

ENGR 3992
Engineering Lab
Wind Tunnel I

Introduction

The Omega WT4401-S wind tunnel may be used to produce very accurate velocities in the center test section (the acrylic section in the center of the wind tunnel). For this experiment you will be using the wind tunnel to produce air drag on several small objects by attaching each object to a small string and suspending the object from a cork that plugs into a compression fitting on one side of the acrylic test section. The objectives for this experiment are as follows:

1. Demonstrate that you can calculate the velocity in the test section of the wind tunnel given environmental conditions,
2. Construct an angle measurement device (materials provided) that will allow you to measure the angle from the vertical for an object experiencing drag,
3. Determine the mathematical nature of fluid drag forces by measuring drag forces on a smooth sphere.
4. Make some basic observations about the drag on rough and irregular objects.

Background

Forces that oppose the motion of an object that result from external fluid flow are generally called *drag forces*. There are several reasons that drag forces exist. One cause of drag is fluid viscosity, which causes friction at interface between the fluid and the solid object. Viscosity also propagates away from the object and tends to cause turbulence in the region of the disturbed flow (called the boundary layer). This causes variations in pressure along the outline of the object (which causes drag – usually reduced drag). Even if turbulence does not exist, the deflection of fluid streamlines around the object cause some drag force. The earliest scientific work on fluid drag was probably done by Galileo who dropped objects from a tower and attempted to account for drag. In general, the difficulty in accounting for drag arises because drag depends on velocity. Many physics texts suggest that the drag force has a linear dependence on velocity at low velocities and a quadratic dependence at higher velocities. For the purpose of this experiment you will assume simply that

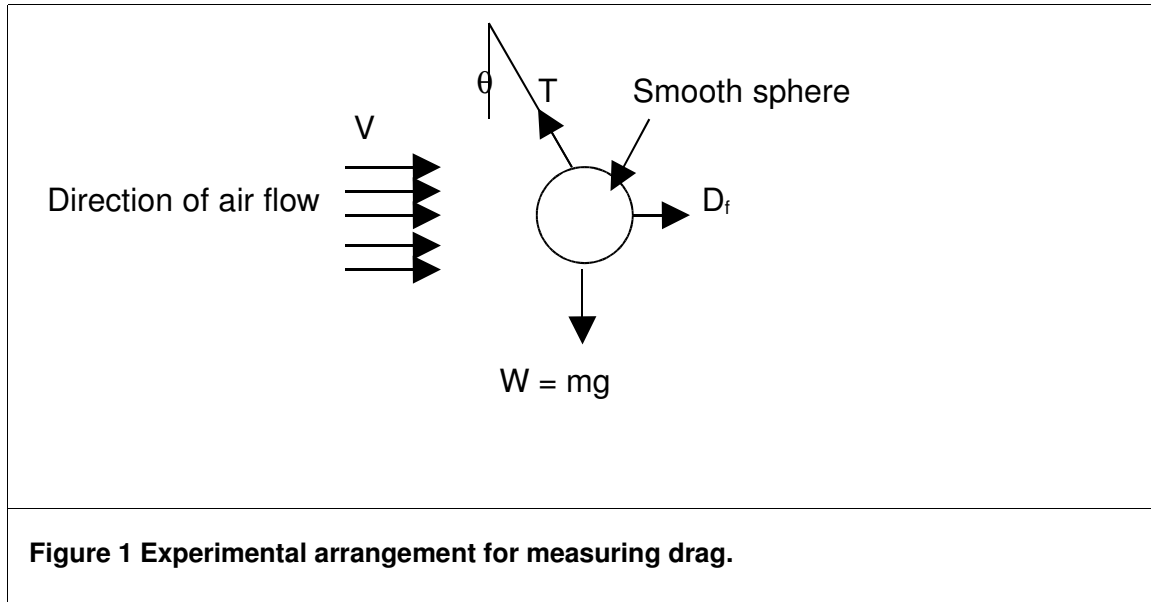
$$D_f = CV^n$$

Equation 1

Where

- D_f = drag force on object [N],
 C = constant determined by experiment [$N/(m/s)^n$],
 V = velocity of the object (m/s).

Falling objects will be considered in another experiment, but for now consider the arrangement shown in Figure 1.



Applying Newton's second law:

$$\rightarrow \sum F_x = D_f - T \sin \theta = 0$$

$$\uparrow \sum F_y = T \cos \theta - W = 0$$

Solving for D_f by eliminating the tension in the string (T) gives

$$D_f = W \tan \theta$$

Equation 2

So finding the drag force is simply a matter of finding the angle θ

The single most used equation in fluid mechanics is probably Bernoulli's Equation (shown here without derivation)

$$\frac{p_1}{\rho_1} + \frac{V_1^2}{2} + gz_1 = \frac{p_2}{\rho_2} + \frac{V_2^2}{2} + gz_2$$

Equation 3

Where

p	=	static pressure,
ρ	=	density of fluid,
V	=	velocity,
g	=	acceleration due to gravity [9.81 m/s ² or 32.174 ft/s ²],
z	=	elevation above a chosen reference.

