4.2 Viscous Flow in Pipes

4.2.1 Introduction

The transport of fluids, gas or liquid, is an important and common operation that occurs in our daily lives. For example, the air conditioning ducts that wind throughout your home or in your car transports hot or cold air. The purpose of this experiment is to develop an understanding of the process.

To simplify our understanding let us consider fluid flow through a circular pipe and that the fluid completely fills the pipe. To characterize the flow, we commonly use the Reynolds number, *Re*. The number is determined by

$$Re_D = \frac{VD}{\nu} \tag{1}$$

Where V is a characteristic velocity of the fluid, D is a characteristic dimension, and ν is the fluid dynamic viscosity. The number can be considered a ratio of the inertia force to the viscous force. In a tube, D is the tube diameter and V is the mass averaged velocity.

Far from the pipe entrance and at relatively low Reynolds number (based on pipe diameter); the flow behaves like layers of fluid with the faster layers sliding across the slower moving layers. Momentum is transferred as slower moving particles move into the faster moving layer and vice versa. At relatively high Reynolds number, the flow no longer behaves so smoothly. Packets of fluid move from one location to another in a random manner. Packets appear and disappear as they move, transferring momentum. At a Reynolds number of 2000 turbulent behavior appears, although it can jump from turbulent to laminar depending on the particular flow conditions. Above a Reynolds number 4000 turbulent flow remains.

At the entrance to the pipe, the fluid velocity is uniform. As the fluid moves through the pipe, the fluid next to the wall is decelerated to zero velocity (no slip boundary condition). Due to fluid viscosity, momentum transfer occurs between the fluid layers or fluid packets creating a velocity gradient within the fluid near the wall, which is referred to as the boundary layer. The farther from the entrance region, the thicker the boundary layer becomes as shown in Fig. 1. Outside the boundary is a core of inviscid fluid that

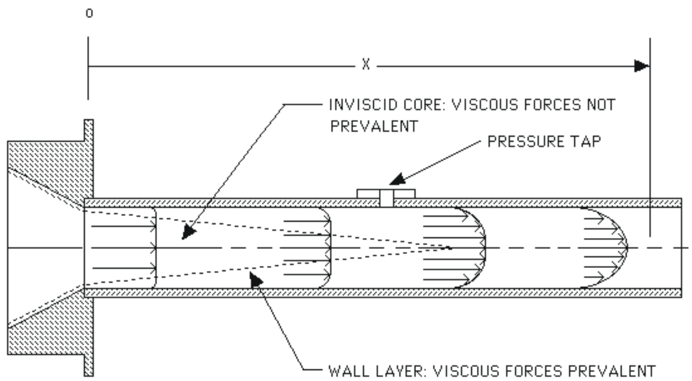

Figure 1: Pipe's Entrance Region

has a larger velocity than the freestream velocity, because it is squeezed as the boundary layer grows. After the boundary layer thickness is on the order of the pipe diameter, the velocity profile remains constant, which is referred to as fully developed flow. The length of pipe where the flow becomes fully developed is referred to as the entrance length. Typical entrance length for laminar flow can be predicted by

$$\frac{L_e}{D} = 0.06\,Re \tag{2}$$

and for turbulent flow

$$\frac{L_e}{D} = 4.4\,Re^{1/6} \tag{3}$$

The objective of this experiment is to study the characteristics of turbulent flow. It will examine the turbulent flow of air in the fully developed region of a pipe.

To determine if the fluid can be modeled as incompressible, the Mach number, *M*, must be determined. The Mach number is a nondimensional number defined as the ratio of the fluid velocity, *V*, to the velocity of sound in the fluid, *c*.

$$M \equiv \frac{V}{c} \tag{4}$$

The velocity of sound for an ideal gas is estimated as:

$$c = \sqrt{kRT} \quad (5)$$

Where k is the ideal gas specific heat ratio, R is the gas constant, and T is the absolute temperature. If the Mach number is less than about 0.2 or 0.3, the fluid is considered as incompressible.

4.2.2 Description of Apparatus

The test setup that you will use is shown in Fig. 2. It consists of a blower, a laminar flow element, a micromanometer, a pipe, and a multitube manometer. The pipe has a diameter, D, of 0.931 in and a length, L, of 6 ft 2.5 in. Pressure taps along the length of the pipe are 10 in apart as shown in Fig. 3.

