Experiment 5 : Airfoil Wake Drag

AS2510 Low Speed Lab

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Aim

To determine the drag generated by the airfoil and calculate its C_d using Wake Drag Theory

Apparatus

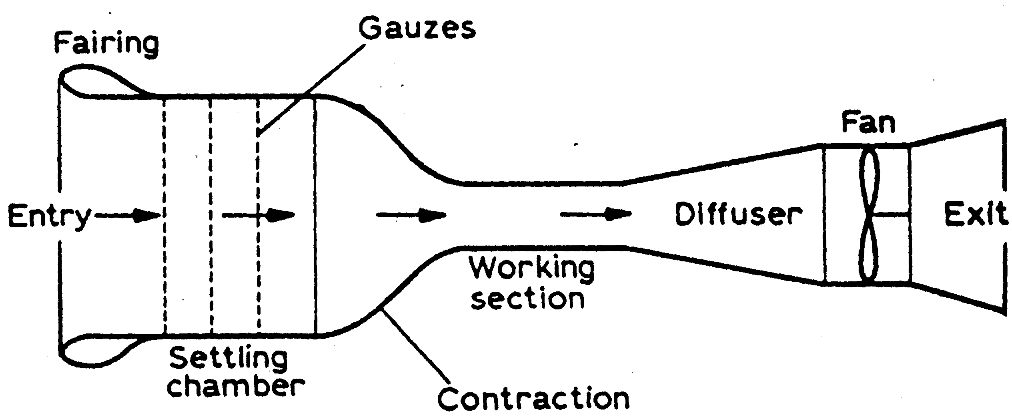

Figure 1: Schematic of open return wind tunnel used in experiment

The apparatus is similar to the one depicted above. The tunnel cross section in the working section is 150 mm x 150 mm throughout. A NACA0015 Airfoil model (with chord length c = 65 mm) is kept in the working section with probes attached to its upper surface only.

Downstream the airfoil, pitot probes are placed symmetrically about the trailing edge of the airfoil to measure the pressure inside the wake generated by the airfoil.

In our experimental set-up, there are 12 ports located at distances y_i from the trailing edge, perpendicular to it :

Port no.	1	2	3	4	5	6	6.5	7	7.5	8	9	10
y_i(mm)	27	21	15	9	3	-3	-6	-9	-12	-15	-21	-27

Table 1: Position of Pressure Probes

To get measurements from this apparatus we use a flow meter.

We use a static pressure tap to measure the static pressure at different points in the flow. We also use a pitot tube to measure and verify the stagnation pressure. These are recordeded with the help of a flow meter.

Since the source of the flow is the atmosphere, we know the stagnation pressure to be equal to the atmospheric pressure. The head loss in the low-speed flow is negligible as compared to the initial stagnation pressure and hence we use the atmospheric pressure as the stagnation pressure.

Principle

A body immersed in a flowing fluid is exposed to both pressure and viscous forces. The sum of the forces that acts normal to the free-stream direction is the lift, and the sum that acts parallel to the free-stream direction is the drag.

Wake surveys are a common method for measuring profile drag. The wake survey measures static pressures and the decrease in total pressure within the wake and compares those values to the free-stream total pressure. This pressure deficit, or essentially the momentum loss of the flow, can then be directly related to the profile drag.

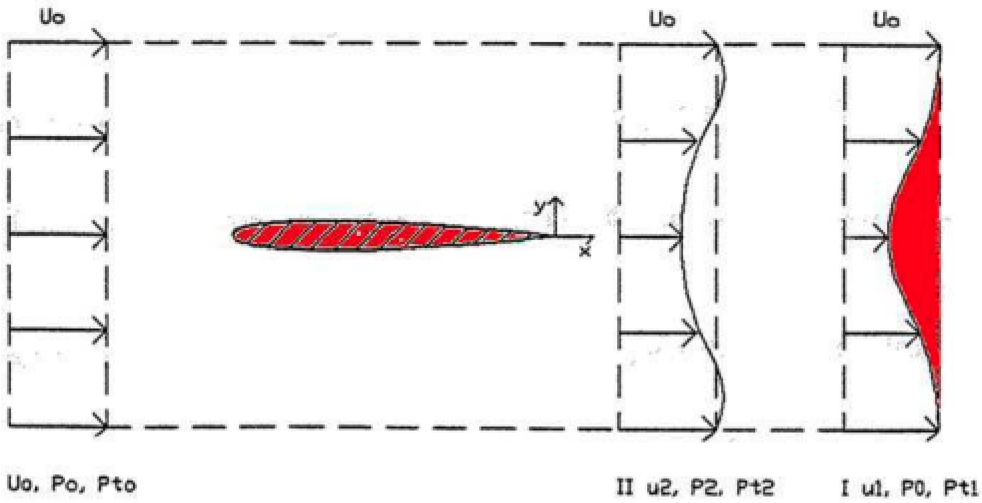

Figure 2: Momentum loss of flow over an Airfoil

The shaded area represents the total moment loss and integrating this area gives the profile drag. A wake survey measures drag by collecting pressure readings in the wake and in the free-stream; the difference in these pressures translates to the loss of momentum in the flow. The losses are greatest in the center of the wake and decrease moving outward until free-stream momentum is achieved.

