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FLOW WITHIN IDEALISED URBAN CANOPY

K. Bezpalcová[1], F. Harms[2], B. Leitl[2], Z. Jaňour[1]

Summary: *The regular obstacle array of the Mock Urban Setting Test (MUST) field site in the Utah West Desert (USA) has been replicated in the large boundary layer wind tunnel at University of Hamburg. The trials run during the field campaign were repeated in the wind tunnel as well as additional measurements of flow. The strong flow inhomogeneities were observed on the vertical profiles of shear stress as well as on the horizontal mean flow for different array orientation.*

1. Introduction

The experiment Mock Urban Setting Test (MUST) was designed to be a near full-scale model of an idealized urban area imbedded in an Atmospheric Surface Layer (ASL), more realistic than wind tunnel experiments but idealized compared to real-life (described in detail in Bitoft, 2001). A wind tunnel model of MUST was then built at the Meteorological Institute at Hamburg University to prove and to extend existing turbulence and dispersion data sets. At a scale of 1:75 the mean flow and turbulence structure within regular obstacle array was simulated. The regular obstacle array of the MUST field site was replicated in the large boundary layer wind tunnel at Hamburg University.

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 set-up by comparison with field results, systematic wind tunnel tests were carried out. Detailed flow and dispersion measurements were carried out for different wind directions and source conditions. 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.

2. Experimental details

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. The test site and the surroundings were predominantly flat and homogeneously covered with a

[1] RNDr. Klára Bezpalcová, Doc. RNDr. Zbyněk Jaňour, DrSc.: Institute of Thermomechanics, Academy of Sciences of the Czech Republic, Dolejškova 5, Prague 8, 182 00, phone: +420.266 053 203, fax: +420.286 584 695; e-mail: bezpalcova@it.cas.cz
[2] Frank Harms, Dr. Bernd Leitl: Meteorological Institute, University of Hamburg, Bundesstrasse 55, 20146 Hamburg, Germany

Figure 1: The field experiment MUST.

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).

Each obstacle was a rectangular container, with a width (*W*) of 12.2 m, length (*L*) of 2.42 m, and height (*H*) of 2.54 m. A total of 120 obstacles was placed in a nearly aligned configuration consisting of 12 rows of 10 containers. 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 field campaign was repeated in the wind tunnel. A boundary layer in the scale of 1:75 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 big wind tunnel WOTAN of Hamburg University.

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 two-components Laser Doppler Anemometry system by Dantec®. The focal distance of the front lens was 500 mm. This set-up provided the measurement volume of dimensions 0.1 x 0.1 x 1 mm. Each point was measured for 180 s, with date rate equals 60 to 800 Hz.

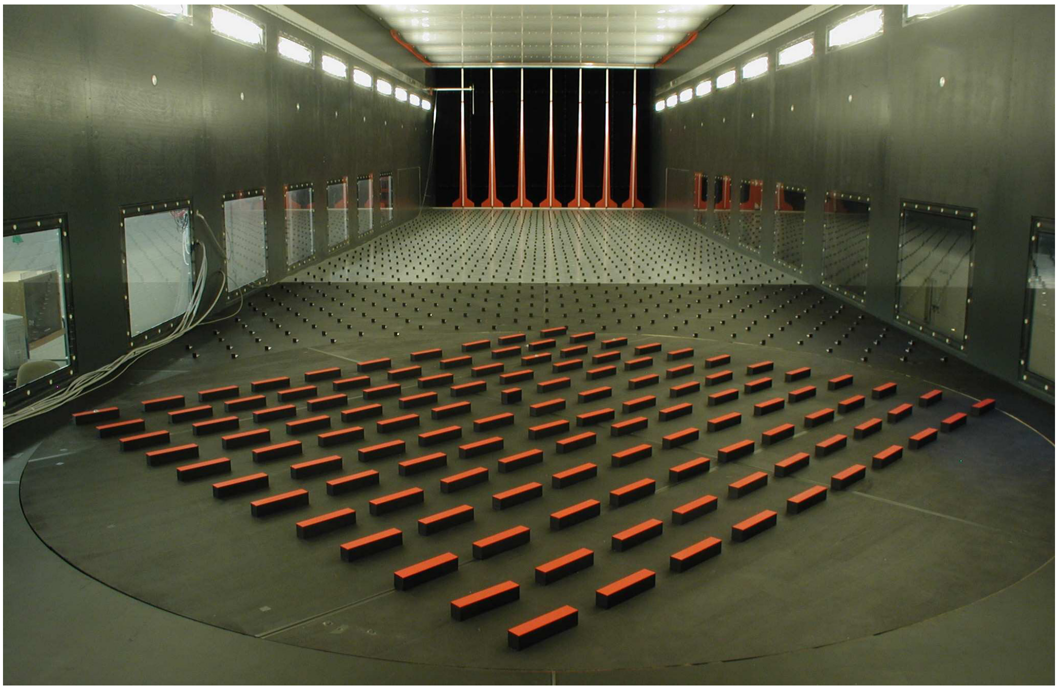

Figure 2: The model of the test site in the wind tunnel.

