Aerodynamics Lab A3- Determining the Lift and Drag Coefficients of a 2D Airfoil

AERSP 305W- Aerospace Technology Laboratory Section A6

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Abstract

The aim of this laboratory is to study the wake velocity profile and determine the lift and drag coefficients of an S805 two-dimensional airfoil at different angles of attack. A comparison will be conducted between the lift and drag coefficients determined in this experiment and previously collected data by the National Renewable Energy Laboratory (NREL) from the same airfoil. The data was collected using a pitot static tube and a hot wire for accuracy.

Introduction

The motivation of this lab is to study the wake velocity profile and determine the lift and drag coefficient of an S805 airfoil at 750,000 Reynolds number. We expect that the experimental data collected from this lab will be similar to the data collected by NREL.

The Wind Tunnel used for this experiment is a closed-circuit design. It contains a nozzle that accelerates the flow and a diffuser that decreases the flow. Figure 1 shows a diagram of the Wind Tunnel, the direction of the flow traveling through it, and the test section for this lab.

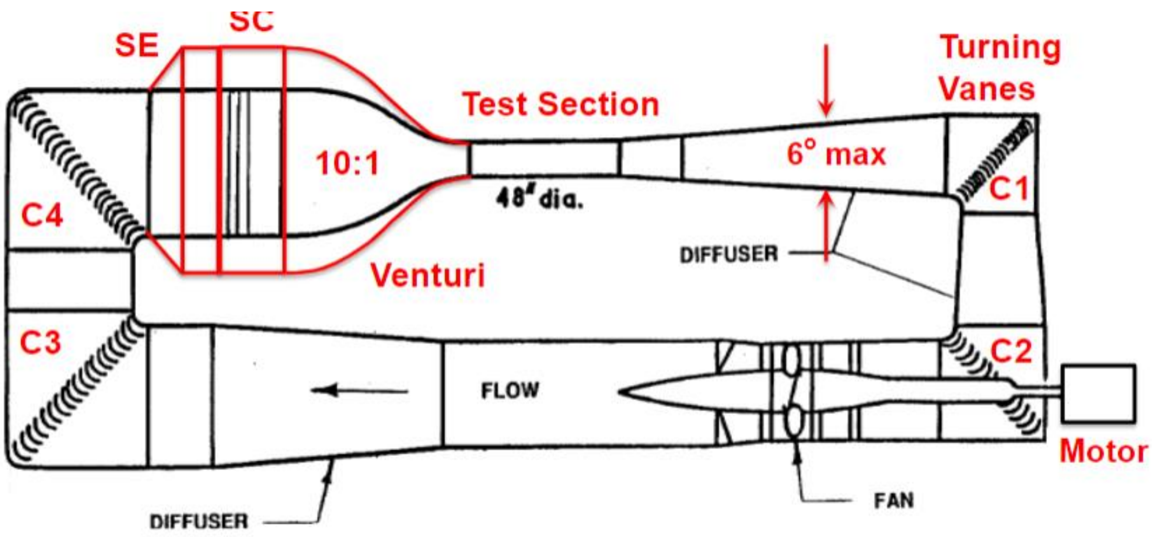

Figure 1. Diagram of the Wind Tunnel

The airfoil used in this lab was an S805 designed in 1988 by Dan Somers to be used in wind energy. This airfoil has 97 pressure taps all over its surface as shown in Figure 2. For this lab only 34 were used, 17 on top and 17 on the bottom. These pressure taps were then connected to a Manometer Bank (Figure 3), which has 36 tubes that can show pressure at each pressure tap on the airfoil.

