PROSPECTING FOR WIND ENERGY

by

Robert N. Meroney*

Fluid Mechanics and Wind Engineering Program

Colorado State University

Fort Collins, Colorado 80523

Submitted to

1978 International Solar Energy Society (ISES)

Solar Diversification Annual Meeting

August 28-31, 1978

Denver, Colorado

*Member, American Chapter,
International Solar Energy Society

June 1978

CEP77-78RNM65

PROSPECTING FOR WIND ENERGY

Robert N. Meroney
Colorado State University
Fort Collins, Colorado
80523 U.S.A.

ABSTRACT

Physical modeling of wind regimes in the Rakaia Gorge region, Southern Alps, New Zealand, was utilized to evaluate the wind energy potential. Wind tunnel measurements were combined with local climatological measurements and a mobile field program to assess site locations for Wind Energy Conversion Systems.

1.0 INTRODUCTION

Similarly to the thoughts of the old, grizzled and weathered miner, a wind prospector's eyes often turn toward the hills or mountains when one speaks of riches to be exploited from the wind. Visions of wind driven power sources have tantalized mankind for centuries; however, past experience with power generation by windmills indicates that the most important factor controlling success or failure of these systems is site wind characteristics. Incorrect placement on a site sheltered by buildings, terrain or agricultural growth may drop performance to one-third of the original expectations. Conversely, the appropriate hill or ridge shape may amplify power available at a given height by an order of magnitude above that over flat terrain! Once a system is designed to operate optimally at one wind speed mechanical, aerodynamic and generating efficiencies may constrain subsequent performance to only linear improvement at higher wind speeds or a cubic loss at lower wind speeds. Recent insights on the influence of terrain suggest that there is significant wind energy available over complex mountain topography. Site selection procedures include statistical climatology, numerical simulation, and physical simulation in meteorological wind tunnels. Laboratory measurements of wind overspeed, streamline patterns, and turbulence changes over idealized topography have been compared with "frozen vorticity" numerical models. [1,2]

New Zealand and the United States have a common WECS siting problem. They are both geographically complex, contain many potentially attractive wind power sites, and yet in many such areas of complex terrain there are "meteorological data" deserts. One such area is the Rakaia River Gorge region on the eastern slope of the Southern Alps in New Zealand. Climatological records obtained from stations somewhat removed from the area suggest moderate to very high wind energy. Local farmer and fishermen wisdom and folklore speak of incredible winds in the gorge canyon. Extended field measurement programs are invariably expensive and time consuming; hence a survey program was proposed to utilize laboratory simulation of the relevant wind characteristics in a meteorological wind tunnel. To evaluate the validity of laboratory simulation methods and provide a confidence measurement bound for laboratory data, a simultaneous limited field measurement program was organized.

2.0 WIND TUNNEL EXPERIMENT

The laboratory method consists of obtaining velocity and turbulence measurements over a scale model of selected terrain placed in a simulated atmospheric flow. The wind characteristics of the simulated atmospheric flow are chosen to reproduce the wind profile shape and length scales of the equivalent prototype situation. Since field profiles are rarely available in advance, velocity profiles and turbulence characteristics are chosen to fit an equivalent class of conditions as recorded by earlier investigators over terrain of similar roughness.

The area studied by means of a laboratory model is located along the Rakaia River as it emerges from the Southern Alps, South Island, New Zealand. The primary terrain features consist of the Rakaia River Gorge which runs generally in a northwest-southeast direction. Gorge walls rise 180 meters, surrounding hills rise to 460 meters. To the south lies the Mount Hutt range which climbs to 2188 m. The range parallels the course of the Rakaia River in this area. To the north lies the Rugged Range but nearby Fighting Hill and Round Hill are the largest features. A model section 6100 m wide by 18,300 m long centered over the Rakaia River Gorge was constructed to a scale of 1:5000.

The construction material was expanded polystyrene bead board cut to 0.61 cm thickness to match 100 ft map contour intervals. This was mounted in layers on a particle board support sheet. The dimensions of the overall model is approximately 5 m long by 1.22 m wide which includes a 1.2 m terraced section upwind to transition the model to the tunnel floor. To provide a greater upwind fetch of equivalent surface roughness an additional 1.22 m x 2.44 m section of polystyrene bead board was mounted immediately upwind of the transition subsection. The total model length was thus 7.3 meters. A 2.5 cm high trip fence and a square bar turbulence grid were placed upwind of the model to produce the desired similitude characteristics. Plaster was smoothed between terrace escarpments and was textured to provide an equivalent surface roughness. This surface roughness was such as to provide a $z_o \simeq 0.01$ mm equivalent to $z_o = 0.05$ m at full scale.

