Redesigning Wind Tunnel for Lift and Drag Measurements on Airfoils

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Abstract

A suction wind tunnel was constructed with no contraction cone and a bounce house blower which sucked air through the tunnel. The wind tunnel was used to measure the lift and drag coefficients of the NACA 4424 airfoil using the Adafruit ADXL345 accelerometer. First, as a proof-of-concept experiment, a hanger was hung vertically from a spring and oscillated, and then the same experiment was done except with a piece of paper on the hanger creating drag force. The drag force induced from the paper was then deduced. The NACA 4424 airfoil was then 3D printed and tested in the tunnel at 100% power, 95% power, 90% power, 85% power, and 80% power. The values recorded were very inaccurate for the drag coefficient, with values of 0.00012 for 100% voltage, $-4.4*10^{-5}$ for 95% voltage, -0.00024 for 90% voltage, $9.3*10^{-6}$ for 85% voltage, and -0.00019 for 80% voltage, with a percent discrepancy of 100% for all drag coefficients. The lift coefficients were 0.012 at 100% with a discrepancy of 28.7%, 0.015 at 95% with a discrepancy of 12.5%, 0.020 at 90% with a discrepancy of 14.5%, 0.021 at 85% with a discrepancy of 18.8%, and 0.043 at 80% with a discrepancy of 148%. The error most likely came from the fluctuation in the readings from the accelerometer.

Introduction

Fluids are defined in physics as a material that when shear stress is applied, deforms without returning to its previous form (Britannica, n.d.). Wind tunnels are used for testing the aerodynamic capabilities of an object. Air is either sucked or blown through the tunnel. The test chamber of a wind tunnel is where the object being tested is placed. This area is generally straight, and the area of the chamber does not change. Contraction cones are also an important part of many wind tunnels. Contraction is used in wind tunnels to speed up airflow and to make the airflow more uniform (Abdelhamed, Yassen, & ElSakka, 2015). Airfoils are the cross-sectional of a wing or other part of an aircraft. Airfoils are supposed to have a high lift to drag ratio. The lift force is vertical, and the drag force is horizontal (Krishna, Thanigaivelan, John, & Joshua, 2021). The goal during the summer of 2021 was to build a wind tunnel and use an accelerometer and a magnetometer to measure lift and drag coefficients.

Any airfoil has a drag and lift coefficient. The drag coefficient of an airfoil is defined as

$$C_D = \frac{Drag\ Force}{\frac{1}{2}\rho V^2 A} \qquad [1]$$

C_D is the drag coefficient, ρ is the density of the fluid, V is velocity, and A is the area of the airfoil. The coefficient of lift is

$$C_L = \frac{Lift\ Force}{\frac{1}{2}\rho V^2 A} \qquad [2]$$

where C_L is the lift coefficient (Samy, Kumaran, Uthayakumar, Sivasubramanian, & Sankar, 2019). .

