Chapter 6

Experiment 3: Drag and Lift for a Clark Y-14 Airfoil with a Leading Edge Slat and a Split Flap

6.1 Objective

In this experiment, students will measure the Lift, Drag, and Pitching Moment of a Clark Y-14 airfoil in a clean configuration, with a slat, with a flap, and with both the slat and the flap. Determination of the pitching moment requires the determination of the location of the aerodynamic center for the clean airfoil. Finally, students will study the influence of changing the flap angle on the aerodynamic properties.

6.2 Overview and Background

6.2.1 Coefficient of Lift, Drag, and Pitching Moment

The lift and drag forces and the pitching moment result from the distribution of viscous and pressure forces on the surface of the airfoil. In the next experiment, students will directly determine the relationship between the lift and drag forces and the pressure and viscous forces. For this experiment, students will use the sting balance to measure the integrated effects of these surface forces and to express those forces in terms of the appropriate non-dimensional coefficients.

The lift force is defined as the component of the force that acts normal to the direction of

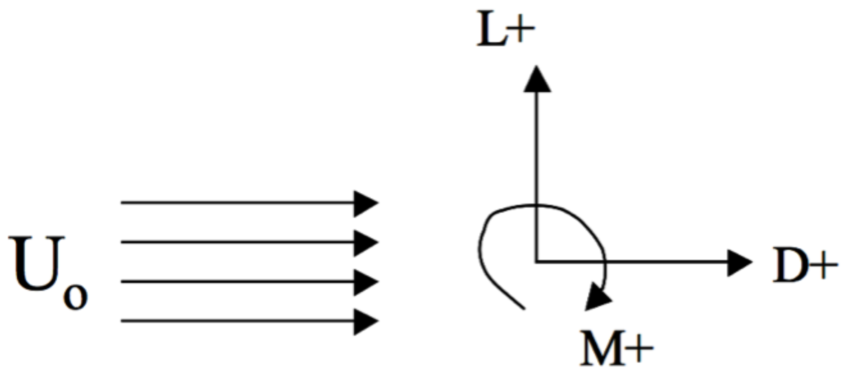

Figure 6.1: Sign Convention for Lift, Drag, and Pitch.

the free stream velocity vector and considered positive upwards. The drag force is the force component that acts in the direction parallel to the free stream velocity vector and considered positive in the downstream direction. The pitching moment is the moment created by the aerodynamic forces acting on the airfoil about a particular reference axis. In aerodynamics, a positive pitching moment corresponds to a moment that would rotate the leading edge upwards (i.e., “nose up”) as shown in figure 6.1. Typically the reference axis coincides with one of three locations: the leading edge of the airfoil, the quarter chord, and the aerodynamic center. At the aerodynamic center, the pitching moment coefficient remains independent of the angle of attack, unlike the other two points. When reporting the pitching moment coefficient, the reference location must be noted. In this experiment, the location of the aerodynamic center and the moment coefficient about the aerodynamic center for the Clark Y-14 airfoil will be determined.

6.2.2 Wind Tunnel Wall Corrections

An airplane flies in practically a limitless volume of air (except during landing and take-off when it flies close to the ground), whereas an airplane model “flies” in a wind tunnel test section in a volume of air confined by the walls of the wind tunnel. This difference gives rise to a number of corrections applied to wind tunnel data to maintain consistency with measurements made in an unconfined volume. These corrections are called “wind tunnel wall” corrections and are described in Chapters 9, 10, and 11 of Barlow *et al.* (1999). Fortunately, many of those corrections are quite small. One correction that must be included, for example, is due to the fact that, when lift is generated, the walls of the wind tunnel force streamlines upstream of the airfoil to be less curved than they would be in an unconfined space (Barlow *et al.*, 1999, pg. 358). The magnitude of the corrections depend on the shape, chord length and wingspan relative to the test section width and height. From experimental comparisons of tests in the UCI wind tunnel and a large tunnel with negligible wall effects, the following are suggested as additive corrections:

$$\Delta\alpha = 1.7C_L \tag{6.1}$$

$$\Delta C_D = 0.03C_L^2 \tag{6.2}$$

Example: Lift and drag coefficients are obtained using the sting balance in the UCI Wind Tunnel for the angle of attack $\alpha = 10°$. The measured results are $C_L = 1.0$ and $C_D = 0.2$. To correct for wall effects, apply equations 6.1 and 6.2 as follows:

$$\alpha' = 10 + (1.7)(1.0) = 11.7$$

$C'_D = 0.2 + (0.03)(1.0)^2 = 0.23$

6.2.3 Operation of the Sting Balance

Remember that the sting balance reads normal, F_n, and axial, F_a, forces. These forces coincide with the lift, L, and drag, D, only at zero angle of attack. The relationships between lift and drag and the normal and axial forces at angle of attack ? are as follows:

$$L = F_n \cos\alpha - F_a \sin\alpha \tag{6.3}$$

$$D = F_a \cos\alpha + F_n \sin\alpha \tag{6.4}$$

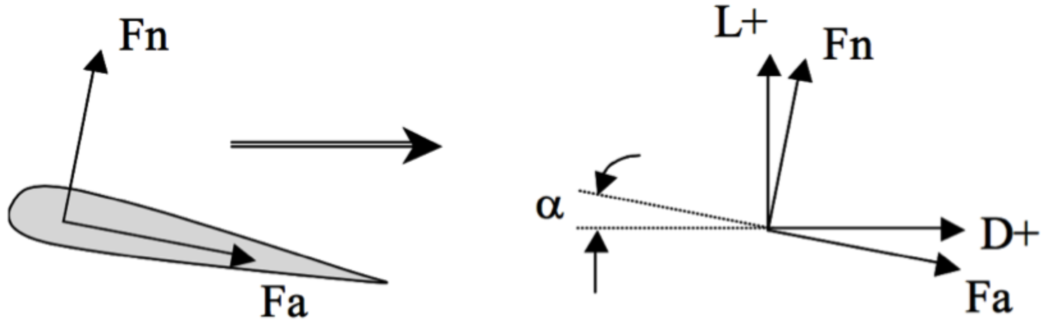

Figure 6.2: Relationship Between Lift vs. Drag Coordinates and Normal Force vs. Axial Force Coordinates.

Note however, the sting balance reads the axial force as a negative value in the downstream direction. The balance reads moments about an axis called the sting balance moment center. Calibration of the sting balance moments requires determining the location of the sting balance moment center. The location of the balance moment center can be determined by placing a weight at different locations along the calibration barrel (with the barrel horizontal) and extrapolating the distance where the moment would become zero.

6.2.4 Characteristics of a Clark Y-14 Airfoil

Uncharacteristically of airfoils, the Clark Y-14 airfoil has a straight lower surface that is considered the chord line the chord line. Traditionally the chord line forms a straight line from the leading edge to the trailing edge of the airfoil. Consequently, the angle of attack can be set with the digital inclinometer by aligning the inclinometer with the lower surface. In this experiment, the measurement will be done from the outside of the test section window with the wind tunnel running. NACA Technical Report number 628 contains he lift, drag, and pitching moment coefficients versus angle of attack. Students will use the tabulated NACA data for comparison with the experimentally obtained values in this experiment. Accurately comparing the experimental data to the NACA data requires an uncertainty analysis. This statistical measure allows for definitive conclusions on whether the data sets agree or not within statistical certainty.

6.3 Experimental Details

This experiment requires testing four different airfoil configurations: clean, with slat, with slat & flap and, with flap. Additionally, students will determine the influence of flap angle by testing two additionally flap angles. For the stated configurations test at the following conditions:

1. Clean airfoil: 10 m/s, 20 m/s, and 25 m/s.

2. Airfoil with slat: 20 m/s with a slat separation of 5 mm.

3. Airfoil with slat & flap: 20 m/s with a slat separation of 5 mm and a flap angle of 45°.

4. Airfoil with flap: 20 m/s with a flap angle of 45°.

5. Flap variation: 20 m/s with a flap angle of 30°.

Students will determine the lift, drag, and pitching moment coefficients for each configuration. In aerodynamics, knowing when an airfoil stalls is important. Experimentally, there are three ways to determine the stall point: a drop in C_L, a drop in the pitching moment, or tufts. Due to the sting balance supporting the wing, the lift coefficient may appear to increase after stall. The drop in the pitching moment (T_y) becomes difficult to discern at lower speeds. For this reason, black threads (called "tufts") are taped at their upstream ends at various positions across the span of the airfoil to serve as a visual indicator of stall. When the threads remain aligned in the downstream direction the flow remains attached but as the tufts being wiggling indicates boundary layer separation. Separation over the majority of the wing indicates stall. Using one or all of these indicators will allow the students to determine the stall point of the airfoils. Pay careful attention to stall to ensure data is only taken up to 8° past stall and not always up to 30°.

Procedure

1. Calibrate F_x, F_z, and T_y following the calibration procedure of Experiment 3.

2. Determine the sting balance moment center by placing a weight at different locations along the calibration barrel, measuring the moment arm from a fixed point.

3. Insert the clean airfoil configuration into the wind tunnel, ensuring the airfoil is level.

4. Record the normal and axial force and pitching moment readings with the speed off for angle of attack values of -6 to 30 by 2 degree increments. (These values compensate for the weight of the model and is often referred to as the "tare" weight of the balance.)

    (a) The angles should be referenced to the flow direction found in previous labs.

    (b) Record these values in your data sheets not within the LabView program.

