MEMORIAL UNIVERSITY OF NEWFOUNDLAND
Faculty of Engineering and Applied Science

FLUID MECHANICS LABORATORY

Spring 2003

MEASUREMENT OF AIRFLOW

Objective
To measure air flow-rate using three different techniques.

Lab
The schematic of the apparatus is shown in figure 1. The air flowrate will be measured with: (a) Orifice plate, (b) Venturi meter and (c) Pitot-static tube. Familiarize yourself with the apparatus and the procedure for performing the experiment.

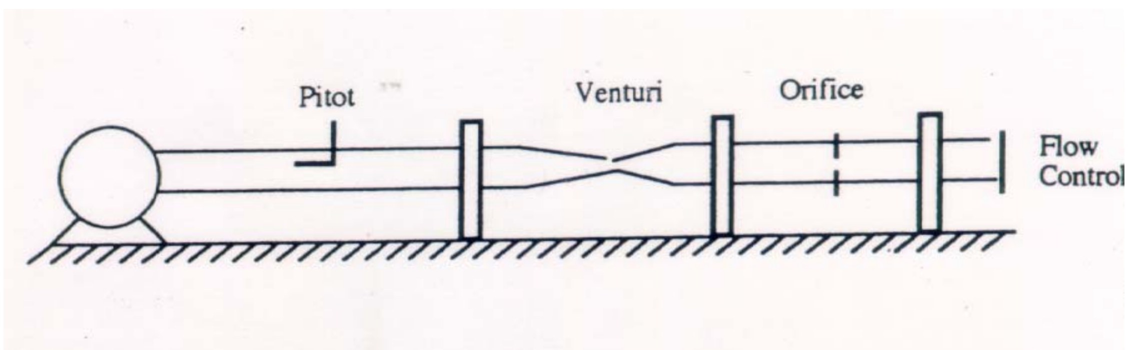

Figure 1: Schematic of the lab facility

Theory
An effective way to measure the flowrate through a pipe is to place some type of restriction within the pipe and to measure the pressure difference between the low-velocity, high-pressure upstream section, and the high-velocity, low-pressure downstream section. Two commonly used types of flow meters are the *orifice meter* and the *venturi meter*. The volumetric flowrate (Q) for these two devices are given by:

$$Q = C\,A_2\sqrt{\frac{2(p_1 - p_2)}{\rho\left[1-(A_2/A_1)^2\right]}} \qquad (1)$$

where A_1 = Area of pipe upstream from restriction
A_2 = Flow area of pipe at restriction
p_1 = pressure upstream from restriction
p_2 = pressure at restriction
ρ = density of fluid
C = correction factor for energy losses

For the venturi:

$C = 0.985\ C_E$, where C_E (expansion factor) is obtained from the chart (Fig 2).
D_1 = 5.5 inches (diameter of pipe upstream of restriction)
D_2 = 3.5 inches (diameter of at restriction)

For the sharp-edged orifice with pressure tappings at D upstream and D/2 downstream of the orifice:

D_1 = 5.5 inches
D_2 = 4.25 inches

$$C_d = f(\beta) + 91.71\beta^{2.5}\,\mathrm{Re}_D^{-0.75} + \frac{0.09\beta^4}{1-\beta^4}F_1 - 0.0337\beta^3 F_2 \quad (2)$$

$$f(\beta) = 0.5959 + 0.0312\beta^{2.1} - 0.184\beta^8 \quad (3)$$

$$\beta = D_1 / D_2 \quad (4)$$

F_1= 0.4333 and F_2= 047 for sharp-edged D-D/2 orifice

$\mathrm{Re}_D = \dfrac{\rho V_D D_1}{\mu}$ Where V_D= average velocity in pipe (upstream of the restriction)

$\mathrm{Re}_D = \dfrac{4\rho Q}{\pi D_1 \mu}$ Alternate equation of Re where Q is the volumetric flow rate

Replacing *β, F_1 and F_2* with the corresponding values, the equation for C may be simplified as follows:

$$C = C_E C_d = C_E(0.6054 + 48.18\,\mathrm{Re}_D^{-0.75}) \quad (5)$$

Where C_E is obtained from Fig. 2

In a square section of the duct a pitot-static tube is used to measure the velocity at several points of the cross section of the duct. The volumetric flowrate can then be calculated as:

$$Q = \int_A v\,\mathrm{dA} = \overline{\mathrm{V}}\mathrm{A} \text{ or } \overline{V} = \frac{1}{A}\sum v_i A_i \quad (6)$$

where v = local velocity
$\overline{v}$ = average velocity across the cross section
v_i = local or point velocities measured by pitot tube
A_i = Surface area of the segment for which pitot measurement was done

For the pitot-static tube, the velocity is given by:

$$v = \sqrt{2\,\Delta p/\rho} \qquad (7)$$

Experimental Procedure

There are a couple of issues you should be careful about when you do your lab:

1- There are three flow measurement devices in the lab namely Pitot tube, Venturi meter and Orifice meter. The governing equations are given above.

2- Pitot tube measures the localized (point) velocity of the fluid. Therefore to have the average velocity of fluid across the square section of the air conduit, it is necessary to measure the local velocity at several points and use the definition for average velocity as:

$$\bar{V} = \frac{\int_A v\,dA}{A} \quad \text{or.} \quad \bar{V} = \frac{1}{A}\sum v_i A_i$$

Make sure that you read the local velocities at least at 10-12 points and use the above equation to calculate the average velocity and total flow rate as $Q=VA$.

