SIMULATION OF MUST EXPERIMENT USING RANS K-EPSILON MODEL: VALIDATION AGAINST WIND TUNNEL MEASUREMENTS AND ANALYSIS OF SPATIAL AVERAGE PROPERTIES

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INTRODUCTION

In the frame of the COST 732 Action of the European commission a simulation of the flow field over the MUST-wind tunnel configuration has been performed with a CFD-RANS model. The MUST (Mock Urban Setting Test) is an experiment carried out in the great basin desert (USA) to investigate dispersion over an array composed by 12 by 10 containers. This configuration was chosen to represent an urban environment. In order to have more controlled conditions, the geometry of the MUST field experiment was reproduced, in scale, in the wind tunnel of the University of Hamburg and the wind tunnel data were used to validate the model simulations. The turbulent flow was modeled by solving RANS equations using a k-epsilon model as turbulent closure. A detailed analysis of agreements and disagreements between wind tunnel and numerical data is made. In addition, the behavior of some spatial average properties such as dispersive stress or mean profiles inside the array is studied. The array is divided into several units (representative portion of the array) in order to analyze the spatial average properties inside each one. Such information can be very useful to develop parameterizations for models that need to run with a resolution which is too coarse to explicitly resolve buildings (not building resolving models).

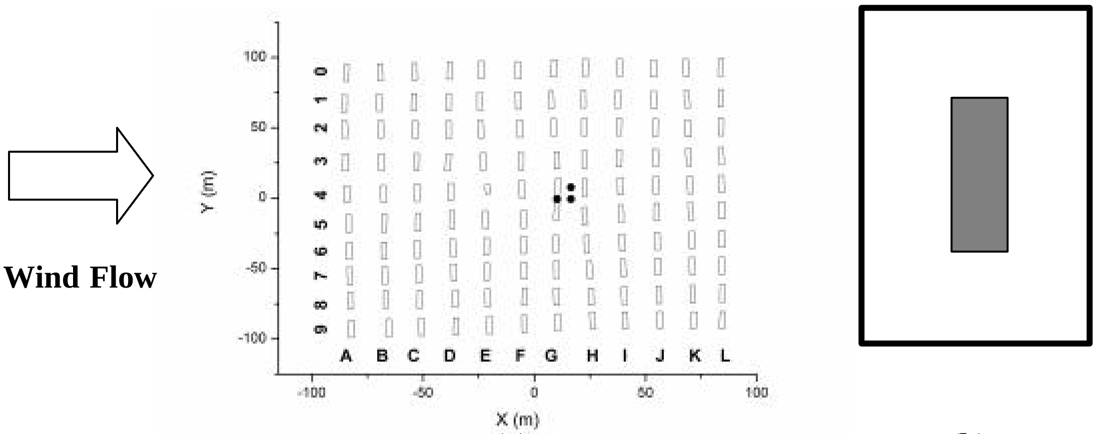
MUST DESCRIPTION

The array of the MUST field experiment is composed by 12 by 10 containers placed in an aligned configuration. The average obstacles separation is 12.9 m in the lengthwise direction and 7.9 m in the spanwise direction. Each container is 12.2 m long, 2.42 m wide and 2.54 m high, except the VIP container (H5) that was 6.1 m long, 2.44 m wide and 3.51 m height (Figure 1). In addition, the array is not perfectly square and alignment error occurred. Details are given in Biltoft C.A. (2001). The irregular geometry of the array is reproduced in the wind tunnel experiment.

MODEL DESCRIPTION AND CASE STUDIED

RANS simulations are performed using the CFD model FLUENT. The simulations are based on the steady state Reynolds Averaged Navier-Stokes (RANS) equations and the standard k-ε turbulence model. In the cases studied, the angle between the wind flow and the lengthwise direction of the array is 0º (Figure 1). Two different geometries are simulated (Figure 1): a) the total array with the same geometry as field and wind tunnel experiments; b) a simplified geometry formed by a representative unit cell of the array (one container and volume of air around it) with periodic boundary conditions in the streamwise direction and symmetry boundary conditions in the spanwise direction. This simplified geometry represents the central portion of an infinite regular array.

