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WIND SPEEDS OVER 2-DIMENSIONAL HILLS: WIND TUNNEL MEASUREMENTS AND NUMERICAL SIMULATIONS

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INTRODUCTION

The accurate prediction of wind speeds and turbulence over steep hilly terrain remains a difficult task. This paper presents the recent progress of a research program which aims to provide improved prediction techniques. In particular we aim to achieve more accurate calculation of mean wind speeds and turbulence for application to the siting of wind turbines on windy hill-top sites, and improved estimation of annual electricity generation from a wind farm.

The research has consisted of two parts: a wind tunnel study of wind speeds over two-dimensional hills, and numerical modelling of the equivalent hill configuration using a CFD (computational fluid dynamics) program.

WIND TUNNEL STUDY

A literature review found few comparable wind tunnel studies, particularly for wind speeds over multiple or irregular 2-dimensional hill configurations. These included studies by Counihan (1974) and Ferreira et al (1995). Wind tunnel studies of wind speeds over hills have been the subject of ongoing research at Canterbury University, including the work of Bowen and Lindley (1977), Pearse et al (1981) and others.

Two sets of 1:1000 scale, sinusoidal, 2-dimensional hills have been constructed for use in Central Laboratories wind tunnel. The first set are steep hills with a height of 200mm and a base length of 400mm. The second set are shallow hills with a height of 200mm and a base length of 800mm.

Wind tunnel measurements of mean speed and rms speed have been completed for the empty tunnel and for the single steep hill case. The boundary layer simulation was approximately Terrain Category 1 (Z_0=0.002m). The wind tunnel reference speed at hill height was 10.8m/s. The test Reynolds number (based on hill height and reference wind speed) was therefore 1.5×10^5. This is significant, as Ferreira has shown that a substantial change in flow conditions occurs for Reynolds numbers less than 10^5.

The measured wind speeds for the single steep hill are presented in Figure 1 (The dimensions are presented in metres for nominal full-scale distances). An upwind reference mean wind speed of 1.0 at the hill height has been assumed for the plots.

The maximum mean speed (non-dimensionalised using the reference speed) from the experimental results was 1.36, while the maximum speed up ratio was 2.14.

NUMERICAL MODELLING

Numerical modelling has been performed using the FIDAP v5.0 fluid dynamics analysis package. This is a general purpose finite element fluid analysis program, which uses the standard high Reynolds number k-ϵ turbulence model, except at the hill surface where a one element thick layer of special elements is employed.

The literature includes previous comparable studies by Paterson and Holmes (1993), Ferreira et al (1995) and Finardi (1995).

The FIDAP results for the single steep hill are shown in Figure 2. The FIDAP results for three consecutive steep hills are shown in Figure 3.

Comparing the wind tunnel and FIDAP results, it can be seen that many of the broad features of the wind speed distribution are similar. However, there are also some important differences, particularly near the crest of the hill and on the upwind slope. There is a substantial difference between the rms speeds on the upwind slope, with the FIDAP values being around twice the wind tunnel measured values. The reasons for these differences require further research.

The program FIDAP v5.0 is several years old and has been superseded by later versions. We understand that the revisions to the program have features which should achieve a more accurate analysis. The revisions include, for example, the ability to include a surface roughness parameter to increase the ground roughness of the terrain. This feature is not available in version 5.0, and so a smooth surface has been assumed for the current analysis.

The maximum mean speed (non-dimensionalised using the reference speed) given by the FIDAP analysis was 1.50, while the maximum speed up ratio was 2.41.

CONCLUSIONS

An ongoing research program is in progress to perform a wind tunnel study of wind speeds over a range of different hill configurations. The wind tunnel results have been compared with the equivalent configurations analysed using a CFD computer program. The results are broadly similar, but there are also some substantial differences, particularly near the hill crest. Additional work on both aspects of this research is planned, including wind tunnel measurements on several different hill configurations.

