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Prospecting for Wind Energy: A Field Assessment of Physical Modelling

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SUMMARY There are still no satisfactory ways of prospecting for and evaluating potential wind energy sites without extensive and long term meteorological measurements. Physical simulation of wind régimes found over complex terrain offer significant advantages in terms of time, expense and control of independent variables. Both terraced and contoured models of the Gebbies Pass of Banks Peninsula in the South Island of New Zealand were prepared to an undistorted geometric scale of 1:4000 and surveyed in an atmospheric boundary layer wind tunnel. The laboratory simulation results are compared with field measurements taken in the modelled region to examine the viability of the method. Preliminary results show promising agreement between field and wind tunnel tests.

1 INTRODUCTION

The results of this study can be used to advantage in several applications. In terms of energy production from Wind Energy Conversion Systems (WECS) it is essential that the validity of wind tunnel modelling be determined to allow quick, easy and cheap assessments of potential regions and sites, in particular where terrain enhanced areas are being considered since this often involves complex terrain.

A comprehensive understanding of the structure of the wind in complex terrain is required if turbines, buildings or structures are to be built on the terrain. This also applies to new buildings and structures being erected in a town or city which is located in complex terrain, e.g. Wellington, New Zealand.

The passage of pollutants over simple two-dimensional or isolated three-dimensional hills have been studied. The prediction of flow patterns in an actual complex terrain situation becomes essential in situations where life is at risk. These could include:

1) The release of a toxic gas in, say, Wellington, New Zealand. Here a knowledge of the stagnation regions in the surrounding valleys (suburban areas) would be invaluable.

2) In the event of a nuclear accident involving the release of a radioactive cloud, the knowledge of its passage over the surrounding terrain would again be invaluable.

3) In the area considered in this study it is planned that a liquified petroleum gas storage depot be established, this being at a port a few kilometers north of Gebbies Pass. In the event of a leak of this gas during a northeast or easterly wind, a knowledge of the probable passage of the gas over the surrounding complex terrain, including Gebbies Pass, could prevent a major disaster by allowing an early evacuation of the areas likely to be most affected by the gas.

2 PHYSICAL MODELLING

When simulating wind characteristics over irregular terrain, it is essential that the two flow systems are thermally, dynamically and kinematically similar. This means that after suitable adjustments of the units of length, time etc. the equations describing the flow are applicable to both model and prototype.

Meroney *et. al.* (1978) discuss the problem of obtaining similarity and suggest that to obtain surface-boundary similarity, the following are required:

a) surface roughness distribution with "aerodynamically rough" behaviour;
b) topographic relief;
c) surface temperature distribution;

and for approach flow characteristics similarity, the following are required:

i) distribution of mean and turbulent velocities;
ii) distribution of mean and fluctuating temperatures;
iii) zero longitudinal pressure gradient;
iv) if the flow is thermally layered, quality of the ratio of inversion depths is required.

One of the requirements suggested by Meroney *et. al.* for fully rough flow was

$$\frac{u_* \lambda}{\nu} > 100$$

u_* = friction velocity
ν = kinematic viscosity
λ = roughness element height (the polystyrene sheet used was assessed to be 0.05-0.2 mm)

Taking $\lambda \simeq 0.1$, this term (0) 10^3..............

Values for the Gebbies Pass model taken at the gradient height and 3mm above the surface area are (0)10^5 and (0)10^4 respectively.

3 LABORATORY MEASUREMENTS

3.1 Location of the Modelled Region

The area considered in this study is situated on Banks Peninsula in the South Island of New Zealand, see Fig.1. The prevailing winds for this region are from the northeast and southwest, the actual saddle in Gebbies Pass lying at right angles to these winds. This is clearly shown together with the major terrain features in Fig.2 which represents the view from a point northeast of the Gebbies Pass region.

The Port Hills range rises to above 600m and is, generally, sparsely covered with vegetation other than grass. The region is also bounded by the Mt Herbert Range which is generally about 500m high.

