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Pressure drop measurements and friction factor estimation in a 10-cm circular pipe airflow

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1 Pipe wall roughness estimation

The results from four series of experiments are shown here. Tests 1, 2 and 3 correspond to pipe lengths of 5.65 m, 5.00 m and 4.35 m, respectively. These measurements were taken on a segment of the pipe enclosing three holes drilled for the seeder nozzles and a junction between two pipe elements.

Test 4 measurements were taken on a 3.55 m segment of the pipe devoid of any disturbances. The purpose of these preliminary experiments is to:

- verify that the measured pressure drop is proportional to the pipe length between the two pressure taps
- quantify the effect of the disturbances in tests 1, 2 and 3 on the resulting friction factor
- determine the relative roughness of the pipe

Test 5 measurements were performed over a 7.61 m segment of the pipe enclosing a junction between two pipe elements. Results obtained are similar to tests 1, 2 and 3.

For all data points the air properties are calculated from the measured air temperature in the pipe, atmospheric pressure and 0% humidity.

On figure 1 the pressure drop in Pa is plotted against the Reynolds number for the different tests. The Reynolds number is computed as

$$Re = \frac{4QD}{\mu \pi D^2}$$

where D is the pipe diameter, Q the mass flow rate and μ the dynamic viscosity from Sutherland's formula for ideal gases.

Figure 2 shows the pressure gradient obtained by dividing the pressure drop in Pa by the distance between the two pressure taps. As expected the curves from the three first tests overlap but the pressure gradient for test 4 is lower, presumably due to the presence of the drilled holes and pipe junction in tests 1, 2 and 3. At $Re = 5 \times 10^4$ there is a 5% difference between test 4 and the three first experiments.

Figure 3 shows the D'Arcy-Weisbach friction coefficient as a function of the Reynolds number. f is compared to solutions of Colebrook's equation for values of the relative roughness ϵ/D ranging from 1×10^{-4} to 1×10^{-3}, plotted in grey.

For all tests the evolution of the measured friction factor as Re increases does not follow Colebrook's equation, although the data seem to approach the grey curves at the higher Re tested. The reason for this is unknown.
On figure 4 the relative roughness corresponding to each pressure drop measurement was computed by inverting Colebrook's equation. For $Re > 4 \times 10^4$ ϵ/D seems to stabilize around 1×10^{-4} for test 4 and 3×10^{-4} for tests 1, 2 and 3.

2 Wall friction in the test section

In this section, additional measurements are presented on the section of the pipe used for the interface tracking experiments of November 2009 (see figures 5 and 6). The two pressure inlets are separated by a distance of 2.22 m, without any pipe junctions or drilled holes. Results agree with the data from test 4 in section 1, also obtained on a 'smooth' portion of the pipe.

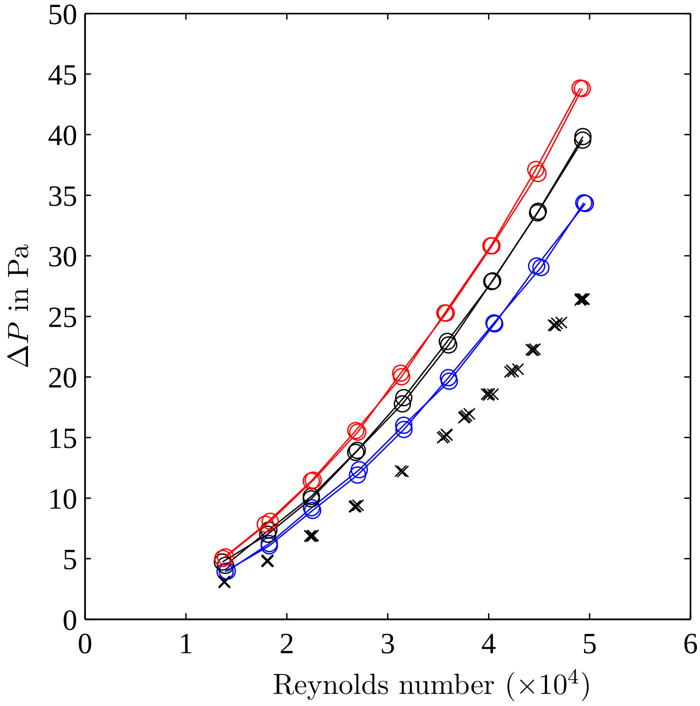

Figure 1: Pressure drop in Pa as a function of the Reynolds number. Red curve: test 1, black curve: test 2, blue curve: test 3, black crosses: test 4.

