THE ASKERVEIN HILL EXPERIMENTS

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Summary

A co-operative full-scale experiment to measure the wind flow and turbulence characteristics over a low smooth hill is described and some typical field results presented. This field experiment together with associated numerical prediction and wind-tunnel modelling programmes,have provided an excellent data set for the study of boundary-layer flow over low hills.

Introduction

This paper reports on the Askervein Hill project which was established in June 1982 as Task VI of the International Energy Agency Programme of Research and Development on Wind Energy Conversion Systems (Study of local Wind Flow at Potential WECS Hill Site). The participants in the project are Canada (Operating Agent), Denmark, Germany, New Zealand and the United Kingdom. The objective is to improve our understanding of the boundary-layer flow over relatively low smooth hills by carrying out a major co-operative field experiment to measure in detail, the spatial characteristics of mean wind and turbulence over a typical wind-turbine hill site. A suitable hill called Askervein was previously located in the Outer Hebrides and a preliminary field test was carried out in September-October 1982 with the main field study one year later. Full details of these two co-operative field experiments and the accumulated data are given in [1] and [2].

These data will also be used to assess the accuracy of a number of supplementary wind-tunnel model tests (some of which have already been reported in [3],[4]) and a numerical prediction model [5],[6] developed at AES, Canada. A series of journal papers is being prepared to cover the field, model and numerical activities. By an intercomparison of these data, it is hoped to refine the numerical and wind-tunnel modelling techniques to ensure that they adequately simulate the full-scale flow. The techniques can then be applied to other sites with confidence avoiding the necessity for complex and costly full-scale measurements. The accumulated field and model data and the experience gained will also be invaluable for other wind engineering applications, particularly for the prediction of wind loading on structures at exposed hill sites.

Askervein Hill Site and Field Tests

Askervein is an isolated hill of elevation 126 m ASL located near the west coast of the island,South Uist in the Outer Hebrides, Scotland. The smooth hill is elliptical in plan with a 2 km long major axis orientated near the NW-SE direction and a 1 km long minor axis. A 2 m contour interval map of Askervein is shown in Figure 1. To the west of the hill, from which sector the majority of the winds blew during the field tests, there is a flat uniform fetch of 3 to 5 km covered by heather, grass and low rocks to the coastline. The estimated surface roughness length, $Z_o \simeq 0.03$ m. The western foot of the hill has an approximate elevation of 10 m giving a hill height h = 116 m for winds from this sector. A typical value of L = 220 m, defined as the distance from the hilltop to the upstream point where the elevation is half its maximum, may be taken for this sector, giving a value of $h/L \simeq 0.53$. The summit of the hill is marked as HT on Figure 1 and a second position called Centre Point (CP) was chosen as an additional reference point marking the centre of the wind-tunnel models. A Base Station (BS) was established near the foot of the hill to assist the field activities, while an upstream Reference Site (RS) (not shown) was located about 3 km to the SSW of the hill for detailed measurements of the undisturbed wind flow prior to its modification by the hill.

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The preliminary 1982 field test was mainly concerned with mean-flow measurements whilst the main 1983 test recorded both turbulence and mean-flow data. On both occasions 50 m towers were deployed on the hilltop (HT) and at the upwind reference site (RS). These masts supported sonic, propeller and cup anemometers to measure vertical profiles. In addition to some 30 m and 16 m towers, about fifty 10 m posts and towers were deployed along the lines A, AA and B indicated in Figure 1, carrying one cup anemometer each at a height of 10 m. In the 1983 field test, line A was instrumented with 3 component propeller anemometers for detailed turbulence measurements. Airsonde and Tala kite profiles provided additional profiles for heights above 50 m. During the main 1983 test intensive measurements were taken over a two week period for wind directions in the 140° - 285° sector with 10 m mean wind speeds at RS between 5 and 15 m/s. Over this period, 95 hours of mean wind and 30 hours of turbulence data were successfully recorded [2].

