Experiment - 5

# Pressure distribution over a circular cylinder

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## 1. Aim :

- Analysing pressure distribution and flow behaviour through a circular cylinder.
- Comparison of Theoretical and Experimental Coefficient of pressure at different points on circular cylinder.

## 2. Apparatus :

Required apparatus for performing this experiment are:

- Manometer
- C15-10 Armfield tunnel
- Pitot-static Probe
- Fan


Figure 1: C15-10 Armfield

# 3. Theory :

Considering a circular cylinder immersed in a uniform flow,the streamlines are shown as :

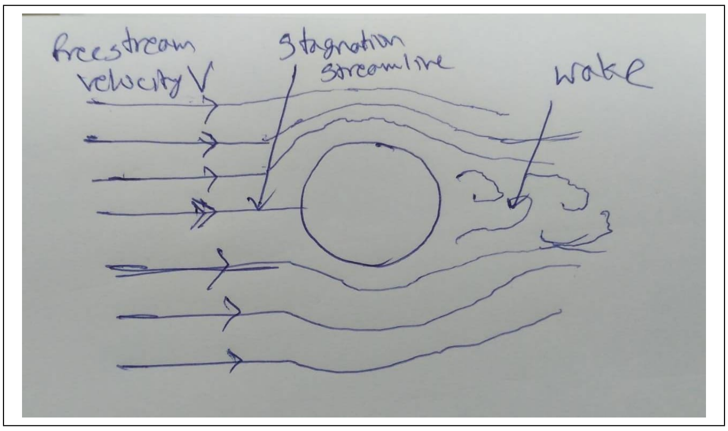


Figure 2: Streamlines of a flow through a circular Cylinder

At stagnation point ($P = P_0$),no lifting flow or drag exists.Here velocity becomes maximum and pressure becomes minimum. The pressure exerted by the fluid on the on the front half of the cylinder is higher than pressure exerted on rear half.If the difference of this pressure is multiplied by projected area Drag Force is obtained.Unequal pressure distribution is observed across the cylindrical surface.

For flow around a circular cylinder can be considered as a uniform flow with a doublet. Therefore,

$$W(z) = U_{\infty}Z + \frac{K}{Z}$$

Stream function($\Psi$) $= U_{\infty}rsin\theta - \frac{Ksin\theta}{r}$
Velocity potential ($\phi$) $= U_{\infty}rcos\theta + \frac{Kcos\theta}{r}$

Velocity components are given by,

$$V_r = \frac{1}{r}\frac{\delta\psi}{\delta\theta} = cos\theta(U_{\infty} - \frac{K}{r^2})$$

$$V_{\theta} = -\frac{\delta\psi}{\delta r} = -sin\theta(U_{\infty} + \frac{K}{r^2})$$

Velocity components on the surface of cylinder(r = a) are:
$V_{rs} = 0, V_{\theta s} = -2U_\infty sin\theta$

For $\theta = 0°$ and $180°$ , $V_{rs} = V_{\theta s} = 0$
These are the points denoting stagnation point. The velocity decreases from a value of $2U_\infty$ at $\theta = 90°$ to $U_\infty$ on moving away in a normal direction.
Applying Bernoulli equation,

$$P_\infty + \frac{\rho U_\infty^2}{2} = P_s + \frac{\rho V_{\theta s}^2}{2}$$

Substituting for $V_{\theta s} = -2U_\infty sin\theta$

$$C_p = \frac{P_s - P_\infty}{q_\infty}$$

$$C_p = 1 - 4\sin^2\theta$$

In the graph of $C_p$ vs $\theta$ it is observed in region to the right of the centreline seperation of flow is observed as viscous force dominates here.

Due to pressure difference flowing fluid exerts **Drag** . Skin friction between the fluid and the cylinder causes drag force.Coefficient of Drag ($C_d$) is calculated by :

$$C_d = \frac{D/l}{(1/2)\rho v^2 S}$$

S = $2\pi$ R

# 4. Procedure :

1. In wind tunnel test section is set.
2. Pitot-static probe is connected to manometer.
3. Fan speed is fixed.
4. Required readings are taken.

