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HCDE 539 Autumn 2018; P5. Project Report

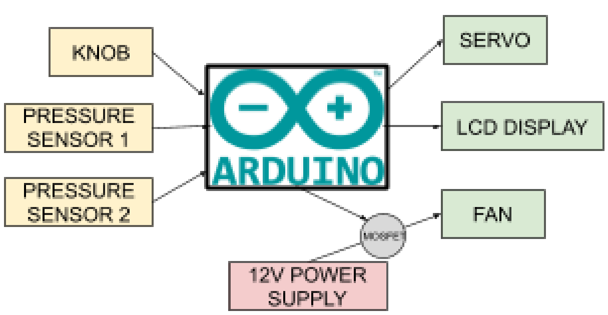
Mini Wind Tunnel

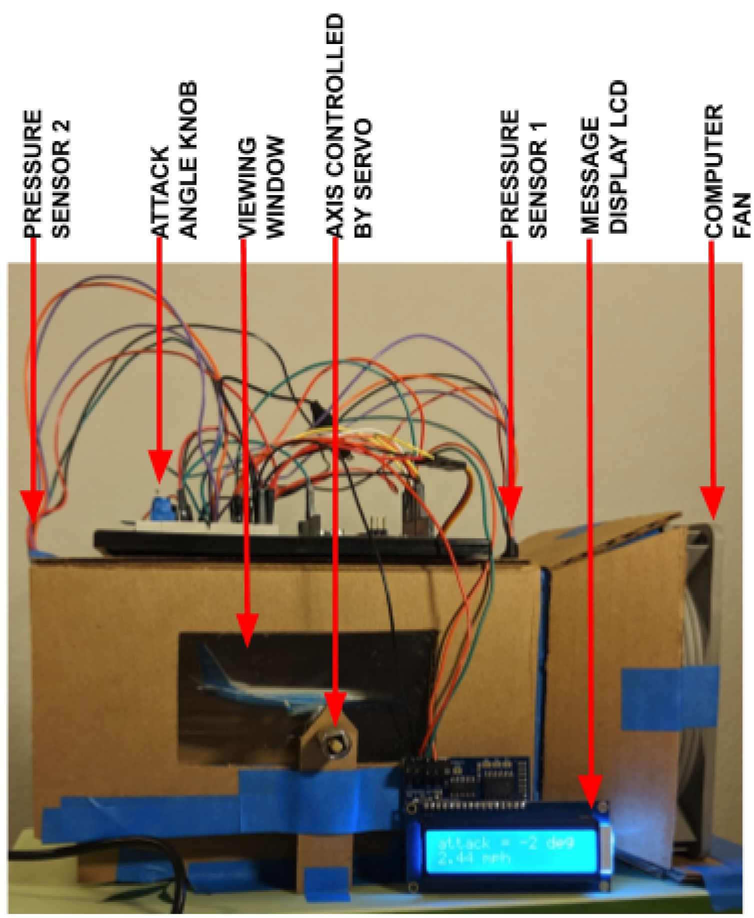
Conveying basic concepts of aerodynamic wind tunnels -- adjusting an airfoil and calculating wind speed from pressure differences along a duct

A cardboard wind tunnel using a 12V computer fan and a model airplane on an axis controlled by a servo. The user can control the angle of attack of the plane via a potentiometer knob that is connected to the servo. The system has one pressure sensor in the airstream of the fan, and another pressure sensor behind the model plane. The code uses a pressure difference between the two sensors to compute the duct wind speed on the rear side of the plane in the path of the air stream. It prints this speed and the angle of attack on an LCD display.

