DATE

EXPERIMENT NO.: 1

SHEET NO.

MEASUREMENT OF PRESSURE DISTRIBUTION AROUND A CYLINDER

OBJECTIVES:

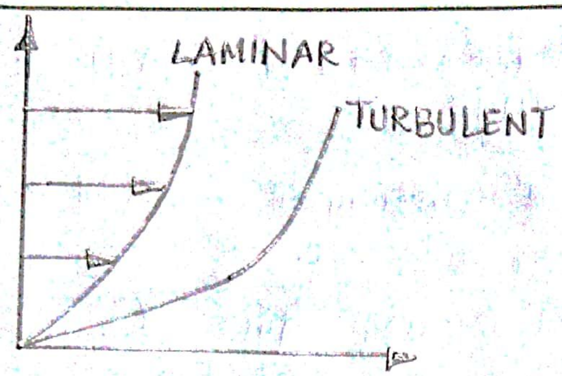
- Determination of pressure distribution and coefficient of pressure for the cylinder
- Comparison of experimental and theoretical values of C_P for the cylinder.

EXPERIMENTAL SETUP:

- Wind Tunnel
- Circular cylinder attached with a small pressure tapping
- Manometer

THEORY: When a flowing fluid is brought to rest isoentropically, the pressure at the point of rest is called total pressure or stagnation pressure. It is a conceptual pressure in the sense that the value of total pressure can be ascribed to each point in the flow whether the fluid at that point has come to rest or not.

There is no lift in purely symmetric flow. When there is viscosity, a boundary layer develops which is suscep--table to separation. It forms a wake and inside the wake the pressure is low. Thus behind the cylinder, pressure drop takes place. Due to unbalanced or unsymm--etric pressure distribution, there is an unbalanced force in the direction of flow. If flow separation is delayed then the width of wake is reduced. Thus force unbalance is lower and drag is smaller.



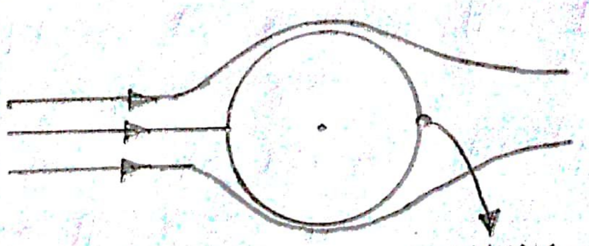
Pressure drag is lower for turbulent case as compared to laminar case.

There are 3 types of drag:

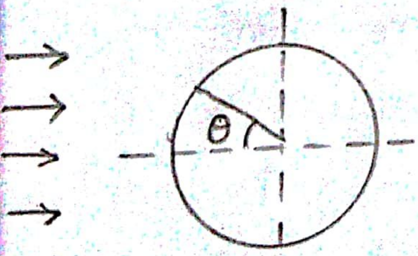
1) skin friction drag
2) Pressure drag/form drag.
3) Induced drag

For airfoils, skin drag is important. on a streamline body, pressure drag is small, while for a bluff body like cylinder, pressure drag is more dominant.

In theoretical analysis, the flow is considered to be invis-
-cid.



Here also, pressure is stagnation pressure.



$$P_{stag} = P_\infty + \frac{1}{2}\rho u_\infty^2$$

$$\frac{C_P}{C_{P_0}} = \frac{P - P_\infty}{P_{stag} - P_\infty} = \frac{P - P_\infty}{\frac{1}{2}\rho u_\infty^2}$$

$$\Rightarrow C_{P_{\theta_0}} = \frac{P_{stag} - P_\infty}{\frac{1}{2}\rho u_\infty^2} = 1 \qquad \left(C_{P_{\theta_0}} = C_{P_\theta} \text{ @ } \theta = 0^\circ\right)$$

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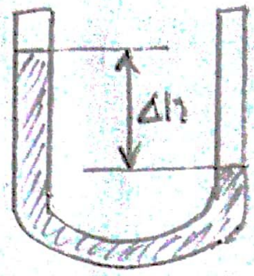
$$\Delta P = (\rho_w - \rho_a) g \Delta h \approx \rho_w g \Delta h$$



$$\frac{c_p}{c_{p_{\theta_0}}} = \frac{\Delta h \rho_w g}{\Delta h_0 \rho_w g} \Rightarrow \boxed{c_p = \frac{\Delta h}{\Delta h_0}}$$

