Drag measurement

key words: Air resistance, pressure and friction drag, bluff and stream line body, surface roughness.
goals: Estimate air resistance of a cylinder. Pressure on the cylinder surface and momentum loss in the cylinders wake will be measured.

1 Introduction

As an object moves through a fluid it experiences forces from the interaction with the fluid. Forces in the direction of the object's motion are referred to as **drag**. Drag forces act against the object motion, and are in general dependent on the velocity. Depending on the flows conditions different phenomena could be responsible for drag creation. In this exercise we will focus on **pressure** and **friction** drag.

Unsymmetrical pressure distribution on the surface of a body will manifest itself as a force acting on that body. Part of that pressure force[1] acting against the objects movement could be considered as pressure drag P_{xp}. By friction drag we will refer to the force resulting from shear stresses on the body's surface. Lets designate it by P_{xf}. The sum of the two yields the **profile** drag P_x.

Which of the two drag components is dominative for the profile drag depends on the body's shape and position against the flow. A good example is a flow past a flat plate. If it is aligned with the flow the drag force is an effect of friction (tangential stresses) only. While it being perpendicular to the flow will result with pressure drag being the important one.

In general it is customary to refer to bodies as **bluff** if pressure drag is higher than friction drag ($P_{xp} \gg P_{xf}$) and **streamlined** if the opposite is true ($P_{xp} \ll P_{xf}$). See Fig.1 for reference.

To investigate aerodynamic forces the following methods could be used:

1. Employment of momentum conservation principle.
2. Pressure distribution and tangential stresses measurement.
3. Direct force measurement (e.g. weighing method which is covered in exercise 7).

[1] The other part could be responsible for lift force.

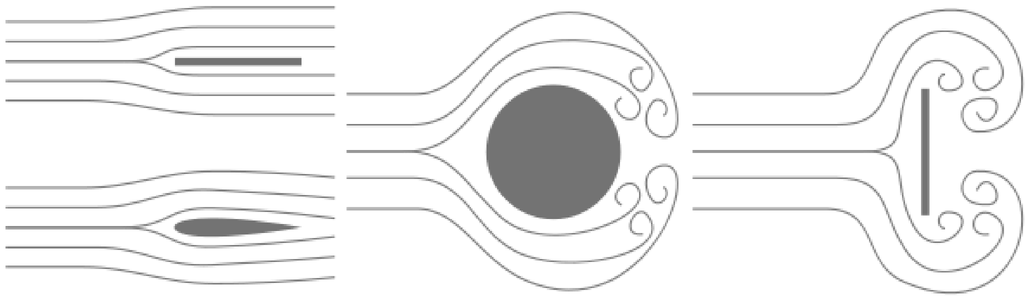

Figure 1: Flat plate and an airfoil as an example of stream line bodies (left) with low pressure drag. Bluff shapes (right) have relatively high pressure drag. From `http://en.wikipedia.org/wiki/File:Flow_plate.svg`

2 Momentum method

The rate of change of momentum must be equal to the sum of forces acting on that system. Or so the Newton's second law states. Therefore by measuring momentum change one might calculate the the forces exerted on the flow (or on the object being flown by).

Consider an example in Fig.2. Force F is a force with which a cylindrical object acts against the flow. As the fluid moves around the investigated body some of its momentum is lost. This is reflected by change in the velocity profile in the wake of an object. By writing the momentum equation for the ABCD contour one might calculate the drag forces[2]. The resulting formula would be (assuming $p_1 = p_2$):

$$-F = P_x = \int \rho V_2 (V_1 - V_2) dy \tag{1}$$

Lets introduce the drag coefficient C_d. It relates drag force P_x, square of the velocity, density and the cross-sectional area A of a body. It is defined as:

$$C_d = \frac{2Px}{\rho A V_\infty^2} \tag{2}$$

Assuming a unitary length of the cylinder ($A = d * 1$) and modifying the equation so dynamic pressure ($q = \frac{\rho V^2}{2}$) is used one would get the following equation for the drag coefficient.

$$C_d = \frac{2}{d} \int \frac{\sqrt{q_2}}{\sqrt{q_\infty}} (1 - \frac{\sqrt{q_2}}{\sqrt{q_\infty}}) dy \tag{3}$$

[2] You should be able to do that after Fluid Mechanics I.

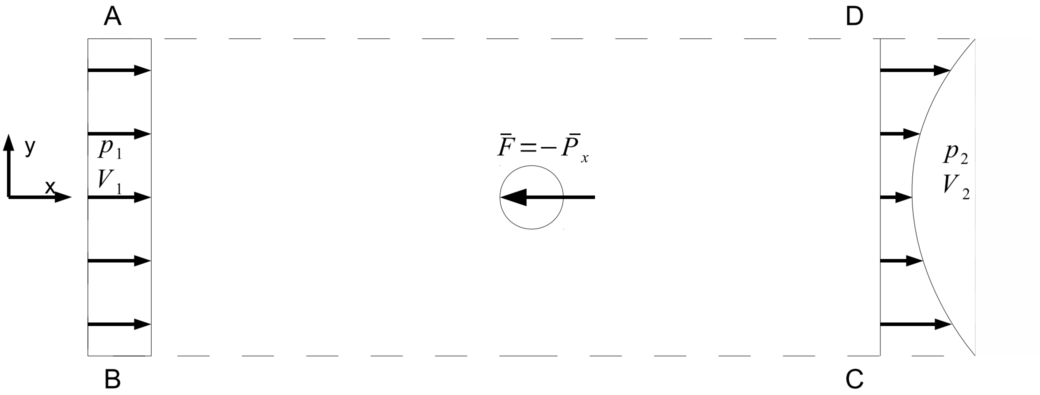

Figure 2: Ilustration to the drag measurment using the momentum method.

As one might notice it is enough to measure the dynamic pressure in the wake to calculate drag coefficient.

3 Pressure method

To calculate the pressure drag it is necessary to know the pressure distribution on the surface of the body being investigated. In general this can only be achieved through experiment. Once this is know pressure drag can be found. In case of a cylindrical shape of radius s the following formula is valid:

$$P_{xp} = \int_0^{2\pi} p(r) r cos(\Theta) d\Theta \tag{4}$$

Further using dynamic pressure q, for a cylinder of length L (area $A = Ld$) it is possible to define the pressure drag coefficient C_{dp}.

$$C_{dp} = \frac{P_{xp}}{qdL} \tag{5}$$

4 Measurements and calculations

4.1 Momentum method

1. Note ambient pressure, temperature and undisturbed flow conditions.
2. Measure pressure distribution in the wake of the investigated object.

3. Do plots of pressure distribution in the wake.

4. Apply numerical integration procedure of your choice to calculate drag coefficient in accordance with formula 3.

5. Calculate method calibration coefficient $K = \frac{C_{model}}{C_{momentum}}$ using model values of drag coefficient.

6. Repeat pressure measurements for different surface roughness.

7. Perform the experiment at different flow regime.

4.2 Pressure distribution method

1. Measure pressure distribution on the surface of the investigated cylinder.

2. Plot pressure distribution as a function of Θ

3. Calculate pressure drag coefficient.

4. Compare the result with the drag coefficient measured with the momentum method.

Dear student,
should you have any remarks, observations or comments concerning this instruction, please do not hesitate to make them.