The ground is simulated by wall functions with a roughness of z_0 = 0.017 m and the containers surfaces by smooth walls. The top of the numerical domain is located at 6H, where H is the height of the VIP container for the total geometry and is the height of the container for the simplified geometry. Symmetric boundary conditions are assumed at the top. For the total array, at the lateral limits of the domain symmetric boundary conditions are also assumed. At the inflow boundary of the complex geometry case, wind tunnel measurements of velocity and turbulent kinetic energy are used. The ε profile (not measured) is calculated assuming that $e_{in} = C_m^{3/4} k_{in}^{3/2} / (kz)$, where k_{in} is turbulent kinetic energy inflow and κ is von Karman's constant (κ = 0.4). For the simplified geometry case, the flow is driven by a pressure gradient in the streamwise direction. An irregular mesh with $1.5 \cdot 10^6$ of hexahedral cells approximately is used for the complex geometry. The resolution of the grid close to each container is 4 cells in the streamwise direction, 10-15 cells in the spanwise direction and 10 cells in the vertical direction. Similar resolution is used in the simplified geometry (4 cells in the streamwise direction, 15 cells in the spanwise direction and 10 cells in vertical direction). In addition, a test concerning grid independence has been carried out using the simplified geometry and doubling the number of the grid points.



(a) (b)

Fig. 1; Top view of (a) MUST real configuration (b) simplified geometry.

COMPARISON AGAINST WIND TUNNEL DATA

Vertical profiles of velocity components are compared. The positions investigated in this work are shown in Figure 1a (black dots). The profiles a, b and c are located in the spanwise street canyon (between containers G5 and G4), in the intersection (between containers G5, G4, H5 and H4) and in the streamwise street canyon (between containers G4 and H4) respectively. Velocities are normalised by U_{refwt}. U_{refwt} is the inflow velocity at z = 7.29 m.

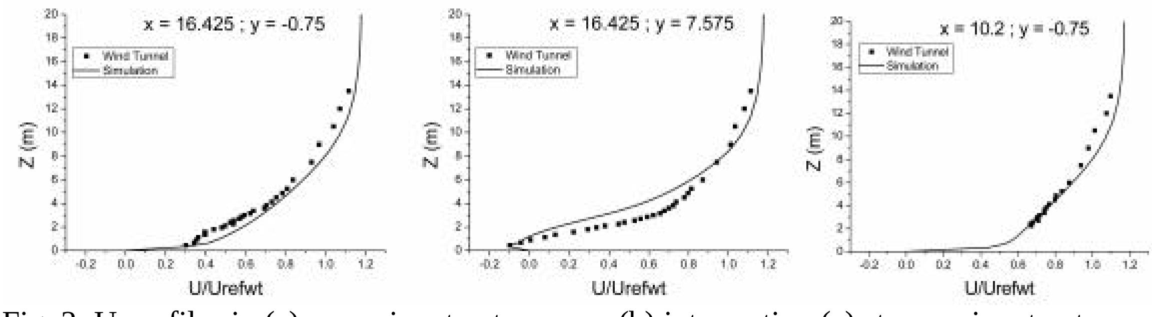


Fig. 2; U profiles in (a) spanwise street canyon, (b) intersection (c) streamwise street canyon.

More vertical profiles are analysed in similar position (not shown here). In general, an overestimation of the intensity of the vertical velocity is detected. Better predictions are found for U velocity. In addition, the worse performance of the simulation is observed in the first containers.

