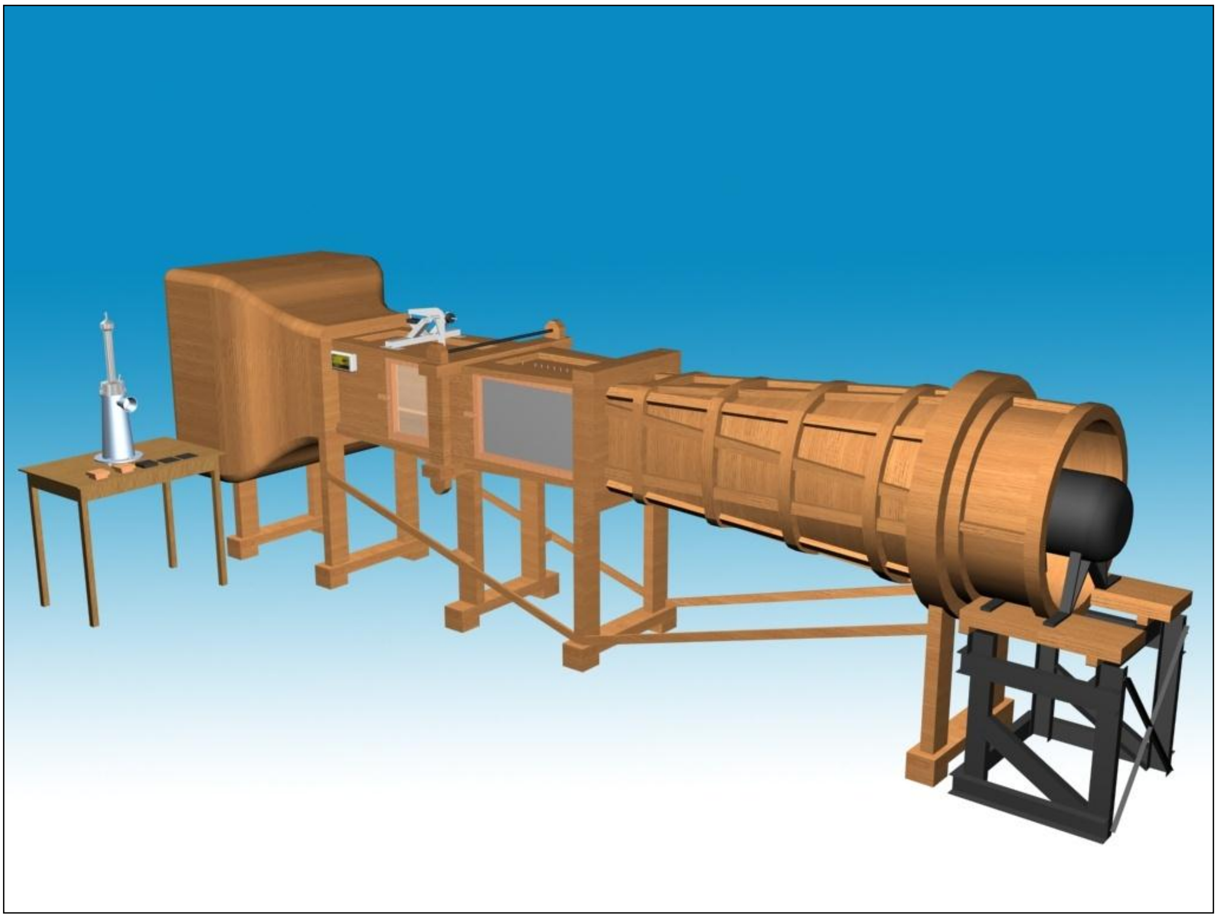


M4

MEASUREMENT OF THE DRAG FORCES ACTING ON A BODY IN A NPL TYPE WINDTUNNEL

1. Objectives of the measurement, practical relevance

Knowing the forces and moments acting on a body is of importance when designing buildings and vehicles. In the present measurement we are going to examine the drag forces arising when placing different plates in the wind tunnel, perpendicular to the flow. We will make comparisons of the forces acting on similar bodies with slightly varied geometries. There are two main types of bodies, which can be examined.