In an inviscid flow,

$$\boxed{c_{p_{th.}} = 1 - 4\sin^2\theta}$$

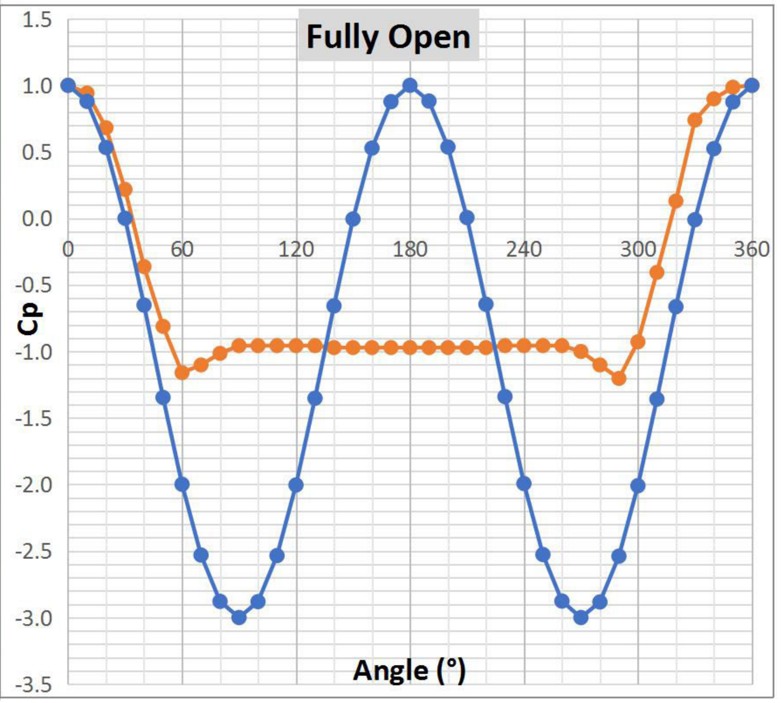
Coefficient of drag: $c_D = -\frac{1}{2}\int_0^{2\pi} c_p \cos\theta \, d\theta$

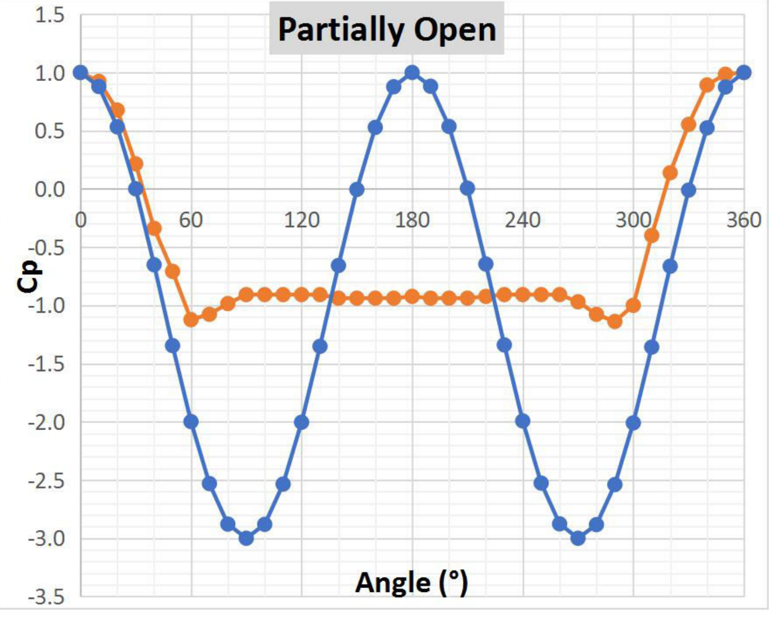
$$C_D = \frac{F_D}{\frac{1}{2}\rho u_\infty^2 A}$$