Experimental Methods

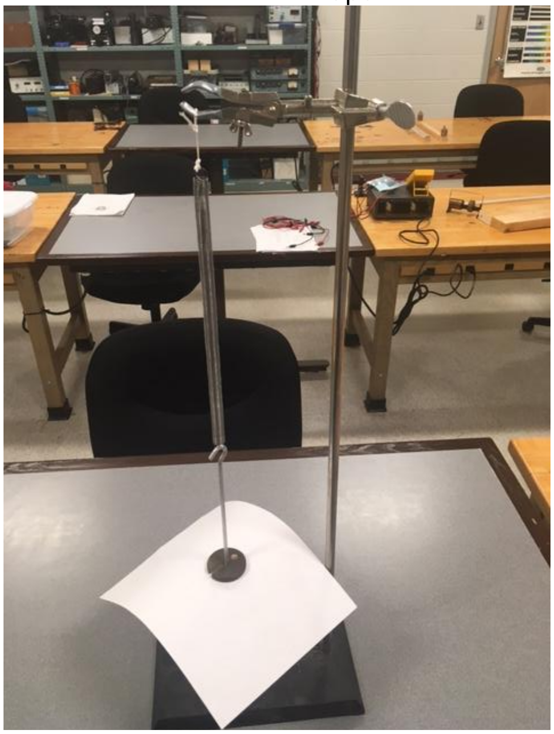
As a proof of concept for measuring drag an experiment by LoPresto and Holody was performed. A 0.2 kg weight was put on a 50 kg holder. The holder was attached to a spring, which was hung from a ring stand. The spring was oscillated, and the acceleration was measured with an accelerometer. Then the same experiment was performed, except there was a piece of paper on the holder to increase the drag. Then the values were entered and plotted in Mathematica with time on the x-axis and acceleration on the y-axis. The data sets with paper and without paper were each had their own graphs. The functions for acceleration were determined and plotted using the FindFit and the fitTrue functions. The acceleration functions were integrated twice to find the functions for position, and these functions were graphed. Two local maxima were found with the FindMaximum function, and these two values were plugged into the equation

$$b = \frac{2m}{T} ln\ ln\ \frac{x_1}{x_2} \qquad [3]$$

where b is the damping constant, m is mass, T is period of oscillation, and $x_1$and x_2 are the position values found with FindMaximum (LoPresto & Holody, 2003). The values found for b were 0.0567 without the paper, and 0.162 with the paper.

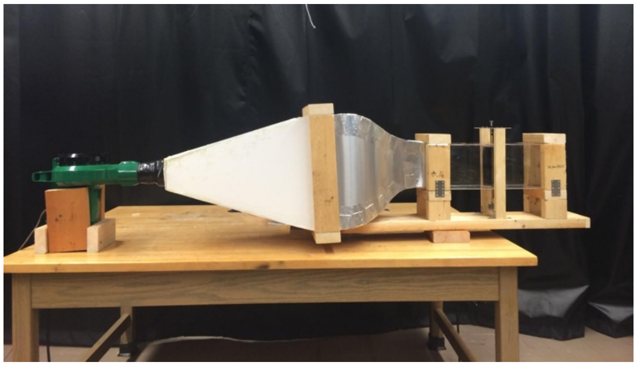
Without Paper:

With Paper:



The wind tunnel made by Branch Vincent was reworked before testing could be done. Originally, the intent was to create a wind tunnel with the same contraction cone as Kao, Jiang, and Fang, but instead a simpler wind tunnel with just a test chamber connected to a bounce house blower (Kao, Jiang, & Fang, 2017). The contraction cone was scrapped because it would have been too hard to build in the summer. Also, it was decided that a contraction cone was not needed. The opening in the bounce house blower was as big as the test chamber, and so the tunnel would have widened just to contract again. The wind speed was acceptable for the tests, and the wind was laminar enough, so the contraction cone was not needed to make the wind laminar. One other difference in this wind tunnel is that its cross-section is circular, not rectangular. Circular wind tunnels are more laminar than rectangular ones. Rectangular wind tunnels have different wind speeds on the corners (Kao, Jiang, & Fang, 2017). Another difference from the original wind tunnel is that the new one sucks air through the wind tunnel instead of blowing air out. The blower from the bounce house blower did not give a laminar airflow. One edge of airflow blew air much faster than the rest of the airflow. The suction part of the blower has a much more laminar airflow. It is not a perfectly laminar airflow, as the edges of the airflow was faster than the center, but it was much more laminar than the blower part. The suction part had a plastic netting barrier blocking the suction, so it was cut off and then filed and sanded to smooth the air hole out.