Results and Discussion

Some typical field data are presented here to indicate the extent of some changes to the mean flow and turbulence due to the presence of the hill. Figure 2 shows the mean velocity and horizontal RMS turbulence velocity $\sigma_h(\sim\sigma_u)$ profiles above HT compared with the undistorted upstream profiles at RS. The data were taken using cup anemometers during Askervein '82 [1] with a wind direction of 235°, nearly normal to the major hill axis.

Current understanding of the effects of smooth low 2D hills on the mean wind flow is largely based on the analytical theory presented by [7]. A useful measure of the modification to the mean flow speed is given by the fractional speed-up ratio,

$$\Delta S = [U(\Delta Z) - U_0(\Delta Z)]/U_0(\Delta Z) = \text{Amplification} - 1$$

where $U(\Delta Z)$ is the local mean velocity at a height ΔZ above the local terrain and $U_0(\Delta Z)$ is the undisturbed upstream velocity at the same height ΔZ. A recent paper [8] reviews simple prediction rules for estimating the maximum values of ΔS near the surface over a hill. Using these rules for Askervein for the field test conditions gives a maximum ΔS value = 1.8 h/L ~1.0 at HT which agrees quite well with the measured ΔS profile in Figure 2. This large increase in velocity is directly responsible for the general decrease in turbulence intensity (shown in Figure 2 as the fractional change in turbulence intensity $\Delta\tilde{T}$, defined in the same manner as ΔS above). However there is also a substantial decrease in σ_u evident in Figure 2 as predicted by [9] and others using rapid distortion theory, but the expected increase in σ_u in an inner-layer close to the hill top surface where there is a substantial increase in shear stress, is not clear. Figure 3 presents data for a typical run during Askervein '83 [2] showing the variation of conditions over the hill along line A at a constant height ΔZ = 10 m above the hill surface. The large increases in turbulence on the lee side are probably associated with flow separation.

Preliminary comparisons between the full scale, the wind tunnel and numerical modelling test results have been very encouraging and will be the subject of further publications.

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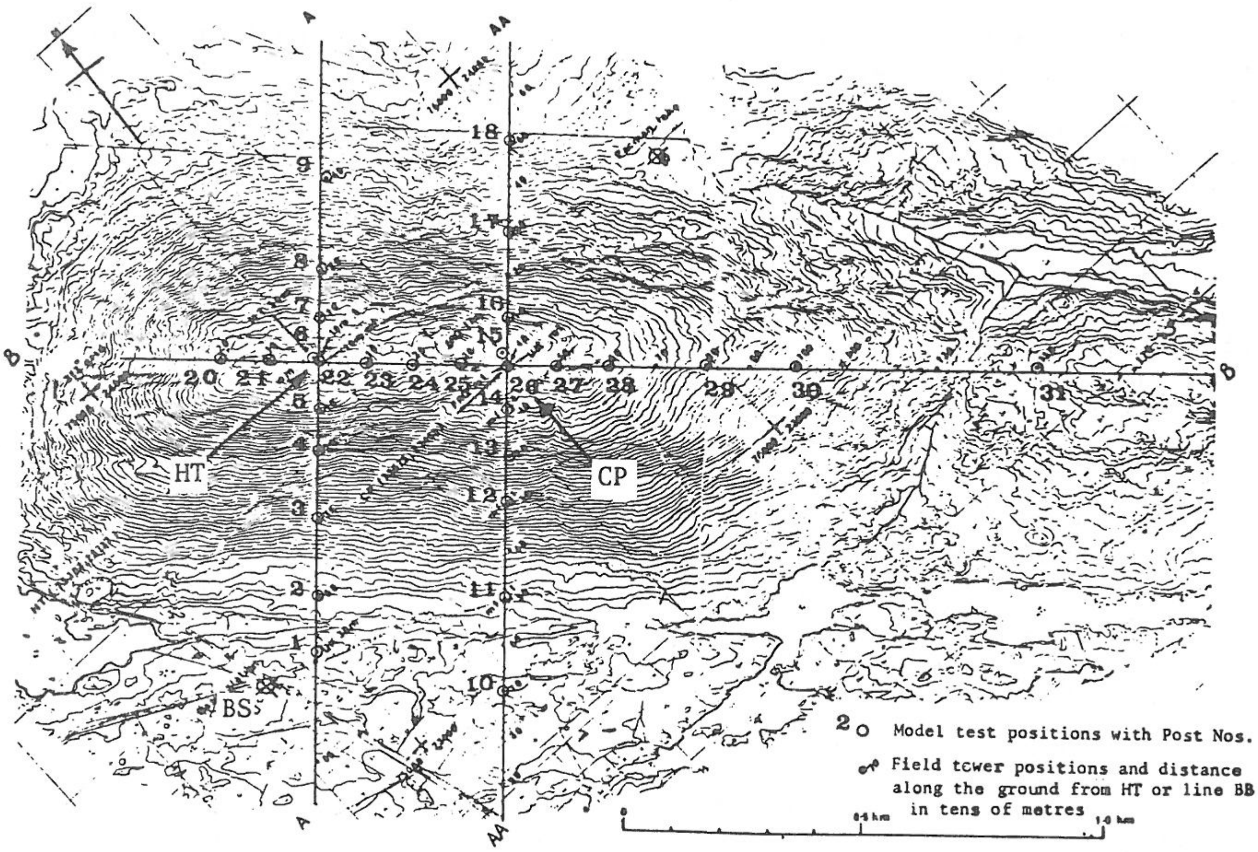

