THE ASKERVEIN HILL PROJECT: OVERVIEW AND BACKGROUND DATA

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Abstract. The Askervein Hill project was a collaborative study of boundary-layer flow over low hills carried out under the auspices of the International Energy Agency Programme of R & D on Wind Energy Conversion Systems. Two field experiments were conducted during September–October 1982 and 1983 on and around Askervein, a 116 m high hill on the west coast of the island of South Uist in the Outer Hebrides of Scotland. During the experiments, over 50 towers were deployed and instrumented for wind measurements. The majority were simple 10 m posts bearing cup anemometers but, in the 1983 study, two 50 m towers, a 30 m tower, a 16 m tower, and thirteen 10 m towers were instrumented for 3-component turbulence measurement.

The present paper provides an overview of the project as a whole, including details of the instrumentation and a summary of the data obtained. Additional papers in the series, which are to appear in this journal*, will consider different aspects of the experimental data and related numerical-model and wind-tunnel studies.

1. Introduction

This paper is the first of a series describing field measurements undertaken as Task VI of the International Energy Agency Programme of Research and Development on Wind Energy Conversion Systems (WECS) together with related wind tunnel and numerical model studies. Task VI was a project to 'carry out a major cooperative field experiment to measure, in detail, the spatial characteristics of mean wind and turbulence over a typical WECS hill site'. Results of the project will of course have application in other areas as well. These include the wind loading of buildings and structures erected on hills and the dispersal of pollutants around them. The hill selected for the study was Askervein, a 116 m high (126 m above sea level) hill on the west coast of South Uist, one of the islands of the Outer Hebrides, Scotland. Groups participating in the experiment were from the Atmospheric Environment Service (AES), Canada, the Riso National Laboratory (RISO), Denmark, the University of Hannover (U. of H.), Germany, the University of Canterbury, New Zealand and both the Building Research Establishment (BRE), and ERA Technology Ltd. (ERA) in the United Kingdom. The abbreviations given above will be used throughout the series of papers on the project.

The main objective of the Askervein study was to further our understanding of boundary-layer flow over relatively low hills, especially as it relates to WECS siting. Factors of particular significance include the mean wind 'speed-up' and the modifications to the turbulence which occur as air flows over a hill. Detailed results will be given in some papers in the series (e.g., Salmon *et al.*, 1987; Mickle *et al.*, 1987) while

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data from the field experiments will be used in others to evaluate and refine physical (wind tunnel) and mathematical modelling techniques (e.g., Teunissen *et al.*, 1987; Raithby *et al.*, 1987). The aim of the present paper is to provide a description of the project and its overall objectives together with details of the site, the instrumentation used and a summary of the data obtained. It is intended to serve as background for subsequent papers.

A preliminary experiment (Askervein '82) was conducted in September–October 1982 and the main field experiment took place a year later. This will be referred to as Askervein '83. Reports by Taylor and Teunissen (1983, 1985), which we shall refer to as ASK82 and ASK83, document the data collected during the two field studies. The original detailed program of work for the project set the goals of Askervein '82 as:

(a) a thorough field intercomparison of the different mean wind and turbulence sensors to be used in the main experiment;

(b) resolution of the mean wind field in selected vertical cross-sections through the hill using cup anemometers on 10 m masts and TALA kite systems; and

(c) initial comparisons of wind speed, direction and turbulence characteristics between the hilltop and the upwind reference location.

Similar goals for the 1983 experiment were:

(a) detailed resolution of mean wind and turbulence fields in several vertical cross-sections through the hill using 10 m towers and tethersonde profiling systems; and

(b) a detailed study of the characteristics of turbulence above the hilltop to heights of at least 50 m.

In our revised plans, drawn up in May '83, we amended the original instrumentation lists to replace tethersonde systems by TALA kite systems. With this minor change, we were able to meet most of the goals stated above, although the data give wind and turbulence variations along lines at a fixed height (usually 10 m) above ground level plus one or two vertical profiles rather than throughout complete vertical cross-sections.

2. Scientific and Technical Basis for the Study

Although there had earlier been a number of measurements of wind speeds on hilltops (see, for example, Davidson *et al.*, 1964) and some theories concerning the speed-up caused by terrain features (see Golding, 1976, Ch. 7), a detailed and quantitative theory of boundary-layer flow over low hills has only been established in the last few years. Developments are still in progress on some aspects of the theory but the key paper is probably that by Jackson and Hunt (1975). Working in terms of a 'fractional speed-up ratio'.

$$\Delta S = \frac{U(x, \Delta z) - U_0(\Delta z)}{U_0(\Delta z)} \tag{1}$$

where Δz is height above the local terrain and $U_0(\Delta z)$ is the 'undisturbed' upstream velocity profile, they developed a theory to predict ΔS within a near-surface or 'inner' layer for flow over low two-dimensional hills. Mason and Sykes (1979) extended the theory to three-dimensional hills while Walmsley *et al.* (1982) and Taylor *et al.* (1983a) discussed further extensions to the theory and applications to real terrain.

Hunt (1980) has reviewed simple rules of thumb for estimating maximum, near-surface, values of ΔS above hill and ridge tops. He suggests that for 2D ridges:

$$\Delta S \simeq 2 \frac{h}{L} , \tag{2}$$

where h is the hill height and L is defined as 'the distance from the hilltop to the upstream point where the elevation is half its maximum'. For a three-dimensional, axially-symmetric hill, Hunt implies that the 2D result will apply but Taylor and Lee (1984) suggest that

$$\Delta S \simeq 1.6 \frac{h}{L} \tag{3}$$

is probably a better estimate. For typical low hill sites ($h \sim 100$ m, $L \sim 250$ m), we can thus find increases of order 60% in near-surface wind speed while for slightly steeper hills, increases up to 100% are not uncommon. Since kinetic energy fluxes and, hence, the power available to a WECS are proportional to the cube of the wind speed, these increases are of enormous significance in the selection of suitable sites for wind turbines as well as to the potential wind loads on structures, which depend on the square of the speed. In addition to modifications to the mean flow, the straining of the flow during its passage over a hill will modify the turbulence structure. There are some theories concerning this phenomenon (see, for example, Hunt, 1980) and a few measurements have been made (e.g., Bradley, 1980; Mason and King, 1985) but there is still relatively little known about turbulence structure in the flow over hills. This will be of considerable significance to the design of large WECS or other structures to be erected on hilltop sites.

