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Experimental investigation of longitudinal velocity distributions in a boundary layer wind tunnel

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SUMMARY:
The paper presents an experimental study performed in the TASL1-M boundary layer wind tunnel (BLWT) from the Aerodynamics and Wind Engineering Laboratory "Constantin Iamandi" (LAIV) from the Technical University of Civil Engineering in Bucharest, Romania (UTCB). To determine the longitudinal velocity distributions in the experimental vein longitudinal median plane, a Constant Temperature Anemometer (CTA) was used. The focus is on accurately replicating wind speed distribution, turbulence intensity distribution, and power density function to simulate all parameters defined in wind codes. The paper describes the experimental set-up in detail, including the wind tunnel's specifications, variable roughness system, turbulence generators, and measurement equipment. Six measurement sets were acquired for different roughness heights, and non-dimensional longitudinal velocity distributions were measured in the wind tunnel function of non-dimensional height. The results were compared to Eurocode, and the velocity profiles were expressed using the law of the wall for fully rough surfaces and compared to theoretical results.
Keywords: BLWT, CTA, law of the wall

1. INTRODUCTION

The accelerated development of computing resources created the context in which Computational Fluid Dynamics (CFD) started to be used at a higher pace in engineering and scientific fields. In computational wind engineering (CWE), it is well-known that best practice guidelines for CFD simulations exist for pedestrian comfort, indoor ventilation, or pollutant dispersion studies (Blocken et al., 2007). Their usage is now accepted, and numerical simulations are carried out regularly for these problems. CFD could still not fully penetrate the field for other related wind engineering problems, where high velocity and shear flow around bluff bodies are present. Although the CPU processing power is higher than ever, more is needed to tackle problems in an industrial environment using Large Eddy Simulations or even hybrid turbulence models. It sometimes is difficult even in academia due mainly to the high computational and postprocessing resources that are still necessary. Thus, in wind engineering, the boundary layer wind tunnel (BLWT) is still a valid and essential tool used alone or in conjunction with complementary CFD simulations.
When determining the natural wind action on structures, BLWT must be able to simulate all parameters defined in codes and standards in the experimental vein (EN 1991-1-4:2005). The velocity distribution, the turbulence intensity distribution, and the power density function must be correctly replicated.

On the other hand, when BLWT data is used together with CFD simulations, the boundary conditions used for numerical set-up have to be accurately determined when only a partial fluid domain is used to minimize the computational effort (as often is the case). In this paper, longitudinal velocity measurements were performed using a CTA in a BLWT, and relevant results were compared to Eurocode. Next, the velocity profiles were expressed using the law of the wall for fully rough surfaces and compared to theoretical ones.

2. EXPERIMENTAL SET-UP

Measurements were performed in the downwind experimental vein of TASL1-M BLWT from LAIV-UTCB (Vlăduț et al., 2017). The wind tunnel has a square cross-section with a characteristic length of 1750 mm. The longitudinal dimension of the experimental vein where measurements were performed equals 3170 mm. Before the experimental vein, there is a segment with a length of 15050 mm where the boundary layer develops. On the floor of this portion, a variable roughness system is placed. It's formed from 560 bricks placed on 14 independent segments (40 bricks/segment) that may be controlled independently. Each brick has a horizontal area of 100 mm x 54 mm, and the vertical brick's dimension can be varied between 0 mm and 200 mm using a step with a minimum value of 1 mm. Before the variable roughness system, five 1 m tetrahedral spires and a castellated barrier are placed to increase the turbulence intensity.

