EXPERIMENTAL ANALYSIS OF WIND TUNNEL SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

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Abstract. *Experiments are carried out to evaluate the characteristics of the UNNE Wind Tunnel (TV2) to verify its applicability to similarity studies and experimental simulations of the atmospheric boundary layer using two different velocities. A part-depth atmospheric boundary layer is simulated using a technique which combines surface roughness on the floor and Standen spires. Atmospheric boundary layer simulation implies the modeling of mean velocity distributions and turbulence quantities which are of influence in engineering problems such as turbulence intensities, velocity fluctuations spectra and space correlations. A hot wire anemometry system is used for the measurements of mean velocity and velocity fluctuations. Data acquisition is performed by means of an A/D converter board connected to a personal computer. Experimental results are presented in form of velocity and turbulence intensities profiles as well as power spectral distributions of the longitudinal component of the velocity fluctuations which are compared with atmospheric data. The obtained results show an acceptable suburban reproduction of the velocity profiles and turbulence intensities. In general, the characteristics of the turbulent flow at low speed are similar to those of the high speed flow simulation.*

1. INTRODUCTION

The experiments were realized in the wind tunnel (TV2) of the Universidad Nacional del Nordeste at Resistencia Chaco, Argentina. This is a low velocity atmospheric boundary layer wind tunnel, built with the aim to perform aerodynamic studies of structural models and dispersion of pollutants analysis. The tunnel's length is 7.50 m; the air enters through a contraction, passing through a honeycomb to reach a 4.45 m long square test section (0.48 m x 0.48 m) (Figure 1).

Figure 1. The wind tunnel (TV2) of the Universidad Nacional del Nordeste

The simulation of natural wind on the atmospheric boundary layer was performed by Standen part-depth simulation method using two spires as vortex generators in combination with roughness elements, to simulate the lowest part of the boundary-layer thickness according to Argentinean Standard CIRSOC 102 as a class III ground, Fig 2. The roughness elements dimensions were 0.012 m x 0.012 m x 0.009 m and were made of wood; the distance between each other was 0.03 m and was designed in agreement with Counihan techniques. The vortex generator height was 0.37 m and the boundary-layer thickness simulated was 0.33 m.

The mean height of the obstacles was considered to be about 10 m, while the boundary layer thickness was zg = 420 m. Similar classification is given by Brazilian Standard NBR-6123, to a class IV ground. In the potential law for velocity distribution the values for the exponent α was approximately 0.25. A mean scale factor of 1:800 for this atmospheric boundary layer simulation was obtained through the method proposed by Cook (1978).

Mean velocity measurements were performed by means of a Pitot Prandtl tube connected to a micromanometer. Velocity and longitudinal velocity fluctuations were measured by a Dantec 56 constant temperature hot wire anemometer, with a true-RMS voltmeter, connected to a Stanford SR560 amplifier with low and high-pass analogical filters. Data was obtained with acquisition frequencies of 900 Hz and 3000 Hz.

The measurements were made over the full boundary layer height in the middle center section, which was 3.6 m downstream of the generators. The evaluation of the atmospheric boundary layer was done using two different velocities, firstly operating the wind tunnel at high speed, with a maximum velocity reaching at 19 m/s, and then operating the tunnel with low speed, with a maximum velocity reaching at 1.36 m/s.

Figure 2. Part-depth generator and roughness elements.

2. MEAN VELOCITIES DISTRIBUTION

The mean velocity distribution as a function of height is one of the parameters required to describe the atmospheric boundary layer flow simulated. There are several laws which can be employed of wind profile modeling, like power law or logarithmic law.

