COMPUTATIONAL SIMULATION OF WIND FLOW BEHIND A RECTANGULAR BUILDING

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1. Introduction

A computational model has been developed to determine wind characteristics in the wake of a rectangular building. A length of the recirculation zone behind the building has been determined using the Reynolds-Averaged-Navier-Stokes (RANS) equations. Tests were performed for rural, suburban, and urban type terrains.

2. Numerical Setup

In numerical simulation, investigated building geometry corresponds to Mavroidis and Griffiths (2009), who exposed a rectangular building with length a = 10.96 m, width b = 4.24 m and height h = 1.56 m to the atmospheric boundary layer flow.

The computational domain was generated in the FLUENT pre-processor Gambit. The overall dimensions of the computational domain were 26h in longitudinal direction (9h in front of building), 8h in vertical direction and 22h in lateral direction, where h is the height of the building. The generated mesh consisted of approximately 1.2 million control volumes with a very fine mesh around the building, which is getting coarser away from the building. The height of the first control volume immediately above the ground surface and in the vicinity of the building walls was 0.1h. The height of control volumes increases with the factor 1.1 when increasing the distance from the ground floor and from the walls of the building.

In this study, tests were performed for wind direction normal to the longer, as well as to the shorter building side, Figure 1 and 2.

Numerical simulations were carried out using the commercial CFD code Fluent 6.2 based on the finite volume method and Reynolds-Averaged-Navier-Stokes (RANS) equations using the assumption of the incompressible, turbulent flow.

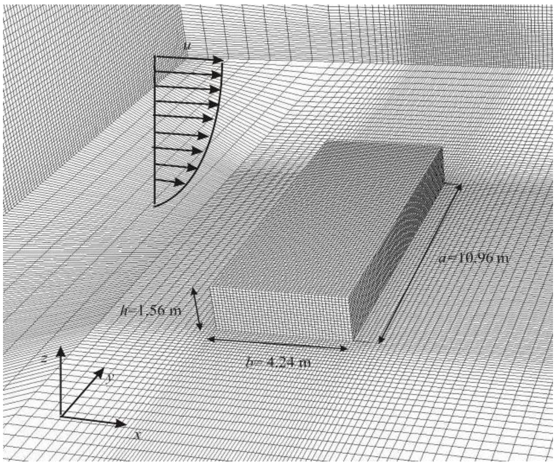

Figure 1. Configuration with wind flow normal to the longer building side

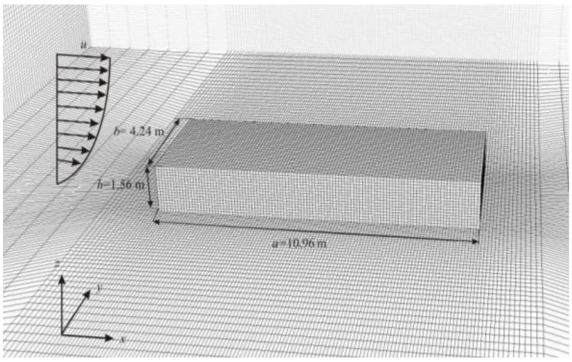

Figure 2. Configuration with wind flow normal to the shorter building side

The standard k-ε turbulence model with standard wall functions, originally suggested in Launder and Spalding (1974), was applied in this study. The nondimensionalized distance between the first node and the wall in the near-wall region was between 30 and 1000. The model constants were C_μ = 0.09, $C_{1\varepsilon}$ = 1.44, $C_{2\varepsilon}$ = 1.92, σ_k = =1.0, σ_ε = 1.3. As the preliminary tests showed that the wind characteristics in the investigated configurations using the suggested k-ε turbulence model could be considered as the steady flow, all simulations were carried out under the assumption of the steady flow.

The investigated geometry and inlet flow conditions were set to comply with Mavroidis and Griffiths (2009), who exposed the building to the atmospheric boundary layer flow in an open-field type terrain, i.e. the aerodynamic roughness length is z_0 = 0.01 m and the power law exponent α was calculated to be α = 0.11 using the equation proposed by Counihan (1975)

$$\alpha = 0.0961 \log z_0 + 0.016 (\log z_0)^2 + 0.24 \quad (1)$$

Two additional tests were carried out to investigate effects of the terrain roughness on the wake dimensions behind the building. For that purpose the terrains characterized with aerodynamic roughness length z_0 = 0.001 m and z_0 = 0.1 m were selected. The corresponding power law exponents α for these two additional terrains, calculated using the Eq. (1), are α = 0.096 for z_0 = 0.001 m and α = 0.16 for z_0 = 0.1 m. These values of α were used to define the power law equation for the mean velocity profile at the inlet of the computational domain.

