24th of April 2019

Environmental data analysis

Lab session:
Hot-wire investigation of a turbulent boundary layer

Introduction

The goal of the present study is to determine the characteristics of a turbulent boundary layer developing over roughness elements. The boundary layer is characterized by the main statistics of its velocity components that allows for the estimation of turbulence flow parameters such as the boundary layer thickness, the roughness length, the friction velocity, etc. Here, the focus will be put on the characteristics of the longitudinal component.
The instantaneous longitudinal velocity of the flow will be measured as a function of the distance from the bottom wall z via the use of a thermal anemometer (also referred to as hot-wire anemometer). After its proper calibration, the anemometer will allow for the computation of the main statistics of the longitudinal velocity (the probability density functions and the corresponding mean velocity, standard deviation, skewness, flatness, etc).
These quantities, computed as a function of the wall distance will give important information about the structure of the boundary layer flow.

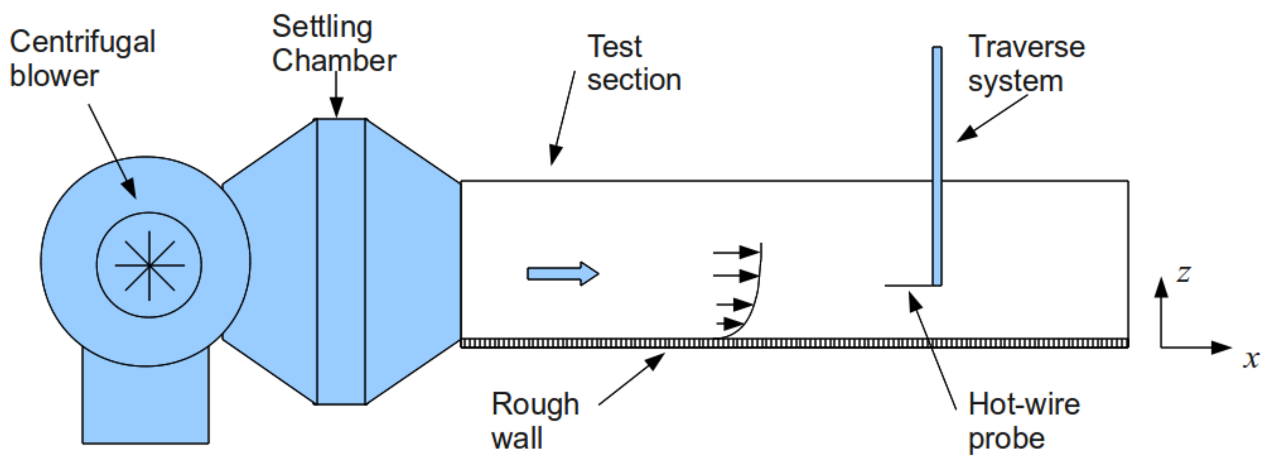

Figure 1: experimental setup

Experimental setup

The experimental setup used to perform the investigation of the turbulent boundary layer flow is described in figure 1. It mainly consists of a wind tunnel, equipped with a variable-speed blowing fan, a test section, the bottom wall of which is equipped with a rough surface, a vertical traverse system allowing the displacement of the hot-wire probe, and a Pitot probe. In order to perform measurements, a differential manometer is connected to the Pitot probe and gives the difference of pressure between the dynamic pressure and the static pressure in mm of water. A thermal anemometer connected to the hot-wire probe and a computer equipped with an acquisition system are employed to perform measurements of the instantaneous longitudinal velocity.

Calibration of the hot-wire anemometer

The calibration of the anemometer is a crucial step in hot-wire experiments and must be performed with great care. This preliminary phase is used to relate the voltage output E of the anemometer and the longitudinal velocity of the flow U via the use of the King's law:

$$E^2 = a + bU^n$$

To ensure the maximum precision, the probe must be located outside the boundary layer, at a distance $z \approx 20\text{cm}$ from the wall, the boundary layer thickness being of the order of 10cm. Steps in velocity are performed by varying the rotation frequency of the fan, and for each step, the voltage delivered by the anemometer and the pressure difference measured by the manometer connected to the Pitot probe are recorded.

- The rotation frequency of the fan will be varied from 0 to 40 Hz, by steps of 5Hz. **Be careful, DO NOT GO BEYOND 40 Hz**,
- For each velocity step, the indication given by the manometer will be noted and used to compute the reference velocity of the flow U,
- In the same time, the voltage output E of the anemometer is recorded and its mean value computed,
- The average of the square of the voltage E will be plotted as a function of the mean velocity U. The parameters a, b and n from the King's law will be determined.

Choice of acquisition parameters

Preliminary measurements performed in this flow allowed the estimation of the mean longitudinal velocity $\overline{U}$ and the standard deviation σ_u at different height h from the wind tunnel floor (table 1). The height of the boundary layer δ (or boundary layer thickness) is approximately 90mm. δ can be used as an estimation of the integral length scale L_u of the flow, which can be related to the integral time scale T_u by $L_u = T_u \overline{U}$.
By using these preliminary data, compute the minimum time of measurement and the minimum number of samples needed to compute the mean value $\overline{U}$ of u with an accuracy of 0.5%.

h (mm)	$\overline{U}$ (m/s)	σ_u (m/s)
7	2,1	0,45
16	2,8	0,43
32	3,2	0,37

Experiments

As recalled in the introduction, the goal of these experiments is to determine the characteristics of the longitudinal velocity component as a function of the distance of the wall, via the computation of its main statistics.
To carry out the experiments, the rotation speed of the fan is set at 30Hz and the probe is traversed across the boundary layer. Measurements are performed from $z \approx 5\text{mm}$ to $z = 85\text{mm}$ every 10mm (i.e. 9 locations).

The sampling frequency and the record length will be set according to the values found in the above paragraph. From these recordings, the time history of the longitudinal velocity will be computed and analyzed.

Post-processing

At each height z, the main statistics of the flow can be computed and analyzed in terms of

- the accuracy of the mean velocity $\overline{U}$ and the standard deviation σ_u,
- magnitude of the mean flow,
- intensity of the fluctuations, which represent a fraction of the turbulent kinetic energy,
- characteristics of the fluctuations (shape of the density probability function, is the signal a Gaussian process ?, etc),
- etc.