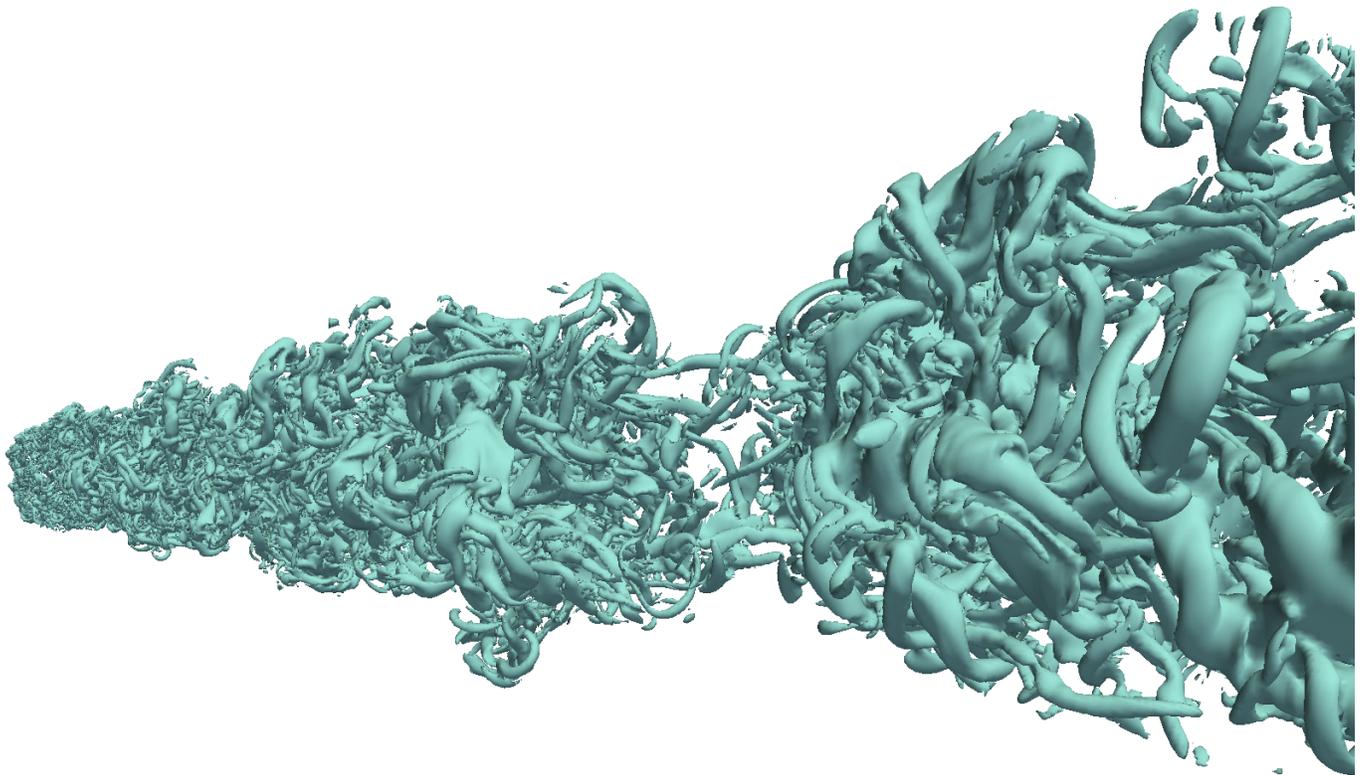# Université de Grenoble
UFR PHITEM M2 TMA

Advanced experimental methods

Multi-hole pitot tubes for the study of planar turbulent wakes.

Martin Obligado, based on the notes by Christophe Brun
(Dated: 02.10.2022)