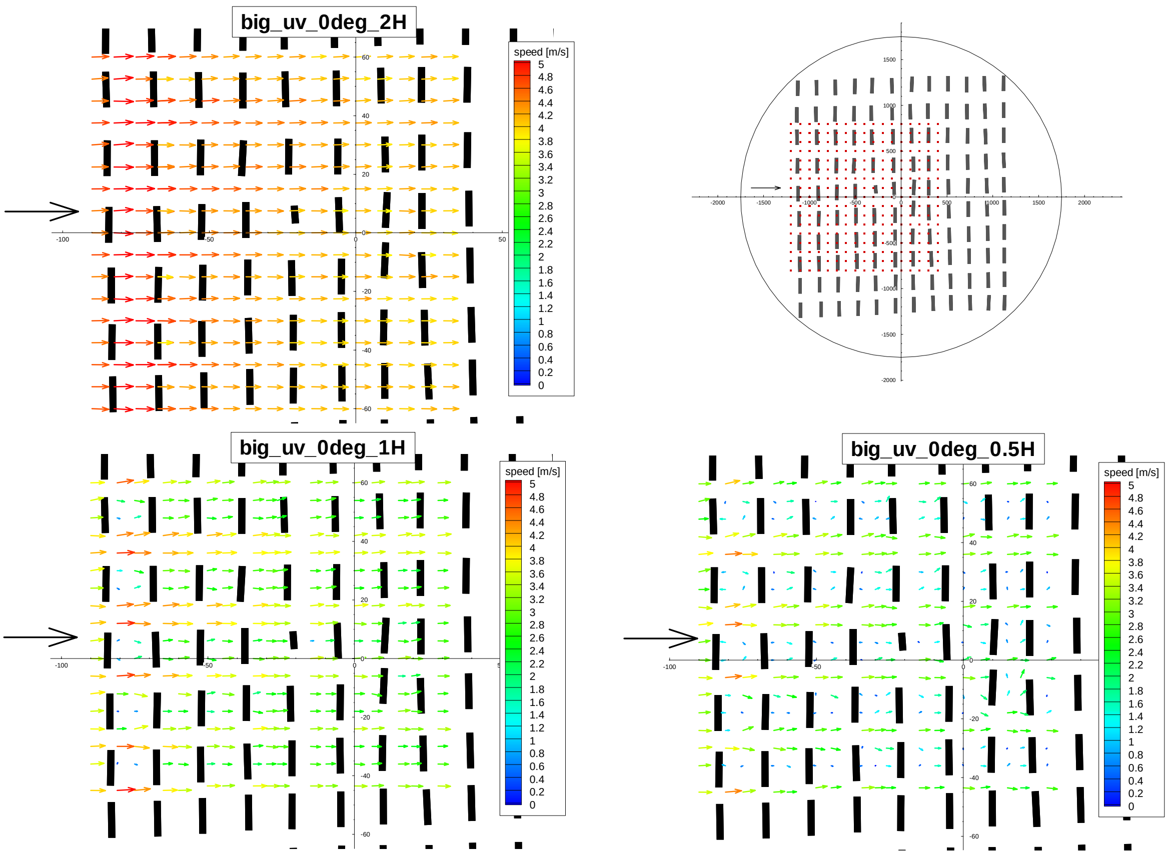

Figure 3: The flow field at three horizontal planes (at double container height 2H, at container height 1H, and at half of the container height 0.5H) with approaching wind direction 0°.

3. Results

The measurements were conducted by 2D Laser Doppler Anemometry and therefore only two-velocity component could be measured simultaneously. First part of measurement was focus on flow in vertical planes (*u* (the prevailing wind direction) and *v* (the normal component at horizontal plane) component were measured) for different wind direction. The results were obtained at three different heights and they are shown in Figures 3, 4, and 5.

The first set-up was impinging flow normal to the array (wind direction 0°, Fig. 3). The blockage effect of the first container row causes the acceleration of the flow at the beginning of the array at double container height. The individual containers were creating 'horseshoe' vortexes and this was the strongest effect visible in the lower levels (at container height 1*H*, and at half of the container height 0.5*H*).