The Jackson–Hunt theory postulates that Reynolds stresses will play a significant role in modifying the flow only within an inner layer of depth l which is defined by the equation

$$\frac{l}{L} \ln(l/z_0) = 2\kappa^2 . \tag{4}$$

Here z_0 is the surface roughness length and κ is the von Kármán constant, which we shall take as 0.4. Jensen *et al.* (1984, p. 51) propose an alternative to Equation (4) based on a similar scale analysis but assuming a logarithmic profile within the inner layer (see Taylor *et al.*, 1987). This leads to the equation

$$\frac{l}{L} \ln^2(l/z_0) = 2 \kappa^2 \tag{5}$$

and considerably lower values for the inner-layer depth. We shall denote the solution to (5) by l^* to distinguish it from the original Jackson–Hunt value. Although it is not formally defined as such, several authors have found it useful to identify l or l^* as the height of the maximum velocity perturbation ($\Delta U = U(x, \Delta z) - U_0(\Delta z)$) above a hilltop.

In our typical case with $L = 250$ m, setting $z_0 = 0.03$ m we obtain values of $l \simeq 13$ m and $l^* \simeq 3.5$ m. Britter *et al.* (1981) argue that for $\Delta z \ll l_T$ (where l_T is an inner layer depth for turbulence and $l_T \simeq l$) the turbulence is in an approximate local equilibrium with the velocity shear while for $\Delta z \gg l_T$ the turbulence changes can be estimated from 'rapid distortion theory'. Data from the Askervein experiments will be used to test these hypotheses.

Several field studies of the detailed structure of boundary-layer flow over low hills have been carried out recently including those on Brent Knoll (Mason and Sykes, 1979), Kettles Hill (Taylor *et al.*, 1983), and Blashaval (Mason and King, 1985). None of these has been as extensive or detailed as the Askervein experiment, but they have provided many useful ideas and hypotheses which we can test with the Askervein data. In the case of Kettles Hill, some comparisons are also being made between field data and detailed numerical and wind tunnel models (Teunissen *et al.*, 1982; Teunissen, 1983). Further details on recent field studies are given in the review by Taylor *et al.* (1987).

3. Site Details, Askervein

From the outset, our aim was to mount the Task VI field experiment at a site which would be potentially suitable as a location for a WECS installation. We therefore set out to locate a well-exposed coastal hill with good speed-up characteristics, which was not heavily forested. Our goals in site selection were first of all that the hill should be:

(a) a potentially good WECS hill site;

(b) suitable from a numerical modelling point of view;

(c) such that representative measurements could be made at moderate heights (say ~ 10 m) on the hill and over the surrounding terrain; and

(d) easily accessible.

In physical terms we sought a hill which:

(i) was reasonably isolated and had a uniform upwind fetch for the prevailing wind;

(ii) possessed a 'spectral gap' between the dominant wavelength of the hill and the size of the roughness elements;

(iii) had a uniform ground cover, preferably grass, heather or low scrub, and a minimum of trees or buildings; and

(iv) if possible, though not essential, was axially symmetric or approximately two-dimensional or, alternatively, was located in an area with a well-defined predominant wind direction.

Following discussion of some possible sites in Jutland (Denmark), Canada and Germany, the participants agreed that hills in the Outer Hebrides of Scotland offered the best potential sites for the proposed experiment and that Askervein on South Uist would be our first choice. ERA Technology Ltd. (the U.K. participant) were able to secure the agreement of the local land owners and tenants and to arrange permission for the experiments; at that stage Task VI started to become a reality.

Askervein, or Askernish hill as it is sometimes referred to locally, is located near the west coast of South Uist, toward the southern end of the outer Hebrides island chain. The hill coordinates are 57° 11 N, 7° 22′ W. It is essentially elliptical in plan form with a 1 km minor axis and a 2 km major axis. The major axis is oriented along a generally NW–SE line. The predominant wind directions during September and October (the period of the experiments) are from the SW and S at the nearest meteorological station (Benbecula). Moderate-to-strong winds are the norm at that time of year.

The Ordnance Survey (OS) map of the area, a portion of which is shown as Figure 1,

