1.1 External Flow

1.1.1 Introduction

The drag force due to external flow over bodies is commonly written in terms of a drag coefficient as

$$F_D = AC_D \frac{1}{2g_c} \rho V^2 \qquad (1)$$

Where V is the approaching fluid velocity and ρ is the approaching fluid density. A is a characteristic area usually taken as the projected frontal area. The constant C_D is known as the drag coefficient.

For incompressible flow, the drag coefficient is a function of the body shape and the Reynolds number. Figure 1 shows the variation of C_D with Re for cylinders in crossflow. At low Reynolds number C_D decreases with increasing Reynolds number. The increase is associated with the viscous shear forces similar to that seen in viscous theory over a flat plate, referred to as skin-friction drag. The drag is attributed to the viscous effects in the boundary layer growing around and near the cylinder surface. Beyond $Re = 10^3$, the flow pattern changes and it is seen that C_D is approximately constant at 0.47 up to a Reynolds number of 10^5. For other body shapes, the C_D variation with Re have the same characteristics, namely, nearly

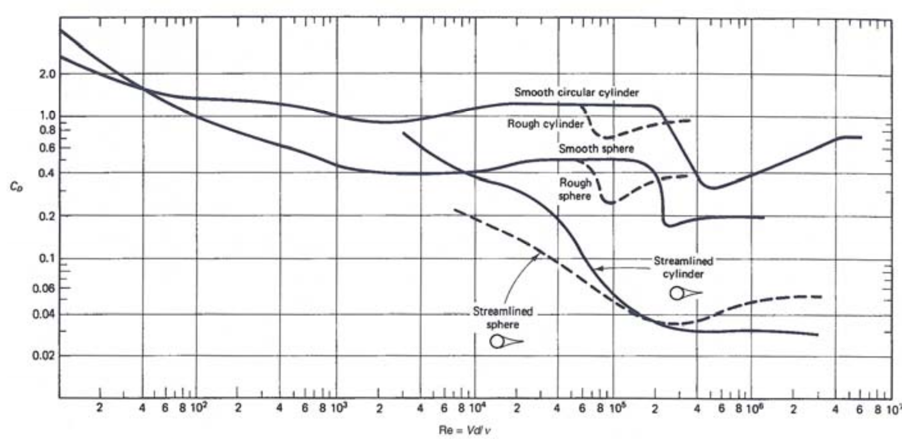

Figure 8.8 Drag coefficients for flow around a cylinder and a sphere. (See E. Achenbach, *J. Fluid Mech.*, Vol. 46, 1971, and Vol. 54, 1972.)

Figure 1: Drag coefficient for flow around a cylinder.

constant for a certain range of Reynolds number. The constant value is characteristic of a blunt body and form drag. Near a Reynolds number of 2×10^5 there is a drastic decrease in the drag coefficient due to a change in flow pattern due to the boundary layer. At Reynolds numbers below this critical number the boundary layer is laminar and separation occurs midway between the front and rear of the cylinder. Nearly the rear half of the cylinder is subjected to low pressure similar to a blunt body. At larger Reynolds number the boundary layer transitions to turbulent flow. The turbulent boundary layer has more momentum and remains attached to the cylinder farther downstream against the adverse pressure gradient. Since the separation is further back on the cylinder, there is some pressure recovery and the pressure at separation is larger than separation at the top of the cylinder. Therefore the pressure difference between the front and rear surfaces of the cylinder is less above the critical Reynolds number and yields a lower drag coefficient.

The objective of this experiment is to use your understanding of external flow around a cylinder, to determine the drag coefficient for this flow under a limited range of Reynolds numbers.

1.1.2 Description of Apparatus

The apparatus of this experiment consists of: a windtunnel, a smooth cylinder, balance, small weights, level, pitot tube, thermocouple, and a blower motor and exhaust. Figure 2 shows the windtunnel and the test section with the cylinder attached to the balance. The smooth cylinder is vertically attached to the balance so that it is placed in cross-flow. Figure 3 shows the geometry of the tube and balance. The balance rotates about point O as the drag force acts on the cylinder. Small weights are added to the top of the balance to counterbalance the drag force, the cylinder weight, and the balance weight to keep the cylinder in the vertical position. A level is provided to insure the cylinder is vertical. A moment balance can determine the drag force. Upstream of the test section, a pitot tube and thermocouple measure the air velocity and air temperature, respectively.