# 5. Observation :

## 5.1 For Velocity = 10.2 m/s :

Table 1: **Theoretical and Experimental $C_p$ at different points on the surface of a cylinder for velocity 10.2 m/s**

| Points | Angle(in degrees) | Gauge Pressure(in mm of water) | Theoretical $C_p$ | Experimental $C_p$ |
|---|---|---|---|---|
| $P_1$ | 0 | 0.3 | 1 | -0.044 |
| $P_2$ | 20 | 2.6 | 0.532 | -0.379 |
| $P_3$ | 40 | 9.9 | -0.653 | -1.442 |
| $P_4$ | 60 | 14.4 | -2 | -2.098 |
| $P_5$ | 80 | 13.7 | -2.879 | -1.996 |
| $P_6$ | 100 | 13.2 | -2.879 | -1.923 |
| $P_7$ | 120 | 13.5 | -2 | -1.967 |
| $P_8$ | 140 | 12.0 | -0.653 | -1.748 |
| $P_9$ | 160 | 14 | 0.532 | -2.040 |
| $P_{10}$ | 180 | 0.3 | 1 | -0.044 |

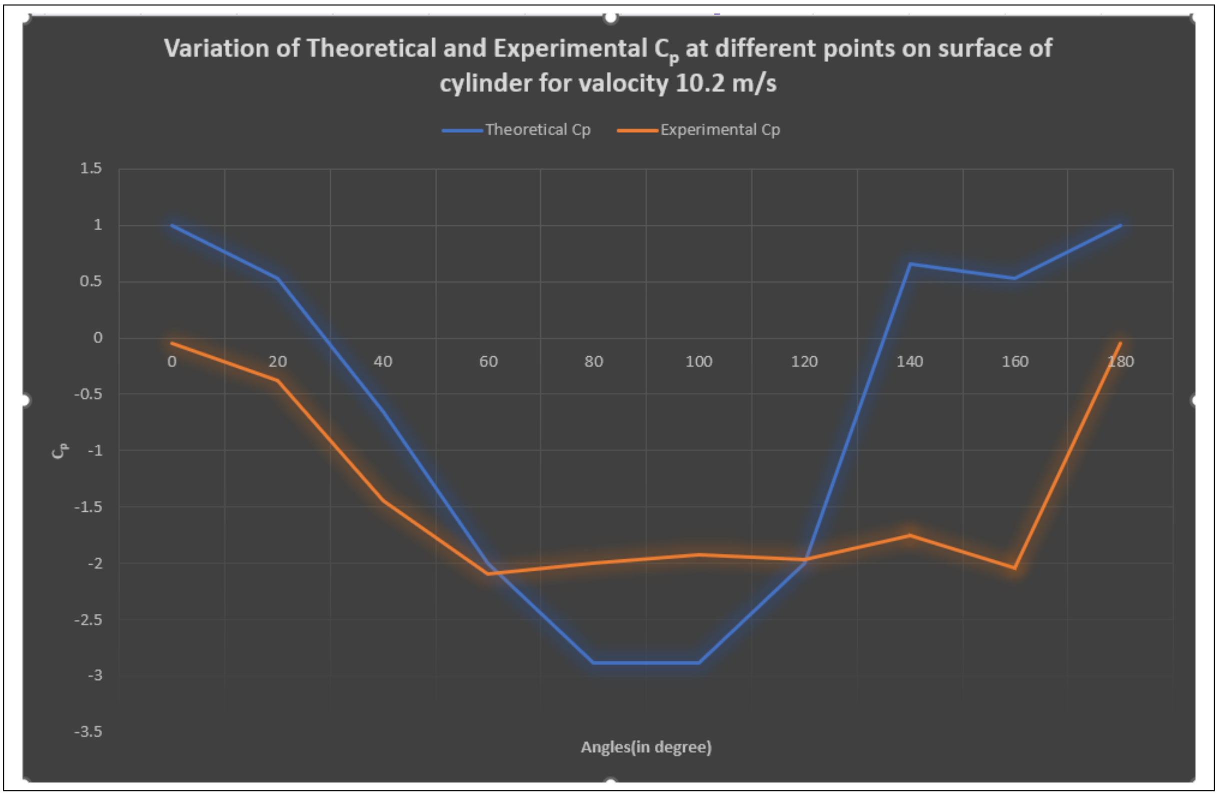


Figure 3: Variation of theoretical and experimental $C_p$ with Angles

## 5.2 For Velocity = 8.1 m/s :

Table 2: **Theoretical and Experimental $C_p$ at different points on the surface of a cylinder for velocity 8.1 m/s**

| Points | Angle(in degrees) | Gauge Pressure(in mm of water) | Theoretical $C_p$ | Experimental $C_p$ |
|---|---|---|---|---|
| $P_1$ | 0 | 0.3 | 1 | -0.069 |
| $P_2$ | 20 | 1.9 | 0.532 | -0.439 |
| $P_3$ | 40 | 4.4 | -0.653 | -1.017 |
| $P_4$ | 60 | 8.3 | -2 | -1.918 |
| $P_5$ | 80 | 8.2 | -2.879 | -1.895 |
| $P_6$ | 100 | 8 | -2.879 | -1.848 |
| $P_7$ | 120 | 8.1 | -2 | -1.871 |
| $P_8$ | 140 | 7.3 | -0.653 | -1.687 |
| $P_9$ | 160 | 8.2 | 0.532 | -1.895 |
| $P_{10}$ | 180 | 4.4 | 1 | -1.017 |

