J2.11 FLOW AND TURBULENCE SURROUNDING A BUILDING CLUSTER

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1. Introduction

Air quality as well as dispersion of biological and chemical contaminants within urban and industrial areas are strongly influenced by building clusters that perturb local winds (Hosker 1987). Although air circulation and turbulence in the vicinity of a single building, a few buildings or sparsely located buildings have been studied extensively, only a few studies exist on detailed flow patterns within and surrounding a building cluster. Yet, such details are of great importance in predicting the dispersion of material from sources located near the buildings or concentrations of material advected past buildings.

2. Experiment

In order to address such issues, an experimental program was conducted at the U.S. Army Dugway Proving Ground, dubbed the Mock Urban Setting Test (MUST), in which the authors were participants. The goal was to investigate the flow through an urban building cluster and to gather dispersion data useful for evaluation of urban dispersion models. The MUST set up consisted of a 180 m x 176 m rectangular array of 120 containers (12 x 10 array) that simulated an urban environment, and the natural background flow was allowed to pass through this simulated urban cluster.

The equipment used included a balloon carrying tethersondes that were vertically traversed at a site 420 m northeast of the center of the building cluster, which provided background profiles of important meteorological quantities. Sonic anemometers located at the southern (upwind) side as well as inside the grid provided mean and turbulent characteristics of the flow. In the analysis, the cases where wind was coming from south-southeast (i.e. normal to the longer side of containers) were investigated. In this case the ratio of face-to-face spacing to container height was S / H = 5, which implies the presence of an isolated flow regime according to the classification of Hussain and Lee (1980).

3. Numerical model

The flow in and around the same building configuration was also investigated using a 3D numerical model that employs a conventional turbulent kinetic energy - dissipation (k-ε) closure scheme. The model used in this study is the same as the one in Baik et al. (2002). In this work numerical calculations did not include heat and dispersion equations.

Wind speed and turbulent kinetic energy were calculated and compared with those obtained during the experimental program. Flow patterns through the container array were also obtained.

4. Results

Measurement results presented here were gathered on September 24, 2001 during 23.00 to 24.00 LST, under stable atmospheric conditions. The velocity profile of the incoming wind can be described by the power law:

$$\frac{U}{U_{hs}} = \left(\frac{h}{h_s}\right)^p \quad (1)$$

where U_{hs} is the velocity at the reference height h_s (in this case h_s = 16 m was the height of the highest sonic in the entrance region). The exponent p obtained here is double the exponent typical of wind-speed profiles over urban and suburban terrain (McDonald et al. 2000) and has a value 0.57. This value was obtained by fitting (1) to measurements taken by sonic anemometers at the southern sonic tower and those obtained by the meteorological balloon. Fig. 1 shows the velocity profile of incoming wind where points represent measured values and the curve is a power law fit.

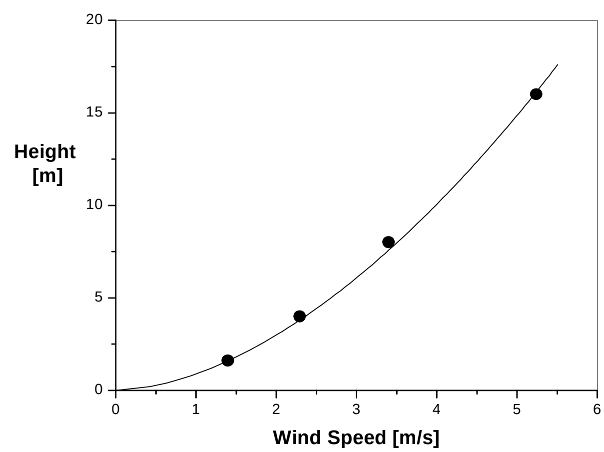

Fig. 1. Wind profile at the entrance region.

Profiles of turbulent kinetic energy of incoming flow could not be obtained in this experiment since the tower consisted of one 3D and three 2D sonics; the variance of the vertical wind component was not available from all sonics. The profile of turbulent kinetic energy in the

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entrance region (k_0) was estimated from the kinetic energy of mean flow (Kim and Baik 1999) using the equation:

$$k_0 = 0.005U^2 \qquad (2)$$

Fig. 2 compares experimental (points) and calculated values (curve) of non-dimensional wind speed near the center of the array (in the canyon between the 5^{th} and 6^{th} row of containers). The non-dimensionalisation has been performed using the height of containers (H = 2.6 m) and the wind speed at this height at the entrance region (U_H).

