AM5820
Wind Tunnel and Numerical Experiments

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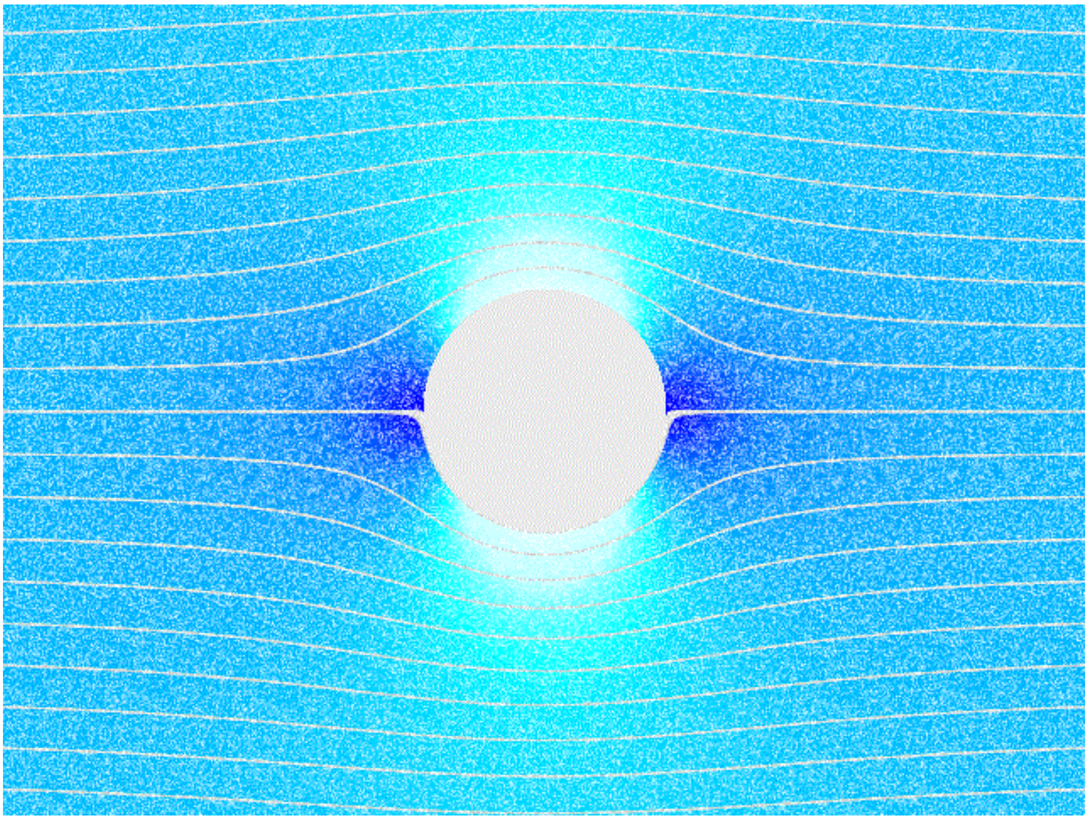
Pressure distribution over a circular cylinder



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Objective

The aim of this experiment is to measure the experimental pressure distribution over a circular cylinder with its axis perpendicular to the flow. Then compare the variation of theoretical & experimental values of coefficient of pressure C_p with angle θ.

Introduction

For inviscid flow, there is no friction to cause boundary layer separation, vortices, or a subsequent wake. However, inviscid flow over a cylinder will generate areas of different pressure gradients. Potential flow around a cylinder is a classical solution for the flow of an inviscid, incompressible fluid around a cylinder that is transverse to the flow. Far from the cylinder, the flow is unidirectional and uniform. The flow has no vorticity and thus the velocity field is irrotational and can be modeled as a potential flow. The non-lifting flow over the cylinder can be realized by combining a uniform flow and a doublet.

