

**CHARACTERIZATION OF THE TURBULENT BOUNDARY LAYER WITH AN ATMOSPHERIC WIND TUNNEL: PRELIMINARY RESULTS**

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**Abstract:** We have performed some measurements to characterize an atmospheric wind tunnel at the Institute for Technological Research (IPT) and then some question related to environmental pollution were investigated. We determined the roughness length  $z_0$ , and friction velocity  $u_*$ , based on vertical velocity profiles and an estimate of inertial sub-layer thickness was obtained by assuming that within it  $z_0$  and  $u_*$  are almost constant. The influence of floor roughness configurations and the presence or not of vortex generators were taken into account. The study of spectra of times series and velocity field within a urban canyon model are consistent with the literature.

**Keywords:** atmospheric wind tunnel, boundary layer, velocity profile, spectral analysis, flow field.

## 1. INTRODUCTION

There has been an increasing awareness of the importance of atmospheric wind. Recent catastrophes (such as the Katrina hurricane in the USA or the Catarina hurricane in Brazil, the first ever recorded) and increasing concern for pollution dispersion in urban canopies resulted in a large demand for wind related studies. Wind is a complex phenomenon and close to the surface, usually the area of interest, turbulence is very important. Numerical modeling is still far from accurate predictions of wind related phenomena near the surface. Experimental simulations in wind tunnels are still the only accurate way of determining the effects of wind.

The problem of wind tunnel testing involves more than just appropriate instrumentation. Correct characterization of the atmospheric wind is essential if accurate results are required. The accuracy and uncertainty of the wind tunnel

modelling will depend on how well the boundary layer is modeled.

The simulation of the planetary boundary layer (PBL) in wind tunnels require the knowledge of the dynamical properties of flow, e.g. mean velocity and turbulence intensity, in several tunnel positions and in absence of models. The undisturbed flow properties depend on fan rotation rate and of elements that generate turbulence, namely: floor roughness, barrier-vortex generator system, lateral walls and the ceiling. The flow response due changes in those elements must therefore be well-characterized in order to identify the influence of the model on the simulated PBL. Besides the work of characterization, we have followed Kastner-Klein et al. [6, 7] in the study of pollutants dispersion in street canyons. The using of street canyon model has been an suitable choice because its simplified geometry.

## 2. METHODOLOGY AND PERFORMED TESTS

The IPT atmospheric boundary layer wind tunnel (see Figure 1) is briefly described in Marciotto et al. [1] and follows the prescription of Counihan [2].

There was two phases in this work: the first one was constituted by measurements of flow mean velocity performed with an Airflow static pitot tube and a Scanivalve pressure transducer. Vertical profiles of velocity were obtained. Tests with pitot tube were performed by considering two types of surface roughness, namely, smooth and rough. In the second case the configurations of roughness elements, which is constituted of wooden blocks, differed either in its distribution on the floor or height. We have also changed the configuration of the tests in function of the presence or not of the barrier-

