WIND TUNNEL MODELLING OF THE MUST EXPERIMENT

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INTRODUCTION

Dispersion of pollutants in urban areas is still one of the most challenging tasks in environmental sciences. Complex processes like the dispersion of car exhaust in street canyons or the dispersion of accidental releases of harmful substances in built-up areas are not yet fully understood. For a better understanding of the driving phenomena it is helpful to first study flow and dispersion within an idealized urban roughness. An example of a simplified roughness setup at full scale is the Mock Urban Setting Test – MUST, carried out at US Army‘s Dugway Proving Ground. In order to extend the field data set as well as to enhance the representativeness of the MUST data it was decided to carry out a complementing study in a boundary layer wind tunnel.

At the beginning of the extensive measurement campaign an atmospheric boundary layer flow at model scale was established. Then a specific set of field experiments was replicated in the wind tunnel. After the validation of the model setup by comparison with field results, systematic wind tunnel tests were carried out. Detailed flow and dispersion measurements were carried out especially (but not only) for -45° approach wind direction. The temporal and spatial resolution of the wind tunnel data was chosen to match as close as possible to the grid resolution of standard micro-scale numerical models, since the whole wind tunnel campaign was intended to provide a comprehensive data set for numerical models validation and evaluation exercise. This data set became The Test Case 1 under COST 732 action “Quality Assurance and Improvement of Micro-Scale Meteorological Models”. Only some exemplary results are shown in this paper, the detail wind tunnel experimental set-up and results discussion see *Bezpalcova* (2007).

FIELD CAMPAIGN

The field measurements were carried out in September 2001 at Horizontal Grid on the U.S. Army Dugway Proving Ground, located in the Great Basin Desert of north-western Utah. A site which should represent an idealised urban setting was created on the flat basin. A total of 120 obstacles were placed in a nearly aligned configuration consisting of 12 rows of 10 containers. Each obstacle was a rectangular container, with a width of 12.2 m, length of 2.42 m, and height of 2.54 m. The overall width and length of the obstacle array were 193 m and 171 m, respectively. Various 2D and 3D sonic anemometers and high-resolution concentration detectors were placed around, above, and throughout the array on various towers. Details of the instrumentations deployed and the experiments conducted in MUST are given in *Biltoft* (2001) and *Yee* (2004).

The test site and the surroundings were predominantly flat and homogeneously covered with a mixture of sparse greasewood and sagebrush during the experiment. The average momentum roughness length, z_0, and the displacement height, d_0, which were determined from mean wind profiles measured under near-neutral stratification (where the mean wind speed variation with height can be represented by a simplified semi-logarithmic relation) were approximately

0.045 m and 0.37 m, respectively. Both z_0 and d_0 were not dependent on wind direction (Yee, 2004).

Fig. 1; The MUST field campaign: containers and measurement towers.