In general, the power law relation is defined in the form,

$$\frac{\bar{u}}{\bar{u}_{\text{ref}}} = \left(\frac{z-d}{z_{\text{ref}} - d} \right)^{\alpha} \quad (2)$$

where $\bar{u}$ is the mean velocity in longitudinal direction at a height z above the surface, $\bar{u}_{\text{ref}}$ is the mean velocity in longitudinal direction at the reference height z_{ref}, d is the displacement height and α is the power law exponent. In addition, x-, y-, z-directions in this study denote longitudinal, lateral, and vertical direction, respectively, and $z_{\text{ref}} = h$ = 1.56 m in all configurations.

In the test with terrain roughness z_0 = 0.01 m the reference velocity $\bar{u}_{\text{ref}}$ is 5.3 m/s, for z_0 = 0.001 m the reference velocity $\bar{u}_{\text{ref}}$ is 5.1 m/s, and for z_0 = 0.1 m the reference velocity $\bar{u}_{\text{ref}}$ is 5.6 m/s.

Turbulence kinetic energy k and turbulence dissipation rate ε at the inlet of the computational domain were calculated from the ESDU 85020 (1985) for the rural, suburban, and urban type terrain, i.e. for the aerodynamic surface roughness length z_0 = 0.001 m, z_0 = 0.01 m, z_0 = 0.1 m, respectively. The equations used for this purpose are,

$$k = \frac{3}{2} \left(u_{\text{avg}} I_u \right)^2 \quad (3)$$

$$\varepsilon = C_{\mu}^{3/4} \frac{k^{3/2}}{L_{u,x}} \quad (4)$$

where u_{avg} = 10 m/s is the freestream velocity, I_u is the turbulence intensity in longitudinal direction, $L_{u,x}$ is the integral length scale of turbulence.

Boundary conditions applied in this study are reported in Table 1.

The flow field is initialized by the values set at the inlet of the computational domain. The convergence criteria of the scaled residuals for all variables and the continuity equation are set as 10^{-6}.

In each configuration, wake length behind the building was determined as the largest closed vorticity isoline.

Table 1. Boundary conditions applied in computational simulation

Computational domain boundaries	Boundary conditions
Inlet	$\frac{\bar{u}}{\bar{u}_{\text{ref}}} = \left(\frac{z-d}{z_{\text{ref}} - d} \right)^{\alpha}$ $v = 0, w = 0$ $k = \frac{3}{2} \left(u_{\text{avg}} I_u \right)^2$ $\varepsilon = C_{\mu}^{3/4} \frac{k^{3/2}}{L_{u,x}}$
Outlet	Outflow
Top wall	Freeslip wall
Side walls	Freeslip wall
Bottom and building walls	Wall

3. Results

Mean velocity profiles corresponding to rural, suburban, and urban type terrains modified along the domain, as presented in mean velocity profiles given at the building position, Figure 3. At this position, mean velocity profiles, normalized using the corresponding reference velocity recorded at the building height, show little difference to each other. However, differences in turbulence kinetic energy profiles *k*, reported for various terrains in Figure 4, are expected to predominantly determine wake dimensions behind the building, as e.g. Castro and Robins (1977) demonstrated that the size of the cavity region is reduced by the presence of upstream turbulence. In particular, increase in the aerodynamic surface roughness length z_0 was observed to considerably contribute to an increase in the turbulence kinetic energy *k*. Turbulence dissipation rate ε, reported in Figure 5, was observed to be larger close to surface for rougher terrains, while away from surface recorded values differ insignificantly.