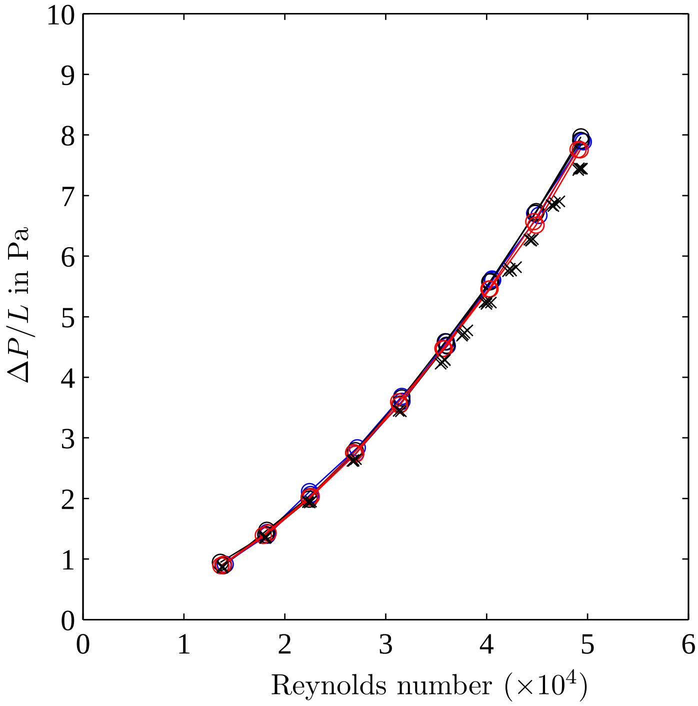

Figure 2: Pressure gradient in Pa/m as a function of the Reynolds number. Red curve: test 1, black curve: test 2, blue curve: test 3, black crosses: test 4.

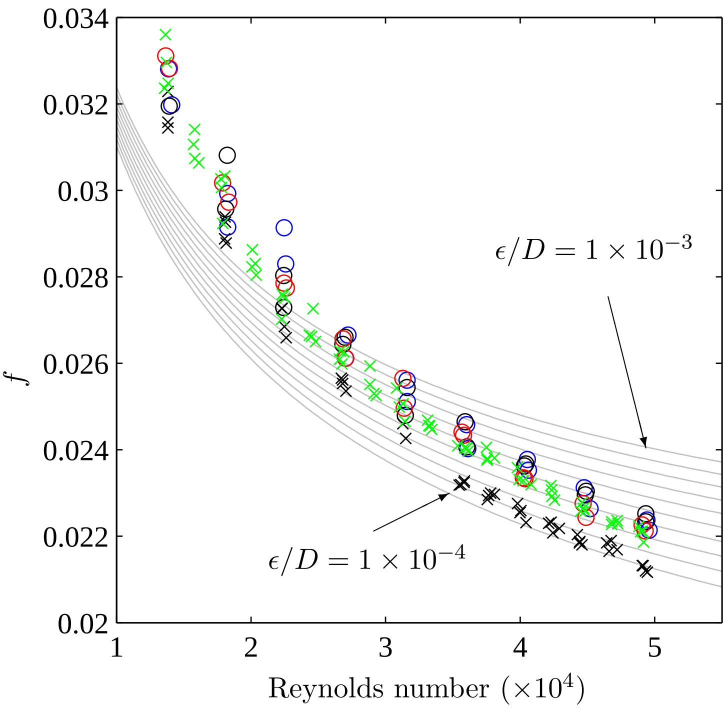

Figure 3: Friction factor f as a function of the Reynold number. Circles: tests 1, 2 and 3. Black crosses: test 4. Green crosses: test 5. The grey curves are the solution of Colebrook's equation for values of the relative roughness ranging from $\epsilon/D = 1 \times 10^{-4}$ to 1×10^{-3}.

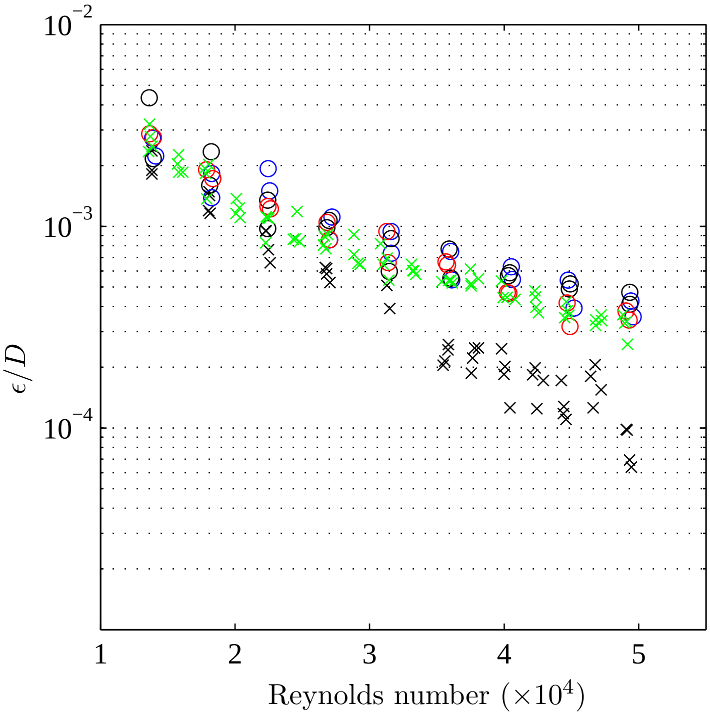

Figure 4: Relative roughness ϵ/D computed from the friction factor f as a function of the Reynold number. Circles: tests 1, 2 and 3. Black crosses: test 4. Green crosses: test 5.

