Computational Fluid Dynamics (CFD) Modelling Of Wind Flow in and Around Forest Canopies.

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ABSTRACT

Using the well known k-ε turbulence model [1], a CFD study has been carried out and compared to a wind tunnel study to assess its accuracy in modelling wind flow through and around a forest canopy. Adding additional source and sink terms to the turbulence model, has been common practice when taking into account the effect of trees on the approaching wind field. This research is looking at four different sets of closure coefficients, which define the source and sink terms, to see which can most accurately simulate the wind tunnel study.

KEYWORDS

Forest Canopy, Turbulence Modelling, Computational Fluid Dynamics.

1 INTRODUCTION

Utilising the framework of the well known k-ε turbulence model, many researchers have proposed modifications to predict canopy influences on approaching wind flows. The difference in these models is how they define the additional source and sink terms of the transport equations for turbulence kinetic energy (TKE), k, and its dissipation rate, ε. Equations 1 and 2 show the mathematical definition of these source/sink terms.

$$S_k = \rho C_d A(z) \left(\beta_P |U|^3 - \beta_D |U| k \right)$$ **Equation 1**

$$S_\varepsilon = \rho C_d A(z) \frac{\varepsilon}{k} \left(C_{\varepsilon 4} |U|^3 - C_{\varepsilon 5} |U| \varepsilon \right)$$ **Equation 2**

Where ρ is the density of air, C_d is the canopy drag coefficient (0.2 for this work), A(z) is the Leaf Area Density (LAD) of the canopy, k is the TKE, ε is the turbulence dissipation rate, and $|U|$ is the modulus of the wind speed. β_p, β_d, $C_{\varepsilon 4}$, and $C_{\varepsilon 5}$ are constants. In this work, a CFD study will be carried out to try and simulate flow through a forest canopy, using different combinations of the above mentioned constants. The results from the CFD study have been

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validated against a wind tunnel study [2] to see which set-up produces the most accurate representation of the wind tunnel study.

Canopy model	**Scheme 1 [3, 4]**	**Scheme 2 [5]**	**Scheme 3 [6]**	**Scheme 4 [7]**
β_p	1.0	1.0	1.0	1.0
β_d	5.1	4.0	0	4.0
$C_{\varepsilon4}$	0.9	1.5	1.95	1.5
$C_{\varepsilon5}$	0.9	1.5	0	0.6

Table 1.Summary Closure Coefficients

2 CFD

The simulations for this work were done using the Reynolds Averaged Navier-Stokes (RANS) equations implemented in the commercial CFD software ANSYS CFX 12. ANSYS CFX is based on a coupled solver for mass and momentum and uses an algebraic multi-grid algorithm for convergence acceleration. Utilising the k – ε turbulence model, the vertical velocity variation can be plotted and compared with measured data.

2.1 Simulation Setup

The forest canopy was modelled as a simple rectangular volume, contained inside a larger rectangular volume. The forest was simulated as a porous domain, allowing air to pass through it, with its LAD profile shown in figure 1, taken from [8]. To cut down on computational time, only half the forest canopy was modelled; by assuming a plane of symmetry along the boundary through the centre of the geometry.

The forest canopy has a half width of 3m, a height of 7.5m, and a depth of 5.6m. The inlet of the domain has a half-width and half-height of 50m. The flow domain extends 100m from the inlet. The upstream face of the canopy was 200m downstream of the inlet. The flow domain was large enough so that its walls would not influence with the flow close to and around the forest canopy.

So that the solver can reach a suitable solution, it is necessary to apply appropriate boundary conditions to the domain and the geometry. A free slip boundary condition was implemented at the top and side walls of the domain. A logarithmic wind profile was applied to the inlet of the domain with a zero differential pressure at the outlet. Values for k and ε were defined manually at the inlet of the domain, as were the source and sink terms for canopy. The ground surface had a no slip wall condition applied, with its roughness (equivalent sand grain roughness) set to 30 times that of the aerodynamic roughness length, [8, 9].

An unstructured tetrahedral mesh was used close to and inside the forest canopy, to ensure that the greatest changes in flow and pressure would be picked up accurately by the solver. Close to the inlet, outlet, and above the canopy section a swept mesh was used. This better resolves the undisturbed wind flow, parallel to the canopy, seen in these areas of the domain.

