NUMERICAL SIMULATION OF FLOWS AROUND BROAD-LEAF TREES

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ABSTRACT

A numerical model is established to predict flow past discrete broad-leaf trees so as to provide a handy tool for pedestrian wind analysis during the preliminary design stage for local wind environments. In the study, a tree factor was proposed to reflect the effect due to the existence of the trees. Besides the applications of numerical computations in flow analysis, wind tunnel measurements were also performed to guide and confirm the numerical simulations. Results showed that the calibrated tree factor generally increased with increases of the volume ratio and horizontal thickness of the tree body. Based on the calibrated relationship of the tree factor, finally, additional numerical computations were performed to simulate flow past an isolated tree and dual trees in a tandem and a side-by-side arrangement. The predicted downstream wind velocity profiles appeared in good agreements with the measurement results.

KEYWORDS: LARGE EDDY SIMULATION, WIND TUNNEL TEST, POROUS BODY

Introduction

Planting trees in building areas can not only upgrade the local landscape but to some extent improve the wind environment, particularly regarding the reduction of wind speed in the pedestrian level. Therefore, how to analyze the wind flow in areas with trees becomes an important task for the designers during the planning stage. Commonly, wind tunnel experiments can be employed to analyze the wind flow problem. Besides the amount of human labor and time required in the experimental work, technical difficulties (such as the scale effect) are generally encountered. On the other hand, numerical simulations can be another alternative for the analysis.

The flow pattern around a tree may appear somewhat different from that around an impermeable solid body due to its porous nature. As a part of fluid penetrates the tree, the shedding vortices can interact with the penetrating flow and disturb the formation of the downstream wake. Physically, this extent of the interaction effect may depend on the porosity and thickness of the tree.

The goal of the study is to establish a numerical model, capable of correctly predicting flows past discrete broad-leaf trees so as to provide a handy tool for pedestrian wind analysis during the preliminary design for local wind environments. Besides numerical computations, wind tunnel measurements were also performed to guide and confirm the numerical simulations.

Numerical Method

A weakly-compressible-flow method [Song and Yuan (1988)] with large-eddy simulation was used to simulate the wind flows. In the computational space containing twigs and leaves, the governing momentum equation was modified by adding a source term [Shaw and Schumann (1992)] to reflect the existence of the tree body as (bar denotes space-average):

$$\frac{\partial \overline{u_i}}{\partial t}+\frac{\partial \overline{u_i}\,\overline{u_j}}{\partial x_j}=-\frac{\partial}{\partial x_j}\left(\frac{\overline{p^*}}{\rho}\right)+\frac{\partial}{\partial x_j}\left(\frac{\tau_{ij}}{\rho}\right)+(f_D)_i \tag{1}$$

where ρ, u, p and τ are respectively air density, velocity, pressure and total stress; and

$$\overrightarrow{f_D}=\left[-C_{Da}\,u\left|\overrightarrow{V}\right|,-C_{Da}\,v\left|\overrightarrow{V}\right|,-C_{Da}\,w\left|\overrightarrow{V}\right|\right]^T \tag{2}$$

The tree-body factor, C_{Da}, reflects the combined effect due to drag as well as the leaf surface area and needs to be calibrated by experiments.

Calibration of Tree-body Factor

A number of parallel leaf strings, arranged evenly in a rectangular shape, were set in the direction perpendicular to the flow direction in a wind tunnel under a uniform approaching flow (see Fig. 1). By varying the rigidity (γ; the volume ratio of tree body) and horizontal width (B), the mean and root-mean-square velocity profiles were measured at various downstream sections. On the other hand, a try-and-error method was conducted in the numerical simulations to find out the value of C_{Da}, which leads to the best-fit outcome between the numerical and measurement profiles. Accordingly, Fig. 2 illustrates the contours of C_{Da} as functions of γ and B.

