CFD Simulation of Flow over a Mock Urban Setting

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Extended abstract

The aim of the work is to provide data analysis about the use of OpenFOAM for modelling atmospheric flows, with the help of data obtained in the COST 732 framework (Quality Assurance and Improvement of Microscale Meteorological Models) over a mock urban setting [1]. The investigations were carried out with OpenFOAM, compared to wind tunnel, Fluent and MISKAM data, and showed that OpenFOAM can be a suitable tool for atmospheric flow modelling. The work is relevant for the OpenFOAM community because it deals with environmental problems, with which CFD and OpenFOAM might be a good tool to deal. As I can see from the forum it is an interesting topic for several users. It also validates OpenFOAM data with wind tunnel measurements, with the help of statistical analysis recommended by the COST 732 framework, thus helps to make the code accepted.

COST is an intergovernmental European framework for international cooperation between nationally funded research activities. The COST Action 732 (Quality Assurance and Improvement of Microscale Meteorological Models) program was carried out to perform proper quality assurance method for microscale meteorological models which can model urban pollution dispersion and therefore are used in environmental impact studies and decisions with economic and political consequences. In this framework several CFD codes were evaluated, e.g. Fluent, CFX, MISKAM, Star-CD. The first step of the simulations was to determine the wind field above a mock urban setting which consists of 120 containers as obstacles. The arrangement has been investigated in a boundary layer wind tunnel by Leitl et al [2]

The modelled geometry can be seen in Figure 1. The flow enters the domain from the inlet side, perpendicular to the containers longer length. The containers are in ordered rows and columns, representing street canyons, thus the behaviour of the flow in an urban environment can be observed. The outlet of the domain is on the opposite side of the inlet. The computational grid used for the OpenFOAM simulations was taken from the Fluent simulations to provide identical environment for comparison. In the wind tunnel measurements 21 reference profiles were measured (Figure 2). The 21 reference profiles are located in the street canyons and behind the buildings, so the fairly undisturbed flow and the wake behind the buildings can also be investigated.

