ASEN 2002 Aerodynamics of a Cambered Airfoil Lab

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Section A - Airspeed Calculation and Airspeed Model:

The airspeed calculations were made using two different measurement configurations (Pitot-Static Probe and Venturi Tube), as well as two different measurement devices (U-tube Manometer and a Pressure Transducer). These devices primarily measured pressure differentials, which we could then use in our calculations of airspeed using the equations provided in Appendix B of the lab document. The equations resulted from simplifying Bernoulli's Equation to solve for V.

In both the Pitot-Static and the Venturi configurations, the velocities measured by the U-tube manometer had a much higher magnitude than those measured by the pressure transducer at the same voltage. However, measurements taken with the U-tube manometer introduce the possibility of human error, and as such we determined that the pressure transducer was likely the more accurate form of measurement.

The mathematical model that related airspeed to input voltage is AirSpeed = 2.409135(Voltage) + 0.151410

Section B - Airspeed Measurement Uncertainty:

The primary sources of uncertainty in the measurement of airspeed are random fluctuations in the measurement, errors associated with measurement hardware and the errors provided by the sensor manufacturer. The largest source of uncertainty comes from the errors quoted by the manufacturer. This uncertainty stems from the errors in the measurement of differential pressure, atmospheric pressure and atmospheric temperature. In our uncertainty analysis, we have only taken manufacturer quoted errors into account. In order to improve the system accuracy, we could take more measurements and factor in all sources of error in our uncertainty analysis.

The error bars plotted through the readings of the U-tube manometer are lower than that of the pressure transducer, therefore the U tube manometer provides a more accurate measure of the velocity.

Section C - Boundary Layer Influence:

The boundary layer was computed by first calculating the freestream and boundary layer velocities using differential pressure measurements found at each port. A mathematical model was constructed for each port to model the relationship between freestream velocity and Y axis measurements. These models were then used to calculate the Y location at 95% of the freestream velocity (thus calculating the boundary layer height), and then compared to theoretical predictions for laminar and turbulent flow boundary layer heights.

The boundary layer thickness has a range between ~4 to ~8 mm across the 11 ports. The first four ports recorded boundary layer thicknesses similar to the laminar boundary layer height, while the last 7 port boundary layer heights were more similar to the measurements predicted by the turbulent flow model.

Given that more ports shared similarities with turbulent flow than laminar flow, we predict that the boundary layer is more turbulent than laminar. However, it should be noted that the first few ports appeared to be near laminar flow, which agrees with ideas discussed in class that the flow will transition from laminar flow in the front to turbulent flow in the back of the wing.

Section D - Post processing and Calculation of Force Coefficients:

The procedure to post-processed the measurements of the surface pressure coefficient and lift coefficients took extensive MATLAB code. Initially, to calculate the pressure coefficients of every angle of attack, with their respective airspeeds, we utilized Equation (2) in Appendix C. By taking the scanivalve data, as well as the collected PitotDynamicPressure data, we were able to implement these into Equation (2) to calculate the pressure coefficients. Next, by using Equations (16) and (17) of Appendix E, we used our pressure coefficients to calculate Cn and Ca, which then was used to calculate lift and drag coefficients. In order to calculate these coefficients, we implemented Equations (20) and (21) of Appendix E into MATLAB.

The only possible source of uncertainty in the lift and pressure drag equations is the calculated coefficient of pressure. The coefficients of lift and drag both relay on Equations (16) and (17). Furthermore, the only uncertainty within Equations (16) and (17) is the calculated coefficient of pressure which relays on recorded data.

By extrapolating the coefficient of pressure between port 8 and 10, as well as extrapolating between ports 12 and 14, the estimate of the trailing edge (port 11) pressure coefficient is reasonably accurate. The data calculated for the trailing edge matched in magnitude and trend when compared to additional coefficients of pressures at various ports.

Section E - Airfoil Static Pressure Coefficient Distribution:

When properly normalized , the coefficient of pressure increases as the airspeed increases.

