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LES evaluation of wind-induced responses for an isolated and a surrounded tall building

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ABSTRACT

Aerodynamic response of a standard tall building (commonly known as the CAARC model) is investigated using LES. The LES employs the Consistent Discrete Random Flow Generation (CDRFG) technique to generate the inflow boundary condition allowing accurate depiction of the turbulence spectra and coherency. The building aerodynamic behavior is investigated for two configurations (an isolated building and a building with complex surrounding buildings) and the results are compared with a previous wind tunnel test. It is found that pressure and other wind-induced responses, such as top displacement, top acceleration and base moments, obtained from the LES are in a good agreement with those in the wind tunnel. The average difference between LES and wind tunnel results is found to be 4% for the pressures and 6% for the dynamic responses for the simulated wind directions, which emphasizes the accuracy of the employed model. As expected, comparison between the results for the isolated and the complex surrounding configuration showed 50% and 40% difference for mean and *rms* pressure coefficients, respectively. The employed LES model leads to an acceptable estimation for the wind pressure distribution and responses of the study building in a time-efficient manner. Therefore, it is expected to encourage the use of CFD in similar wind engineering applications in the future.

1. Introduction

Wind is a governing design load case for flexible structures such as tall buildings. Boundary layer wind tunnel testing has been widely used over the past five decades to evaluate structural design loads and responses. With the recent advancements in the computer technology, Computational Fluid Dynamics (CFD) analysis, particularly those based on Large Eddy Simulation (LES), are becoming useful in many wind engineering applications. For example, LES was utilized by Tominaga and Stathopoulos [1,2] to study the dispersion around a building and street canyon while Gousseau et al. [3] studied the dispersion in a city center. Jiang [4] and Durrani et al. [5] utilized LES to study the natural ventilation of buildings caused by thermal and pressure forces. Abdi and Bitsuamlak [6] studied the velocity speed up factors resulting from various topographic structures. In applications related to building aerodynamics, many researchers evaluated forces and pressure distribution acting on tall buildings, such as Nozawa and Tamura [7], Huang et al. [8], Tamura [9], and Braun and Awruch [10], Dagnew and Bitsuamlak [11] and Aboshosha et al. [12]. A recently detailed review is provided by Dagnew and Bitsuamlak [13]. This review highlights the different types of turbulence modeling and inflow boundary conditions (IBC) used in literature. These studies showed encouraging results in predicting the forces and mean pressures using LES.

Table 1 summarizes the scope and the main findings of previous numerical studies focusing on building responses. As indicated from the table, most of these studies were conducted on isolated buildings where the influence of the surroundings was not considered. It is well-known from experimental wind tunnel engineering that the effect of the surroundings can be significant.

Proper inflow boundary condition is essential for accurate LES modeling of building aerodynamics [14,11]. According to the Keating et al. [15] IBC can be generated using three methods (i) precursor database [16,17], (ii) recycling method [18,7,19], and (iii) synthesizing the turbulence [20–22]. The first two methods require prior simulations to generate the inflow which can be computationally expensive compared to the synthesizing the turbulence method.

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Table 1
Scope and the main findings of previous studies focused on building responses.

Reference	Turbulence model	Scope	Findings/comments
Nozawa and Tamura [7]	LES	Pressure distribution on low-rise buildings employing the recycling method to generate the inflow	Good agreement was found for the peak pressures obtained from the model with those from wind tunnel
Huang et al. [8]	RANS and LES	Aerodynamic behavior of the CAARC building using RANS and LES models	LES with a dynamic sub grid scale (SGS) model lead to satisfactory predictions for mean and dynamic wind loads
Zhang and Gu [25]	RANS	Aerodynamic behavior of buildings with staggered arrangement	Good agreement with wind tunnel results in terms of mean pressure, base force and base moment coefficients
Tamura [9]	LES	Employed LES models in different wind engineering applications including tall buildings in a city center	LES model led to encouraging results in terms of base moment spectra
Braun and Awruch [10]	LES	Aeroelastic LES model of the CAARC building	Good agreement was found with other experimental and numerical predictions in mean pressures, however lesser agreement was found in the rms pressures
Dagnew and Bitsuamlak [11]	LES	Effect of various inflow conditions on the aerodynamic behavior of the CAARC building	Good agreement with experimental results was found for LES model adopting fluctuations generated using the synthetic IBC
Aboshosha et al. [12]	LES	Developing a new turbulence inflow generator for LES evaluation of tall building aerodynamic responses	Very good matching between the results from the numerical model and the wind tunnel was found, indicating the importance of consistent inflow turbulence generation

Recently, the authors have developed an efficient inflow generator based on synthesizing the turbulence, which is named the Consistent Discrete Random Flow Generator (CDRFG) [12]. This method is able to properly model the statistical properties of the inflow represented in the turbulent spectra as well as the coherency function, which are very important characteristics for accurate evaluation of building aerodynamics [23,24].

