AE 3610, Lab #02

It’s Mind-Blowing the Pressure We’re Under

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Group A11

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Introduction

Wind tunnels are important because they allow us to gather data from airfoils without needing to create an entire aircraft. For this experiment, because it is conducted in a wind tunnel, we were able to attach pressure-sensing probes along the upper and lower sides of an airfoil as well as in the wake of the airfoil. In the wind tunnel, we are also able to use an airfoil that simulates an "infinite" airfoil, which means we do not have to take into account effects of a three-dimensional flow. For this lab, Team A11 measured surface pressure distribution along a symmetric airfoil. We also conducted a survey of both the boundary layer of the wind tunnel floor itself and the wake behind the mounted airfoil specimen in the wind tunnel.

Data Results

Raw Data

Pressure Data

Figure 1 displays a schematic of all the connections and interfaces of the pressure sensors used to collect data in this lab. The team used the various types of pressure data gathered by the Scanivalve, Baratron, and FlowKinetics to characterize local airspeed.

Wind Tunnel Characterization

The first thing the team did was to characterize the airspeed of the wind tunnel using the Baratron and FlowKinetics. We brought the wind tunnel up to max speed and slowly turned down the dial, gathering data. (Figure 4) The Baratron received pressure data from the ceiling probe and transverse probe and converted it to voltage, transmitting the voltage to the NIDAQ, which was then captured by the computer interface. FlowKinetics Data was on a separate system, using its own port and only served as a "reality check" for the team as we conducted our experiments.

The FlowKinetics information in Figure 4 was collected by manually recording visual data from the FlowKinetics box while turning the dial to control the wind tunnel. The wind tunnel's maximum speed was about 16.5 m/s according to the Baratron and 15.9 m/s according to the FlowKinetics.

Surface Pressure Distribution

One experiment was performed to collect pressure distribution data along the airfoil at various angles of attack. Figures 1 and 2 show the connections to the 2 Scanivalve boxes from the ceiling static tap and the ports along the airfoil and from the Scanivalve boxes to the computer, where information was collected using Scanivalve software. Team A11 first determined how the angle of attack effected the software's live data collection, and used the visual feedback to decide on which angles of attack to choose for data collection. We chose 0 degrees, 8 degrees, 12 degrees, and 16 degrees. We measured data for 10 seconds at the wind tunnel's maximum speed setting to get a clear picture of what data is relevant. Figures 5, 6, and 7 show the reduced data from this experiment.

Boundary Layer Survey

A traversing probe, which is a probe attached to a stepper motor, was utilized to constantly take data from the bottom of the wind tunnel floor to 4 inches from the bottom.

Wake Survey

The same traversing probe from the Boundary Layer Survey was also utilized to measure air pressure "behind" the mounted airfoil. Figures 9 and 10 show the characteristics of the airspeed downwind of the airfoil sample. The airfoil was mounted at a slight angle of attack (around 4 degrees) to produce a wake.

Reduced Data

Wind Tunnel Speed Characterization

Figure 4 shows a chart of the wind tunnel speed corresponding to its control settings. Airspeed data was taken by the Baratron and converted to mmHg using the Baratron's stated conversion factor:

$$1.016 \text{ mmHg} = 1 \text{ V} \qquad \text{(Eq1)}$$

To calculate velocity, it is necessary to utilize Bernoulli's equation, which states that static and dynamic pressure add to a constant value. The Baratron measures the difference between that constant value (the total pressure) and static pressure and reports it as voltage. Since the Baratron also measures ambient density, we can rearrange Bernoulli's equation to solve for velocity:

$$v^2 = 2(P_{tot} - P_{static}) / \rho \qquad \text{(Eq2)}$$

Surface Pressure Distribution

From Scanivalve's collected data of pressure reported in mmHg, the following equation was used to normalize the data in coefficient of pressure:

$$C_P = (P - P_\infty) / q_\infty \qquad \text{(Eq3)}$$

Figures 5, 6, and 7 show the plots of the coefficient of pressure calculated with Eq3 for the angles of attack decided by the team.

Boundary Layer Survey

Figure 8 shows the curve of the acceleration of air along the boundary layer and outside of it. Each point in Figure 8 is an average of points at each step of the motor. Height data in Figure 8 was normalized by prescribed height of the boundary layer, which was found to be 2.2 inches.

Velocity in Figure 8 was normalized by the maximum velocity determined by the Wind Tunnel Speed Characterization section of this experiment.

Wake Survey

Similarly to the Boundary Layer Survey, each point in Figure 9 represents an average of the points of data collected at each step of the motor.

