SIMULATION OF FLOW IN AN IDEALISED CITY USING VARIOUS CFD CODES

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INTRODUCTION

Urban air pollution is getting one of the most important issues in environmental problems in cities. To determine the wind field and the concentration distribution in urban micro-scale areas (length scale up to 5 km) use of obstacle resolving methods are necessary. Traditional solution is the physical modelling in wind tunnels, but also numerical simulation (CFD) can be used for this purpose. Different requirements at the environmental regulatory side (e.g. large amount of modelled buildings, fast model preparation, limited simulation time and computer capacity) make simpler methods necessary, at the expense of more limited accuracy. The micrometeorological flow and dispersion models fulfils the mentioned requirements.

This paper is submitted for the special session of HARMO11. The COST Action 732 is addressed for the improvement and quality assurance of micro scale obstacle accommodating meteorological models and their application to the prediction of flow and transport processes in urban or industrial environment. Within the framework of this COST action an exercise is planned where several groups run models for verification the Best Practice Guideline. This guideline is focusing for CFD simulation of flows in the urban environment and prepared by the international community of CFD experts involved in this action. The data set concerns the MUST experiment, where dispersion experiments were conducted for an array of obstacles, 120 standard shipping containers, thus simulating an idealised city. A notable feature of the MUST data set is that the experiment was conducted as a full scale experiment in the real atmosphere (*Yee, E. and Biltoft, C.A.*, 2004), as well as in a wind tunnel (*Bezpalcova, K. and Harms, F.,* 2005). The pollutant transport research group at the Department of Fluid Mechanics of the Budapest University of Technology and Economics started simulations of flow within this idealised city using two commercial CFD codes. MISKAM and FLUENT are slightly different, the first one is a special code for simulating flow and dispersion processes in urban environment, while the FLUENT is a general commercial CFD code. This paper presents the first results of flow simulations in 0 degree MUST case, which means that the flow is perpendicular to the longer side of the containers.

USED NUMERICAL METHODS

As mentioned above two different CFD codes were used for flow simulation. MISKAM is a three-dimensional, non-hydrostatic flow and dispersion model for micro-scale prediction of wind and concentrations distribution in urban areas. The simulation of building influence and concentration of the flow is made possible by rectangular block structures. FLUENT is a widely used commercial CFD code with wide range of simulation parameters from various types of turbulence models to different types of practicable grids. These features allow large flexibility for the users of FLUENT.

Numerical set-up for FLUENT simulations

In case of FLUENT simulations version 6.3.26 was used with realizable k-ε turbulence model. The boundary layer close to the wall was handling with non-equilibrium wall functions; and second order upwind scheme was used for advective terms for all variables. The used grid was block structured with 1.5 million cells. The simulations run in full scale and wind tunnel scale (1:75) to decrease wall y+. The reference velocity was set 1 and 10 m/s in both scales.

Numerical set-up for MISKAM simulations

For the MISKAM runs version 5.01 under WinMiskam 2.01 was used with single precision mode with k-ε turbulence model (there is only one turbulence model in MISKAM with unchangeable constants). Three different Cartesian grid were used, the minimum cell size were 1, 0.8, 0.5 m accordingly. Hereby in case of the coarse grid both the position and the size of the containers had to be adapted. In case of two finer grids only the position had to be adapted due to the Cartesian grid. The reference velocity was 1 m/s in all cases. MISKAM uses first order upwind schemes for advective terms.

