A NEW BOUNDARY LAYER WIND TUNNEL

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The upgraded boundary layer wind tunnel at the Aerodynamics and Wind Engineering Laboratory "Constantin Iamandi" is able to generate a velocity field and turbulent structure adapted to new climate change conditions. The tunnel can model more complex wind engineering phenomena and acquire data using modern precision measurement techniques. Static and dynamic wind effects on structures, building aerodynamics, snow drifting, combined wind and rain action, pollution, wind energy are all included in a list of possible applications of the largest research infrastructure for wind engineering in Romania.

Keywords: aerodynamics, simulation, boundary layer, wind engineering

1. Introduction

A new Boundary Layer Wind Tunnel (BLWT) is operational at the Aerodynamics and Wind Engineering Laboratory "Constantin Iamandi" (LAIV) of the Hydraulics and Environmental Protection Department from the Technical University of Civil Engineering Bucharest. This research infrastructure was refurbished based on the old TASL1 BLWT, during a period of 18 months, between 2013 and 2015. The refurbishment process was possible due to a POS CCE grant, awarded to the project entitled "Extending the TASL Boundary Layer Wind Tunnel Capabilities in order to cope the Climate Change Challenges" (acronym IVAN). The objective of the project was to refurbish an existing research infrastructure (TASL1 BLWT) in order to be able to perform modern research investigations on climate change influences on the building environment. The project also aimed to develop a modern and competitive infrastructure adapted to perform climate change research studies, an area that gets an increasing importance in world's scientific research. A high scientific level of research and

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educational environment will lead to an increase of international visibility and to the development of the existing human resource and will also attract new researchers in the LAIV team. Using this infrastructure our research team, will be able to provide a more accurate and efficient support to industrial partners that require data on the wind behaviour of taller and more slender buildings.

Climate change led to meteorological phenomena of a greater (often extreme) intensity, the consequence being an increase in complexity of the wind engineering problems as well as to the occurrence of new problems that need to be investigated, in the BLWT.

In this respect the old infrastructure was modified, and new modern equipment was purchased in order to increase the BLWT performances and be able to correctly reproduce and investigate complex wind engineering phenomena.

Some of the wind engineering problems that can be investigated in the new, upgraded BLWT are:

- Static wind effects on structures, obtained from measurements of instantaneous (time dependent) and/or mean static pressure distribution on the surface of a rigid model. Results are presented as time dependent variations of forces and moments. This type of investigation is suited for civil engineering buildings, exterior installations, technological equipment, cooling towers, solar panels etc.
- Dynamic wind effects on structures, obtained by asserting the oscillatory behaviour of an aeroelastic model. This category includes wind action on high raised buildings, television towers, high industrial chimneys, towers, suspended bridges, water towers, emerged parts of oil rigs, wind turbines etc.
- Urban aerodynamics and pedestrian comfort. The investigated parameters are the velocity and turbulent characteristics near the ground in the area where pedestrian activity is located. The results consist in sets of measures that are to be taken for a particular site in order to maintain velocity and turbulence levels in the comfort range.
- Combined wind and snow action. Snow drift and wind produced snow deposits on building rooftops or in different sensible areas like roads, bridges, airports and industrial sites are investigated.
- Combined wind and rain action. Effects of wind driven rain on building facades, rooftops, glazed surfaces are investigated
- Dispersion of gaseous pollutants in the atmosphere. The concentration of gaseous pollutants is investigated in the areas adjacent to the source.

2. The old wind tunnel (TASL1)

The TASL1 was an open circuit BLWT, the fan being placed downstream the experimental vein. It was built in the 1990’s. The airflow was controlled by an axial fan driven by a 75 kW electric motor with adjustable speed (continuous from 0 to 100%) which enabled a maximum velocity of 15 m/s. The TASL1 BLWT had two experimental zones, both with a cross-section of 1.75×1.75 m^2. The first zone, used for experiments that require a constant velocity profile was situated upstream the long vein near the air inlet. The second zone, situated downstream of the long vein, towards the suction side of the fan, was used for experiments requiring a well-developed boundary layer velocity profile. The turbulence intensity had a minimal value of 2% and the thickness of the boundary layer was about 1000 mm.