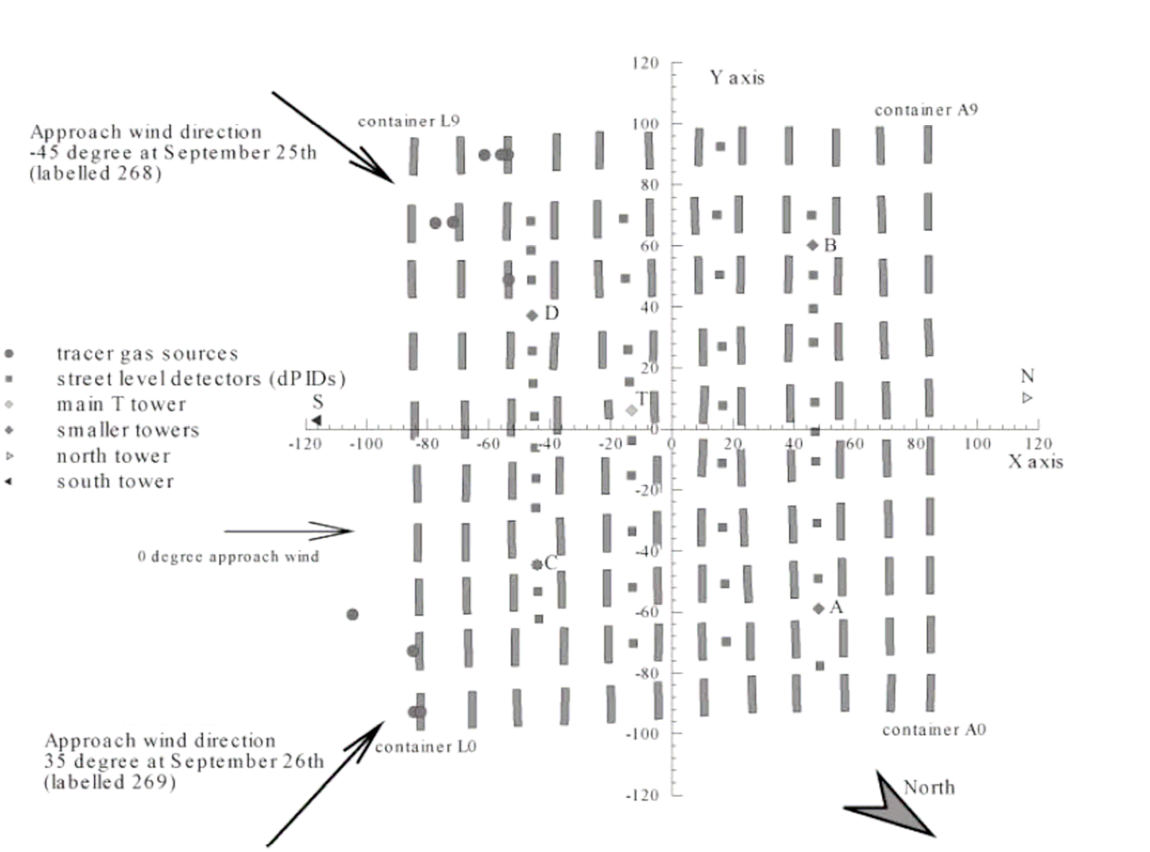

Fig. 2; The MUST field campaign: sketch of the experiment layout.

WIND TUNNEL EXPERIMENT

Model of the test site, including slight irregularities in the container placement in the field, was model in the large wind tunnel 'WOTAN' of Hamburg University in the scale 1:75. A boundary layer, which models in its lower part the mean and turbulent conditions in the field

Yee (2004) and tabled properties *VDI Guidelines* (1999), has been generated in the wind tunnel in the same scale of 1:75 as the model was built.

Detailed measurements of the flow properties (i.e. shear stress profiles, development of the flow within the canopy, dependency on different wind directions, etc.) were recorded using Laser Doppler Anemometry. The concentration measurement was conducted using Fast Flame Ionization Detector which provides a frequency response of about 100 Hz, therefore concentration fluctuation statistics.

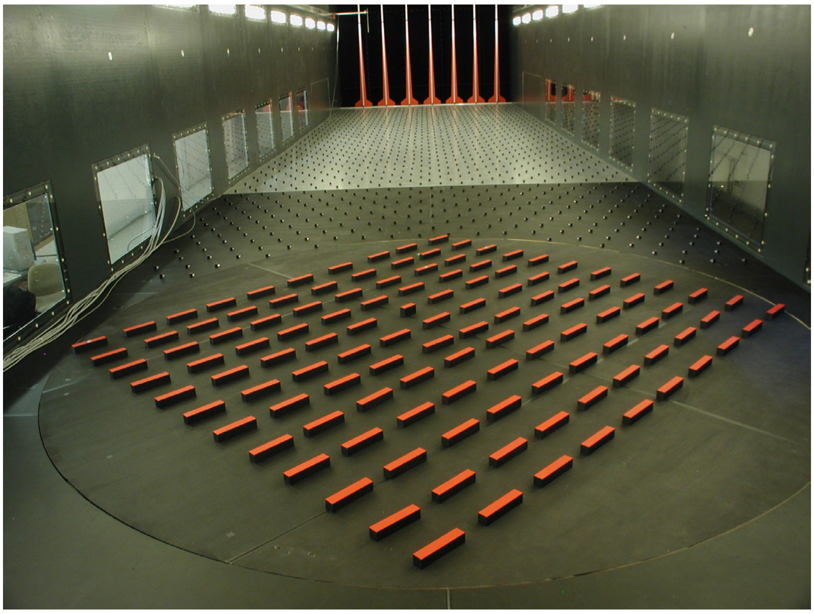

Fig. 3; The MUST wind tunnel model inside the large wind tunnel of Hamburg University.

