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Influence of turbulence of oncoming flow on the admittance function of local pressures on a building roof

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SUMMARY:
This paper investigates the influence of turbulence intensity in the oncoming flow on the admittance function of local pressures on a building roof. Using Large-Eddy Simulations (LES), the study analyzes the power spectral densities of wind pressure at selected points on the roof of a model building and their relationship to wind turbulence. The results show that while the overall pressure distribution scales with the turbulence intensity of the oncoming flow, and that the pressure spectra on the roof, near the leading edge, although being affected by level of turbulence, yield very similar admittance functions in the bubble near the leading edge.

Keywords: Wind pressure, large eddy simulation, velocity–pressure admittance.

1. INTRODUCTION

In wind engineering, aerodynamic admittance functions are essential for modeling how structures, such as buildings and bridges, respond to fluctuating turbulence components. These functions typically quantify the resultant pressure in relation to the wind spectrum, which characterizes turbulence across a range of frequencies. Admittance can be understood in several contexts. One key interpretation is related to the size effect, also known as aerodynamic admittance (Vickery, 1968). This concept reflects how the resultant pressure on a surface is reduced due to its finite size and the imperfect correlation of wind pressures across the surface. It is also applied in bridge engineering, where the fluctuations of pressures around a bridge deck are modeled by multiplying an admittance function by the wind spectrum. Davenport introduced six admittance functions for drag, lift, and moment, as well as for two components of turbulence (Davenport, 1962). Furthermore, aerodynamic admittance is used to estimate the base moment and shear force in buildings with various aspect ratios (Kareem, 1982), as specified in various international codes and standards (ASCE7, AS1170.2, NRCC, EN1991-1.4, AIJ). In a different context, admittance functions are useful in numerical implementations of spectral analysis methods, especially when discretizing random fields, such as turbulence (Denoël and Maquoi, 2012). Within Davenport's wind loading framework, the term "mechanical admittance" refers to the frequency response function of the structure.

Aerodynamic admittance functions can also find applications in the determination of local wind pressures on buildings. Early works have shown that the quasi-steady theory can predict average loads well and pressure near the stagnation point, while it struggles in areas of flow separation, necessitating refined models (Letchford et al., 1993). Several empirical studies (Snæbjörnsson and

Geurts, 2006) , like those by Kawai (1996), Sharma (1996), Geurts (1997), and Snæbjörnsson (2002) have correlated pressure spectra with upstream wind velocity, suggesting the potential for generalized models across building types for the windward faces of mid- and high-rise buildings. In these works, the admittance function on the windward face of a building takes the general form

$$|\chi(f_r)|^2 = \frac{S_p(f)}{(\rho C_p U_\infty)^2 S_u(f)} = (1 + n f_r^\alpha)^{-\beta}$$

where n, α and β vary across models, and where f_r is a reduced frequency. This expression indicates how the power spectral density of the actual pressure $S_p(f)$ relates to the pressure that would be obtained with the quasi-steady approach (ρ, C_p, U_∞ are respectively the air density, the mean pressure coefficient and the average wind velocity at considered height above ground). In a review paper, Hunt et al., 1990 indicates that understanding how incident turbulence interacts with the turbulence and vortex shedding in the wake of a bluff body was understood through some of the mechanisms only. Computational methods, such as large-eddy simulations (Lamberti and Gorlé, 2020; Li et al., 2021), have further enhanced understanding of aerodynamic behavior under turbulence. Integrating aerodynamic admittance functions into design practices improves the accuracy of peak load estimations (Pomaranzi et al., 2022).

2. MATERIALS AND METHODS

2.1. Governing equations

The experimental model consists of a building with rectangular floor plan and dimensions of 2000 x 1000 x 300 mm (H x W x b), as illustrated in Figure 1, inside a 8 x 35 x 15 m (H x W x b) domain. To predict wind loading on the building facades, LESs are performed using Cadence's CharLES finite volume solver, which employs a low-Mach isentropic formulation. The solver has previously been used for wind loading simulations of the same building (Ciarlatani et al., 2023). We generate the incoming ABL with a synthetic turbulence generator (Xie and Castro, 2008) for two different turbulence intensities corresponding to streamwise turbulence intensities of 3% (ABL 1) and 4% (ABL 2) at the building location roof height. Pressure and velocity are sampled both on the building surface and in its vicinity over a period of 300s, with sampling frequency 2500 Hz.