Air is supplied to the pipe by the blower. Upstream of the blower is a laminar flow element, which is used to measure the flow. The flow rate can be read from the differential pressure-sensing device connected to the laminar flow element. The laminar flow element is shown in Fig. 4. Essentially, the laminar flow element contains a fin honeycomb structure through which the air is forced to pass. The passages are small, forcing the flow to remain laminar. A slight differential pressure is created across the element and is indicated by the reading on the voltmeter. The voltmeter reading can be converted to difference in pressure using the calibration chart. The pressure drop is proportional to the flowrate.

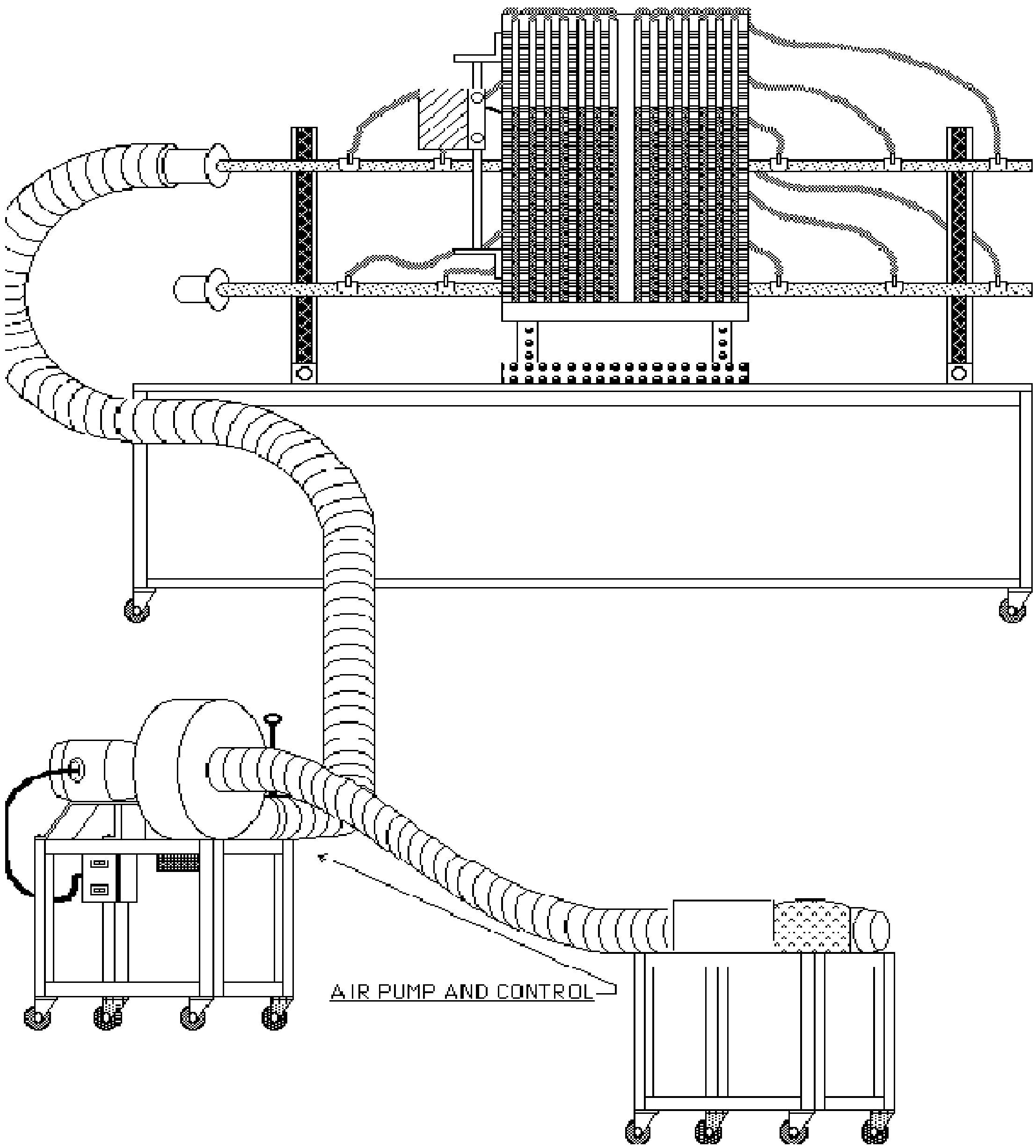

Figure 2: Test Apparatus

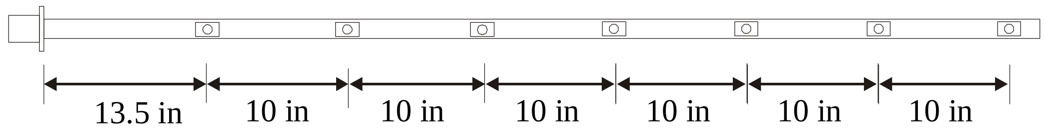

Figure 3: Schematic of Pipe

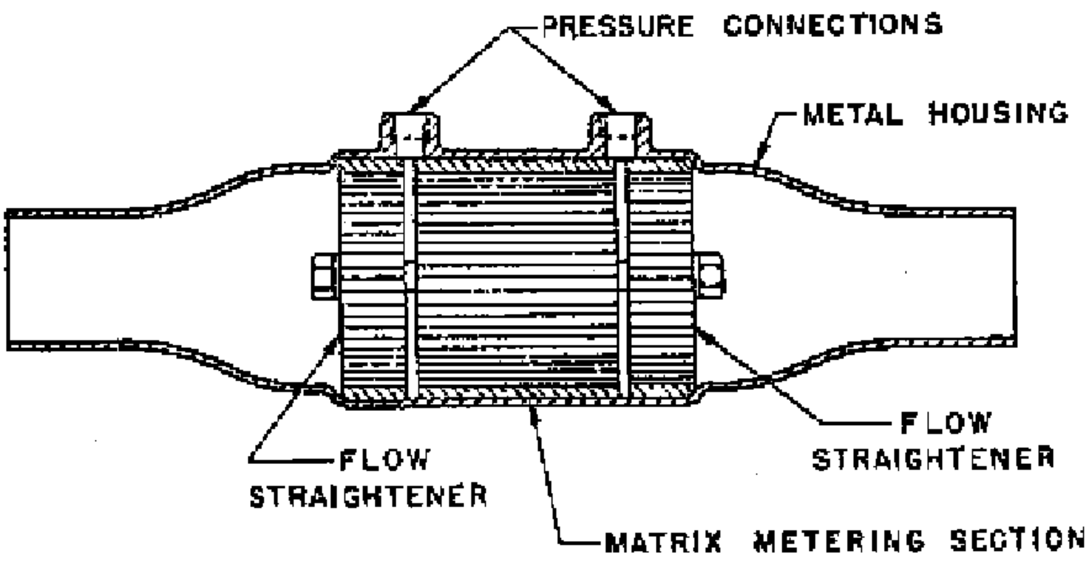

Figure 4: The Laminar Flow Element

Viscous Flow Worksheet

The following equipment arrangement is to be used for proper operation of the element:

1. List objectives of this experiment.

2. Remove the cover from the inlet side of the laminar flow element.

3. Confirm that the outlet from the laminar flow element is connected to the inlet of the fan. Flexible hose connections are provided in the lab.

4. Confirm that the outlet of the fan is connected to the particular experiment of interest. Again, use flexible hose connections.

5. Confirm that the laminar flow element is already connected properly to the electronic differential pressure-sensing device.

6. Turn on blower.

7. The following procedure should be followed in measuring an air flow rate:

   - Note that a particular flow rate is set by the fan. A vertical rod at the outlet side of the fan housing serves as the flow-regulating valve.