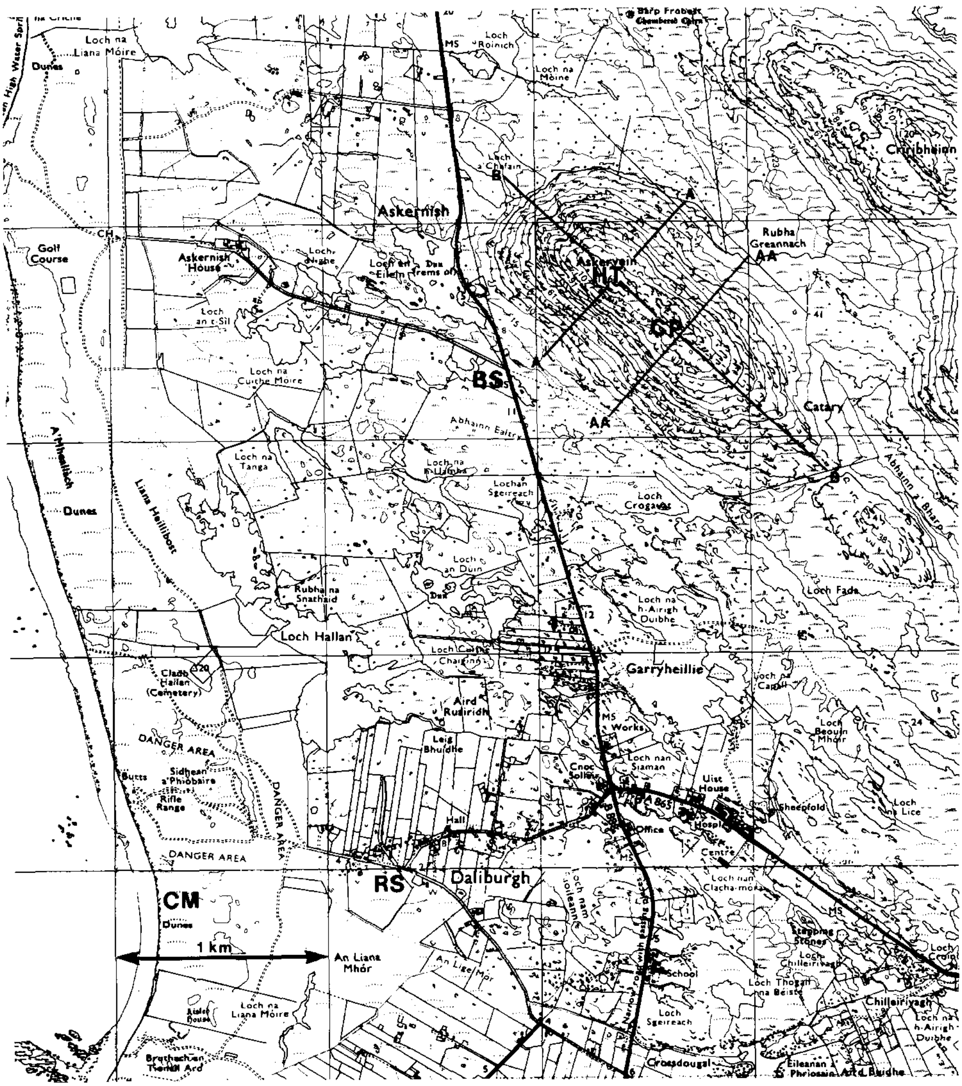


Fig. 1. Contour map of Askervein Hill and surrounding terrain. Contour intervals are 7 or 8 m (25 ft.). HT–Hilltop, CP–Centre Point, BS–Base Station, RS–Reference Site, CM–Coastal Machair Site (Machair–a flat or low lying plain or field–Scottish Gaelic)

shows that the hill is relatively isolated, apart from the hills Criribheinn and Layaval to the NE and E, i.e., downstream of the hill for the prevailing wind direction. To the SW, there is a flat uniform fetch of about 3–4 km to the coastline where there are sand dunes and low (~ 5 m) cliffs. The ground cover (see Figures 2 and 3) is mostly heather, grass, low scrub and some flat rocks, plus some small lochs in the upwind terrain. Although the terrain has features at all length scales, especially on the NE face of the hill, it was anticipated that the main features of the wind field modifications would be controlled by the overall shape of the hill and that there would be no difficulty in making representative measurements at a height of 10 m above the surface. The hill is neither axisymmetric nor two-dimensional. Its width-to-length ratio is, however, greater than 2D for SW flow and some comparisons with 20 models may be appropriate.

Fig. 2. Askervein Hill from the south-southwest.

Logistically the hill is a very good site, with the exception that it is too rugged and steep to drive over. This problem was overcome by helicopter lifts of equipment to the hilltop. A base station (BS in Figure 1) was established near the foot of the hill for logistical operations while an 'upstream' reference site (RS) was located about 3 km to the SSW of the hill near Daliburgh (see Figures 1 and 4). The reference site was used to make detailed measurements of the undisturbed flow prior to its encounter with the

Fig. 3. View from hilltop looking southwest.

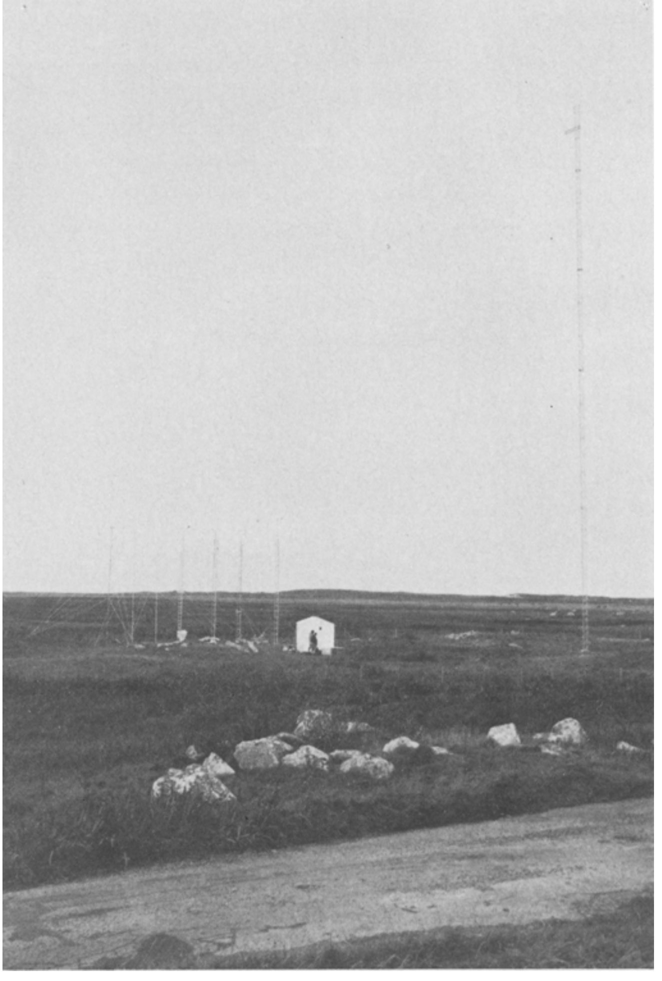


Fig. 4. View of Reference Station (RS) looking approximately south–southwest, showing 50 m tower and some 10 m towers used for anemometer intercomparisons.