Figure 1. High resolution contour map of Askervein Hill (Contour interval 2m).

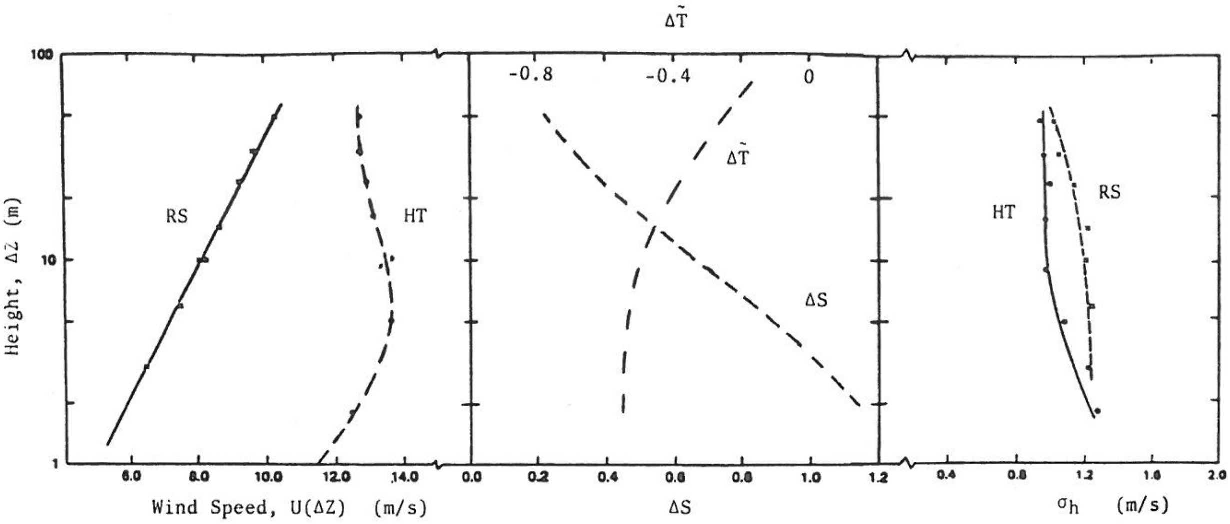

Figure 2. Typical field results from cup anemometerson 50 m towers at RS and HT from Askervein '82 for wind direction 235°, showing profiles of mean wind speed $U(\Delta Z)$, fractional speed-up ratio ΔS, standard deviation of the horizontal wind speeds σ_h and the fractional change in turbulence intensity $\Delta\tilde{T}$.