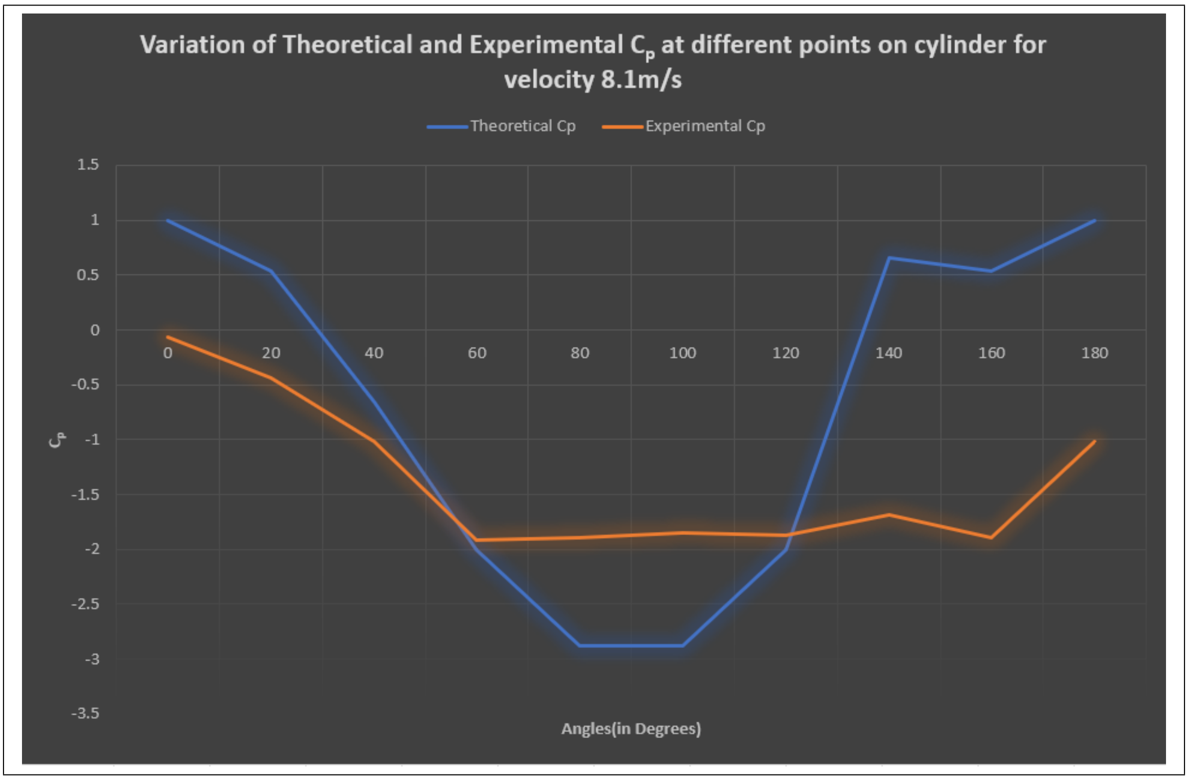


Figure 4: Variation of theoretical and experimental $C_p$ with Angles

### 5.3 For Velocity = 14.3 m/s

Table 3: **Theoretical and Experimental $C_p$ at different points on the surface of a cylinder for velocity 14.3 m/s**

| Points | Angle(in degrees) | Gauge Pressure(in mm of water) | Theoretical $C_p$ | Experimental $C_p$ |
|---|---|---|---|---|
| $P_1$ | 0 | 0.6 | 1 | -0.044 |
| $P_2$ | 20 | 5 | 0.532 | -0.371 |
| $P_3$ | 40 | 12.9 | -0.653 | -0.956 |
| $P_4$ | 60 | 20.3 | -2 | -1.505 |
| $P_5$ | 80 | 19.5 | -2.879 | -1.446 |
| $P_6$ | 100 | 19.1 | -2.879 | -1.416 |
| $P_7$ | 120 | 19.4 | -2 | -1.438 |
| $P_8$ | 140 | 17.3 | -0.653 | -1.282 |
| $P_9$ | 160 | 20.1 | -0.532 | -1.490 |
| $P_{10}$ | 180 | 0.3 | 1 | -0.022 |

