CFD-aided wind tunnel investigation of pedestrian wind

Bogusz Bienkiewicz\(^a\), Munehito Endo\(^a\)

\(^a\)Wind Engineering and Fluids Laboratory, Dept. of Civil Engineering, Colorado State University, USA

ABSTRACT: A case study illustrating application of CFD to aid wind tunnel investigation of pedestrian wind environment is presented. Three-dimensional, steady-state calculations involving k-\(\omega\) turbulence model were carried on an unstructured grid. Utilization of a simple computational model allowed for timely desktop analysis of various configurations, before and during wind tunnel testing. The numerical results were primarily used as computer-aided flow visualization. Flow patterns inferred from numerical and experimental results were overall in a good agreement, while the agreement for the wind speed ratio was location dependent.

KEYWORDS: Computational modeling, wind tunnels, pedestrian wind.

1 INTRODUCTION

Advances in numerical techniques, versatility and user-friendliness of CFD software packages, coupled with increasing power of desktop computing, continue to expand range of application of computational modeling in wind engineering studies. Routine use of this tool to solve “real life” (practical) problems remains limited (especially for external flows) due to inherent complexity of such tasks. However, utilization of CFD in combination with other techniques, including experimental studies, has been shown to be quite effective in providing guidelines/preliminary solutions, etc., in a number of wind engineering investigations, including pedestrian wind comfort assessments, e.g. Ferreira et al. [1], He & Song [2], and others.

This paper presents a case study illustrating application of CFD in computational wind engineering (CWE) analysis of pedestrian wind environment, a part of an effort described in more detail by Bienkiewicz & Endo [3]. CWE simulations were performed to aid physical modeling carried out in a boundary-layer wind tunnel. The objective of this effort was an assessment of pedestrian wind comfort for a proposed building complex shown in Figure 1. Numerical simulations were carried out using a simplified geometry of the buildings, schematically depicted in Figure 2. Calculations were performed before and in parallel with wind tunnel testing. The numerical results primarily served as computer-aided flow visualization. They were used to: (1) identify critical areas for measurement of the pedestrian-level wind speed; (2) attain further insight into physical phenomena identified from wind tunnel testing; and (3) aid selection of countermeasures to improve pedestrian wind comfort.

Figure 1. Rendering of proposed building complex

Figure 2. Computational model
Numerical simulations were performed using a commercial software package implemented on a personal computer. Three-dimensional, steady-state calculations were carried out on an unstructured grid. The numerical results were compared with wind tunnel measurements of pedestrian-level wind speed. Both the numerical and experimental phases of the study are described in the paper.

2 COMPUTATIONAL AND PHYSICAL MODEL
A simplified geometry of the building complex (shown in Figure 1) was employed in numerical and physical modeling. An idealized configuration depicted in Figure 2 was assumed in CFD calculations. The computational domain was discretized using approximately $10^6$ cells and non-uniform grid, of optimized mesh topology. The mean velocity and turbulence intensity profiles representative for open terrain wind exposure, depicted in Figure 3, were used as inflow boundary conditions. The outflow boundary condition was set of a “pressure-out” type. The symmetry boundary condition was set for the top and side walls of the computational domain. The wall boundary conditions were set for the remaining surfaces. Various turbulence models and discretization schemes were considered during preliminary computations. The $k-\omega$ turbulence model was found to be most optimal choice for three-dimensional, steady-state simulations. Calculations were initiated using the first order discretization. After 10-20 initial iterations, the second order (upwind) discretization for momentum, turbulence kinetic energy and specific dissipation rate, combined with standard discretization for pressure, was activated. A relatively low number of iterations (300-370) was required to attain acceptable convergence of the flow field.

The wind-tunnel modeling was carried out in the Environmental Wind Tunnel (EWT), one of the boundary-layer wind-tunnel facilities of the Wind Engineering and Fluids Laboratory (WEFL), at Colorado State University. A 1:250 geometrical scale model of the proposed buildings was employed in this study, see Figure 4. Measurements of pedestrian-level wind were made using vertical hot-film probes, in conjunction with constant temperature anemometers. The measured pedestrian-level wind was ultimately expressed as the 2-meter (in prototype) wind speed ratio - the ratio of the wind speed at a given location to the reference speed (the mean wind speed or the mean plus three standard deviations, for respectively the mean and gust speeds).

3 RESULTS AND DISCUSSION
Representative numerical and experimental results – 2-meter wind speed ratios – are presented and compared in Figures 5 through 9. The overall comparisons of the CFD and experimental
mean wind speed ratios are depicted in Figures 5 and 6, for two representative wind directions. It should be noted that the experimental contours (Figures 5b and 6b) resulted from interpolation of the measurements taken at 186 locations. An overall good agreement between the compared contours can be seen. The experimental data is shown in more detail in Figure 7, where the mean and effective gust wind speed ratios are depicted for two representative cases – measurement locations along two lines, Line 1 and Line 2.

![Figure 5. Numerical and experimental mean wind speed ratio, wind normal to building A](image)

![Figure 6. Comparison of mean wind speed ratio, wind oblique to building A](image)

![Figure 7. Experimental mean and effective gust wind speed ratios for two representative directions, Line 1 and 2](image)

The related numerical results are presented in Figure 8, where the normalized velocity $U_{\text{total}}$ (representative of the mean wind speed ratio) and its components (along flow $x$, cross flow $y$ and vertical $z$) are depicted for Line 1 and Line 2. The numerical ($U_{\text{total}}$ in Figure 8) and experimental (mean in Figure 7) wind speed ratios are compared in Figure 9, for the two considered locations (Line 1 and 2). A reasonable agreement between the compared data can be seen in regions of decelerated and accelerated flows, respectively upstream and to the side of the building complex. In areas of flow separation and recirculation, the discrepancy between the compared data was found to be significant. This disagreement is not totally unexpected due to the constraints imposed by the employed computer model. Bias in the experimental (hot film) data acquired in regions of flow high turbulence intensity, separation and recirculation precludes further comparative quantification of the accuracy of the obtained numerical results.
4 CONCLUDING REMARKS
Application of CFD to aid experimental investigation of pedestrian-level wind was found to be useful in preliminary assessment of the wind environment. A simple computational model and integration scheme allowed for timely desktop analysis of various configurations, before and during wind tunnel testing. Flow patterns inferred from numerical and experimental results were overall in a good agreement, while the agreement for the wind speed ratio was location dependent. In regions of decelerated flow upstream and accelerated flow around the buildings complex, the computed speed ratio was in a reasonable agreement with the experimental data. Significant discrepancy between the compared data was found in regions of flow separation and recirculation. Limited accuracy of the experimental (hot film) data in these flow regimes did not allow for reliable quantification of the above mismatch.

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6 REFERENCES