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ME224 Lab 5

Experiment 5: Pressure distribution for flow around a circular cylinder

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Aim: To study the pressure distribution for flow around a circular cylinder and compare it with the theoretical predictions

* Working and Calculations

Last two digits - 94

Using sr no - $(94-76) = \boxed{18}$

[Diameter of cylinder = 8 mm]

→ For Rough Ck Cylinder, using sr no 18 ⇒ Given: Angular Position$(\theta) = 85°$

$h_2 - h_1 = -16.6$ cm

~~Common for Rough and Smooth cylinders~~

$$\text{Using } \theta = 0 \text{ to find } V_\infty = \sqrt{\frac{2(P_0 - P_\infty)}{\rho_{air}}} = \sqrt{\frac{2\rho g(h_2-h_1)}{\rho_{air}}} = \sqrt{\frac{2\times1000\times(.16)\times9.8}{1.2}} = 51.12077203 \text{ m/s}$$

$$R_e = \frac{\rho V D}{\mu} = \frac{\rho V D}{\rho \nu} = \frac{51.12077203\times0.008}{0.000016} = 25560.38602$$

$$\text{We know experimental } C_p = \frac{P_{\theta=85} - P_\infty}{\frac{\rho V_\infty^2}{2}} = \frac{2\rho g(h_2-h_1)}{\rho V_\infty^2} = \frac{2\times1000\times9.8\times-16.6}{1.2\times(51.12077203)^2} = \boxed{-1.0375}$$

$$C_{p\,theoretical} = 1-4\sin^2\theta = 1-4\sin^2 85 = \boxed{-2.96962}$$

→ For smooth cylinder using sr no 18 - Given: Angular Position$(\theta) = 85°$

$h_2 - h_1 = -16.7$ cm

$$V_\infty = \sqrt{\frac{2(P_{\theta=0} - P_\infty)}{\rho_{air}}} = \sqrt{\frac{2\times\rho g(h_2-h_1)}{\rho_{air}}} = \sqrt{\frac{2\times1000\times9.8\times(15.3)}{1.2\times100}} = \boxed{49.989999} \text{ m/s}$$

$Re = \frac{\rho v D}{\rho \nu} = \frac{vD}{\nu} = \frac{49.989999 \times 0.008}{0.000016} = \boxed{24995}$

We know $C_p|_{expt} = \frac{P_\theta - P_\infty}{\frac{\rho V_\infty^2}{2}} = \frac{2\rho g(h_2-h_1)}{\rho V_\infty^2} = \frac{2\times1000\times9.8\times(-16.7)}{1.2\times(49.989999)^2} = \boxed{-1.091503268}$

$C_p|_{theoretical} = 1-4\sin^2\theta = 1-4\sin^2(85) = -2.96962$

* Sources of error

1) Human error while setting angle of the cylinder during the experiment
2) Parallax error while reading the heights h_1 and h_2 from the manometer
3) We assume that air flow from the blower is uniform and there are no fluctuations
4) We assume the air flow to be inviscid (for theoretical C_p), while there are always viscous forces.

* Questions and answers

Q1) When there is flow separation, we observe a favourable pressure for $\theta \in (0,90)$ and then a recovery adverse pressure from $90° < \theta < 180°$. This ensures 0 drag force. Due to the flow separation, the body experiences a recovery pressure only till the point of separation. The smaller is the angular position of the point of separation, less is the recovery and more the drag force

Q2) In laminar flow (low Re):
The boundary layer is laminar and inertial forces are lower compared to viscous forces. Adverse pressure balances inertial forces and point of separation comes early. This reduces pressure recovery and causes more drag.

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In Turbulent Flow (High Re):
The boundary layer is turbulent, and inertial forces are more than viscous forces hence more adverse pressure is required to balance ~~inertial~~ inertial forces. This causes flow separation to occur at a larger angular position. This increases pressure recovery and causes lower drag.

Increased Roughness:
Rough surfaces cause the boundary layer ~~to~~ to turn turbulent and hence reduces drag. The point of separation would have a larger angular position.

Q3) Roughness causes fluid flow to turn turbulent which results in the point of separation to have a larger angular position. This results in more pressure recovery and drag reduces.

Q4) Birds have feathery bodies so as to reduce drag during flight. ~~Be~~ Feathers make their bodies rough and make the boundary layer turbulent.