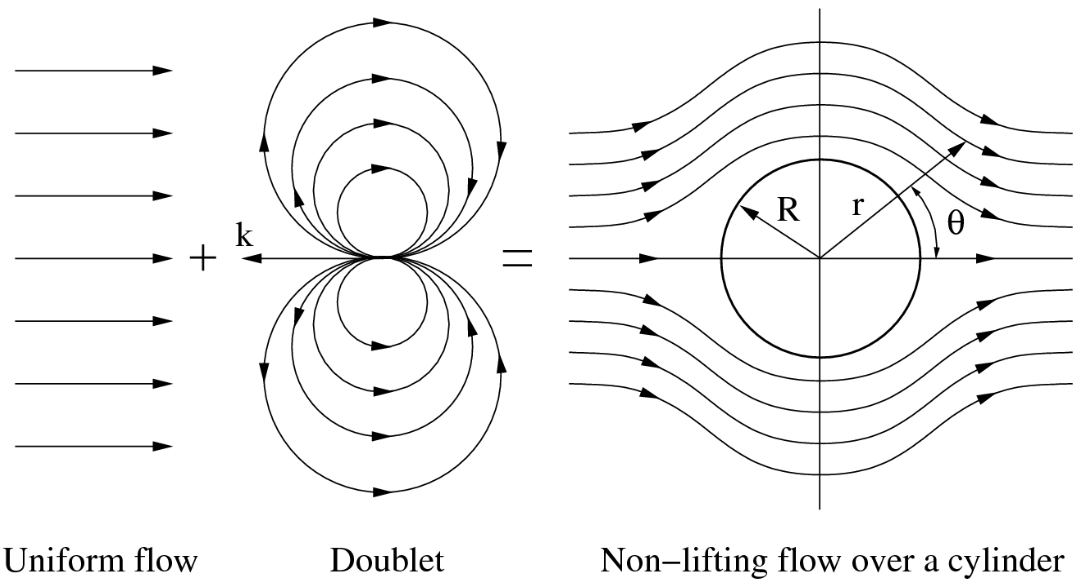


Fig. Flow realization over a circular cylinder

The stream function for the combined flow is

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

The velocity field is obtained by differentiating above equation

$$V_r = \frac{1}{r}\frac{\partial\psi}{\partial\theta} = \left(1 - \frac{R^2}{r^2}\right)V_\infty \cos\theta\,, \qquad (a)$$

$$V_\theta = -\frac{\partial \psi}{\partial r} = -\left(1 + \frac{R^2}{r^2}\right) V_\infty \sin\theta\,, \qquad (b)$$

The velocity distribution on the surface of the cylinder is given by equations (a) & (b) with $r = R$, resulting in

$$V_r = 0$$

$$V_\theta = -2V_\infty \sin\theta$$

$$V_c = \sqrt{{V_r}^2 + {V_\theta}^2} = 2V_\infty \sin\theta, \qquad (c)$$

Practical Applications

The circular cylinder resembles chimney in power plants, where flow of the wind will induce some forces over the chimney. Apart from circular cylinder this experiment can be conducted on models of fully loaded trucks, aero planes, ships, missile forebody. We can find the pressure distribution on these models & understand what conditions the actual prototypes will have to go through. This will help in making safer & secure prototypes.

Equipment description

The apparatus consists of a low-speed subsonic open circuit wind tunnel. The test section of the wind tunnel has a uniform cross-section of 0.6 x 0.6 m^2. Wind tunnel has a fan at one end which sucks in air from the other end. At the entrance of the wind tunnel a honeycomb structure is present so that the inlet velocity of air is properly aligned & uniform. The air flow in wind tunnel is from right to left direction. Therefore, the wake will be created on the left side of the cylinder. After starting the fan, we have to wait for few minutes so that the air velocity sets in.

Experimental procedure

Experiment is started by mounting the circular cylinder in the slot provided in the test section of the wind tunnel perpendicular to flow velocity. To take reading we have to start the digital manometer after connecting it to the pitot tube. The manometer will show the pressure on the port of the cylinder when knob of selection box is at position one & free stream pressure when knob of selection box is at position two. Pressure values shown by manometer is the gauge pressure. Therefore, while noting down we have put a negative sign in front of both cylinder pressure & free stream pressure.

After taking pressure readings at one position $\theta = 0^o$, we have to rotate the cylinder by 5^o and corresponding pressure value is noted down. We will keep rotating the cylinder till the point we have rotated by 180^o.

Raw data & Results

Given,

$$P_\infty = Pressure\ on\ the\ surafce\ of\ cylinder = -296\ Pa$$

$$V_\infty = Free\ stream\ velocity = 22.24\ m/s$$

S.No.	Angle (degree)	P_c (Pa)	C_P (Experimental)	C_P (Theoretical)
1	0	-73	1	1
2	10	-84	0.950672646	0.87938524
3	20	-132	0.735426009	0.53208889
4	30	-214	0.367713004	0
5	40	-321	-0.11210762	-0.6527036
6	50	-424	-0.57399103	-1.3472964
7	60	-517	-0.99103139	-2
8	70	-580	-1.2735426	-2.5320889
9	80	-568	-1.21973094	-2.8793852
10	90	-550	-1.13901345	-3
11	100	-546	-1.12107623	-2.8793852
12	110	-548	-1.13004484	-2.5320889
13	120	-552	-1.14798206	-2
14	130	-560	-1.1838565	-1.3472964
15	140	-565	-1.20627803	-0.6527036
16	150	-576	-1.25560538	0
17	160	-580	-1.2735426	0.53208889
18	170	-582	-1.28251121	0.87938524
19	180	-584	-1.29147982	1