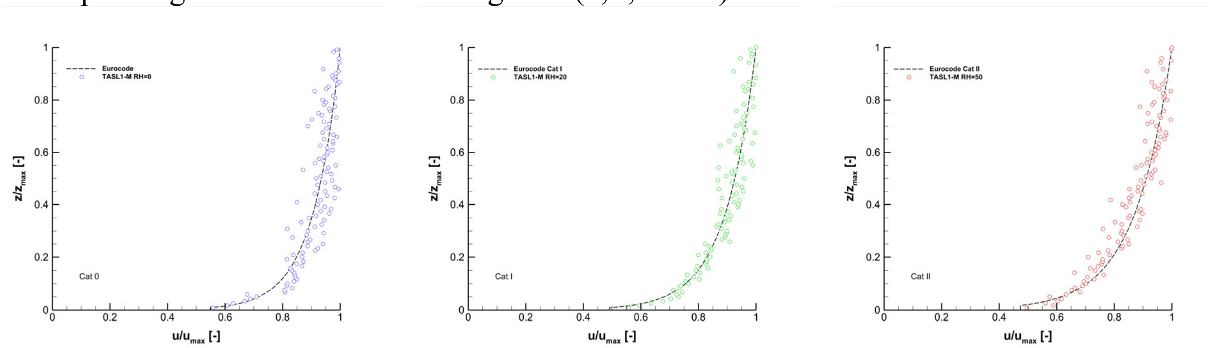
The wind tunnel is equipped with a 200 kW fan. The maximum mean velocity equals 30 m/s, and the airspeed may be continuously varied using a frequency converter. Two Pitôt-static probes are placed upstream of the downwind experimental vein to monitor the wind speed. One is placed at a height equal to 600 mm at 3225 mm before the turntable vertical axis of rotation (TP1) and another in the center of the wind tunnel inlet cross-section after the honeycomb (TP2). To take into consideration the air density variation, a temperature probe is placed at the upper part of the variable roughness section near the TP1 mounting section. For the present experiment, the velocity was set so that the measured value at TP1 was equal to 6.5 m/s.

A 55P16 1D wire probe was connected to a Dantec StreamLine Pro CTA system to measure the longitudinal component of the velocity. A 90P10 temperature probe was mounted in the experimental vein and connected to the CTA system to correct the hot-wire signal. The wire probe was mounted to a traversing system that moved on a vertical axis placed in the median longitudinal plane of the wind tunnel, upwind the experimental section, between 5 mm and 600 mm. The vertical space between two consecutive measurements was set to Δz=5 mm. The acquisition rate was set to 1024 Hz, and each measurement's sampling time T was equal to 10 s.

The first measurements were performed without the spires and castellated barrier assembly and using a "smooth" surface (the roughness system height RH=0 mm) to set up the reference. After that, the turbulence generators (spires and castellated barrier) were placed in the wind tunnel at their designated location. Multiple measurements were performed for different roughness heights RH values along the vertical median axis before the experimental zone. Thus, six measurement sets were acquired for RH values of 0 mm, 10 mm, 20 mm, 30 mm, 40 mm, and 50 mm.

3. RESULTS

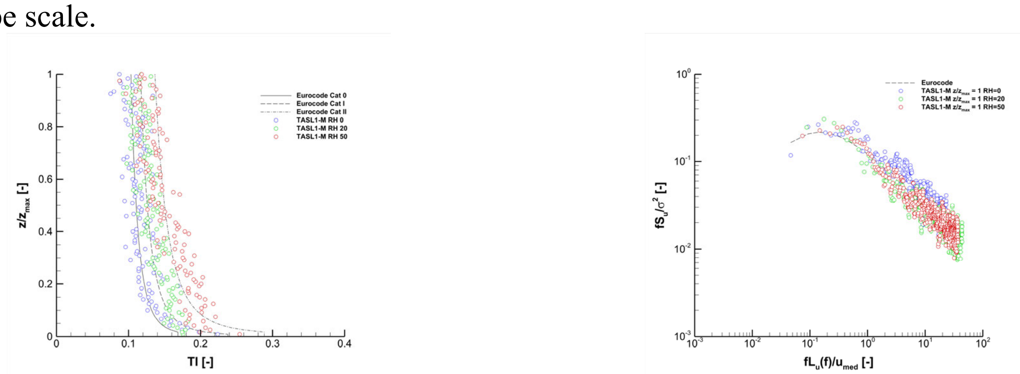
Figures 1 a), b), and c) present the non-dimensional longitudinal velocity u/u_{max} distributions measured in the wind tunnel function of the non-dimensional height z/z_{max} for values of RH equal to 0 mm, 20 mm, and 50 mm. They fit very well with the EN 1994-1-4:2005 prescriptions corresponding to different terrain categories (0, I, and II).



a) b) c)

