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A MODEL FOR FLOW AND DISPERSION AROUND BUILDINGS AND ITS VALIDATION USING LABORATORY MEASUREMENTS

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1. INTRODUCTION

Numerical modeling of airflow and pollutant dispersion around buildings is a challenging task due to the geometrical variations of buildings and the extremely complex flow created by such surface-mounted obstacles. The airflow around buildings inevitably involves impingement and separation regions, a multiple votex system with building wakes, and jetting effects in street canyons. The interference from adjacent buildings further complicates the flow and dispersion patterns. Thus accurate simulations of such flow and pollutant transport require not only appropriate physics submodels but also accurate numerics and significant computing resources. We have developed an efficient, high resolution CFD model for such purposes, with a primary goal to support incident response and preparedness in emergency response planning, vulnerability analysis, and the development of mitigation techniques.

2. NUMERICAL MODEL

Our model is based on solving the three-dimensional, time-dependent Navier-Stokes equations. The basic numerical algorithm is composed of an innovative finite element approach to accurately represent complex building shapes and a fully implicit projection method for efficient time-integration (Gresho and Chan, 1998). For turbulence processes, we have implemented a nonlinear eddy viscosity (NEV) and a Smagorinsky large eddy simulation (LES) submodels. The NEV submodel (Suga 1995) is anisotropic and there is no need for wall functions. Also included are submodels for aerosols, UV radiation decay, surface energy budget, and tree canopy effects. Our model has been developed to run on both the serial and massively parallel computer platforms.

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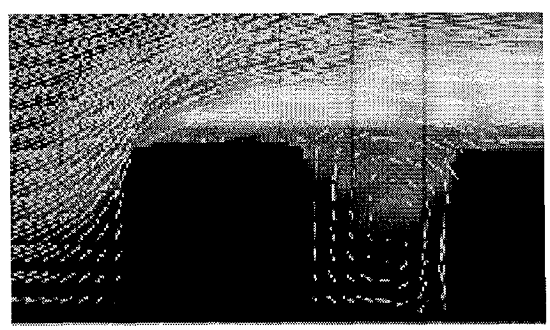
3. MODEL VALIDATION

We have performed model validations using, among others, the tow-tank experimental data from flow and dispersion past a cubical building and similar data around a 2-D array of building blocks in a wind tunnel.

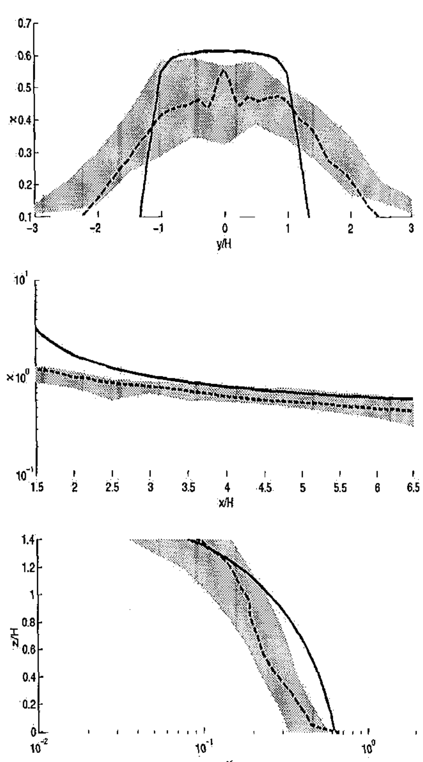
In the first example, our model was used to simulate the flow field around a 2-D array of model buildings conducted at the USEPA Fluid Modeling Facility (Brown, et al., 2000). The predicted flow and turbulence kinetic energy (TKE) fields near the first two buildings from our NEV simulation are shown in the following figure. Our model was able to predict a flow separation and recirculation over the first building and no similar recirculation over the other buildings. Recirculations in all canyons and the TKE field, which has its peak value near the leading edge of the first building, were also well predicted. A similar simulation using LES is in progress and results will be reported later.



In the second example, we present a validation study of flow and dispersion around a cubical building, using both the NEV and LES turbulence submodels. A steady state flow was obtained with the NEV submodel and then used in a separate dispersion simulation. However, an unsteady flow with vortex shedding behind the cube was predicted with LES, thus the dispersion simulation was conducted simultaneously with the flow field calculation.

The main features of the flow, including separations in front of the cube, on the roof and the sides, and recirculating eddies in the wake, are all well predicted by both turbulence submodels. The predicted reattachment lengths are 1.85 by NEV and 1.55 by LES, which are in good agreement with the value of 1.68 measured by Martinuzzi and Tropea (1993) and the value of 1.64 predicted by Shah (1998).

For dispersion assessment, we use the results from a study by Zhang et, al.(1996) for a continuous, ground-level tracer release behind the cube. In the next figure, predicted concentrations are compared with measurements (shaded area) along three lines. The top plot shows the LES capturing the horizontal dispersion, as observed in the experiment, at the outflow at 6H (H being the building height) behind the building. In the middle plot, the LES and NEV results are seen to agree quite well with measured data along the floor of the symmetry plane. Compared in the bottom plot are vertical concentration profiles in the middle of the outflow plane, with higher concentrations near the ground in the NEV simulation due to the absence of vortex shedding.



4. SUMMARY

In this study, our model has been used to simulate two laboratory experiments involving complex flow and dispersion patterns. Our model has been observed to reproduce very well the important features of the experimental results. The LES approach is generally more accurate than the NEV approach; however, it is roughly an order of magnitude more costly.

5. REFERENCES

Brown, M.J., R.E. Lawson, D.S. DeCroix, and R.L. Lee, 2000: Mean flow and turbulence measurements around a 2-D array of buildings in a wind tunnel. 11th Joint AMS/AWMA Conf. on the Appl. of Air Poll. Met., Long Beach, CA., 35-40.

Gresho, P.M. and S.T. Chan, 1998: Projection 2 goes turbulent - and fully implicit. Int. J. of Comp. Fluid Dyn., 9, 249-272.

Martinuzzi, R. and C. Tropea, 1993: The flow around surface-mounted, prismatic obstacles placed in a fully developed channel flow, J Fluids Eng., 115, 85-92.

Shah, K.B., 1998: Large eddy simulations of flow past a cubic obstacle. Ph.D. thesis, Stanford University, Stanford, CA.

Suga, K., 1995: Development and application of a nonlinear eddy viscosity model sensitized to stress and strain invariants. Ph.D. thesis, UMIST, Manchester, UK.

Zhang, Y.S., S. Arya, and W. Snyder, 1996: A comparison of numerical and physical modeling of stable atmospheric flow and dispersion around a cubical building, Atm. Env., 30, 1327-1345.

6. ACKNOWLEDGMENTS

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