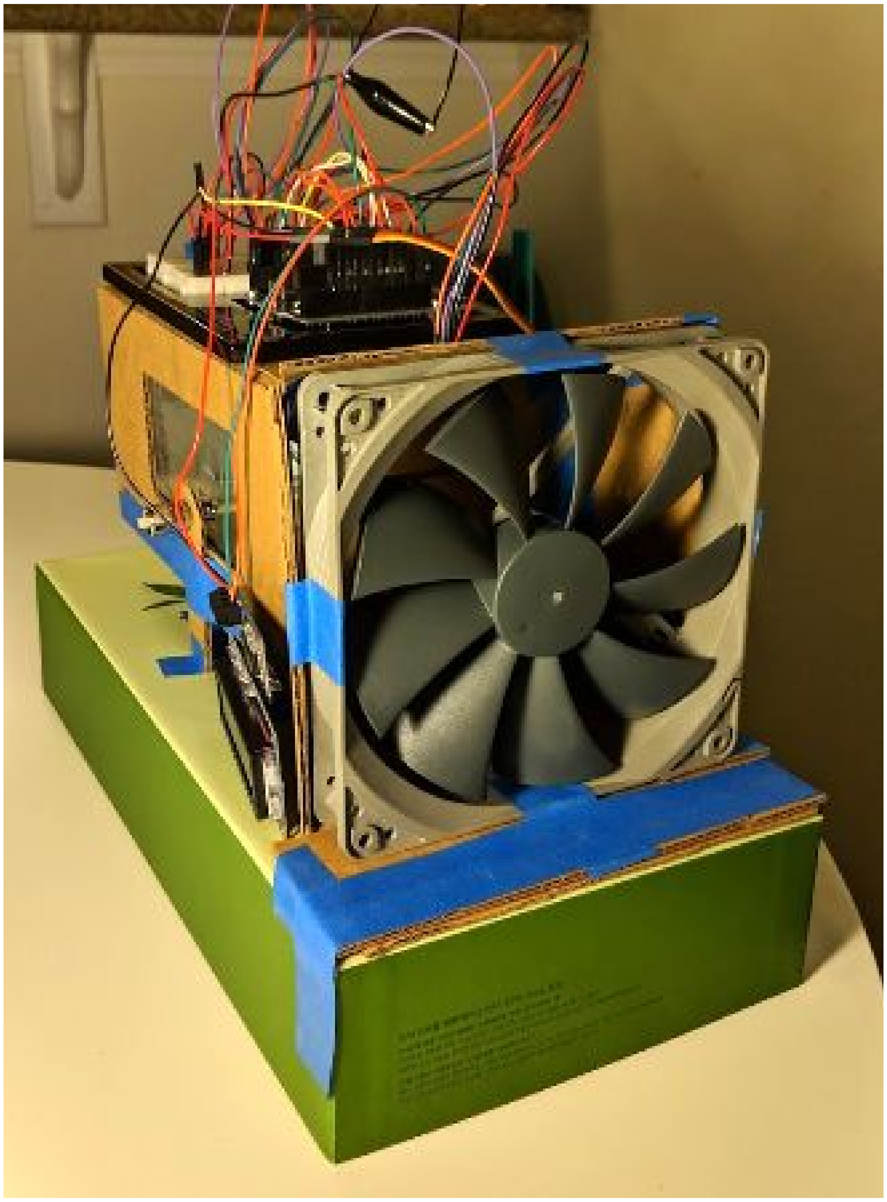
The ATTACK ANGLE KNOB is a potentiometer whose position controls the position of the servo behind the duct (not pictured). The servo position is mapped to the angle of attack of the airplane, which is printed on the MESSAGE DISPLAY LCD, which also displays the theoretical wind speed at the PRESSURE SENSOR 2 location. This system does not take into account friction forces and is not intended for use as a scientific wind tunnel.

LINK TO VIDEO: https://youtu.be/P0JwScpqCy8





Implementation



This project is meant to convey the basic concept of large industrial wind tunnels, which can have scaled down versions of modeled airplanes to test actual airplane aerodynamic performance. The intention of my project was not to be a scaled down wind tunnel, but a demonstration of changing angle of attack to block an airstream.

The fan I bought was a computer fan powered by 12V with airflow of 133.7 m^3/min from the fan's spec sheet[1]. Given that the fan was 5.32" tall x 5.32" wide, the fan airflow was calculated to be 4.55 mph. When the tunnel is contracted to a 4" x 4" duct, the airspeed at the opening of the duct is 8.05 mph. Note that this system is idealized and does not account for friction losses.

The two pressure sensors that I purchased were cheap barometers, BMP280 (spec sheet[2]), that were sensitive enough to measure higher pressure at the pressure sensor 1 location, where the wind speed was maximum ~8.05mph. Therefore I kept this wind speed constant and calculated a wind speed at the pressure sensor 2 location from the pressure differential between P1 and P2. Math is below. Link to Bernoulli's equation for fluid flow: https://www.princeton.edu/~asmits/Bicycle_web/Bernoulli.html.

