Comparison of CFD Results with Experimental Data within a Street Canyon: The Influence of Averaging Time

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Abstract

One of the typical characteristics of turbulent flows is their irregular change in position and time. There are several techniques for studying turbulence phenomena in the urban roughness layer. One method focussing on velocity profiles uses the Reynolds decomposition, which splits the flow into a mean and a fluctuating velocity part. The latter is aggregated in the turbulent kinetic energy (TKE) and can be understood as an index for the strength of the turbulence. due to the dependency of turbulence on both position and time, a temporal averaging is needed to decompose point measurement data. When applying averaging methods to a data set, the length over which the averaging occurs must be defined.

The Reynolds Averaged Navier-Stokes turbulence models (RANS) are often used in urban CFD computations. Both turbulent-viscosity models and Reynolds-stress models are based on the Reynolds Decomposition. Due to the mathematical formulation of the model equations and the nature of the numerical discretization, the results are temporally and spatially averaged fields. This is true for computations that are either steady-state or transient with constant boundary conditions.

In order to be able to compare urban CFD results with experimental field data, an appropriate temporal averaging has to be defined. By a successive analysis of Sonic data from the Basel Urban Boundary Layer Experiment (BUBBLE), a dependency between the time averaging constant and the turbulent kinetic energy magnitude within a street canyon has been found. The poster will show the effects of different temporal averaging lengths on experimental values and their comparison with different spatial resolutions of a three dimensional computational representation of a street canyon within a city block of Basel, Switzerland.

Measurements

During the "Basel Urban Boundary Layer Experiment" (BUBBLE) project a large data set of wind data was collected [1]. One measurement tower with six measurement levels was located in the "Sperrstrasse", a street canyon in Basel, Switzerland (Figure 1). The topology of the surrounding surfaces is of a typical European urban city structure. The tower was located 3m next a north-facing building wall. The instrumentation includes six ultrasonic anemometer-thermometers with a temporal resolution of 20 Hz.

Using 10 min averaged data, the dominating wind directions during the time period 01.11.2001 to 15.07.2002 were analyzed and three situations selected to specify the boundary conditions for the numerical "Computational Fluid Dynamic" (CFD) computations: 130°, 270° and 355°.

Numerical Domain Specifications and Meshes

The geometry was adapted from a high-resolution "Computed Aided Design" (CAD) model. A domain with a spatial extent of 600x400x100m was used to create the numerical meshes. Different mesh types were created and compared with each other to identify the most appropriate mesh specifications. For the presented study, a tetrahedral mesh with at least three prism layers near walls showed the best results. The poster will present the influence of the different mesh resolutions and the geometry in detail. Figure 1 shows part of the geometry with surface grid elements of one of the finer grids. In addition, the measurement tower within the street canyon and the 130° degree inflow condition is illustrated.

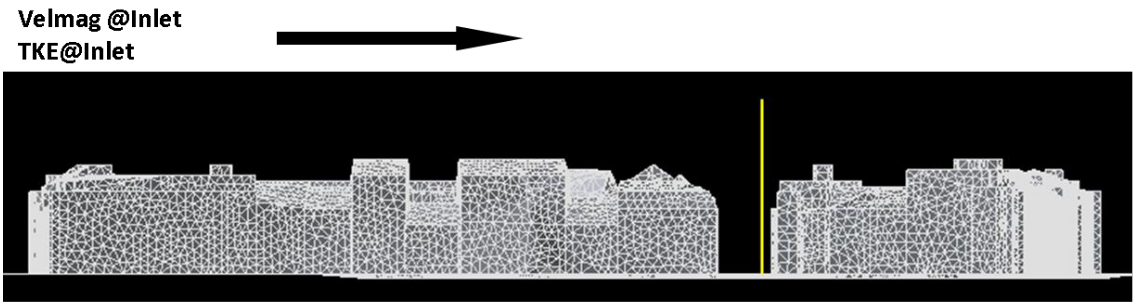

Figure 1 Cross section through the 3 dimensional mesh, Sperrstrasse, Basel. The line indicates the measurement tower and the arrow the 130° inflow condition

Boundary Conditions and Models

All CFD runs were 3D, steady-state calculations and set up with the assumption of thermally neutral stability conditions, which is appropriate for numerical simulations in urban boundary layers [4]. All computations used the "Reynolds Averaged Navier-Stokes Equation" (RANS) and different turbulence models, such as the standard and modified k-epsilon-model, as well as the "SSG Reynolds Stress Model" were tested. For this study only calculations with the standard k-epsilon and the SSG models will be presented. The computations were solved with ANSYS CFX 11.1.

