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A numerical-experimental investigation on the aerodynamic performance of CAARC building models with geometric modifications

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ABSTRACT

This paper presents the results of a numerical-experimental investigation carried out with the purpose to evaluate the aerodynamic performance of CAARC tall building models with different cross-section configurations. A numerical model based on the Taylor-Galerkin two-step scheme and the Finite Element Method is adopted. Turbulence is described using LES and a synthetic inflow turbulence generator. Experimental tests were performed at the Prof. Joaquim Blessmann Boundary Layer Wind Tunnel considering CAARC tall building models with cross-section modifications based on chamfered and recessed corners. Some of the wind tunnel predictions obtained here are compared with results obtained from the numerical model proposed in this work, where two and three-dimensional meshes are utilized. Comparisons are also performed considering results obtained from other authors in similar studies. From the present investigation, it was observed that the wind action on tall buildings is significantly influenced by the geometric configuration of the building corners, which may lead to important reductions in the aerodynamic forces. Through a direct comparison of results between numerical and experimental simulation, we can see that both reach a convergence of results, thus indicating the potential of use of CFD in the modern aerodynamic investigation of buildings.

1. Introduction

The CAARC standard tall building model is an experimental building prototype presenting a simple hexahedral geometry with right-angle corners, which has been widely utilized to calibrate experimental methodologies in wind tunnel tests. Nevertheless, it is well known that certain geometric configurations of building corners can improve the aerodynamic performance of tall buildings by reducing the magnitude of drag and lift forces acting on the building surface. Hence, shape optimization is a major topic in building aerodynamics, where the shape of the cross-section plays an important role. In this sense, a numerical-experimental investigation is proposed in this work in order to evaluate the aerodynamic behavior of tall building models based on the CAARC geometry with corner modifications.

One of the first studies dedicated to wind action on the CAARC building model is due to Wardlaw and Moss (1970), where extensive experimental tests were performed. Later, Melbourne (1980) compared predictions obtained from six different wind tunnel devices to evaluate the reliability of the corresponding experimental data. Whitbread (1975) obtained the aerodynamic coefficients for the CAARC building model using experimental tests in a wind tunnel and Obasaju (1992) determined experimentally the overturning moments and forces referring to a CAARC model considering different incidence angles and different boundary layer profiles. The action of natural winds on the CAARC building model was analyzed by authors such as Tang and Kwok (2004), Chen and Letchford (2004) and Balendra et al. (2005), who also investigated winds under extreme conditions. The influence of geometric configuration over the aerodynamic efficiency of tall buildings was pointed out by Baker (2007) and Xie (2014).

In the field of aerodynamic optimization of buildings, one can observe that significant improvements can be obtained by simply modifying the cross-section configuration slightly. In this sense, it is well known that the shape of the building corners has noticeable influence on the magnitude of aerodynamic forces acting on the building surface. Davenport (1971) is one of the first authors to investigate aspects of aerodynamic optimization applied to buildings, where different geometric configurations were analyzed. He concluded that buildings with circular cross-section behave better in terms of aerodynamic efficiency, followed by buildings with rectangular shape with modified corners. Effects of the corner shape over the flow field around building models were also studied by

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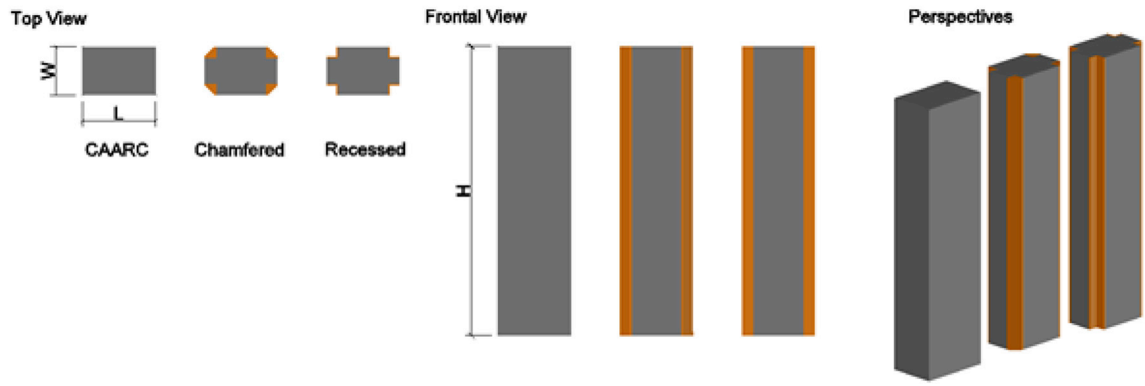

Fig. 1. Reduced models views and perspectives.