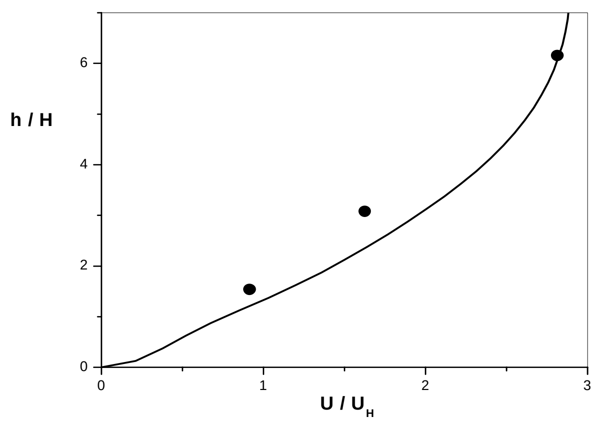

Fig. 2. Comparison of experimental and calculated values of wind speed at the center of the array.

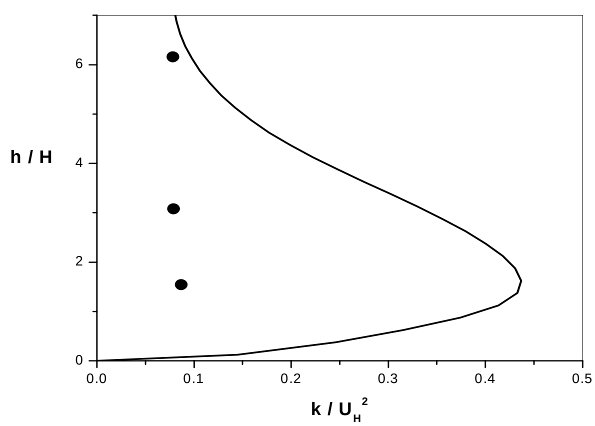

Fig. 3. Comparison of experimental and calculated values of k near the center of the array.

Experimental values were obtained from three sonic anemometers at heights of 4, 8 and 16 m. The plot in Fig. 2 shows a good agreement between measured and calculated values.

A comparison of measured and calculated values of turbulent kinetic energy (k) close to the center of the grid is given in the Fig. 3. Values of turbulent kinetic energy are obviously overestimated, especially at the two lower sonics. At h = 16 m (height of third sonic) the difference between measured and calculated values is smaller. This discrepancy could be a consequence of imprecise estimation of the turbulent kinetic energy profile at the entrance region. It is also known that standard k-ε model generates excessive levels of turbulence (Castro and Apsley 1997), which can be partly attributed to the excess k observed. Ongoing studies are aimed at improving the model predictions and understanding of flow physics.

5. Summary and conclusions

Field measurements of flow characteristics at the entrance and inside of an array of obstacles were presented. These results were compared with those predicted by a numerical model that implements conventional kinetic energy – dissipation closure scheme. Calculated mean wind speeds agree very well with experimental data while the calculated turbulent kinetic energy significantly differs from the measurements, especially at lower levels. This can be a consequence of the unavailability of turbulent kinetic energy profiles in the entrance region of the array. Modifications will be introduced to the model in order to obtain a more accurate estimation of turbulent kinetic energy.

6. Acknowledgement

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7. References

Baik, J.-J., Kim, J.-J. and Fernando, H.J.S., 2002: A CFD model for simulating urban flow and dispersion. *J. Appl. Meteor.* (to be submitted).

Castro I.P. and Apsley D.D, 1997: Flow and dispersion over topography: A comparison between numerical and laboratory data for two-dimensional flows. *Atmospheric Environment*, **31**, 839-850.

Hosker, R.P.,Jr., 1987: The effects of buildings on local dispersion. In: Modeling the Urban Boundary Layer, *Am. Meteor. Soc*., 95-159.

Hussain, T. and Lee, B.E., 1980: A wind tunnel study of the mean pressure forces acting on large groups of low rise buildings. *J. Wind Ind. Aerodyn*.,**6**, 207-225.

Kim, J.-J. and Baik, J.-J., 1999: A Numerical Study of Thermal Effects on Flow and Pollutant Dispersion in Urban Street Canyons. *J. Appl. Meteor*., **38**, 1249-1261.

MacDonald, R.W., Carter, S. and Slawson, P.R., 2000: Measurements of Mean Velocity and Turbulence Statistics in Simple Obstacle Arrays at 1:200 Scale. *Thermal Fluids Report*.