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LES predictions of wind loads on a low-rise building in an urban area

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SUMMARY:

Wind-resistant design of low-rise buildings plays an important role to reduce losses due to extreme wind events. Computational fluid dynamics offers an attractive approach to study wind loads on these buildings. The high-fidelity Large-eddy Simulations (LES) solve for the instantaneous fields allowing direct estimation of turbulent statistics, but validation is needed to assess its accuracy. Validation requires ensuring that the atmospheric boundary layer (ABL) is similar in isolated and urban cases, for both wind tunnel (WT) and LES, and there is good agreement when pressure coefficients are compared. To achieve that, we explicitly consider the roughness elements in the LES, which significantly improve the overall accuracy of the predictions for both the isolated and urban cases. Ongoing work is considering simulations for different wind directions and will compare the existing data with measurements from a different WT. The latter will help in taking into account the repeatability of the experiments.

Keywords: Low-rise building, large-eddy simulation, Wind tunnel

1. INTRODUCTION

Design wind loads on low-rise buildings are usually determined following building codes and standards. Code estimates of pressure coefficients are generally based on WT tests of isolated buildings in open terrain (Khanduri et al., 1998) and do not account for local interference effects due to the presence of surrounding buildings. With the continuous increase in computational power and efficiency, computational fluid dynamics (CFD) offers an opportunity to study these complex urban canopy flows and improve the representation of interference effects when estimating wind loading over low-rise buildings. However, the accuracy and reliability of CFD solutions for wind loading predictions remains a concern that requires further validation efforts (Blocken, 2014).

The objective of the present study is to validate LES predictions of wind pressures on a low-rise building in the presence of interference effects. To do so, we perform wind tunnel experiments and LESs of two configurations: 1) the isolated building and 2) the building in its urban environment. The validation process consists of two steps. First, we determine an LES set-up that correctly reproduces the surface layer turbulence generated in the wind tunnel. Second, we compare the WT and LES pressure coefficient predictions. LESs with two different incoming surface layers are considered to quantify the effect of the turbulence in the upstream wind field on the predictions. This abstract presents initial results comparing mean and root-mean-square (rms) pressure coefficients.

2. WIND TUNNEL AND CFD SET UP

2.1. Wind tunnel experiments

The building being modeled is the Y2E2 building located on Stanford's engineering quad. A 1:100 scale model of the building was constructed for testing in the NHERI Wall of Wind (WOW) WT at Florida International University (FIU) (Gan Chowdhury et al., 2017). The model measures 1m$\times$0.6m$\times$0.25m and has 382 pressure taps at which pressure time series are recorded. The tests that consider the building in its urban area include the surrounding buildings within a 300m radius of the center of the engineering quad.

The wind pressure measurements are performed on: 1) the isolated building and 2) the building in its urban area submersed in a suburban surface layer.The upstream section of the wind tunnel includes roughness elements to generate representative turbulence statistics. For the isolated building case the roughness elements are extended onto the turntable to avoid an unintended decay of turbulence upstream of the building. Wind directions of 0° to 360° are tested in $\sim$ 10° increments and repeatability tests are performed to quantify the uncertainty in the measurements.

2.2. LES set-up

The LESs are performed using the CharLES solver. The simulations are set up to reproduce the WT experiments for the isolated building and the building in its urban environment. Figure 1 shows the computational domains. For the simulations shown in this abstract, the grid size on the building is 3.9mm, which corresponds to an average $y^+ = 150$, and extends 10 layers away from the Y2E2 surface. The grid size of the surrounding area is 15mm. The total number of cells is 5 million and 12 million for the isolated and non-isolated building cases, respectively. Grid dependency will be discussed in the conference presentation.

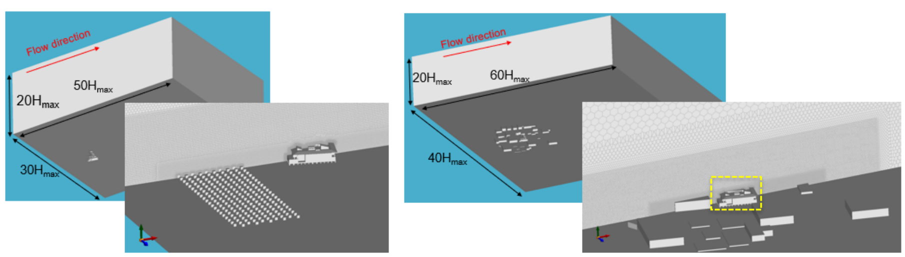


Figure 1. Computational domains for isolated building (left) and in its urban area (right).

At the inlet, a divergence-free synthetic turbulence generator (Xie and Castro, 2008) is used in combination with a gradient-based optimization framework (Lamberti et al., 2018) to match the experimental turbulent velocity statistics at the building location. A common issue with synthetic turbulence generators is the artificial pressure fluctuations that can arise when the inflow is not divergence-free or when there is a boundary condition mismatch between the inflow and the lateral boundaries. The simulations use the VBIC method to eliminate these artificial pressure fluctuations and avoid contamination of the pressure signal at the building (Patruno and Miranda, 2020).