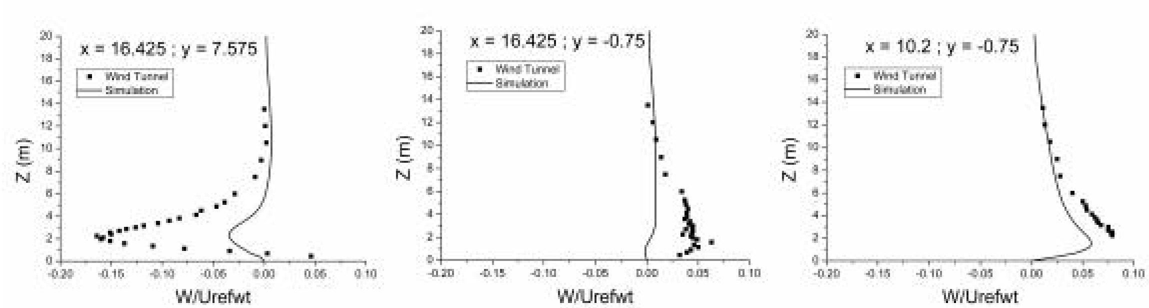


Fig.3; W profiles in (a) spanwise street canyon, (b) intersection (c) streamwise street canyon.

SPATIAL AVERAGE PROPERTIES

In atmospheric modelling over urban environment, it is impossible, for computational reasons, to have a domain large enough to contain the whole city and its surrounding areas and to have a resolution high enough to solve explicitly all the buildings of the city. For this reason, the accuracy of the urban parameterization used to account the effect of the buildings on the spatially averaged (over the grid cell volume of the mesoscale models) variables plays an important role in the modelling process. In this way, CFD models are important tools for this objective. They provide results with high enough spatial resolution to compute accurate values of the average variables (Martilli and Santiago, 2007). The spatial averages should be made over volumes that can be compared to a grid cell of a mesoscale model (usually of the order of few kilometres or several hundreds meters). In this case, the RANS model provides time-(or ensemble-) averaged values (indicated by an overbar) and the spatial averaged values can be seen as space averages of the time- (or ensemble-) averaged fields. The spatial average of a variable ψ can be defined as,

$$< y > = \frac{1}{V_{air}} \int_{Vair} y\,(\vec{x},t)\,d\vec{x} \qquad (1)$$

In this work, spatial averages are made over different portion of the MUST real configuration and over the periodic configuration. The periodic configuration represents a central unit (formed by a container and a canyon) of an infinite regular array. By comparing the two simulations, the influence of the irregularities of MUST array and the edges of the array on the spatial averaged variables can be analysed. The variables averaged are streamwise velocity (<U>), vertical velocity (<W>), turbulent kinetic energy (<TKE>), Reynolds stress ($<\overline{u'w'}>$) and dispersive stress ($<\tilde{u}\tilde{w}>$). The dispersive stress is related to the vortex formed in the street canyons and is defined as,

$$\tilde{u}\tilde{w}_{ij} = \left(<\overline{u}> - \overline{u}_{ij}\right)\left(<\overline{w}> - \overline{w}_{ij}\right) \qquad (2)$$

More details concerning dispersive stress can be found in Martilli and Santiago (2007). In order to compare the MUST array with the periodic simulations the velocities are normalised by U_{ref} and the turbulent kinetic energy and stresses by $U_{ref}^{\ 2}$, where U_{ref} is U at z = 4H (with H the height of the containers). Firstly, the spatial average values over all MUST array are computed and compared with periodic simulation (Figure 4). Small differences are observed for all the average variables, especially for <U>. The higher differences are for Reynolds stress inside the canopy (z/H < 1). This is due to the effect of the irregularities of the MUST array. The value of the dispersive stress can be neglected in comparison with the value of the Reynolds stress. In other cases with a flow regime of skimming flow (Martilli and Santiago, 2007) the dispersive stress takes values comparable with the Reynolds values inside the canopy. However, in this case the ratio between the separation of the containers and their heights is close to 5, away from the skimming flow, therefore the vortex structures inside the street canyon are not responsible for a high vertical transport. The next step is to divide the array in four portions and average the variables in each portion separately (Figure 5). In general, the results for array4_2 and array4_4 are closer to the average values for the periodic case, especially for vertical velocity. This fact indicates that the first upwind row of containers (array4_1 and array4_3) has a strong effect on average properties, even more important than the irregularities in some cases (for example, see Figure 5 for <W>).

