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Towards practical use of LES in wind engineering

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Abstract

This paper reviews large-scale computing results currently obtained by the large eddy simulation (LES) technique for various wind engineering problems. The LES or direct numerical simulation (DNS) techniques should be used to numerically simulate unsteady flow phenomena. LES is appropriate for wind engineering applications because its computational power and memory requirements are reasonable. The present study discusses the applicability of LES to several issues such as wind-resistant design, prediction of wind velocity affected by terrain or ground surface conditions, and estimation of turbulence structures and atmospheric diffusion in urban areas. Thus far, numerical validation has been performed mainly by comparison with experimental data. However, when considering the complexity of actual conditions and the natural wind environment, direct comparison with full-scale measurement data is very important in all cases to verify the effectiveness of LES in wind engineering.

Keywords: LES; Inflow turbulence; Full-scale measurement; Bluff body aerodynamics; Wind in cities; Ground surface condition; Terrain effect; Atmospheric environment

1. Introduction

Large eddy simulation (LES) has become a powerful tool for turbulent flow analysis in the computational wind engineering field as well as in computational fluid dynamics. This has been enabled by the establishment of the following numerical techniques.

(1) Generation of inflow turbulence by numerical or statistical methods.
(2) Sophisticated sub-grid scale (SGS) turbulence modeling for unsteady separated flows with vortex shedding or turbulent boundary layers over complicated undulations with very rough surfaces.

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(3) Numerical discretization with conservation of various physical quantities for modeling complicated geometries.

Development of a numerical modeling has enabled LES to predict wind flows around buildings and structures under conditions very close to the actual state. Therefore, the practical use of LES in wind engineering is now possible. Here we discuss the applicability of LES to wind-resistant design of very large buildings and structures, and determination of wind velocity affected by hilly undulations, complex terrain or ground surface roughness; turbulence structures inside or over urban canopies; and atmospheric dispersion of mass and heat in urban areas. Based on previous examples reviewed in following sessions, the current state and potential for use of LES in wind engineering is examined. In particular, in order to independently estimate the accuracy or reproducibility of numerical results obtained by LES for wind-related natural phenomena, comparison with full-scale measurement data or characteristics presumed by full-scale measurement, rather than wind tunnel test data, is tried for many cases and from as many viewpoints as possible. This paper emphasizes the importance of such a direct comparison.

2. Wind effects on buildings and structures

2.1. Wind loading estimation—AIJ activities in relation to LES for wind-resistant design

The Architectural Institute of Japan (AIJ) established a working group to investigate the applicability of the CFD technique to the wind-resistant design of actual buildings and structures (AIJ, 2005; Tamura et al., 2006a). This investigation has clarified the current state of predictive accuracy of the numerical model and provided a guide for an appropriate numerical model and method. This paper describes the activities of AIJ in estimating the performance and limitations of various types of numerical modeling in computational wind engineering. It deals with low-rise (1:1:0.5) and high-rise (1:1:4) buildings. Both RANS simulation and LES were carried out to determine the aerodynamics of these building models. The computed wind forces and pressures for these simple configurations have been validated by comparison with experimental data. AIJ used these computed data to determine wind loadings on these buildings as predicted by RANS and LES. Fig. 1 displays wind loads on cladding of a high-rise (1:1:4) building estimated by LES (Nozawa and Tamura, 2003) and experiments (Ohtake, 2002), accompanied by AIJ recommendations (AIJ, 2004) determined by considering many field measurement data as well as experimental data. Matching of these results indicates that LES can accurately predict wind loadings on claddings of high-rise buildings of various shapes.

2.2. Generation of inflow turbulence for LES

In many cases in which LES is applied to wind engineering problems, generation of inflow turbulence, which provides time-sequential data with physically corrected spatial structures, is a very important issue, because wind is essentially a turbulent and unsteady flow at very high Reynolds numbers. Thus, the oncoming flow in the computational domain should have these inherent characteristics of natural wind. One method for