Sample Calculation

From Bernoulli's equation,

$$P_1 + \frac{1}{2}\rho_1 {V_1}^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho_2 {V_2}^2 + \rho g h_2, \qquad (d)$$

Since there is no change in height,

$$h_1 = h_2$$

We are doing low speed subsonic test. Therefore, flow can be assumed to be incompressible,

$$\rho_1 = \rho_2 = \rho_\infty$$

Now, equation (d) boils down to,

$$P_1 + \frac{1}{2}\rho_\infty {V_1}^2 = P_2 + \frac{1}{2}\rho_\infty {V_2}^2$$

In our experiment, point 1 is free stream & point 2 is the point on the surface of the cylinder. Therefore, we can write

$$P_\infty + \frac{1}{2}\rho_\infty {V_\infty}^2 = P_c + \frac{1}{2}\rho_\infty {V_c}^2, \qquad (e)$$

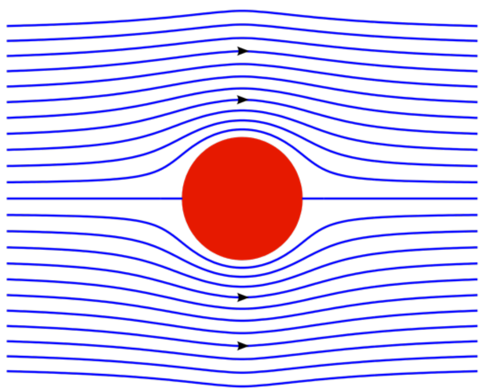
By definition of coefficient of pressure, we can write,