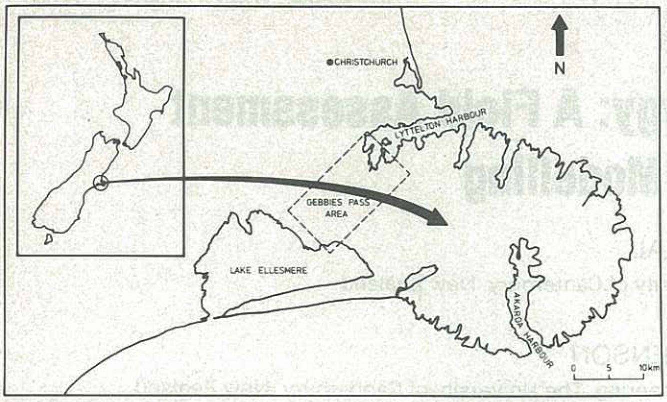


Figure 1 Gebbies Pass Area on Banks Peninsula

Spanning these ranges is the Gebbies Pass Saddle which is approximately 300m high. The flow approaching Gebbies Pass passes from the sea onto very flat grass-covered terrain which also has several shelterbelt stands, these being well established and ranging from thick hedges 5-10m high to conifer trees

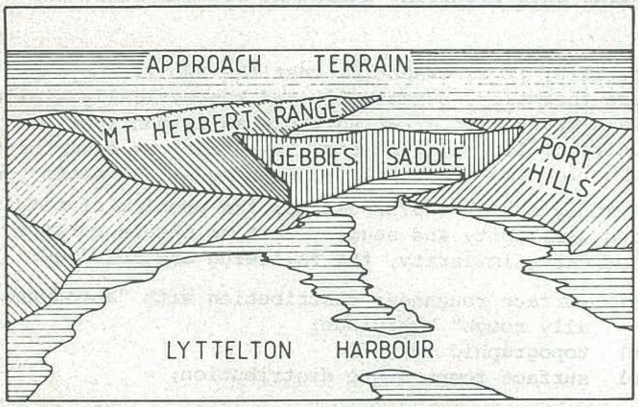


Figure 2 Simplified Schematic of Terrain Features

10-20m high. The flow passes over approximately 3km of this terrain before entering the modelled region.

3.2 Model Construction

A model was constructed using 9mm thick expanded polystyrene-bead board. This was cut to the shape of the terrain contours obtained from a photographically enlarged Lands & Survey Department map, thus producing a terraced finish to the model. A polyfilla non-shrink material was used to fill in the terraces to produce the contoured model. The final form of construction included the modelling of surface roughness elements on the model. The shelterbelts were simulated with an open spun wool approximately 4mm thick whilst the scrub areas, typically 3-5m high, were represented by an open weave type of hessian called scrim. The use of the wool to represent shelterbelts has been justified by other researchers; in particular, Meroney *et. al.* (1978) showed that this material was quite satisfactory.

The scrim material was used because it provided a close physical approximation, in terms of height and density, to the scrub in the modelled region.

Information regarding the effects of the model surface finish needs to be gathered to provide a better appreciation of its importance in topographical modelling of complex terrain. The Gebbies Pass model was analysed in all three states of construction - terraced, contoured and with roughness elements added - although only the terraced and roughness added results will be compared in this paper.

The region under study was split into three models, two of which had a NE/SW alignment, whilst the third incorporated parts of the other models to provide a NNE/SSW alignment. The whole model with model B indicated, is shown in the terraced form of construction in Fig.3. The results obtained over model B will be compared with field results because model B places the Saddle region of particular interest in the centre of the wind tunnel. This feature is important because it reduces the significance of side wall effects.