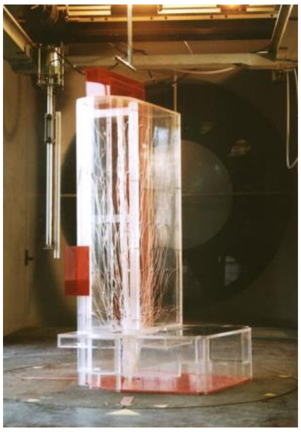
Fig. 1. Static pressure model of a tall building from Bucharest in the TASL-1 BLWT [1].

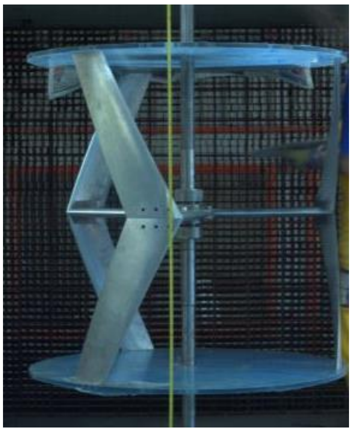
Fig. 2. Vertical axis Achard turbine in the experimental vein of the TASL-1 BLWT [3].


Fig. 3. Casing for small wind turbine at the LAIV research facilities [4].

Over the years, different research projects were conducted, based on both public and private sector funds. Problems on wind loadings on high buildings (Fig. 1), aeroelasticity, pollution, energy (Fig. 2), snow drift, complex aerodynamics (Fig. 3) were investigated [1]-[13].

3. The new wind tunnel (TASL1-M)

The new refurbished TASL1-M BLWT although based on the old TASL1 BLWT, is different and has improved capabilities. In the upgraded boundary layer wind tunnel (Fig. 4), the LAIV team is able to generate a velocity field and turbulent structure adapted to new demands, model accordingly more complex wind engineering phenomena determined by climate change, acquire data using high and modern precision measurements.

Its length is about 27 m, while the active section of the wind tunnel has a length of 18900 mm. The wind speed is continuously adjustable from 0.1 up to 30 m/s, the air flow being controlled by a 200 kW variable speed driven axial fan (Fig. 5). The cross-section of the experimental veins is square, with a characteristic length of 1750 mm.

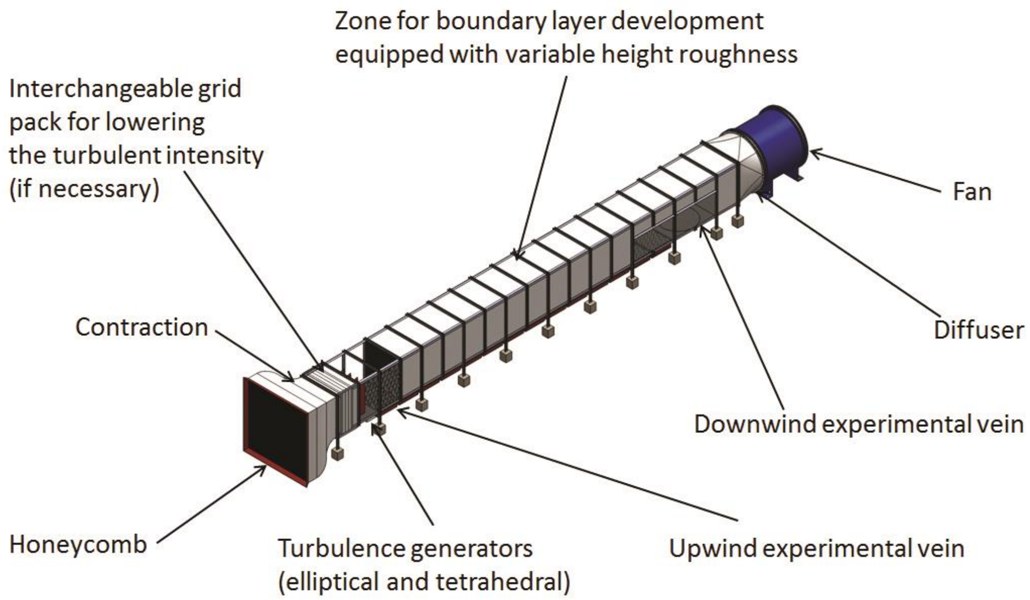

Fig. 4. The TASL1-M BLWT.