From the analysis of the 10 min averaged values for each of the three inflow conditions, 130°, 270° and 355°, different velocity magnitudes were used. The velocity magnitudes varied from approximately 0.5 m/s up to 3.5 m/s in order to represent different wind situations. For the mean velocity boundary conditions, the corresponding values from the highest level of the measurement tower were used. To specify the turbulence intensity at the inflow boundary conditions, two different approaches were applied: 1) using the intensity values from the 10 minute averaged measurement values at the highest level, 2) dependent on the mean velocity at the inlet boundary using an intensity of 5%. A logarithmic inlet profile for the mean velocity and turbulent kinetic energy was applied to the inflow boundary, as suggested by [2] and [3].

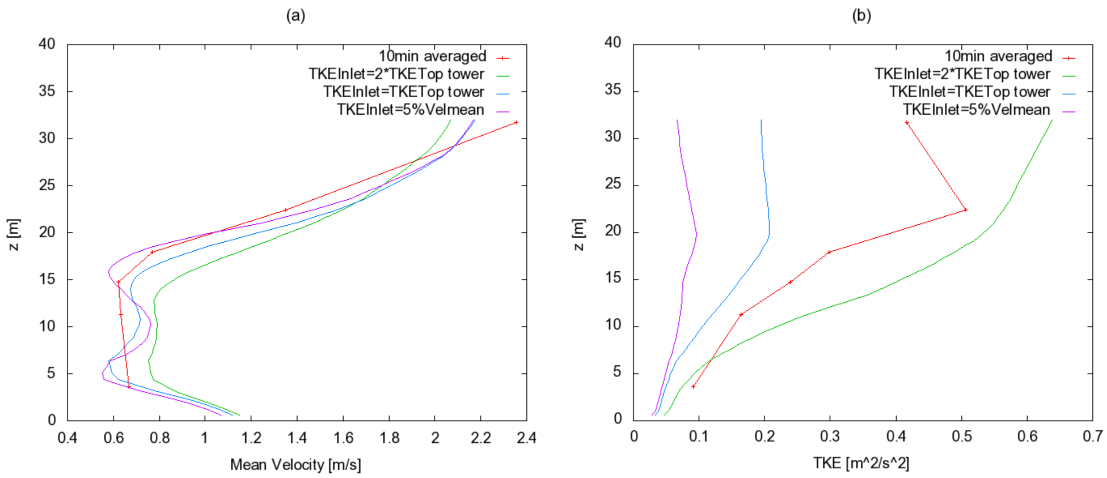

Figure 2: (a) Mean velocity profiles within the street canyon, varying TKE conditions at inflow boundary. (b) Turbulent Kinetic Energy profiles

Averaging Time Intervals

As can be seen in Figure 2, the modelled turbulent kinetic energy values are lower than the 10 min averaged measurement values. If the TKE values of the inlet values are increased, then the correlation between the modelled and the measured profiles improves, however the correlation between the modelled and measured mean velocities decreases. This effect may be alleviated by considering the time interval for which the mean is calculated.

The following graph (Figure 3) shows a comparison of the model output and the corresponding mean TKE profiles derived from the measurements using different averaging intervals for the Reynolds decomposition.

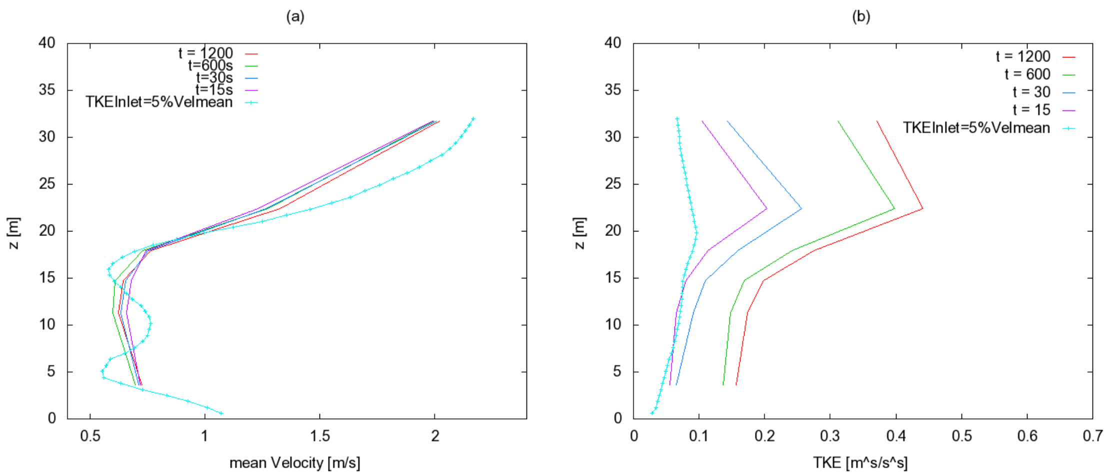

Figure 3: (a) Mean velocity profile within street canyon. (b) Turbulent Kinetic Energy profiles, time averaging periods: 15s - 1200s

References

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[4] Lundquist, J.K., Chan, S. T. (2007); Consequences of Urban Stability Conditions for Computational Fluid Dynamics Simulations of Urban Dispersion, Journal of Applied Meteorology and Climatology **46**; p. 1080-1097

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