Q5) ~~Bet~~ Reading the lower meniscus of water and result in error. We should use a liquid with a contact angle of 90° and a low density so that we get a better resolution.

* Conclusions
→ The point of separation ~~oc~~ occurs later in the rough cylinder than in the smooth cylinder as ~~see~~ observed from the experimental data. This matches our theoretical results as well.

→ Cp(experimental) vs Cp(theoretical) data shows a huge difference. We can comment that fluid flow is viscous in nature, contradicting ~~out of~~ our original assumption.

Denisty of air	1.2	kg/m3
Diameter of cylinder	0.008	m
Kinematic Viscosity of air	1.60E-05	m2/s
Density of Water	1000	kg/m3

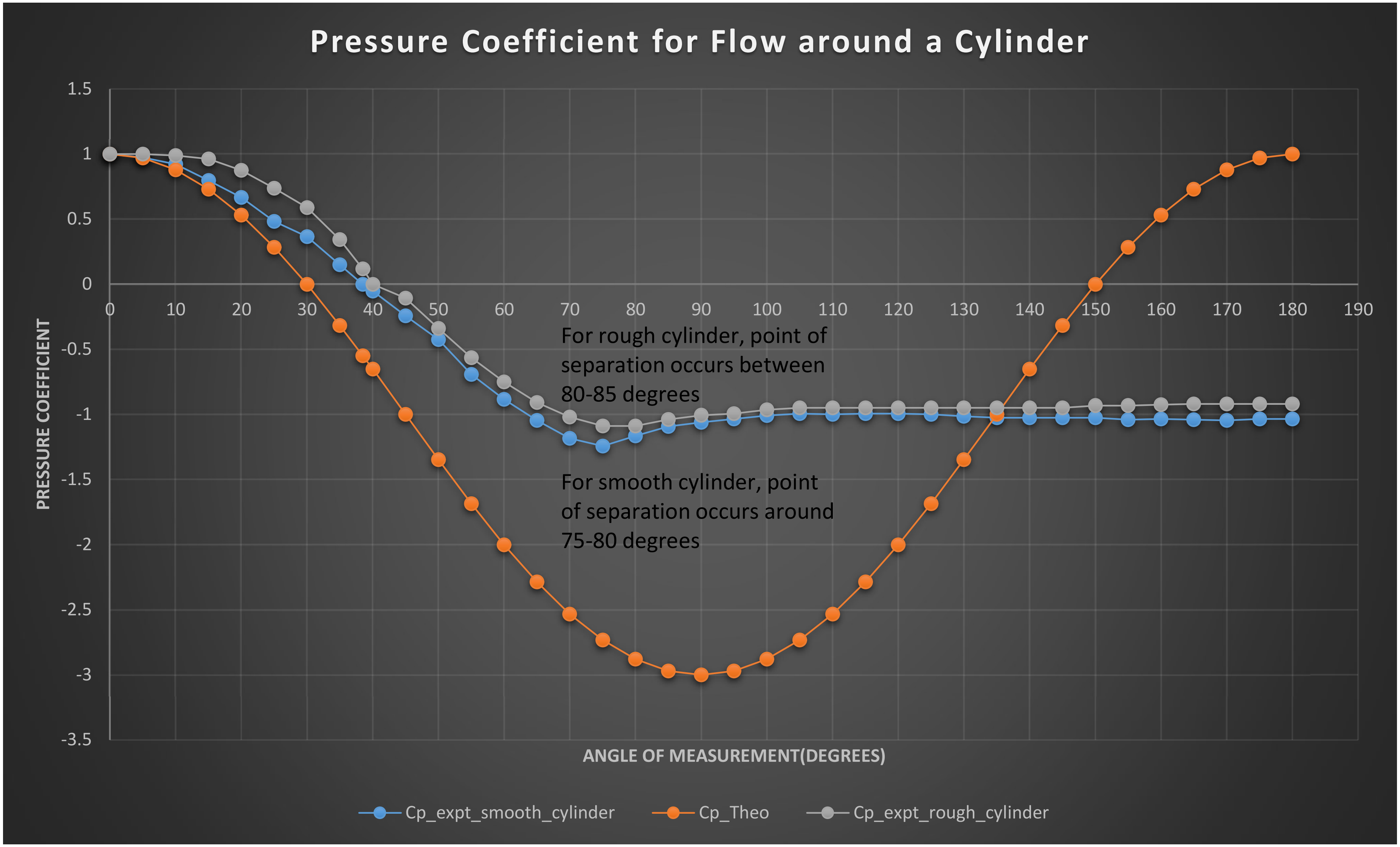
Smooth Cylinder (Fully Open)