The hill sides to either side of the Rakaia River are primarily devoted to sheep paddock. To protect flocks and paddock surface during the high wind event, farmers have planted shelterbelts around most fields. Most of these shelterbelts are mature coniferous tree stands about 20 m high. The tree stands often consist of several rows and appear quite dense. Aerodynamic studies of flow fields behind shelterbelts in New Zealand have been performed by Sturrock [3]. Measurements behind 4 mm high pipe cleaners revealed they simulate the velocity and turbulence field for 1:5000 scale very well; hence pipe cleaner shelterbelts were added to the model to simulate the prototype vegetation.

The Rakaia River Gorge model was studied in an Atmospheric Boundary Layer Wind Tunnel as shown in Figure 1. The model as it appeared in the tunnel is shown in Figure 2. Laboratory measurements include horizontal and vertical profiles of mean wind velocity, longitudinal turbulence, wind direction, turbulence spectra and correlation utilizing hot wire anemometry, pitot-static pressure probes, and cobra pressure probes.

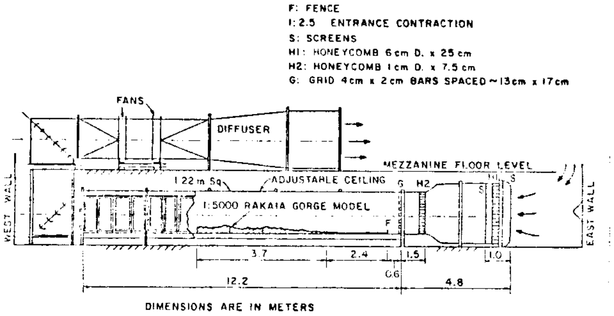

Fig. 1. Boundary layer wind tunnel, Department of Mechanical Engineering, University of Canterbury.

Fig. 2a. Rakaia Gorge Outlet - Mt. Hutt Range in background.

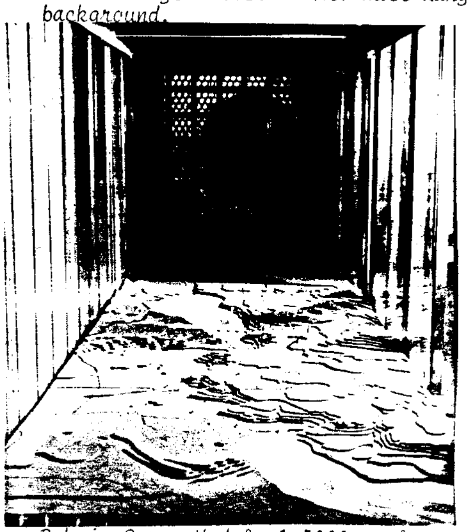

Fig. 2b. Rakaia Gorge Model, 1:5000 scale.

3.0 FIELD EXPERIMENT

Measurements of wind velocity and directions were desired over the Rakaia River Gorge test region to provide a basis for validation of laboratory methodology and physical modeling. Ideally a network of permanent meteorological instruments would be installed on multiple towers with data recording equipment versatile enough to intercept and record a northwesterly wind event. The cost of capitalization and maintenance of such a network was unfortunately prohibitive. An alternative proposed is to place a simple, lightweight cup anemometer on each of several collapsible pole towers and move the towers frequently during a wind event. The effectiveness of such a procedure will depend upon spatial correlation of wind velocities over the same 100 square km region, the quasi-stationarity of the wind event over a 3 to 6 hour period, and the statistical significance of a 15 minute sample at a given point taken once during a 3 to 6 hour recording period. Recent climatological analysis by Corotis [4] suggest high correlation (0.76 - 0.83) over distances less than 22 km and autocorrelation time constants from 3.5 to 7 hours. The criteria for a field station were thus light weight, rapid erection, and low cost. Three masts were constructed of 5 cm diameter thin wall aluminum tube. The tubes were made in two 5 meter sections which could be connected via a simple sleeve joint. Three nylon rope ties were attached at 7.5 m to the upper section and when erected the ties attached to three steel stakes driven at convenient distances from the mast base. The three cup RIMCO anemometers were attached to the top of the mast by a threaded fitting. A 3 lead supply and signal cable led from the anemometer to a power supply and counter module placed at the base of the mast. The entire system was conveniently light and easy to handle. It could be carried on the luggage rack of a passenger car or in the back of a jet boat. Two or three men could erect the tower in 5 minutes and remove it in somewhat less time (Figure 3).

