DATE | EXPERIMENT NO.: 2 | SHEET NO.

BOUNDARY LAYER MEASUREMENT ON A FLAT PLATE

OBJECTIVES:
- Measure and plot the velocity profiles in the boundary layer on a flat plate acted upon by a free jet.
- Calculate the skin friction coefficient at the wall using the velocity distribution.

EXPERIMENTAL SETUP:
- Wind Tunnel
- Pitot static tube
- Projection Manometer
- Traversing Mechanism

THEORY: The manometer used here is a pitot static tube type.

We know,
$$P_{stagnation} = P_{static} + \frac{1}{2}\rho V^2$$
$$\Rightarrow V = \sqrt{\frac{2(P_{stagnation} - P_{static})}{\rho}}$$
$$\Rightarrow \boxed{V = \sqrt{\frac{2\Delta P}{\rho}}}$$

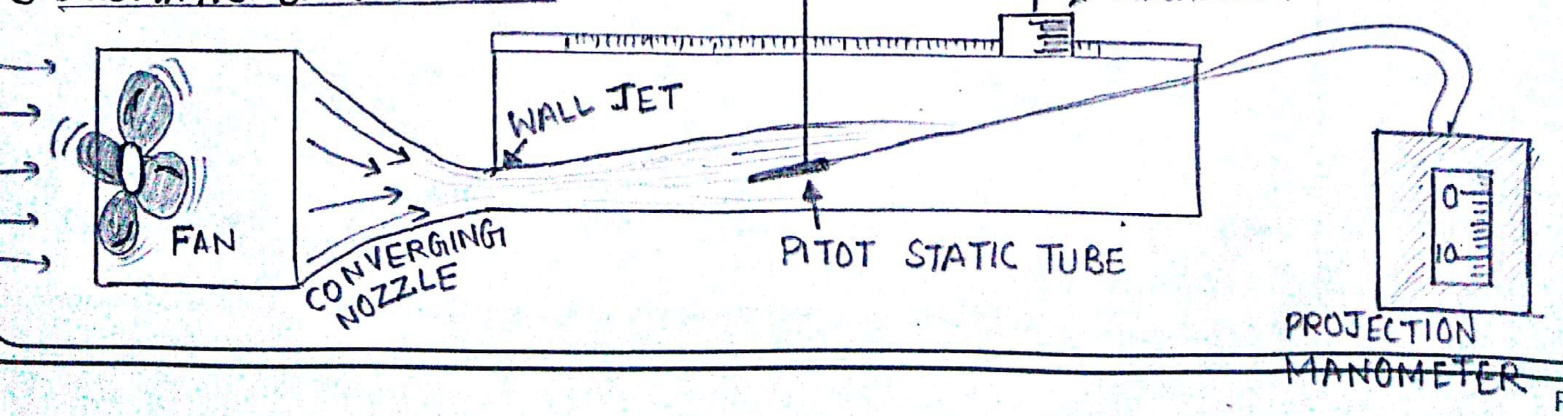
$\rho \rightarrow$ density of air (for free jet)

Also, for the manometer, $\boxed{\Delta P = \rho_f g h}$

$\rho_f \rightarrow$ density of fluid used in the manometer

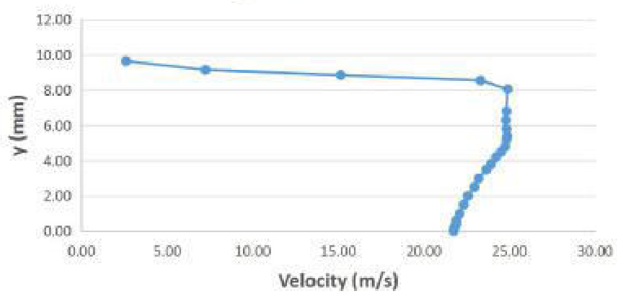
For our experiment, the projection Manometer directly gives us the values of ΔP

SCHEMATIC OF THE SETUP:



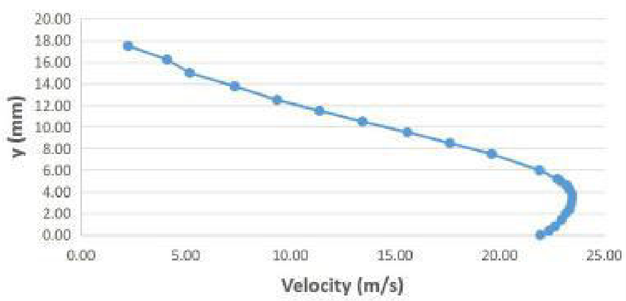
y (mm)	P Measured (Pa)	P Corrected (Pa)	Velocity (m/s)
0.00	274	280	21.75
0.10	274	280	21.75
0.20	275	281	21.79
0.40	278	284	21.90
0.60	278	284	21.90
1.00	283	289	22.09
1.50	289	295	22.32
2.00	296	302	22.59
2.50	306	312	22.96
3.00	313	319	23.21
3.50	325	331	23.65
3.80	333	339	23.93
4.20	341	347	24.21
4.50	350	356	24.52
4.80	357	363	24.76
5.20	359	365	24.83
5.40	360	366	24.86
5.80	359	365	24.83
6.30	358	364	24.80
6.80	359	365	24.83
8.05	361	367	24.90
8.55	316	322	23.32
8.85	130	136	15.16
9.15	25	31	7.24
9.65	-2	4	2.60

Velocity Profile for x=0 cm



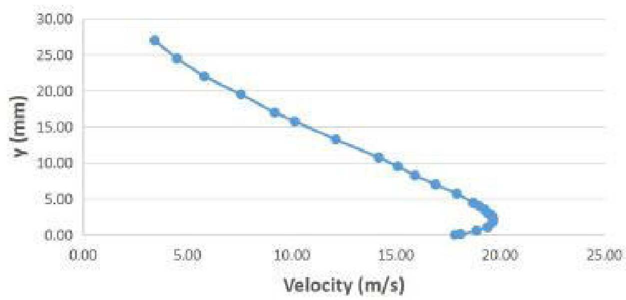
y (mm)	P Measured (Pa)	P Corrected (Pa)	Velocity (m/s)
0.00	279	285	21.94
0.40	290	296	22.36
0.80	298	304	22.66
1.40	306	312	22.96
2.00	312	318	23.18
2.40	317	323	23.36
2.90	319	325	23.43
3.40	320	326	23.47
3.80	320	326	23.47
4.20	317	323	23.36
4.60	313	319	23.21
5.00	305	311	22.92
5.20	301	307	22.77
6.00	278	284	21.90
7.50	222	228	19.62
8.50	178	184	17.63
9.50	138	144	15.60
10.50	101	107	13.44
11.50	71	77	11.40
12.50	46	52	9.37
13.75	26	32	7.35
15.00	10	16	5.20
16.25	4	10	4.11
17.50	-3	3	2.25

Velocity Profile for x=5 cm



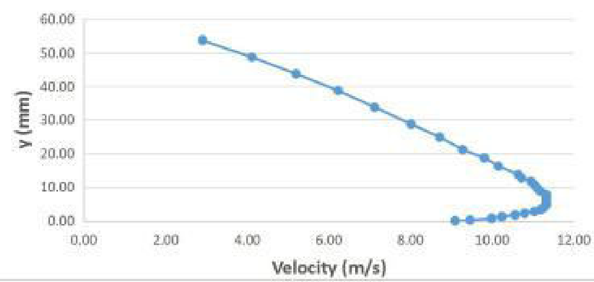
y (mm)	P Measured (Pa)	P Corrected (Pa)	Velocity (m/s)
0.00	182	188	17.82
0.10	188	194	18.10
0.60	205	211	18.88
1.10	217	223	19.41
1.70	222	228	19.62
2.10	223	229	19.67
2.50	222	228	19.62
2.80	221	227	19.58
3.00	217	223	19.41
3.50	214	220	19.28
4.00	208	214	19.01
4.50	201	207	18.70
5.75	184	190	17.91
7.00	163	169	16.90
8.25	144	150	15.92
9.50	129	135	15.10
10.75	113	119	14.18
13.25	81	87	12.12
15.75	55	61	10.15
17.00	44	50	9.19
19.50	28	34	7.58
22.00	14	20	5.81
24.50	6	12	4.50
27.00	1	7	3.44