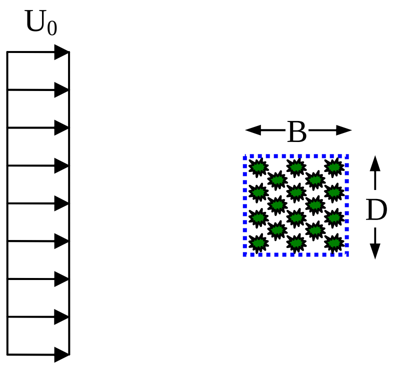

Figure 1: Schematic of Experiments

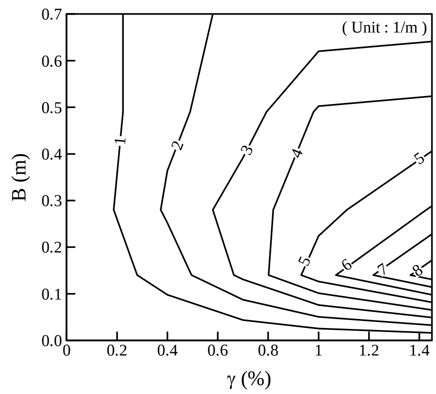

Figure 2: Contour of Tree-body Factor

Flow Simulations

Based on the result in Fig. 2, simulations of uniform flows past an isolated tree, and dual trees in a tandem and a side-by-side arrangement were performed were conducted further to examine the validity of the calibrated C_{Da} variations. In addition, parallel wind tunnel experiments were also carried out to measure the downstream velocity profiles for comparisons.

Typically, Fig. 3 depicts the schematic of the problem of a uniform flow past an isolated tree. In the computation, the axisymmetric tree body was divided into several horizontal layers, and the C_{Da} values associated with the grid cells in each layer were taken from the calibration contour plot (Fig. 2) according to the corresponding horizontal thickness and volume ratio of the tree body. On the other hand, the main tree trunk, a circular cylinder with a diameter of 0.06 m, was treated as a solid body in the flow simulation.

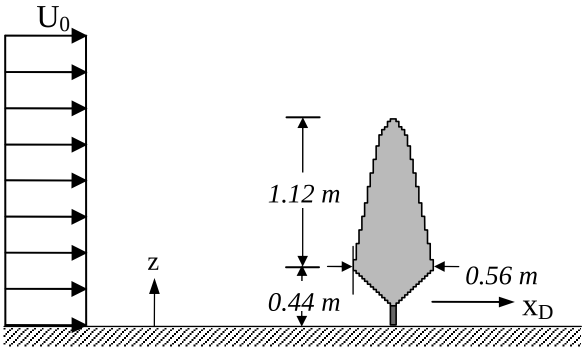

Figure 3: Schematic of Flow past An Isolated Broad-leaf Tree

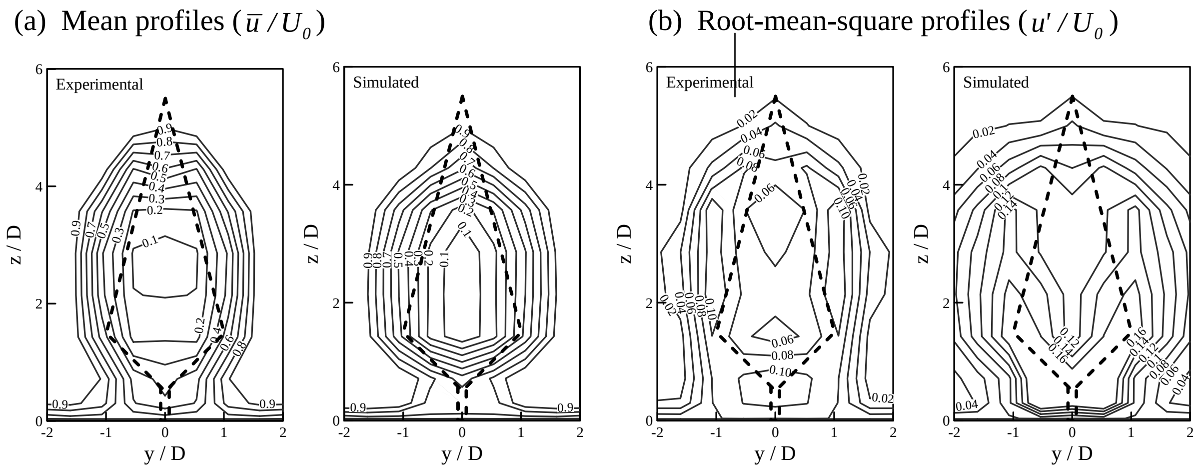

Figure 4: Comparison of mean and rms velocity profiles of an isolated tree (x_D=6D)

The comparisons of normalized mean and root-mean-square velocity profiles at a typical downstream cross-section (x_D = 6D) are shown in Fig. 4. The spatial correlation coefficient of the cross-sectional velocity variations between the experimental and calculated results are respectively 0.965 and 0.864, indicating a well prediction of the flow.

Conclusions

Based on the calibrated contour plot of C_{Da}, simulations of uniform flows past isolated broad-leaf trees were performed and the predicted results, in terms of the downstream mean and root-mean-square velocity profiles, were in good agreements with those from the wind tunnel measurements. This indicates that the C_{Da} contour can be readily used to simulate flows past discrete broad-leaf trees with adequate accuracy.

References

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