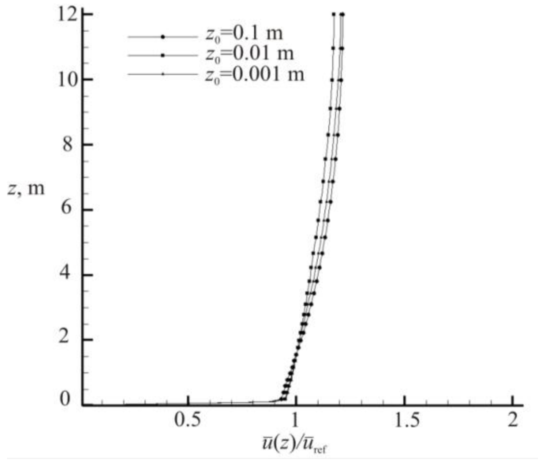

Figure 3. Mean velocity profiles at the building position observed for various terrains

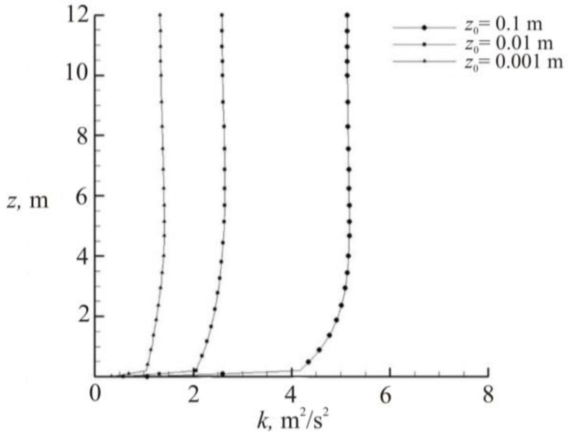

Figure 4. Turbulence kinetic energy profiles at the building position observed for various terrains

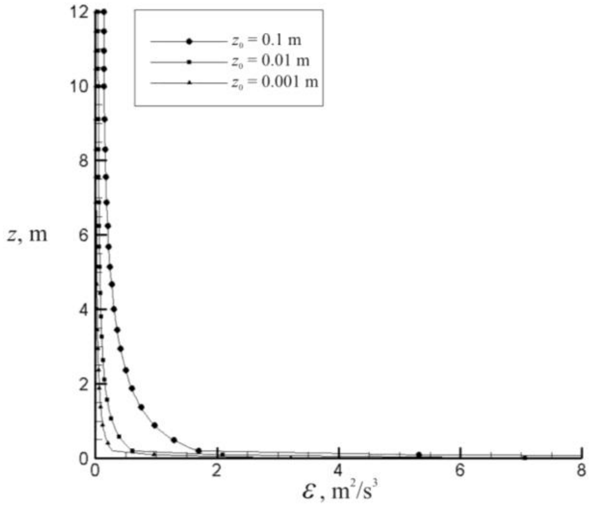

Figure 5. Turbulence dissipation rate profiles at the building position observed for various terrains

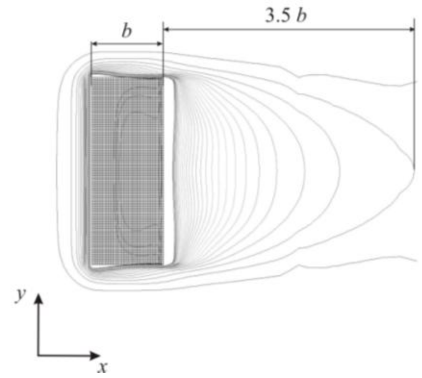

Figure 6. Wake dimensions for aerodynamic surface roughness length z_0 = 0.001 m and wind flow normal to the longer building side

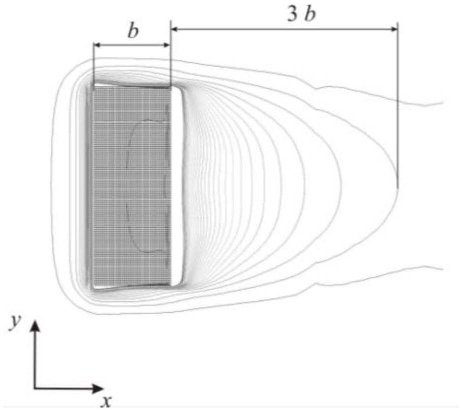

Figure 7. Wake dimensions for aerodynamic surface roughness length z_0 = 0.01 m and wind flow normal to the longer building side

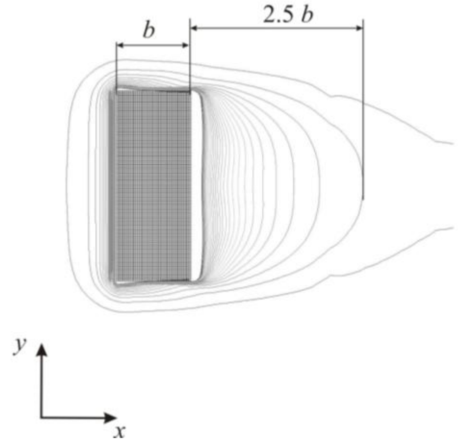

Figure 8. Wake dimensions for aerodynamic surface roughness length z_0 = 0.1 m and wind flow normal to the longer building side

