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LARGE SCALE STRUCTURES IN FULLY DEVELOPED TURBULENT PIPE FLOW: AN EXPERIMENTAL STUDY IN CICLoPE

AT THE ROOT OF FRICTION

Everytime a fluid is bounded by a wall, a thin vorticous layer will form on the surface of the body, where the effects of friction are experienced: the boundary layer. In aerospace applications, at very **high Reynolds numbers**, the **boundary layer is turbulent**, and therefore, it is associated to larger values of friction.

At subsonic cruising speeds, at least **50% of the total drag of conventional takeoff and landing is due to skin friction**. Considering that the annual fuel cost for all American airlines is $10 billion, even **a reduction of 20%** of the skin-friction would translate in an annual **saving of $1billion**.

To tackle the crucial task of drag reduction, for both an environmental and economical point of view, it is of foremost importance to go to the root of the problem and investigate the processes happening in the turbulent boundary layer. Due to its chaotic nature, studying its behaviour is not as trivial as it may seem.

INVESTIGATING TURBULENT BOUNDARY LAYER

SCALING – A QUEST FOR UNIVERSALITY

Classical theory describes the mean velocity profile of a high Reynolds number turbulent boundary layer as divided in three main regions. The inner, where viscosity plays a dominant role, the outer, where turbulent stresses are, and the overlap region, lying between the two. Here, the behaviour is described by a **logarithmic law** governed by **κ, the Von Karman constant**, whose value and behaviour are still object of an intense ongoing debate. When undertaking the mission of drag reduction, being able to **model the boundary layer**, and therefore make **accurate predictions, is key**. Numerical codes are closely related to the value of κ: for a given value of the Von Karman constant, the model will return a certain friction prediction.

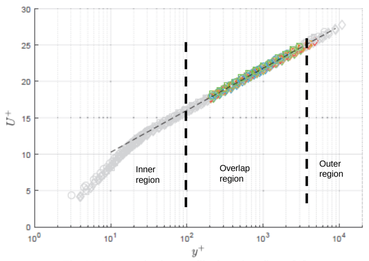

Fig.1 Mean velocity profile for pipe flow. [1]

In this regard, answers to these questions need to be found:

- Is κ universal?
- If it is not, what parameters influence its value?
- Is there an alternative law?

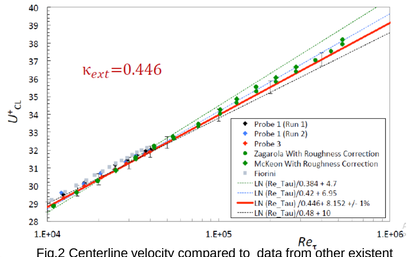

Fig.2 Centerline velocity compared to data from other existent facilities. [2]

Experiments at CICLoPE reveals that **κ is not universal**, and the flow in this region can be described by an alternative **model based on a double logarithmic law**, and therefore two Von Karman coefficients. In this framework, one κ shows a universal nature, with the most accepted value of 0.384, whilst the value of the other one is influenced by pressure gradient, and therefore on the type of flow one is flow. For the fully developed pipe flow this value is found to be 0.446.

VISUALISATION OF LARGE SCALE STRUCTURES

Turbulent boundary layers are **highly chaotic and randomic** characterised by a wide range of scales, making modelling and experimental measurements a real challenge. However, the flow hides structures that somehow exhibit an **organised architecture** and extend in the streamwise direction for several boundary layer thicknesses, therefore known as **large or very-large scale motions** (LSMs and VLSMs) .

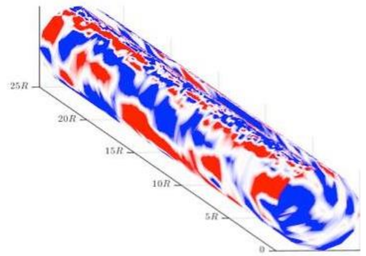

Fig.3 LSMs visualisation: blue regions are low momentum parts, corresponding to large-scale structures. Preliminary results from CICLoPE

Despite the vast literature on this topic, no unanimous consensus has been achieved on the issues of their nature, origin and interaction with other scales. On an intuitive level, they are often pointed at as the **primary responsible for dissipation in turbulent boundary layer**.

My objective is:

- To **visualise** VLSMs
- Understand and **quantify their energetic contribution**
- Possible flow control applications

To this end, adding a structural approach to the statistical one is very important, since statistics do not allow to see what happens in the flow, but let only the mean flow to be observed.

EXPERIMENTAL TOOLS

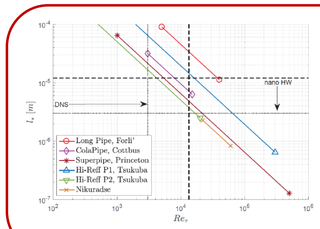

Fig 4 Comparison to existing facilities.

A challenge to face when studying wall bounded flows adopting an experimental approach, is the decrease of the dimensions of the vortices near the wall as the Reynolds increases. Existent facilities are forced to choose between standard tools of measurements, high accuracy and high Reynolds numbers. The CICLoPE laboratory, thanks to the impressive dimensions of its test section, the Long Pipe, was born to solve this problem, **allowing to achieve high Reynolds number range and perform high accuracy measurements with standard hot wire anemometers**.

Total length: 120m
Pipe length: 111.5m
Diameter: 0.9m± 01mm
Max speed: 60m/s
Fan power: 380kW

Inner surface roughness <0.2μm
Temperature variation <0.1°C

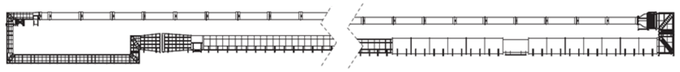

Fig.5 Sketch of CICLoPE

Fig. 6 Picture of the Long Pipe.

HOT WIRE SENSORS

Most of the velocity measurements are performed with constant-temperature hot wire anemometers. They are custom-made in the laboratories, with the aid of a micro-manipulator, since the length of the wire is of maximum 1mm and its diameter between 5 μm and 2.5 μm. The wire material is Platinum.

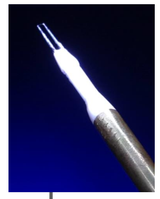

Fig. 7 Home made hot wire probe

[1] Fiorini, T 2017 Turbulent pipe flow – High resolution measurements in CICLoPE. PhD thesis, University of Bologna
[2] Nagib, H. M., Monkewitz, P. A, Mascotelli, L., Fiorini, T., Bellani, G., Zheng, X., Talamelli, A., (2017), Centerline Karman "Constant" Revisited And Contrasted To Log-layer Karman Constant At CICLoPE. *10th International Symposium on Turbulence and Shear Flow Phenomena, Chicago, USA*

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