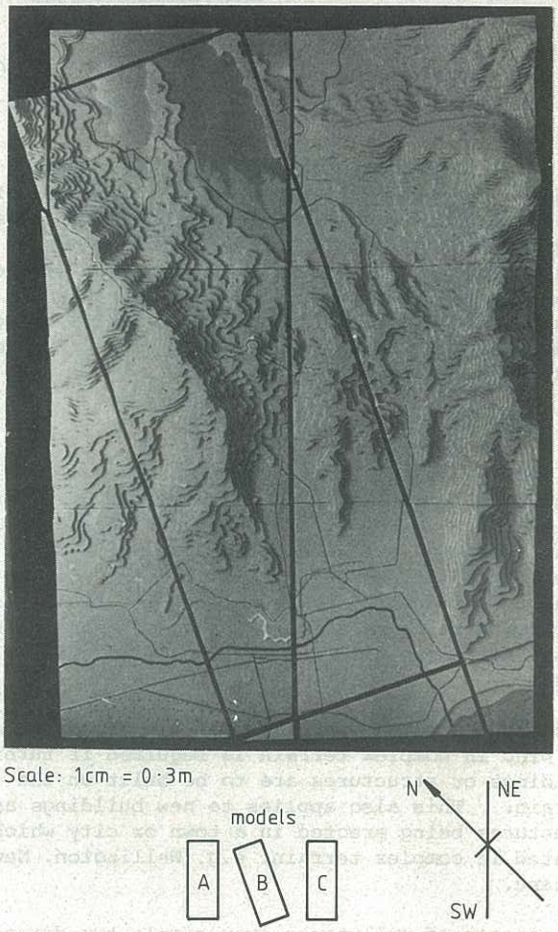


Figure 3 Aerial View, Gebbies Pass Model, Terraced

3.3 Simulated Atmospheric Boundary Layer

The laboratory measurements were made in a 1.2m x 1.2m cross section boundary layer wind tunnel at the Department of Mechanical Engineering at the University of Canterbury, Christchurch, New Zealand. Details of this facility have been given by Raine and Stevenson (1977).

Measurements of the velocity and turbulence intensity profiles, roughness length and the longitudinal component of the energy spectrum up to a height of 20m were made on the approach terrain with a field data acquisition system incorporating fast response propeller anemometers, a multiplexor and a 7-track magnetic tape recorder. Details of this facility have been given by Flay (1978).

The results obtained with this equipment combined with the results from other researchers using similar flat rural terrain were used in establishing the correct approach flow characteristics in the simulation.

In establishing the correct simulation, a combination of honeycombs, a square bar grid, trip fences, and added tunnel floor surface roughness were used.

3.4 Flow Measuring Equipment

3.4.1 Flow visualisation

1) Beads - Polystyrene beads, 2mm diameter, were placed upstream of the model. The wind tunnel free stream velocity was slowly increased until all the beads had moved onto the model. A free stream velocity of 4.0 m/s was then established and the bead deposition areas noted, this being referred to as the low-speed test. The free stream velocity was then increased to 5.7 m/s and the resulting bead deposition areas noted. Observation of the bead trajectory and behaviour behind hills and ridges provided information regarding turbulence.

2) Flags - Balsa wood flags, 4mm high x 10mm long were mounted on pins with a plastic bead as a retainer and bearing. These were placed at the points to be analysed with the flag centreline at approximately 10mm above the model surface. The flag alignment was recorded with a free stream velocity of 9.87 m/s, this being the velocity used for the hot film survey of the model.

3.4.2 Pressure probe equipment

A United Sensor 5-hole Cobra probe was used to measure the flow directions of the analysis points to a greater accuracy, ±0.5°, than was possible with the flag technique.

3.4.3 Hot film anemometry

A TSI hot film anemometer system was used to obtain a voltage output proportional to the mean and rms velocity in the longitudinal direction. Until recently, the output signal from the linearised anemometer unit had to be read with voltmeters or passed into analog equipment such as a correlator or spectrometer to provide information on velocities, autocorrelations and energy spectra. However, the digitising of the wind tunnel by Pearse (1979) has meant that the signal from the lineariser can be fully analysed by being connected on-line to a mini-computer.

4 FIELD MEASUREMENT PROGRAMME

Wind velocity measurements over the Gebbies Pass region were required to provide a basis for validation of the laboratory study. The ideal situation would require long term velocity data for many points in the region together with time and direction information. In the absence of such information a mobile survey technique was developed. This involved teams of personnel covering the area in a short time span, 5-7 hours, with a lightweight portable anemometer system which involved Rimco cup anemometers attached to the top of 10m aluminium towers. The towers were 5 cm diameter tubing 5m long and were joined with a sleeve. A 3-lead supply and signal cable led from the anemometer to a power supply and counter module. The system was allowed to run for 5 minutes and the count recorded. Application of the calibration coefficient provided a value of the mean velocity. At the same time an average windspeed was being measured at a tower upstream of the complex terrain, this being used as a reference value for normalising the field day data. During the course of the study, six such field days were performed.

5 RESULTS AND CONCLUSIONS

Some results for model B and two field days will be discussed, the full analysis being given by Neal (1979).

