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MODELING OF THE ATMOSPHERIC BOUNDARY LAYER USING A WIND TUNNEL WITH DISCONTINUITY

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Abstract: *In many wind engineering laboratories the atmospheric boundary layer is modeled using wind tunnels with a long test section. Our team has designed and accomplished a wind tunnel with a sharp widening of the cross section which leads to a shorter experimental area. For this type of tunnel the construction, operation and maintenance costs are lower. The experimental results showed that this type of wind tunnel ensures very good conditions for the atmospheric boundary layer modeling. The positive conclusions of the experimental tests encouraged us to continue the research by developing other studies in the way in which the velocity and turbulence profile can be changed depending on the desired application.*
Key words: *Wind tunnel, atmospheric boundary layer*

1. INTRODUCTION

Different procedures were conceived in order to simulate the wind mean velocity profile in the test section of the atmospheric wind tunnels (Cermak, 1971). These procedures depend on the tunnel type used for the atmospheric boundary layer simulation (Cermak & Cochran, 1992). Therefore, in the classic wind tunnel with a relatively short test section, which length are in the range of 3 - 4 m, the vertical wind profile simulation is obtained in an artificial way using passive systems (rods, nets, grids, etc.) or active devices (Simiu & Scanlan 1978). One of the experimental methods conceived for achieving laboratory atmospheric boundary layer tests is the sharp enlargement of the wind tunnel cross section. The study of this type of wind tunnel was a concern of the Aerodynamic and Wind Engineering Laboratory team from the Technical University of Civil Engineering Bucharest.

2. POWER LAW

The power law describes the mean wind velocity profile over horizontal lands with uniform roughness. The used mathematical relationship is (Mihu, 1999):

$$U(z_{g1}) = U(z_{g2}) \left(\frac{z_{g1}}{z_{g2}} \right)^{\alpha} \qquad (1)$$

Where z_{g1} and z_{g2} are the heights above the Earth's surface and α is an exponent dependent on the nature of the land roughness.

Regarding the power low the following simplifications can be made (Monin, 1973):

a) The exponent α is constant all over the thickness of the atmospheric boundary layer, up to $z_{g=\delta}$, where the velocity is equal to the geostrophic wind velocity G. Based on the aforementioned, a simplified relationship of the power low can be written as (2).

b) The thickness of the atmospheric boundary layer δ is dependent on the α exponent.

$$U(z_g) = G \left(\frac{z_g}{\delta} \right)^{\alpha} \qquad (2)$$

The values for the α exponent and for the thickness of the atmospheric boundary layer δ were given by Davenport (Davenport 1968) (Figure 1).

3. ATMOSPHERIC BOUNDARY LAYER MODELING USING A WIND TUNNEL WITH DISCONTINUITY

A wind tunnel with artificial boundary layer which can simulate both the mean velocity profile and the appropriate level of turbulence is the wind tunnel with a sudden widening of the cross-section, called wind tunnel with expansion step or wind tunnel with discontinuity. This wind tunnel was conceived and studied in the Aerodynamic and Wind Engineering Laboratory from the Hydraulic and Environmental Protection Department, Technical University of Civil Engineering Bucharest.

The wind tunnel with discontinuity assures the accomplishment of the mean velocity profiles according to the power law by a sharp enlarging of the cross-section placed upstream to the test section just near the contraction cone. The enlargement is shaped as an expansion step. The existence of such a discontinuous surface leads to a very complex movement, known as two-dimensional motion with fluid flow separation and vortex zone formation. The separation process takes place when the fluid passes over the superior edge of the expansion step, and is associated with high velocities and pressure variations. The fluid motion along a discontinuous wall develops a flow which leads to a mean velocity profile and a turbulence level capable to assure the atmospheric boundary layer dynamic characteristic simulation conditions in the test section of the tunnel.

The aim of the measurements developed in the wind tunnel with discontinuity designed by Aerodynamic and Wind Engineering Laboratory was to determine the mean velocity profiles and the turbulent intensity for different flow regimes. The measurements were made in the test section, placed at the distance x = 1280 mm downstream the contraction cone. The used measuring devices were a hot wire and a laser anemometer. Figure 3 shows the mean velocity profiles for the considered section, using the hot wire anemometer (Termo 1, Termo 2 and Termo 3) and the laser anemometer (Laser 1 and Laser 2). In figure 4 are plotted the vertical distribution of the turbulent intensity measured in the same section and using the same measuring devices.

The experimental tests are showing that the mean velocity profiles achieved on the experimental measurements are quite the same as the Davenport profiles, characterized by α exponents corresponding to a wide range of land roughness (α = 0.16…0.32).