Power law exponent approximation, has no theoretical basis, but, comparison of laboratory and prototype measurements leads to very satisfactory results. It is defined by Eq. (1), where z_R is the reference height at which the velocity is equal to the reference velocity, u_R. This law has the advantage of having one scaling parameter the exponent α, which must be the same in model and prototype. This exponent depending on the roughness of the surface, is equal to 0.15 for smoother surfaces as open field and equal to 0.24 for rougher surfaces as suburban areas.

$$\frac{u_z}{u_R} = \left(\frac{z}{z_R}\right)^{\alpha} \tag{1}$$

In a neutral surface layer, the velocity profile follows the logarithmic law. The mean velocity distribution is given by Eq. (2) where u is the mean velocity at the height of z above the surface, u* the friction velocity, z_0 the surface roughness length, d the zero plane displacement, and k the Von Karman constant (0.4). This law gives the variation of the mean wind speed with height following the assumptions that the shearing stress is independent of height and the mixing length depends only on the fluid and the distance from the ground (Blessmann, 1995).

$$u = \frac{u^*}{k} \ln\left[\frac{(z-d)}{z_0}\right] \tag{2}$$

The logarithmic law is valid in a height about 10 to 100 m in the atmosphere over uniformly rough terrain. For a wind tunnel with neutral turbulent boundary layer, it is valid up to a height of fifteen per cent of the thickness of the boundary layer (Plate, 1982).

The surface roughness length meaning is similar to the exponent α of the power law, because changes with the roughness of the surface, is equal to 30 mm for open field and equal to 500 for suburban areas.

In a previous work (Alvarez y Alvarez and Wittwer, 2006), to process wind profile data of simulated atmospheric boundary layer flows in the wind tunnel so as to obtain the two important wind profile parameters, the surface roughness length z_0 and the friction velocity u*, a method that used the mean velocity profile and also the turbulence intensity profile had been employed (Liu *et al*, 2003).

3. TURBULENCE QUANTITIES

One of the turbulence quantities used to describe the wind velocity turbulence is the turbulent intensity, defined as the ratio of the root-mean-square of the velocity fluctuations, to a reference flow velocity.

The temporal autocorrelation function describes the general dependence between a value of a fluctuating velocity determined in a time t, u(z,t) and another value determined in a time t+τ, u(z,t+τ).

The energy spectral density S_u describes how the energy of a signal is distributed with frequency. Modeling of the spectrum implies that the shape of the spectrum is the same in model and prototype, but this condition cannot be satisfied in the strict sense, because of the difference in the nature of energy production and energy dissipation. Dissipation governs the highest frequency ends of the spectrum and together with viscosity determines the scaling for this range. Production acts at low frequencies and is scaled by parameters of the mean motion. Production and dissipation ranges are connected through the inertial sub range in which the -5/3 law of Kolmogoroff is valid (Plate, 1982).

Power spectral density functions of the longitudinal component of turbulence of atmospheric wind can be represented by several mathematical expressions suggested by different authors. In this work the Vón Kármán (ESDU) atmospheric spectrum given by the Eq. (3) is used to make a comparison with measured data. Where S_u is spectral density function, n the frequency and L_u, the longitudinal integral length scale of the turbulence.

$$\frac{S_u\,n}{\sigma^2} = 4\frac{L_u\,n}{u}\left[1+70.78\left(\frac{L_u\,n}{u}\right)^2\right]^{-5/6} \tag{3}$$

4. RESULTS

The logarithmic law describing the mean velocity profile is valid in the overlap region of a turbulent flow. In this ABL, atmospheric boundary layer simulation, the thickness of this region was 0.12 m, which is the 15 % of the boundary layer thickness. The logarithmic law parameters were determined employing a method developed by Liu e*t al* (2003) and the results are summarized in Table 1.

Table 1. Obtained results

Speed Simulation	z_0 + d (mm)	z_0 (mm)	d (mm)	u* (m/s)
High	0.8	0.25	0.55	0.94
Low	3	1.88	1.12	0.09

The power law exponent approximation was applied to describe velocities distribution of the larger part of the inner layer for both simulations and results were compared with the logarithmic profile calculated. The α exponent obtained was similar in low and high speed ABL simulation. Results show a good fit with the power law in both cases for the larger part of the inner layer and it is demonstrated that logarithmic law only gives good results in the layer closer to the ground (Alvarez y Alvarez and Wittwer, 2006).

Figure 3 shows mean wind and turbulence intensities vertical profiles obtained from the wind tunnel experiment using two different velocities. In both situations the boundary layer reaches a height of 30 cm. At high speed simulation the highest velocity reaches 19 m/s, while, at low speed simulation reaches 1.39 m/s. The turbulence intensity presents slightly greater values in the case of low velocity. This has been observed in other opportunities by other authors at low speed part-depth ABL measurements.