The flow visualisation tests showed that model B was not subjected to major flow direction changes. The points analysed on the model formed a grid pattern as shown in Fig.4, thus allowing the study of cross sections, longitudinal and lateral, through the model.

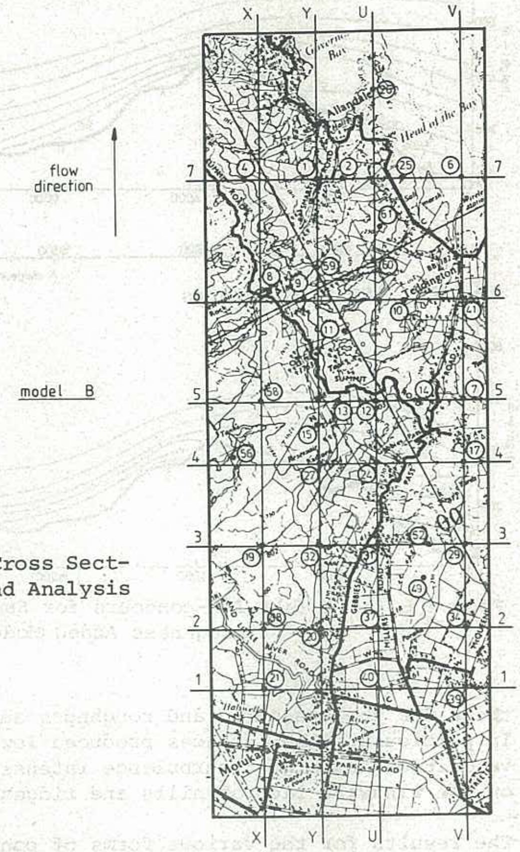


Figure 4 Cross Sections and Analysis Points

Iso-contour diagrams were prepared from the laboratory velocity and turbulence intensity measurements. These took the form of isotach and isoturb contour plots, such as those given for the terraced and roughness added form of construction for longitudinal cross sections YY given in Figs. 5 and 6.

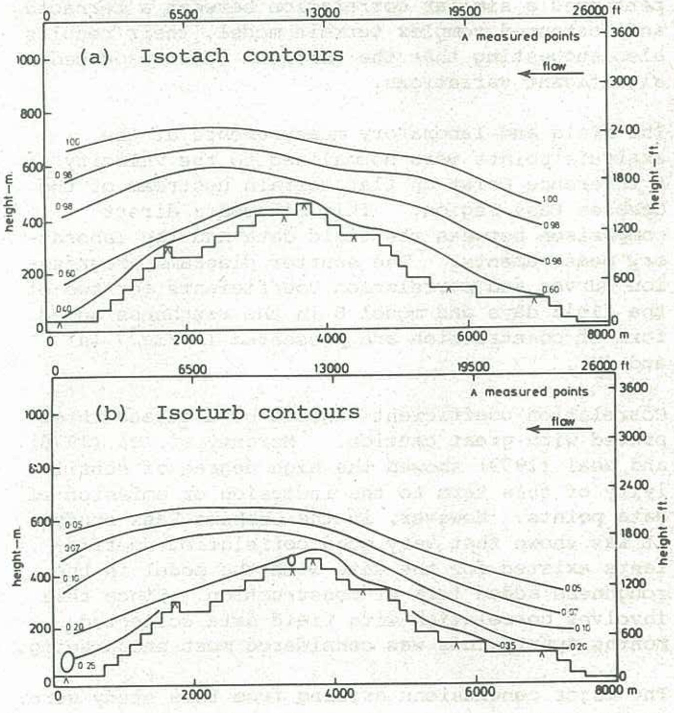


Figure 5 (a) & (b): Iso-contours for Section YY, Terraced Model

The results obtained with the model in the terraced form of construction were markedly different to