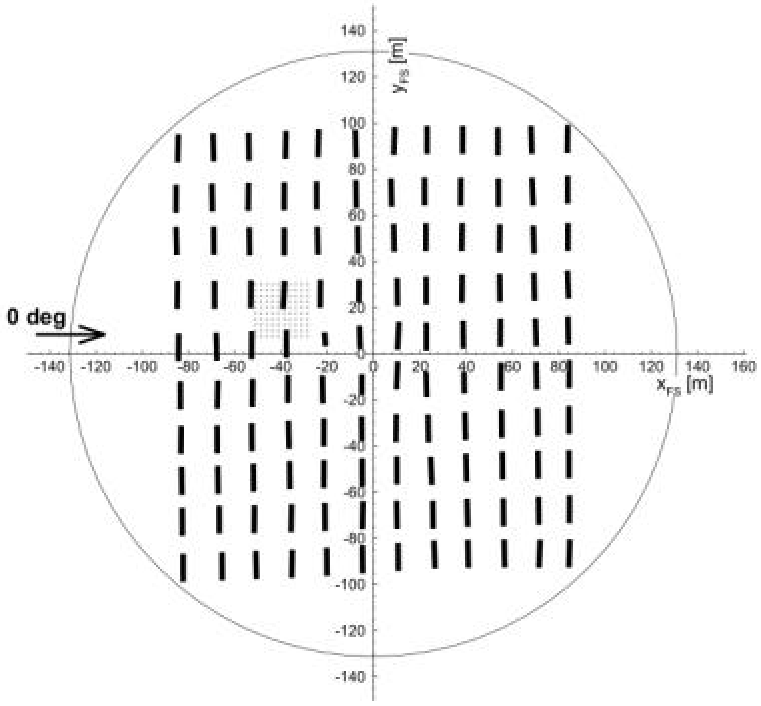

Fig. 1; Array of obstacles (MUST) and the fine measuring grid.

RESULTS

The results presented here through velocity profiles, contour plots and validation metrics. The place of velocity profiles and contour plots adjusted to the wind tunnel measurements, therefore the values are compared with values obtained by wind tunnel measurements.

Generally speaking that in case of dimensionless values there is no considerable effect of reference velocity. Beside the used resolution in case of full scale runs the wall y+ values are higher than the operating range of wall functions, so the scale was decreased to the wind tunnel scale. Therefore the wall y+ values comes to closer to the operating range, although it seems the full scale runs provide similar velocities obtained by wind tunnel measurements. The detection of the reason of this behaviour is the task of the following weeks. In comparison the velocity profiles for U and W component, the MISKAM runs provide better values downstream. In case of FLUENT simulations the upwind values are closer to the wind tunnel values.

The velocity obtained by MISKAM runs was validated against the wind tunnel experiments in three planes and nine profiles using BOOT software (*Chang, J.C. and Hanna, S.R.*, 2004). Only several of the calculated measures published here. The perfect model would have the correlation coefficient (R), and the fraction of predictions within the factor of two of observations (FAC2)=1.0, the fractional bias (FB), and the normalised mean square error (NMSE)=0.0. Generally speaking that in case of profiles there is no considerable effect of grid resolution on horizontal velocity components, and the values of collected validation metrics are close to the required values. Regarding the vertical components only the finest grid provides acceptable values in R and FAC2. This behaviour basically caused by the small value of vertical velocity component and in case of coarse grid the non-exact place of the containers. Besides sometimes the place of the profiles slightly differs from the wind tunnel positions due to the resolution. In horizontal planes considering the U component of the velocity the R tends towards the perfect value decreasing the heights, the behaviour of FAC2 is out of accordance. In case of FB and NMSE there is a characteristic decreasing (towards zero) with increasing height. Considering the V component it is hard to find any trend.