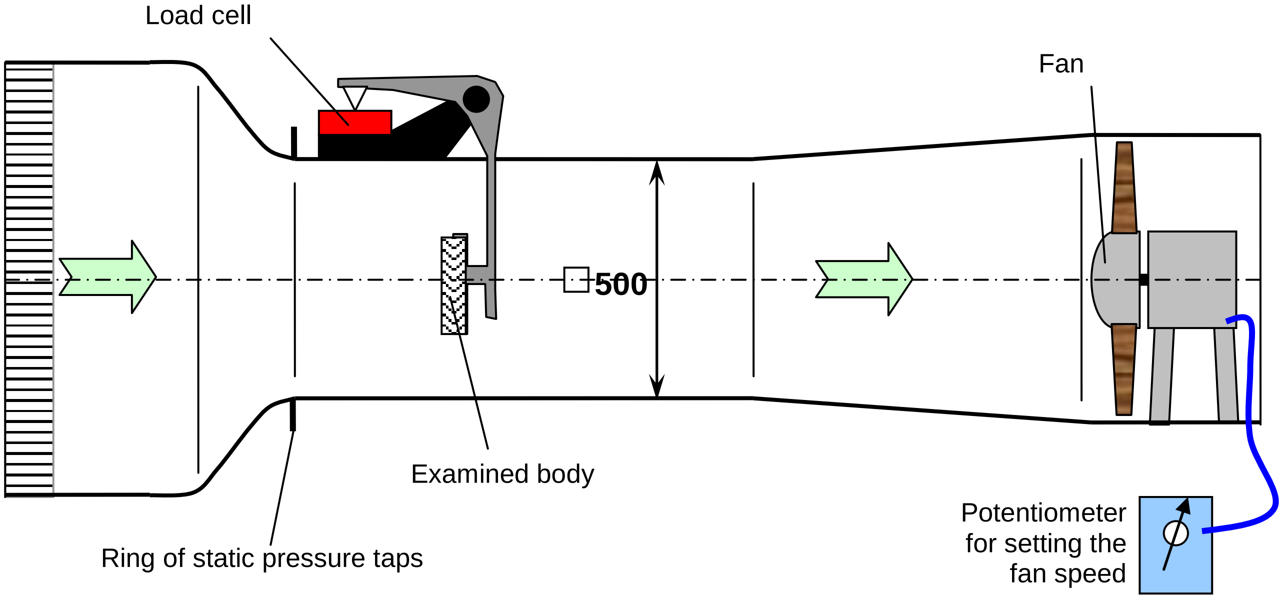
A: In this assignment blocks with different radius rounds are to be placed in the wind tunnel, perpendicular to the flow. The change of the drag coefficient is to be investigated with respect to the change in the radius of the round.

B: In this investigation different perforated plates are to be placed in the wind tunnel, perpendicular to the flow. The drag coefficients should then be compared with respect to the porosity of the material.

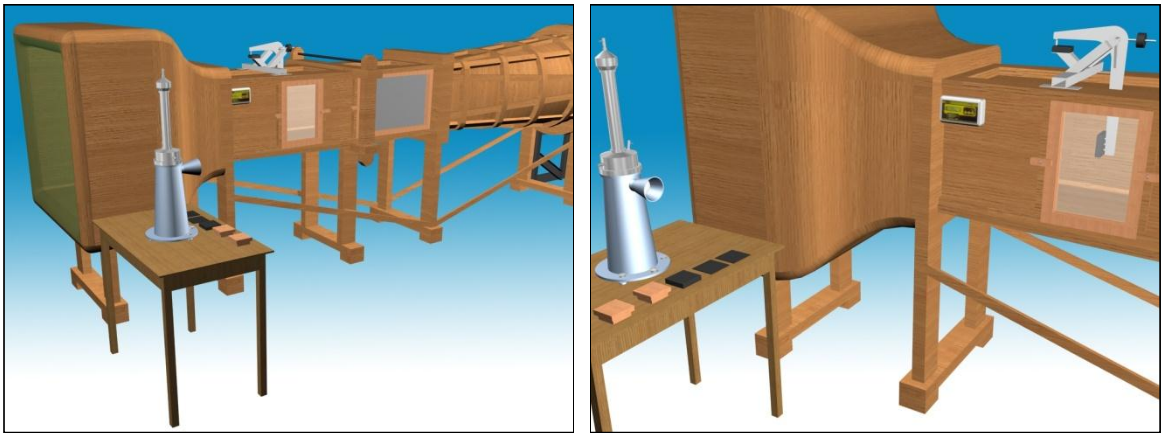
2. Description of the measuring system

The NPL (*National Physical Laboratory*) type open-return wind tunnel, which can be found at the department, has a closed measurement section measuring $500 \times 500[mm]$ with a length of $2[m]$. Upstream of the measurement section can be found the inlet with a confuser and flow conditioners, which guarantee a constant velocity distribution throughout the cross-