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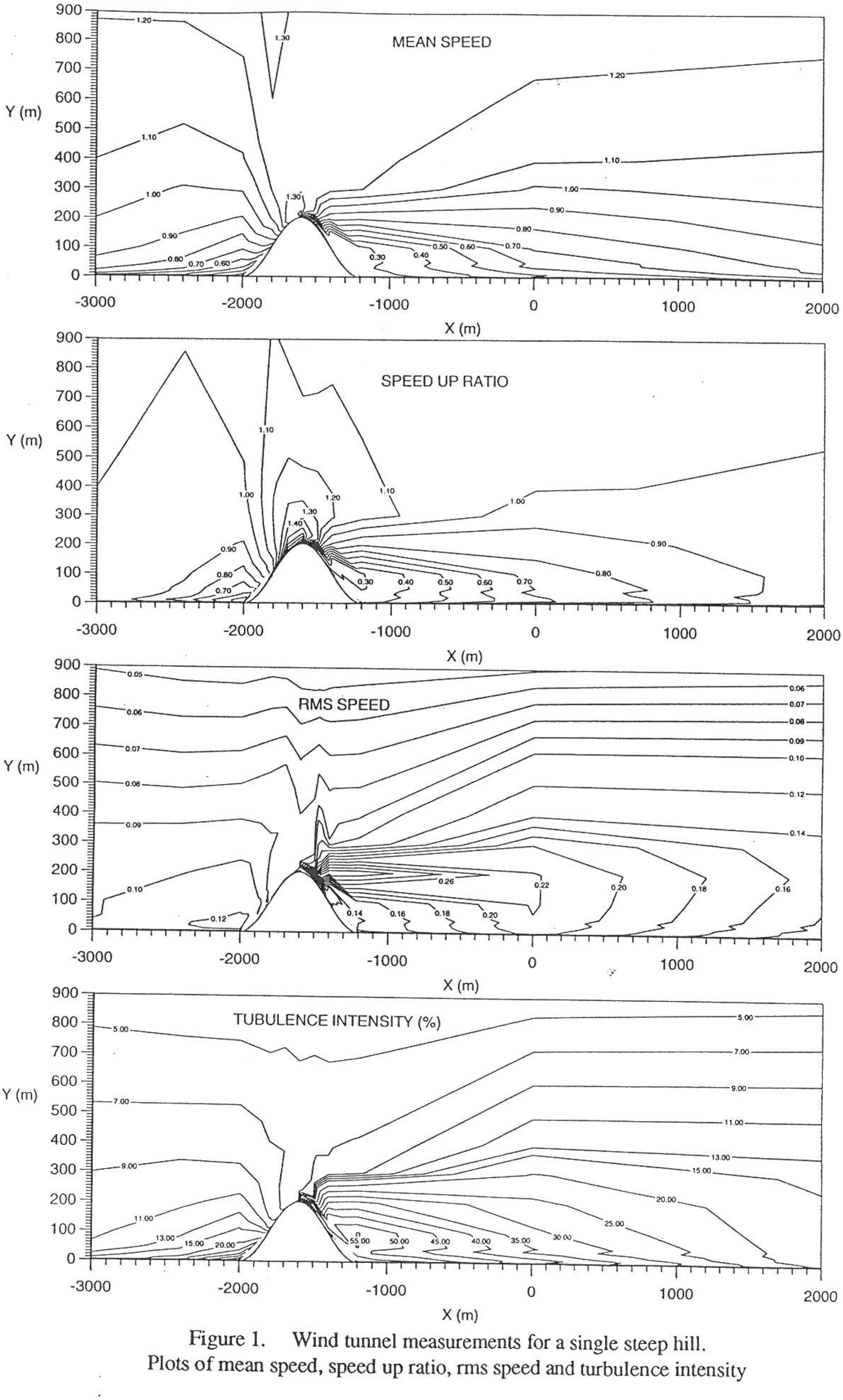

Figure 1. Wind tunnel measurements for a single steep hill.
Plots of mean speed, speed up ratio, rms speed and turbulence intensity

