

AE305 LAB-1 Round Turbulent Jet (Vertical Traverse)



Fig. 1: Round Jet Apparatus

PRINCIPLE AND TASK

Engineers learning about aerodynamics and fluid mechanics need to understand how fluid behaves as it emerges from different apertures or holes. They can then use this knowledge to predict the behaviour of air and fluids when passing through or around the parts of their own designs.

The apparatus explains the difference between a 'submerged' and 'free' jet and how the submerged turbulent jet of air mixes with the surrounding air.

AIMS

To produce charts of velocity distribution along the vertical centreline and radial axis of the jet.

To use experiment results to determine the length of the centreline of the jet core at a given velocity, both as a defined length and as a ratio of its distance to jet radius.

SETUP AND PROCEDURE

1. Connect the pressure tapplings from the Air Box and Pitot probe as shown in Fig. 2.

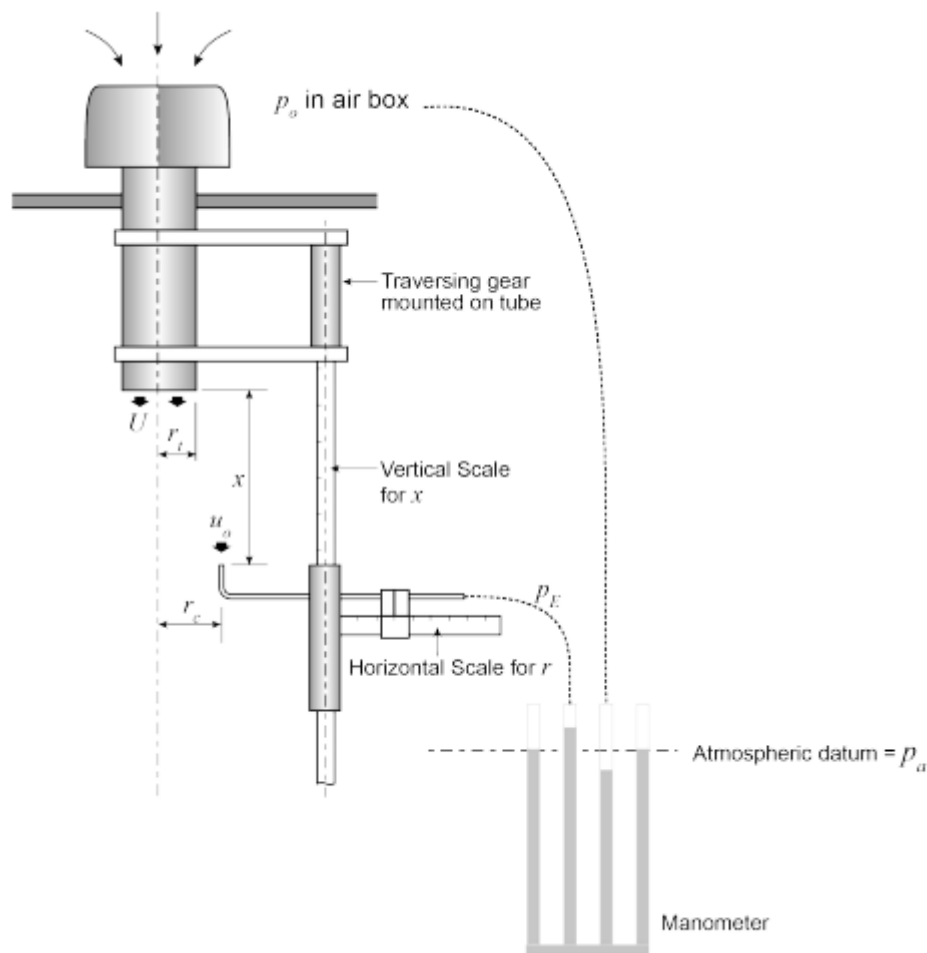


Fig. 2: Arrangement of the apparatus.

2. Note the ambient air pressure and temperature.
3. Connect the Air Box and Pitot probe connections to the manometer as shown earlier in this guide.
4. Refer to the technical details, or for better accuracy, measure the internal diameter of the jet tube outlet. From this, determine the diameter r_t .
5. Adjust the Pitot tip to the centre line of the tube and directly at its exit.
6. Note the horizontal and vertical readings of the traverse. These are the zero datum values for vertical (x) and radial (r) movement.

