BBAA VI International Colloquium on:
Bluff Bodies Aerodynamics & Applications
Milano, Italy, July, 20-24 2008

NUMERICAL SIMULATION OF PLUME DISPERSION AROUND AN ISOLATED CUBIC BUILDING : COMPARISON BETWEEN RANS AND LES COMPUTATIONS

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Keywords: CFD, Dispersion, Cubic Building, RANS, LES

1 INTRODUCTION

Prediction of plume dispersion near buildings is very important for the design of exhaust stacks and air intakes to avoid adverse air quality impacts. Several studies have been carried out on CFD prediction based on a RANS model for dispersion around buildings, but the prediction accuracy is not clear. The authors have examined the performance of various revised k-ε models for the dispersion field around a building and confirmed that all RANS computations under-predicted the horizontal concentration diffusion, although some revised k-ε models yielded much more accurate results than the standard k-ε model [1].

However, few studies have evaluated the basic performance of LES in modeling the dispersion field for a simple configuration in comparison with the RANS model.

The purposes of this study are to confirm the accuracy of LES in modeling dispersion around a bluff body and to clarify the mechanism of the discrepancy in relation to the RANS computation.

2 COMPUTATIONAL DETAILS

2.1 Flow field

The flow field selected as a test case was that around a cubic building with a flush stack at the rooftop placed within the neutral surface boundary layer. Wind tunnel measurements were performed by Li and Meroney [2]. The case of a central roof stack with 0º wind direction is adopted in this study. The Reynolds number based on H_b and $\langle u_b \rangle$ was 1.1×10^4. (H_b is the cube height and $\langle u_b \rangle$ is mean inlet velocity at H_b)

2.2 Numerical method

1) RANS

The RNG k-ε model (hereafter RNG) shows best agreement with the experiment of the four types of turbulence models in the previous study [1]. The turbulent Schmidt number is set to 0.7.

2) LES

The standard Smagorinsky model (C_S=0.12) was used for the sub-grid scale eddy viscosity model [3].

2.3 Boundary conditions

The computational domain and boundary conditions are summarized in Fig. 1. This domain was discretized into 86(x)×76(y)×46(z) grids. The minimum grid width was 0.0045H_b. These conditions are the same in both computations.

1) RANS

The vertical distributions of the quantities at the inflow boundaries were based on the experiment. The generalized log law was used for the solid boundary.

2) LES

A separate LES computation of turbulent boundary layer flow was conducted to generate inflow turbulence. The inflow generating method used here was that proposed by Kataoka [4]. For the boundary condition at the solid walls, a linear or 1/7 power law distribution of instantaneous velocity was assumed. The computations were conducted for 132 non-dimensional time units, t* ($=t \times \langle u_b \rangle / H_b$) to determine the time averaged values.

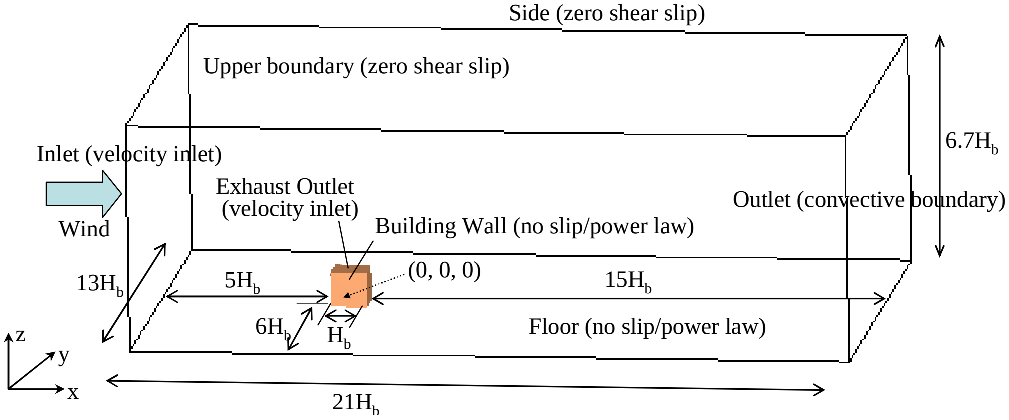
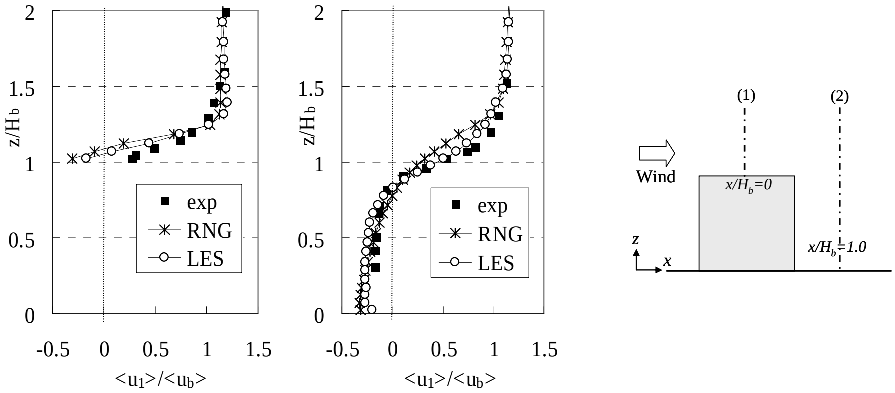


Figure 1: Computational domain and boundary conditions (LES).