The wind direction 0°, Fig. 4, was typical by the strong channelling of the flow. This is most evident at half container height, where the flow direction inside the field is parallel with the container orientation and not with the impinging flow. This effect is still clear at 1*H* and some inkling is also apparent at double container height.

The last array orientation, where the containers had the smallest aerodynamic resistance (wind direction 90°, Fig. 4), caused the strong flow channelling without shift of wind direction. The channelling and lack of resistance increase the wind speed at half container height approximately by factor of 2.

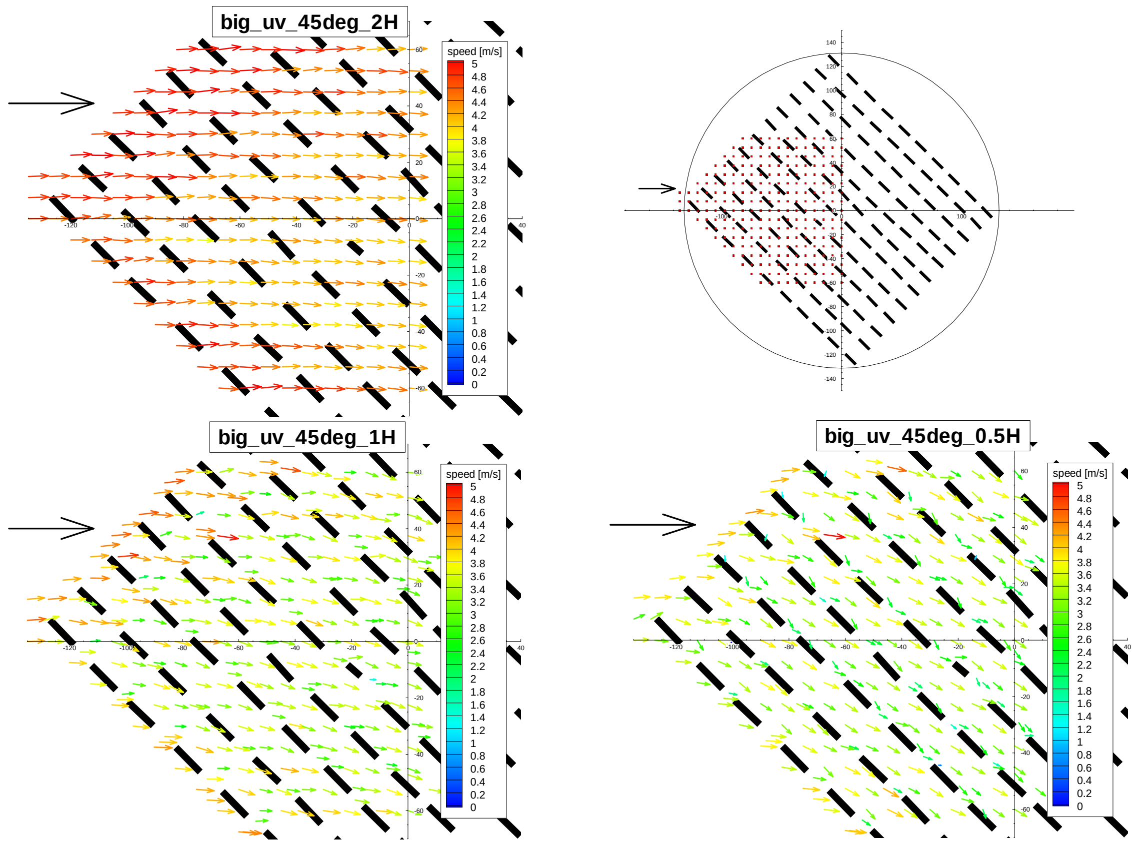

Figure 4: The flow field at three horizontal planes (at double container height 2*H*, at container height 1*H*, and at half of the container height 0.5*H*) with approaching wind direction 45°.