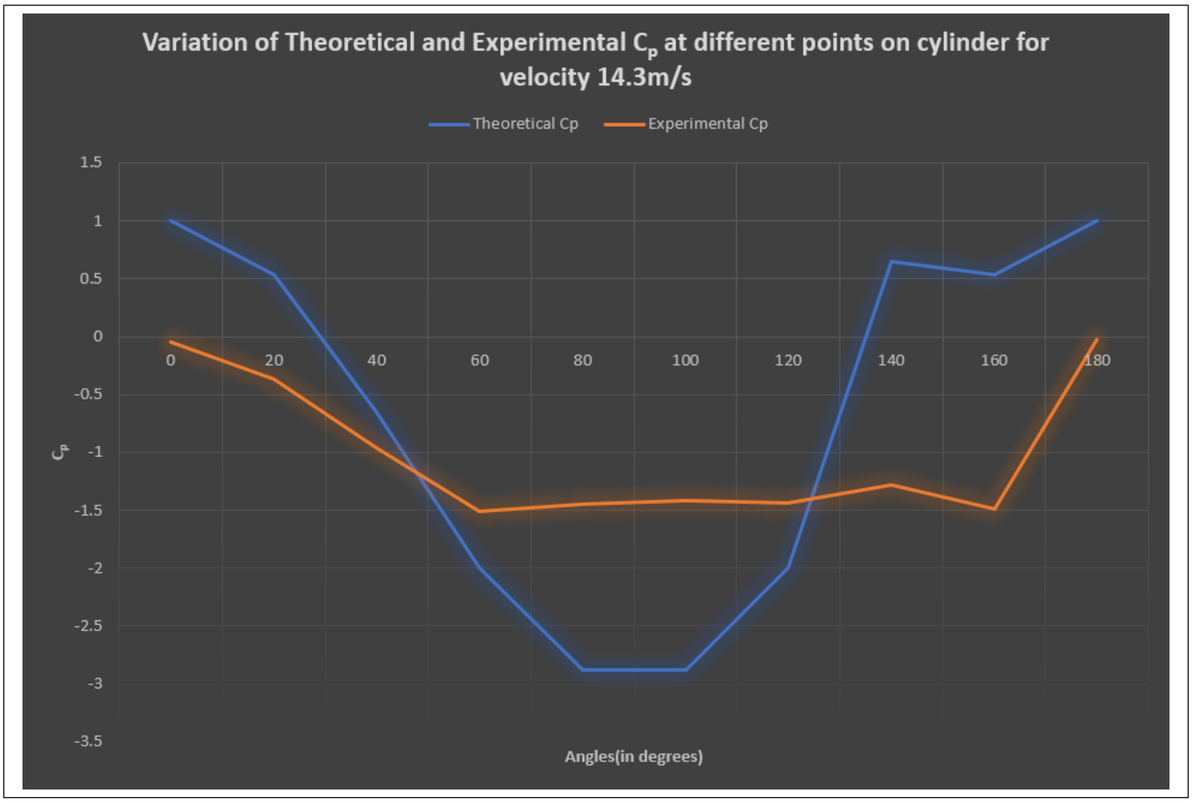


Figure 5: Variation of theoretical and experimental $C_p$ with Angles

**Drag vs Velocity :**

Table 4: **Variation of Drag with Velocity**

| Sl No. | Velocity | Drag($\theta = 0°$ to $\theta = 180°$ | Coeff of Drag($C_d$) |
|---|---|---|---|
| 1 | 8.1 | 0.54 | 0.135 |
| 2 | 10.2 | 1.24 | 0.196 |
| 3 | 12 | 1.82 | 0.207 |
| 4 | 14.3 | 2.63 | 0.211 |
| 5 | 16 | 3.43 | 0.220 |
| 6 | 18 | 4.25 | 0.215 |