In this short abstract, focus is set on the 300 x 280 mm area located on the roof of the building, near the leading edge, under a wind incidence of $\alpha = 10°$ and $U_\infty = 7.73$ m/s, see Figure 1. Among other quantities, the longitudinal component of the wind velocity is analyzed at point P (see Figure 1), located at roof level, 80 mm ahead of the building. It is used to define the admittance functions of the pressure on the roof, at 10 selected points located a distances (in mm) 5, 12.3, 26.9, 48.3, 75.9, 109.2, 147.3, 189.2, 234, 280 from the leading edge of the building. These points are labeled $1, \cdots, 10$. The admittance functions are determined with the H_2 estimator for SISO systems, i.e. as the ratio of the Power Spectral Densities (PSDs) of the pressures on the roof and of the wind velocity at point P. These PSDs are calculated with Welch's periodogram method, on windows of 1024 data points, without overlapping, which corresponds to a frequency resolution of 2.44 Hz.

3. RESULTS AND DISCUSSION

Figure 1 shows the maps of the average pressure coefficient on the roof as well as the RMS values. The contour maps are very similar for the two ABLs. A cut along the centerline of the building,

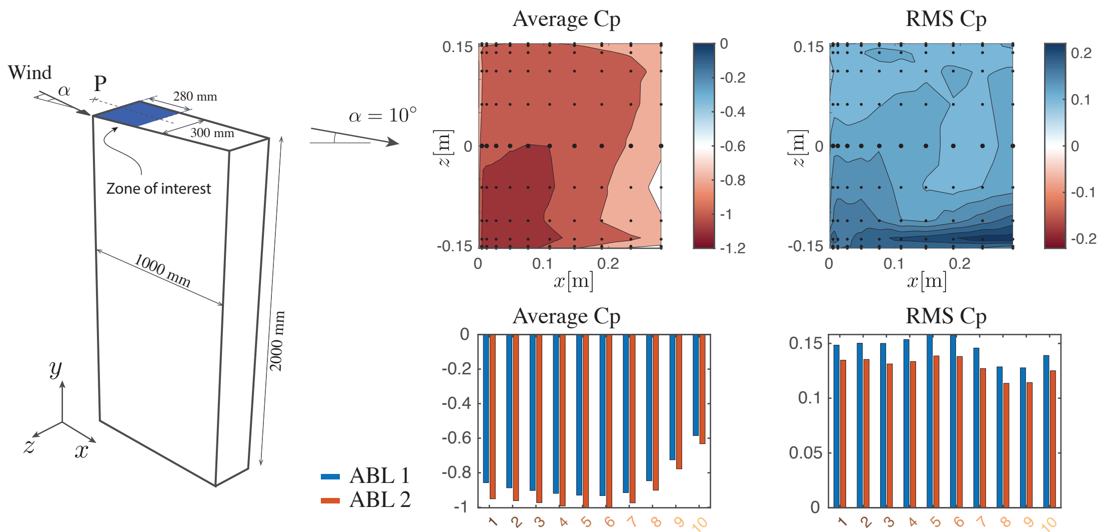

Figure 1. Illustration of the modeled building. The considered zone on the roof is represented by the dark blue tile. Right: maps of average and RMS (top view) and cut line for 12 selected taps along the centerline of the building