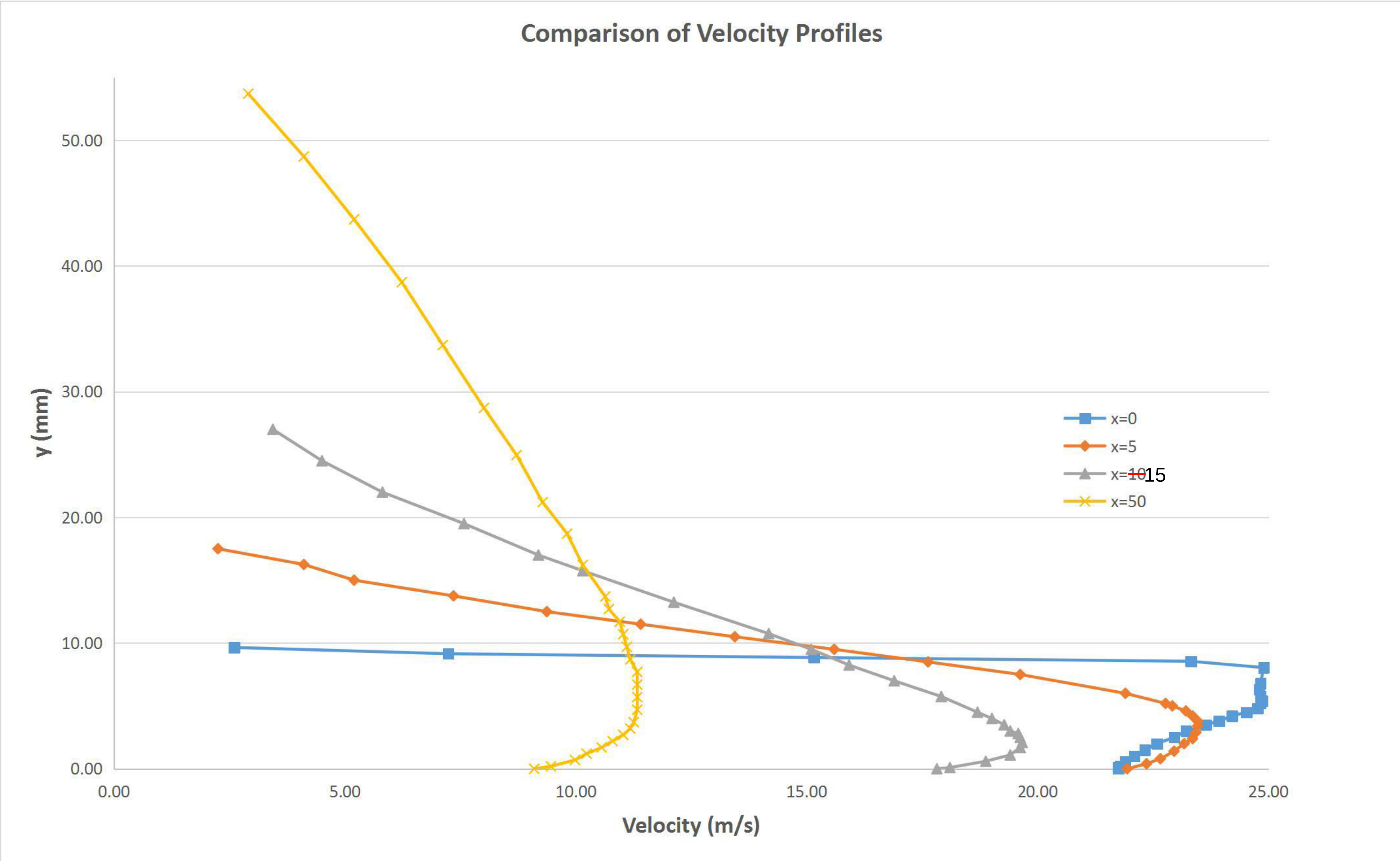
Velocity Profile for x=~~10~~ 15 cm



y (mm)	P Measured (Pa)	P Corrected (Pa)	Velocity (m/s)
0.00	43	49	9.10
0.20	47	53	9.46
0.70	53	59	9.98
1.20	56	62	10.23
1.70	60	66	10.56
2.20	63	69	10.80
2.70	66	72	11.03
3.20	68	74	11.18
3.70	69	75	11.26
4.70	70	76	11.33
5.70	70	76	11.33
6.70	70	76	11.33
7.70	70	76	11.33
8.70	68	74	11.18
9.70	67	73	11.10
10.70	66	72	11.03
11.70	65	71	10.95
12.70	62	68	10.72
13.70	61	67	10.64
16.20	55	61	10.15
18.70	51	57	9.81
21.20	45	51	9.28
24.95	39	45	8.72
28.70	32	38	8.01
33.70	24	30	7.12
38.70	17	23	6.23
43.70	10	16	5.20
48.70	4	10	4.11
53.70	-1	5	2.91