FLOW FIELD

The wind tunnel measurements of the flow field inside the container array significantly extended the MUST field measurements and highlight the influence of the irregular array arrangement on the obtained results. The horizontal velocity measurement at the 2H (two container heights) level for various wind directions showed no effects of the container array on the flow direction and only minor effect on the wind speed. Inside the canopy the flow was guided by the containers. The street canyons oriented along the *x*-axis were approximately 1.5 wider than the street canyons oriented along the *y*-axis (12.9 and 7.9 m, respectively, see Fig. 2 for reference). These street canyons were also much longer since the container walls, which were creating these canyons, were 12.2 m long in contrast with 2.42 m of the walls in the street canyons oriented along the *y*-axis. Therefore the flow preferred the street canyons oriented along the *x*-axis (called the wide street canyons) and if the wind approached under an oblique angle, i.e. different from 0° and -90°, it adapted to the array geometry very quickly: below the shallow transition zone around the container height the velocity vectors were oriented parallel with the wide street canyons.

The comparison between the wind tunnel and MUST field data has been shown on the vertical profiles of the mean wind speed and vertical momentum flux at the position of the T tower (Fig. 4). The values of momentum fluxes agree very well, whereas the mean velocity profiles differ significantly inside and directly above the container array (the field values are about 1 m/s smaller at the 1, 4, and 8 m levels; the same values in the wind tunnel and field were measured at the 16 m level). The reason for this difference can be the MUST field atmospheric thermal stratification, which was E (slightly stable conditions) or F (moderately stable conditions) class according to the Pasquill's stability classes classification. A stable stratification of ABL is characterised by a suppressed mean wind speed and turbulence level in the Surface Layer. Since we observed only a suppressed mean wind speed, the turbulence level had to be increased by the mixing effects of the containers.

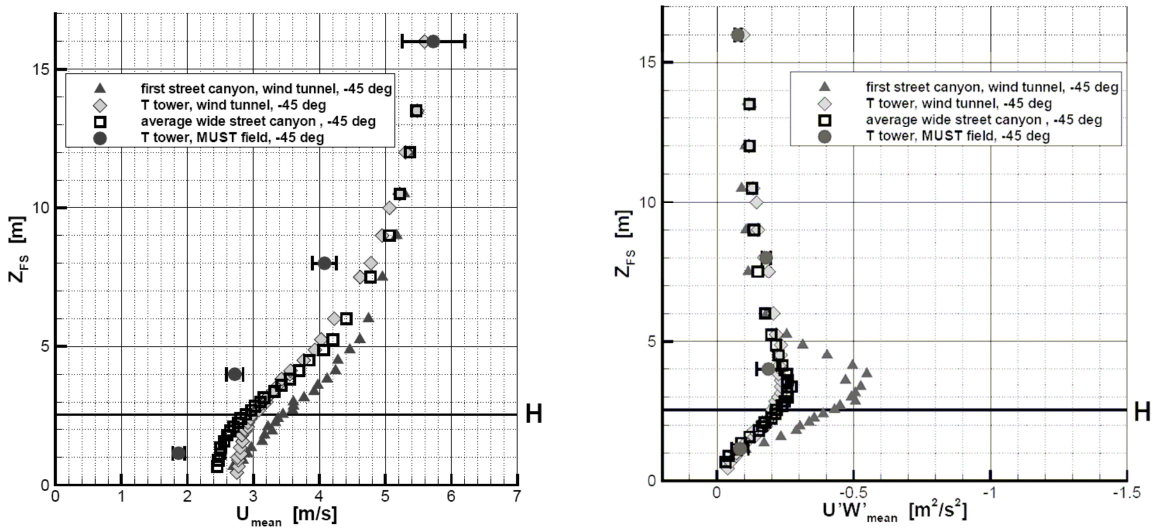

Fig. 4; The vertical profiles of the mean wind speed (left chart) and the vertical momentum flux (lower chart) for -45° approach wind direction.

CONCENTRATION MEASUREMENT

The mean concentration was calculated as a zero central moment of the dimensionless concentration time series calculated according to equation

$$c^* = \frac{c\,U_{ref}\;H^2}{Q},$$

Where c is the measured volume concentration, U_{ref} is the reference wind speed measured at 8 m level on the south tower (see Fig. 2), H=0.034 m is height of the containers in the model scale, and Q is the source strength. The approach wind direction, source, and detector positioning is depicted in Fig. 2, exact coordinates of the sources and detectors can be found in *Bezpalcova* (2007).