The upwind experimental vein ensures a constant velocity profile. For lowering the turbulence intensity, an interchangeable grid pack may be placed downstream the honeycomb. The downwind experimental vein, were a well-developed boundary layer velocity profile is required, is placed near the fan. The boundary layer development zone is situated between the two experimental veins. This area is equipped with a variable height roughness system which is able to automatically modify the roughness on the bottom of tunnel by adjusting the height of 560 bricks between 0 and 200 mm. The bricks can be adjusted by groups of 40 on 14 independent sections of the zone (Fig. 6). Upstream the variable roughness zone, vortex generators ("Counihan" type or tetrahedral, depending on the tests performed in the tunnel) and castellated walls are placed in order to increase the turbulence level in the downwind experimental vein. Variations - between 0.1% and 40% can be achieved.

In the downwind experimental vein, the boundary layer thickness can vary between 800 and 1200 mm. The simulated ABL is characterized by a coefficient α (Davenport power law) varying from 0.08 to 0.4 or by a K coefficient (Prandtl logarithmic law $K = [k/\ln(10/z_0)]^2$) varying between 0.3 and 30 (where k is the von Kármán constant and z_0 is the surface roughness length). The velocity profile, turbulent intensity and power spectrum modelled in the downwind experimental vein are compiling with the EUROCODE standard.

Fig. 5. The 200 kW axial fan of the TASL1-M BLWT.

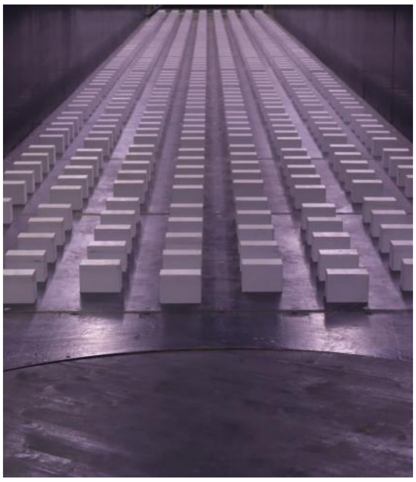

Fig. 6. The variable roughness system of the TASL1-M BLWT.

The tunnel is equipped with high end measurement equipment: 3 velocity component LDV system from Dantec Dynamics; 3 velocity component CTA system from Dantec Dynamics; 2D PIV system from ILA GmbH; 300 miniature pressure transducers (0…500 Pa); 128 rapid (data acquisition rate up to 25 kS/s) miniature pressure transducers (0…500 Pa); complex data acquisition system (DAC) based on PXI technology from National Instruments with 320 analogue channels and 192 digital channels, ATOS 3D scanner for snow drifting investigations, artificial rain system etc.

4. Experimental setup

In order to be able to use the refurbished research infrastructure, the performances of the TASL1-M BLWT had to be assessed. Thus, in a first stage, velocity measurements were performed in the downwind experimental vein, in a median vertical plane, in order to determine mean axial velocity ($\bar{u}$) distributions and turbulence intensity (*TI*) profiles, respectively.

Measurements were performed with the spires, the castellated walls and the interchangeable grid pack for lowering the turbulence intensity removed from the wind tunnel. Thus, a lower turbulence intensity level was expected in the downwind experimental vein.

Velocity profiles were investigated for 2 different floor roughnesses (*RV*), namely *RV*=0 mm and *RV*=50 mm. For each *RV* setting, six different sets of measurements were performed, using different settings on the frequency converter that supplies the fan. The frequency *f* was incremented in steps of 5 Hz, the first *f* setting being equal to 5 Hz.

In order to monitor the axial velocity in the free stream (u_∞), a Pitot-static probe was placed in the middle of the vertical transversal plane, upstream the upwind experimental vein. The pressure taps were connected to two miniature pressure transducers and simultaneously, to a Type "C" – E. Vernon Hill micromanometer.

Although, the angular velocity of the fan was constant, since the aeraulic characteristics of the BLWT were modified by varying the roughness height, different values of the mean axial velocity were obtained for the same *f* setting. In Table 1 we present the values of u_∞ for each combination of *f* and *RV* used during the experiments.