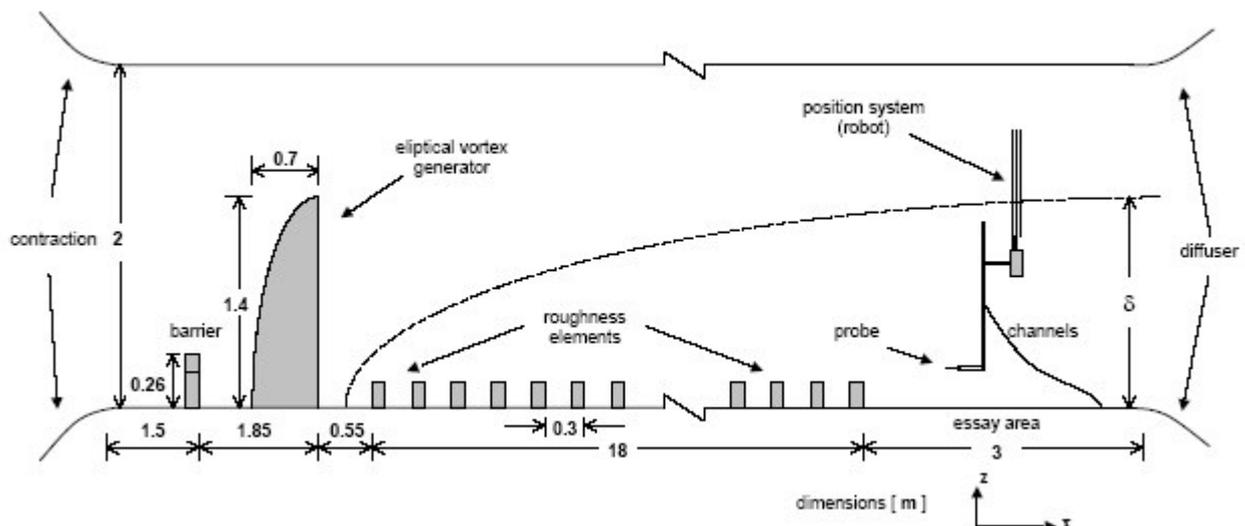


Fig. 1. Schematic view of the IPT wind tunnel.

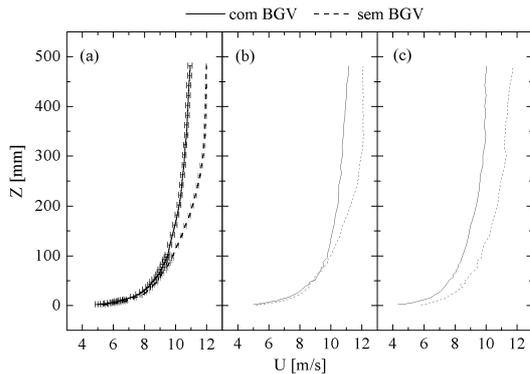
vortex generator (BVG system, or simply BVG) as well as in function of the fan rotation rate (200, 300 e 400 rpm). The pressure transducer can make measurements with frequency as high as 120 Hz so that we are able to obtain a pressure time series, although this processes is not very clear owing to turbulence.

In the second phase of the work, we obtain the turbulence intensity and time series utilizing a Dantec unidirectional hot-wire anemometer. The hot-wire has been calibrated whenever it was used by means of a fourth-order polynomial. The range of calibration has been kept from 0 to 25 m/s, with log distributed velocities, which is quite adequate since the velocities measured in the IPT wind tunnel were not lower than 1 m/s or higher than 20 m/s.

### 3. RESULTS AND DISCUSSION

#### 3.1. Mean velocity profiles and pressure fluctuation

Figure 2 shows the vertical profiles of the longitudinal velocity calculated from the average of ten transversal profiles of flow. We observe that in the presence of BVG the flow velocity is smaller due to a larger energy loss of the mean flow. Since there is more turbulence in that case, it is expected larger velocity fluctuations so that the dispersion of data is greater. In the central region of tunnel the mean velocities are practically equal for heights inferior to 0.1 m. (Figure 2b). Near the lateral wall of tunnel, the velocity with the presence of BVG is smaller than of that in its absence over all vertical levels, as it can be seen in Figure 2c. We observe that in absence of BVG, the boundary layer is about 0.3 m in height and it is well defined (Figures 2a and 2c). On the contrary, in the presence of the BVG system we observed the flow shearing does not vanish within the vertical domain we have studied (0.5 m).

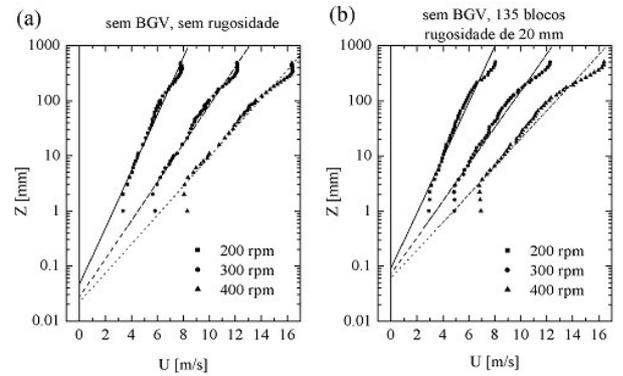


**Fig. 2.** (a) Spatial (transversal) averaged velocity profile, (b) profile observed in central part of the tunnel and (c) observed close to lateral wall. Continuous line means with BVG and dashed line means without BVG.