Table 1. Collected validation metrics calculated from MISKAM runs

	XY planes / XY points for profiles			MISKAM 1 m resolution				MISKAM 0.8 m resolution				MISKAM 0.5 m resolution			
Variables	**x (m)**	**y (m)**	**z (m)**	**FB**	**NMSE**	**R**	**FAC2**	**FB**	**NMSE**	**R**	**FAC2**	**FB**	**NMSE**	**R**	**FAC2**
U/Uref	—	---	1.275	0,275	0,170	0,945	0,634	0,127	0,120	0,951	0,725	0,200	0,130	0,945	0,706
	—	---	2.55	0,166	0,060	0,882	0,964	0,116	0,040	0,839	0,970	0,308	0,140	0,853	0,744
	—	---	5.1	-0,092	0,010	0,676	1,000	-0,066	0,010	0,634	1,000	0,140	0,030	0,762	1,000
V/Uref	—	---	1.275	2,020	-824,210	0,758	0,197	1,854	112,350	0,782	0,193	2,317	-62,240	0,757	0,207
	—	---	2.55	1,701	41,410	0,665	0,197	1,595	29,600	0,686	0,174	2,153	-99,950	0,642	0,167
	—	---	5.1	1,462	21,980	0,742	0,311	1,437	24,050	0,678	0,315	2,603	-44,290	0,448	0,197
U/Uref	-83.925	-7.575	---	-0,005	0,000	0,976	1,000	0,009	0,000	0,979	1,000	0,046	0,000	0,991	1,000
	-75.825	-7.576	---	0,012	0,010	0,991	1,000	0,030	0,010	0,993	1,000	0,046	0,000	0,996	1,000
	-75.826	2.85	---	-0,093	0,030	0,995	0,839	-0,157	0,040	0,992	0,903	0,076	0,010	0,999	0,935
	-21.3	-3.375	---	-0,127	0,020	0,980	1,000	-0,134	0,020	0,985	1,000	0,032	0,000	0,996	1,000
	-13.275	-3.376	---	-0,090	0,020	0,972	1,000	-0,107	0,020	0,972	1,000	0,042	0,000	0,998	1,000
	-13.276	6.075	---	0,295	0,200	0,991	0,467	0,315	0,180	0,984	0,467	0,431	0,230	0,970	0,433
	38.775	-1.125	---	-0,073	0,010	0,977	1,000	-0,109	0,010	0,986	1,000	0,121	0,020	0,997	1,000
	46.725	-1.126	---	-0,017	0,020	0,992	1,000	-0,066	0,010	0,992	1,000	0,151	0,020	0,991	1,000
	46.726	8.7	---	0,096	0,050	0,989	0,759	0,146	0,050	0,982	0,793	0,392	0,210	0,947	0,586
W/Uref	-83.925	-7.575	---	0,854	0,920	0,904	0,000	0,886	1,010	0,898	0,000	0,569	0,400	0,536	0,696
	-75.825	-7.576	---	1,238	2,550	0,285	0,000	1,233	2,500	0,467	0,000	0,447	0,230	0,762	0,871
	-75.826	2.85	---	2,423	-23,730	0,709	0,000	2,328	-29,280	0,790	0,000	3,027	-11,110	0,781	0,161
	-21.3	-3.375	---	1,545	7,710	0,330	0,000	1,838	28,120	0,055	0,000	1,769	20,850	-0,738	0,136
	-13.275	-3.376	---	1,342	3,740	-0,545	0,067	1,957	95,620	-0,299	0,000	1,508	6,770	-0,075	0,167
	-13.276	6.075	---	1,912	65,680	0,565	0,100	1,560	10,130	0,721	0,033	1,677	14,400	0,839	0,033
	38.775	-1.125	---	0,951	2,900	0,961	0,190	1,144	4,480	0,961	0,190	1,089	4,470	0,915	0,190
	46.725	-1.126	---	1,534	7,320	0,760	0,034	1,174	2,790	0,766	0,000	0,762	0,930	0,764	0,448
	46.726	8.7	---	1,187	2,970	0,937	0,000	1,306	4,020	0,969	0,034	1,344	4,420	0,922	0,034

Fig. 2 and 3 shows horizontal and vertical velocity profiles close to the downstream end of the array of obstacles. The full scale simulations (FS) provides closer horizontal velocity component values than the wind tunnel scale (WT), the grid resolution has considerable effect in case of MISKAM simulation, the coarse grid under-predict the measured values like the wind tunnel scale FLUENT simulations. The full scale FLUENT and the fine grid MISKAM runs slightly over-predict the wind tunnel data (see Fig. 2). Due to the small value of vertical velocity component it is hard to find any trend which is worthy of note. Close to the ground all the runs slightly under-predict, at higher over-predict the wind tunnel data, but this is not considerable.