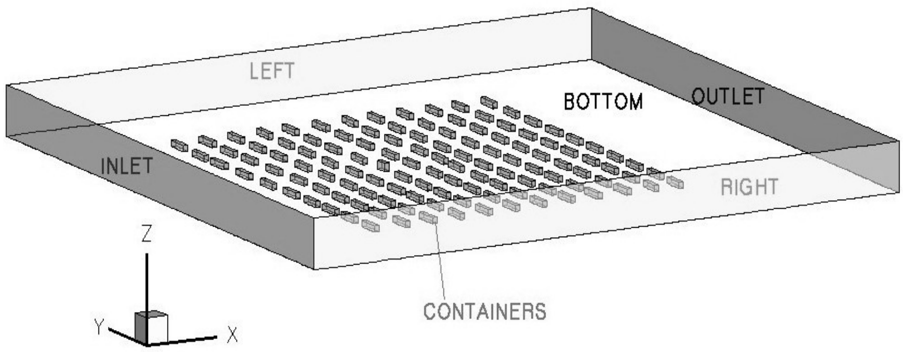

Figure 1: Modelled geometry

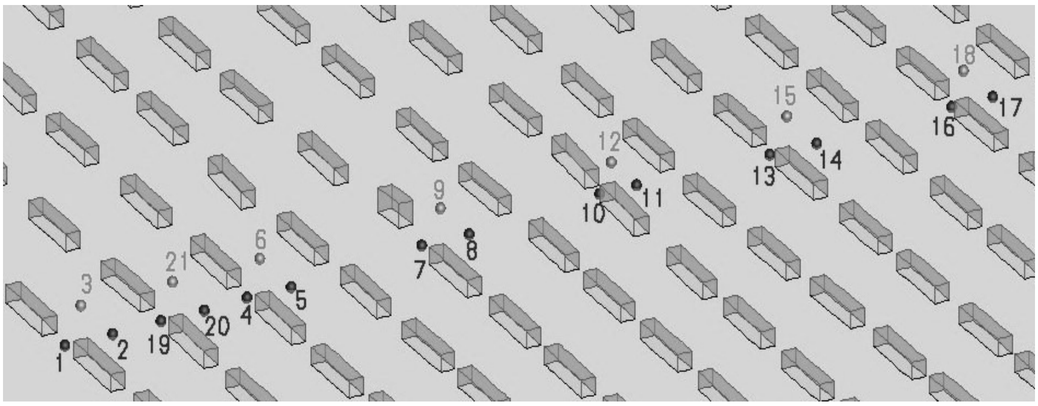

Figure 2: Velocity profile measurement points

The boundary conditions were set to symmetry on the left, right and top of the domain. The bottom of the domain and the wall of the containers were modelled using nutRoughWallFunction, with a roughness height of 0.017 m and roughness constant 0.5. The runs were also carried out with simple nutWallFunction without rougness as a reference. The outlet was set to uniform fixed value, 0 in case of the pressure and zeroGradient in case of the velocity. The inlet boundary condition was defined by a power law profile for the velocity, while epsilon and k profiles were set to values defined by the measured wind tunnel profile to provide correspondance.

SimpleFoam solver was used with three turbulence models: k-epsilon, realizable k-epsilon and k-omega SST, but proper convergence was reached only in case of the k-epsilon models. The k-omega results are dealt with only to see how ”bad” results behave during the evaluation. The results are also compared to MISKAM and Fluent results. The Fluent runs were carried out with realizable k-epsilon model and roughness wall treatment, on the same grid and with the same inlet profiles. In MISKAM model several boundary conditions are treated differently [3]. The inlet profile is set by defining roughness height and reference velocity at a reference height and it sets a logarithmic profile in the beginning of the simulation in a 1D case of identical horizontal grid spacing. Wall roughness is only defined by the roughness height; no roughness type is taken into account. MISKAM uses strictly Cartesian grid, and the *k-ε* turbulence model modified by Kato and Launder [4].

The results will be first evaluated by comparing the u and w velocity component profiles, one in the street canyon and one in the wake of the buildings (Figure 3-6, label explanation in Table 1)). Data is processed in Tecplot 360 using the foamToTecplot360 utility.