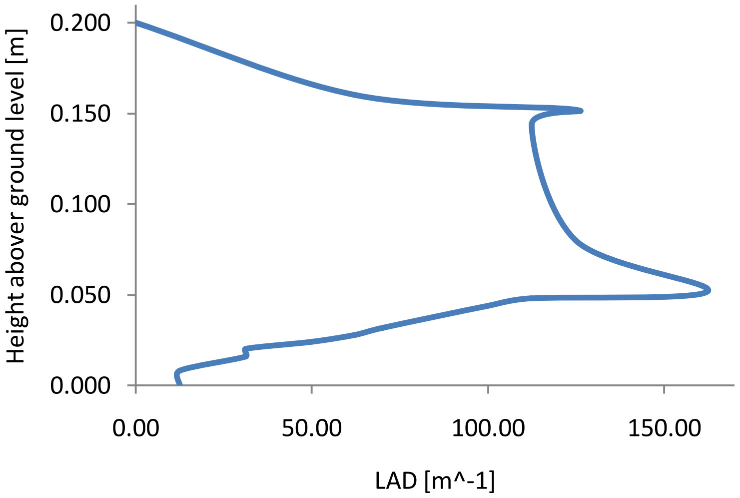

Figure 12: LAD of Forest in Simulations

3 RESULTS AND ANALYSIS

The vertical velocity profiles at various horizontal distances were compared with wind tunnel measurements from [2]. Figure 2 shows a comparison of the vertical wind profiles between scheme 1 and the wind tunnel simulation and table 2 shows the percentage difference between the magnitudes. The x axis is horizontal distance normalised to the canopy height.

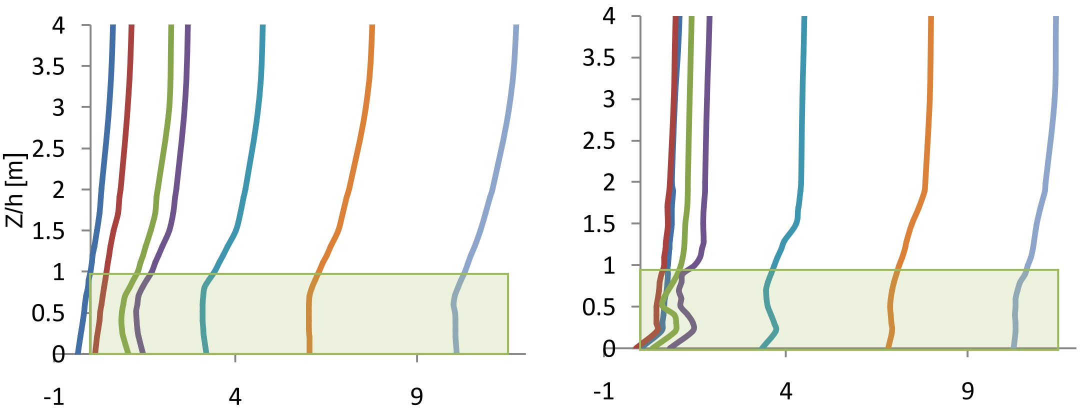

Figure 2. Comparison of vertical wind speed profiles between wind tunnel data and scheme 1. Left hand plot is the wind tunnel, right hand plot is the CFD simulation

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	X/h						
	-1	-0.5	0.5	1	3	6	10
Z/h							
0.2	-26.30%	-20.67%	33.84%	48.07%	66.88%	72.90%	-65.83%
0.4	-23.06%	-32.52%	38.42%	46.36%	61.34%	62.53%	-84.45%
0.5	-24.66%	-37.16%	-39.15%	13.71%	42.85%	56.98%	-4.70%
0.6	-26.88%	-35.83%	-43.67%	8.48%	24.02%	70.00%	89.70%
0.8	-24.72%	-34.06%	-5.22%	-30.27%	11.75%	40.48%	26.71%
0.9	-25.64%	-31.28%	-1.35%	-51.60%	-6.09%	18.34%	30.78%
1	-32.38%	-24.53%	-5.58%	-3.54%	-25.19%	4.40%	17.23%
1.1	-32.37%	-28.01%	-7.84%	4.40%	-27.05%	-6.42%	11.74%
1.2	-32.94%	-25.64%	-12.27%	-0.29%	-23.33%	-7.14%	4.85%
1.3	-36.51%	-28.66%	-18.21%	-5.72%	-25.53%	-19.62%	-4.94%
1.5	-36.51%	-31.14%	-29.76%	-27.76%	-7.90%	-25.75%	-19.26%
1.7	-43.08%	-45.25%	-36.30%	-26.26%	-14.24%	-10.69%	-22.16%
1.9	-43.85%	-42.41%	-39.20%	-32.09%	-16.50%	-5.03%	-19.80%
2	-50.45%	-42.43%	-41.25%	-31.85%	-18.93%	-9.54%	-25.74%
6	-48.53%	-38.66%	-38.22%	-31.86%	-43.51%	-43.99%	-46.83%

Table 2. Percentage difference between wind tunnel data and simulation scheme 1

A negative percentage difference shows an overestimation in wind speed by the simulation and a positive difference an underestimation.

4 CONCLUSIONS

The setup used in this work has identified the advantage of using the k-ε turbulence model to predict wind flow through and around forest canopies, using the modifications outlined in [3-7]. If magnitude is not taken into account then there is good agreement in the profiles produced by the CFD simulations. There are some differences in the profile just upwind of the forest but this can possibly be resolved with mesh refinement. From Table 2 it can be seen that the model overestimates the wind speed above the canopy for all horizontal sampling points. This would imply that the inlet profile is too high and is causing the wind speed to recover momentum far more quickly than in the wind tunnel simulation. Further work is needed to look at the inlet profile, mesh sensitivity, and LAD of the forest canopy to help improve its accuracy. The initial signs for this work are very promising; with some small modifications and further investigation the errors in magnitude should be greatly reduced.

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