The comparison of the street level detected concentrations (measured at z=1.6 m = 0.63H) for the 2681849 campaign (see *Biltoft,* 2001) is shown in Fig. 5. The left chart shows the first and the second detector row, the left shows the third and the fourth row. The error bars in the figures are based on the ensemble standard deviations for the corresponding averaging time. The reason for greater error bars on the field values is the much shorter averaging time in the field than in the wind tunnel. It should be mentioned that the detector rows did not lie in a line perpendicular to the wind direction. Therefore the shapes of the mean concentration horizontal profiles created by detector lines are not symmetric and the position of the plume centreline tends towards the right hand side (in the fourth detector row the plume centreline is already out of the container array). The qualitative comparison of the MUST field data and the wind tunnel data is reasonable: the corresponding curves have the same shape - the maximum of the mean concentration was reached at the same position. The absolute wind tunnel values near the plume centreline was about two thirds of the field values, however, the plume edge values were in a very good agreement.

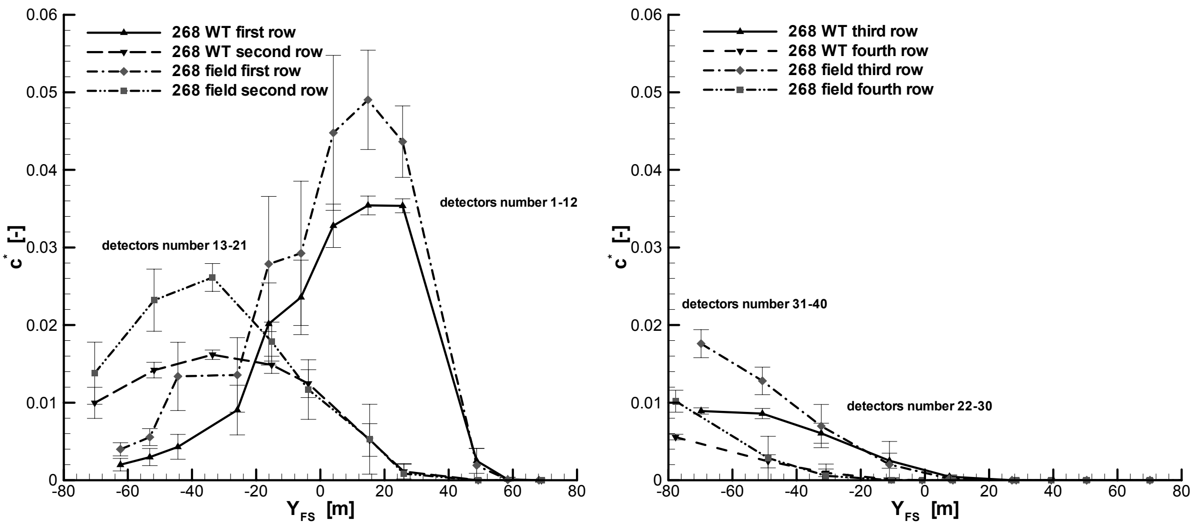

Fig. 5; Comparison of the MUST field (depicted by the squares and diamonds) and wind tunnel (depicted by the triangles) mean dimensionless concentration for the trial 2681849 (-41º wind direction and source no. 29). The first and second row of detectors (x=-50 and -10, respectively, see Fig. 2) is shown in the left chart, the third and fourth row of detectors (x=16 and 45, respectively) is shown in the right chart.

CONCLUSION

The wind tunnel measurement shows good agreement with the field observations, however some contrasts were found, too. The control environment during the wind tunnel campaigns provides the wind tunnel experimental data with the confidence limits.

The data are available for numerical model evaluation within the COST 732 action: "Quality Assurance and Improvement of Micro-Scale Meteorological Models".

REFERENCES

Bezpalcova, K. 2007: Physical Modelling of Flow and Diffusion in Urban Canopy, Ph.D. thesis, Faculty of Mathematics and Physics, Charles University in Prague, 193 pp.

Biltoft, C. A., 2001: Customer Report for Mock Urban Setting Test, DPG Document No. WDTCFR-01-121, West Desert Test Center, U.S. Army Dugway Proving Ground, Dugway, Utah, 58 pp.

VDI Guidelines 3783, part 12 (1999) Environmental Meteorology, Physical modelling of flow and dispersion processes in the atmospheric boundary layer, application of wind tunnels, Issue German/English, VDI Handbuch Reinhaltung Luft, Band 1b, Vorentwurf August 1999.

Yee, E. 2004: Concentration Fluctuation Measurements in a Plume Dispersing Through a Regular Array of Obstacles. *Boundary-Layer Meteorol.* **111**, 363–415.