I. THE FLOW BEHIND A CYLINDER

A closed-loop wind-tunnel (LEGI) is available for this work. It is composed of a convergent section followed by a square test section of constant area of $0.75 \times 0.75 \ cm^2$, then of a return loop with chamber of tranquillisation (*see figure 1*). It allows average speeds $\bar{U}$ between 4.0 and 40 $m.s^{-1}$ approximately. The flow is made completely homogeneous transversely by a series honeycomb structures and grids.
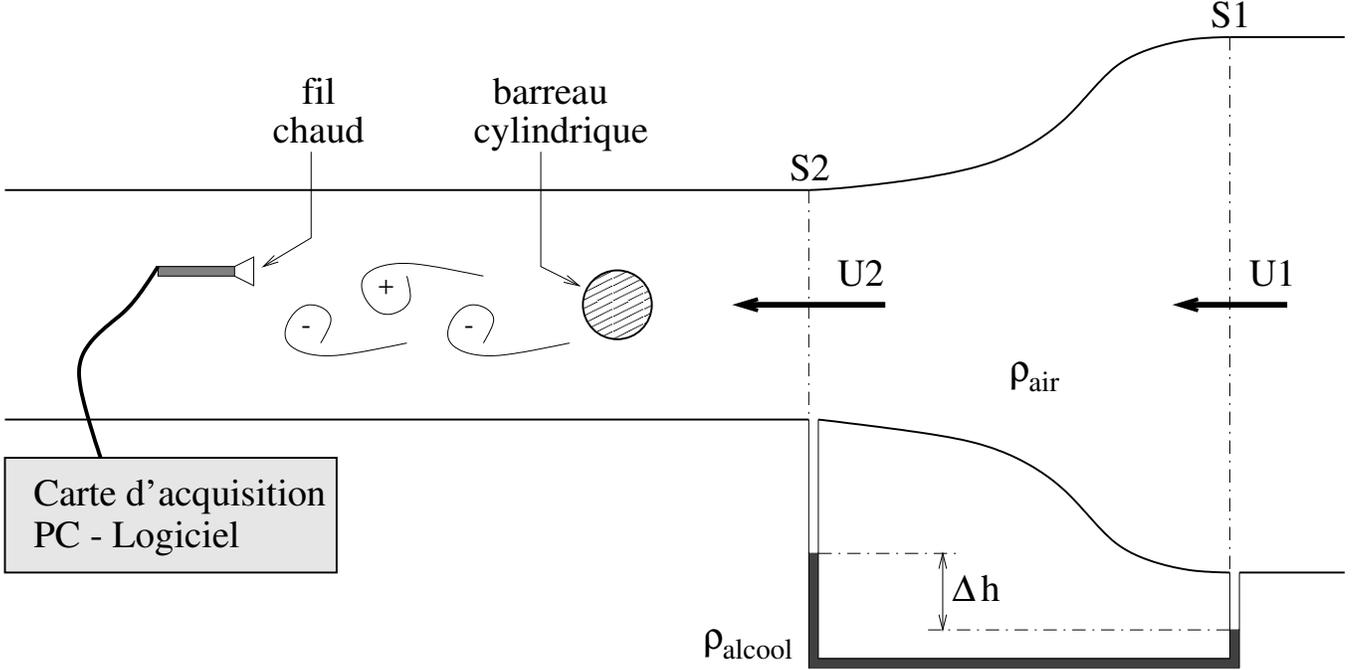

FIG. 1. Schema of the wind-tunnel

For this particular experiment, a cylinder with a diameter $D = 4cm$ is placed normal to the incoming mean flow.

Q1 : Considering the flow is air ($\nu = 1.5 \ 10^{-5} \ m.s^{-2}$), give the range of Reynolds numbers Re that can be achieved with this experimental set-up.

Depending on the Reynolds number (Re) of the flow around the cylinder, various regimes are possible (*see figure 2*). In particular, as soon as the Re exceeds a critical value Re_c of the order of 39, the flow is destabilized and vortices parallel to the axis of the cylinder develop downstream [5, 6] the wake. An street of alternating vortices, known as Benard-Karman, is formed.

Beyond that, for $Re > 1000$, the vortex street becomes turbulent. Sufficiently far from the cylinder, turbulence develops and any trace of the eddies disappears. The wind-tunnel therefore generates different types of speed signals:

- A quasi-periodic regime, at low Re, just behind the cylinder on the way of vortices.

- A turbulent regime, at large Re, where far from the cylinder there is fully developed turbulence.

- Intermediate regimes between these two.