Sr. No.	Angular Position	h2 (upstream) (cm)	h1 (cylinder) (cm)	h2-h1 (cm)	Vinfi (m/s)	Re	Cp_expt	Cp_Theo
					needs to be calculation only once	needs to be calculation only by once		
0	0	7.9	-7.4	15.3	49.989999	24995.00	1	1
1	5	7.7	-7.2	14.9	49.989999	24995.00	0.973856209	0.969615506
2	10	7.3	-6.8	14.1	49.989999	24995.00	0.921568627	0.879385242
3	15	6.3	-5.9	12.2	49.989999	24995.00	0.797385621	0.732050808
4	20	5.3	-4.9	10.2	49.989999	24995.00	0.666666667	0.532088886
5	25	3.9	-3.5	7.4	49.989999	24995.00	0.483660131	0.285575219
6	30	2.9	-2.7	5.6	49.989999	24995.00	0.366013072	0
7	35	1.2	-1.1	2.3	49.989999	24995.00	0.150326797	-0.315959713
8	38.5	0	0	0	49.989999	24995.00	0	-0.550097891
9	40	-0.4	0.4	-0.8	49.989999	24995.00	-0.052287582	-0.652703645
10	45	-1.9	1.8	-3.7	49.989999	24995.00	-0.241830065	-1
11	50	-3.4	3.1	-6.5	49.989999	24995.00	-0.424836601	-1.347296355
12	55	-5.5	5.1	-10.6	49.989999	24995.00	-0.692810458	-1.684040287
13	60	-7	6.5	-13.5	49.989999	24995.00	-0.882352941	-2
14	65	-8.3	7.7	-16	49.989999	24995.00	-1.045751634	-2.285575219
15	70	-9.4	8.7	-18.1	49.989999	24995.00	-1.183006536	-2.532088886
16	75	-9.8	9.2	-19	49.989999	24995.00	-1.241830065	-2.732050808
17	80	-9.2	8.6	-17.8	49.989999	24995.00	-1.163398693	-2.879385242
18	85	-8.6	8.1	-16.7	49.989999	24995.00	-1.091503268	-2.969615506
19	90	-8.4	7.8	-16.2	49.989999	24995.00	-1.058823529	-3
20	95	-8.2	7.6	-15.8	49.989999	24995.00	-1.032679739	-2.969615506
21	100	-8	7.4	-15.4	49.989999	24995.00	-1.006535948	-2.879385242
22	105	-7.9	7.3	-15.2	49.989999	24995.00	-0.993464052	-2.732050808
23	110	-7.9	7.4	-15.3	49.989999	24995.00	-1	-2.532088886
24	115	-7.9	7.3	-15.2	49.989999	24995.00	-0.993464052	-2.285575219
25	120	-7.9	7.3	-15.2	49.989999	24995.00	-0.993464052	-2
26	125	-7.9	7.4	-15.3	49.989999	24995.00	-1	-1.684040287
27	130	-8	7.5	-15.5	49.989999	24995.00	-1.013071895	-1.347296355
28	135	-8.1	7.6	-15.7	49.989999	24995.00	-1.026143791	-1
29	140	-8.1	7.6	-15.7	49.989999	24995.00	-1.026143791	-0.652703645
30	145	-8.1	7.6	-15.7	49.989999	24995.00	-1.026143791	-0.315959713
31	150	-8.1	7.6	-15.7	49.989999	24995.00	-1.026143791	0
32	155	-8.2	7.7	-15.9	49.989999	24995.00	-1.039215686	0.285575219
33	160	-8.1	7.7	-15.8	49.989999	24995.00	-1.032679739	0.532088886
34	165	-8.2	7.7	-15.9	49.989999	24995.00	-1.039215686	0.732050808
35	170	-8.3	7.7	-16	49.989999	24995.00	-1.045751634	0.879385242
36	175	-8.2	7.6	-15.8	49.989999	24995.00	-1.032679739	0.969615506
37	180	-8.2	7.6	-15.8	49.989999	24995.00	-1.032679739	1

Denisty of air	1.2	kg/m3
Diameter of cylinder	0.008	m
Kinematic Viscosity of air	1.60E-05	m2/s
Density of Water	1000	kg/m3