Velocity Profile for x=50 cm




Comparison of Velocity Profiles
y (mm)
Velocity (m/s)
x=0
x=5
x=~~10~~15
x=50
0.00
10.00
20.00
30.00
40.00
50.00
0.00
5.00
10.00
15.00
20.00
25.00

CALCULATIONS:

Density of the air $= \rho_a = \dfrac{P_{atm}}{RT}$

$$\Rightarrow \rho_a = \frac{101325}{287 \times 298} \ kg/m^3$$

$$\Rightarrow \boxed{\rho_a = 1.184 \ kg/m^3}$$

Sample Calculation

For $x = 0\,cm$ and $y = 4.5\,mm$, $\Delta P = 356\,Pa$

$$\therefore V = \sqrt{\frac{2\Delta P}{\rho}} = \sqrt{\frac{2 \times 356}{1.184}}$$

$$\Rightarrow V = 24.52 \ m/s$$

Calculation of skin factor coefficient C_f

$$C_{fx} = \frac{\tau_w}{\frac{1}{2}\rho U_\infty^2} = \frac{\mu \frac{du}{dy}\Big|_{y=0}}{\frac{1}{2}\rho U_\infty^2}$$

C_{fx} = Skin friction coefficient at x

$\frac{du}{dy}\Big|_{y=0}$ = velocity gradient at $y=0$

U_∞ = free stream velocity

μ = Dynamic viscosity of air

$$\boxed{\mu @ 298K = 1.836 \times 10^{-5} \ \frac{kg}{ms}}$$

$U_\infty = 24.9 \ m/s$

① At $x = 0\,cm$,

$$\frac{du}{dy} = \frac{21.7867 - 21.7479}{(0.2 - 0.1) \times 10^{-3}} = 388 \ s^{-1}$$

$$\therefore C_{f_{x=0}} = \frac{1.836 \times 10^{-5} \times 388}{0.5 \times 1.184 \times (24.9)^2}$$

$$= 1.941 \times 10^{-5}$$

② At $x = 5\,cm$

$$\frac{du}{dy} = \frac{22.3607 - 21.9413}{0.4 \times 10^{-3}} = 1048.5 \ s^{-1}$$

$$\therefore C_{f_{x=5cm}} = \frac{1.836 \times 10^{-5} \times 1048.5}{0.5 \times (1.184) \times (24.9)^2}$$

$$= 5.245 \times 10^{-5}$$

③ At $x = \cancel{10}\ 15$ cm

$$\frac{du}{dy} = \frac{18.1026 - 17.8204}{0.1 \times 10^{-3}} = 2822\ s^{-1}$$

$$\therefore C_{f_{x=\cancel{10}\ 15\,cm}} = \frac{1.836 \times 10^{-5} \times 2822}{0.5 \times 1.184 \times (24.9)^2}$$

$$= 1.412 \times 10^{-4}$$

④ At $x = 50$ cm

$$\frac{du}{dy} = \frac{9.4619 - 9.0978}{0.2 \times 10^{-3}} = 1820.5\ s^{-1}$$

$$\therefore C_{f_{x=50\,cm}} = \frac{1.836 \times 10^{-5} \times 1820.5}{0.5 \times 1.184 \times (24.9)^2}$$

$$= 9.106 \times 10^{-5}$$

⑥ DISCUSSIONS:

Q1 How do you know whether the B.L. is laminar or turbulent?

Ans. To establish if the boundary layer is laminar or turbulent, we have to seek help from the Reynolds Number.