The curve figure 3 represents the frequency f_0 of the vortices of vortices as a function of Reynolds number Re around a cylinder. This frequency is characterised by the Strouhal number:

$$S_t = \frac{\text{characteristic time for the advection}}{\text{instability's characteristic time}}. \tag{1}$$

Q2 : Deduce/find the expression of St as a function of f_0, $\bar{U}$ and D.
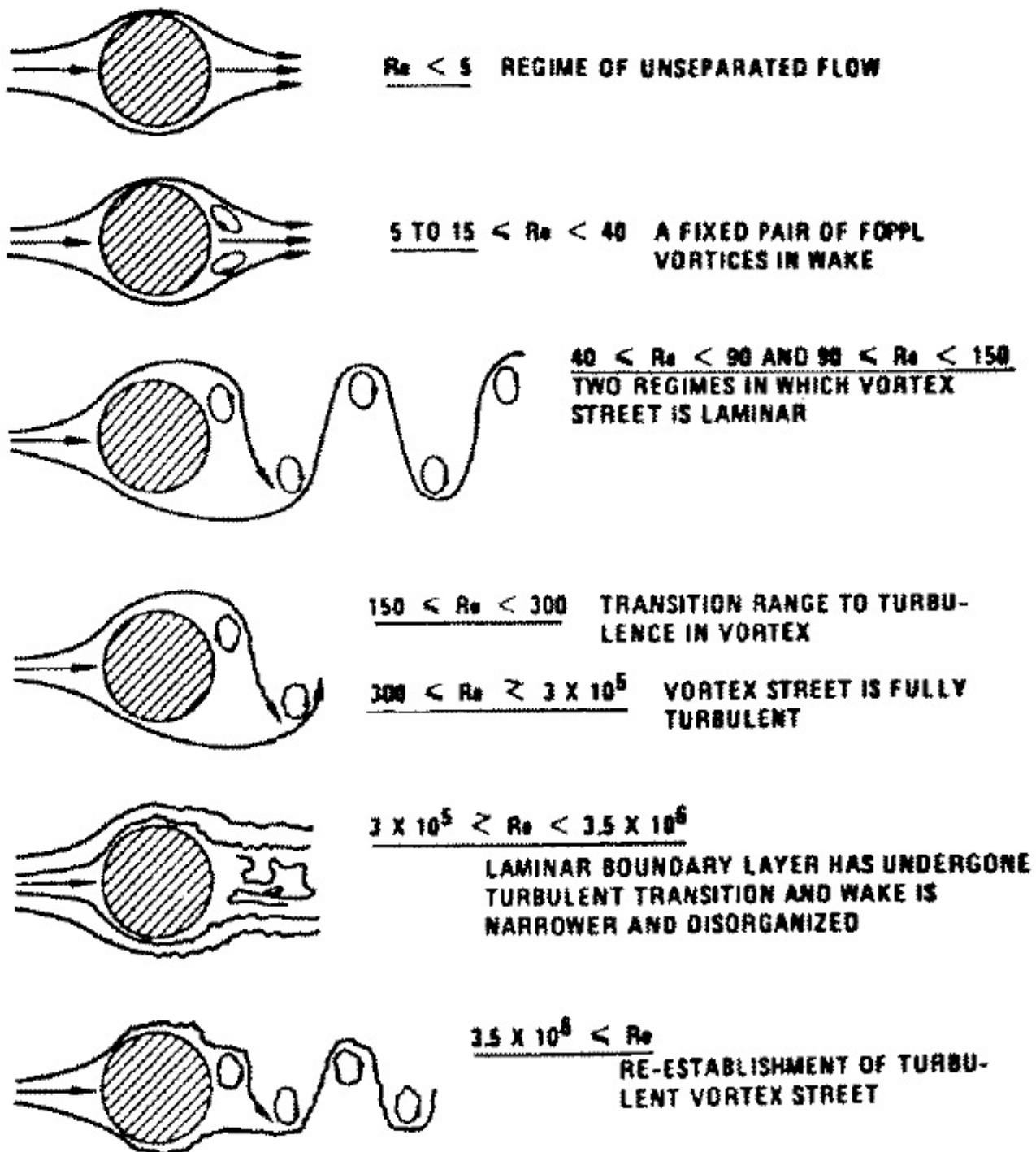
FIG. 2. Different wakes behind a cylinder depending on *Re*. Image taken from [1].
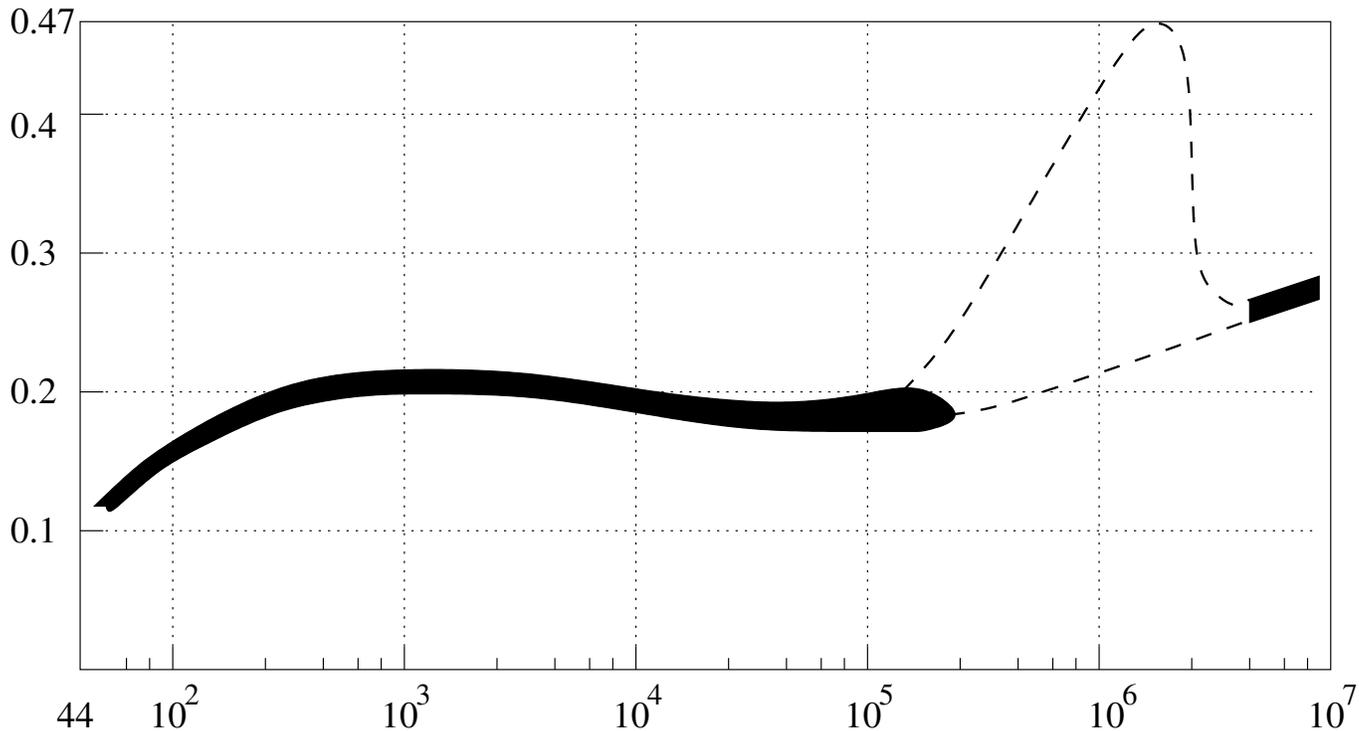
II.   OVERVIEW

