Aerodynamics of Flow Around an Airfoil

Experiment 3

1 Objective

The objective of this experiment is to determine the aerodynamic drag forces, F_D, experienced by an airfoil placed in a uniform free-stream velocity, U_∞. Velocity profiles will be taken upstream and downstream from the airfoil at various angles of attack. Drag will then be approximated from these profiles.

2 Background

The total drag on any body consists of skin friction drag ($F_{D,\mu}$) and form drag ($F_{D,p}$) as shown in equation 1. Skin friction drag is a result of the viscous forces acting on the body while form drag is due to the unbalanced pressure on the body (high pressure on front and low pressure on rear). The sum of the two is the total or profile drag (F_D).

$$F_D = F_{D,p} + F_{D,\mu} \tag{1}$$

The airfoil used in this experiment is the NASA Energy Efficient Transport (EET) airfoil. This is a supercritical airfoil which is becoming a standard testing platform for experiments in transonic and supersonic regimes. The supercritical nature of this airfoil allows it to perform much better in these regimes, as it reduces the wave drag on the upper surface. Figure 1 illustrates the profile of the NASA EET airfoil.

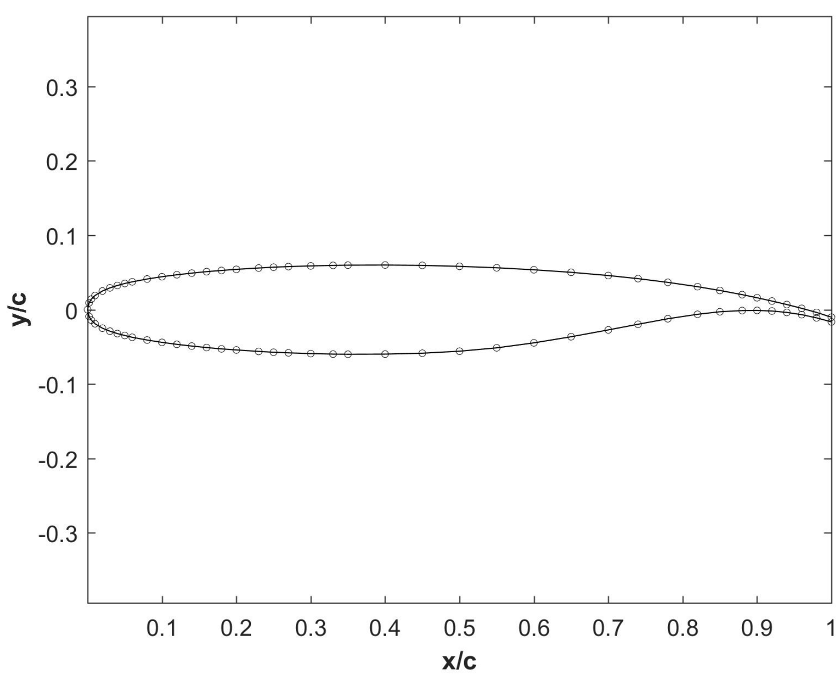


Figure 1: NASA EET Profile

3 Drag Measurements

3.1 Prediction of Drag from Wake Measurements

By measuring the velocity profiles in the wake of the airfoil and using conservation of linear momentum, the drag force on the airfoil can be determined, provided that the flow is steady. Figure 2 shows a control surface around the airfoil. Velocity profile is measured at one upstream and two downstream locations (Section I and II). Since the flow is incompressible the net mass flow entering the control volume should be equal to the net mass flow exiting the control volume. The expression for conservation of mass is shown in Eq. 2. The width of the test-section which is also the span of the 2D airfoil is denoted by s. U_∞ is the incoming free-stream velocity, $u_1(y)$ and $u_2(y)$ are the velocity profiles at sections I and section II, respectively.