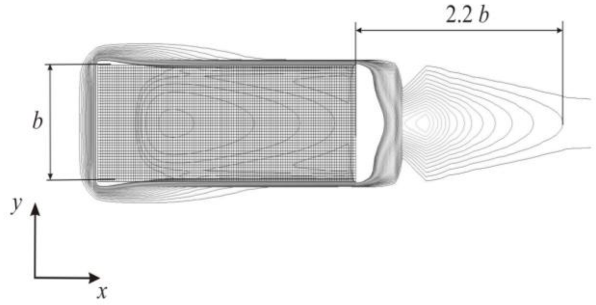

Figure 9. Wake dimensions for aerodynamic surface roughness length z_0 = 0.001 m and wind flow normal to the shorter building side

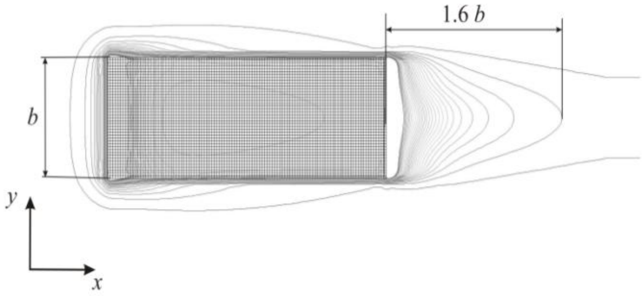

Figure 10. Wake dimensions for aerodynamic surface roughness length z_0 = 0.01 m and wind flow normal to the shorter building side

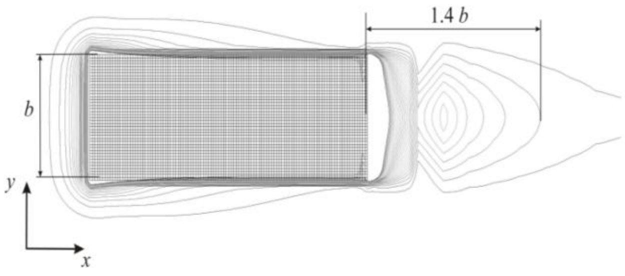

Figure 11. Wake dimensions for aerodynamic surface roughness length z_0 = 0.1 m and wind flow normal to the shorter building side

Computational results for aerodynamic surface roughness length z_0 = 0.01 m reported in Figures 7 and 10 show good agreement with full-scale measurements by Mavroidis and Griffiths (2009), as previously reported in Barić et al. (2010). Results reported in Figures 6 to 11 indicate a decrease in the longitudinal wake dimension behind the building in tests with stronger turbulence due to rougher terrain. These results are in agreement with Laneville et al. (1975), Castro and Robins (1977), who reported an intensified exchange of momentum between the wake and undisturbed flow behind the building for stronger turbulence in the wind flow.

For wind normal to the longer building side and the aerodynamic surface roughness length z_0 = 0.001 m the wake length is 3.5*b*, for z_0 = 0.01 m the wake length is 3*b*, for z_0 = 0.1 m the wake length is 2.5*b*. For wind normal to the shorter building side and the aerodynamic surface roughness length z_0 = 0.001 m the wake length is 2.2*b*, for z_0 = 0.01 m the wake length is 1.6*b*, for z_0 = 0.1 m the wake length is 1.4*b*.

4. Concluding remarks

A computational model has been developed to determine wind characteristics in the wake of a rectangular building for rural, suburban, and urban terrain exposure. Numerical simulations were carried out using the commercial CFD code Fluent 6.2 based on the finite volume method and Reynolds-Averaged-Navier-Stokes (RANS) equations using the assumption of the incompressible, turbulent flow. The standard k-ε turbulence model with standard wall functions was applied.

Investigated building geometry and computational results obtained in configuration with the aerodynamic surface roughness length z_0 = 0.01 m agree well with full-scale measurements carried out by Mavroidis and Griffiths (2009). The computational results indicate a reduced wake length behind the building for rougher terrains, i.e. for stronger wind turbulence in the oncoming flow, in agreement with Laneville et al. (1975), Castro and Robins (1977).

5. References

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