Objectives

1. To directly measure lift and drag of a symmetrical NACA airfoil at various angles of attack
2. Determine coefficient of lift and drag and compare to published values

Apparatus

The apparatus includes an Engineering Laboratory Design wind tunnel with a 12 inch test section, NACA 0012 test foil, (00 = symmetrical, 12 = ratio of foil thickness*100 divided by chord length), lift and drag dynamometer, Pitot tube, digital display meter. The arrangement of the experimental apparatus is shown in Figure 1.

![Figure 1. Illustration of the wind tunnel apparatus](image)

![Figure 2. Illustration of the airfoil and angle of attack (α)](image)

Procedure

You are required to plot data as you perform the lab. You may use the computer in 015, which has Excel.

1. Calibrate the lift/drag dynamometer
   a. Loop a small bridle made of string around the airfoil as illustrated in Figure 3
   b. Measure the loading angle (β)
   c. Load the string with a known weight
   d. Resolve the weight into lift and drag components. Also, record the value of lift and drag as displayed by the meter (in millivolts). Plot these values to determine calibration
   e. Repeat steps c. and d. for at least seven known weights
2. Position the blower to give a Reynolds number of 160,000 (do not exceed 160,000)

\[ Re = \frac{\rho_{\text{air}} U c}{\mu_{\text{air}}} \]  

where \( \rho_{\text{air}} \) and \( \mu_{\text{air}} \) are found from reference data, \( c \) is the chord dimension and Velocity (\( U \)) is found from Bernoulli’s equation where

\[ \frac{\rho_{\text{air}} U^2}{2g_c} = p_{\text{pitot}} - p_{\text{static}} = p_{\text{dynamic}} \]  

This is accomplished by solving for \( U \) needed to attain a Re of 160,000.

3. For the velocity calculated in (2.), measure the drag on the dynamometer’s loading arm (located in the test section), without the airfoil. This is the baseline drag value.

4. Determine lift and drag acting on the foil for various angles of attack (\( \alpha \))
   a. Place the model at neutral position (\( \alpha = 0 \)). **Remember lift force = 0 at \( \alpha = 0 \) by definition.** If the value <> 0, then you must make it by using its value as your reference.
   b. For the velocity calculated in 2, measure the lift and drag as displayed on the meter
   c. Repeat step b. for at least eight different angles of attack
   d. Record lift and drag dynamometer voltages vs. \( \alpha \) (and remember Step 3,4a)
   e. Record the value of the dynamic pressure from the Pitot-Static tube arrangement.

5. Determine the stall angle
   a. Using the results of (4.) identify the two angles of attack which bracket the stall angle. (Stall angle is the angle at which lift is a maximum for a given air speed)
   b. Determine the exact stall angle by taking at least five measurements of lift and drag between the two angles of attack determined in step a.
Requirements for analysis (laboratory write-up)

1. Plot the calibration of the lift and drag measurements and include regression analysis. Include calculations of force vectors in the write-up (Appendix).

2. Show your calculation of Reynolds number and consider similarity.

3. Plot the coefficients of lift ($C_{\text{lift}}$) and drag ($C_{\text{drag}}$) versus angle of attack ($\alpha$). Use the following equations to calculate drag and lift coefficients:

\[
C_{\text{drag}} = \frac{\text{Drag force}}{\left( \frac{\rho \text{ air} U^2}{2g_c} \right) \text{(chord length)(foil width)}}
\]

\[
C_{\text{lift}} = \frac{\text{Lift force}}{\left( \frac{\rho \text{ air} U^2}{2g_c} \right) \text{(chord length)(foil width)}}
\]

4. Plot NACA 0012 airfoil data for lift and drag coefficients, and $C_{\text{lift}}$ for a flat plate versus $\alpha$ for your Re, along with your data. Compare the results. $C_{\text{lift}}$ for a flat plate is $2\pi \sin(\alpha)$.

5. Examine your flat plate results. Comment where the approximation of $2\pi \sin(\alpha)$ will break down. Justify your answer.

6. Include a uncertainty analysis of your calculation of $C_{\text{drag}}$ at the stall angle.

7. Compare your results if Re was actually much higher than 160,000 – i.e. Re=1,000,000

8. Consider your results if you decided to subtract reference voltages from the raw data instead of reference forces. Plot the different resulting $C_{\text{lift}}$ and $C_{\text{drag}}$ curves.

References

Munson, Young, and Okiishi, *Fundamentals of Fluid Mechanics*
Zucker, *Fundamentals of Gas Dynamics*
Zucrow and Hoffman, *Gas Dynamics*