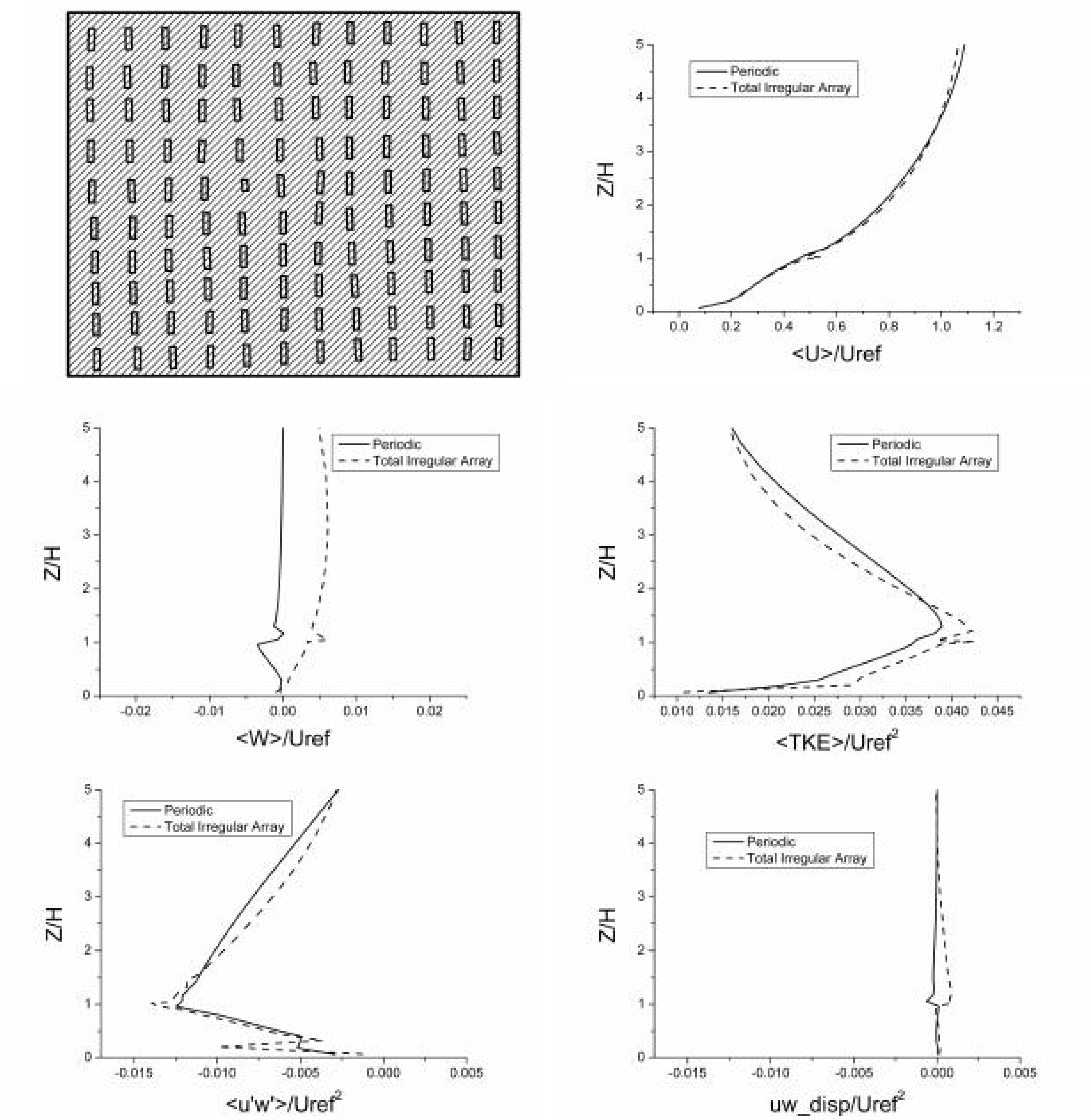


Fig.4; Spatial average variables for the periodic case and the total irregular array.

CONCLUSIONS

The flow over an irregular and an infinite regular array with the configuration of MUST experiment has been simulated. The comparison against wind tunnel measurements indicates a good estimation of U, but an underestimation of W. The average properties over different arrays have been analysed finding only small differences between the irregular and the periodic cases. In addition, a small value of the dispersive stress has been observed due to the large separation between containers in comparison with their heights.