section of the measurement section. The ring of pressure taps, which can be found after the confuser, is used to measure the difference between the wind tunnel and the atmosphere, Δp_r. This pressure difference is used to calculate the velocity, which would be measured in the middle of the measurement section.
The measurement of Δp_r can be made using a Betz manometer, digital manometer, or any other pressure measuring device. Here the digital manometer will be used.
After the measurement section of the wind tunnel, there is a diffuser, which is followed by the fan which sucks the air through the wind tunnel. The fan is spun using a dc motor, the speed of which can be set to any value between $0 \div 1500[RPM]$ using a potentiometer. In this way, the velocity in the wind tunnel can be set between $0 \div 15 \left[\frac{m}{s}\right]$. The body, which is to be examined, is to be attached to the arm, which extends into the measurement section from the top of the wind tunnel. Here the forces acting on the arm in the tunnel are measured using a load cell.



Measurement set-up for the NPL wind tunnel



3. Detailed description of the measurement and the variables to be measured

The forces acting on a body placed in a flow, as well as the definition the drag coefficient can be found in many textbooks.
This measurement set-up makes it possible to measure the forces acting on the body in the direction of the wind velocity, ergo the drag forces. The goal of the measurement is to find the

velocity of the wind and the forces acting on the body as a result of this. From this data the drag coefficient can be calculated.

$$F_d = c_d \frac{\rho}{2} v_\infty^2 A$$

Where $c_d[-]$ is the drag coefficient, $v_\infty[{}^m/_s]$ is the wind velocity, $A[m^2]$ is the cross-section of the body, which is perpendicular to the flow direction, and $\rho \left[{}^{kg}/_{m^3}\right]$ is the density of the air. The v_∞ can be determined using the Δp_r. This is necessary, since we are unable to measure the dynamic pressure at the point where the examined body is situated. For this reason, a measurement was made prior to this, by which the uniform velocity distribution in the tunnel was examined, as well as the relationship between the pressure drop measured on the ring of pressure taps and the dynamic pressure in the measurement section.

$$p_d = k\,\Delta p_r$$

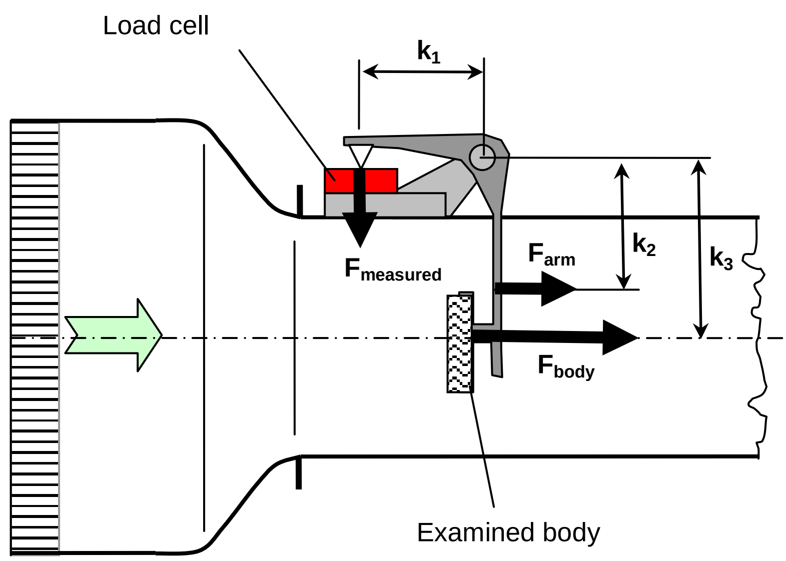
Where $k[-]$ is a constant for when no turbulence generating elements are used upstream of the measurement section.

$$k = 1.015[-]$$

Therefore the velocity can be calculated using the following equation:

$$v_\infty^2 = \frac{2}{\rho} p_d$$

The Reynolds number needs to be calculated as well, for which the value of the kinematic viscosity needs to be calculated using the table found on the department webpage.
It is a good idea to measure the velocity using the Prandtl tube in at least one point as well, in order to check the accuracy of the calibration. This should be done along the centerline of the measured object, but far enough upstream of the objects, so that the disturbing affects of the body placed in the flow do not affect the flow in the vicinity of the Prandtl tube.
The forces acting on the body can be calculated by setting up an equilibrium equation for the moments.