hill. Although existing maps of the hill site were considered to be very good in terms of surface detail, they unfortunately had a contour interval of 7–8 m (metric conversion of 25 feet). This was marginal for the manufacture of detailed, relatively large-scale, wind-tunnel models of the hill and for application of the numerical models to be used. Consequently a custom-made, high-resolution, 2 m-contour-interval map was produced from 1 : 10 000 stereo photo pairs purchased from the Ordnance Survey in the U.K. The new map (Figure 5) covers only the hill and its immediate surroundings and was originally drawn at a scale of 1 : 2000. The summit of the hill is at a height of 126 m above sea level at location 075 383 E, 823 737 N, these numbers referring to the standard U.K. Ordnance Survey grid, which is overlaid on the figure. Since the summit point is

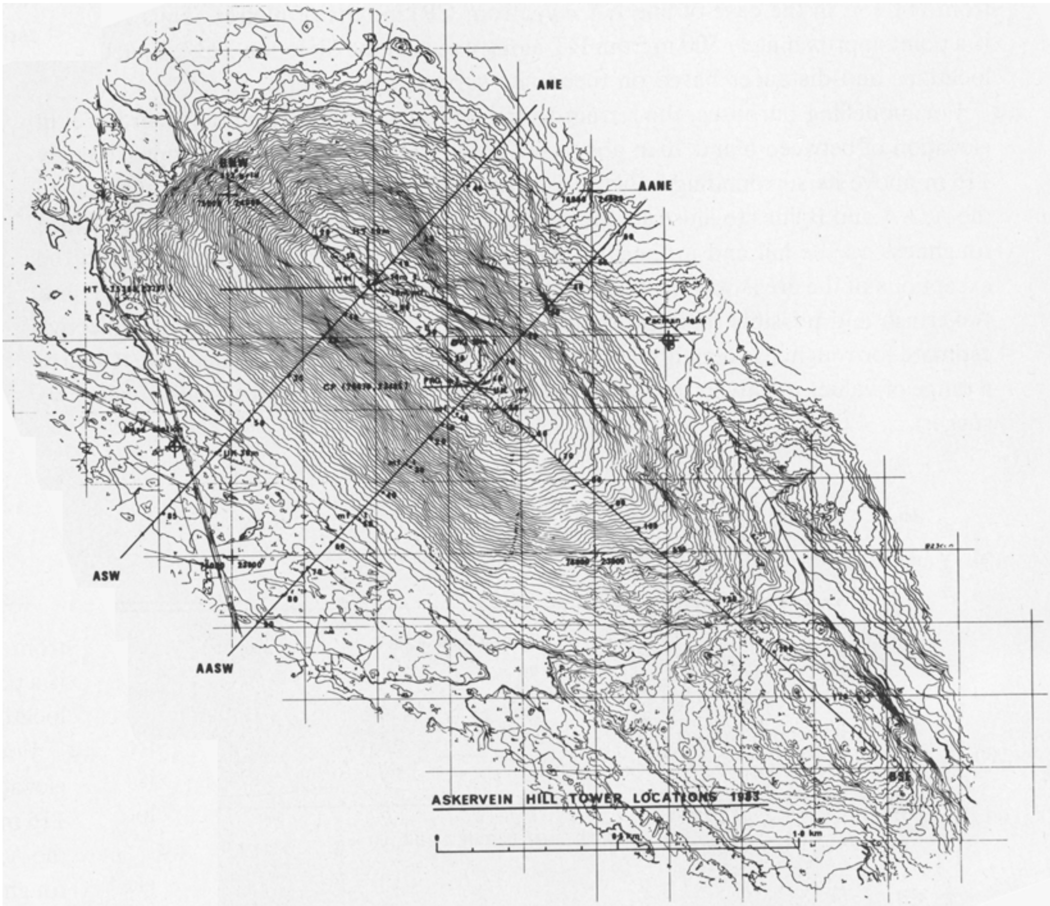


Fig. 5. Detailed contour map of Askervein Hill showing tower lines and locations. Towers (•) are 10 m high unless otherwise indicated (e.g., UK 30 m). The 10 m tower locations are labelled (10, 20, 30, etc.) with their approximate distance in tens of metres from HT (lines, A, B) or CP (line AA). Contour interval is 2 m with some auxilliary contours at 1 m intervals.

somewhat to the NW end of the hill, a second reference location ('centre point' or CP) was chosen (at 075 678 E, 823 465 N) as an additional point of reference on the hill. This also served as the centre for the wind-tunnel model of the hill (see Teunissen *et al.*, 1987). Note that on the OS grid, RS is at 074 300 E, 820 980 N. All grid coordinates are based on our 1983 survey.

During the experiments, most of the instrument towers and posts were deployed in approximately linear arrays through CP or HT. The main lines chosen were oriented at 043° (grid) and 133° (grid), approximately NE–SW and SE–NW along the minor and major axes of the hill, respectively. They are shown in Figure 5 and referred to as lines A, AA, and B, as shown. Locations along these lines are denoted by a code which includes the line identifier (e.g., A), the direction (e.g., SW) and the horizontal distance from HT (or, in the case of line AA *only*, from CP) in tens of metres. Thus ASW 50 is a point approximately 500 m from HT along line A in the direction 223°. Exact tower locations and distances based on theodolite surveys are given in ASK83.

