

MEEN 335 Core Measurements Laboratory

Lab 08: Characterization of flow past a circular cylinder using LDV technique.

Spring 2019

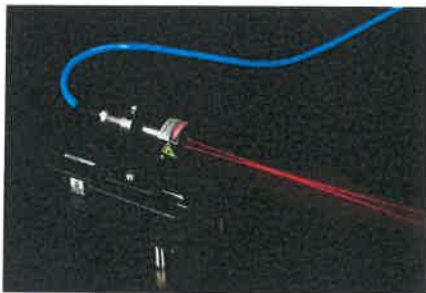
Laboratory Overview:

The purpose of this laboratory session is to:

- Understand the principles of Laser Doppler Velocitometry (LDV) and gain hands-on practical experience on LDV technique.
- Measure the velocity of the flow downstream and upstream of a circular cylinder.
- Obtain velocity profile downstream and upstream of the cylinder.
- Determine the Reynolds number and Strouhal numbers.
- Estimate the Drag on the cylinder.

Laboratory Safety Requirements:

- Laboratory safety requirements are to be reviewed prior to running this experiment otherwise serious harm or injury could result. Safety glasses must be worn at all times.



Laser Probe



LASER SAFETY

Laser light is emitted by the MiniLDV probe. MiniLDV laser are Class IIIB laser devices

Laser light can be harmful to your eyes.

UNDER NO CIRCUMSTANCES LOOK DIRECTLY INTO THE LASER BEAMS OR THEIR REFLECTIONS, OR PUT YOUR HEAD IN A POSITION WHERE YOU MIGHT INADVERTENTLY DO THIS.

Do not try to gain access to the rear of the water tunnel where the laser beams will exit from the test section

therefore also fluctuates. The frequency of this fluctuation is proportional to the velocity of the particle normal to the fringes.

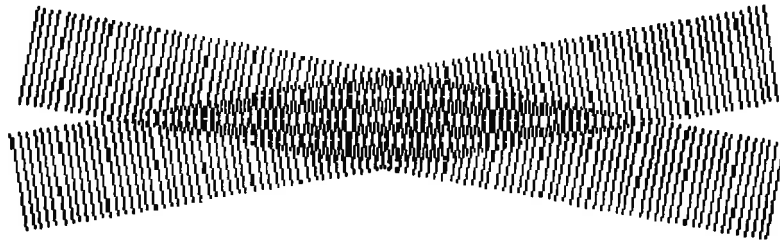


Figure 2. Detail of the measurement volume showing the formation of fringes. Lines represent the peaks of the light

To detect this frequency, the light scattered by the particle is collected by a second lens (the receiving lens) and focussed onto a photodetector which converts the fluctuations in light intensity into fluctuations in a voltage signal. An electronic device known as a signal processor is then used to determine the frequency of the signal and therefore the velocity of the flow.