The subscripts 1 and 2 represent different locations along a fluid streamline and it has been assumed that there are negligible energy losses between 1 and 2. Note that in using Eq. 3 one must use care in making sure units are consistent (since numerous units are used for pressure). If English units are used then sometimes the constant $g_c = 32.174 \text{ lb}_m - \text{ft} / (\text{lb}_f - \text{s}^2)$ will need to be used. If one assumes that the fluid is incompressible ($\rho_1 = \rho_2$), which is a reasonable assumption even for a compressible fluid as long as the velocity of the fluid is less than around 1/3 of the speed of sound in that fluid), that changes in elevation are negligible ($z_1 = z_2$), and that V_1 is small compared to V_2 then Eq. 3 may be solved for V_2

$$V_2 = \left[\frac{-2\Delta p}{\rho} \right]^{1/2} \quad \text{Equation 4}$$

where

$$\Delta p = p_2 - p_1$$

Equation 4 will not actually be used in this experiment, but as Eq. 4 indicates the velocity in the test section is dependent on the pressure change between the relatively stationary air outside the wind tunnel (1) and the accelerated air in the wind tunnel's test section (2). The wind tunnel is used by actually measuring the pressure difference between outside the wind tunnel and the test section. The wind tunnel has been very accurately calibrated as a function of this pressure difference. The best way to use the wind tunnel to produce exact well-known velocities in the test section is to use the technique shown in wind tunnel reference manual. This procedure may be carried out as follows:

1. Use a Omega digital thermometer with an attached thermocouple to measure the temperature (T) in the laboratory.
2. Find the local pressure by going to www.srh.noaa.gov (p).

3. The local pressure is standardized to sea level and room temperature. Apply Eq. 5 to find the actual pressure (p_{act}).

$$p_{act} = p \times \exp\left(-\frac{gz}{g_c RT}\right) \quad \text{Equation 5}$$

Where

p_{act}	=	the actual local pressure,
p	=	the standard pressure as reported by the National Weather Service,
g	=	acceleration due to gravity (9.81 m/s ² , 32.174 ft/s ²),
g_c	=	32.174 lb _m – ft / (lb _f – s ²) [1 for SI units],
z	=	elevation above sea level (use 1000 ft for the lab),
R	=	gas constant for air: 0.287 kJ/(kg-K), 53.3 ft-lb _f /(lb _m -R),
T	=	absolute temperature in K or R.

There is a barometer in the lab. You should also use this barometer to find the actual local pressure. Compare the two values you have obtained for local pressure. Use the value from the barometer for other subsequent calculations.

4. Since the calibration of the wind tunnel was carried out under slightly different conditions than the lab conditions another correction must be made to find the corresponding Δp for the Engineering Laboratory. An Excel spreadsheet contains column1 and column2 data for this wind tunnel. Column 2 on each page of the report must be multiplied by the following correction factor to reflect the Δp that will be observed for a particular velocity in the wind tunnel test section.

$$K = \frac{p_s}{p_{act}} \times \frac{T}{T_s} \quad \text{Equation 6}$$

where

p_s	=	standard pressure [29.92 inHg or 760 mmHg],
T_s	=	standard temperature [530°R or 294.25 K].

5. Finally, the values in column 2 from the calibration reports should be multiplied by K from Eq. 6. The values that result are the Δp values that will be read from the pressure meter attached to the wind tunnel. These Δp values correspond to air velocities shown in the same row on the calibration reports.

Methodology

1. Using a piece of Plexiglas each group should construct a protractor to measure the angle of deflection, θ . A very fine point black marker and a straightedge should be used. Before duct taping your measuring device to the test section of the wind tunnel make sure of the following criteria are satisfied:
 - a. One may measure angles with a precision of 1/10 of a degree,
 - b. The center point the protractor is aligned with the point of attachment of the string (to the wind tunnel) that is attached to the object.
2. Prepare for your measurements by figuring out what Δp values you need for the widest range of velocities possible. Use the process in the Background section (I have produced a spreadsheet that may be used as well). Consider that the wind tunnel may be used in three configurations: No restrictive plate, restrictive plate A, and restrictive plate B; which provide lower velocities, respectively.
3. Make measurements of the angle of deflection for the supplied smooth sphere (ping pong ball) for as many velocities as possible. You should make multiple measurements of the angle at each velocity. **BEFORE OPERATING THE WIND TUNNEL CAREFULLY READ THE MANUAL AND MAKE SURE YOU KNOW HOW IT SHOULD BE OPERATED!!!**
4. Make measurements of the angle of deflection for a golf ball (try out the lightweight plastic ball and the regular weight golf ball). Based on this data you should make some conclusions about the differences between a dimpled surface and a smooth one.

Your reports should be turned in one week after you have completed the conduction of the experiment. The analysis in your report should contain an detailed analysis of your data including error analysis. Additionally, you should make a conclusion (or conclusions) about drag forces and the value of n in Eq. 1.