Discussion

Supplement Questions

Endplate?

When I previously conducted an experiment that utilized an endplate and compared lift and drag coefficients of a specimen with an endplate to one without an endplate, I noticed that the lift coefficient generally lowered due to the presence of an endplate. The difference in pressure over the top and bottom of a wing is what causes lift, so I can extrapolate that the pressure difference over the top and bottom of the wing would decrease as a result of adding an endplate. The effect would perhaps increase as one approaches the end of the span towards the endplate.

Honeycomb and screens

The wind tunnel operates by drawing in air with a fan. Because the fan rotates, the air that it draws in rotates. For the wind tunnel to operate properly, the air needs to “straighten” out. It travels through screens and honeycomb, expands and contracts to shed rotation energy.

Low-Turbulence argument

The wind tunnel is called the “low turbulence” wind tunnel because the screens and honeycomb in the settling chamber remove the rotation and turbulence from the air. The effect can be proven by measuring the boundary layer on the chamber floor, as we did in this experiment. One can use

Blasius's equation or Prandtl's approximation (Figure 11) and the measured boundary layer thickness to determine if there is a turbulent boundary layer or not.

Additional Discussion

Something that puzzles me is how all the connections that are just air tubes (Figure 1) can function appropriately. What happens if there is a kink in the tube? The air pressure propagates at the speed of sound in the tube, but if there is any velocity within the air tube, doesn't the skin friction cause the air to speed up within the tube?

Tables and Figures

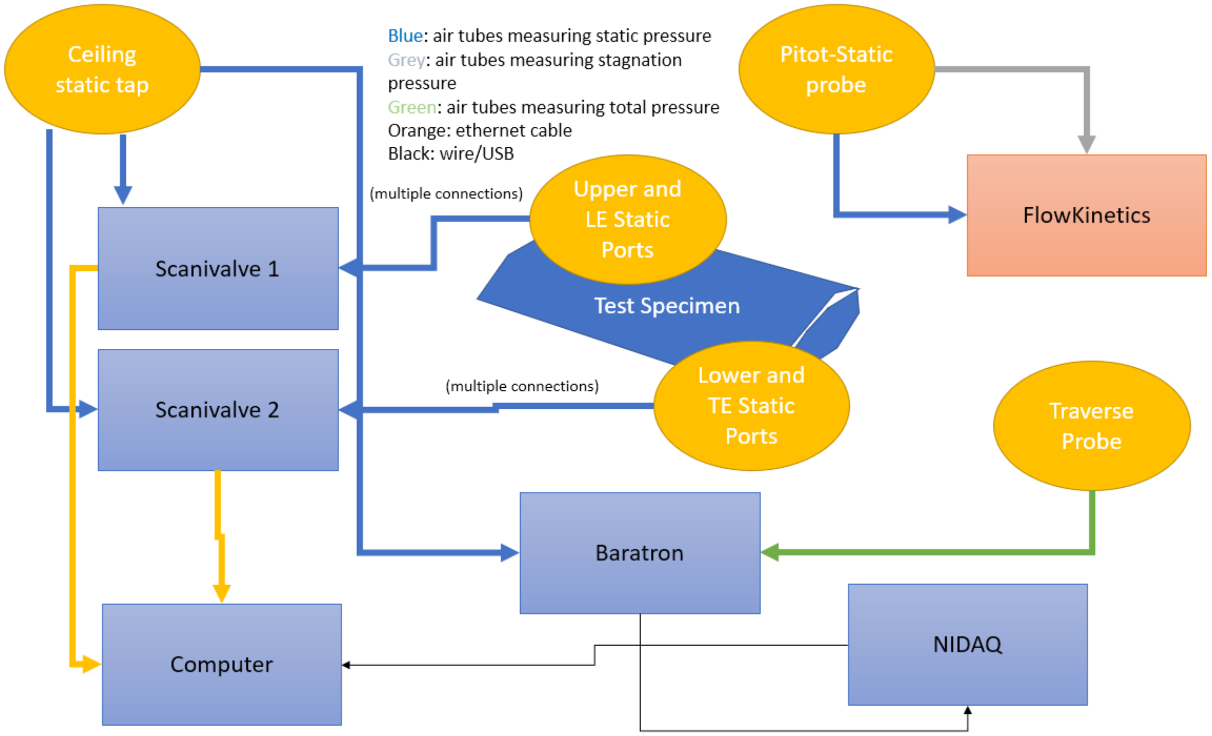


Figure 1. A schematic displaying the various pressure sensor equipment in the low-turbulence wind tunnel for our experiment set-up.