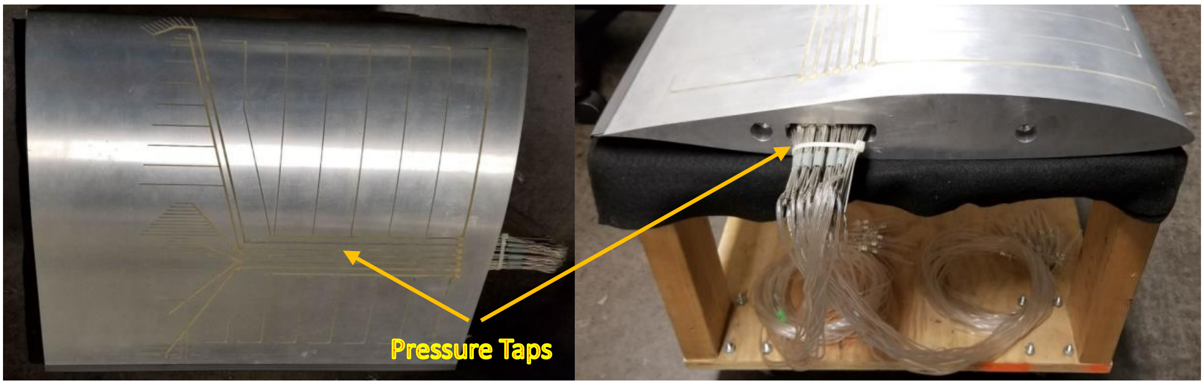

Figure 2. S805 Airfoil with pressure taps

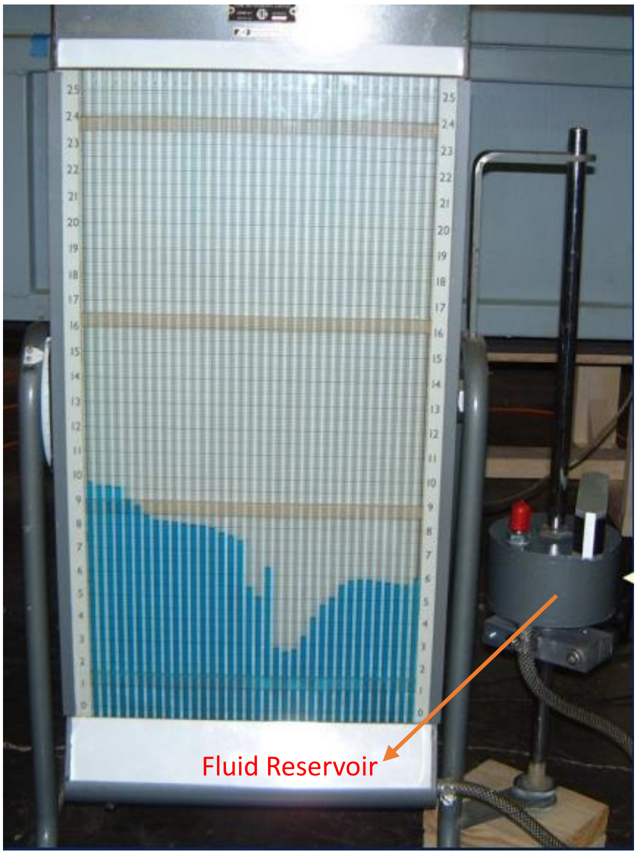

Figure 3. Manometer Bank

For 2D wake measurement, we used a hot wire anemometer (Figure 4) and a 1/16” pitot-static probe (Figure 5) connected to a pressure transducer (Figure 6), which were downstream from the airfoil mounted on a long metal sting attached to motorized traverse, which will be used to systematically move this sting through the wake of the airfoil while a LabVIEW records the voltages from the hot-wire anemometer and the pressure transducer.

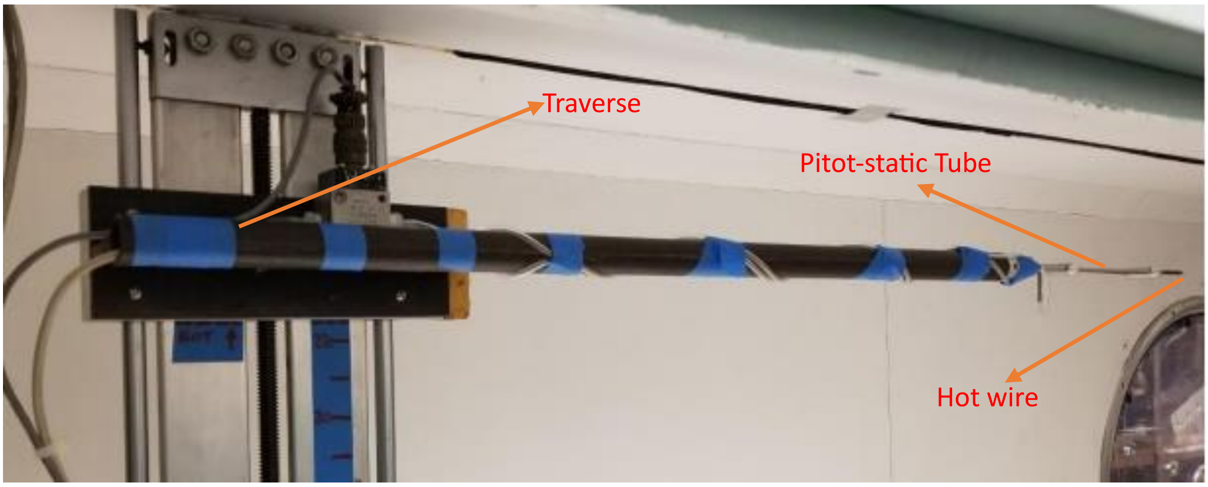

Figure 4. Hot wire anemometer and Pitot-static tube attached to the Traverse

Figure 5. Pitot Static Tube

Figure 6. Pressure Transducer

To calculate the lift and drag coefficient on a 2D airfoil, we need to know the density of the air *(ρ)*, the velocity of air inside the wind tunnel (v), the chord length of the airfoil (c), and the pressure on the airfoil. For the lift coefficient we use the pressure (l) we get from pressure taps on the airfoil. For the drag coefficient, we use the pressure (d) from wake data which we get from the LabVIEW DAQ. So:

Lift coefficient:

$$c_l = \frac{2l}{\rho v^2 c} \tag{1}$$

Drag coefficient:

$$c_d = \frac{2d}{\rho v^2 c} \tag{2}$$

Using equations 1 and 2 we can calculate the lift and drag coefficients of S805 airfoil at 750,00 Reynolds Number. To get this Reynolds Number (Re) the following equation was used:

$$Re = \frac{\rho U c}{\mu} \tag{3}$$

Where U is velocity, c is chord length of the airfoil and μ is viscosity.

Procedure

The equipment used to complete this experiment was the wind tunnel, thermometer, barometer, manometer bank, S805 airfoil, pump, power box, speed adjusts dial, pitot-static probe, LabView DAQ, hot wire anemometer, and pressure transducer. A wind tunnel is a large tube that contains a powerful fan used to move air through the tube. Figure 7 shows the test section area of the wind tunnel used for this lab. A barometer is a scientific instrument that is used to measure the air pressure in an environment. A thermometer is a device used to measure the temperature in an environment. For the lab, the value from the digital thermometer and barometer was used to determine density using the ideal gas law. We also used these values to determine the velocity needed to achieve 750,00 Reynolds number using equation 3. Using the experiment results from lab A2:

$$c = 19.7 \text{ inches} \tag{4}$$

$$\mu = 3.8 \times 10^{-7} \text{ slugs/ (ft sec)} \tag{5}$$

$$\rho = 0.0023 \text{ slugs/ ft}^3 \tag{6}$$

$$\text{Pressure Transducer Calibration constant} = 2.788 \tag{7}$$

we slowly increase the speed of the wind tunnel, using the speed adjust dial, to the velocity that corresponds to this Reynolds Number.

Now we set the airfoil to the angle of attack assigned to our lab section, which was 10 and -9 degrees as shown in Figure 8. Then Manometer bank was angled which provided the best resolution of data without spilling any liquid into the airfoil's pressure tubes. While we recorded the manometer data, the LabView DAQ used the traverse to measure the hot wire and pitot-static wake survey. These steps were repeated for the -9-degree angle of attack.

Figure 7. Test section of Wind Tunnel

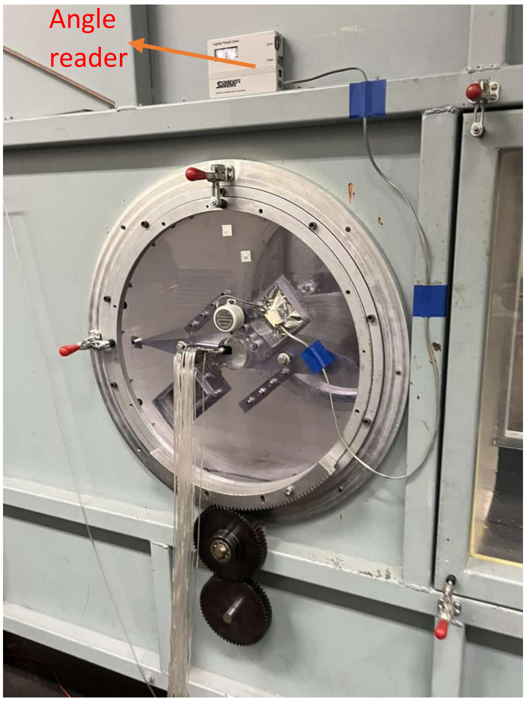

Figure 8. 2D Airfoil Experiment Setup

Results and Discussion

Calculating Lift coefficient

Below is the Pressure coefficient data, represented in Figures 9 and 10, collected over different pressure taps on the airfoil. This data was collected from the Manometer Bank and was processed from inches of water to pressure coefficients.

In Figure 9, the data is for the angle of attack of 10 degrees, and for the upper surface, there is a spike in the value of the pressure coefficient starting at a lower value than the lower surface and gradually increasing compared to the pressure coefficient values for the lower surface. This is because the value of the angle of attack is positive which makes the airfoil produce a positive lift.

In Figure 10, the data is for the angle of attack of -9 degrees, and it shows that the pressure coefficient for the upper surface starts at a higher value compared to the lower surface and decreases exponentially compared to the pressure coefficient for the lower surface. This is because the angle of attack is negative which makes the airfoil produce a negative lift.

These Pressure coefficients were then used to find the Lift coefficients for different values of the angle of attack. For our lab section, we were assigned angles of attack of 10 degrees and -9 degrees. The data from different sections were then processed and the lift coefficient for other values of the angle of attack was plotted in Figure 11.

