Experiment Experiment 8 : Drag calculation using C_p Distribution over Cylinder

AS2510 Low Speed Lab

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Aim

To determine the C_p distribution over a cylinder, and determine its drag and C_D

Apparatus

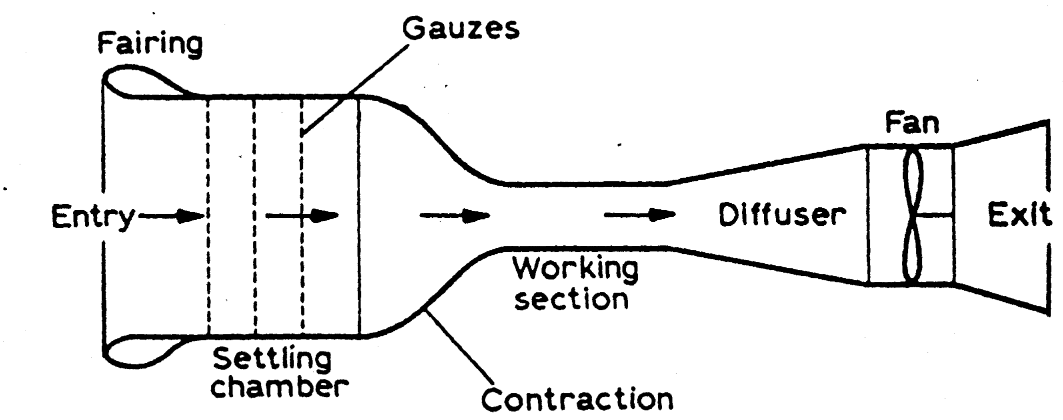

Figure 1: Schematic of open return wind tunnel used in experiment

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 plain cylinder model (with chord length c = 30 mm) is kept in the working section with 10 equispaced tapping points (18^{circ} apart) around half of the circumference that allows the pressure distribution around the cylinder to be measured. The cylinder can be rotated through 180^{circ} to plot the pressure distribution over the circumference.

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 recorded 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.

The flow over the cylinder can be modeled as a potential flow which is the solution to the following Laplace Equation

$$\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial \phi}{\partial r}) + \frac{1}{r^2}\frac{\partial^2 \phi}{\partial \theta^2}$$

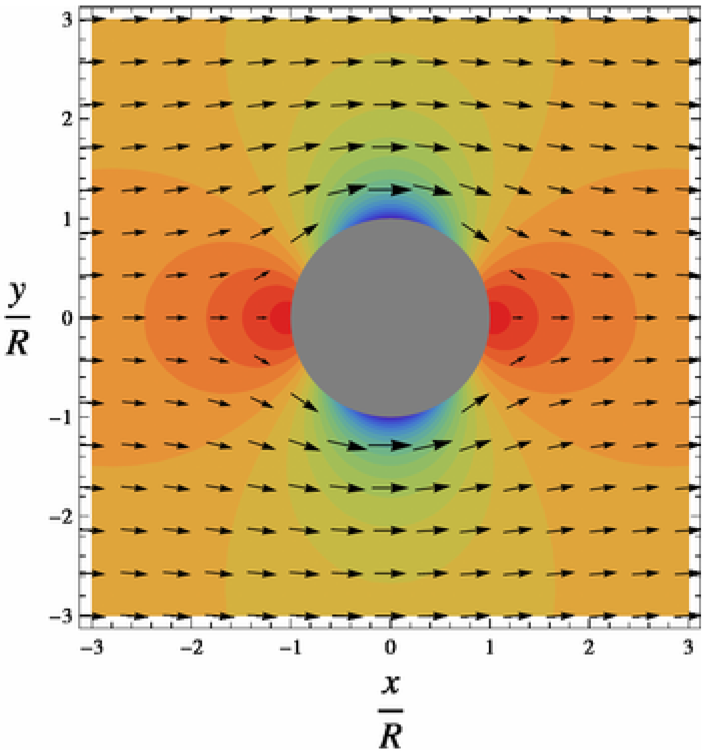

Figure 2: Potential flow around a cylinder

Since the cylinder is not permeable, there is only tangential velocity along it's surface. The potential flow modeling gives this velocity as

$$V_\theta = -U(1 + \frac{R^2}{r^2})sin\theta$$

Using Bernoulli's Equation between a point as infinity and a point on the surface of the cylinder, we can get the pressure distribution on the surface of the cylinder. For the surface of the cylinder, r = R.

The pressure coefficient is calculated using

$$C_p = \frac{p - p_\infty}{0.5\rho_\infty V_\infty^2} = 1 - 4sin^2\theta$$

We use discrete integration to calculate the Drag. The drag coefficient is then calculated using

$$C_L = \frac{L}{0.5\rho_\infty V_\infty^2 bc}$$

Procedure

1. Set-up the apparatus with a steady flow
2. Measure the pressure at different locations using the pressure probes on the apparatus
3. With the pressure measurements, stagnation pressure calculate the Pressure Coefficient.
4. Plot the variation of Pressure Coefficient about the surface of the cylinder.
5. Calculate the Drag and Drag Coefficient