This TP aims to:

FIG. 3. Strouhal number as a function of Re

- Get familiarised with the experimental study of a flow in a wind tunnel (LEGI).

- Use this wind tunnel to study the wake downstream of a cylinder with a circular cross-section in a turbulent regime.

- Measure the instantaneous velocity at different points of the wake.

- Perform a statistical analysis of the signal obtained in order to characterise the different scales of turbulence.

- Analyse the results and compare them to similarity laws known, as studied in Fluid Mechanics and turbulence courses.

III. SIMILARITY LAWS

A. Theory

The profile of a planar wake is given by $\overline{u}(x,y) = U_o - u_d(x,y)$ with $u_d(x,y)$ the mean streamwise velocity deficit. We will look for self-preserving solutions with the form, $u_d(x,y) = u_o(x)\,f(\eta)$ with $\eta = y/\delta(x)$ (δ being the wake's half width) and $u_0 = U_0/U_\infty$. State the streamwise scalings of $u_o(x)$ and $\delta(x)$ for a planar wake. Which is the definition of $\delta(x)$ and how you would measure it?

Further information about this flow can be found at [2–4].

IV. PITOT TUBE

We will use a Pitot tube to measure the velocity upstream the cylinder. This device provides the pressure difference ΔP between points A and B, as show in figure IV.