Figure 4 shows the normalized autocorrelation function for both simulations. At the high speed simulation the correlation time is about 0.03 s, while, at low speed simulation is about 0.3 s. Consequently, the temporal scale will be smaller in the high speed simulation. In both cases, the correlation time diminishes while the height and velocity increase, so according to Taylor’s hypothesis the space scales keep approximately constant.

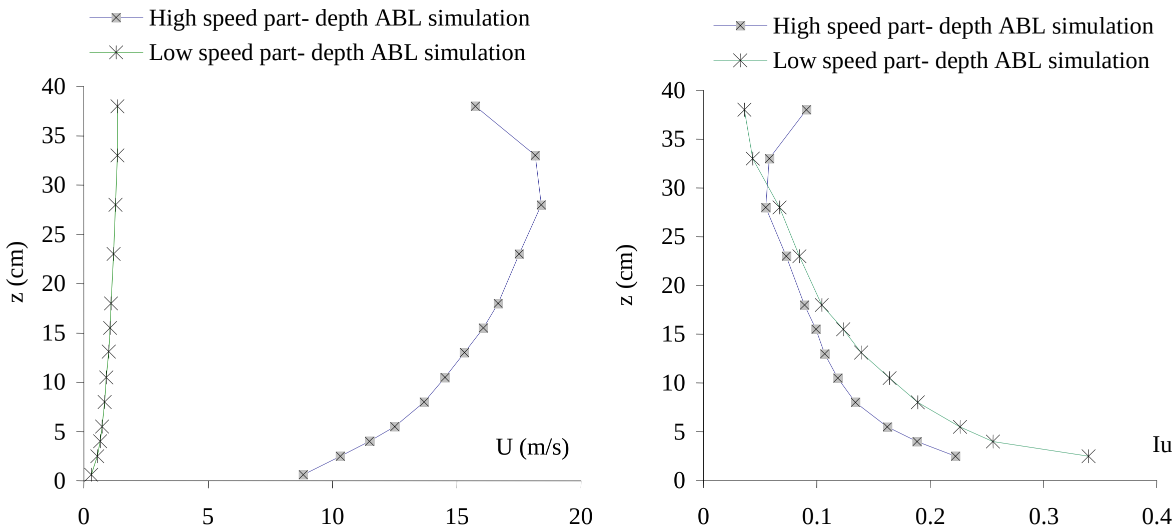

Figure 3. Mean wind and turbulence intensity profiles.

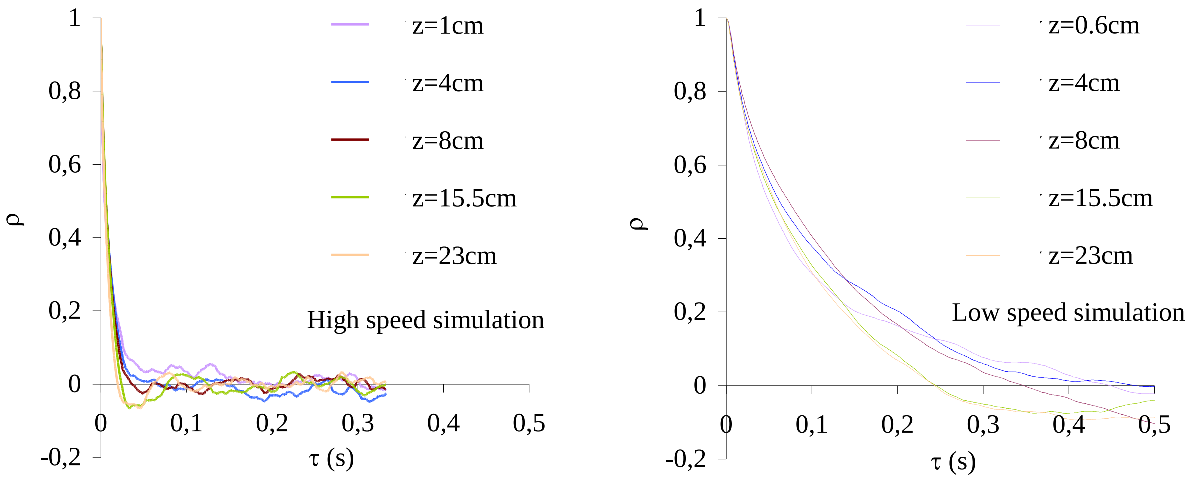

Figure 4. Normalized autocorrelation function for high and low speed simulations.

