycomb section, passes through a contraction funnel into a test section, and exits through the end of the tunnel where the fan sucks the air. The test section allows mounting aerodynamic models, visualizing smoke patterns, and wind speed vs PWM relation.

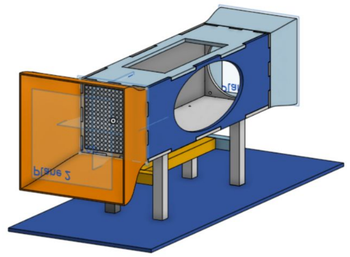


Figure 1. CAD Design of Wind Tunnel

Electronics and Sensors:

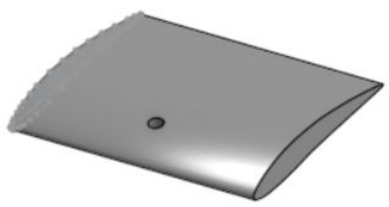
Sensors Used:

- Handheld anemometer for calibration
- 1 kg load cell for lift force measurement
- HX711 amplifier module
- Arduino Uno for data collection and control
- LCD screen for live data display

Workflow:

- Sensors feed data to the Arduino.
- LCD displays wind speed and lift in real time
- Pulse-width modulation controls fan speed
- System calibration with known values

Aerodynamic Model: USA 28 Airfoil



Challenges

- Securing the airfoil to load cell
- Debugging inconsistent readings from the HX711 module
- Stabilizing fluctuating sensor values for lift force at low speeds (unresolved)
- Calibrating the load cell for small, precise force measurements
- Library issues: several HX711 options

Wind Speed vs PWM Calibration

To control and reproduce specific wind speeds, we mapped PWM input values to measured wind speeds using the anemometer.

We calculated the lift using standard kinematics. Which can be compared to the theoretical lift using the airfoil's surface area.

$$F_L = mg$$

$$F_L = C_L \frac{\rho V^2}{2} A$$

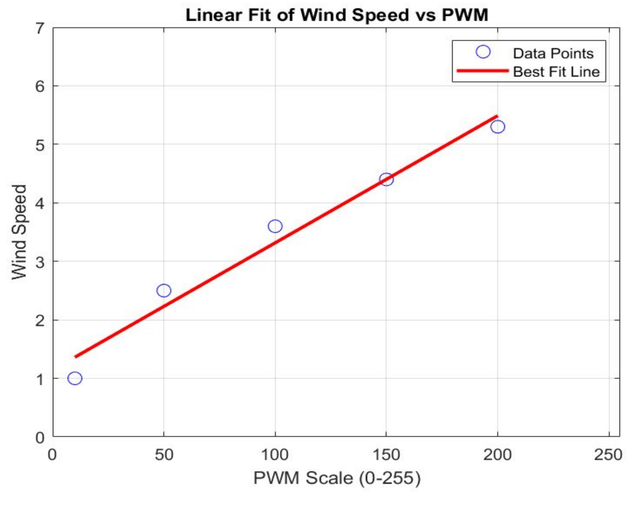


Figure 2. Linear Fit of Wind Speed vs PWM

Conclusion and Future Work

Our low-cost wind tunnel effectively demonstrated aerodynamic principles and allowed lift testing of a USA 28 airfoil with real-time sensing. The simple modularity and visuals makes this system suitable for undergraduate experiments related to lift, drag, and power generation.

For the future, we'd like to fabricate better laminar flow parts, create adjustable angle of attack, build windmill module, and increase user-friendliness.

Acknowledgements

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References

GitHub Repository. https://github.com/Charles-Thacher/WindTunnelSketch
GrabCAD. "DIY Wind Tunnel." GrabCAD Community Library. https://grabcad.com/library/diy-wind-tunnel-2