For modelling purposes, the terrain to the SW of the hill can be taken to have an elevation of between 6 and 10 m above sea level. The hill height is then approximately 116 m above its surroundings. Figure 6 shows cross-sections of the topography along the A, AA and B lines to illustrate the spectral gap (ii). As far as we can tell, the surface roughness on the hill and in the surrounding terrain was essentially uniform with the exceptions of the areas with cottages or other buildings in the vicinity of Daliburgh and Askernish and possibly the sand dune areas near the coastline. Our initial subjective estimate for roughness length was $z_0 \sim 0.05$ m while profile measurements at RS gave a range of values mostly in the 0.01–0.03 m range. As a single representative value, we suggest $z_0 = 0.03$ m.

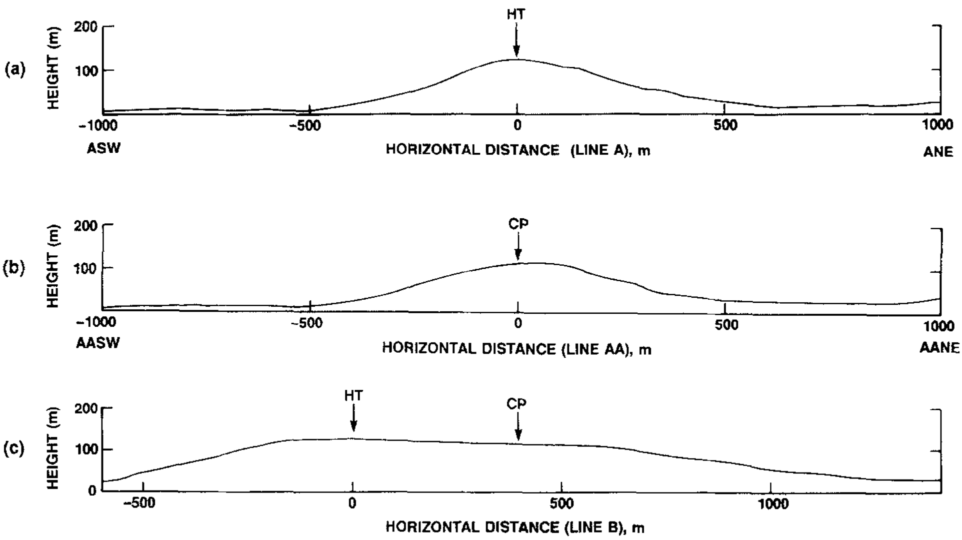


Fig. 6. Topographic cross-sections through the hill, no vertical exaggeration. (a) Along line A. (b) Along line AA. (c) Along line B.

4. Instrumentation and Data Acquisition

Details of the instrumentation and data acquisition systems deployed in the two field experiments are given in ASK82 and ASK83. These ranged from manually read, run-of-wind anemometers to sonic anemometers with on-line mini-computer data analysis. Since the different groups participating in the experiment used different instruments, data acquisition systems and procedures, we ran careful intercomparison tests at the reference site during both the '82 and '83 experiments. These provided ratios of mean wind and turbulence parameters measured by various sensors to those measured by a standard sonic anemometer system. In general, we have not adjusted the data presented based on these intercomparison tests, but we shall use the ratios where appropriate for data interpretation.

The anemometers and towers deployed in the '82 and '83 experiments were similar and, as already noted, are described in detail in the two project reports. Tower locations during Askervein '83 are shown in Figure 5; Askervein '82 locations were similar. The anemometry used in the '83 experiment can be summarized as:

(1) Two '50 m towers' (actually 48 m), one at RS and one at HT. Both towers supported cup anemometers and 'tilted' Gill UVW anemometers (i.e., with the vertical-component axis titled at 45° to the geopotential vertical) for wind speed and turbulence profiles. (Unfortunately, the Gill UVW data from the HT tower appear to have been irrecoverably contaminated.) In addition, sonic anemometers installed at 10 and 47 m at RS and at 2, 4, 6, and 47 m at HT produced several useable data sets.

(2) A 30 m tower (BRE) instrumented with Gill UVW anemometers (4) located near the base of the hill on the SW side, at ASW60, a 16 m tower with Gill UVW anemometers (3) and cup anemometers (3) at CP′ (near CP, see Figure 5) and a 17 m tower with cup anemometers (3) and a vane located at RS.

(3) Fifteen 10 m towers supporting Gill UVW anemometers for turbulence, mean speed and direction measurement. These were deployed at RS and along the A and AA lines through HT and CP, respectively.

(4) Thirty-five 10 m posts supporting cup anemometers for mean wind speed measurements. These were placed along the AA and B lines through CP during Askervein '83 and along the A and B lines during Askervein '82. Five of these posts, deployed in the AA line, also carried direction vanes during the 1983 experiment.

(5) TALA (Tethered Aerodynamic Lifting Anemometer) kites which were used during some periods of the experiment to provide upstream wind speed profiles to heights of ~ 500 m (using a multiple-kite system) and profiles above the hill (single-kite system).

In addition to the anemometry, other instruments were deployed to provide background temperature, humidity, precipitation, and pressure data. In particular, for Askervein '83, the temperature difference (16.9 m–4.9 m) was monitored at RS to provide an estimate of the gradient Richardson number while AIRsonde releases were made during the main observation periods in both Askervein '82 and '83 to provide information on temperature and humidity profiles to several kilometers. Wind speed and direction profiles were also obtained by visual tracking of the AIRsondes when conditions allowed. Estimates of geostrophic wind speed and baroclinicity were made from published large-scale surface, 85 and 70 kPa maps.

Data from the anemometers and other systems were recorded and analysed in a variety of ways by the different participating groups. Details are given in the ASK82 and ASK83 reports. The 'mean flow' data from the 10 m cup anemometer posts (see 4 above) were recorded and reported as 30 min averages for selected periods, usually of 2 hr total duration, in Askervein '82. In Askervein '83 these data were logged continuously throughout the experiment (except for some periods with battery power failures) as consecutive 10 min averages. Turbulence data were recorded for selected periods only and, in general, have been processed as 30 min blocks, the data from several blocks being combined to form a 'run'. Lists of mean flow (MF) and turbulence (TU) runs are given below (Tables I to V).