The Old Wind Tunnel:



The Redesigned Wind Tunnel:

The airfoil tested over the summer was NACA 4424. 4424 was chosen because it was a standard airfoil with known values for lift and drag coefficients. The airfoil was found on airfoiltools.com and was plotted using the airfoil plotter on airfoiltools.com. The airfoil length was set to be 5 centimeters, and then the airfoil was imported to tinkercad. Once in tinkercad, the width of the airfoil was increased to 5 centimeters. The tinkercad file was exported to a SD card and printed from a 3-D printer. The airfoil had a hole drilled through the side of it, and a thin metal rod was stuck through it out the other side of the airfoil and glued to the airfoil. The airfoil was put inside the wind tunnel through a hinge that was put in the top of the airfoil. The metal rod was put through two holes on each side of the wind tunnel.

The airfoil was tested at 100%, 95%, 90%, 85%, and 80% maximum voltage. The method used to measure lift and drag was to use an accelerometer to measure the acceleration. The accelerometer was the Adafruit ADXL 345. It has three axes that it can measure the acceleration. The sensitivity of the accelerometer can be set to four settings ranging from ±2g to ±16g (Earl, ADXL345 Digital Accelerometer Overview, 2013). The accelerometer was calibrated using gravity, knowing that the acceleration due to gravity at the Earth's surface is 9.81 $\frac{m}{s^2}$. The accelerometer was placed on a block shaped item and recorded the values of Earth's gravity for each axis. (Earl, ADXL345 Digital Accelerometer Programming and Calibration, 2013). The values were then used in a two point calibration to calibrate the accelerometer (Earl, Calibrating Sensors Two Point Calibration, 2015). The accelerometer was placed on the end of the airfoil, as at the end the airfoil would not affect the lift and drag as much as if it were more towards the front of the airfoil. The presumption was that the air flowing over the airfoil would be mostly directed over the accelerometer by the front of the airfoil. The wind speed was not measured with an anemometer, but with a pressure sensor. The anemometer on hand was too big to easily fit into the wind tunnel and it was broken. The pressure sensor was used to measure the pressure difference between the atmosphere and inside the test chamber with the wind blowing. The pressure difference was used to find velocity using Bernoulli's Equation, which is

$$p + \frac{1}{2}\rho v^2 + \rho g h = constant \qquad [4]$$

where p is pressure, ρ is density, v is velocity, g is acceleration due to gravity, and h is height. The Bernoulli Equation for one dimensional motion of a fluid perpendicular to the force of gravity can be written

$$p_1 - p_2 = \frac{1}{2}\rho(v_2^2 - v_1^2) \qquad [5]$$

Knowing that the air in the atmosphere is still, the velocity of the air at room temperature is

$$v = \sqrt{\frac{2(p_1 - p_2)}{\rho}} \qquad [6]$$

(Bernoulli's Equation, n.d.). All tests were measured at an angle of attack of 0°.

The other method that was thought of but not used was to use a magnetometer to measure the force generated by the wind. The magnetometer was a clear plastic tube with two magnets inside. One magnet would have been placed at the bottom of the tube, and the other magnet would have been floating a couple of inches over the other magnet because of the magnetic force. The floating magnet had a metal rod sitting on top of it. The airfoil would have been attached to the rod. The idea was that when the wind blew over the airfoil, the force on the rod and magnets would change, and the magnetic field strength would change, and from the magnetic field change find the force generated by the wind. The reason this message was not utilized was that for the drag the magnetometer would have blocked airflow. The reason the magnetometer was not used for the lift was because the lift was not large enough to generate a change in magnetic force.

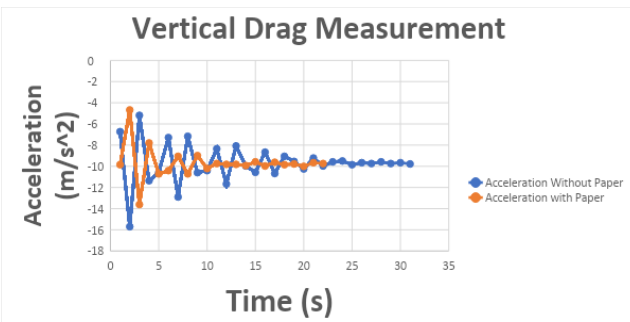
Data

Data for vertical drag test:

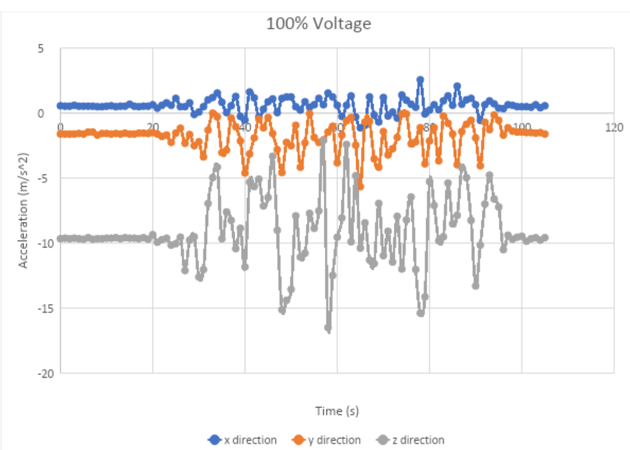
	Without Paper	With Paper
Mass (kg)	0.25	0.25
Period (sec)	2.53	6.3
Distance 1 (m)	0.902	0.466
Distance 2 (m)	0.677	0.0603
b	0.056708152	0.162289963

B is the calculated drag coefficient.

Graph for the vertical drag test:

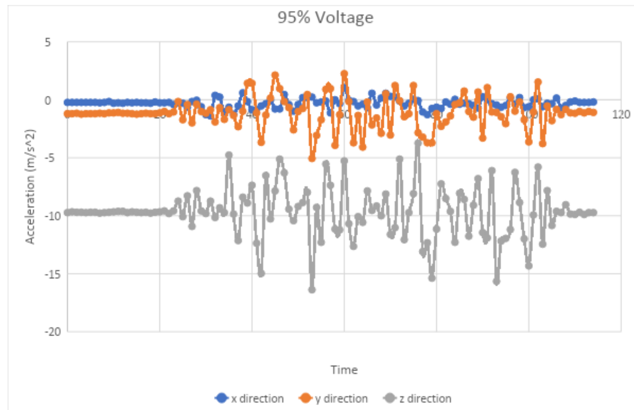


Graph and data for the measurements for NACA airfoil 4424 at 100% Voltage:



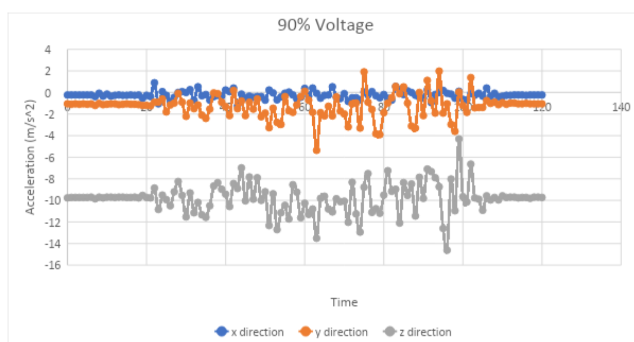
Drag Coefficient	0.000196
Drag % Discrepancy	99.92233
Lift Coefficient	0.012401
Lift % Discrepancy	28.72937

Graph and data for the measurements for NACA airfoil 4424 at 95% Voltage:



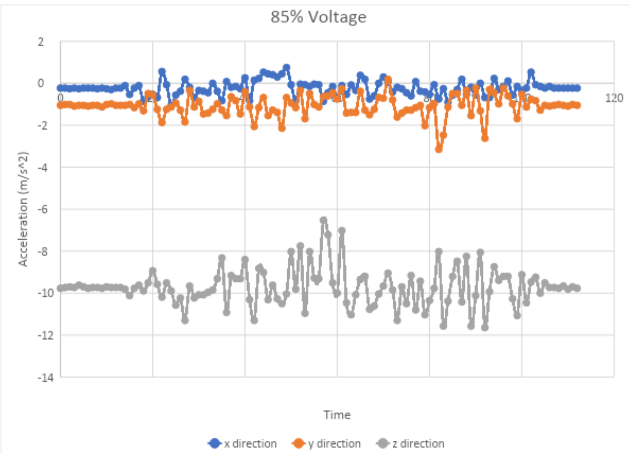
Drag Coefficient	-4.4E-05
Drag % Discrepancy	100.0175
Lift Coefficient	0.015218
Lift % Discrepancy	12.53918

Graph and data for the measurements for NACA airfoil 4424 at 90% Voltage:



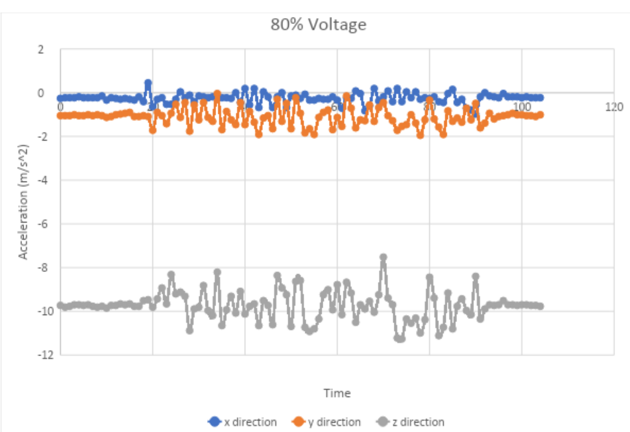
Drag Coefficient	-0.00024
Drag % Discrepancy	100.095
Lift Coefficient	0.019919
Lift % Discrepancy	14.47595

Graph and data for the measurements for NACA airfoil 4424 at 85% Voltage:



Drag Coefficient	9.27E-06
Drag % Discrepancy	99.9963
Lift Coefficient	0.020674
Lift % Discrepancy	18.8189

Graph and data for the measurements for NACA airfoil 4424 at 80% Voltage:



Drag Coefficient	-0.00019
Drag % Discrepancy	100.0751
Lift Coefficient	0.043182
Lift % Discrepancy	148.1734

Discussion

The results obtained were not particularly accurate. The values obtained for the drag and lift coefficients were compared to existing computational calculations for NACA 4424 done by Pattanashetti, Mahadeva, Suresha C N. Their simulation was like the experiment done here in that the simulation was done at room temperature and 1 atm (Pattanashetti, Mahadeva, & C N, 2020). The percent discrepancy between their values and the values listed here for the drag coefficient are 99.9% for 100% voltage, 100% for 95% voltage, 100% for 90% voltage, 100% for 85% voltage, and 100% for 80% voltage. For the lift, the discrepancy was 28.7% for 100% voltage, 12.5% for 95% voltage, 14.5% for 90% voltage, 18.8% for 85% voltage, and 148% for 80% voltage. The lift values were far more accurate for the lift than the drag, except for at 80% voltage.

The main factor in the error in the data is the accelerometer's imprecise measurement. The accelerometer was set to ±2g, but even still the acceleration recorded varied wildly, when the values should have been far more stable. Because of this, the ADXL345 is not a good way to measure acceleration in a subsonic wind tunnel. Another factor that probably contributed to the error was the angle of the accelerometer. Since the airfoil is not flat, the calculation had to be corrected for the angle of the accelerometer. This was done by plotting the airfoil and then finding the trendline for the back end of the airfoil, where the accelerometer was. However, the airfoil was eyeballed at a 0° angle of attack. If the airfoil was at an angle of attack that was not zero, then the results would have been effective. Another possible error was that the airflow was not perfectly laminar. The velocity of wind in the center of the test chamber was somewhat less than on the edges. The airfoil and the pressure sensor were both placed in the center, but they both certainly had slightly different wind speeds over them.

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