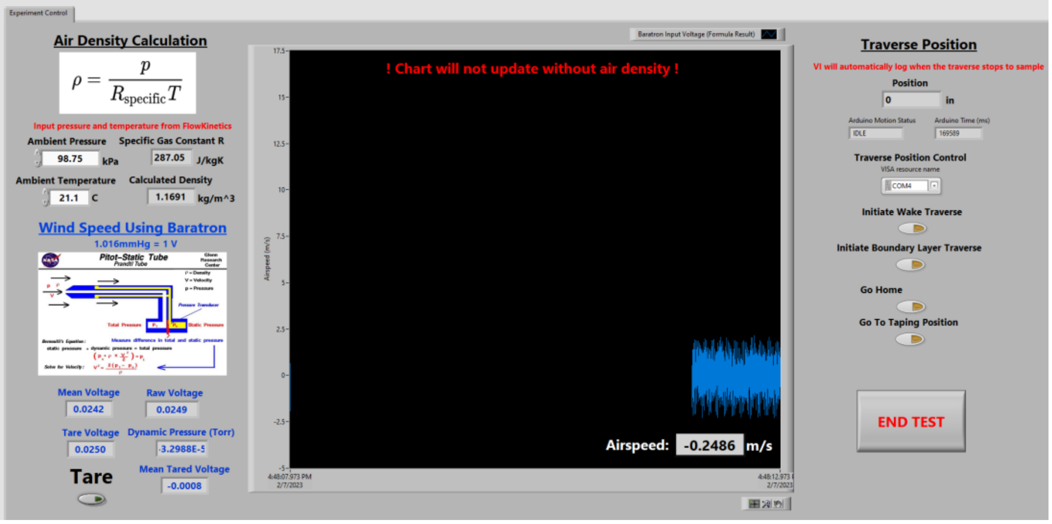
Scanivalve 1 Ports

1 – LE
2 – U1
3 – U2
4 – U3
5 – U4
6 – U5
7 – U6
8 – U7
9 – U9
10 – U10
11 – U11
12 – U12
REF - ceiling static tap

Scanivalve 2 Ports

1 – L1
2 – L2
3 – L3
4 – L4
5 – L5
6 – L6
7 – L7
8 – L8
9 – L9
10 – L10
11 – TE
REF - ceiling static tap

Figure 2. A detail schematic of the ports of the Scanivalve boxes. U, L, LE, and TE stand for Upper surface, Lower surface, Leading Edge, and Trailing Edge, respectively.



Input pressure and temperature from FlowKinetics

Ambient Pressure: 98.75 kPa

Specific Gas Constant R: 287.05 J/kgK

Ambient Temperature: 21.1 C

Calculated Density: 1.1691 kg/m^3

1.016mmHg = 1 V

Mean Voltage: 0.0242

Raw Voltage: 0.0249

Tare Voltage: 0.0250

Dynamic Pressure (Torr): -3.2988E-5

Mean Tared Voltage: -0.0008

! Chart will not update without air density !

Airspeed: -0.2486 m/s

VI will automatically log when the traverse stops to sample

Position: 0 in

Arduino Motion Status: IDLE

Arduino Time (ms): 169589

VISA resource name: COM4

Figure 3. A screenshot of the Labview VI showing ambient temperature, pressure, and calculated density.

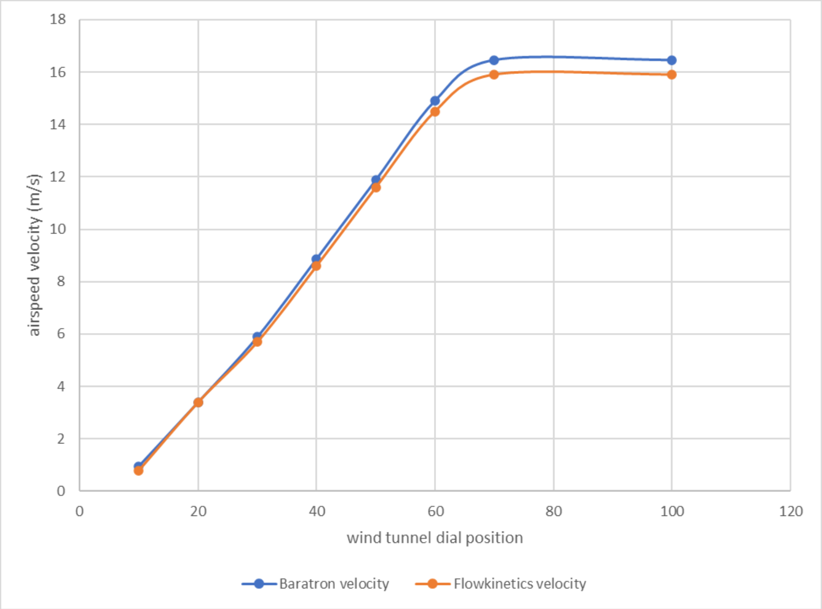


Figure 4: Wind tunnel velocity vs. control dial position. Contains both the Baratron voltage-derived velocity and the FlowKinetics velocity information.