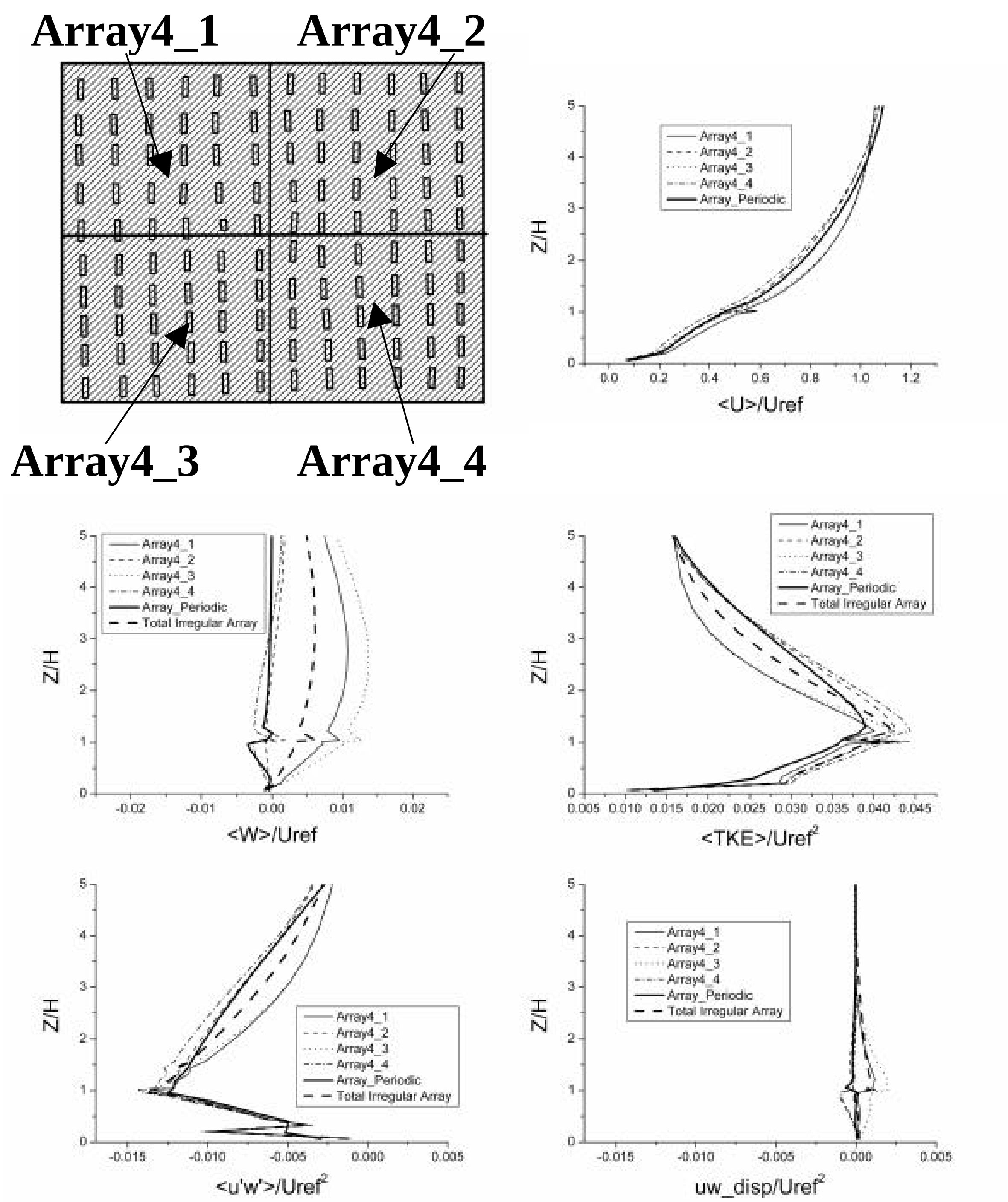


Fig.5; Spatial average variables for the periodic case and for 4 portions of the total array.

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