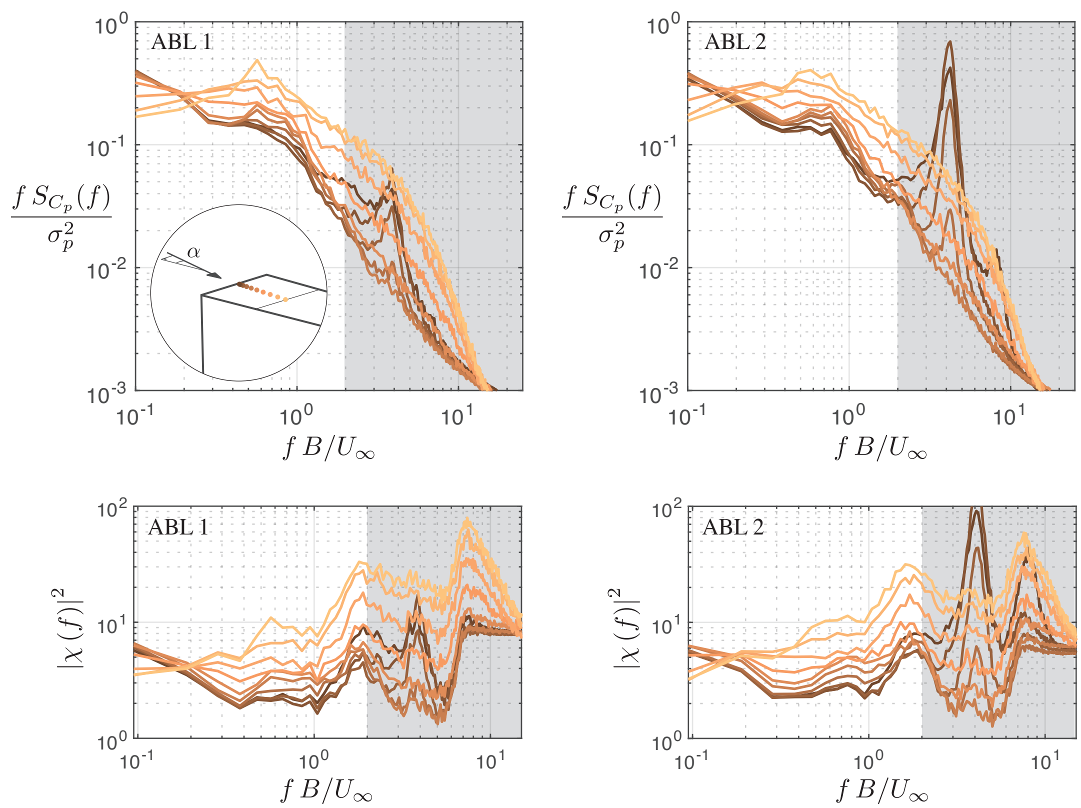

Figure 2. Top: PSDs of the pressure on the roof for the two ABLs. Bottom: Velocity-pressure admittances. Results are shown as a function of the reduced frequency $f_r = fB/U_\infty$, where $B = 0.3$m and $U_\infty = 7.73$m/s.

$z = 0$, shows that the average and RMS pressure coefficients are indeed very similar, in trends, with a consistently smaller RMS for ABL 2, with a reduction of about 10%.

Figure 2 shows the normalized PSDs of the wind pressure $fS_{C_p}(f)/\sigma_p^2$ for the 10 selected points on the roof. The PSDs in the rear part of the considered area are represented with lighter yellow tones (points 8, 9, 10). These PSDs are very similar for the two ABLs. The darker lines, associated with the pressure taps closer to the leading edge, also have a similar trend in the frequency range $fB/U_\infty \in [0;2]$. However, for $fB/U_\infty\, 2$ (greyed background), they show a significantly different behavior. The flow in the primary bubble (Buresti, 1998) located very near the leading edge, a phenomenon that is difficult to capture near the singularity, is recirculating in a rather narrow frequency band $fB/U_\infty \in [3;5]$. This process is seemingly more regular when the ABL is less turbulent, which favors the regular detachment of eddies from the leading edge. The secondary recirculation bubble is less affected by the turbulence of the oncoming flow. Consequently the admittance functions of the pressures along the roof, have very similar patterns, as shown in the bottom part of Figure 2. The full paper will cover additional cases and extend the analysis of the influence of the ABL on the pressures at other places of the building, including the leeward faces.

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