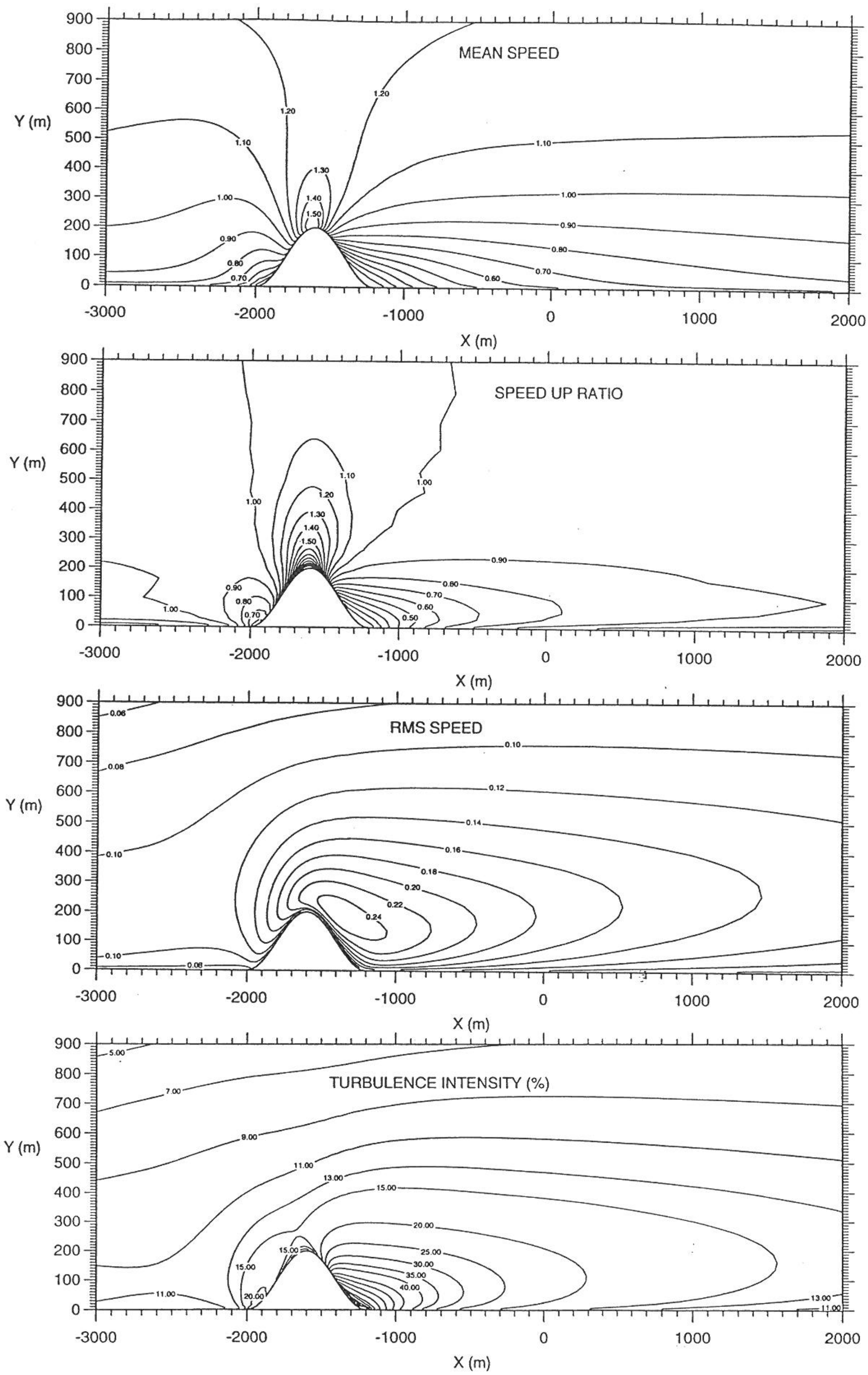

Figure 2. FIDAP analysis for a single steep hill.
Plots of mean speed, speed up ratio, rms speed and turbulence intensity