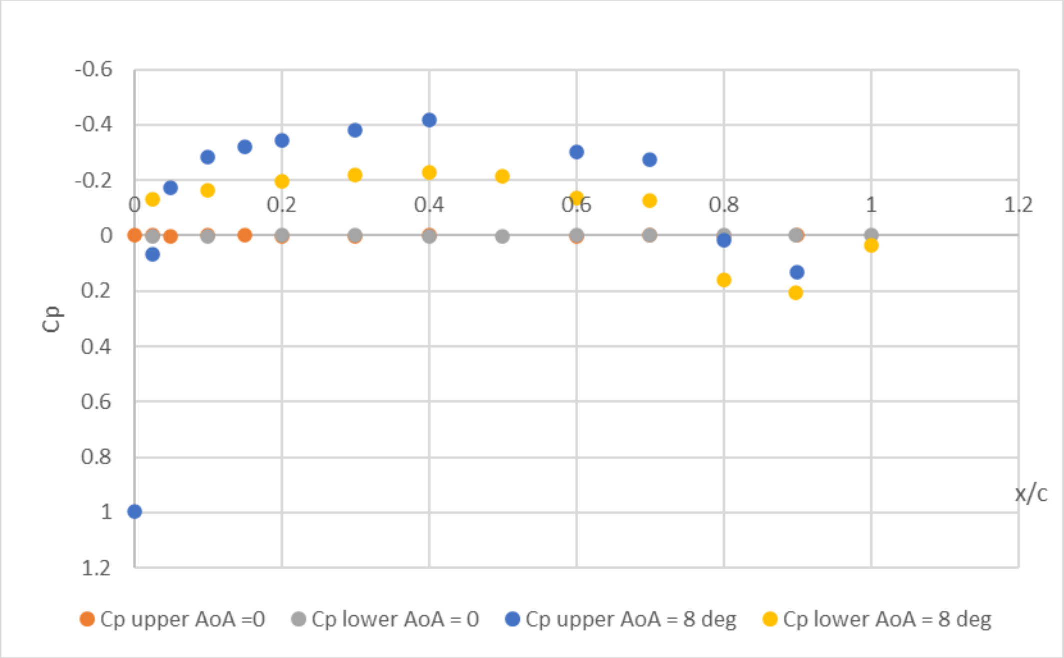


Figure 5: Chordwise pressure coefficient vs. non-dimensional chordwise position, x/c, where c is the airfoil chord length for zero angle of attack and 8 degrees angle of attack. Each point is an average of all measurements.