Low-rise buildings (building Jensen number, $h/z_0 = \mathcal{O}(1-10)$) are embedded in the roughness sublayer. The low Jensen number makes numerical simulations particularly challenging because it is difficult to achieve the high turbulence intensities that occur close to the ground using only the optimized digital filter turbulence. To support generating turbulence intensities that match the WT experiments, we imported 10 rows of roughness elements upstream of the building location. Figure 2 shows the mean velocity and turbulence intensities at the building location obtained with and without the roughness elements. The mean, minimum, and maximum values obtained from WT measurements at different spanwise locations on the turntable are included for comparison. The

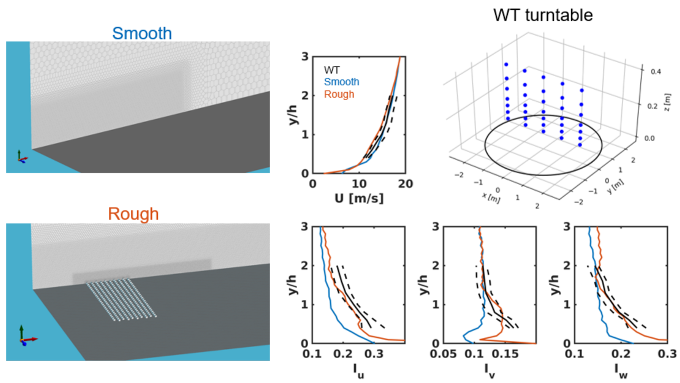


Figure 2. Boundary layer statistics comparison of wind tunnel experiments and LES.

results demonstrate that the inclusion of the roughness elements is of fundamental importance for obtaining representative turbulence statistics in the roughness sublayer, where low-rise buildings reside. The influence of obtaining sufficiently high turbulence intensities in the LESs is investigated next by comparing results for the pressure coefficients obtained from simulations without and with the roughnesses.

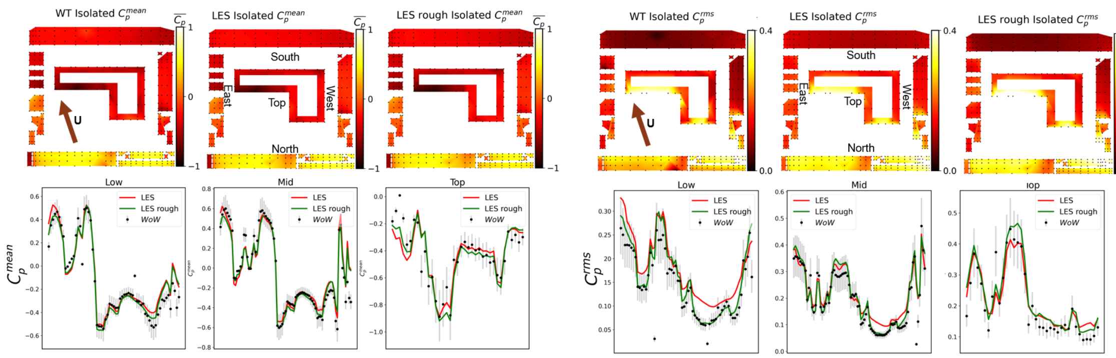
3. RESULTS

Figures 3a and 3b compare C_p^{mean} and C_p^{rms} for the isolated building with and without the upstream roughness elements, respectively. C_p^{mean} is in good agreement with the WT data for both cases, which indicates that the roughness elements do not affect the mean statistics significantly. In contrast, the C_p^{rms} results for the rough simulations agree significantly better with the WT data.

Figures 4a and 4b compare the results for the building in its urban area with and without the upstream roughness elements, respectively. Interestingly, both C_p^{mean} and C_p^{rms} predictions are improved by the presence of the roughness elements. This result indicates that the wind pressures on the building affected by the interaction between the unsteady flow features (shear layers, wakes, etc.) generated by the surrounding buildings, and the incoming ABL turbulence.

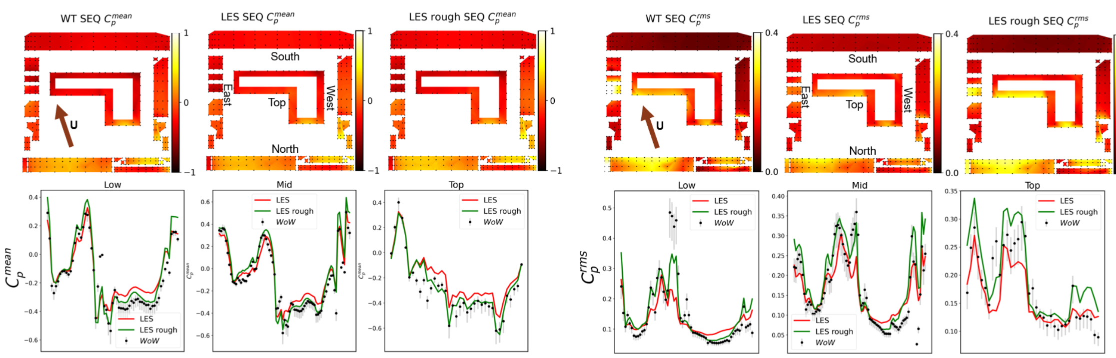
4. CONCLUSIONS

This study aims to validate LES for predicting wind loads on low-rise buildings in an urban canopy. The results demonstrate the importance of accurately reproducing the turbulence intensities in the roughness sublayer, which can be achieved by including upstream roughness elements in the LES. The inclusion of the roughness elements is shown to improve the C_p^{mean} and C_p^{rms} predictions for both the isolated and the urban case. In ongoing work, we are considering results for the full wind rose, and we are exploring how far upstream one should include buildings present in the real urban area to eliminate the effect of the upstream turbulence on the Y2E2 wind pressure predictions.



(a) Mean pressure coefficient **(b)** RMS pressure coefficient

Figure 3. Contours and profiles at 3 different heights of mean and rms pressure coefficient for the isolated building. WT mean with min and max due to the variability in the incoming WT ABL are compared to the LES.



(a) Mean pressure coefficient **(b)** RMS pressure coefficient

Figure 4. Contours and perimeters at 3 different heights of mean and rms pressure coefficient for the urban area. Mean with min and max due to the variability of the incoming WT ABL are compared to the LES.

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