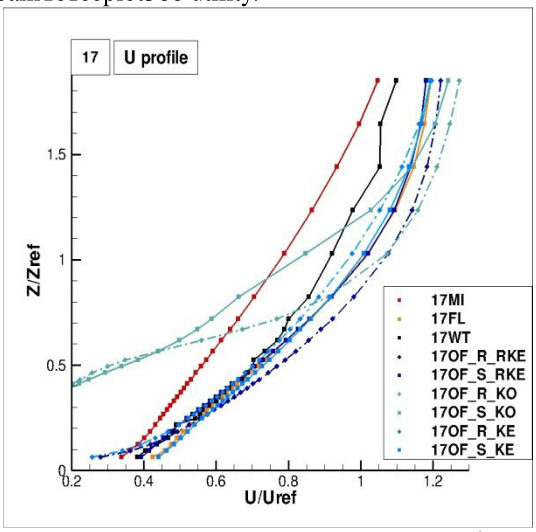

Figure 3: Velocity profile of u component at 17th profile

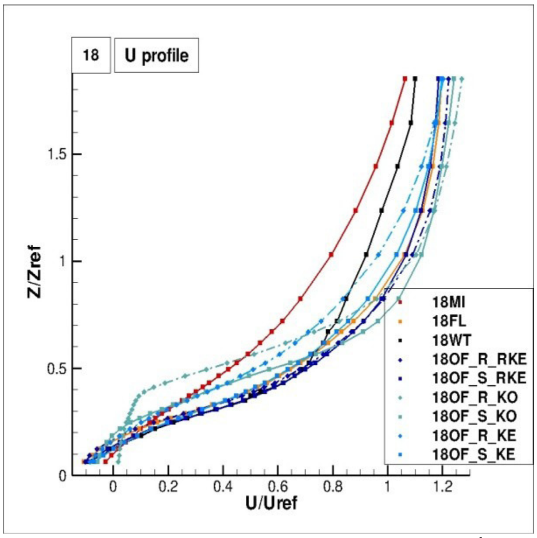

Figure 4: Velocity profile of u component at 18th profile

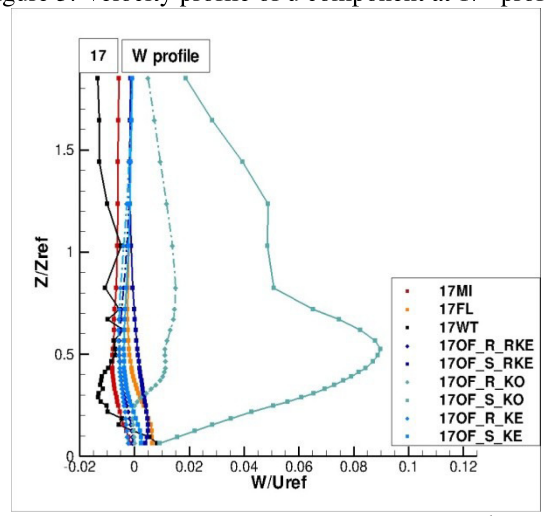

Figure 5: Velocity profile of w component at 17th profile

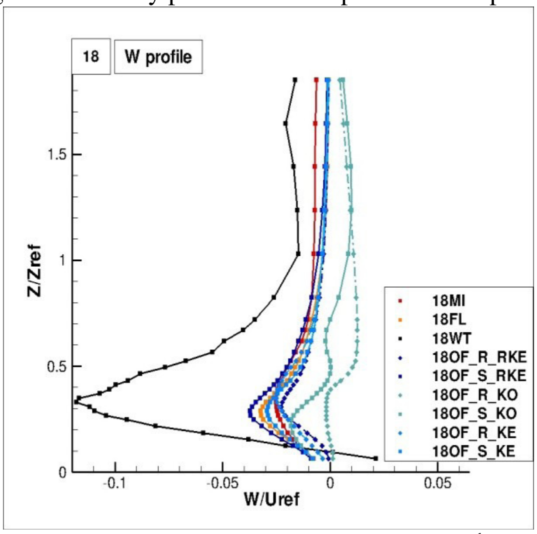

Figure 6: Velocity profile of w component at 18th profile

MI	MISKAM simulation
WT	Wind tunnel measurements
FL	Fluent simulation
OF_R_RKE	OpenFOAM realizable k- ε simulation with rough wall
OF_S_RKE	OpenFOAM realizable k- ε simulation with standard wall
OF_R_KO	OpenFOAM k- ω simulation with rough wall
OF_S_KO	OpenFOAM k- ω simulation with standard wall
OF_R_KE	OpenFOAM k- ε simulation with rough wall
OF_S_KE	OpenFOAM k- ε simulation with standard wall

Table 1: Test cases

Statistical validation of data will be carried out by the recommendations of Chang, Hanna [5], who suggest a method for atmospheric dispersion problems accepted by the COST 732 framework. Visual evaluation of data is achieved by plotting the simulation results against the observations, in our case the wind tunnel measurements; this plot is the scatter plot (Figure 7).

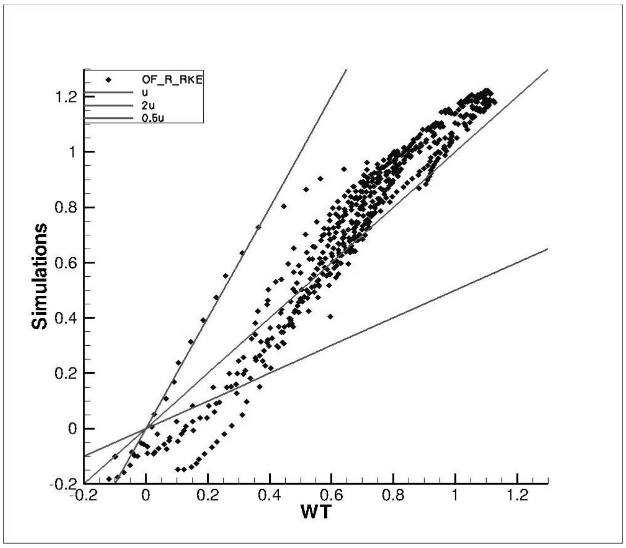

Figure 7: Scatter plot of the realizable k-epsilon data against the wind-tunnel results, u velocity component