Rough Cylinder (Fully Open)

Sr. No.	Angular Position	h2 (upstream) (cm)	h1 (cylinder) (cm)	h2-h1 (cm)	Vinfi (m/s) calculation is needed only once	Re calculation is needed only once	Cp_expt	Cp_Theo
0	0	8.2	-7.8	16	51.12077203	25560.39	1	1
1	5	8.2	-7.8	16	51.12077203	25560.39	1	0.969616
2	10	8.1	-7.7	15.8	51.12077203	25560.39	0.9875	0.879385
3	15	7.9	-7.5	15.4	51.12077203	25560.39	0.9625	0.732051
4	20	7.2	-6.8	14	51.12077203	25560.39	0.875	0.532089
5	25	6	-5.8	11.8	51.12077203	25560.39	0.7375	0.285575
6	30	4.8	-4.6	9.4	51.12077203	25560.39	0.5875	0
7	35	2.8	-2.7	5.5	51.12077203	25560.39	0.34375	-0.31596
8	40	0.9	-1	1.9	51.12077203	25560.39	0.11875	-0.6527
9	43.5	0	0	0	51.12077203	25560.39	0	-0.89533
10	45	-0.9	0.8	-1.7	51.12077203	25560.39	-0.10625	-1
11	50	-2.8	2.6	-5.4	51.12077203	25560.39	-0.3375	-1.3473
12	55	-4.7	4.3	-9	51.12077203	25560.39	-0.5625	-1.68404
13	60	-6.3	5.7	-12	51.12077203	25560.39	-0.75	-2
14	65	-7.6	6.9	-14.5	51.12077203	25560.39	-0.90625	-2.28558
15	70	-8.5	7.8	-16.3	51.12077203	25560.39	-1.01875	-2.53209
16	75	-9.1	8.3	-17.4	51.12077203	25560.39	-1.0875	-2.73205
17	80	-9.1	8.3	-17.4	51.12077203	25560.39	-1.0875	-2.87939
18	85	-8.7	7.9	-16.6	51.12077203	25560.39	-1.0375	-2.96962
19	90	-8.4	7.7	-16.1	51.12077203	25560.39	-1.00625	-3
20	95	-8.3	7.6	-15.9	51.12077203	25560.39	-0.99375	-2.96962
21	100	-8.1	7.3	-15.4	51.12077203	25560.39	-0.9625	-2.87939
22	105	-7.9	7.3	-15.2	51.12077203	25560.39	-0.95	-2.73205
23	110	-7.9	7.3	-15.2	51.12077203	25560.39	-0.95	-2.53209
24	115	-7.8	7.4	-15.2	51.12077203	25560.39	-0.95	-2.28558
25	120	-7.8	7.4	-15.2	51.12077203	25560.39	-0.95	-2
26	125	-7.8	7.4	-15.2	51.12077203	25560.39	-0.95	-1.68404
27	130	-7.8	7.4	-15.2	51.12077203	25560.39	-0.95	-1.3473
28	135	-7.8	7.4	-15.2	51.12077203	25560.39	-0.95	-1
29	140	-7.8	7.4	-15.2	51.12077203	25560.39	-0.95	-0.6527
30	145	-7.8	7.4	-15.2	51.12077203	25560.39	-0.95	-0.31596
31	150	-7.8	7.1	-14.9	51.12077203	25560.39	-0.93125	0
32	155	-7.8	7.1	-14.9	51.12077203	25560.39	-0.93125	0.285575
33	160	-7.7	7.1	-14.8	51.12077203	25560.39	-0.925	0.532089
34	165	-7.7	7	-14.7	51.12077203	25560.39	-0.91875	0.732051
35	170	-7.7	7	-14.7	51.12077203	25560.39	-0.91875	0.879385
36	175	-7.7	7	-14.7	51.12077203	25560.39	-0.91875	0.969616
37	180	-7.7	7	-14.7	51.12077203	25560.39	-0.91875	1



Pressure Coefficient for Flow around a Cylinder
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
PRESSURE COEFFICIENT
ANGLE OF MEASUREMENT(DEGREES)
For rough cylinder, point of separation occurs between 80-85 degrees
For smooth cylinder, point of separation occurs around 75-80 degrees
Cp_expt_smooth_cylinder
Cp_Theo
Cp_expt_rough_cylinder