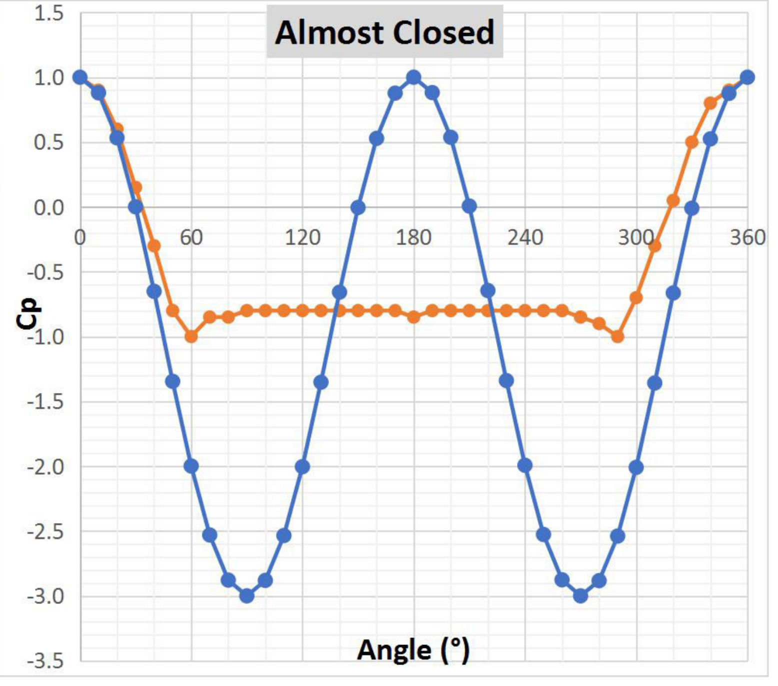
SCHEMATIC OF THE SETUP:

Refer Question 1 of the "Discussions"

			Fully Open		Partially Open		Almost Closed	
Angle (°)	Angle (Rad)	Cp_th	Δh	Cp	Δh	Cp	Δh	Cp
0	0.00	1.00	-6.9	1.00	-6.5	1.00	-2.0	1.00
10	0.17	0.88	-6.5	0.94	-6.0	0.92	-1.8	0.90
20	0.35	0.53	-4.7	0.68	-4.4	0.68	-1.2	0.60
30	0.52	0.00	-1.5	0.22	-1.4	0.22	-0.3	0.15
40	0.70	-0.65	2.5	-0.36	2.2	-0.34	0.6	-0.30
50	0.87	-1.35	5.6	-0.81	4.6	-0.71	1.6	-0.80
60	1.05	-2.00	8.0	-1.16	7.3	-1.12	2.0	-1.00
70	1.22	-2.53	7.6	-1.10	7.0	-1.08	1.7	-0.85
80	1.40	-2.88	7.0	-1.01	6.4	-0.98	1.7	-0.85
90	1.57	-3.00	6.6	-0.96	5.9	-0.91	1.6	-0.80
100	1.74	-2.88	6.6	-0.96	5.9	-0.91	1.6	-0.80
110	1.92	-2.53	6.6	-0.96	5.9	-0.91	1.6	-0.80
120	2.09	-2.00	6.6	-0.96	5.9	-0.91	1.6	-0.80
130	2.27	-1.35	6.6	-0.96	5.9	-0.91	1.6	-0.80
140	2.44	-0.66	6.7	-0.97	6.1	-0.94	1.6	-0.80
150	2.62	0.00	6.7	-0.97	6.1	-0.94	1.6	-0.80
160	2.79	0.53	6.7	-0.97	6.1	-0.94	1.6	-0.80
170	2.97	0.88	6.7	-0.97	6.1	-0.94	1.6	-0.80
180	3.14	1.00	6.7	-0.97	6.0	-0.92	1.7	-0.85
190	3.31	0.88	6.7	-0.97	6.1	-0.94	1.6	-0.80
200	3.49	0.54	6.7	-0.97	6.1	-0.94	1.6	-0.80
210	3.66	0.01	6.7	-0.97	6.1	-0.94	1.6	-0.80
220	3.84	-0.65	6.7	-0.97	6.0	-0.92	1.6	-0.80
230	4.01	-1.34	6.6	-0.96	5.9	-0.91	1.6	-0.80
240	4.19	-1.99	6.6	-0.96	5.9	-0.91	1.6	-0.80
250	4.36	-2.53	6.6	-0.96	5.9	-0.91	1.6	-0.80
260	4.54	-2.88	6.6	-0.96	5.9	-0.91	1.6	-0.80
270	4.71	-3.00	6.9	-1.00	6.3	-0.97	1.7	-0.85
280	4.88	-2.88	7.6	-1.10	7.0	-1.08	1.8	-0.90
290	5.06	-2.54	8.3	-1.20	7.4	-1.14	2.0	-1.00
300	5.23	-2.01	6.4	-0.93	6.5	-1.00	1.4	-0.70
310	5.41	-1.36	2.8	-0.41	2.6	-0.40	0.6	-0.30
320	5.58	-0.66	-0.9	0.13	-0.9	0.14	-0.1	0.05
330	5.76	-0.01	-5.1	0.74	-3.6	0.55	-1.0	0.50
340	5.93	0.52	-6.2	0.90	-5.8	0.89	-1.6	0.80
350	6.11	0.88	-6.8	0.99	-6.4	0.98	-1.8	0.90
360	6.28	1.00	-6.9	1.00	-6.5	1.00	-2.0	1.00