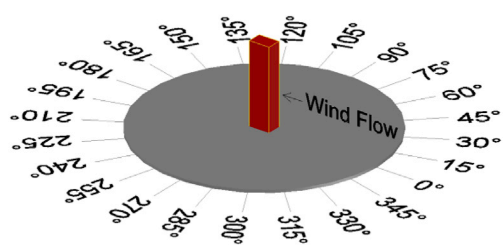

Fig. 2. Wind flow incidence angles in relation to the reduced models.

Stathopoulos (1985) and Kwok et al. (1988) evaluated the aerodynamic performance of the CAARC tall building model by using cross-section configurations with right-angle and chamfered corners. Later, Jamieson et al. (1992) determined the pressure distribution over building facades experimentally considering rectangular models and modified corners. One can see that models with rounded corners obtained the larger values in terms of maximum pressure suction in the last third of the building height. On the other hand, models with chamfered corners led to smaller pressure suction coefficients.

Tamura and Miyagi (1999) used two and three-dimensional building models to determine drag and lift coefficients considering laminar and turbulent flow conditions and different corner configurations. Extensive experimental tests were performed by Tanaka et al. (2012) to determine the aerodynamic performance of building models with several geometric configurations. Building models with triangular shape were analyzed experimentally by Bandi et al. (2013), where aerodynamic coefficients and the influence of the torsion angle on the aerodynamic behavior were evaluated. The influence of corner modifications on the aeroelastic behavior of tall building models was analyzed by Kawai (1998) and Zhengwei et al. (2012). Recently, Kim et al. (2015) analyzed effects of the number of cross-section sides on the structural response of building models subject to wind action, as well as the influence of torsion as function of the building height.

With the constant improvements in the computers technology, numerical procedures of Computational Wind Engineering (CWE) has been successfully employed to simulate the wind action on structures (see, for instance, Blocken, 2014). Hirt et al. (1978) is one of the first authors to evaluate the aerodynamic behavior of structures numerically, where bluff bodies were analyzed and predictions compared with experimental results. Later, Hanson et al. (1982) and Summers et al. (1986) presented numerical results referring to aerodynamic analysis of different structures, which are relevant to the field of Wind Engineering. In the last decades, many investigators have adopted the Texas Tech building model to validate their numerical models (see, for instance, Selvam, 1992; Selvam, 1996; Mochida et al., 1993; He and Song, 1997; Senthooran et al., 2004).

The CAARC building model was first investigated numerically by Huang et al. (2007), where aerodynamic analyses were employed considering a finite volume scheme and different turbulence models. Later, Braun and Awruch (2009) utilized a finite element model and LES

Table 1
Strouhal number as function of incidence angle and cross-section configuration.

Wind	CAARC (0.11)		CAARC (0.23)		Chamfered (0.11)		Recessed (0.11)	
θ (°)	0	90	0	90	0	90	0	90
St	0.15	0.09	0.14	0.09	0.14	0.11	0.17	0.12

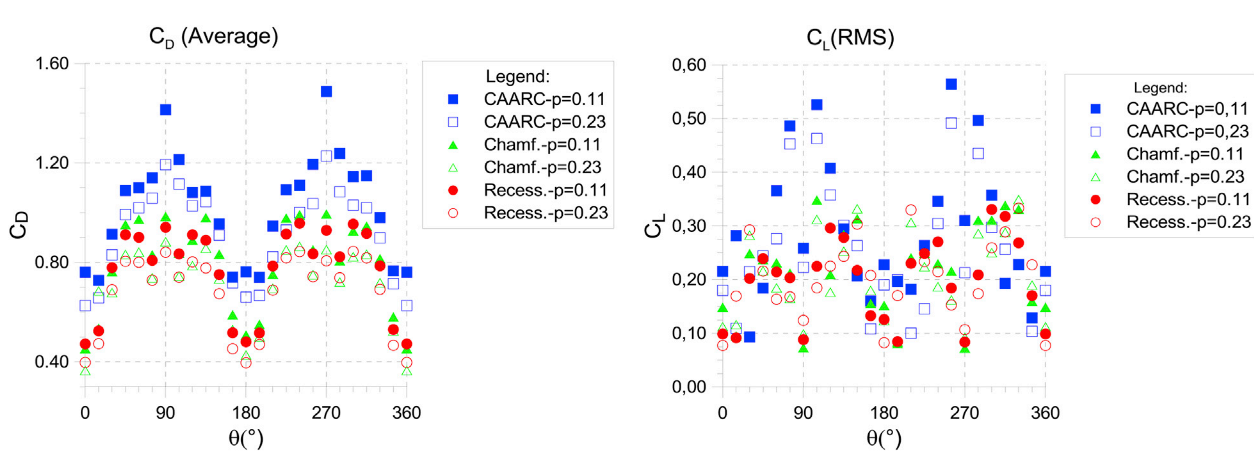

Fig. 3. Drag (mean) and Lift (rms) coefficients as function of incidence angle.

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