In Fig. 4 the points and vectors shows the wind tunnel data, the contour and the stream-traces represents the MISKAM values at Z=0.9 m high (among the containers). In this case the fine grid means the fine resolution of velocity measurements in wind tunnel (see also Fig. 1.) At the high amount of measuring points the colour of points represented the wind tunnel data is the same or close to the background colour. This means that considering absolute value of velocity there is no influential differences between the measured and the simulated value. The vectors more or less, mainly more are parallel to the stream-traces, fore-spoken that beside the absolute values, the direction of simulated velocity vectors are correct.

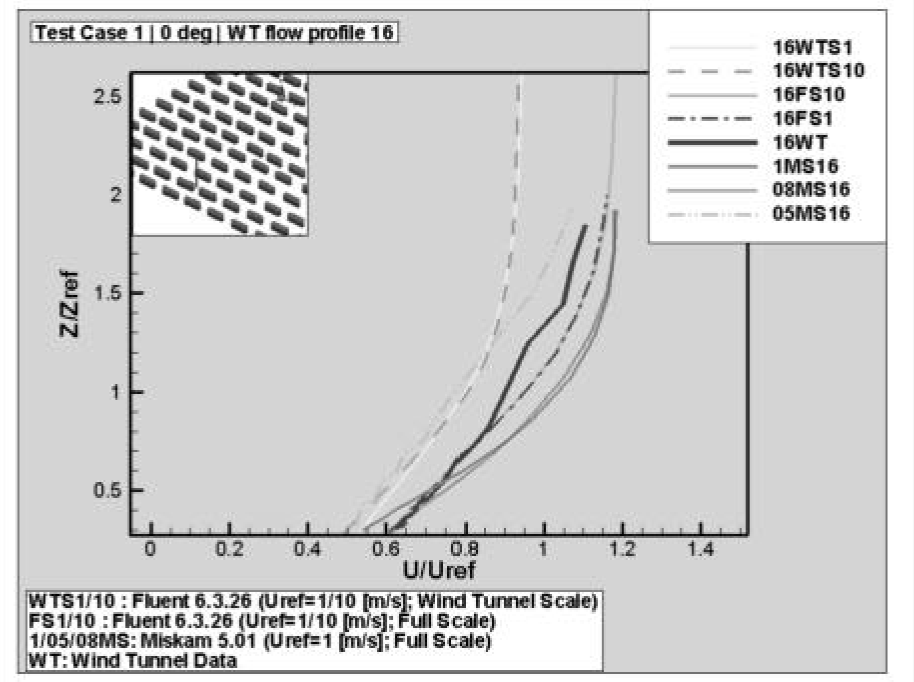

Fig. 2; Horizontal velocity profiles close to the downstream end of the array of obstacles