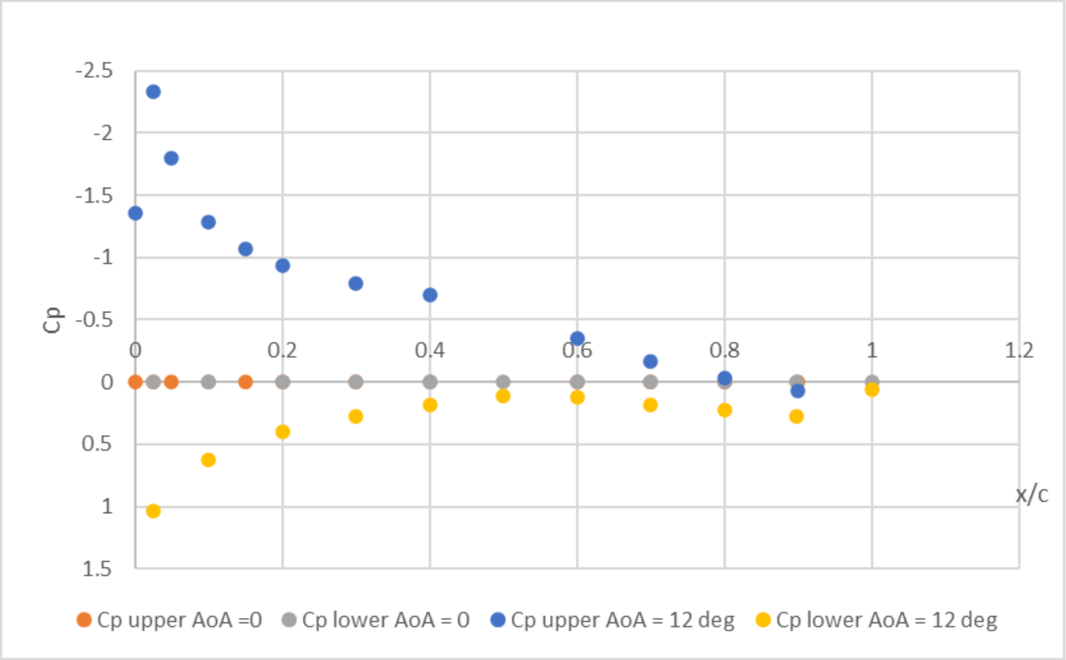


Figure 6: Chordwise pressure coefficient vs. non-dimensional chordwise position, x/c, where c is the airfoil chord length for zero angle of attack and 12 degrees angle of attack. Each point is an average of all measurements.

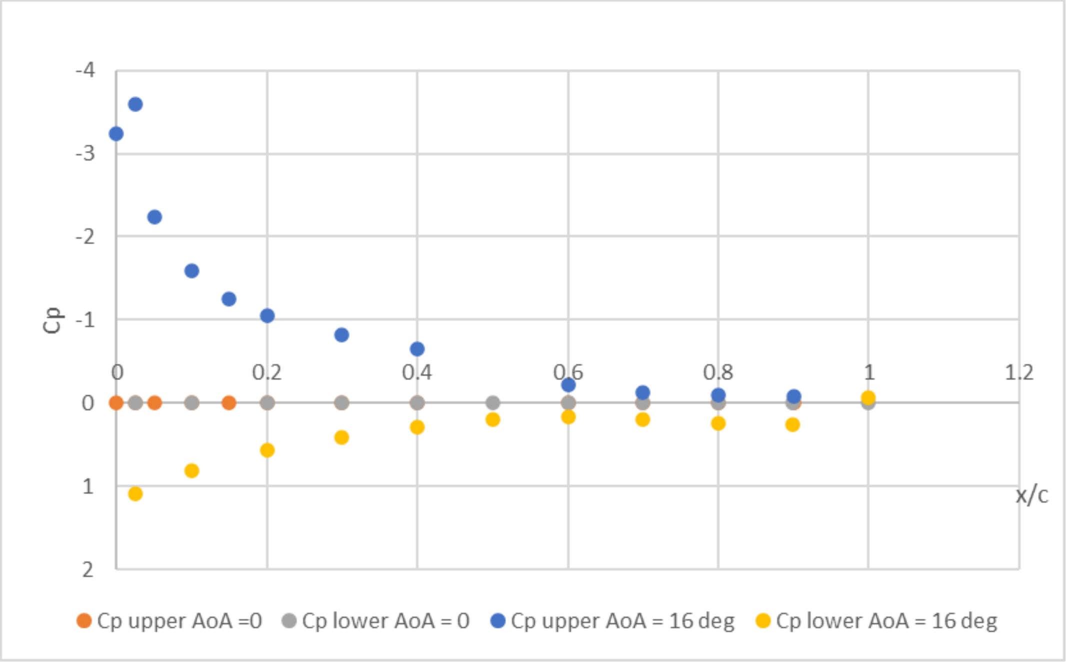


Figure 7: Chordwise pressure coefficient vs. non-dimensional chordwise position, x/c, where c is the airfoil chord length for zero angle of attack and 16 degrees angle of attack. Each point is an average of all measurements.