It is important to find the forces acting on the arm which is supporting the body, so that it can be subtracted from the results, since we are only interested in the forces acting on the body. In order to determine this force, we need to place the body in front of the arm, blocking the wind where it would be blocked during the regular measurement, while not attaching the body to the arm. In this way we can determine the moment acting on the arm (M_{arm}). We can therefore write an equilibrium equation for the moments when the body is not attached to the arm.

$$k_1 F_{meas.arm} = M_{meas.arm},$$

Taking the forces acting on the body into account, this equation becomes:

$$k_1\ F_{meas.} = M_{corr.arm} + k_3\ F_{body}$$

Since the air velocity most likely varies somewhat between the two measurements, a correction must be applied to the results.

$$M_{corr.arm} = M_{meas.arm} \left(\frac{v_{meas.}}{v_{meas.arm}}\right)^2$$

Using the above equation we can find the forces acting on the body:

$$F_{body} = \frac{k_1 F_{meas.} - M_{corr.arm}}{k_3}$$

4. The measurement procedure

During the measurement, the group needs to measure the drag coefficient for at least 4-5 bodies (be those form one group, or more groups), for different Reynolds numbers.

After understanding how the measuring instrumentation works, the first step is to check the calibration of the load cell. If it is incorrect, then the load cell has to be calibrated.

After the calibration, the forces acting on the arm are need to be measured. This needs to be done at 4-5 different Reynolds numbers, ergo 4-5 different velocity settings for everybody.

The density of the air (ρ) can be calculated using the atmospheric pressure (p_0) and the temperature (T).

$$\rho = \frac{p_0}{R\ T}$$

Where $R = 287 \left[\frac{J}{kgK}\right]$ is the gas constant.

5. Processing of the results, and comparing those to the results found in the literature

During the processing of the results the drag coefficients are compared with respect to the radius of the rounding of the edges. Instead of comparing the results with respect to a dimensional radius, a dimensionless ratio is to be used in the graphs (radius divided by the length of the blocks edge). Therefore the drag coefficient should be graphed as a function of the dimensionless ratio. In the case of the perforated plates, the dimensionless porosity $\left(A_{free}/A_{total}\right)$ should be used. The results should also be compared as a function of the Reynolds number.

The results need to be compared to results found in the literature, if they are available. These results are available in many fluid mechanics textbooks. An evaluation of the measurement error also needs to be conducted. In this measurement the absolute and relative errors need to be calculated for the drag coefficients. This can be done using the following equations and values:

Drag coefficient: $c_d = \frac{F_d}{\frac{\rho}{2} v_\infty^2 A}$

Absolute error: $\delta c_d = \sqrt{\sum_{i=1}^{n} \left(\delta X_i\ \frac{\partial c_d}{\partial X_i}\right)^2}$

Relative error: $\frac{\delta c_d}{c_d}$

- Pressure difference measured on the manometer: $X_1 = \Delta p, \qquad \delta \Delta p = 2[Pa]$

- Load cell: $X_2 = F_d$, $\delta F_d = 0.02[N]$

The different groups which can be investigated are:

Group A: marked with a letter A (4 pieces)
Group B: marked with a letter B (4 pieces)
Group C: marked with a letter C (4 pieces)

Remember that during the labs:

- Before turning any measurement device on, or in general during the lab, make sure that safe working conditions are ensured. The other participants have to be warned of the starting of the machines and of any changes that could endanger the members of the lab.
- The atmospheric pressure and room temperature should be recorded before and after every measurement.
- The measurement units and other important factors (e.g. data sampling frequency, data of calibration) of every recorded value of the applied measurement devices should be recorded.
- Type and construction number of the applied measuring instrument should be included in the final report.
- Checking and harmonizing of the units of the recorded values with those used in further calculations.
- Manometers should be calibrated if necessary.
- The measurement ports of the pressure meter should be carefully connected to the correct pressure ports of the instrument.
- If inlet or outlet tubes are to be assembled with fans, connections should be airtight as escaping/entering air can significantly modify the measurement results