While it is difficult to measure the velocities in the wake, Bernoulli's equation provides a relationship between velocity, static pressure, and dynamic pressure

$$p_0 = p_\infty + 0.5\rho u^2$$

Applying the continuity and momentum equations on the control volume on the test-section excluding only the airfoil, we get an integral equation of drag.

$$\boxed{D = \int_{II} \rho u (u - U_\infty)\, dy}$$

the velocity u at various y locations can be found from the Bernoulli's equation

$$u(y) = \sqrt{\frac{2(p_0(y) - p_\infty)}{\rho}}$$

Procedure

1. Set-up the apparatus with a steady flow
2. Measure the static pressure upstream using the pressure probes on the apparatus
3. measure the total pressure downstream using the pitot tube
4. With the static pressure , stagnation pressure measurements calculate the Drag.

Results

Calculations & Results

Atmospheric Pressure (p_o) : 101325 Pa
Density (ρ_∞) = 1.2754 kg/m^3

Static Pressure upstream p_∞ = 101,069.92 Pa
Angle of Attack = 2 degrees
U_∞ = 20 m/s
c = 65mm

Port no.	y-coord (in mm)	gauge pressure (mm H_2O)	total pressure (Pa)	velocity u (m/s)	$\lvert u-U_\infty \rvert$ (m/s)	$u\lvert u-U_\infty \rvert$ $(m/s)^2$
1	27	-0.6	101,319.12	19.77	0.23	4.59
2	21	-0.6	101,319.12	19.77	0.23	4.59
3	15	-0.65	101,318.63	19.75	0.25	4.97
4	9	-0.7	101,318.14	19.73	0.27	5.35
5	3	-0.8	101,317.15	19.69	0.31	6.10
5.5	0	-2.7	101,298.52	18.93	1.07	20.19
6	-3	-8.3	101,243.60	16.50	3.497	57.71
6.5	-6	-4.2	101,283.81	18.31	1.69	30.87
7	-9	-0.8	101,317.15	19.69	0.31	6.10
8	-15	-0.7	101,318.14	19.73	0.27	5.35
9	-21	-0.6	101,319.12	19.77	0.23	4.59
10	-27	-0.6	101,319.12	19.77	0.23	4.59