Reynolds Number, $Re = \frac{\rho u h}{\mu}$ where h is the channel height

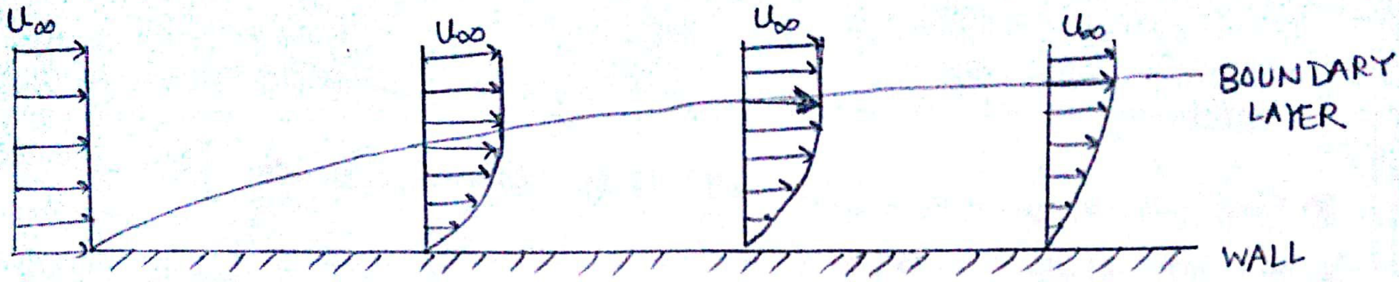
Here, for the given setup, $u_\infty = 24.9$ m/s, $h = 10$ mm

$$\therefore Re = \frac{1.184 \times 24.9 \times 10 \times 10^{-3}}{1.836 \times 10^{-5}} = 16058$$

The reynolds number at which flow over a flat plate becomes Turbulent is around 10^5. So, even for the highest velocity, the reynolds number is well below 10^5. So, the flow is predominantly laminar.

Q2 Indicate the difference in velocity profiles over a flat plate in case of:
a) Uniform flow over the plate
b) Wall jet over the plate.

Ans a) Uniform flow over the plate

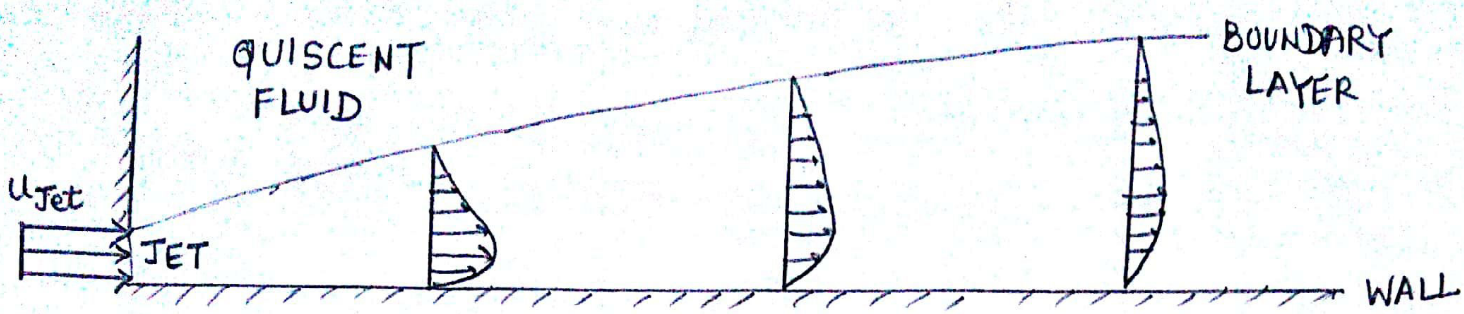


In the case of a uniform flow over a flat plate, the velocity increases, often parabolically (laminar flow) as we move towards the boundary (away from the wall). This boundary is defined as the edge of the region where the velocity is 99% of the free stream velocity. Also, the boundary layer thickness increases at a decreasing rate and reaches a constant as we move away from the edge in the downstream direction of the flow

(b) the case of wall jet over the plate

In this case, the velocity at the wall is zero (no-slip condition). As we move away from the wall (plate), the velocity increases at a decreasing rate, reaches a maxima and again starts decreasing until it reaches zero. This region of velocity variation constitutes the boundary layer in this case.

As one moves downstream, the boundary layer thickness keeps on increasing and the velocity profile becomes flatter (to maintain the volume flow rate).



Q3: ~~How~~ Describe the construction of a Pitot static tube with the help of a diagram. How can this device be calibrated. Discuss the use of a Pitot tube in a compressible flow.