CALCULATIONS :

$$C_D = -\frac{1}{2}\int_0^{2\pi} C_p \cos\theta \, d\theta$$

By simpson's $\frac{1}{3}$ rule,

$$\int_a^b f(x)dx = \frac{h}{3}\left[f(a) + f(b) + 4\sum_{\substack{i=1\\ i=i+2}}^{n-1} f(x_i) + 2\sum_{\substack{i=2\\ i=i+2}}^{n-2} f(x_i)\right]$$

where $h = \frac{b-a}{n}$ $\quad n \rightarrow$ number of intervals.

Case : $\theta = 10°$ (for fully opened case)

$C_{P_{th}} = 1 - 4\sin^2\theta = 0.879$

$\Rightarrow \boxed{C_{P_{th}} = 0.879}$

$C_p = \frac{\Delta h}{\Delta h_0} = \frac{-6.5}{-6.9} = 0.94$

$\Rightarrow \boxed{C_p = 0.94}$

For calculating C_D (fully opened case)

$$C_D = \frac{1}{2}\int_0^{2\pi} C_p \cos\theta \, d\theta = \frac{1}{2}\cdot\frac{2\pi}{36}\cdot\frac{1}{3}\left[f(0) + 4\sum_{i=odd} f(x_i) + 2\sum_{i=even} f(x_i) + f(2\pi)\right]$$

$$\Rightarrow C_D = \frac{\pi}{108}\left[1\cos 0 + 4(0.94\cos(10°) + \ldots) + 2(0.68\cos(20°) + \ldots + 1\cos 2\pi\right]$$

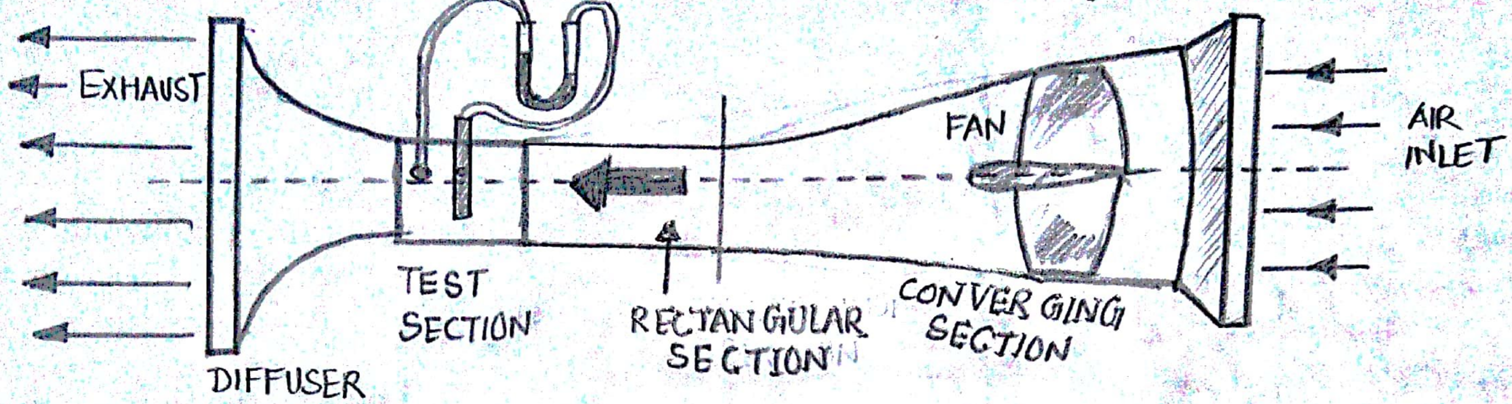
$$= \frac{\pi}{108} \times 39.473$$

$\Rightarrow \boxed{C_D = 1.148}$

DISCUSSIONS:

Q1. With the help of a schematic diagram of a wind tunnel describe its different components.