The roughness length  $z_0$  and the shear velocity  $u_*$  were calculates by fitting a logarithmic profile to the data (Figure 3). The  $z_0$  and  $u_*$  values are between 0.2–0.5 mm and 0.47–0.51 m/s, respectively, for the conditions tested. For calculating the  $z_0$  value that could be considered the most representative only points of Figures 3a and 3b which lie on the inertial sub-layer should be used. Within this

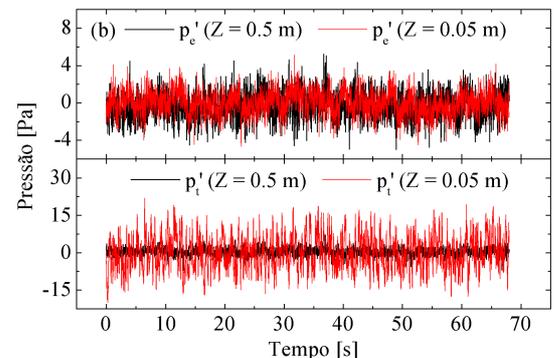
region the  $z_0$  and  $u_*$  present only a bit of variation as the fit is made. We have considered the region of less variability as that most representative of the inertial sub-layer thickness. Our results show that the best set of points to represent the inertial sub-layer is between  $Z = 6$  mm e  $Z = 47$  mm, yielding  $\Delta Z = 41$  mm. This value is about 14% ( $= 41/300$ ) of the boundary layer height (without BVG), which is a result compatible with values adopted in literature [3].

Besides mean velocity profiles is possible to obtain pressure time series with the static pitot tube since a rapid response transducer is available. In the Figure 4 are shown two pressure time series at different heights with sampling rate of about 110 Hz at. The turbulence intensity of dynamical pressure falls from 6.8% at the height of 50 mm to 1.4% at 500 mm, whereas the turbulence intensity of



**Fig. 3.** (a) Without and (b) with roughness and BVG system.

static pressure keep almost the same value of 1.2%. The first case is of course associated with the velocity fluctuation within the boundary layer. However the static pressure is a process independent of boundary layer height and must keep approximately constant according with the classical Prandtl theory of the boundary layer [4]. The study of static pressure fluctuation is still very incipient. Its importance resides in the fact that the balance of the turbulent energy equation cannot match, at least in atmospheric boundary layer problems, if the pressure term (the so called *return to isotropy term*) is not considered [3]. Beyond that, its spectral behavior also seems somewhat different from that of the famous  $-5/3$  Kolmogorov law [5] (see next section).



**Fig. 4.** Pressure time series. Static and dynamical pressure fluctuation are represented, respectively, as  $p_e$  and  $p_i$ .

### 3.2. Spectral analysis

As part of the process of characterizing of the wind tunnel we have obtained 1 kHz sampling rate time series for period of 60 s. The unique parameter changed in this experiment was the fan rotation rate, which varied from 50 rpm to 450 rpm with steps of 50 rpm, totaling nine series. The spectra are shown in Figure 5. The universal Kolmogorov law is represented by the dashed line and correspond to that range in which the turbulent kinetic energy is converted from larger to smaller eddies. This is the so called inertial subrange which in our experiment ranges from about 0.3 Hz to about 10 Hz.

