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Summary. Wind Energy represents the most technically advanced and diffused renewable resource. The lack of available sites for on-shore wind farms has spurred interest for unconventional locations, such as the urban environment. As production coincides with consumption, urban wind energy might reduce infrastructural costs associated to traditional sites. However, hardly few (if any) applications have so far succeeded in providing a reliable source of power output, fostering scepticism towards the whole wind energy sector. This might be attributed to the lack in understanding of the performance of wind turbines in the highly turbulent inflow present in the built environment. Therefore, a "back to basics" approach is needed to understand the effect of a turbulent inflow on the aerodynamic performance of wind turbine aerofoils. One particularly disguised issue is the effect of the integral length scale towards the negligibility of the effects of turbulence. A wind turbine aerofoil model with chord *c* is therefore tested in the wind tunnel under different turbulent inflows, where turbulence intensity (*I*) and integral length scale (*LS*), are varied independently. Unlike what it is stated in literature, results might suggest that an effect of turbulence is noticed even if *LS*>>*c*.

Introduction. Wind energy is steadily settling its prominent position in the energy provision market [1], being rightly considered the most reliable and readily available non-fossil source of energy [2]. While many suitable locations are becoming unavailable, at least three wind energy trends are perceptible, i.e. building larger converters, new more performant typologies and exploiting unconventional locations. The urban environment presents some interesting features for urban wind energy (UWE) such as the local increase in the mean velocity [3]. However, due to the many obstacles wind encounters, free stream turbulence (FST) is highly enhanced [4]. As a result, the performance of converter is heavily affected leading to a chronical inefficiency of the technology due to the poor power production [5]. Although the aerodynamic performance is mostly responsible for this issue [6], only few studies have concentrated on the topic, so far giving few indications to designers (table 1). This might be largely explained with the difficulty in controlling turbulence characteristics at the inlet of both wind tunnel and numerical models [7].

Table 1 – Experiments on effect of turbulent inflow on WT blades: PG/AG Active/Passive grid, pt pressure taps

Authors/year	chord c [m]	grid type	t. int. I [%]	len. sc. LS [m]	measures	Notes
Devinant et al. 2002 [8]	0.3	PG	16	-	43 pt	-
Amandolèse and Széchényi, 2004 [9]	0.5	PG	7.5	-	25 pt	oscillating aerofoil
Swalwell et al., 2004 [10]	0.125	PG	13	0.16	28 pt	thick aerofoil
Sicot et al., 2006 [11]	0.3-0.07*	PG	16	-	43 pt; PIV*	*small blade for PIV
Maldonado et al., 2015 [12]	0.25	AG	6.1	0.15	32 pt	Rough blade
Li et al., 2016 [13]	0.14	PG	13.9	-	46 pt	Low Re custom. blade

Effect of the integral length scale of turbulence on a wind turbine aerofoil. In this study, the effect of turbulence on the aerodynamic performance of a typical wind turbine aerofoil with chord *c* is investigated in the wind tunnel. The aim is to understand whether the effect of turbulence is negligible based on the integral length scale *LS* of turbulence. In fact, FST causes a delay in aerofoil stall and an increase in Lift and aerodynamic performance due to the increased transport of momentum for the boundary layer [14]. However, it is debatable whether this is the case for *LS*>>*c*. To investigate this, a set of passive grids has been developed so that *I* and *LS* are varied independently (fig. 1a). The grids, with varying porosity *β~0.5-0.65* have been alternately placed at the inlet nozzle of the University of Liège Wind Tunnel Lab (Belgium), where the experiment has been conducted. The presence of an expansion in the wind tunnel test section has greatly helped in achieving *LS~30* cm together with *I~15* %. As it experiences a smooth stall mechanism, and it is optimised towards roughness insensitiveness, the Delft wind turbine aerofoil *DU96w180* is tested for *α=4-14-24* deg. To fulfil the aim, a value of $c < LS/2$ should be at least aimed. Therefore, two models with *c=0.125* and *0.05* m have been chosen for the experiment. The model (fig. 1b) has been printed with selective laser sintering, along with *40* pressure taps for the measurements of the fluctuating pressure field (fig. 1c). Reynolds effects might be present due to the low Reynolds number range used, i.e. *Re~15'000-25'000*. However, these seem to disappear when turbulence is introduced in the inflow. Preliminary results are shown in figure 1d. The integral length scale seems to catalyse the effect of FST in the aerodynamic performance at least for small angles of attack, which is compatible with the annulment of Reynolds effects. These results emphasise the importance of research in the topic of bluff body aerodynamics and the effect of turbulence on the aerodynamic performance. The expected output is an improvement of 2D aerofoil data to account for the effect of turbulence in the design of efficient urban wind turbines.

