Numerical Simulation of Air Flow and Gas Dispersion around Obstacles

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Abstract

Computations of the mean and turbulence flows over three-dimensional hill of conical shape have implemented. Beside the standard $k-\varepsilon$, two other modifications proposed by Detering & Etling and Duynkerke for atmospheric applications were also considered. These predictions were compared with the data of a wind tunnel experiment. From the comparison, it was concluded that all three models predict the mean flow velocities equally well while only the Duynkerke's model accurately predicts the turbulence data statistics. It also concluded that there are large discrepancies between model predictions and the measurements near the ground surface.
The flow field, which was obtained by using the Duynkerke's modification, was used to simulate gas dispersion from an upwind source. The calculation results are verified based on the measurement data. Modifications of the turbulent Schmidt number were carried out in order to match the measured results. The code was used to investigate the influence of the recirculation zone behind a building of cubical shape on the transport and dispersion of pollutant. For a stack behind and near the obstacle, some conclusions about the effect of the stack height and stack location were derived.

1. Introduction

To simulate turbulent flow in the atmospheric boundary layer, the first-order closure model (K-theory) has been widely employed [1]. However, it is usually fail to describe ABL in complex conditions. On the other hand, the second-order closure is too complicated and too expensive to simulate ABL. Therefore, an immediate approach, $k-\varepsilon$ model have been considered to be a successful compromise between capability and simplicity.
The objective of this study is also related to the application of $k-\varepsilon$ model for simulation of wind field and pollutant dispersion. Beside the standard $k-\varepsilon$, two other modifications ([2], [3]) for atmospheric applications were also considered. The calculation results are verified based on the measurement data. Modifications of the turbulent Schmidt number were carried out in order to match the measured results. The code was also used to investigate the influence of the recirculation zone behind a building of cubical shape on the transport and dispersion of pollutant.

2. Description of theoretical models and solution procedure

The study was performed using three $k-\varepsilon$ turbulence models, i.e. the standard $k-\varepsilon$ model and two its modification proposed by Detering and Duynkerke ([2], [3]). The RANS equations were solved by the SIMPLE method [4]. The finite volume method is applied on a staggered grid.

3. Results

The experiment of von-Karman Institute (VKI) [5] was employed to verify and compare three models. Fig. 1 and Fig. 2 shows two comparisons among computed and measured results of flow fields. In the case of concentration simulation, the closest agreement with the experiment data was found in the case of $Sc_{t,y} = 0.61$ and $Sc_{t,z} = 0.83$ (see Fig. 3).

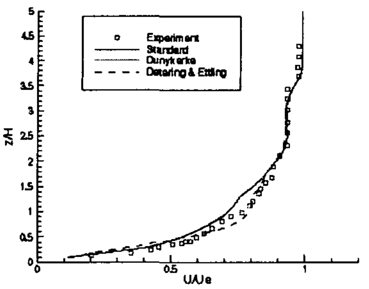

Fig. 1: Mean velocity profiles at $x = -H$ and $y = 0$.

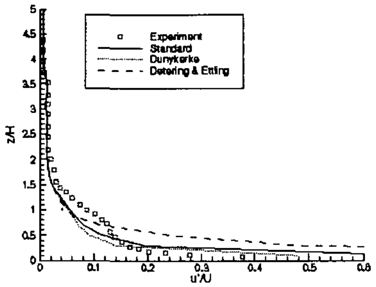

Fig. 2: Streamwise velocity fluctuation at $x = -H$ and $y = 0$.

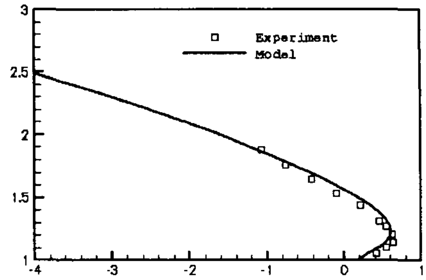

Fig. 5: Vertical concentration profiles above the crest of hill z/H vs $\log(\chi)$

The effects of recirculation zone behind a building on ground-level concentration released from a stack near building were investigated. The mean ground level concentration for different stack heights and stack locations are shown in Fig. 4.

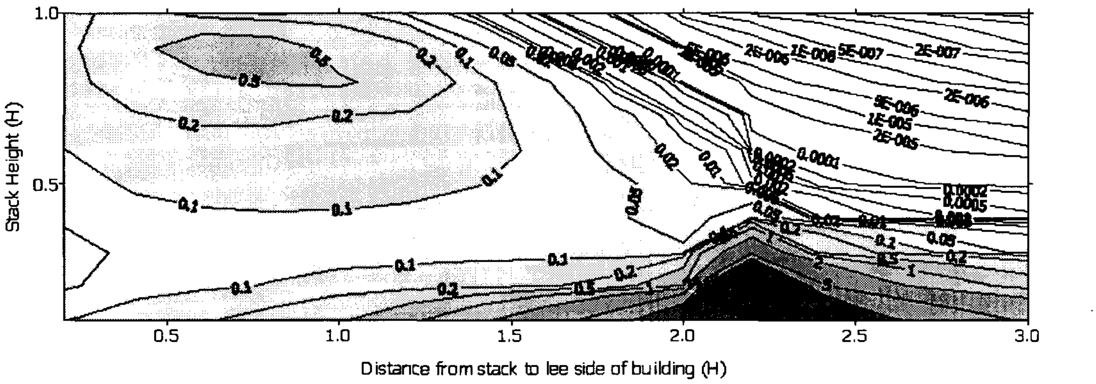

Fig. 4: Mean ground-level concentration contours as a function of stack height and stack location.

4. Conclusions

All three models predict the mean flow velocities equally well while only the Duynkerke's model accurately predicts the turbulence data statistics. There are large discrepancies between model predictions and the measurements near the ground surface.

The simulated concentration field is highly sensitive to the specification of eddy mass diffusivity and a non-isotropic dispersion model based on $k - \varepsilon$ turbulence closure scheme with $Sc_{t,x} = Sc_{t,y} = 0.61$ and $Sc_{t,z} = 0.83$ gave the calculation results agree well with the experiment.

The existence of a building can cause the ground level concentration increase as many as several hundreds times. The effect of building on the ground level concentration of pollutants may be very weak when the stack height is greater than the building height about 1.2 times or when the distance from the stack to the building greater than the length of recirculation zone. It may very strong when the emission point locate near the center of main vortex or when the flow near the emission point is downward strongly.

References

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