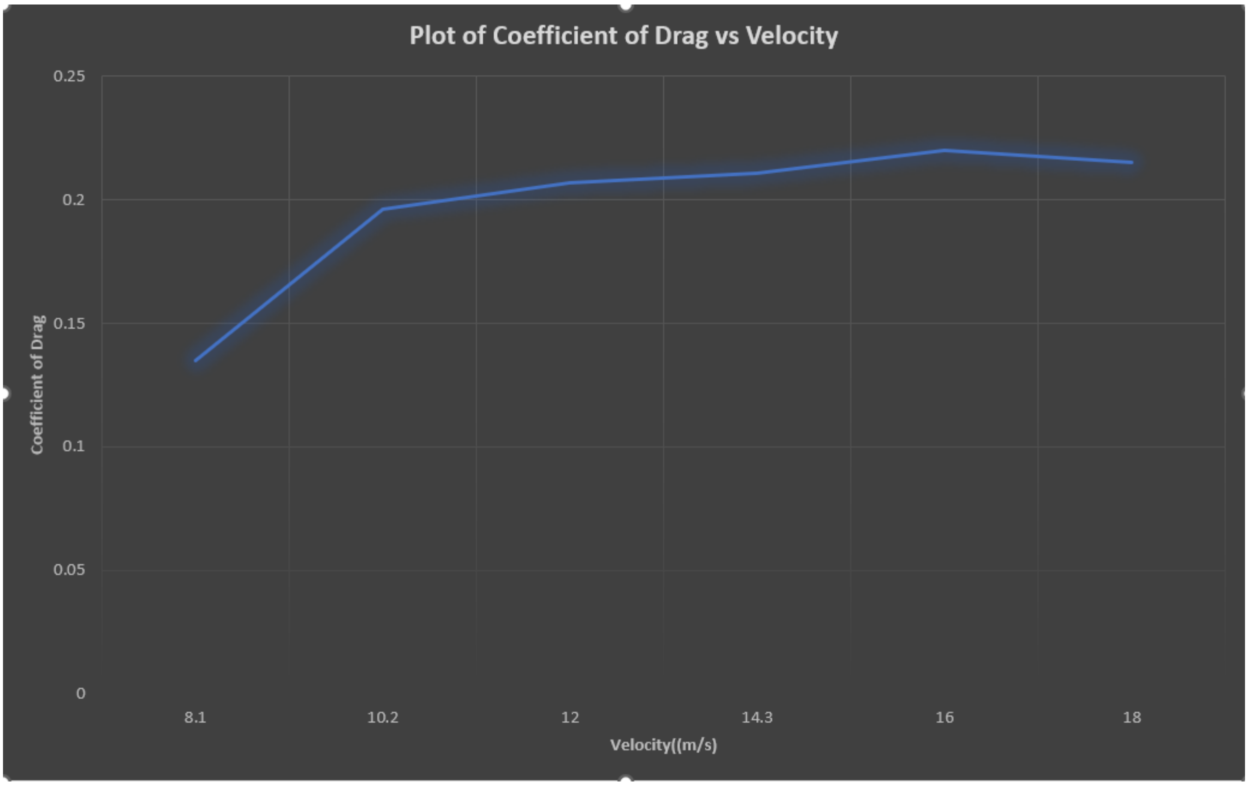


Figure 6: Variation of theoretical and experimental $C_p$ with Angles

# 6. Calculations :

## 6.1 Calculation of Coefficient of Pressure :

Coefficient of Pressure :

$$C_p = \frac{P - P_\infty}{\frac{\rho v^2}{2}} = 1 - 4sin^2\theta$$

For velocity 10.2 m/s ,
Gauge pressure at 0° = -0.3 mm of water = 2.94 = P-$P_\infty$
Experimental $C_p = \frac{P-P_\infty}{\frac{\rho v^2}{2}} = \frac{-0.3\times9.8}{(1/2)\times1.293\times10.2^2} = -0.044$

Theoretical $C_p = 1 - 4sin^2\theta = 1$ (Putting $\theta = 0°$ )

### 6.2 Calculation of coefficient of Drag :

**Drag :**

$$D/l = \sum_{i=1}^{10} (P - P_\infty) r (cos\theta_i) \Delta\theta_i$$

For velocity 10.2 m/s ,

$$D = 1.24N$$

**Coefficient of Drag :**

$$C_d = \frac{D/l}{(1/2)\rho v^2 S} = \frac{1.24}{(1/2) \times 1.293 \times 10.2^2 (2\pi \times 15 \times 10^{-3})} = 0.196$$

## 7. Sources of Error:

- Error due to instrumental defect.
- Error may occur in taking readings before flow becomes steady.
- Error due to environmental effect like temperature,pressure change.
- Error in measurement due to presence of zero error in parameters.

## 8. Conclusion :

- Theoretical seperation point is found just before 120° ($\approx$ 110°) but experimentally it is found between $140° and 160°$ .
- Experimental variation of $C_p$ deflects a litle from thepretical variation of $C_p$ with angles.
- Drag first increases then remains almost constant on increasing flow velocity.