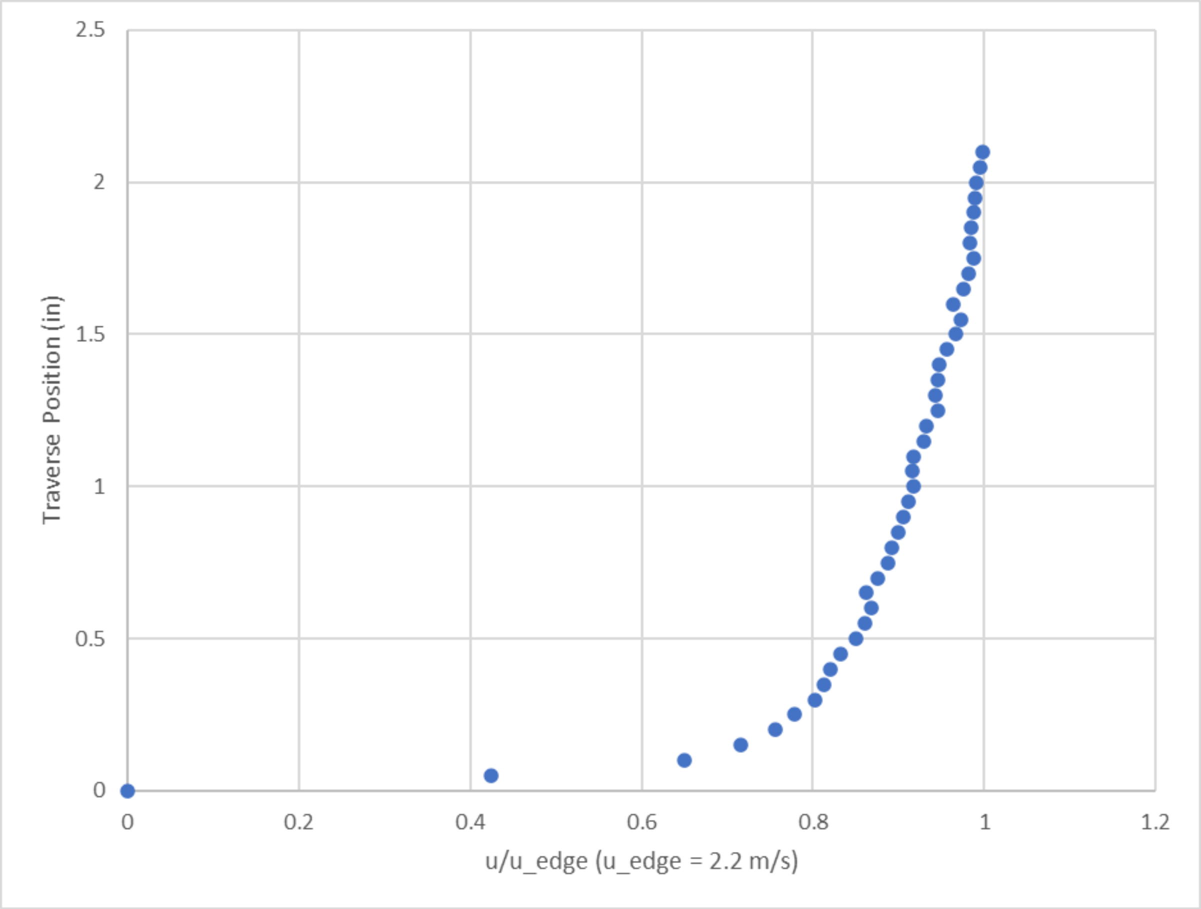


Figure 8: The shape of the non-dimensional boundary layer profile. y/δ as y-axis and u/u_{edge} as x-axis. Data is cropped to the edge of the boundary layer.