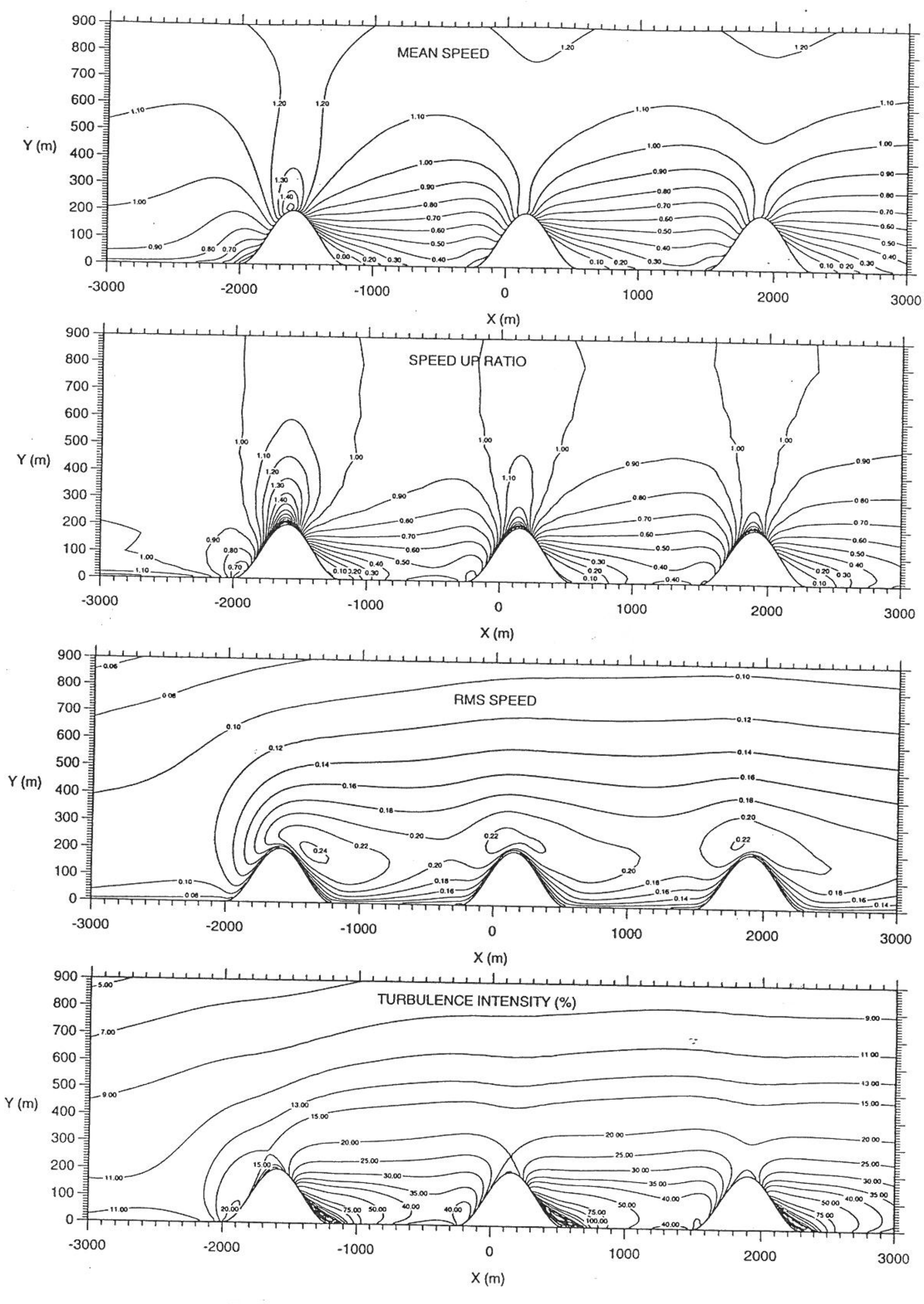

Figure 3. FIDAP analysis for a three steep hills.
Plots of mean speed, speed up ratio, rms speed and turbulence intensity