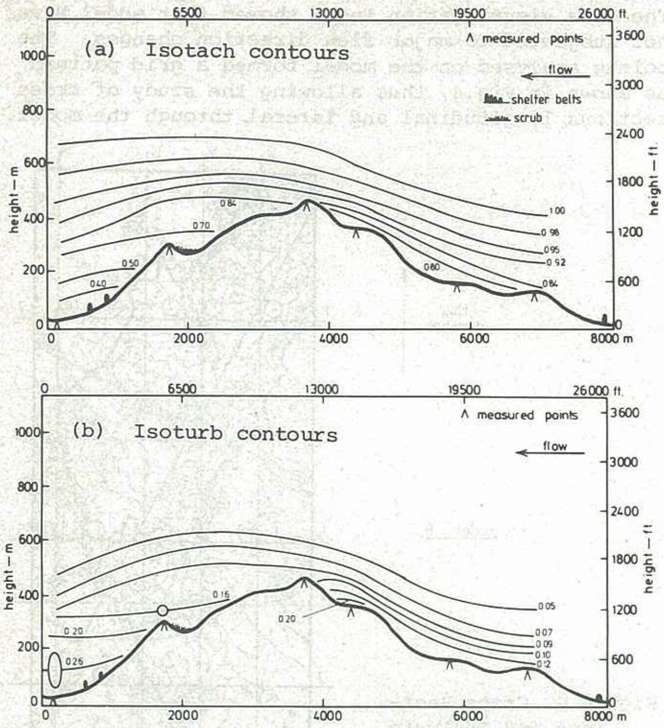
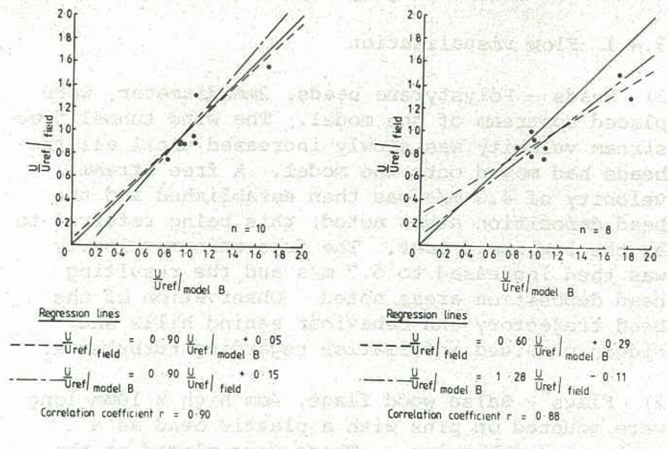


Figure 6 (a) & (b): Iso-contours for Section YY, Roughness Added Model



a) Field Data Collected on 14/12/78 b) Field Data Collected on 9/8/79

Figure 7 (a) & (b): Scatter Diagrams Between Field and Model B with Roughness Added

those for the contoured and roughness added models. In particular, the terraces produced lower velocities and higher turbulence intensity values on the windward face of hills and ridges.

The results for the various forms of construction were compared by statistical correlation and scatter diagrams. The correlation between the terraced and other forms of construction was typically poor, 0.5 to 0.6 at a prototype height of 20m, an improvement to 0.67 was found for a prototype height of 160m. Meroney *et. al.* (1978) performed a similar correlation between a terraced and contoured complex terrain model, their results also suggesting that the terraced model produced significant variations.

The field and laboratory measurements at the analysis points were normalised to the velocity at a reference point on flat terrain upstream of the Gebbies Pass region. This allowed a direct comparison between the field data and the laboratory measurements. The scatter diagrams, regression curves and correlation coefficients for two of the field days and model B in the roughness added form of construction are presented in Fig.7 (a) and (b).

Correlation coefficients should be used and interpreted with great caution. Meroney *et. al.* (1978) and Neal (1979) showed the high degree of sensitivity of this term to the inclusion or omission of data points. However, in the Gebbies Pass study it was shown that very good correlation coefficients existed for the data with the model in the roughness added form of construction. Since this involves correlation with field data collected months apart, this was considered most encouraging.

The major conclusions arising from this study were:

1) Approach flow characteristics could be simulated correctly, these being confirmed by field measurements on the prototype.

2) Accurate reproduction of surface roughness and terrain shape were required to produce equivalent wind speeds close to the ground, i.e., in the bottom 100m of the boundary layer.

3) Terraced models were shown to be unsatisfactory for WECS site selection tests. However, for heights greater than two terrace heights, this type of model could be useful, in particular, for pollutant dispersion studies.

4) Physical modelling reproduced the relative wind speeds in a complex terrain situation to produce sample correlation coefficients of 0.71 to 0.97, thus being similar to the range of variability found between the data from the various field days.

6 REFERENCES

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