- Which is the relation between ΔP and the freestream velocity U_∞?

- The device also gives the atmospheric pressure P_0 as well as the atmospheric temperature T_0. How is this used for computing U_∞

FIG. 4. Sketch of a pitot tube.

V.   THE 3D COBRA PROBE

We measure the time-series of the velocity of the flow with a high-temporal frequency 3D pitot. We have the documentation of the principle of operation of the Cobra probe.

- Calibrate the Cobra for a still fluid ('zero' the captor). Then start the wind tunnel.

- We will acquire the signal at a maximum sampling frequency of 1 KHz. What is the number of samples N needed to have 60 s of signal?

  Enter the parameters into the data acquisition software.

- Determine the speed upstream of the wind tunnel U_∞ with the Pitot tube and Bernoulli's equation. Check the consistency of the Cobra measurement by comparing to the Pitot measurement of the wind tunnel upstream.

- Register the average and RMS velocities. Deduce the turbulence intensity I_{uu} ($\langle u(t)\rangle/u_{rms}(t)$) in the wind tunnel.

$$u_{rms}(x,y) = \sqrt{\overline{u'^2}}, \text{ avec } u'(x,y) = u(x,y) - \overline{u}(x,y).$$

VI.   POWER SPECTRAL DENSITY

A.   Study for one experimental point

For the highest Re studied, place the wire at the centre of the wake. Compute:

- The temporal signal

- Its probability density function (PDF)

- Its power spectral density (provide an interpretation of this result).

- Its mean value and std.

The post-processing will be performed using matlab (commands "hist" for the PDF, "pwelch" for the PSD and "mean" and "std"). Plot the results and analyse them.

B.   Change the freestream velocity

- Which is the effect on the PSD of a velocity change? Try two different Re. Try to adimensionalize the results using U_0, f_0 and D.

- Plot (in logarithmic scale), the adimensionalized spectra obtained.

C.   If time allows....

We will explore the advantages and limitations of the algorithm *pwelch* from matlab (used to estimate the PSD) by changing the numbeer of segments averaged for each PSD.

D.   Experiment

For the intermediate Re studied (provide the exact value):

- Measure and plot $u_o(x)$. Compare with the analytical solution.

- For two different fixed values of x, measure and plot a vertical profile, $u_d(y)$ (one for $x \leq 10D$ and other for $x > 10D$). Compare with the analytical solution

- Plot altogether the profiles obtained, analyse he results.

VII.   SUBSEQUENT DATA ANALYSIS

- Propose a fitting function for the vertical profiles. Can they be approximated by a Gaussian distribution?

- From the result above, the wake width δ can be estimated as the standard deviation of the profile. Plot the self-similar functions $f(\eta) = f(y/\delta)$. Do they collapse?

- Discuss the quality of the collapse in terms of the Reynolds number. Comment on possible interferences, such as the walls of the wind tunnel.

- Are the PSD those expected for a turbulent flow? Why? Which are the differences with an homogeneous and turbulent flow?

- With the PSD, you can estimate a Strouhal number (hint: use results out of the cylinder's axis). Compare with the results from figure 3.

---

[1] Robert D Blevins. *Flow-induced vibration*. New York, NY (USA); Van Nostrand Reinhold Co., Inc., 1990.
[2] T Dairay, M Obligado, and JC Vassilicos. Non-equilibrium scaling laws in axisymmetric turbulent wakes. *Journal of Fluid Mechanics*, 781:166–195, 2015.
[3] H Djeridi, Marianna Braza, Rodolphe Perrin, Gilles Harran, Emmanuel Cid, and Sebastien Cazin. Near-wake turbulence properties around a circular cylinder at high reynolds number. *Flow, Turbulence and Combustion*, 71(1-4):19–34, 2003.
[4] William K George. The self-preservation of turbulent flows and its relation to initial conditions and coherent structures. *Advances in turbulence*, pages 39–73, 1989.
[5] Anatol Roshko. Experiments on the flow past a circular cylinder at very high reynolds number. *Journal of Fluid Mechanics*, 10(03):345–356, 1961.
[6] CHK Williamson. Evolution of a single wake behind a pair of bluff bodies. *Journal of Fluid Mechanics*, 159:1–18, 1985.