At low angles of attack, the pressure distribution increases as the angle of attack approaches zero. Comparing the AoA of -9 to the AoA of 0 figures, the pressure distribution with an AoA of 0 ranges from -1 to 0.8 while the pressure distribution for an AoA of -9 only ranges from -1 to 0.4.

The largest difference in the surface pressures between the top and bottom of the airfoil varys between the angle of attack and the airspeed. But, for an AOA of 13 and an airspeed of 16 m/s, the largest difference occurs between a unit length of 1 and 0.8. This indicates that the pitching moment on the Clark Y-14 airfoil occurs at the trailing edge of the airfoil.

Some flow separation can be observed at lower angles of attack, typically between unit lengths of 0.6 and 0.8 in. As the angle of attack increases, this separation of flow decreases and eventually becomes negligible. This indicates that flow separation is largely present in negative attack angles of the Clark Y-14 airfoil.

Section F - Lift and Pressure Drag Coefficients:

The lift and drag coefficients vary differently with angle of attack. The lift coefficient continues to decrease until the angle of attack is between -9 and -7. After this, the coefficient steadily increases until it rapidly drops at the end. Similar to the lift coefficient, the drag coefficient decreases till the angle of attack is roughly -3 and after has a steady increase. Unlike the lift coefficient, the drag coefficient does not see a sharp drop once higher angles of attacks have been reached. The minimum drag coefficient is achieved at an airspeed of 9 m/s, -3 angle of attack, and has a value of 0.0229865.

The maximum lift coefficient varies with the tunnel velocity. For an airspeed of 9 m/s, the maximum lift coefficient is equal to 0.868364 and occurs at an angle of attack of 15, while the maximum lift coefficient for an airspeed of 16 m/s occurs at an angle of attack of 5 and is equal to 1.07998. Finally, with an airspeed of 33 m/s, the maximum lift coefficient is equal to 1.52236 and has an angle of attack equal to 11.

The lift produced at an angle of attack varys from 0.259372 - 0.59447, with their respective airspeeds. The lift is equal to zero $\pm$ 0.003 at an angle of attack of -4.

Comparing the Coefficient of Lift and the Coefficient of Drag to the NACA Airfoil Y-14 Coefficient of Drag vs Angle of Attack figures from the quad chart, the overall trend between the plots is similar. In the linear lift slope regions, both the Coefficient of Lift figure, as well as the NACA Airfoil Y-14 figure, show a steady increase into a sharp fall. Systematic errors or variations could potentially be sourced from the data collected.

Conclusions:

Throughout the project, we made many significant findings about the functioning of a low speed wind tunnel, the forces acting on a Clark Y14 airfoil, and the most effective method of calculating airspeed. We found that when calculating airspeed, it was most effective to use pressure transducers combined with either Pitot-Static Probes or Venturi Tubes. We found that these methods reduced the likelihood of human error and resulted in consistent measurements throughout the experiment. The tunnel wall boundary layers did impact the centerline airspeed by increasing the airspeed by an average of 2.94 m/s. The best way to mitigate this effect in the future would be to introduce flow straighteners, changing the air properties such as temperature and pressure, or changing the Reynolds number.

The key difference between the NACA results and our results is how smooth the NACA slopes are. Our data slope varies from increasing to decreasing depending on the angle of attack. But, overall the key similarity between the NACA results and ours is the overall trend of the lift and drag coefficients when compared to angle of attack. The ability to quantify the lift and drag forces from measurements of the static surface pressure around the Clark Y-14 airfoil worked flawlessly. The method for quantifying lift and drag follow similar paths. Both require calculating the normal and axial force for each angle of attack, with the only difference being how their equations are aligned. The lift coefficient takes the difference while the drag coefficient takes the sum between the normal and axial force, respectively to their angle of attack. The lift, nor the drag, had an advantage over the other when comparing the two. Overall, this project has helped us learn the basic concepts and definitions associated with flow measurements, wind-tunnel testing, and two-dimensional flow around airfoils.