Figure 1. a) Schematic of passive grid used to generate inflow tur.3+bulence; b), c) experimental setup at the university of Liège; d) preliminary results showing the effect of LS.

References.

[1] EWEA, "Wind in power - 2015 European statistics," 2016.

[2] I. Dincer, "Renewable energy and sustainable development: a crucial review," *Renew. Sustain. Energy Rev.*, vol. 4, no. 2, pp. 157–175, 2000.

[3] B. Blocken, J. Carmeliet, and T. Stathopoulos, "CFD evaluation of wind speed conditions in passages between parallel buildings—effect of wall-function roughness modifications for the atmospheric boundary layer flow," *J. Wind Eng. Ind. Aerodyn.*, vol. 95, no. 9–11, pp. 941–962, Oct. 2007.

[4] S. Emeis, "Current issues in wind energy meteorology," *Meteorol. Appl.*, vol. 21, no. 4, pp. 803–819, Oct. 2014.

[5] L. C. Pagnini, M. Burlando, and M. P. Repetto, "Experimental power curve of small-size wind turbines in turbulent urban environment," *Appl. Energy*, vol. 154, pp. 112–121, Sep. 2015.

[6] K. Sunderland, T. Woolmington, J. Blackledge, and M. Conlon, "Small wind turbines in turbulent (urban) environments: A consideration of normal and Weibull distributions for power prediction," *J. Wind Eng. Ind. Aerodyn.*, vol. 121, pp. 70–81, 2013.

[7] P. W. Bearman and T. Morel, "Effect of free stream turbulence on the flow around bluff bodies," *Prog. Aerosp. Sci.*, vol. 20, no. 2–3, pp. 97–123, Jan. 1983.

[8] P. Devinant, T. Laverne, and J. Hureau, "Experimental study of wind-turbine airfoil aerodynamics in high turbulence," *J. Wind Eng. Ind. Aerodyn.*, vol. 90, no. 6, pp. 689–707, 2002.

[9] X. Amandolèse and E. Széchényi, "Experimental study of the effect of turbulence on a section model blade oscillating in stall," *Wind Energy*, vol. 7, no. 4, pp. 267–282, 2004.

[10] K. Swalwell, J. Sheridan, and W. Melbourne, "The effect of turbulence intensity on performance of a NACA 4421 airfoil section," *42nd AIAA Aerosp.*, 2004.

[11] C. Sicot, P. Devinant, T. Laverne, S. Loyer, and J. Hureau, "Experimental study of the effect of turbulence on horizontal axis wind turbine aerodynamics," *Wind Energy*, vol. 9, no. 4, pp. 361–370, Jul. 2006.

[12] V. Maldonado, L. Castillo, A. Thormann, and C. Meneveau, "The role of free stream turbulence with large integral scale on the aerodynamic performance of an experimental low Reynolds number S809 wind turbine blade," *J. Wind Eng. Ind. Aerodyn.*, vol. 142, pp. 246–257, 2015.

[13] Q. Li, Y. Kamada, T. Maeda, J. Murata, and Y. Nishida, "Effect of turbulent inflows on airfoil performance for a Horizontal Axis Wind Turbine at low Reynolds numbers (Part II: Dynamic pressure measurement)," *Energy*, vol. 112, pp. 574–587, 2016.

[14] T. Burton, D. Sharpe, N. Jenkins, and E. Bossanyi, *Wind Energy Handbook*. New York: John Wiley & Sons, Ltd, 2011.