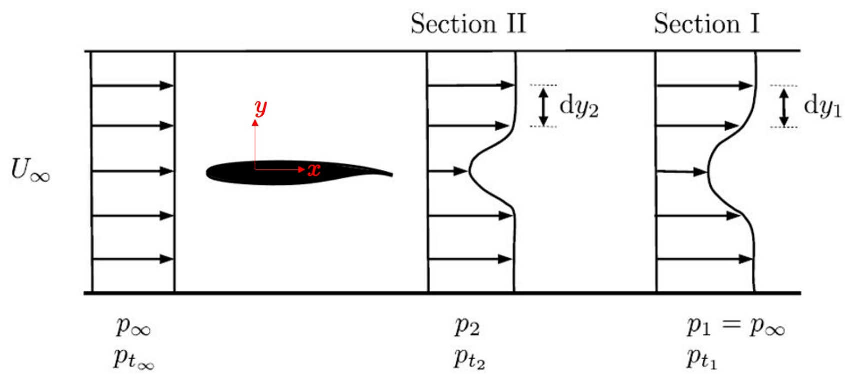


Figure 2: Schematic of Part I experimental setup

$$\int \rho U_\infty s dy = \int \rho u_1(y) s dy = \int \rho u_2(y) s dy \tag{2}$$

The velocity at any location can be measured using a pitot-static probe. A brief description of the probe and the equation for calculating velocity is given in Sec. 3.1.1.

The rate of change of flow-momentum between an upstream and any downstream location is equal to the reaction force applied by the wing-section on the flow. This reaction force in the x direction is the total drag force (F_D). Equation 3 shows the conservation of linear momentum in the x direction between upstream and any downstream location.

$$\int \rho [U_\infty]^2 dy = F_D + \int \rho [u_1(y)]^2 dy = F_D + \int \rho [u_2(y)]^2 dy \tag{3}$$

Equations 2 and 3 can be used to obtain F_D as shown in Eq. 4.

$$F_D = \rho s \int u_1(y)(U_\infty - u_1(y)) dy = \rho s \int u_2(y)(U_\infty - u_2(y)) dy \tag{4}$$

The drag on a model is commonly presented in its non-dimensional form, also known as the coefficient of drag, C_D. The drag coefficient is calculated as

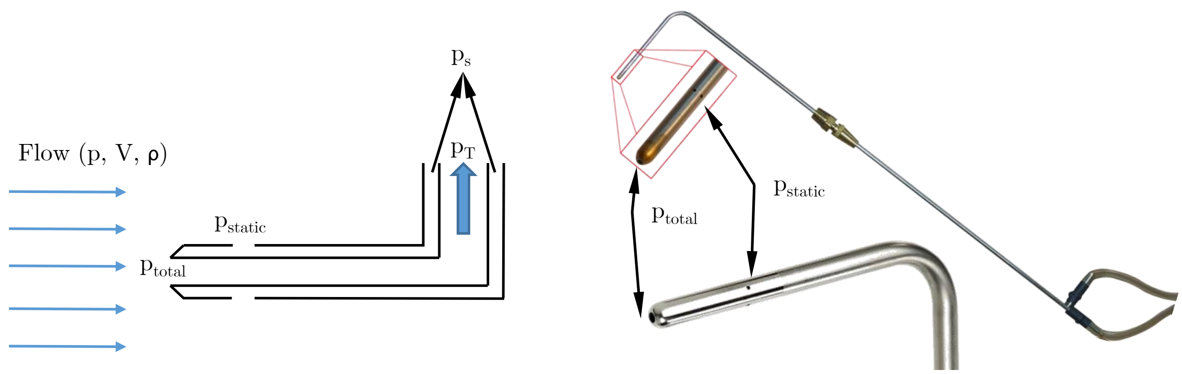
$$C_D = \frac{F_D}{\frac{1}{2} \rho {U_\infty}^2 s c} \tag{5}$$

wnere c is the chord length of the airfoil.

3.1.1 Pitot-static Probe

A pitot tube along with a static wall pressure tap can be used in the wind tunnel to measure the velocity. The assumption we have to make is that the static pressure is constant everywhere in a *uniform* free-stream inside the wind tunnel. This is a reasonable assumption considering that there is no pressure loss, therefore, no pressure gradient, in the tunnel.