Ans.



OPEN RETURN WIND TUNNEL

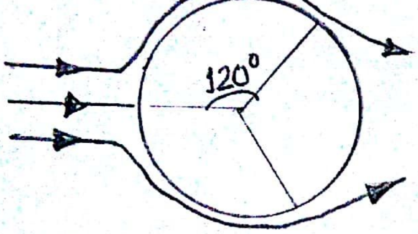
Components of the wind tunnel

- **FAN:** The fan is needed to draw air from air inlet.
- **CONVERGING SECTION:** It is needed to increase the speed of the incoming air
- **RECTANGULAR SECTION:** It is needed for the complete development of the velocity (profile) which comes from converging section.
- **TEST SECTION:** In the test section, the cylinder is placed and is connected to the manometer. The other end of the manometer is connected to a stable point downstream.
- **DIFFUSER:** It is required to reduce the velocity of exiting air.

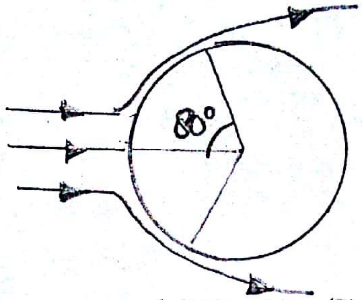
Q2. Comment on the difference between Cp values obtained experimentally and theoretically.

Ans. In the theoretical case, flow is considered to be inviscid. So, no flow separation takes place and pressure distribution is sinosoidal and symmetric.

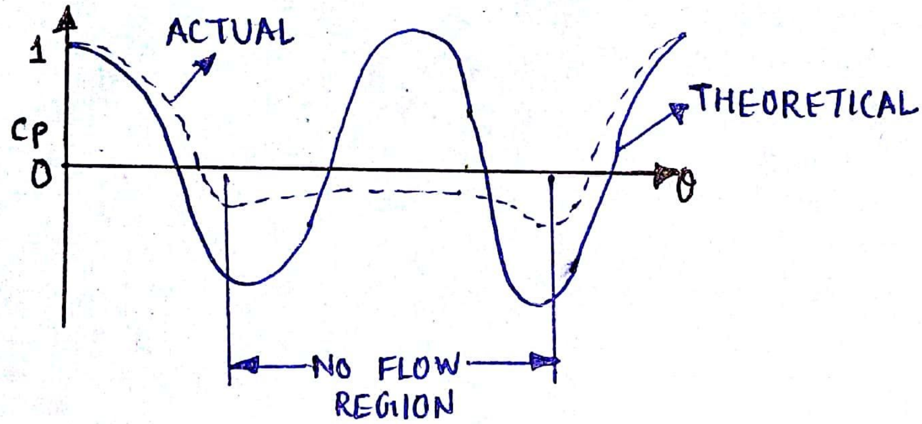
For viscid flow, boundary layer separation takes place at a certain angle after which there is no flow around the cylinder. This angle is small for laminar flow and larger for turbulent flow.



TURBULENT FLOW



LAMINAR FLOW



In case of theoretical calculations, the assumptions are:

i) flow is irrotational

ii) inviscid

iii) incompressible

These assumptions are not valid in practical situation which results in deviation from theoretical results.

Q3. what is separation?

Ans. Laminar flow is vulnerable to adverse pressure gradient on the end of the cylinder and separation occurs at about 80° which is not predicted in inviscid theory

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In case of turbulent flow, the increased transport of momentum from the free stream to the wall increases the stream wise momentum in the boundary layer. The flow does separate but it occurs at a greater angle (about 120°)

Due to adverse pressure gradient the fluid in proximity to the surface gradually starts separating from the boundary layer provoking a backflow. This is called boundary layer separation.

Q4 What is drag? Name a few methods for reducing it.

Ans. Drag is the opposing force exerted by the moving fluid past the body or for a body moving in a fluid.

Drag can be reduced by making holes on the surface and altering the boundary layer thereby reducing the drag due to boundary layer.

Design of the geometry should be such that boundary layer separation is avoided or kept at a minimum as in the case of a streamlined flow.