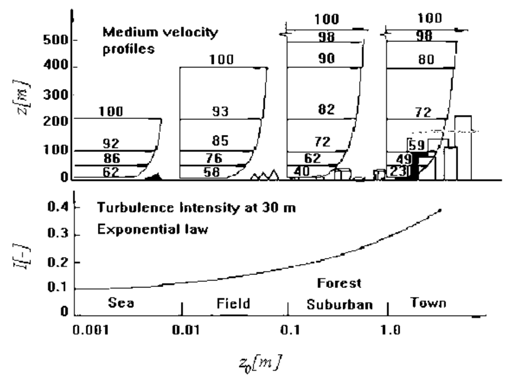

Fig. 1. Mean velocity profiles based on power law and turbulence intensity in the atmospheric boundary layer for different land roughness types

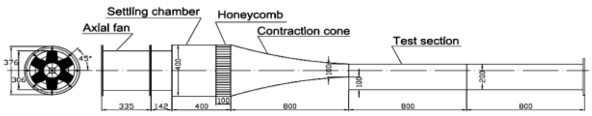

Fig. 2. Wind tunnel with discontinuity designed by the Aerodynamic and Wind Engineering Laboratory

Regarding the turbulent structure of the flow, the turbulent intensities are described by a classical distribution, which is characteristic for the atmospheric boundary layer. It must be mentioned that for different air velocities the level of turbulence in the test section of the tunnel doesn't vary too much.

4. FUTURE RESEARCH

The subsequent experiments will follow the decrease of the turbulence level inside the test section of the wind tunnel while maintaining the obtained mean velocity profiles. The low scale turbulence in the wind tunnel is necessary to be ensured for experimental tests related to the modeling of the atmospheric contamination processes.

Also the future experimental tests are focused on the shortening of the test section length without affecting the mean velocity profiles distribution according to Davenpot's power low. For achieving this aim the authors have proposed a possible solution, namely providing a transversal air stream on the general flow direction, along the vortex present in the separation area. This can be achieved by the injection and aspiration of air at the bottom of the expansion step. It is hoped that by applying the aforementioned solution the vortex area length, on the air stream direction, can be considerably reduced. This will lead to a power low mean velocity profile at a shorter distance downstream the expansion step. The future experiments will analyze also the turbulent intensity by measuring and plotting of profiles corresponding to the air stream inside the tunnel.

Using the flow visualisation system endowed by the Aerodynamic and Wind Engineering Laboratory, two-dimensional experiments on the mean velocity field distribution and measurements on the flow in the expansion step area at different Reynolds numbers corresponding to the flow conditions will be made. Also another part of the future research is focused on the three-dimensional numerical modelling of the air flow in the expansion step area and in the test section of the wind tunnel. The results obtained from both researches, which will start in the second half of the year, will be published next year.

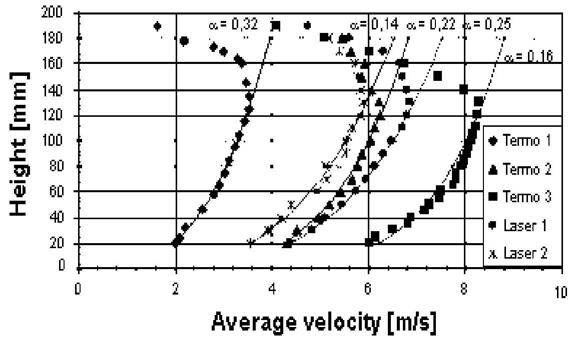

Fig. 3. Mean velocity profile in the test section of the wind tunnel with discontinuity at x = 1280 mm distance downstream the contraction cone

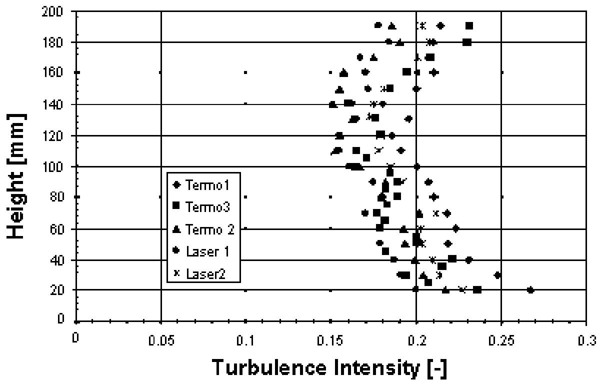

Fig. 4. Vertical distribution of the turbulent intensity in the test section of the wind tunnel with discontinuity at x = 1280 mm distance downstream the contraction cone

5. CONCLUSION

The experimental research revealed that for different type of terrain roughness, the atmospheric boundary layer can be modeled with very good results regarding the mean velocity profile as well as the turbulent structure using the wind tunnel with discontinuity. Using such a wind tunnel has many benefits like the low costs for the construction, operation and maintenance of the experimental equipment, compared to those needed for the classical wind tunnels. Also depending on the type of research, the modification of the mean velocity profiles can be relatively easy achieved.

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