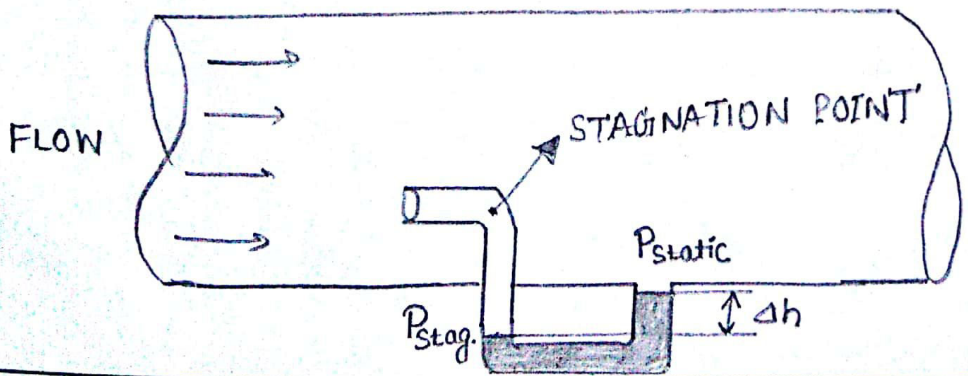
Ans A traditional pitot tube consists of a tube pointing opposite opposite to the direction of fluid flow, i.e. upstream. After a certain fixed distance after entry, a 90° bend is provided so that the fluid is brought to rest, hence creating a stagnation point. So,

$$P_{stagnation} = P_{static} + P_{Dynamic}$$

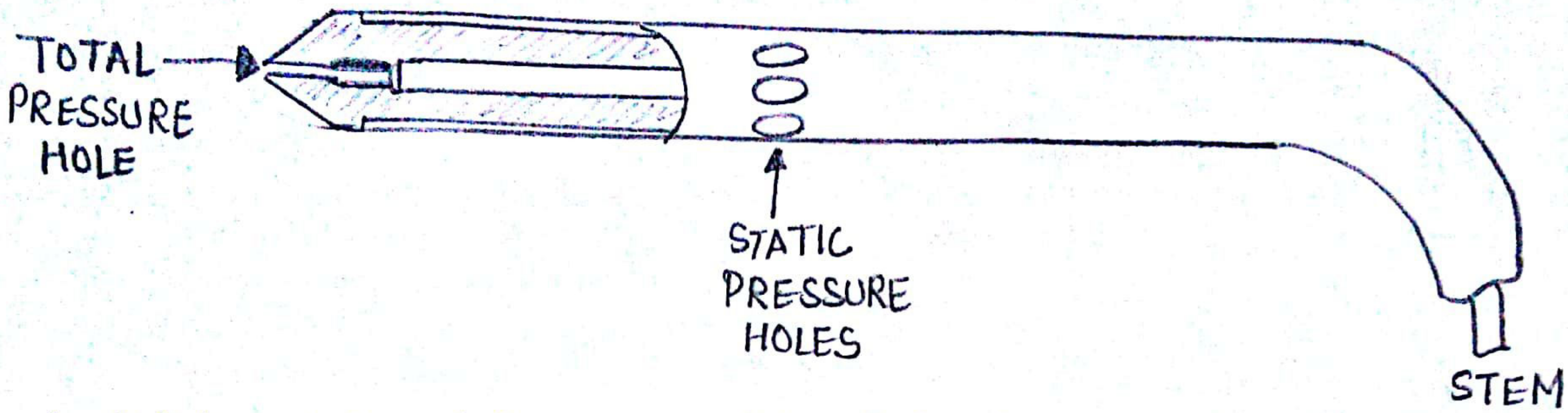
$$\Rightarrow P_{stagnation} = P_{static} + \frac{1}{2}\rho V^2 \qquad \rho \rightarrow \text{density of fluid}$$

Then, the flow velocity is $V = \sqrt{\frac{2(P_{stagnation} - P_{static})}{\rho}} = \sqrt{\frac{2\Delta P}{\rho}}$

This ΔP can be found through the manometer tubes



A pitot-static tube simplifies this setup by removing the bent part. In this type of tube, the hole measuring the velocity pressure and the holes measuring the reference or static pressure are incorporated in the same device.



A pitot static tube is calibrated by keeping it once directly in the flow direction and once in a perpendicular direction. That way, one can get the range of readings in which the test readings will vary.

In a compressible flow, some energy is lost, so the velocity predicted is less than the actual velocity. Pitot tubes are used in aircrafts which fly in the compressible flow region, so these deviations must be small.