Spectra of the longitudinal component of turbulence are obtained through the application of an algorithm based on the Fast Fourier Transform to the measured series. Dimensionless spectra function is presented in Fig. 5. It can be appreciated that the levels of energy are of the same order for high and low speed simulation, nevertheless a displacement of the range of frequencies exists. Spectra are well defined to about 100 Hz and 1000 Hz to low and high speed simulation, respectively.

In Figures 6 and 7 dimensionless spectra are compared with atmospheric data using the von Kármán formulation, for two values of z and for low and high speed simulations. The analysis reveals that in general high speed spectra fit adequately and in a wider range of frequency to atmospheric data. In low speed simulation spectra distortions are observed to high and low frequencies.

5. CONCLUSIONS

The purpose of this paper has been to evaluate the characteristics of part-depth atmospheric boundary layer simulation using two different velocities.

Mean wind speed profiles shows an adequate fit with the power law in high and low speed simulation for the larger part of the inner layer and it is demonstrated that logarithmic law only gives good results in the layer closer to the ground. In general, the characteristics of the turbulent flow at low speed are similar to those of the high speed flow, although turbulence spectra of the longitudinal velocity fluctuations in high speed simulation fit more adequately and in a wider range of frequency to atmospheric data. This happened because at higher velocities Reynolds numbers are higher; too, therefore there is more similarity with atmospheric flow. For this reason this analysis will be complemented, in a future, with a comparison with the results obtained in a larger wind tunnel.