The performance measures recommended by Chang and Hanna are fractional bias (*FB*), normalised mean square error, (*NMSE*), correlation coefficient (*CORR*) and fraction of predictions within a factor of two of observations (*FAC2*), they are presented in Table 2 for *u* components. Hit rate data are included, in which case a hit means when simulation data are in a given absolute and relative deviation of observations. Absolute deviation was chosen 0.05 m/s , relative was 0.3.

u	***Hit rate***	***FB***	***NMSE***	***CORR***	***FA2***
WT	1.00	0.000	0.00	1.000	1.000
FL	0.80	-0.088	0.03	0.957	0.922
OF_R_RKE	0.85	-0.083	0.03	0.968	0.910
OF_S_RKE	0.81	-0.093	0.04	0.951	0.926
OF_R_KO	0.69	0.018	0.07	0.906	0.793
OF_S_KO	0.67	0.009	0.10	0.855	0.800
OF_R_KE	0.81	0.019	0.03	0.967	0.876
OF_S_KE	0.81	-0.092	0.03	0.950	0.936
MI	0.78	0.133	0.04	0.944	0.871

Table 2: Statistical measures of the profile comparison for u velocity component

Pollutant dispersion studies were also carried out in the COST 732 framework, on the same geometry, but in a 45 degree flow case. The computational domain can be seen in Figure 8.

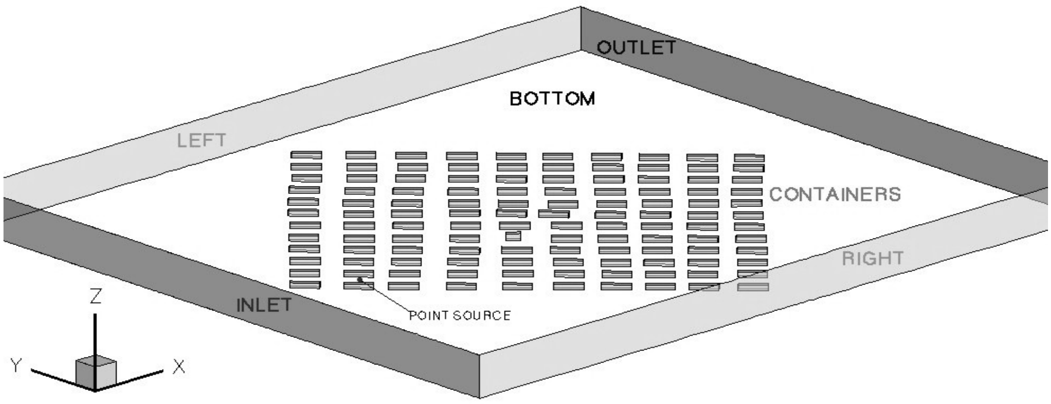

Figure 8: Computational domain in the 45 degree case

The same evaluation process will be carried out on this geometry, including turbulent dispersion based on the scalarTransportFoam solver modified for turbulent transport. The solver modification have already been carried out by adding turbulent viscosity to the transport equation. Defining a point source in the original mesh is the next step to be able to model pollutant dispersion. The original 0 degree geometry will be further investigated with boundary conditions better fitting for the atmospheric conditions from the damBreak tutorial; and for the k-omega SST turbulence model from the motorBike tutorial.

As a conclusion we can say that the simulations carried out with OpenFOAM are in good agreement with the wind tunnel measurements and the other RANS CFD models investigated in the COST 732 program. The horizontal velocity prediction performance of the model should be improved. The investigation shows that OpenFOAM can be used for the purposes aimed in the COST 732 framework.

Key words: Urban ventilation, COST 732, validation metrics

References

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