NOTE



To help find the centreline, move the Pitot from one side of the tube to the other and average the two readings.

7. Adjust the air flow from the bench to give a pressure at the Pitot of roughly 870 N.m^{-2} (88.7 mm H_2O).

NOTE



The pressure readings may fluctuate due to turbulence. Use pipe clamps on the pipe between the Pitot and the manometer to help damp the pulsations.

8. Move the Pitot vertically down in steps as shown in the results table to measure the pressure vertically along the centreline of the jet.

DATA SHEET

x (mm)	P		u_0 (m.s ⁻¹)	u_0/U (m.s ⁻¹)
	mmH ₂ O	N.m ⁻²		
0				
50				
75				
100				
125				
150				
175				
200				
225				
250				
300				
350				
400				
450				
Ambient Air Temperature: Ambient Air Pressure: Velocity U at tube exit:			Reynolds Number: Jet Tube Radius r_t:	

RESULTS ANALYSIS

In each table of results, convert the readings from mmH₂O to N.m⁻².

For the vertical traverse:

- Remembering to convert into the correct SI units, use the ambient temperature and pressure readings to calculate the air density. Use this with the pressure directly at the $x = 0$ datum point to calculate the velocity U at the tube exit.
- Calculate the Reynolds number for the air at the tube exit.
- Find the local velocities (u_0) along the jet axis and finally the dimensionless velocity ratio u_0/U .
- Create a vertical velocity distribution chart of u_0/U (vertical axis) against distance x . Make the horizontal axis at the top of the chart.
- Note that the chart has two slopes. The initial slope has a slow descent, then it turns into a second slope with a steeper descent. Extend the second slope backwards and note where it crosses the horizontal axis. This shows the length of the core centreline with respect to the tube exit (x_c).
- Now divide this by the radius r_t to express it as a ratio to the jet radius.
- Compare the shape of the chart with that of (Figure 3) in the theory.

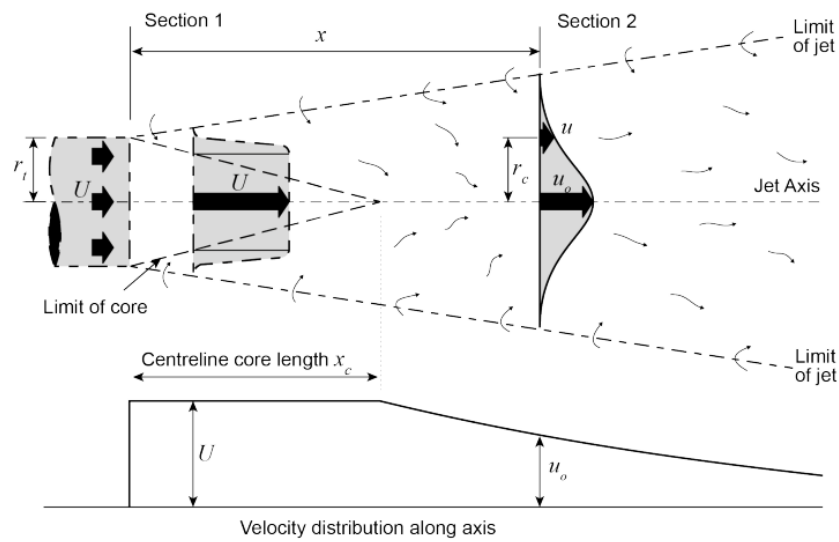


Fig. 3: Round turbulent jet.