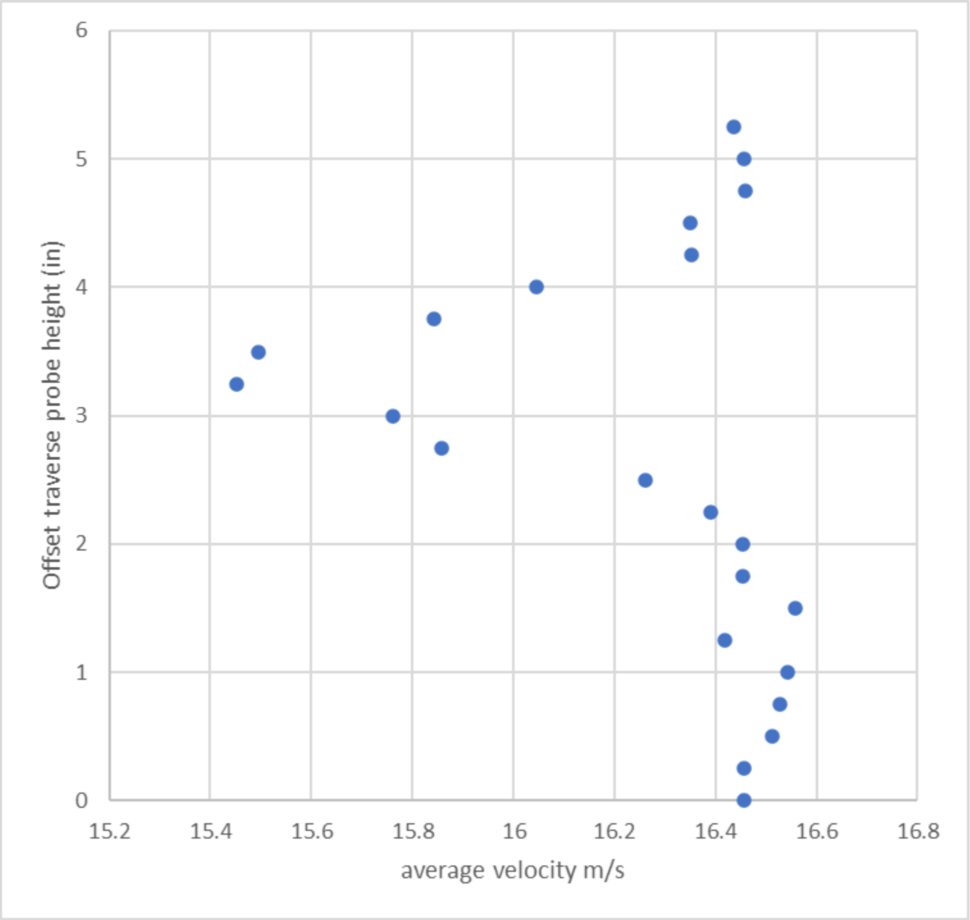


Figure 9: The variation in the stream-wise velocity component u through the wake behind the airfoil. Y as the vertical axis and u as the horizontal axis.

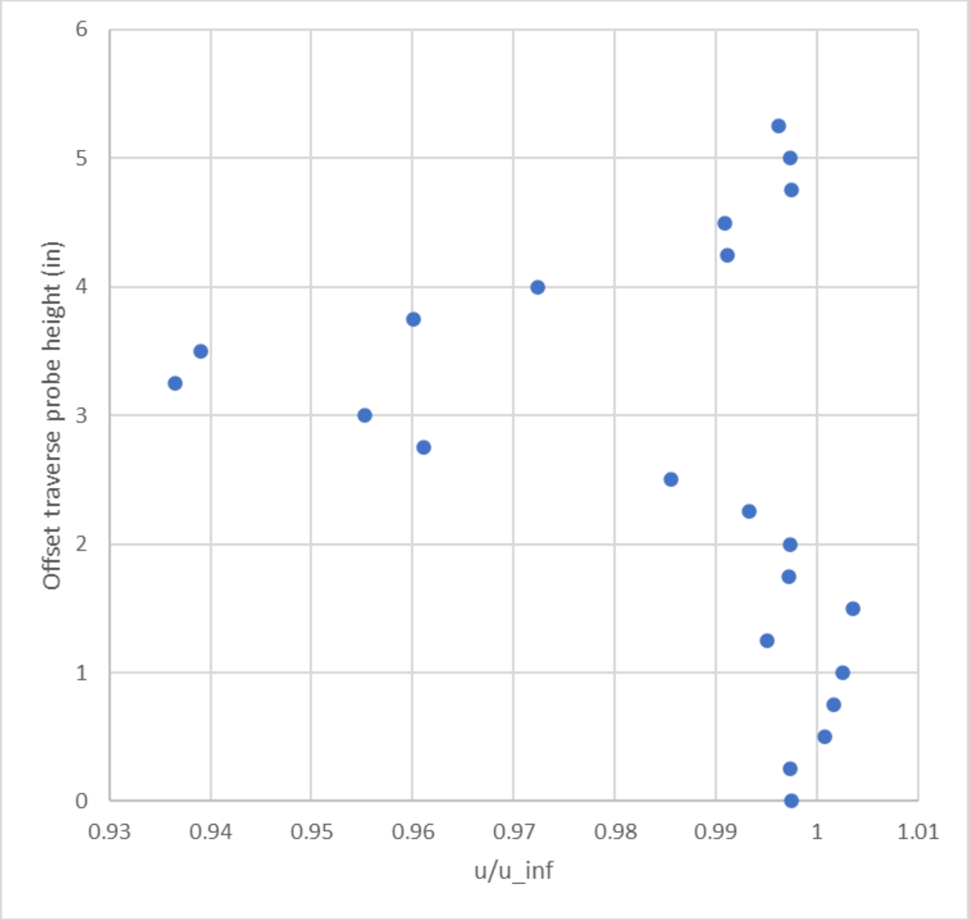
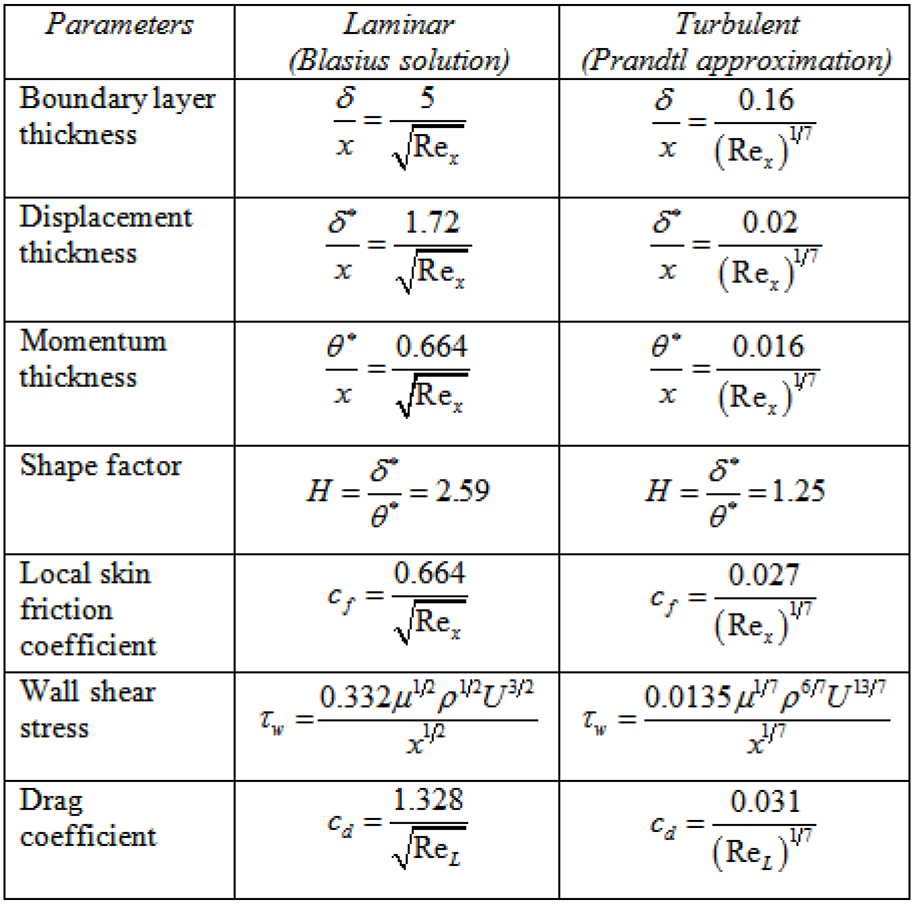