Figure 1. Non-dimensional longitudinal velocity u/u_{max} distributions function of the non-dimensional height z/z_{max}. a) RH=0 mm, terrain category 0, b) RH=20 mm, terrain category I, and c) RH=50 mm, terrain category II

Figure 2 a) shows turbulence intensity TI distributions function of non-dimensional height z/z_{max} for the same RH values and terrain categories as in Figure 1. As with longitudinal velocity, the turbulence intensity profiles were compared to code prescription, indicating an excellent agreement. The experimental velocity profiles overlapped with the code considering a scale of 1:200. Thus, z_{max} in the wind tunnel, equal to 600 mm, corresponds to a height of 120 m at the prototype scale.



a) b)

Figure 2. a) Turbulence intensity TI distributions function of the non-dimensional height z/z_{max} b) power spectral density function z/z_{max}=1. RH=0 mm – red circles, terrain category 0, RH=20 mm – green circles, terrain category I, and RH=50 mm – blue circles, terrain category II

Figure 2 b) presents the nondimensional power density spectrum for $z=z_{max}$, and RH equals 0 mm, 20 mm, and 50 mm compared to the Eurocode power spectral density function corresponding to terrain categories 0, I, and II, respectively. The experimental data fit the code prescription.

To simulate the characteristics of the simulated atmospheric boundary layer (ABL) in TASL1-M BLWT using CFD simulations, the values for aerodynamic roughness z_0 must be known and also their relation to the sand-grain roughness height k_s. Thus, the results were plotted as dimensionless mean streamwise speed $u+$ ($u^+ = u/u^*$) function of dimensionless wall unit $z+$ ($z^+ = u^* z/\nu$) using the equation:

$$u^+ = \frac{1}{k}\ln(z^+) + B - \Delta B(K_s^+) \qquad (1)$$

where k is the von Karman constant, B is the integration constant with a value resulting from experiments equal to 5.3378, and $K_s^+ = u^* k_s / \nu$ is the dimensionless physical roughness height. In Figure 5, the universal law of the wall is plotted along with the results obtained from experiments in TASL1-M BLWT for different RH heights. With black circles are plotted the results obtained using RH=0 and no spires and castellated barrier, which fit the theoretical findings of Schlichting (Schlichting & Gersten, 2017). Values for RH, ΔB, and K_s^+ are plotted for their corresponding data obtained experimentally and theoretical curves.

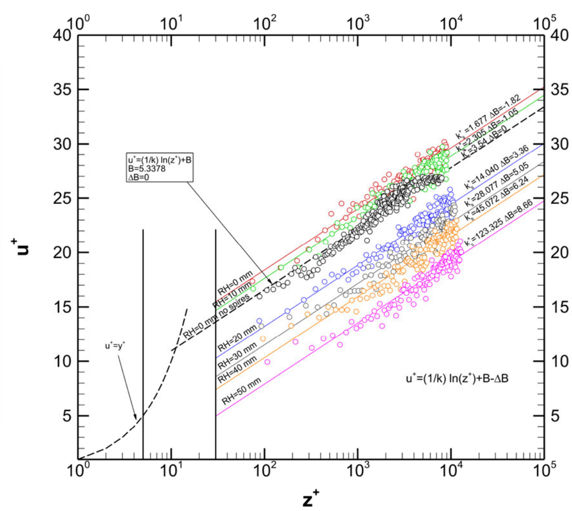


Figure 3. Law of the wall for smooth and roughened surfaces. Experimental results TASL1-M – LAIV UTCB

Between z_0 and k_s, the following relation was found irrespective of roughness configuration given by RH value $k_s = 32.8 z_0$ corresponding to a value of 0.2986 for the roughness constant C_s to be used in CFD software.

4. CONCLUSIONS

The TASL1-M BLWT at the LAIV-UTCB can accurately simulate the velocity distribution, turbulence intensity distribution, and power density function required to determine the natural wind action on structures. The measured velocity profiles were compared to Eurocode recommendations, showing good agreement. The data obtained using RH=0 and no spires and castellated barrier, fit the theoretical findings of Schlichting for smooth surfaces. Combining BLWT experiments with CFD simulations using appropriate boundary conditions could provide more accurate predictions of natural wind action on structures and improve their design and safety.

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