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[1] https://noctua.at/en/nf-p14s-redux-1500-pwm/specification

[2] https://cdn-shop.adafruit.com/datasheets/BST-BMP280-DS001-11.pdf

P_1 = Pressure at pressure sensor 1 at maximum wind speed output, Pascals
P_2 = Pressure at pressure sensor 2 after airplane, Pascals
g = gravitational acceleration
ρ = 1.225 kg/m^3 , density of air at sea level and 15 deg Celsius
$h_1 = h_2$ Elevation above sea level
V_1 = Velocity at pressure sensor 1, 8.04 mph = 3.60 meter/s
Solve for V_2 , wind speed at pressure sensor 2

Bernoulli's equation: $P_1 + \frac{1}{2}\rho V_1{}^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2{}^2 + \rho g h_2$

$$P_1 - P_2 = \frac{1}{2}\rho(V_2{}^2 - V_1{}^2)$$

$$\frac{2}{\rho}(P_1 - P_2) + V_1{}^2 = V_2{}^2$$

$$V_2 = \sqrt{\frac{2}{\rho}(P_1 - P_2) + V_1{}^2}$$

The actuator was a potentiometer knob on top of the duct, whose position controlled a servo that rotated the axis that the airplane was superglued to. Another action was plugging in the system to a power source (laptop) to turn on the system, turning on the fan and the LCD display. The sensors were the two pressure sensors and the output was the angle of attack and P2 wind speed reading on the LCD display.

As for the angle of attack of the airplane model inside the wind tunnel, changing the angle had no correlation to the wind speed at pressure sensor 2, which I was expecting, because the effective area of the plane normal to the airstream was very small. See below for sample serial monitor output. Had I put something in the tunnel that had a larger cross sectional area, it would have noticeably reduced the wind speed at the pressure sensor 2 location with changing angle of attack. Also, had I used a more granular pressure sensor that could more precisely read the low pressure void behind the airplane model, the P2 pressure reading would be more accurate with changing attack angle.