In Figure 11, the data of pressure coefficient versus the angle of attack was compared with the data acquired by NREL for a 750,000 Reynolds number. We can see that the data from both are very similar to each other.

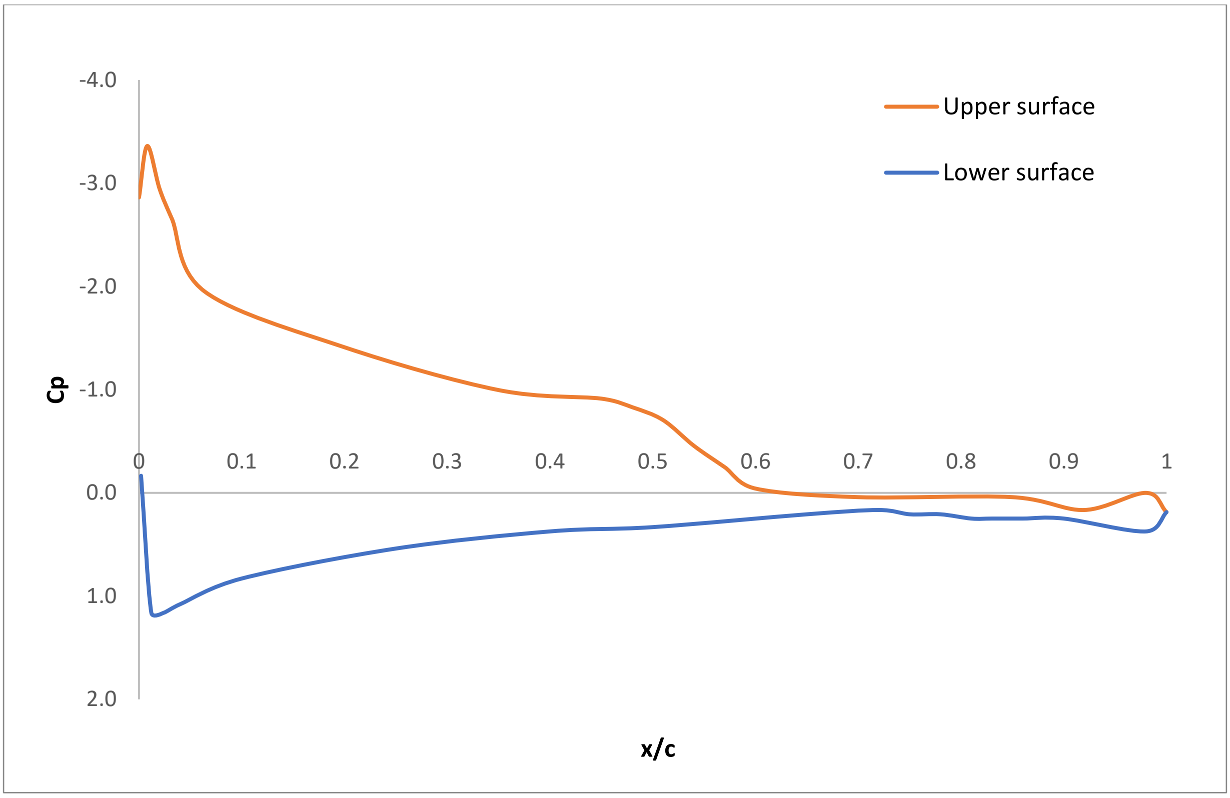

Figure 9. Graph of Pressure coefficient versus x/c for alpha at 10 degree

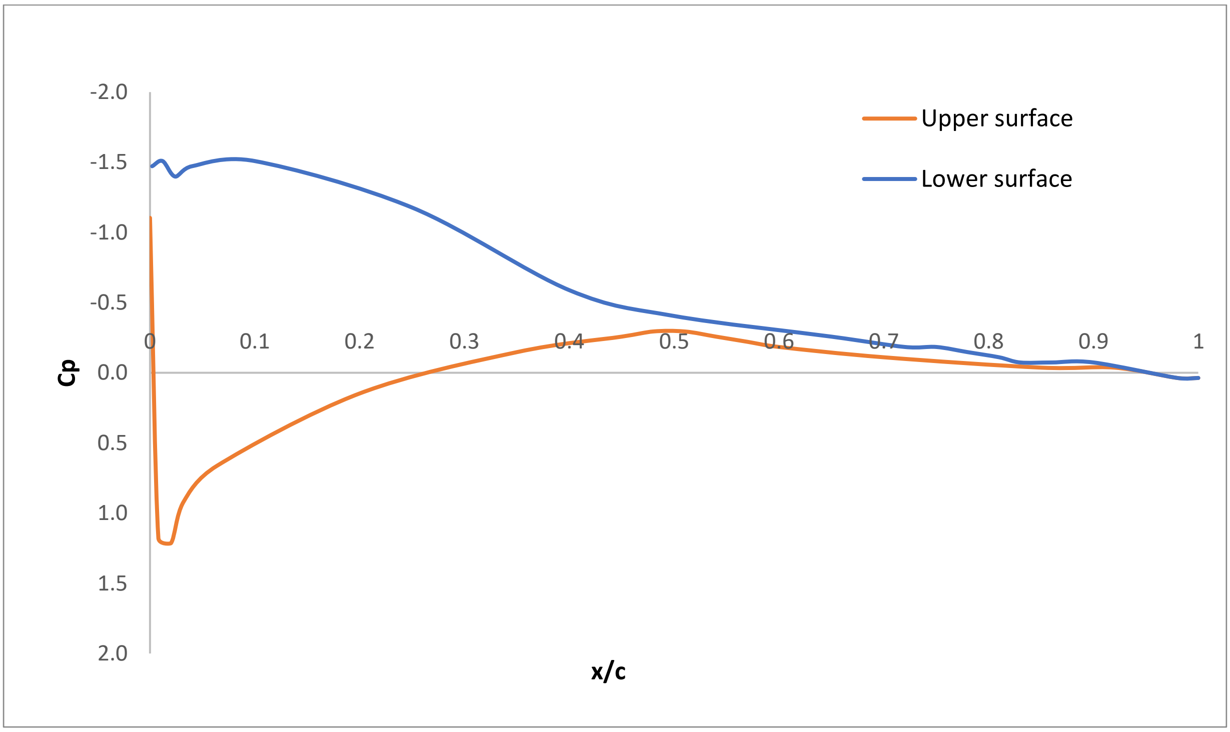

Figure 10. Graph of Pressure coefficient versus x/c for alpha at -9 degree

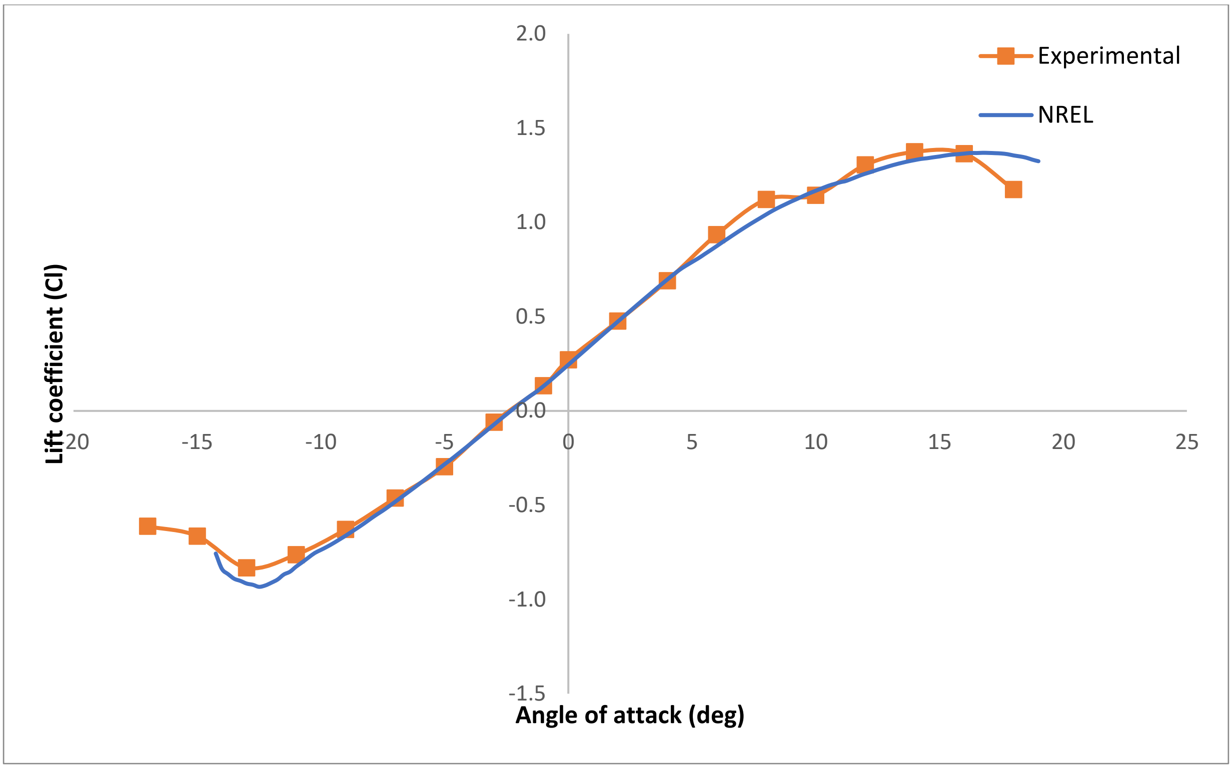

Figure 11. Graph of Lift coefficient versus angle of attack

Calculating Drag coefficient

To study the wake velocity profile and to find the drag coefficient, the data was collected using LabVIEW DAQ and the instrument used were a hot wire anemometer and a pitot static tube. The traverse moved the instrument systematically to get data for different positions. These data were converted from volts to their respective units using the pressure transducer constant.