More recently, CFD based wind engineering applications are maturing for use in aerodynamic optimization of tall building corners [26–28].

Dagnew and Bitsuamlak [29] attempt to simulate wind load for a building immersed in the city but did not produce good comparison with the wind tunnel data. This was primarily due to the computational resource limitations and the quality of the adopted inflow turbulence generation technique. These non-satisfactory results motivated the authors to develop a new IBC technique [12], which was assessed using an isolated building. The current study builds on the findings of that previous research to assess the pressure distributions and building responses of a tall building located in a complex surrounding. The Commonwealth Advisory Aeronautical Research Council (CAARC) building is considered. This building is used by many researchers to calibrate and validate wind tunnel experiments and numerical models, such as in Wardlaw and Moss [30] and Melbourne [31]. Results of the wind tunnel conducted by Dragoiescu et al. [32] are used to validate the LES model.

The study is divided into five sections. In Section 1 (this section), an introduction on the previous LES studies on tall buildings is presented. Section 2 briefly describes the CDRFG technique used for synthesizing the IBC for the sake of completeness. In Section 3, details about the wind tunnel experiment conducted by Dragoiescu et al. [32] are provided. Section 4 describes the LES model utilized to predict the forces and responses of the CAARC building. In Section 5, the LES results and discussions are provided and comparisons are made with the corresponding values from the wind tunnel experiment and other numerical simulations from the literature, whenever applicable.

2. Inflow turbulence generation

Inflow boundary condition is generated using the Consistent Discrete Random Flow Generator (CDRFG) technique. Details of that technique, including a Matlab source code, are provided in Aboshosha et al. [12], however, a brief description of the method is presented here for completeness. The steps illustrated by the flow chart given in Fig. 1 are followed.

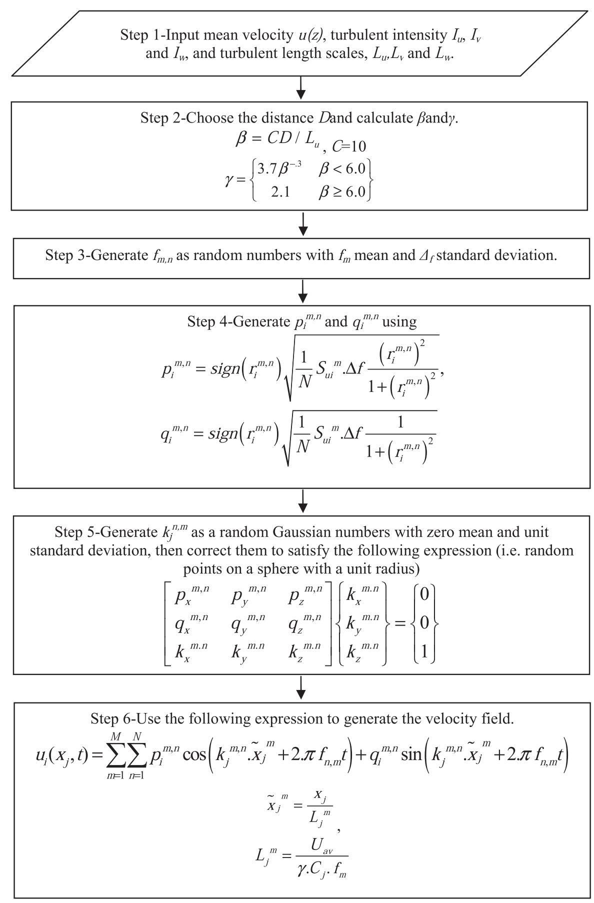

Fig. 1. CDRFG technique flow chart (Aboshosha et al. [12], reproduced with permission).

- In Step 1, mean velocity, turbulence intensity, and turbulence length scale profiles measured from the wind tunnel are fitted to the power law profiles. Table 2 summarizes the flow characteristics including: mean velocity, turbulence intensity and length scale profiles in addition to the coherence function. Fig. 2 shows the profiles measured from the wind tunnel compared to those used in the LES. As indicated in Fig. 2, the LES profiles match with the wind tunnel profiles with an average regression coefficient of 0.94.