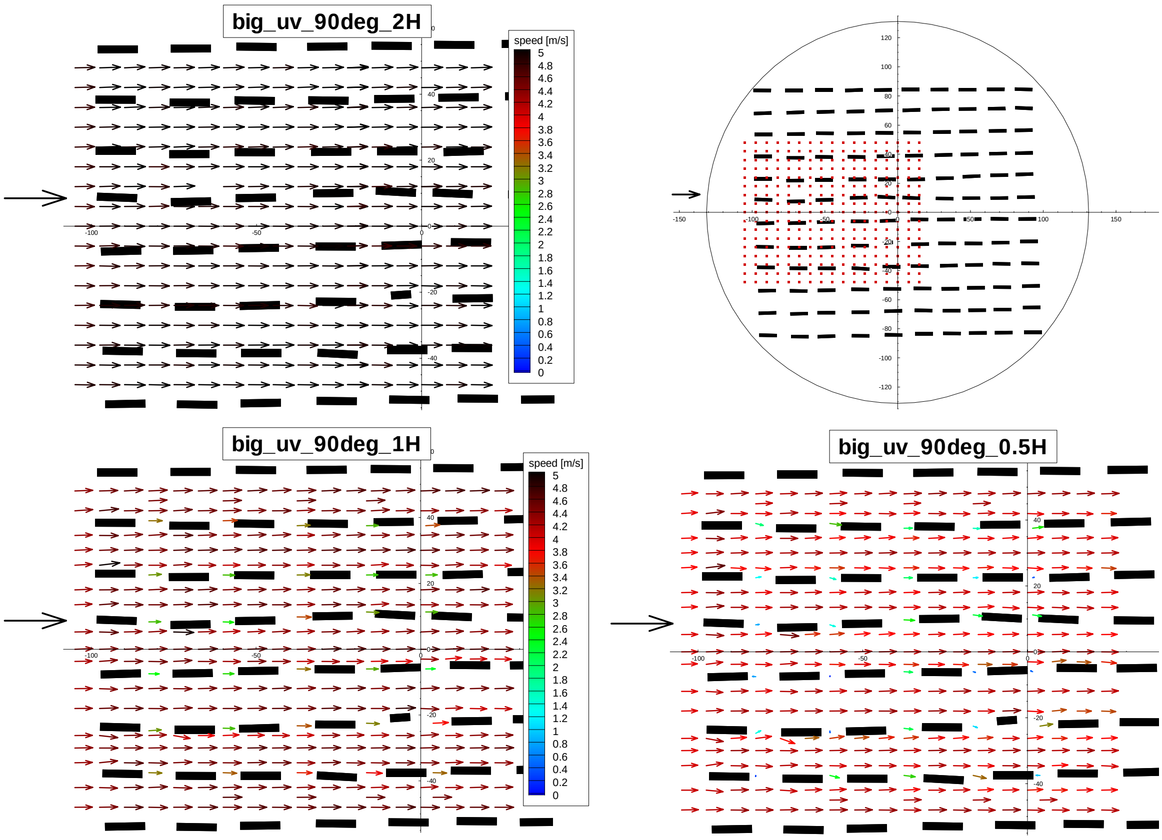

Figure 5: The flow field at three horizontal planes (at double container height 2*H*, at container height 1*H*, and at half of the container height 0.5*H*) with approaching wind direction 90°.

The second part was focus on vertical profiles of *u* and *w* (the vertical velocity component) and mainly on the Reynolds shear stress $\overline{u'w'}$, which is mean value of turbulent fluctuation product. The vertical velocities are strongly influenced by the thermal stratification of the atmospheric boundary layer. Therefore for comparison of field and wind tunnel result is important to model a proper stratification of the atmosphere.

Majority of the MUST field campaigns were carried out during the night and that together with the desert surrounding ensures mainly stable stratification at the test site. The others study (Nelson et al. 2004) used data obtaining during measurement in stable stratified ASL. Our intention is to model the test site in the wind tunnel with neutrally stratified ASL. Hence we have chosen only two days (25th and 26th September 2001, labelled 268 and 269, respectively) with relatively strong wind (between 7 and 11 m/s at elevation 32m) breaking stable stratification in the ASL. The highest mast within the test site stood approximately in the middle of the field (Fig. 6). The height was 32 m (12.6*H*) and five 3D sonic anemometers were located on it at different heights. Different colours are used for vertical profiles of normalised mean wind speed (Fig.7 left) and Reynolds shear stress (Fig.7 right). Averaging time for each profile was 200s. Blue and green colour is used for measurement carried out on the 25th September and the 26th September, where the wind direction varied from -40° to -

51°, from 28° to 45° respectively, in the respect to the field. Rough indication of wind directions for both days is depicted in Fig.6.