However, the situation will be very different for measurements taken inside a wake behind a bluff body where a significant amount of pressure variation (both total and static) exists across the wake profile. In order to accurately determine the velocity profile in the wake, a pitot-static tube should be used to allow for the total and static pressure to be measured at each location. The pitot-static tube, a sketch of which is shown in figure 3, is a combination of the static tube and a pitot (total pressure) tube.



(a) (b)

Figure 3: (a) Schematics of a pitot-static probe and (b) Photos of example pitot-static probes from Aerolab, LLC and United Sensor Corporation.

The velocity at the point of measurement can be computed using Eq. 6.

$$u = \sqrt{\frac{2 \times (p_T - p_s)}{\rho}} \tag{6}$$

It is usually more difficult to accurately measure the static pressure. The difference between the true and measured static pressure may be due to: misalignment of the tube axis and the flow velocity vector, finite tube diameter (streamlines next to the tube must be different from those in the undisturbed flow, hence the mere presence of the probe results in a static pressure value that is different from the actual pressure of the undisturbed flow), and/or influence of the tube support leading edge.

4 Apparatus Used in Experiments

1. Closed-circuit Wind Tunnel
2. Pitot-static probe
3. 3D Printed NASA EET Airfoil
4. Analog output pressure transducer (PX138-0.5DV)
5. Analog/Digital computer based DAQ system
6. Linear traverses (x,y) with stepper motor (y)
7. Motor controller

5 Experimental Procedure

NOTE: The Instructor will explain the procedure to operate the wind tunnel in a safe manner. Please follow the instructions carefully and do not use the wind tunnel prior to being instructed. Always start the wind tunnel at low speeds and vary the speeds slowly.

5.1 Wake Measurement

1. Ensure the wind tunnel breaker is switched on and the cooling water is running. Slowly ramp the tunnel frequency drive to 20Hz.
2. Ensure that the pitot-static tube is within the test section of the wind tunnel. Align the pitot-static tube such that it is in line with the quarter-chord of the airfoil (point of rotation). The pitot-static tube can be traversed in the x-direction manually and in the y-direction via stepper motor. First, reach x/c=-1, then use the LabVIEW Compumotor_Move VI to control the stepper motor to reach y/c=0, approximately.
3. With the pitot-static tube properly centered, move it 45mm downwards using the LabVIEW Compumotor_Move VI.
4. Measure and record the upstream dynamic pressure by using the LabVIEW Airfoil_Pressure_Profile VI. Use the static pressure of the tunnel, p_∞. Name the file [alpha_0_xbc_-1_pt-pinf]. Record the pressure from LabVIEW on your data sheet for each vertical location. The program waits for an input to move to the next point.
5. Change the static reference pressure to p_2 and repeat Step 4. Name the file accordingly: [alpha_0_xbc_-1_pt-p2].
6. To move downstream of the airfoil, the pitot-static tube must pass over the airfoil. Use the LabVIEW Compumotor_Move VI to move 90mm upwards. Then manually traverse the system to x/c=1. Ensure downwards motion is unobstructed, then move downwards to the start location.
7. Repeat Step 5 for x/c=1. Change the file names to the correct x/c location.
8. Move to the x/c=1.5 location and repeat Step 5. Change the file names to the correct x/c location.
9. Turn the tunnel off and change the airfoil's angle of attack (α) to 8°.
10. Repeat Step 8 for $\alpha = 8°$. Change file names accordingly.
11. Repeat Step 7 for $\alpha = 8°$. Change file names accordingly.
12. Use previous knowledge from Step 6 to move the pitot-static tube upstream of the airfoil to x/c=-1.
13. Repeat Steps 4 and 5 for $\alpha = 8°$. Change file names accordingly.

Note: Please ensure all data files are copied from your file folder for processing. (USB Drive or E-MAIL)