Results

Calculations & Results

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

V_∞ = 22 m/s
Free Stream Pressure (P_∞) = 101,016.3532 Pa

To obtain the static pressure from the experimental readings, we use the following :

$$static\ pressure = absolute\ pressure = atmospheric\ pressure + gauge\ pressure$$

$$gauge\ pressure = measurement \times conversion\ factor$$

After which, the pressure coefficient is calculated using

$$C_{p_i} = \frac{p_i - p_\infty}{0.5\rho_\infty V_\infty^2}$$

	gauge pressure (mm H_2O)	static pressure (Pa)	theoretical C_P	experimental C_P
Port 0	0	101325.00	-2.6	-0.400
Port 1	-1.4	101311.27	-2.6	-0.400
Port 2	-12.8	101,199.45	-4.1	-0.630
Port 3	-45.8	100,875.86	-4.3	-0.661
Port 4	-75.8	100,581.66	-7.6	-1.169
Port 5	-75.4	100,585.58	-6.3	-0.969
Port 6	-73.1	100608.13	-8.2	-1.261
Port 7	-76.2	100,577.73	-8.1	-1.246
Port 8	-76.8	100,571.85	-8	-1.230
Port 9	-77.5	100,564.98	-8	-1.230
Port 10	-78.3	100,557.14	-7.4	-1.128

Table 1: Experiment Readings for Upper Surface

C_p variation on the cylinder's surface

The plot below shows the variation in free-stream velocity along the apparatus.

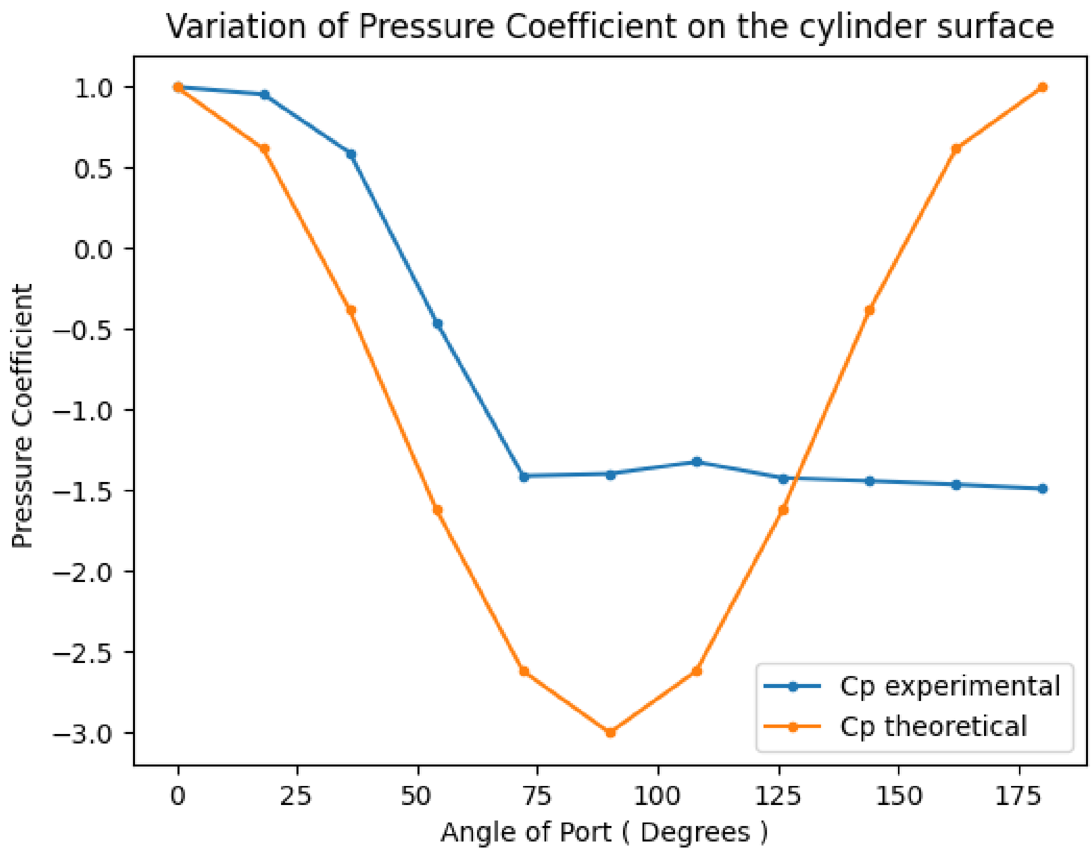

Figure 3: Plot showing the variation of C_p along the cylinder's upper surface

The variation will be similar for the lower surface owing to the symmetry of flow about the cylinder's diameter along the direction of the flow.

Calculation of Drag and C_D

To find the Lift, we need co-ordinates for the ports on the cylinder's surface.

Port no.	0	1	2	3	4	5	6	7	8	9	10
y	0	4.635	8.817	12.135	14.266	15	14.266	12.135	8.817	4.635	0

Table 2: Position of Pressure Probes on the Airfoil Section

Summing over the horizontal pressure forces on panels between the ports to obtain the drag

$$Drag\ per\ unit\ length\ (N/m) = 2 \times \sum_{i=1}^{10} \frac{(p_{i+1} + p_i)}{2} \frac{(y_{i+1} - y_i)}{1000}$$

Thus, we get $\boxed{Drag\ per\ unit\ span = \mathbf{16.3948\ N/m}}$

We can now calculate C_D as

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

Thus, we get $\boxed{C_D = \mathbf{1.77}}$

Inference

We can see that the expected distribution of pressure is not the same as the experimental distribution. This is because the flow is not ideal and separates from the surface of the cylinder. Ideal flow consideration does not take into account the viscous effects of the fluid.

Using Potential, theoretically, there is no drag. In reality, viscous forces exist and hence there is drag due to flow separation.