Figure 3 shows the working of LDV

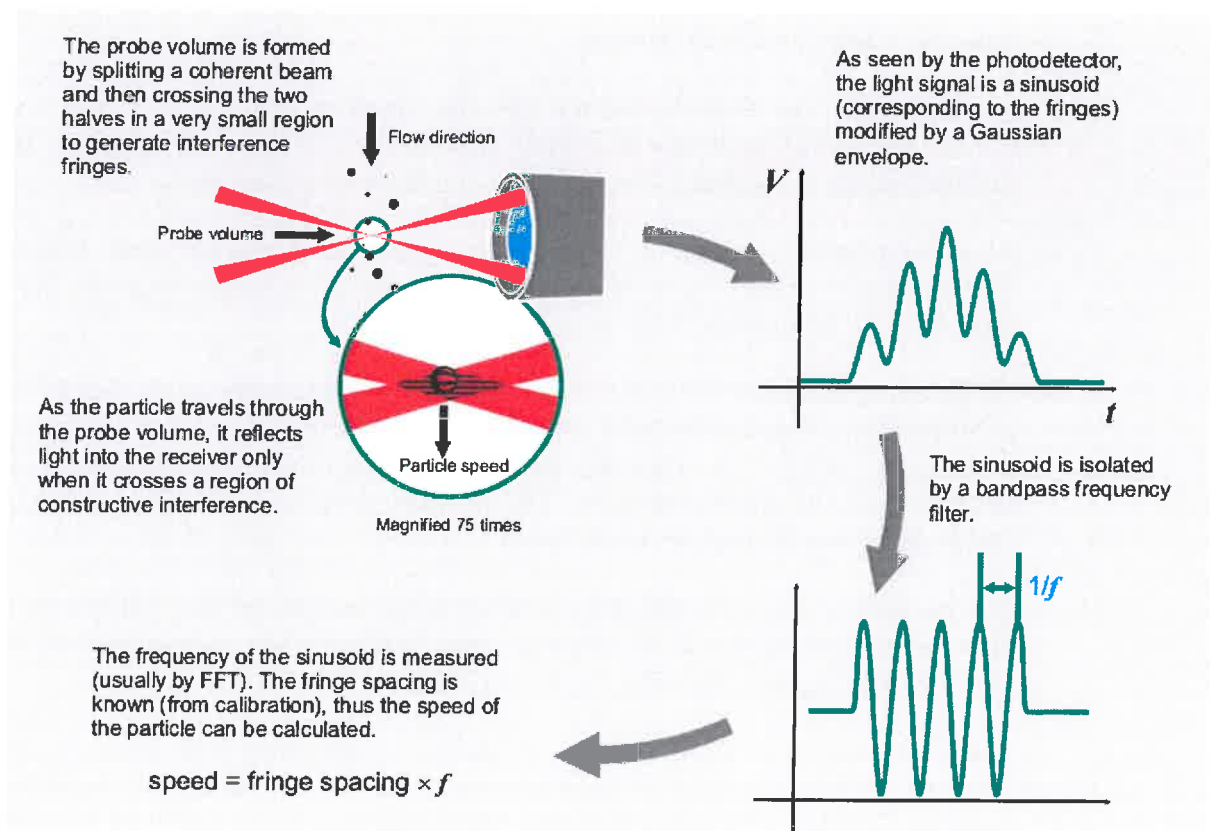


Figure 3. Working Principle of LDV

$$St = \frac{fd}{U}$$

where f is the frequency of the flow (e.g. vortex shedding frequency), d is a characteristic diameter of the cylinder and U is a characteristic velocity.

The Strouhal Number is important for analyzing unsteady, oscillating flow problems. The Strouhal Number represents the ratio of inertial forces due to the unsteadiness of the flow or local acceleration to the inertial forces due to changes in velocity from one point to another in the flow field.

The Strouhal Number is a function of the Reynolds number, typically between $20 < Re < 20,000$.

B. Finding the drag from the measured velocity

The calculation of the drag coefficient of a cylinder examined the momentum loss in the wake from the velocity measured with the LDV apparatus. The analysis is based on a control volume analysis using the geometry shown in the Figure 9 below.

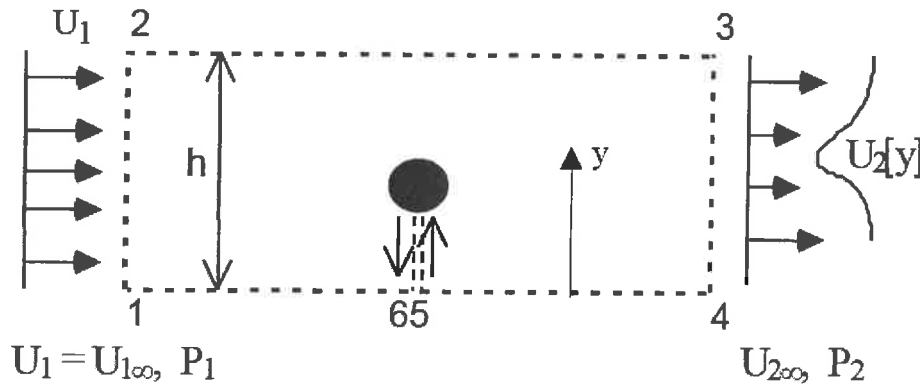


Figure 9. Geometry for control volume analysis

The integral form of the mass conservation equation is given as:

$$\oint \rho \vec{U} \cdot d\vec{A} = 0 \quad (9)$$

Since there is no fluid flow through the top and bottom surfaces of the control volume above, the integral becomes

$$\int_1^2 \rho \cdot U_1 dy - \int_1^2 \rho \cdot U_2 dy = 0 \quad (10)$$

Using the geometry above, this integral can be re-written as

$$\int_0^h U_1 dy - \int_0^h U_2 dy = 0 \quad (11)$$

and, since the upstream flow velocity is uniform this simplifies to give

$$\text{Drag} = \frac{1}{2} \rho U_{1\infty}^2 \int_0^h \frac{U_2(y)}{U_{2\infty}} 2 \left(1 - \left(\frac{U_2(y)}{U_{2\infty}} \right) \right) dy \quad (21)$$

The Drag coefficient C_D is defined by normalizing the Drag by the dynamic pressure $\frac{1}{2} \rho U_{1\infty}^2$ and the projected area of the cylinder $A_p = D \cdot (b=1)$ where D is the diameter of the cylinder and $b=1$ is the unit length of the cylinder. The Drag coefficient per unit length of cylinder is:

$$C_D = \frac{\text{Drag}}{\frac{1}{2} \rho U_{1\infty}^2 \cdot A_p} = \frac{\text{Drag}}{\frac{1}{2} \rho U_{1\infty}^2 \cdot D} \quad (22)$$

2.0 Experimental Background

A. Water Tunnel

The water tunnel used in this lab is an closed design, Figure 10, the system is built of Plexiglas with interchangeable 5 x 5 cm² test section, miniLDV sensor, a 3-D Traverse System, and related computational and signal processing software.