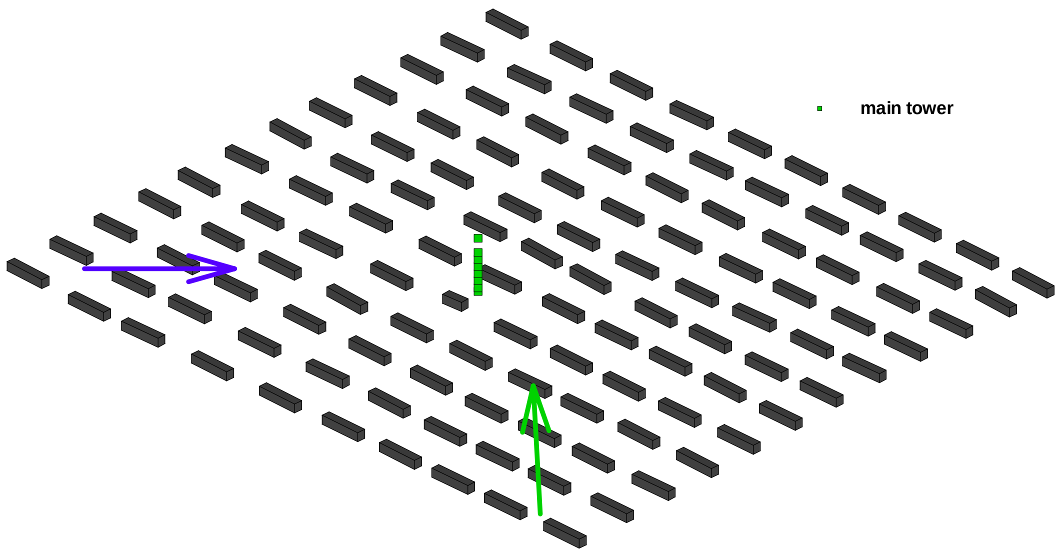

Figure 6: MUST field side, blue and green arrows show nominal wind directions for the approaching wind on the 25th September and the 26th September, respectively (not in the scale). Presented measurements were taken at the main tower at different elevations.

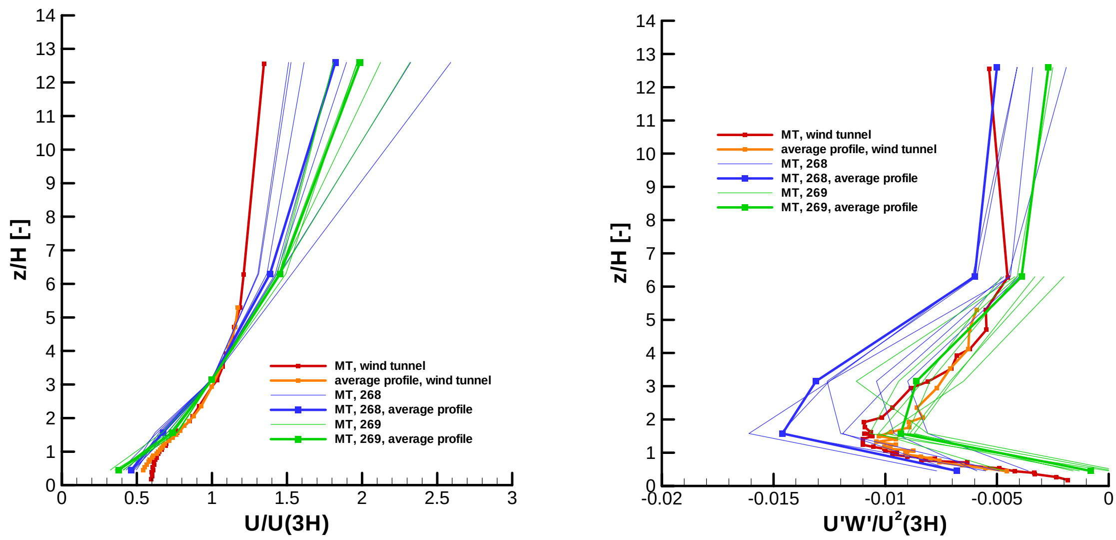

Figure 7: Vertical profile of normalized mean wind speed (left) and Reynolds shear stress (right) at main tower with wind direction 45°.

The wind tunnel modelling (red line) shows good agreement with the field observations, however some contrasts were found, too. The field measurements on the main tower in the middle of the array showed the maximum of Reynolds shear stress at about 1.6 of container height, which corresponds with another field observations (Rotach, 1993; Feigenwinter, 1999). The wind tunnel modelled data pointed out that the Reynolds shear stress maximum is not so evident (because of much more measurement points), better to say a region with

Reynolds shear stress maximum. The position of the maximum region were observed at approximately container height (average profile – orange line in Fig.7) except of the main tower (red line in Fig.7), where the flow was influenced by measurement device car, which was slightly higher than the containers (the height was app. 1.4 times higher).

4. Conclusion

The wind tunnel modelling can truly repeat the atmospheric boundary layer field campaign when carefully justify the modelling conditions. The wind tunnel can also provide much detailed and reliable data, and can detect the field measurement weaknesses.

5. Acknowledgement

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