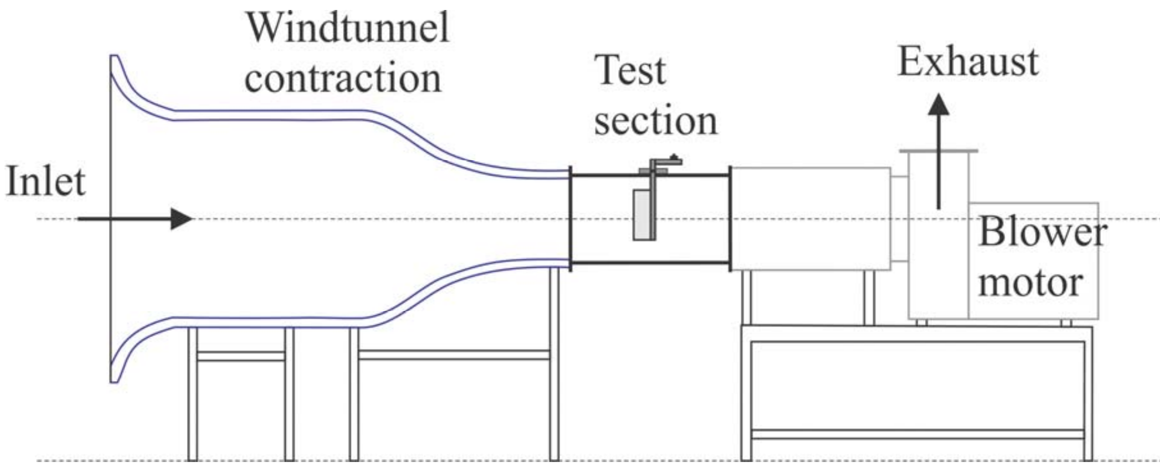

Figure 2 – Windtunnel and test section

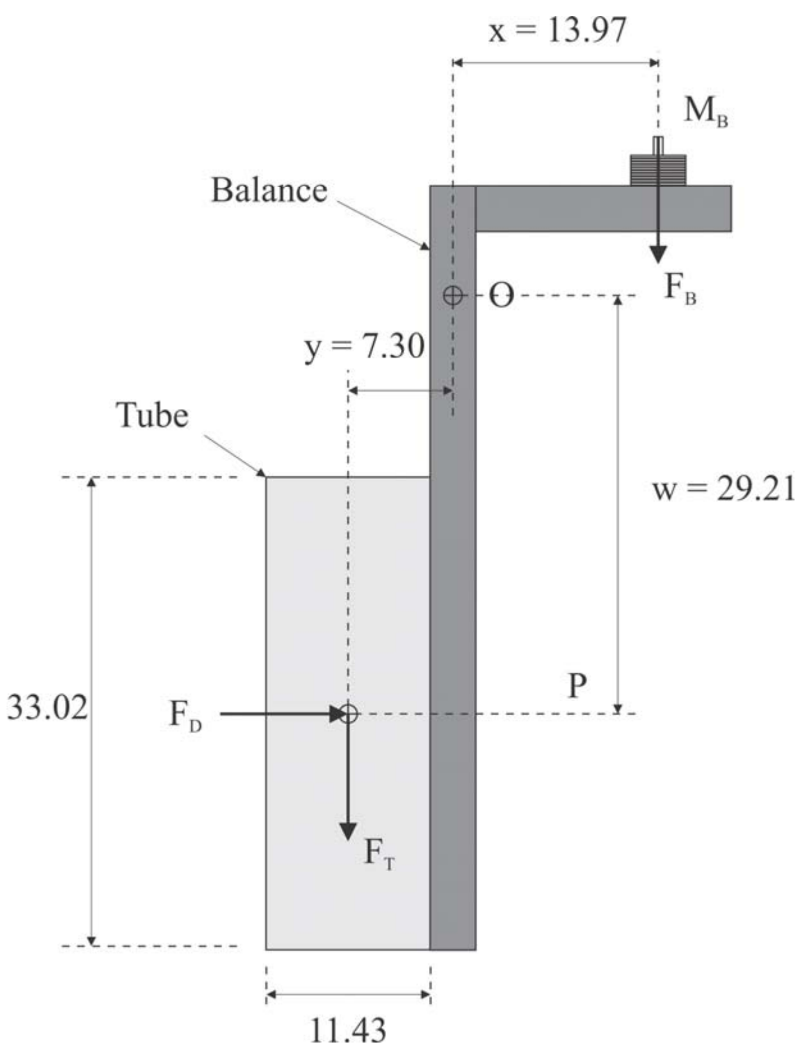

Figure 3 - Test section's cylinder and balance (dimensions in cm)

1.1.3 Safety Guidelines

- Wear necessary eye protection.
- Do not start blower without instructor presence.
- Do not place objects upstream or downstream of windtunnel or in test section.

1.1.4 Experimental Procedure

1. List objectives of this experiment.

2. Determine the counterweight necessary to balance the cylinder so that it is vertical and record. Place the level supplied on top of the balance to measure the cylinder orientation.

   Cylinder and Balance Force ________________ g

3. Have the instructor turn on the blower motor. Adjust the blower speed until the first speed listed in the following worksheet is achieved. The pitot tube is connected to a pressure gauge with a readout in feet per minute (fpm). Record the speed.

4. The drag force pushes the cylinder and rotates the balance such that the cylinder is no longer vertical. Add additional counterweights necessary to rebalance the cylinder so that it is vertical. Again use the level to insure the cylinder is vertical. Record the additional number of counterweights added.

5. Record the air temperature measured by the thermocouple. Assume the pressure in the test section is one atmosphere minus the test section's dynamic pressure.

6. Readjust the blower speed three more times and at each blower setting repeat steps two through four.

	Air Speed [fpm]	Added Mass [g]	Air Temperature [C]	Reynolds Number Re	Drag Force [N]	Drag Coefficient C_D
1	800					
2	1650					
3	2200					
4	2700					

Calculation Worksheet

Show the calculations for one set of data collected on this page. Compare with expected value.