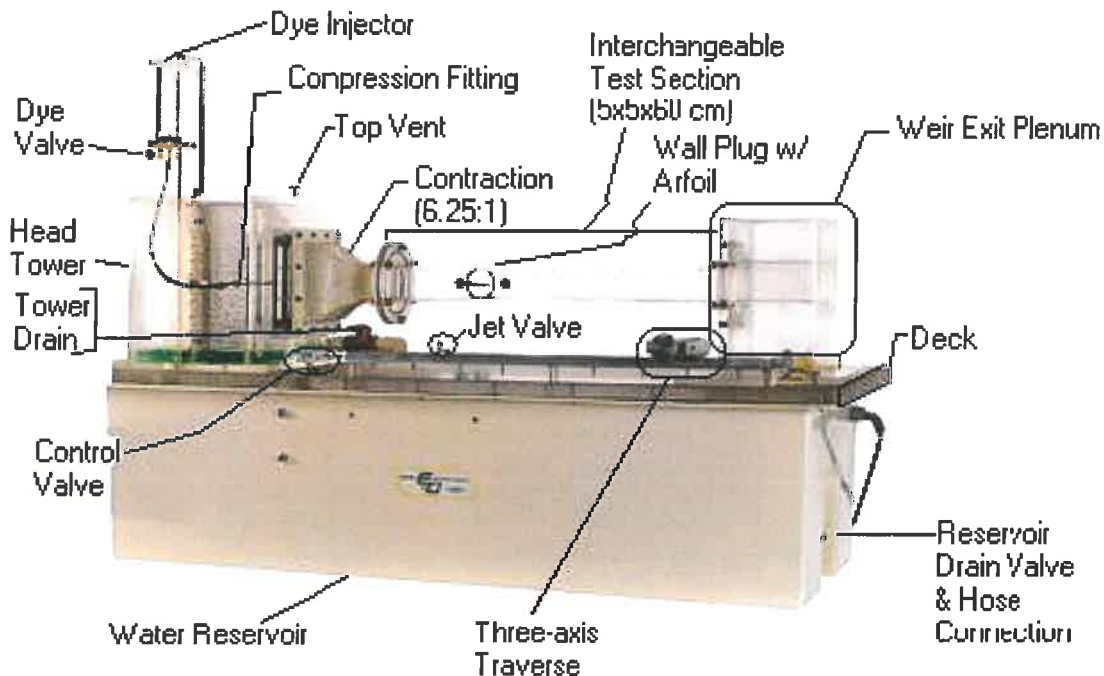


Figure 11 ELD closed loop water tunnel.

Water flow is provided by an oil-filled submersible pump, capable of delivering 40 + gallons per minute. Flow arrives in the test section through a settling chamber containing a plastic honeycomb and three 60% porosity screens designed to straighten the flow, make it more uniform and reduce turbulence levels. A contraction at the downstream end of the settling

3.0 Experimental Analysis

This section describes the experimental set-up and measurement procedure for this lab session.

3.1 Experimental set-up

The following apparatus is supplied:

- ELD 12" Open Circuit Wind Tunnel, Figure 11.
- Brass Cylinder
- LDV system

3.2 Measurement procedure

1. Install the wall plug with the attached cylinder into the Interchangeable Model Test Section.
2. Install the Interchangeable Model Test Section and Weir Exit Plenum into the Fluid Laboratory System . Ensure the wall plug is mounted in the wall opposite the miniLDV sensor.
3. Secure the flow and drain the Test Section.
4. Remove the Wall Plug and measure the cylinder diameter with a calipers. Replace the Wall Plug.
5. Start the submersible pump and establish desired flow by varying the valve.
6. Setup the MiniLDV. Refer to Appendix B for operation of MiniLDV.
7. Turn on the LDV system. Once the system is turned on and the BP software initialized, two red beams should be visible emerging from the probe and passing through the water tunnel test section.

7.5		
10		
20		
30		
40		
50		

MEASUREMENT SPECIFICATIONS	
Velocity range	1 mm/sec to 300 m/sec
Repeatability	0.1%
Accuracy	99.7% typical
PROBE VOLUME	
Size (air) (x by y by z)	30 by 60 by 200 μ m to 100 by 200 by 1200 μ m (depends on standoff distance)
Standoff distance (air)	1.30, 1.97, 3.94, 5.91, or 9.45 inches (33, 50, 100, 150, or 240 mm)
PROBE SPECIFICATIONS	
Probe weight	250g
Dimensions	1.25" (32 mm) diameter, 6.5" (165 mm) long
LASER SPECIFICATIONS	
Laser power	60 mW
Wavelength	660nm
Laser type	Class IIb
OPERATING PARAMETERS	
Temperature	0 to 65°C
Pressure	Up to 35 bar