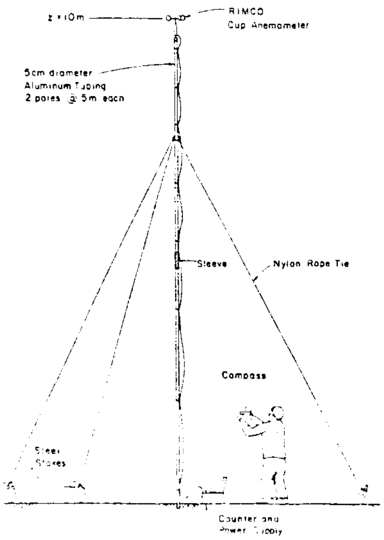

Fig. 3. Portable tower and anemometer, Rakaia River Gorge field experiment.

On two spring days, selected for strong adiabatic down valley wind flow, three teams of investigators surveyed up to 27 sites on either side and within the river gorge. Measurements consisted of wind speed and direction at a 10 meter height on lightweight portable towers. All measurements were completed during the course of a five hour stationary wind event and normalized against continuous records taken from a New Zealand Wind Energy Task Force anemometer near terrain center.

4.0 RESULTS AND CONCLUSIONS

A series of contour diagrams were prepared from the laboratory velocity and turbulence intensity measurements into isotach and isoturb charts. Figures 4 and 5 show a typical pair of such drawings. Note the wide variation in wind speed near ground level between points within the gorge and the nearby hill top. Simutaneously large relative gustiness exists within the river gorge when compared to the hill crest. Horizontal sections prepared for a 10 meter equivalent height reveals the river valley and gorge consistently has lower wind energy than the surrounding ridges.

The laboratory simulation results were compared with the available field data by means of statistical correlation and scatter diagrams. The model and field results were used to assess the value of the laboratory experiments for assisting WECS siting field programs. A thorough search of the literature reveals that few authors have chosen to compare field and model (either numerical or physical) results in other than qualitative terms. Recently Fosberg, et al. [5] compared a numerical model which includes terrain, thermally, and frictionally induced perturbations against seven field data sets. Correlation coefficients determined for the velocity and direction results were 0.60 and 0.62 respectively. These limited results may be used as a context within which to judge the efficacy of the present physical model or as a statement of reasonably current alternative modeling capacity. A typical scatter diagram result is shown in Figure 6. Plotted on the scatter diagram

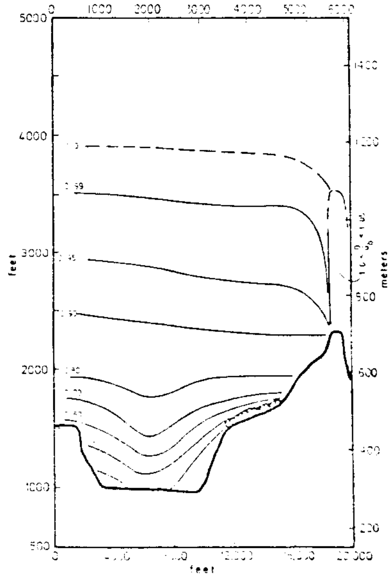

Fig. 4. Typical vertical section isotachs.

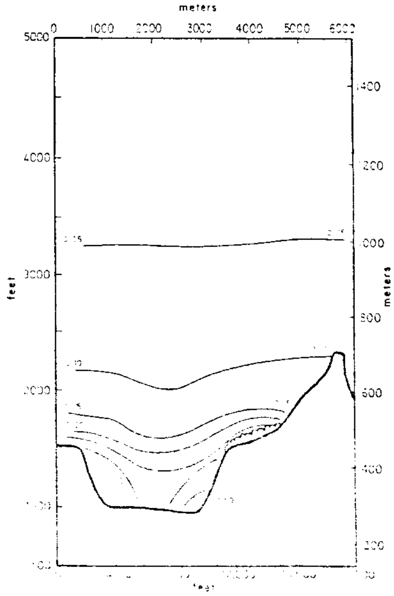

Fig. 5. Typical vertical section isoturbs.