Table 1

Axial velocity in the free stream (u_∞) for different combinations of *f* and *RV* settings

f [Hz] / *RV* [mm]	5	10	15	20	25	30
0	3.22	6.07	9.07	11.86	14.73	17.20
5	2.95	5.75	8.73	11.58	14.45	17.10

In order to measure the velocity distributions in the downwind experimental vein, a Dantec Dynamics FiberFlow LDA was used. Measurements were performed starting from a height of 10 mm above the wind tunnel floor and up to a maximum height of 900 mm. Using the same horizontal plane as a reference, the vertical distance between two consecutive vertical measurement points was of 5 mm. For each point, 10000 values were acquired, with a mean sampling rate of 1 kS/s.

5. Results

As we previously mentioned, the velocity measurements were performed between 10 mm and 900 mm, measured along a vertical axis, in a median longitudinal plane, in the downwind experimental vein. For the measurements characterized by a roughness height *RV*=0 mm, the thickness of the boundary layer (h_{max}) was determined to be equal to 300 mm. For the cases were the *RV* setting was equal to 50 mm, the measured h_{max} had a value of 500 mm. For all cases, the maximum axial velocity in the boundary layer was considered at an elevation $h \cong h_{max}$.

In Fig. 7 and Fig. 9 we present the dimensionless axial velocity (u/u_{max}) variation with respect to the dimensionless height (h/h_{max}) for RV=0 mm and RV=50 mm, respectively. As one may observe, the point cloud, in both cases, agglomerates around a very well-defined zone, regardless the value of the velocity in the free stream, u_∞, suggesting an internal similitude property of the BLWT. In the same figures, the log laws (LLG) given by Eq. 1 which best approximates the mean axial velocity distributions are also plotted,

$$\bar{u} = \frac{u_*}{k} \ln\left(\frac{h}{z_0}\right) \tag{1}$$

where u_* is the friction velocity, k is the von Kármán constant and z_0 is the roughness length. The determined values for u_* and z_0, which corresponds to log laws plotted in Fig. 7 and Fig. 9 are presented in Table 2.

Table 2

u_* and z_0 values corresponding to log-law velocity distributions in the TASL1-M BLWT

RV [mm]	u_* [m/s]	z_0 [m]
0	0.036	3.016×10^{-6}
5	0.085	3.976×10^{-3}

In Fig. 8 and Fig. 10, where the turbulence intensity (TI) variation in the boundary layer is plotted for the investigated cases, the same convergence of the data around a specific zone is observed, irrespective of the free stream velocity value. The turbulence intensity is defined as:

$$TI = \frac{u'}{u} \tag{2}$$

where u' is the root-mean-square of turbulent velocity fluctuations, and u is the measured mean velocity.

As expected, a lower turbulence intensity level is observed for the cases where RV=0 mm if compared with the cases where RV=50 mm.

For the case of the measurements performed using a RV setting equal to 0 mm, the TI varies between 0.05 and 0.1 in the upper part of the boundary layer (h/h_{max} > 0.1), and between 0.1 and 0.3 in the lower part of it. For RV=50 mm, the turbulence intensity level is increased, TI varying between 0.05 and 0.2 in the upper part of the boundary layer and between 0.2 and 0.5 for values of h/h_{max} lower than 0.1.