5. Synopsis

5.1. Askervein 1982

During this preliminary experiment, 'runs' were conducted between 20 September and 3 October 1982. They are indicated in Figure 7, which shows the continuous record of wind speed and direction for the period based on data recorded at Benbecula airport (about 33 km north of Askervein, at a similar west coast location). We were primarily interested in collecting data for wind directions between 180° and 270° with moderate-to-strong wind speeds. It can be seen from the Benbecula data that these conditions occurred on about 5 days in the core observing period. In total we obtained 24 hours of good near-surface mean flow data in 2-hr or 3-hr blocks, although some of these runs were for SE winds. We also collected profile data from the two 50 m towers at RS and HT and turbulence data on selected occasions. Table I lists the designated mean flow (MF) and sonic anemometer (S) runs for Askervein 1982 and shows what data are available. Additional details of the MF runs are given in Table II. AIRsonde soundings at the site and regular upper air soundings from nearby weather stations indicated near-neutral conditions and minimal directional wind shear for all of the designated runs. Estimates of $\partial\theta/\partial z$ in the lowest 500 m based on AIRsonde data are included in Table II. Note that times are British Summer Time (BST = GMT + 1 hr).

5.2. Askervein '83

Askervein '83 was conducted between September 14 and October 18, 1983 with the main observational runs in the period September 25–October 10. The designated mean flow (MF), TALA kite (TK), and turbulence (TU) runs are indicated in Figure 8 and listed in Tables III-V. A total of 44 mean flow and 19 turbulence runs were obtained. Almost all runs had $|\mathrm{Ri}| < 0.015$ and can be regarded as neutrally stratified. The only run with $|\mathrm{Ri}| > 0.025$ is run TU–05D for which Ri = 0.046, which can be considered indicative of weak stable stratification. Table VI is a summary of weather conditions.

All of the designated runs over the 16 day period provided good and interesting data covering a range of wind directions. Monday, 3 October was perhaps the 'best' day for data collection with steady, moderate-to-strong winds from 210° through most of the day. These data may be used rather frequently for illustration but other runs will not be ignored.

From the two field experiments, we have a total of 55 MF runs, ranging in length from $\frac{1}{2}$ to 14 hr each and representing nearly 150 hr of data. The 19 TU runs from Askervein '83 range from $\frac{1}{2}$ to 2 hr each and total 33 hr. Fifteen TALA kite runs of 1–2 hr duration each were also obtained.

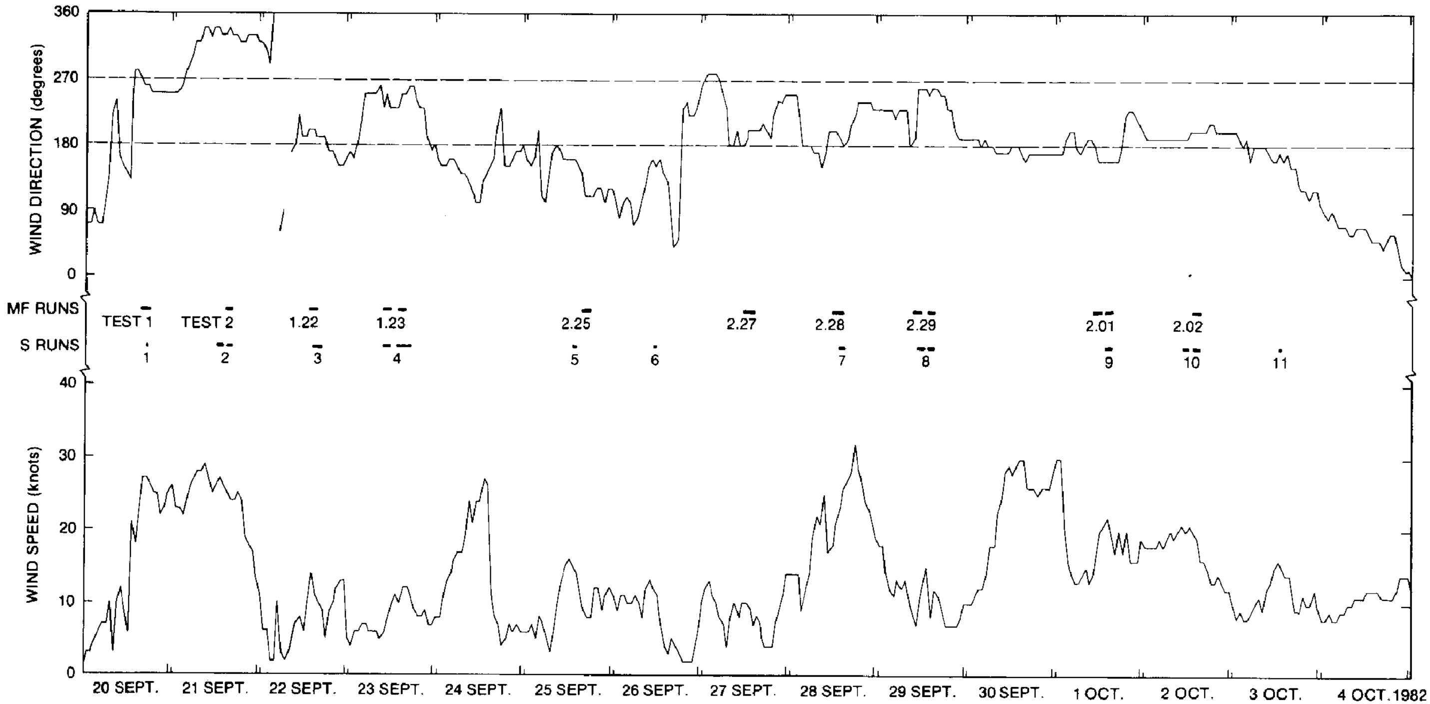


Fig. 7. Benbecula airport surface winds for the period 20 September–4 October 1982 showing Mean Flow and RS Sonic data collection periods for Askervein '82. Large axis-markers on the time axis are at 00 hr BST; smaller ones are at 00 hr GMT. The figure has been plotted using hourly observations reported by the airport meteorological station.