3- An inclined manometer is used to read the pressure differentials in inches of water. Make sure you understand what the readings mean on the manometer. The length readings on the inclined ruler should be corrected for the angle for the accurate vertical water height differences. A correction factor is given on the manometer. You could always find the correction factor yourself by the physical dimensions of the manometer and its angle with horizon.

4- You will probably need static gage pressure (pressure of the flowing fluid) and barometric pressure for density calculations. There is a barometer on the inclined manometer; make sure you have the barometric pressure read before leaving the lab.

Now start the experiments by doing the following:

1- Connect one of the measuring devices to the inclined manometer as shown in Fig. 3.
2- Level the inclined manometer.
3- Start the fan.
4- To avoid air bubbles in the manometer, always connect the high pressure tube of the manometer to the high pressure tapping first. Connect the low pressure tubing afterwards. Also remove the high pressure tubing ***first*** when you are finished with a measurement.

5- Record the pressure difference from the inclined manometer. For the different positions of the manometer tube, the appropriate correction factors will have to be applied. These are given on the manometer.
6- Make sure you read the pressure differences at several points of the cross section of the duct for the pitot-static tube experiments.
7- Read the static pressure for each measurement. Note that the static pressure is the pressure read by a manometer installed on the conduit wall. Therefore, read the manometer when the high pressure tube is connected to the point where you are measuring the flow and the low pressure tube is left to atmosphere. This pressure is the actual pressure of air in the conduit and is needed for air density calculations.
8- Stop the fan.
9- Repeat procedure (1 to 5) for the other two measuring devices.
10- Adjust the flow with the flow control valve and repeat the procedure for different flow rates.

Results

1. Calculate the flowrates from the three different devices. Make sure your units are compatible when performing the calculations. Start calculations with results obtained from *venturi meter* and pitot-static tube. Use the flowrates obtained in the previous calculations for *venturi meter* or pitot-static tube to calculate the Reynolds number (Re_D). Use the value of Reynolds number to calculate the C value for the *orifice meter*, using Equation 5, and find the flowrates. Compare the calculated flow rate with the flow rate you used to start C calculations. Repeat calculations with the new value for the flowrate until the two values (old and new) for flowrates agree with an accuracy better than ±0.5%.
2. Compare the results for different flow measurement devices and discuss any discrepancies.
3. Discuss the physical significance of using the correction factor C in calculating Q.
4. Why is it necessary to use the "average velocity" for calculating flowrates in the pitot-static tube experiments?
5. Why is C different for the orifice meter and venture meter?

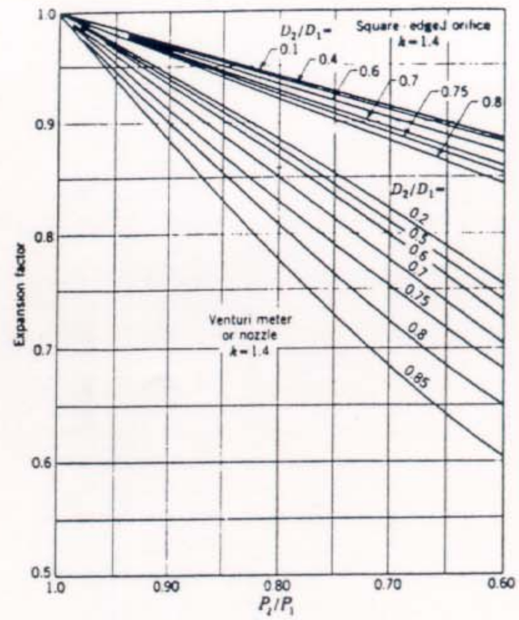

Figure 2 : Compressibility correction factor

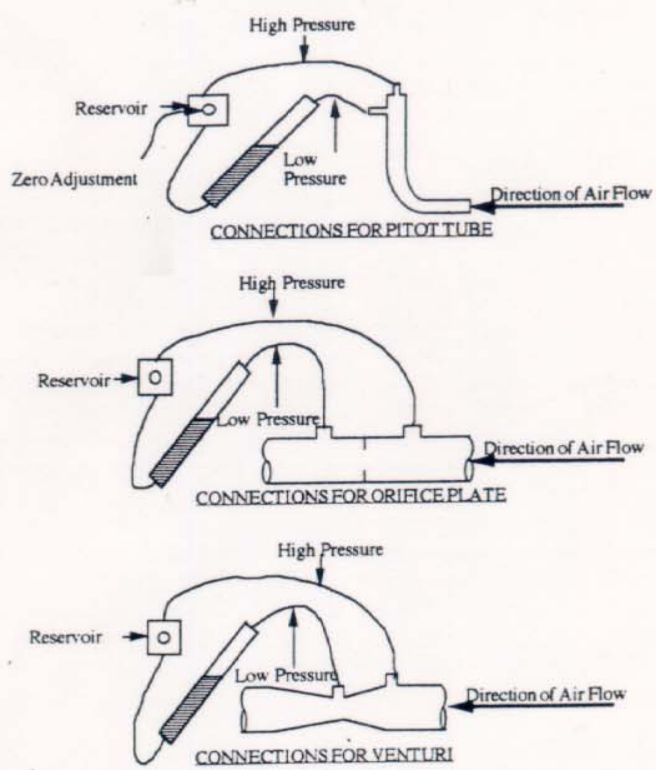

Figure 3 : Differential pressure measurement

Table 1. Flow measurement data

Valve Setting	Static Pressure		Differential pressure	
	Venturi	Orifice Plate	Venturi	Orifice Plate

Table 2. Pitot static tube data