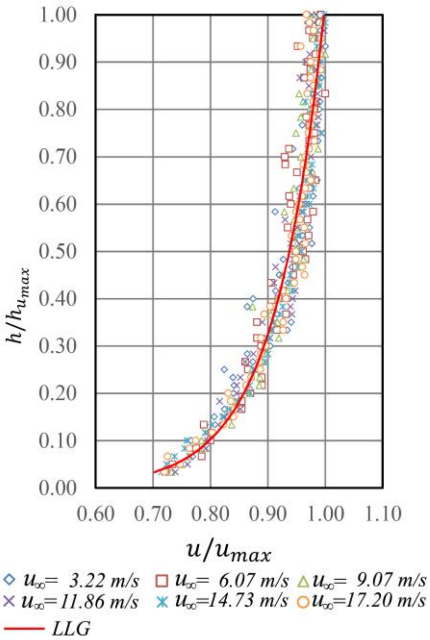

Fig. 7. The velocity distribution profile
RV =0 mm

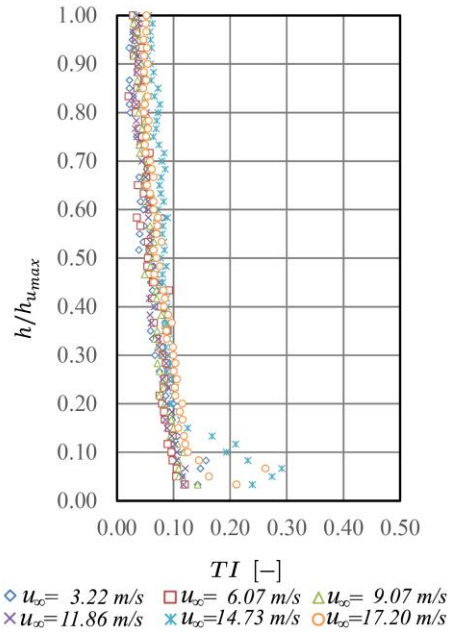

Fig. 8. Turbulence intensity
RV=0 mm

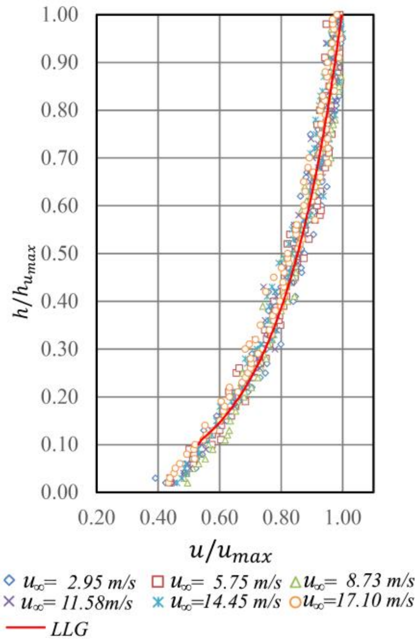

Fig. 9. The velocity distribution profile
RV=50 mm

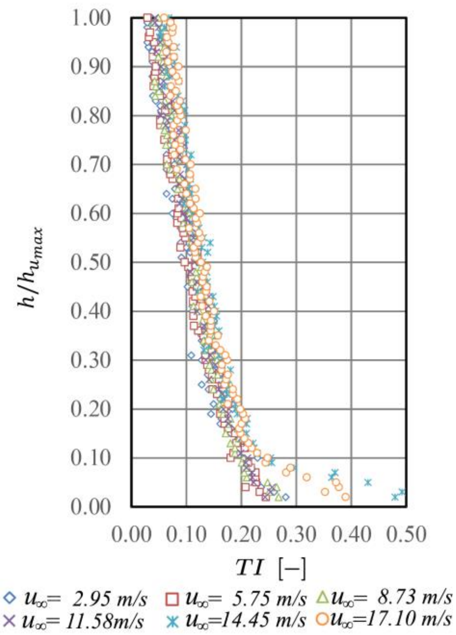

Fig. 10. Turbulence intensity
RV=50 mm

6. Conclusions

A new Boundary Layer Wind Tunnel is operational at the Aerodynamics and Wind Engineering Laboratory "Constantin Iamandi" of the Hydraulic and Environmental Protection Department from the Technical University of Civil Engineering Bucharest. The TASL1-M BLWT was refurbished based on the old TASL1 BLWT (the performances and research equipment of the old tunnel were limited with respect to issues raised by climate change phenomena). In the upgraded boundary layer wind tunnel, the LAIV team is able to generate a velocity field and turbulent structure adapted to new demands, model accordingly more complex wind engineering phenomena determined by climate change, acquire data using high and modern precision measurements.

The roughness of the tunnel floor may be automatically modified using an innovative variable roughness system, while in the older version bricks of different sizes were manually positioned in order to modify the boundary layer properties.

Several measurements performed in order to assess the performances of the TASL1-M BLWT confirm the fact that the velocity and turbulence intensity profiles obtained in the downwind experimental vein are reproducing the atmospheric boundary layer structure.

The TASL1-M BLWT is a competitive research infrastructure adapted to perform climate change research studies, an area that gets increasing importance in world's scientific research. Experimental studies on the influence of climate change in the built environment will be performed at a high scientific level which will lead to an increase of international visibility. The research team using this infrastructure will be able to provide a more accurate and efficient response to industrial partners that require wind effect data for increasingly taller and more slender buildings.

Acknowledgements

The authors acknowledge the support from the European Social Funds grants, POSCCE – Priority axis 2 – RDI: Operation 2.2.1, Intermediary Organization: Romanian Government – Ministry of Education.

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