Figure 10: The normalized velocity profile (u/u_{inf}) through the wake behind the airfoil, where u_{inf} is the wind tunnel freestream velocity. Y is the vertical axis and u_{inf} is the horizontal axis.



Parameters	*Laminar* *(Blasius solution)*	*Turbulent* *(Prandtl approximation)*
Boundary layer thickness	$\frac{\delta}{x} = \frac{5}{\sqrt{\mathrm{Re}_x}}$	$\frac{\delta}{x} = \frac{0.16}{(\mathrm{Re}_x)^{1/7}}$
Displacement thickness	$\frac{\delta^*}{x} = \frac{1.72}{\sqrt{\mathrm{Re}_x}}$	$\frac{\delta^*}{x} = \frac{0.02}{(\mathrm{Re}_x)^{1/7}}$
Momentum thickness	$\frac{\theta^*}{x} = \frac{0.664}{\sqrt{\mathrm{Re}_x}}$	$\frac{\theta^*}{x} = \frac{0.016}{(\mathrm{Re}_x)^{1/7}}$
Shape factor	$H = \frac{\delta^*}{\theta^*} = 2.59$	$H = \frac{\delta^*}{\theta^*} = 1.25$
Local skin friction coefficient	$c_f = \frac{0.664}{\sqrt{\mathrm{Re}_x}}$	$c_f = \frac{0.027}{(\mathrm{Re}_x)^{1/7}}$
Wall shear stress	$\tau_w = \frac{0.332\mu^{1/2}\rho^{1/2}U^{3/2}}{x^{1/2}}$	$\tau_w = \frac{0.0135\mu^{1/7}\rho^{6/7}U^{13/7}}{x^{1/7}}$
Drag coefficient	$c_d = \frac{1.328}{\sqrt{\mathrm{Re}_L}}$	$c_d = \frac{0.031}{(\mathrm{Re}_L)^{1/7}}$

Figure 11: Boundary Layer information (source: GTAE slides for Aerodynamics course)