5. Turn the tunnel on and adjust the speed to the first test speed.
6. With the tunnel on, set the angle of attack to -4 degrees and read the normal and axial forces and the pitching moment.
   (a) Increase the angle in 4-degree intervals to 8 degrees beyond the stall point, without turning the wind tunnel off, recording the normal and axial forces and the pitching moment.
   (b) Reduce the angle of attack by two degrees and then take the same measurements in descending order at 4-degree increments until an angle of attack of -6 degrees.
   (c) Repeat the measurement at -4 degrees.
   (d) Plot C_L, C_D, and C_M versus alpha curves as the data is collected.
7. Repeat step five for the next two speeds for the clean airfoil only.
8. Turn off the wind tunnel and remove the airfoil.
   (a) **DO NOT RECONFIGURE THE AIRFOIL WHILE ATTACHED TO THE STING BALANCE!**
9. Attach the slat separation at 5 mm to the air foil and repeat steps 3-8, excluding step 7.
10. Attach the flap set at 45° to the airfoil with the slat and repeat steps 3-8, excluding step 7.
11. Remove the slat, leaving the flap set at 45° and repeat steps 3-8, excluding step 7.
12. Adjust the flap to 30° and repeat steps 3-8, excluding step 7.

6.4 Specific Results and Questions

6.4.1 Plots and Tables

1. For each configuration and each data set, correct for the tare in the force and moment readings. Convert the corrected normal and axial forces to lift and drag, and then compute the lift, drag, and moment coefficients (about the sting balance moment center) as a function of angle of attack for the two Reynolds numbers. As the last step in your data reduction, correct for the tunnel wall effect. (You may want to consult

Chapter 13 of Barlow et al. (1999), pages 483-489, for a comprehensive description of the procedure.)

2. Determine the aerodynamic center and the section pitching moment coefficient $C_{m,ac}$ about the aerodynamic center for the "clean" airfoil (no slat or flap). See Eqns. (13.6-13.9) in Barlow for calculation procedure of the aerodynamic center and $C_{m,ac}$.

3. For the clean airfoil configuration plot, on a single plot, C_L versus corrected angle of attack for the three test speeds. On another figure, plot corrected CD versus corrected angle of attack for the three test speeds. Finally, plot corrected $C_{m,ac}$ versus corrected angle of attack for the three test speeds. This will produce three plots with three curves each.

4. Plot C_L, corrected C_D, and $C_{m,ac}$, versus corrected α for the clean, slat, 45° flap, and flap/slat configurations at 20 m/s on three plots. This will result in three plots with four curves each.

5. Perform an uncertainty analysis on the data of the clean airfoil.

6. For the clean airfoil, plot the measured results for the lift coefficient (C_L), corrected drag coefficient (C_D), and moment coefficient about the aerodynamic center ($C_{m,ac}$) versus the corrected angle of attack along with the NACA results (NACA results need to be digitized). For the experimental data show error bars showing the uncertainty calculated in step 5. This will result in three plots with two curves each.

7. Plot C_L, corrected C_D, and L/D versus corrected α for the clean, 45° flap, and 30° configurations at 20 m/s on three plots. This will result in three plots with three curves each.

6.4.2 Questions

1. What is the distance between the sting balance moment center and the setscrew? Show a sketch of the sting balance and indicate the locations of the setscrew, the moment center and the relative distance between the two (use the calibration-arm setscrew location instead of the moment center if you used this in your calibration; are they approximately the same?)

2. On the sketch obtained for Question 1, show the airfoil and indicate the distance between the leading edge of the airfoil and the setscrew. Indicate also the distance between the axis of the sting balance and the chord of the airfoil.

3. Determine the aerodynamic center and the pitching moment coefficient about the aerodynamic center for the ?clean? airfoil (no slat or flap). Indicate its location relative to the leading edge on the sketch you drew for Question 1.
4. Why do the slat and flap lead to an increase in the lift?
5. What are the effects of the slat-only on the stall characteristics compared to the clean airfoil and why?
6. What happens to the stall characteristics for the flap only case compared to the clean airfoil and why?
7. Does the increase in the lift coefficient with the slat alone plus the increase in the lift coefficient with the flap alone equal the increase in the lift coefficient when both the flap and slat are mounted on the wing?
8. What is the effect of changing the flap angle on the lift coefficient and the L/D ratio? Are the stall characteristics affected?
9. Determine the "two-dimensional lift curve slope" which is equal to $\frac{dC_L}{d\alpha}$ at $\alpha = 0$. How does it compare to the theoretical lift curve slope?

Chapter 7

Experiment 4: Pressure Distribution Over an Airfoil And Hot-Wire Anemometry

7.1 Objective

The objectives of this experiment are to:

1. Measure the pressure distribution over a Clark Y-14 airfoil at various angles of attack
2. Determine the lift and drag forces from the pressure measurements
3. Compute the corresponding lift and drag coefficients
4. Estimate the drag coefficient from the downstream velocity distribution
5. Compare the lift and drag coefficients computed from the pressure distribution and velocity distribution to those obtained using the sting balance and understand the reason for their difference

7.2 Overview

7.2.1 Lift and Drag Coefficients from Pressure Force Measurements

An airfoil develops lift due to the fact that the pressure on the upper surface is lower than the pressure on the lower surface. The overall pressure distribution can be measured using