   - A differential pressure-sensing device connected to the laminar flow element and it is in turn connected to a voltmeter.

   - The reading on the voltmeter can be converted to difference in pressure between the inlet and the outlet to the laminar flow element using the chart supplied by the manufacturer.

   - The manufacturer of the laminar flow element has supplied a calibration curve, which relates the change in pressure across the element to the flow rate. By locating the proper differential pressure on Fig. 3, the airflow rate can be read directly from the graph.

8. Record pressure distribution along tube with given table.

Measured Flowrate, Q [cfm] ______________

Reference Pressure, P [in of H_2O] ______________

9. Turn off blower.

10. Determine if flow is laminar or turbulent at tube exit.

Calculation:

Reynolds number ________________

Circle one: (a) laminar (b) turbulent

11. Determine location where flow is fully developed.

Calculation:

Entrance Length ________________

12. Determine if flow is compressible or incompressible flow.

Calculation:

Mach Number ________________

Circle one: (a) compressible flow (b) incompressible flow

13. Starting with the Bernoulli's equation (momentum equation), derive the expression for the volumetric flowrate as a function of the measured pressure drop, fluid density, pressure tap spacing, tube diameter, and friction factor.

    Derivation:

14. Determine the friction factor for the tube.

    Calculation:

Friction factor, f ________________

14. Using the Moody diagram, is the smooth tube assumption valid?

15. With the known friction factor, determine the pressure drop profile throughout the entire length of the tube.

Tap #	1	2	3	4	5	6	7
Position X [in]							
Measured Pressure P [in of H_2O]							
Measured Pressure Difference [in of H_2O]							
Predicted Pressure Difference [in of H_2O]							

Discussion of Results and Conclusions