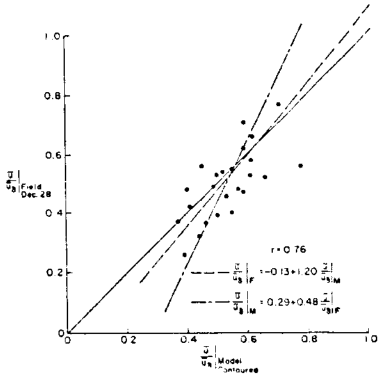

Fig. 6. Scatter diagram field test data, December 28 versus contoured model data.

are the co-correlation lines of the result of regressions of abscissa against ordinate and ordinate versus abscissa. When r = ± 1 these lines will be colinear, when r = 0 the lines will be perpendicular. The lines thus provide visual evidence of the quality of correlation.

Specific results and conclusions resulting from this research are

1. Physical modeling can reproduce wind patterns produced by the atmospheric shear layer flowing over complex terrain to within the inherent variability of the atmosphere to produce stationary results;
2. Physical modeling reproduced the relative wind speeds found over complex terrain by rank to sample correlation coefficient levels equal to 0.78 to 0.95;
3. Physical modeling reproduced the individual day to day quantitative wind speeds found over complex terrain to sample correlation coefficient levels equal to 0.70 to 0.76;
4. Physical modeling reproduced the two field day average quantitative wind speeds found over complex terrain to a sample correlation coefficient level equal to 0.81;
5. Physical modeling reproduced the individual day to day site wind directions found on complex terrain to simple correlation coefficient levels equal to 0.65 to 0.67;
6. Adequate physical modeling of adiabatic shear flow over complex terrain requires attention to surface roughness, terrain shape, and vegetation as well as upstream velocity profile, turbulence intensity, and turbulence eddy structure.
7. Over complex terrain local wind speeds may vary by over 100% in a distance of a few hundred meters as a result of terrain shadowing, flow separation, or flow enhancement;
8. In the Rakaia River Gorge area preferred WECS locations are the surrounding hills and ridges, and not the gorge or river bottons.

Climatology statistics and simulation techniques are the "pick and shovel" of the modern wind prospector. It is expected that rapid and inexpensive site evaluation procedures will eventually coalesce into methods to aid in the early selection of suitable locations for wind-powered electrical generator systems.

5.0 ACKNOWLEDGEMENT

Financial assistance was provided by Department of Energy Contracts EG-77-S-06-1043 and EY-76-S-06-2438, a Fulbright Hays Travel Grant, and an Erskine Lectureship at the University of Canterbury. Drs. A. J. Bowen and D. Lindley, University of Canterbury, assisted during the field portion on this Project.

6.0 REFERENCES

[1] R.N. Meroney, et al. "Wind Tunnel Simulation of the Influences of Two Dimensional Ridges on Wind Speed and Turbulence," Proceedings of International Symposium on Wind Energy Systems, Cambridge, England, 17 pp. September (1976).

[2] R. N. Meroney and R. G. Derickson "A Simplified Physics Airflow Model for Evaluating Wind Power Sites in Complex Terrain," Proceedings of Summer Computer Simulation Conference, Chicago, Illinois, 14 pp. (1977).

[3] J. W. Sturrock "Aerodynamic Structure of Shelterbelts in New Zealand-2: Medium Height to Tall Shelterbelts in Mid Canterbury," New Zealand J. of Science, Vol. 15, No. 2, pp. 113-140 (1972).

[4] R. B. Corotis "Stochastic Modeling of Site Wind Characteristics," Department of Civil Engineering, Northwestern University, DOE Report ERDA/RLO/2342-77/2, 143 pp. (1977).

[5] M. A. Fosberg, et al. "Estimating Airflow Patterns Over Complex Terrain, USDA Forest Service Research Paper RM-162, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, 16 pp. (1976).