Table 2: Experiment Readings Pressure and Velocity in the Wake

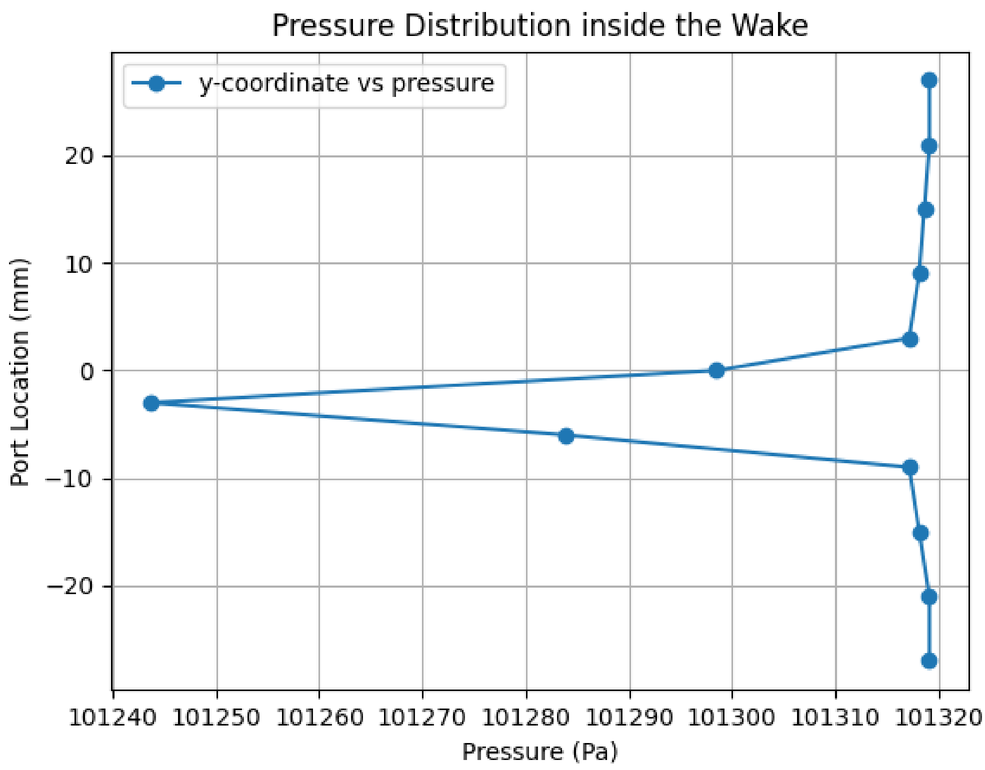

Figure 3: Plot showing the variation of Pressure in the Wake

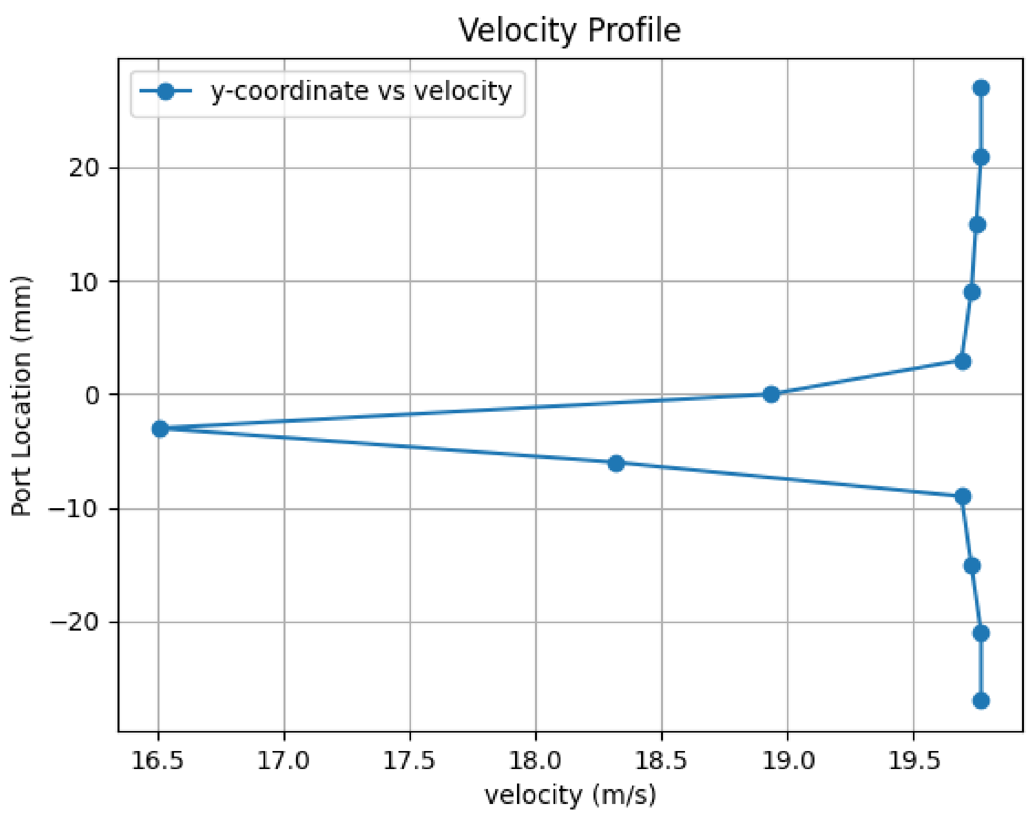

Figure 4: Plot showing the variation of velocity in the wake

We can calculate drag by performing discrete integation, by taking the average of value of velocity at the ports to estimate the flow velocity between them.

$$Drag\ per\ unit\ length = \rho \sum_{n=1}^{11} \frac{(u|u - U_\infty|_i + u|u - U_\infty|_{i+1})}{2} \times \frac{(|y_{i+1} - y_i|)}{1000}$$

Thus $\boxed{\textbf{Drag per unit length = 0.71135 N/m}}$

We can now calculate C_D as

$$C_D = \frac{Drag/span}{0.5\rho_\infty u_\infty^2 c}$$

Thus, we get $\boxed{C_D = \mathbf{0.0429}}$

Inference

We can see that the wake theory is an effective experimental method to determine the drag and drag coefficient of a body in a fluid flow. It is not accurate because the exact location of the wake can not be determined and we assume inviscid flow while simplifying the momentum equation on the control volume.