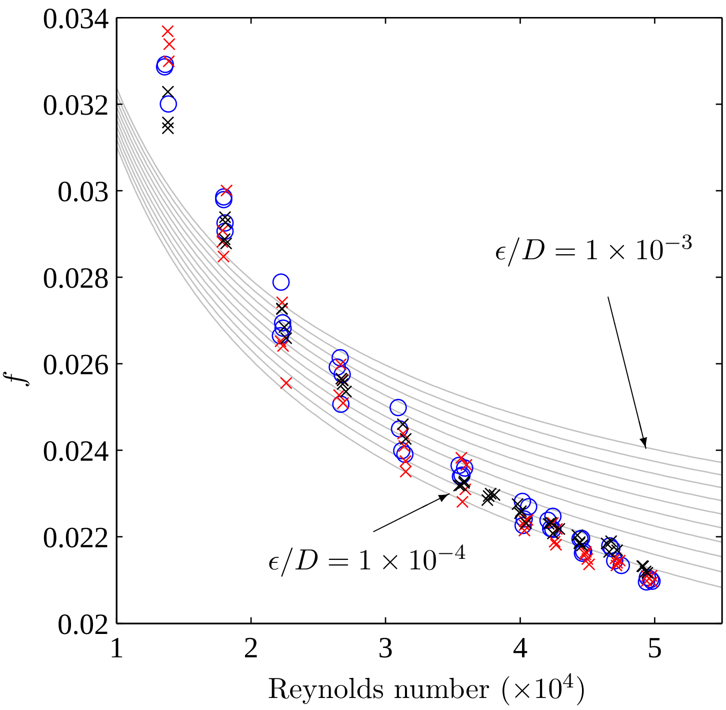

Figure 5: Friction factor f as a function of the Reynold number. Black crosses: test 4 (see section 1). Blue circles: present data, with collecting hose in place. Red crosses: present data, open end. The grey curves are the solution of Colebrook's equation for values of the relative roughness ranging from $\epsilon/D = 1 \times 10^{-4}$ to 1×10^{-3}.

Possible blockage effects at the outlet were investigated by removing the flexible hose collecting the water exiting the pipe in two-phase experiments to leave the pipe open on one end. This did not affect the results significantly.

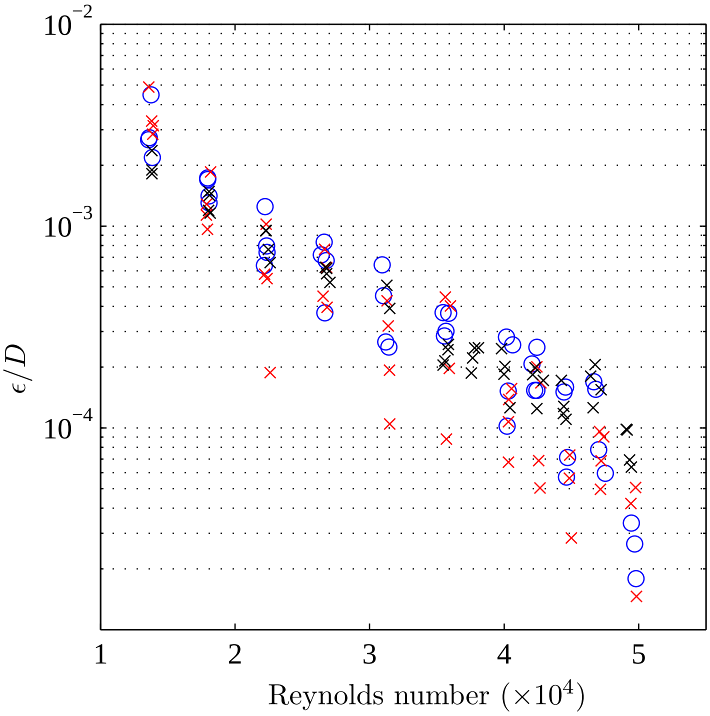

Figure 6: Relative roughness ϵ/D computed from the friction factor f as a function of the Reynold number. Black crosses: test 4 (see section 1). Blue circles: present data, with collecting hose in place. Red crosses: present data, open end.

A The D'Arcy-Weisbach friction factor

For a straight circular pipe and fully-developed flow, the friction factor f is related to the pressure loss by the following equation:

$$\Delta p = \frac{f L \rho \bar{U}^2}{2D}$$

where $\bar{U}^2$ is the bulk velocity and L the corresponding pipe length. If the flow inside the pipe is laminar, $f = 64/Re$ as a direct result of Poiseuille's law. For turbulent flows, the friction factor can be found iteratively from the relative roughness ϵ/D of the pipe according to Colebrook's equation:

$$\frac{1}{\sqrt{f}} = -2 \log \left(\frac{2.51}{Re\sqrt{f}} + 0.269\epsilon/D \right)$$

The solutions of Colebrook's equation for different values of ϵ/D are plotted in the Moody chart.