TABLE I

Summary of available data and definition of experimental runs for Askervein '82

Date 1982	Nominal RS Cond. Wind speed (ms^{-1})	Direction	Mean flow runs (MF)	Sonic runs (S) RS	HT	50 m Profiles		20 m BRE mobile tower	AIR-sonde flights	TALA kite profiles	10 m turbulence data AES	FRG	ERA	BRE	AES[g] T/S at HT	U2A[h] data	
	(10 m)	(10 m)	(Run No.)	(Run No.)		RS	HT		(No.)		(Locations)					RS	HT
18 Sept. Sa						×					RS						
19 Sept. Su						×					RS						
20 Sept. M	10–15	260	RS Intercomp. 1	1												×	
21 Sept. Tu	10–12	310–330	HT Intercomp. 2	2a, 2b		×		At RS			RS			RS		×	
22 Sept. W	5–7	160–180	1.22	3		×		At Rs		BRE	RS			RS		×	
23 Sept. Th	3–7	220–255	1.23a, b	41, b, c, d		×		Near BS[f]	2	BRE	RS	RS	RS	RS		×	
24 Sept. F																	
25 Sept. Sa	6–8	130–140	2.25	5		×	×	Near BS		BRE	RS, HT					×	
26 Sept. Su	6.5	125		6		×				Test of 4 Near Shoreline	RS					×	
27 Sept. M	6	160	2.27			×[a]	×	Near BS	1	BRE	RS[a], HT	CP				×	
28 Sept. Tu	13–16	160–170	2.28	7	×	×	×	Near BS	1		RS, HT	CP	CP			×	
29 Sept. W	6–9	220–280[e]	2.29a, b	8a, b	×	×	×	Near BS	2	BRE	RS, HT	CP	CP		×	×	×
30 Sept. Th										Experiment Attempted							
1 Oct. F	9–13	150–160	2.01a, b	9		×	×	Near BS	2	BRE, FRG	RS, HT	CP	CP		×	×	
2 Oct. Sa	7–11	200	2.02	10a, b	×[b]	×	×		1	BRE, AES, ERA	RS, HT	CP	CP			×	
3 Oct. Su	7–8	150–160		11	×[c]	×	×				RS, HT						
4 Oct. M				12		×	×[d]			Test at 50 m at RS, 4 kites	RS, HT						
5 Oct. Tu						×[d]											
8 Oct. F			MF test at CP ERA & CAN														

Notes:

[a] Partial data only.

[b] Rain for some of this period.

[c] 2 sonic levels only.

[d] Dismantling checks.

[e] Serious wind shifts during run 2.29a.

[f] No 5 m level.

[g] T/S = tethersonde – on cable attached to 50 m tower.

[h] U2A = standard Atmospheric Environment Service cup anemometer.

TABLE II

Additional details of mean flow (MF) runs for Askervein '82

Run*	Duration	Average wind[e] speed at RS (m s^{-1})	Wind direction °grid	$\left(\frac{\partial\theta}{\partial z}\right)_{0-500\text{ m}}$ K m^{-1} × 10^3	Comments
1.22	1400–1600[+]	6.37	180	–	–
1.23a	1000–1200	3.34	230	0.10[b]	Rather low wind speed.
1.23b	1400–1600	6.36	245	0.95	Slight wind shift during run.
2.25	1600–1800	6.50	120	–	Poor direction–upstream hills.
2.27	1200–1500	6.04	165	0.55[d]	Showers during run.
2.28	1200–1500	11.89	175	1.80	Showers during run.
2.29a	1000–1200	5.91	(225)	0.80	Direction change during run.
2.29b	1400–1600	8.29	235	1.55	Steady wind, occasional rain.
2.01a	1100–1300	8.93	165	1.15	Cloudy but dry.
2.01b	1400–1600	10.45	155	0.85[c, d]	–
2.02	1400–1600	9.21	200	0.00[d]	Storms nearby but not on hill.

[+] Times are given in British Summer Time (GMT + 1 hr).

( ) Some wind data are less reliable than others, most should be good to 5°.

* First digit is a guide to the configuration. The next two give the day of the month (September then October) while if two runs were conducted on the same day they are a and b.

[a] Best estimate based on a composite of data from a number of sources including the sonic and 3 cup Gill anemometers at RS, depending on what data were available during each run. Rounded to 5 deg. intervals.

[b] Based on AIRsonde release and averaged over lowest 500 m (applies to all runs).

[c] Strong (2 K) inversion between 1.0 and 1.2 km on this occasion.

[d] Shallow (~30 m) unstable layer near surface on these occasions.

[e] Based on pulsed cup anemometer at 10 m.

TABLE III

Designated mean flow (MF) runs during Askervein '83. Anemometers were at Δz = 10 m for the period 25 September–06 October, 1983 after which the majority of them were lowered to Δz = 3 m

Date	Run number	Time BST	Mean wind speed* (m s^{-1})	Mean direction* °Grid ±5°	Ri[+]	Duration (hours)
September 1983						
Sun 25	MF25	(1600–2130)	5.0	210	0.0098[c]	5.5
Mon26	MF26–A	(0000–0500)	6.0	180	0.0161	5.0
	MF26–B	(0900–1000)	8.0	210	0.0043	1.0
	MF26–C	(1900–2100)	7.8	220	0.0097	2.0
	MF26–D	(2100–0200)	7.1	225	0.0110	5.0
Tue 27	MF27–A	(0300–0430)	6.1	235	0.0126	1.5
	MF27–B	(0430–0700)	5.9	245	0.0134	2.5
Wed28	MF28–A	(0400–0600)	6.8	090	0.0078	2.0
	MF28–B	(0600–0800)	6.5	095	0.0109	2.0
	MF28–C	(0800–1000)	7.2	100	0.0133	2.0
	MF28–D	(2000–1000)	6.0	105	0.0167	14.0