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Angle of Attack = 4 deg; P1 = 101433.54 Pa; P2 = 101431.91 Pa; wind_speed = 1.77 mi/hr
Angle of Attack = 3 deg; P1 = 101431.38 Pa; P2 = 101431.92 Pa; wind_speed = 1.55 mi/hr
Angle of Attack = 3 deg; P1 = 101430.10 Pa; P2 = 101429.78 Pa; wind_speed = 1.64 mi/hr
Angle of Attack = 3 deg; P1 = 101426.25 Pa; P2 = 101424.65 Pa; wind_speed = 1.76 mi/hr
Angle of Attack = -1 deg; P1 = 101431.38 Pa; P2 = 101424.64 Pa; wind_speed = 2.19 mi/hr
Angle of Attack = -4 deg; P1 = 101432.21 Pa; P2 = 101429.34 Pa; wind_speed = 1.88 mi/hr
Angle of Attack = -5 deg; P1 = 101431.38 Pa; P2 = 101426.77 Pa; wind_speed = 2.02 mi/hr
Angle of Attack = -5 deg; P1 = 101428.76 Pa; P2 = 101431.88 Pa; wind_speed = 1.25 mi/hr
Angle of Attack = -5 deg; P1 = 101432.21 Pa; P2 = 101430.60 Pa; wind_speed = 1.76 mi/hr
Angle of Attack = -5 deg; P1 = 101431.78 Pa; P2 = 101431.47 Pa; wind_speed = 1.64 mi/hr
Angle of Attack = -5 deg; P1 = 101428.74 Pa; P2 = 101433.17 Pa; wind_speed = 1.07 mi/hr
Angle of Attack = -5 deg; P1 = 101433.00 Pa; P2 = 101432.31 Pa; wind_speed = 1.68 mi/hr
Angle of Attack = -5 deg; P1 = 101425.30 Pa; P2 = 101426.78 Pa; wind_speed = 1.45 mi/hr
Angle of Attack = -5 deg; P1 = 101433.86 Pa; P2 = 101431.91 Pa; wind_speed = 1.80 mi/hr
Angle of Attack = -5 deg; P1 = 101430.83 Pa; P2 = 101431.47 Pa; wind_speed = 1.54 mi/hr
Angle of Attack = -10 deg; P1 = 101438.53 Pa; P2 = 101425.49 Pa; wind_speed = 2.62 mi/hr
Angle of Attack = -10 deg; P1 = 101438.52 Pa; P2 = 101434.47 Pa; wind_speed = 1.98 mi/hr
Angle of Attack = -10 deg; P1 = 101432.50 Pa; P2 = 101430.21 Pa; wind_speed = 1.83 mi/hr
Angle of Attack = -10 deg; P1 = 101437.19 Pa; P2 = 101433.64 Pa; wind_speed = 1.94 mi/hr
Angle of Attack = -10 deg; P1 = 101430.32 Pa; P2 = 101433.64 Pa; wind_speed = 1.23 mi/hr
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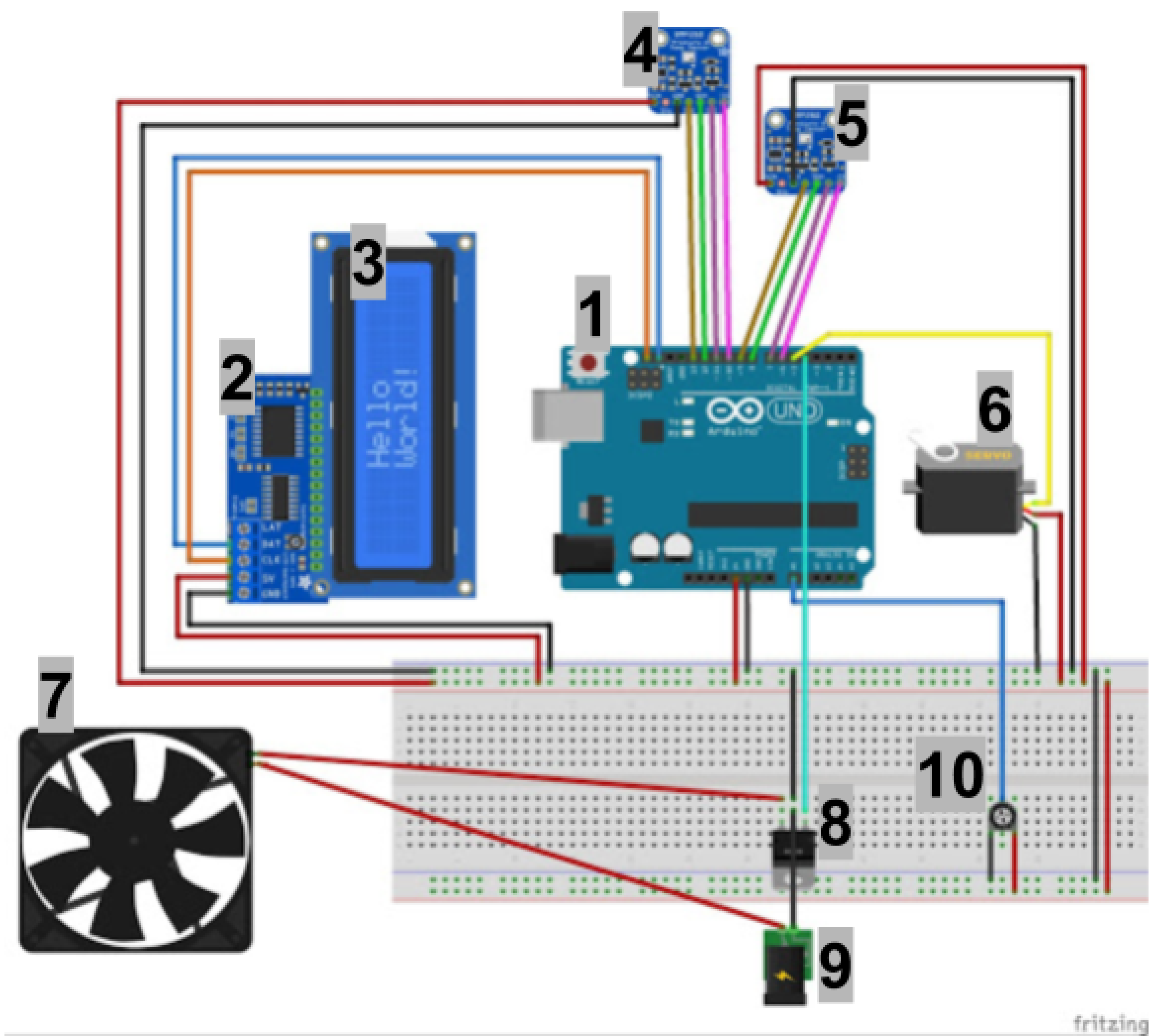
Parts List and Circuit Diagram with Annotations:

1. Arduino uno microcontroller: https://www.adafruit.com/product/50
2. i2c/SPI character LCD backpack: https://www.adafruit.com/product/292
3. Standard LCD 16x2: https://www.adafruit.com/product/181
4. Pressure sensor; BMP280: https://www.adafruit.com/product/2651
5. Pressure sensor; BMP280: see above
6. Micro servo: https://www.adafruit.com/product/169
7. Noctua computer fan; NF-P14s redux-1500 PWM: https://noctua.at/en/nf-p14s-redux-1500-pwm
8. N-channel MOSFET: https://www.adafruit.com/product/355
9. 12 V power supply with female adapter: https://www.adafruit.com/product/798, https://www.sparkfun.com/products/10288
10. Breadboard trim potentiometer: https://www.adafruit.com/product/356



Software:

The Arduino code used 4 libraries:

1. Adafruit sensor master library: https://github.com/adafruit/Adafruit_Sensor
2. SPI library and BMP280 library: https://github.com/adafruit/Adafruit_BMP280_Library
3. Servo library (already downloaded in Arduino IDE software): https://github.com/arduino-libraries/Servo
4. Adafruit Liquid Crystal library: https://github.com/adafruit/Adafruit_LiquidCrystal

Pins:

- SCL, SDA: LCD backpack and display
- Digital 13, 12, 11, 10: Pressure sensor 1, SPI
- Digital 9, 8, 7, 6: Pressure sensor 2, SPI
- Digital 5: Servo
- Digital 4: When the microcontroller is on, pin sends HIGH signal to MOSFET, which then sends 12V power to fan
- A0: potentiometer position

User input: potentiometer knob position

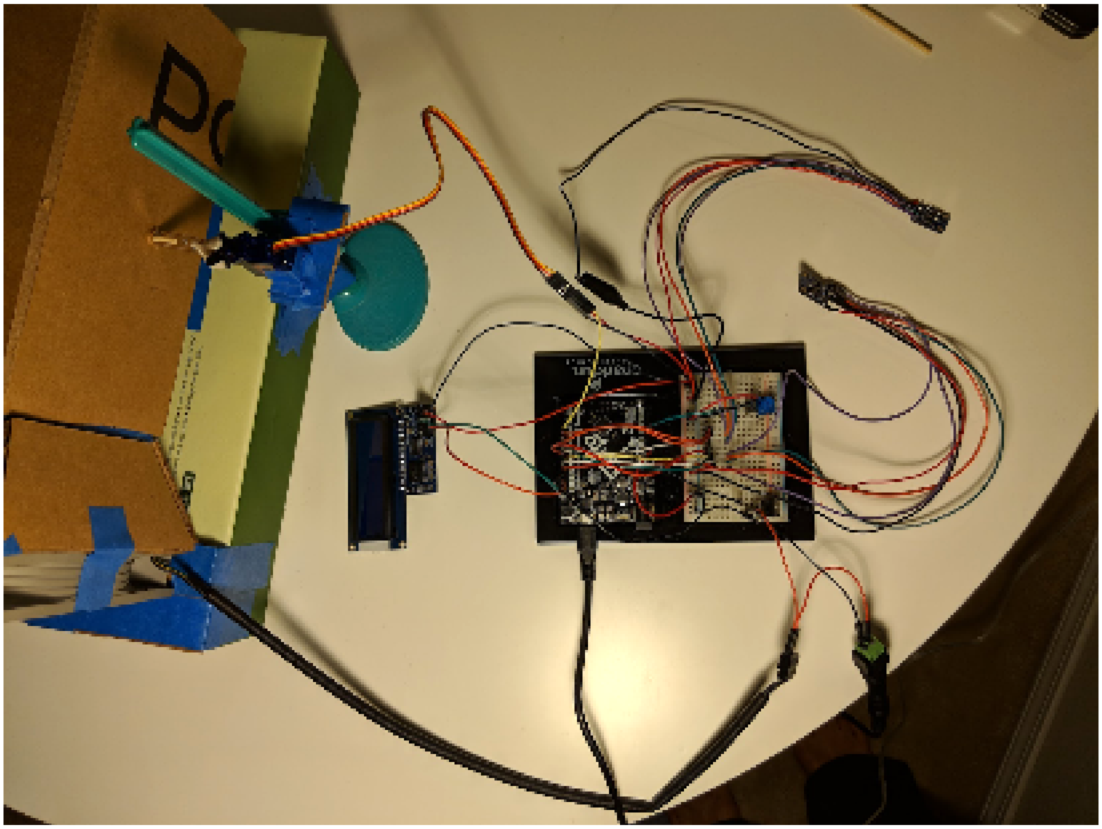
System output: fan turns on, airplane pitch, LCD display: angle of attack and wind speed at P2