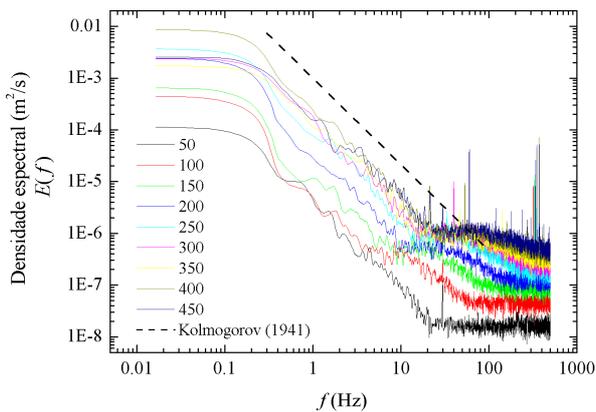


Fig. 5. Spectral density. Dashed line represent the  $-5/3$  Kolmogorov law.

### 3.3. Velocity and variance field in a urban canyon model

A common procedure that has been adopted to study urban dispersion problem is the use of street canyon model [6, 7]. Other urban models are possible, nevertheless the measurement procedures are awkward and the interpretation of results difficult [8, 9]. For representing the street canyon two parallel blocks are used whose dimensions are height = width = 16 cm and length = 64 cm. The canyon was set perpendicular to flow as suggested by [6, 7] and because that is the orientation that corresponds to most inefficient ventilation.

Velocity and standard deviation field for a cross section in middle of the canyon are shown, respectively, in Fig. 6(a) and (b). Note that the area where velocities are lower are situated in the central part of the cross section especially in the in the bottom lee part (dark blue). A low velocity region is also present in center of the cross section between 10 and 12 cm in horizontal direction and 4 and 7 cm in vertical direction. As the velocity field, a similar pattern can also be observed for standard deviation field, which is homogeneous on most of the cross section, not changing by more than 0.1 m/s. Low values in variance or standard deviation mean low turbulence and therefore inefficient pollutant dispersion.

### 4. CONCLUSIONS

We have obtained some characteristics of the IPT wind

tunnel flow which will be important in future studies. Among them we can assess that BVG acts in an expressive way diminishing the mean velocity of flow just above 0.1 m height. In the absence of the barrier-vortex generator system the boundary layer height is estimated in about 0.3 m, and the thickness of inertial sub-layer corresponds to about 14% of the height of boundary layer. We began a study of static pressure fluctuation in order to better comprehend its role in the turbulence field. This subject still needs complementary study.

From velocity time series obtained with a hot-wire anemometer, we can verify spectral behavior of the kinetic turbulent energy. On the intervals of our experiments the inertial subrange corresponds to that of Kolmogorov. Other using of the hot-wire anemometer was the mapping of velocity and standard deviation field, which demonstrates consistent with that of literature and the pattern found for the velocity field matches with that is observed with visualization techniques.

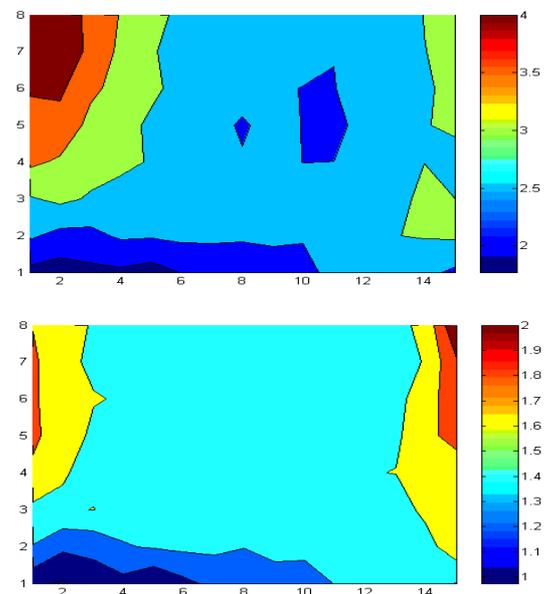


Fig. 6. Velocity field (above) and standard deviation field (bellow) of a cross section in the middle of the canyon. Velocity and standard deviation are in m/s, and the distances are in cm. The flow over the canyon is from left to right.

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