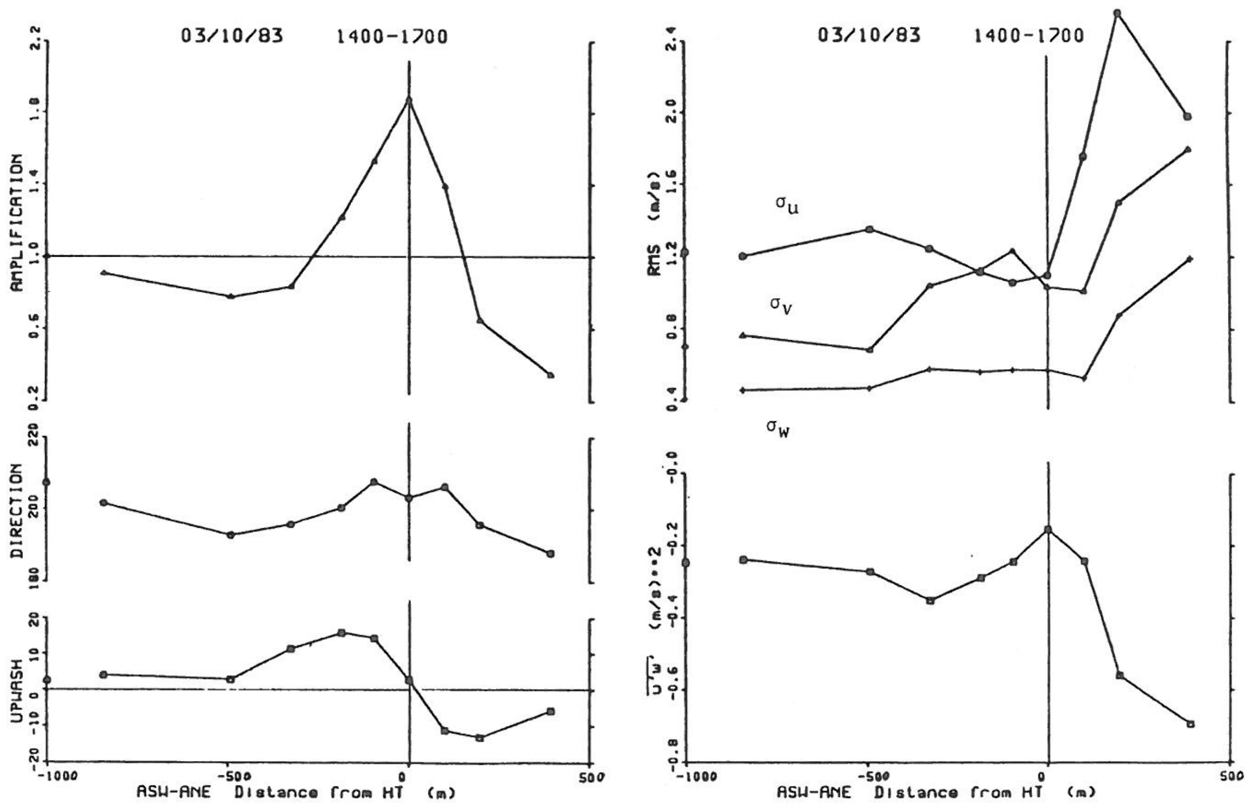

Figure 3. Variations of normalised wind speed (Amplification = $\Delta S + 1$), direction, upwash angle, σ_u, σ_v, σ_w, and $-\overline{u'w'}$ at $\Delta Z = 10$ m along line A during Askervein '83, run TU03A, wind direction 210°.