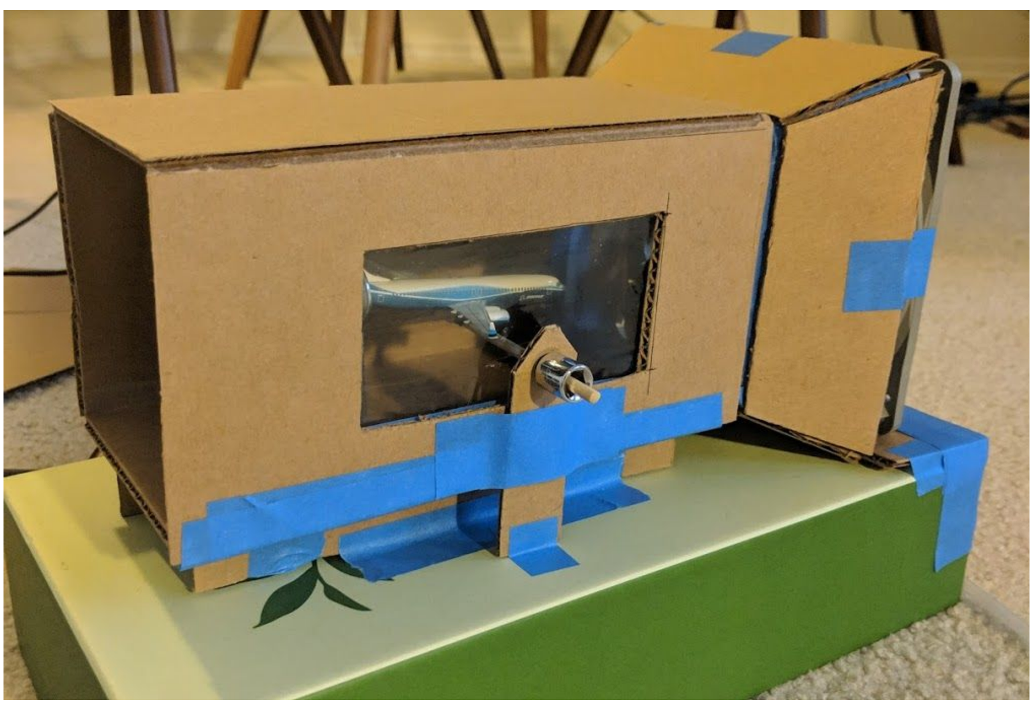
Process:

Overall, my project achieves my original goal of demonstrating wind tunnel concepts. I was able to use a pressure differential from two pressure sensors, and simplified calculations of Bernoulli's equation to compute wind speed behind the model airplane. I wanted to play with PWM of the fan, but I ran out of time. Had I had more time and money to implement a secondary phase of this project, I would use more accurate/sensitive pressure sensors, fabricate a wind duct with fiberglass, and use a more powerful fan capable of higher wind speeds.

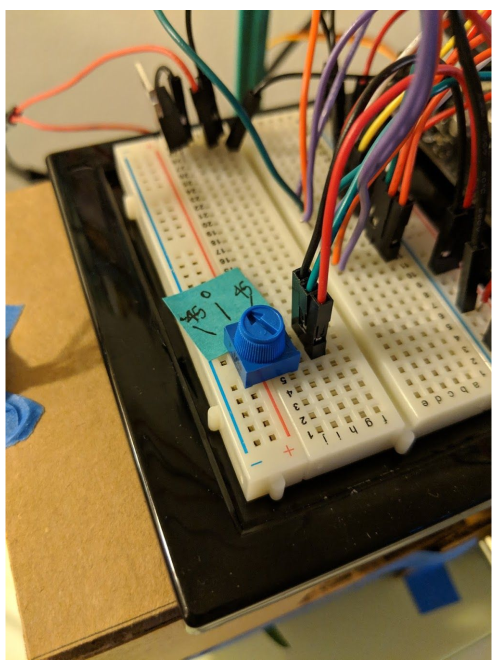
Photo gallery:

Hardware components (top) and cardboard construction with blue tape and superglue (below):





12V Power Supply (top) and potentiometer knob which I had to do some adjusting to find which one kept the airplane at actual angle of attack (below)



Hardware components on top of wind duct, and 12V power source plugged into wall (top) and final system turned on (below):