APPENDIX

Theory

Notation

Symbol	Term	Units
D	Diameter of tube	m
ν	Kinematic viscosity of air	$\text{m}^2 \cdot \text{s}^{-1}$
p, p_a, p_o and p_E	Pressure, ambient pressure, pressure in the Air Box and exit (jet) pressure	Pa or $\text{N} \cdot \text{m}^{-2}$
r_c	Radial position with respect to centreline	m
r_t	Radius of tube	m
R	Gas Constant	$287 \text{ J} \cdot \text{kg}^{-1} \cdot \text{K}$ for air
T and T_a	Temperature and ambient temperature	K or $^{\circ}\text{C}$ where shown
U, u and u_o	Air velocity	$\text{m} \cdot \text{s}^{-1}$
x	Vertical position with respect to tube exit	m
ρ	Density	$\text{kg} \cdot \text{m}^{-3}$
μ	Dynamic viscosity of air (at 20°C)	$1.82 \times 10^{-5} \text{ Pas}$

Table 1 Notation

Conversions - Pressure and mmH_2O

The optional manometer shows pressure in mm of water (mmH₂O), but water density changes slightly with temperature, so this normally has to be allowed for. However, if the equipment is used at around room temperature, it can be assumed that its density remains at around 1000 kg.m⁻³ or 1 kg.L⁻¹.

Pressure in scientific calculations is normally in Pa (pascals) or N.m⁻² (Newton per square metre). Assuming the equipment is used at room temperature, then:

$$1 \text{ mmH}_2\text{O (at room temperature)} = 9.81 \text{ Pa} = 9.81 \text{ N.m}^{-2}$$

Atmospheric pressure is often measured in bar, where 1 bar = 100000 Pa = 100000 N.m⁻²

Gauge and Absolute Pressures

Many scientific experiments use pressures measured with respect to absolute zero (a perfect vacuum). These are termed **absolute** pressures. The pressures used in the experiments with this equipment are all based on the pressures measured by the manometer and relative to atmospheric. These are termed **gauge** pressures and are acceptable for use in the associated theory provided they are consistent.

However, ambient (atmospheric) pressure is always absolute.

Air Density (ρ)

As with most fluids, the density of air changes with pressure and temperature. To accurately compare results of fluid experiments, it is always useful to know the density of the fluid being used.

$$\rho = \frac{P_a}{RT_a}$$

For these air flow experiments, use the ambient temperature and pressure to find the ambient air density around the experiment.

Compressibility and Viscosity

Most gases are fluids that can be easily compressed - their volume and density changes. They are said to be **compressible** fluids. Many liquids such as water are fluids that cannot be easily compressed. They are said to be **incompressible** fluids. However, when gases move at very low Mach numbers (subsonic), they can generally be treated as incompressible flow fluids, as they will not have undergone much compression.

Viscosity is a measure of how easily a fluid flows over or around other objects. A fluid (like honey for example) that flows slowly over other objects may be highly viscous. A fluid (like water or air) that flows easily over other objects has a very low viscosity and may be termed **inviscid**.

Viscosity is a measure of a fluid's resistance to flow. Low viscosity fluids (like water) flow easily. High viscosity fluids (like honey or treacle) flow less easily.

There are two related measures of viscosity:

Dynamic or Absolute Viscosity (μ)

This value is often called simple viscosity. It is the basic measure of viscosity in Pa.s (Pascals per second).

Kinematic Viscosity (ν)

This is the ratio of dynamic viscosity to density, or 'resistive flow under the influence of gravity'. It is measured in $\text{m}^2.\text{s}$ (metres squared per second) or sometimes in Centistokes (cSt).

$$\nu = \frac{\mu}{\rho}$$

Velocity (u or U)

A rearrangement of the standard Bernoulli equation allows the calculation of the local velocity at the position of the Pitot tip, using the pressure at the tip and the air density:

$$\frac{1}{2}\rho u^2 = p_E - p_a$$

When using the optional AF10a manometer, read the Pitot pressure with respect to atmosphere, so the equation reduces to:

$$\frac{1}{2}\rho u^2 = p_E$$

So when using the manometer, velocity at any given position in the jet:

$$U \text{ or } u \text{ or } u_o = \sqrt{\frac{2p_E}{\rho}} \quad (1)$$

Reynolds Number (Re)

During the 19th Century, an Irish physicist, Osborne Reynolds experimented with fluid flow. His experiments led him to create an equation that helps to simplify the variables in many equations of fluid dynamics:

$$Re = \frac{\rho u D}{\mu}$$

or as shown in some textbooks:

$$Re = \frac{u D}{\nu} \text{ (as } \nu = \mu/\rho)$$

In terms of fluid flow from a tube of diameter D , a Reynolds number greater than 4000 indicates turbulent flow. A Reynolds number less than 2300 indicates laminar flow.