In Figure 12(a), the data is position versus velocity for the angle of attack of 10 degrees. The data from the pitot static tube and the hot wire anemometer are almost similar to each other, as these instruments were next to each other inside the wind tunnel. There is some difference of around 10 inches, right where the airfoil is, this is because of the way these instruments read the data. In Figure 12(b), the data is position versus velocity for the angle of attack of -9 degrees, the values less similar to each other around 10 inches. This is again due to the way hotwire and pitot static tube reads the data.

We processed the pitot static data into dynamic pressure and then using Simpson's rule, the drag coefficient was recorded in Table 1. For the data recorded by a hot wire, we use the area of the bulge in Figure 12 to calculate the drag coefficient and recorded it in Table 1. We can see the value of the drag coefficient for the hot wire data doesn't follow the usual trend for the smaller angle of attack values and so to compare the drag coefficient with the NREL data we use Pitot static tube data.

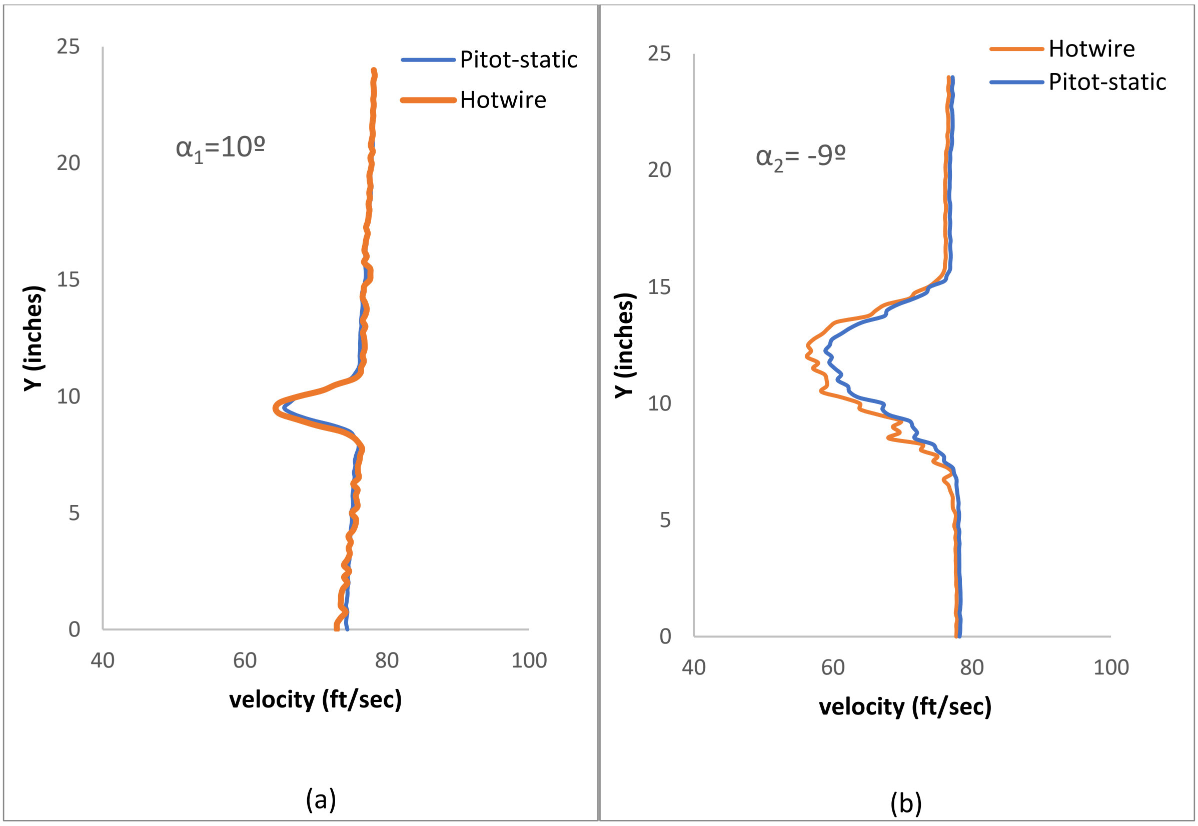

Figure 12. Graph of Wake Velocity versus Position for α_1 and α_2

Table 1. Drag coefficient from Hot-wire (H.W) and Pitot static tube (P-S)