$$C_P = \frac{P_c - P_\infty}{\frac{1}{2}\rho_\infty {V_\infty}^2}, \qquad (f)$$

Using equation (e) in above expression, we get

$$C_P = 1 - \frac{{V_c}^2}{{V_\infty}^2}, \qquad (g)$$

Ideal flow

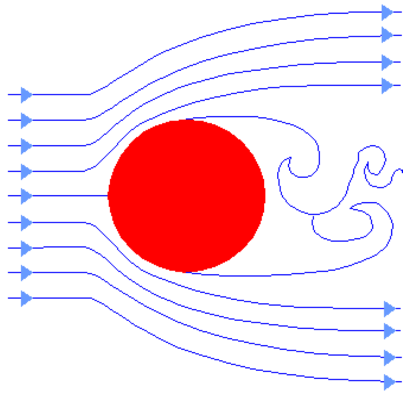


substituting equation (c) in equation (g), we get

$$C_{P,Ideal} = 1 - \frac{(2V_\infty \sin\theta)^2}{{V_\infty}^2}$$

$$\boxed{C_{P,Ideal} = 1 - 4\sin\theta^2}$$

Real flow



At stagnation point

i.e. at $\theta = 0^o$, $\quad V_c = 0$

$$P_\infty + \frac{1}{2}\rho_\infty {V_\infty}^2 = P_c$$

$$(P_c - P_\infty)_{\theta=0^o} = \frac{1}{2}\rho_\infty {V_\infty}^2$$

Substituting above equation in equation (f), we get

$$\boxed{C_{P,Real} = \frac{P_c - P_\infty}{(P_c - P_\infty)_{\theta=0^o}}}$$

Here,

$V_\infty - Free\ stream\ velocity$

$V_c - Velocity\ at\ a\ point\ on\ the\ surface\ of\ the\ cylinder$

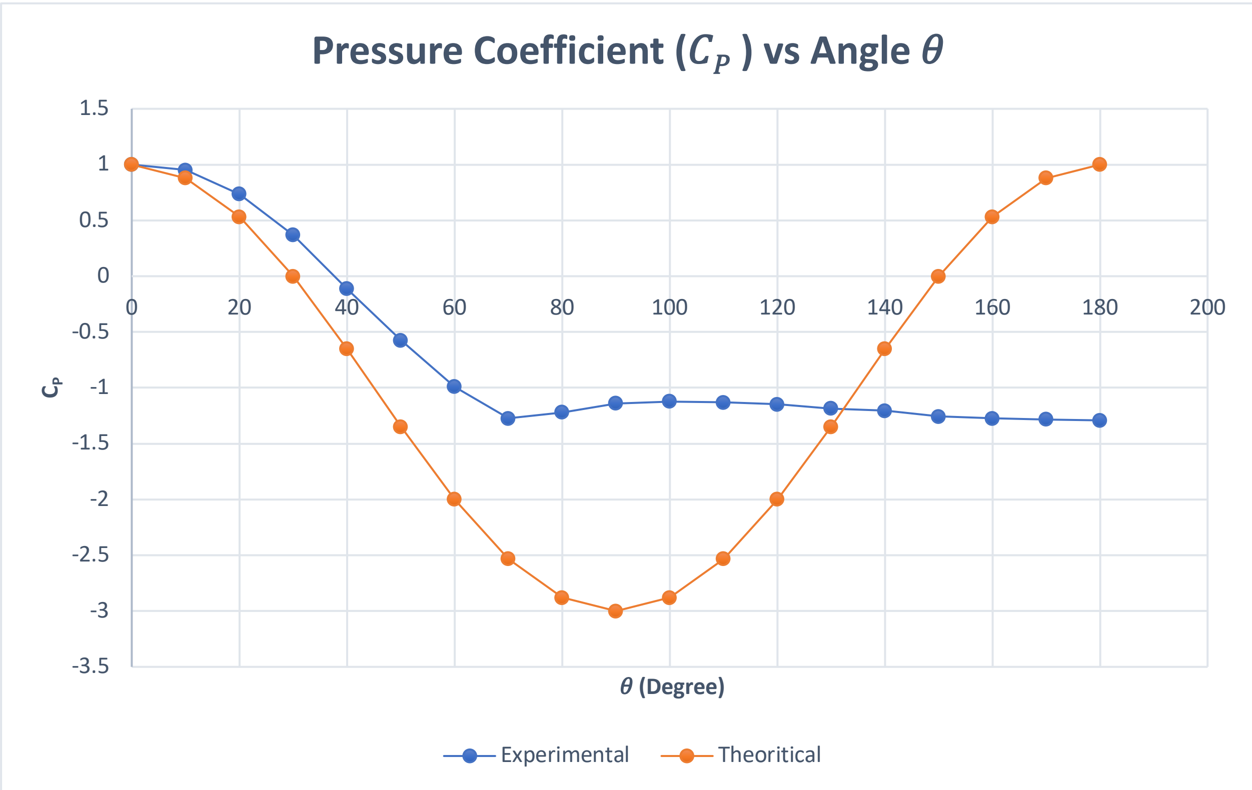
$P_\infty - Free\ stream\ pressure$

$P_c - Pressure\ at\ a\ point\ on\ the\ surface\ of\ the\ cylinder$

$\rho_\infty - Free\ stream\ density$

$\theta - Angular\ position\ of\ the\ port\ on\ the\ cylinder$

Plot



Conclusion

It can be seen from the above plot that from 0^o to 70^o the pressure decreases, but beyond that point it is not able to recover the same pressure as that for the ideal case. However, C_P remains 1 at the front stagnation point (0^o).

Remarks

a) When the cylinder is at 0^o, Is the pressure port measuring the static pressure, dynamic pressure, or total pressure? Justify your answer.

Ans: Total pressure refers to the sum of static pressure, dynamic pressure & gravitational head as expressed by Bernoulli's equation as follows,

$$P_t = P_s + \frac{1}{2}\rho V^2 + \rho g h$$

The height in this case is not changing, therefore gravitational head = 0

$\theta = 0^o$ is the stagnation point, therefore dynamic pressure = 0

So, at $\theta = 0^o$ the total pressure and stagnation pressure are equal.

b) What are the merits and demerits of an open circuit wind tunnel?

Ans: The merits are:

- Low construction cost
- Superior design for propulsion and smoke visualization
- No accumulation of exhaust products in an open circuit

The demerits are:

- Poor flow quality possible in test section
- High operating costs
- Noisy operation

c) Explain the losses in the subsonic wind tunnel?

Ans: Losses are due to:

- Inefficiency of drive unit
- Skin friction
- Flow separation
- Loss of kinetic energy at diffuser exit

d) Explain briefly-Why is C_p measurement important?

Ans: The pressure coefficient (C_p) is a dimensionless number which describes the relative pressures throughout a flow field in fluid dynamics. Every point in a fluid flow field has its own unique C_p.

In many situations in aerodynamics and hydrodynamics, the pressure coefficient at a point near a body is independent of body size. Consequently, an engineering model can be tested in a wind tunnel or water tunnel, pressure coefficients can be determined at critical locations around the model, and these pressure coefficients can be used with confidence to predict the fluid pressure at those critical locations around a full-size aircraft or boat.

e) Are C_p experimental and C_p theoretical similar? If not, why?

Ans: We can see from the plot of C_p vs θ, that its experimental results deviate largely from theoretical results for rear part of the cylinder.

Reason this is happening is due to the wake region created behind the cylinder due to separation effects and boundary layer. Hence, the flow doesn’t come all the way up to 180^o.