3 RESULTS AND DISCUSSION

3.1 Velocity distributions

Firstly, the velocity fields without stack emission obtained by both computations were compared. Fig. 2 shows profiles of streamwise velocities on the roof and behind the cube at the centerline. The computational results were compared with experimental data for a similar flow field [5], because there were no velocity data around the cube in reference [2]. The differences between the velocity distributions of the two models were rather small, but the reverse flows on the roof and behind the cube in RNG were a little larger than those in LES. This means that the mixing effect near the cube in LES was stronger than that in RNG.



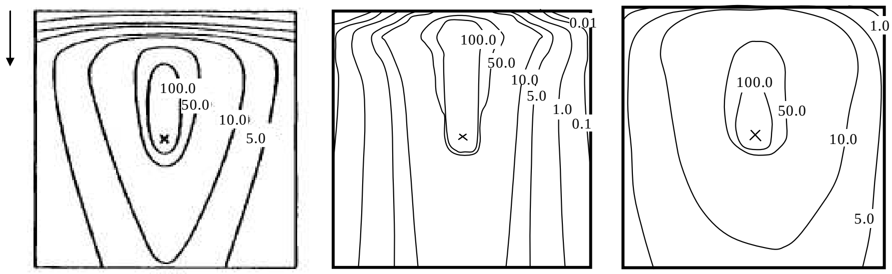
(1) $x/H_b=0$ (2) $x/H_b=1.0$

Figure 2 : Comparison of vertical distribution of streamwise velocity on roof and behind cube at centerline.

3.2 Concentration distributions

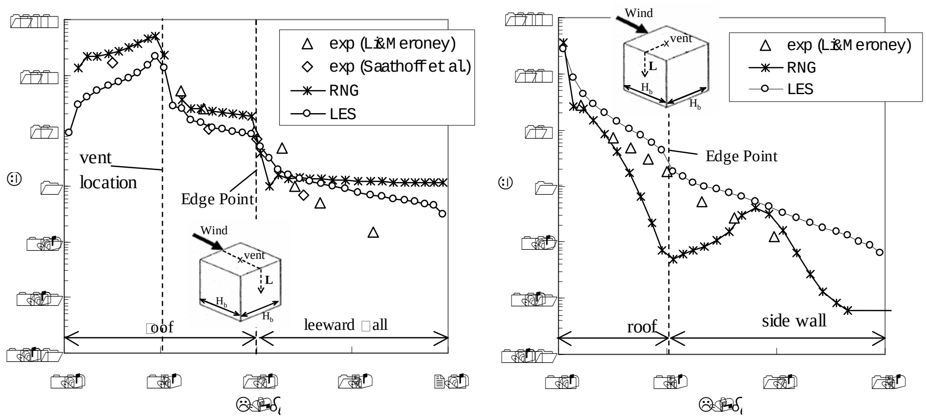
Fig. 3 compares the contours of the dimensionless concentration, K, on the roof surface obtained from the present CFD and the experiment [2]. In this study, dimensionless concentration K was defined as $K=\langle c\rangle H_b^2\langle u_b\rangle/Q_e$, where <c> is mean concentration and Q_e is the plume flow rate.

The high concentration region (K>100) upwind of the stack in RNG was larger than those in LES and the experiment. The contours of K in RNG also expand greatly in the downstream direction. However, the concentrations are widely spread in the horizontal direction in LES. The general distribution of K given by LES is very similar to that of the experiment, although the LES result tends to be a little diffusive.



(1) Exp [2] (2) RNG (3) LES

Figure 3 : Distribution of time-averaged dimensionless concentration K on roof.

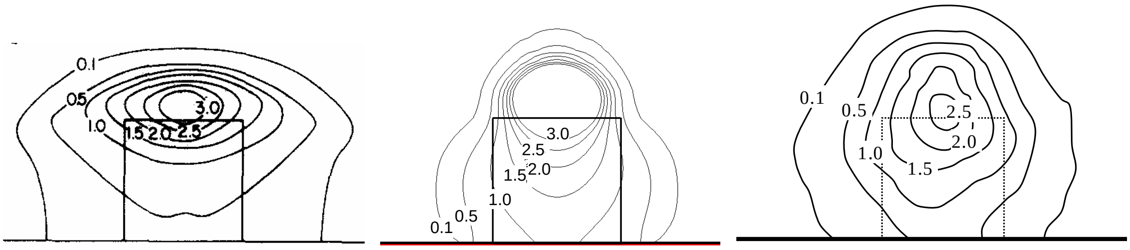


(1) Streamwise direction (2) Lateral direction

Figure 4 : Distribution of dimensionless concentration K on centerline of roof and leeward wall.

The distribution of K on centerline of the roof and the leeward wall is shown in Fig. 4. In the streamwise direction, the values of K given by LES are smaller than those given by RNG. However, in the lateral direction, the LES values are much higher than the RNG values and near the experimental data. In general, the distributions of K obtained by LES show very good agreement. These results are caused by larger lateral turbulence diffusion obtained by LES in comparison with RNG.

Fig. 5 indicates the contours of dimensionless concentration K in the near wake region (x/H_b=1.0). RNG under-predicts the horizontal spread of concentration in comparison with the experiment. However, LES shows better prediction of diffusivity of horizontal concentration.



(1) Exp [2] (2) RNG (3) LES

Figure 5 : Contours of dimensionless concentration K in near wake region (x/H_b=1.0).

4 CONCLUSIONS

Simple LES modeling gives better results than RNG of the distribution of concentration, although the difference between the results of LES and RNG for mean velocity is not so large. The horizontal diffusion of concentration is well reproduced by LES.

RNG (usual RANS computation) underestimates the turbulence diffusion near the cube. This is because the smaller value of turbulent Schmidt number works well in the previous study [1]. This tendency is closely related to the reproduction of unsteady periodic fluctuation around the cube in LES.

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