Alpha (deg)	C_d			Alpha (deg)	C_d		
	H.W	P-S	% diff		H.W	P-S	% diff
-17	0.240	0.226	6.26	2	0.010	0.008	24.4
-15	0.225	0.217	3.82	4	0.008	0.008	6.85
-13	0.208	0.185	12.3	6	0.013	0.009	41.9
-11	0.155	0.134	15.6	8	0.016	0.013	23.2
-9	0.103	0.089	15.2	10	0.021	0.017	21.5
-7	0.046	0.041	11.8	12	0.058	0.052	12.8
-5	0.014	0.014	0.697	14	0.094	0.083	12.5
-3	0.011	0.011	5.04	16	0.141	0.136	3.22
-1	0.008	0.007	10.4	18	0.207	0.207	0.03

In Figure 13, we can see that the experimental drag coefficients for angles of attack between -5 degrees to 10 degrees match NREL's drag coefficients. The values of the angle of attack do not match because of turbulence generated by the airfoil and depending on the size of the test section the NREL's data used, they differ from our experimental data.

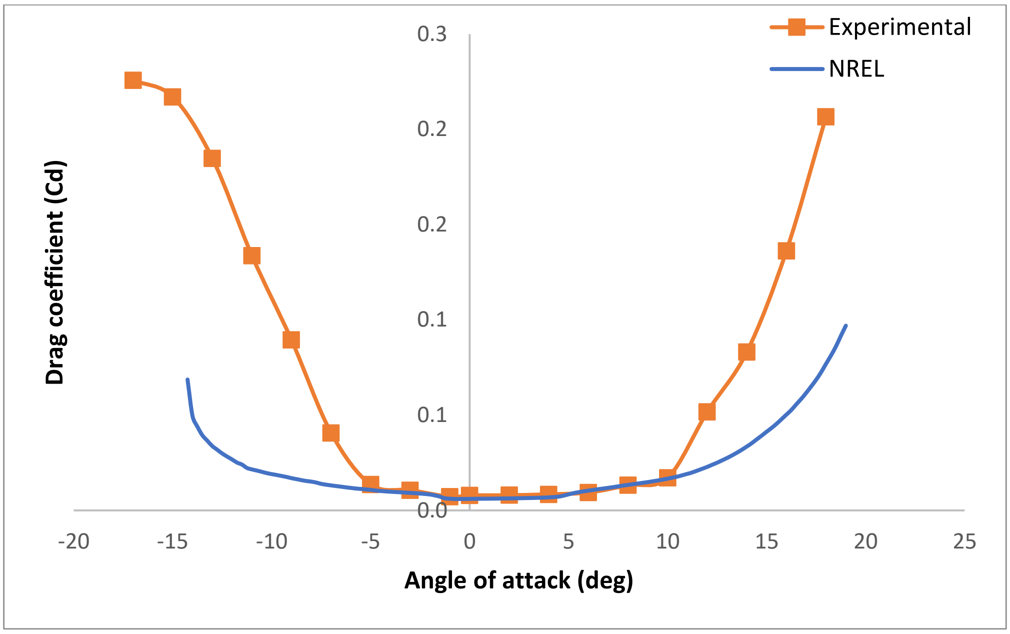

Figure 13. Graph of Drag coefficient versus angle of attack

In Figure 14, the lift coefficient is plotted against the drag coefficient (P-S) and is compared with NREL's data. The experimental values for the drag coefficient from 0 to 0.01 are similar to NREL's values. Values beyond that aren't similar because of turbulence generated by airfoil at those angles of attack. In Figure 15, the graph is zoomed over the drag coefficient from 0 to 0.05. This shows how the lift coefficient changes from positive to negative to the drag coefficient.