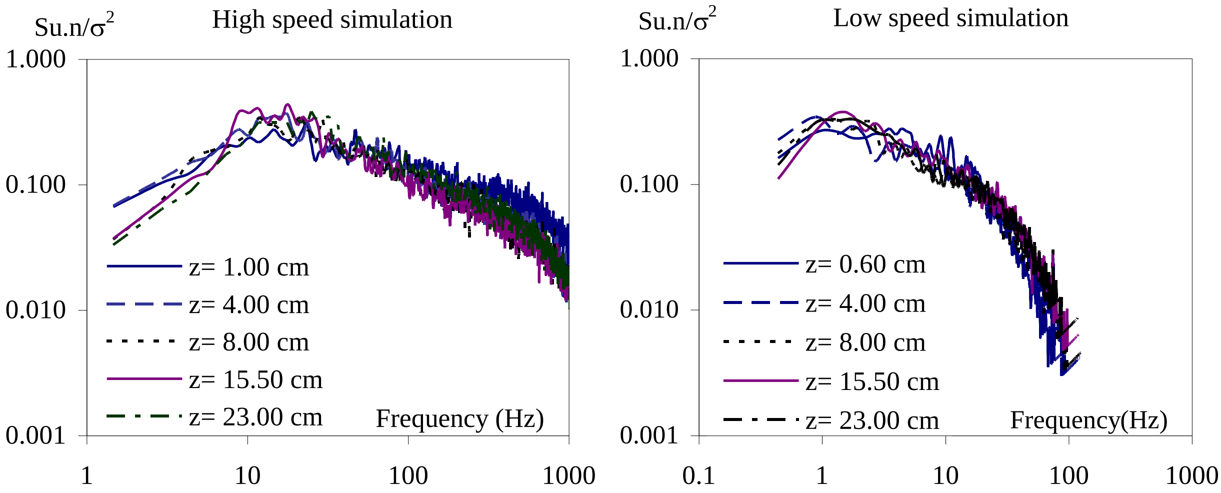

Figure 5. Dimensionless spectra of the longitudinal velocity fluctuation

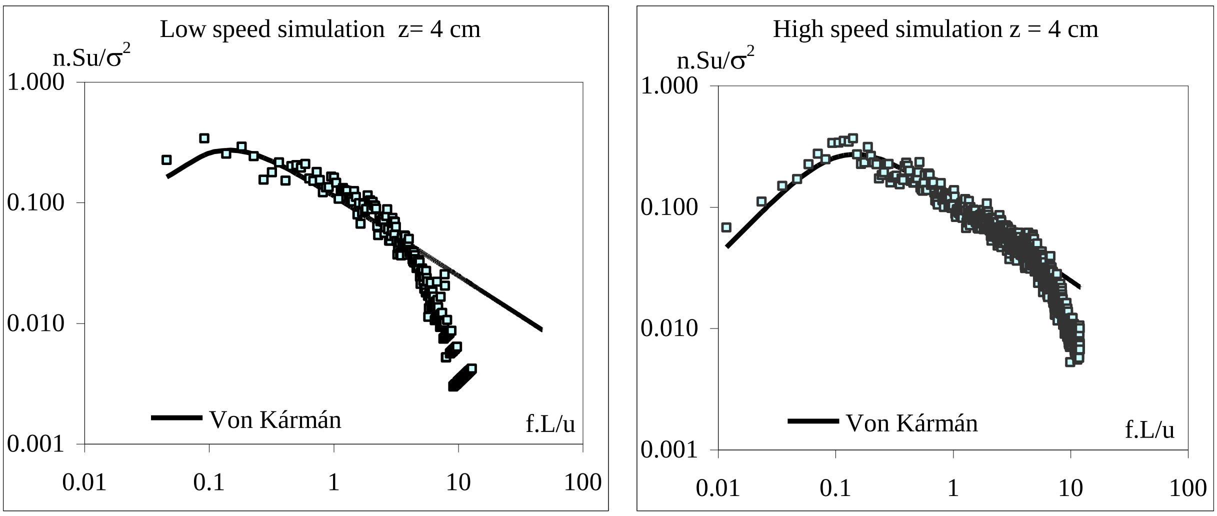

Figure 6. Dimensionless spectra of the longitudinal velocity fluctuation obtained at z = 4 cm and Von Kármán design spectrum.

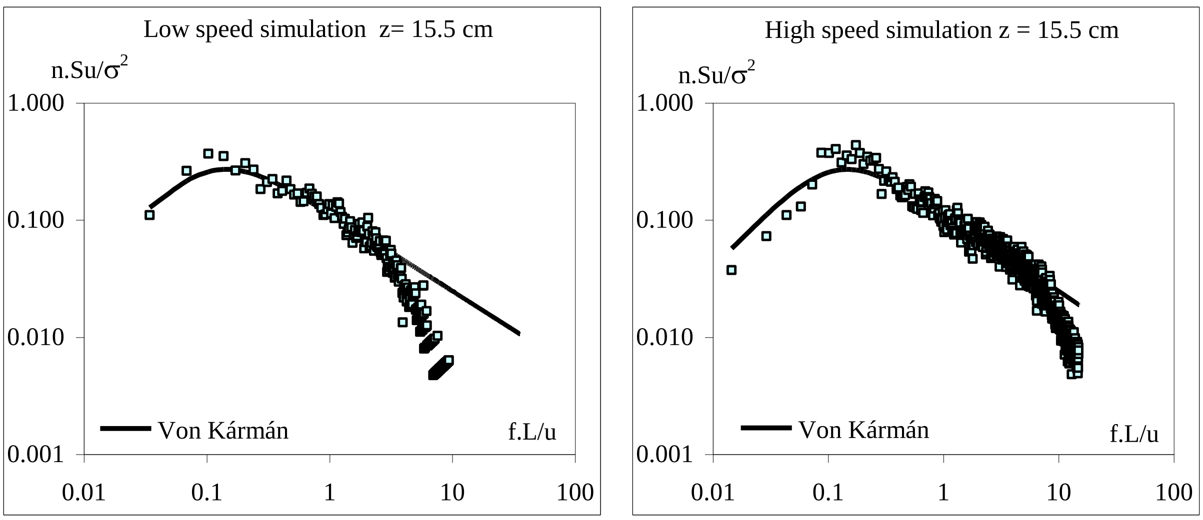

Figure 7. Dimensionless spectra of the longitudinal velocity fluctuation obtained at z = 15.5 cm and Von Kármán design spectrum.

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