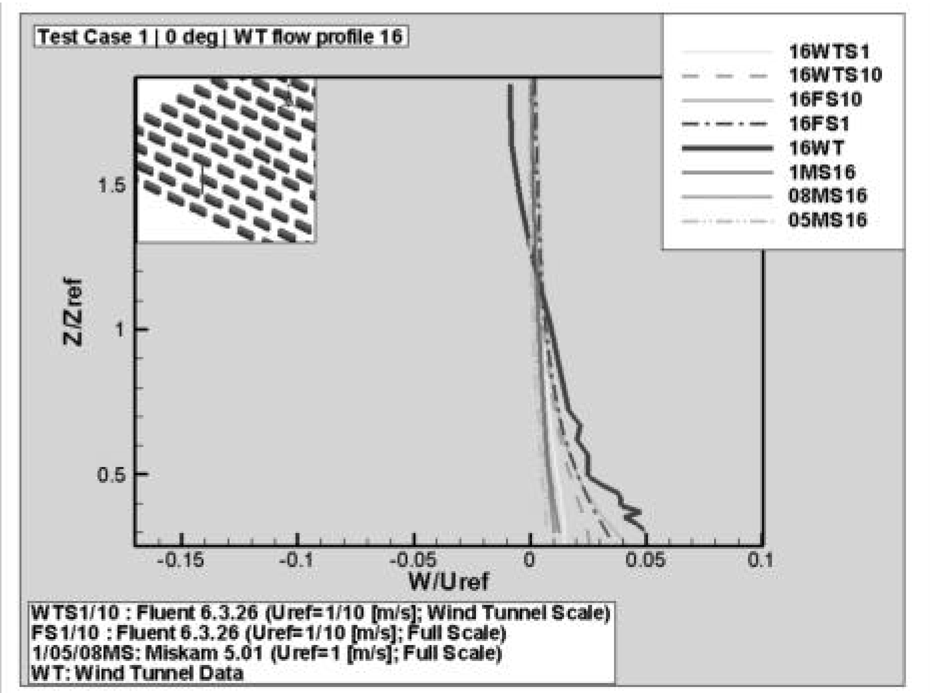

Fig. 3; Vertical velocity profiles close to the downstream end of the array of obstacles

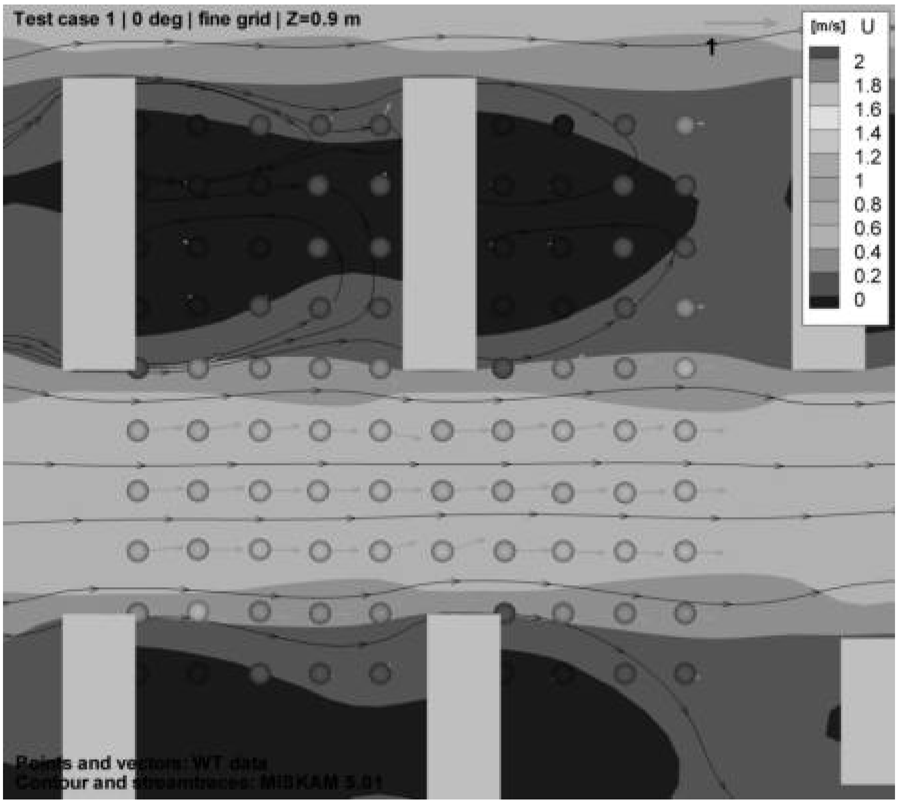

Fig. 4; Velocity in Z=0.9 m plane, comparison of wind tunnel and MISKAM data

SUMMARY

This paper presents several first results about the numerical simulations of flow in an idealised city (MUST experiment). Two kind of commercial CFD code were used, both has strengths and weakness, too. The started work will be continued in the framework of COST Action 732. Few, at least first sight, strange or not interpretable results needs further research in the field of quality assurance and improvement of micro-scale meteorological models, especially CFD codes which work could eventuate the adaptation of CFD codes to everyday use in this special field.

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