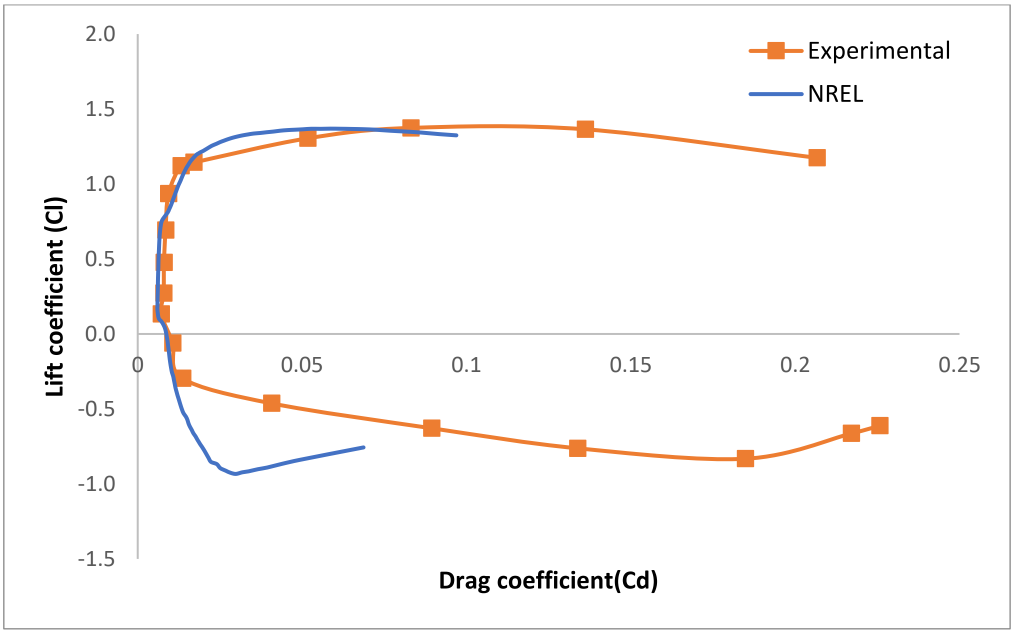

Figure 14. Graph of Lift coefficient versus Drag coefficient

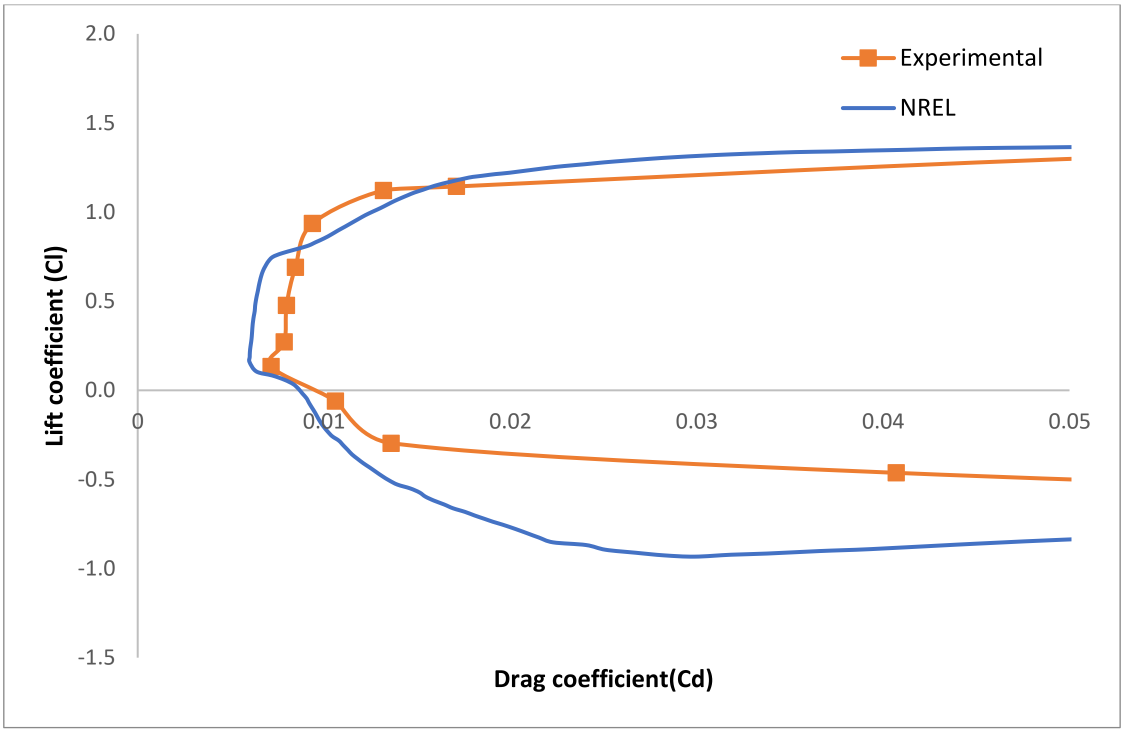

Figure 15. Graph of Lift coefficient versus Drag coefficient (zoomed)

Conclusion

In summary, the goal of this lab was to examine the wake velocity profile and obtain lift and drag coefficients for the S805 airfoil using a hotwire anemometer, pitot-static tube, and manometer bank. The objective was successfully achieved. Wake velocity was calculated using equations and measurements from the pitot-static tube and hotwire anemometer. This data allowed us to determine the drag coefficient. To find the lift coefficient, we used the manometer bank to measure the pressure distribution around the airfoil via pressure taps. The resulting drag and lift coefficients were compared to NREL's values to assess the discrepancy between our experimental outcomes and theirs.

One challenge encountered during this experiment was setting the correct angle of attack for our airfoil section. Our method for adjusting the angle of attack was not precise enough, preventing us from making small, accurate changes. To address this issue, we could implement a motor to rotate the airfoil, similar to the one used in the traverse.