Table III (continued)

Date	Run number	Time BST	Mean wind speed* (m s^{-1})	Mean direction* °Grid ±5°	Ri +	Duration (hours)
Fri 30	MF30–A	(1600–1900)[a]	12.0	130	0.0084	3.0
	MF30–B	(1900–0200)	12.5	135	0.0103	7.0
October '83						
Sat 01	MF01–A	(0200–0500)	13.0	140	0.0091	3.0
	MF01–B	(0500–0900)	14.8	145	0.0059	4.0
	MF01–C	(1030–1200)	10.2	170	0.0028[c]	1.5
	MF01–D	(1400–1600)	9.0	180	−0.0205[c]	2.0
	MF01–E	(1700–1830)	7.5	185	0.0103	1.5
	MF01–F	(2100–2400)	8.0	210	0.0141	3.0
Sun 02	MF02–A	(0200–0700)	6.8	210	0.0166	5.0
	MF02–B	(1400–1600)	10.0	165	0.0026	2.0
	MF02–C	(1600–2000)	11.0	165	0.0074	4.0
Mon 03	MF03–A	(0200–0600)	10.5	205	0.0131	4.0
	MF03–B	(0700–1000)	10.0	210	0.0116	3.0
	MF03–C	(1130–1300)	10.0	210	−0.0017	1.5
	MF03–D	(1400–1700)	8.9	210	−0.0110	3.0
Tue 04	MF04–A	(1000–1300)	7.0	180	0.0090	3.0
	MF04–B	(1830–1930)	11.0	285	0.0067	1.0
	MF04–C	(2300–2400)	10.0	270	0.0132	1.0
Wed 05	MF05–A	(0000–0200)	10.0	258	0.0133	2.0
	MF05–B	(0300–0700)	10.0	263	0.0123	4.0
	MF05–C	(0800–0900)	12.0	268	0.0079	1.0
	MF05–D	(1030–1130)	9.5	285	−0.0011	1.0
	MF05–E	(1330–1700)	7.8	305	−0.0092	3.5
Fri 07	MF07–A[e]	(0230–0500)	8.5	260	0.0046	2.5
	MF07–B	(1200–1400)[b]	9.0	240[d]	0.0004	2.0
	MF07–C	(1400–1600)	10.0	255[d]	0.0005	2.0
	MF07–D	(2200–2300)	11.0	270	0.0029	1.0
Sat 08	MF08	(0200–0400)	9.0	280	0.0045	2.0
Sun 09	MF09–A	(1800–1900)	11.0	275	0.0025	1.0
	MF09–B	(1930–2030)	10.2	283	0.0038	1.0
	MF09–C	(2130–2230)	9.1	268	0.0034	1.0
Mon 10	MF10–A	(0030–0200)	9.0	263	0.0045	1.5
	MF10–B	(0230–0330)	8.8	265	0.0040	1.5

* Based on run-averaged wind monitor data from RS.
+ Based on temperature and velocity differences (16.9–4.9 m) on RS 17 m post.
[a] Anemometer #30 moved during run.
[b] Reference data available only 1300–1400.
[c] Quite variable during these runs.
[d] Direction somewhat unsteady.
[e] Most anemometers moved to $\Delta z = 3$ m for this and subsequent runs.

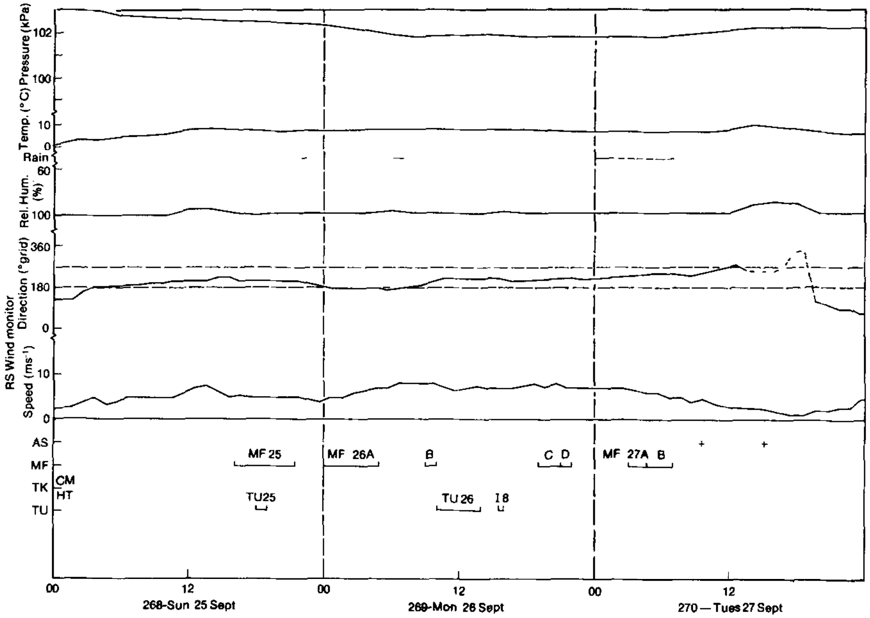


Fig. 8a.

Fig. 8. Wind speed and direction (10 m, RS), surface pressure, temperature and humidity (2 m, BS) during the main observing period of Askervein '83. Main data collection and analysis periods are indicated. Note that relative humidity scale is inverted, numbers on the time axis are Julian day and that HT and CM (Coastal Machair - See Figure 1) are locations for the TALA kite (TK) runs; AS–AIRsonde flights, MF–mean flow run, TK–TALA kite profile, TU–turbulence run, I–Anemometer intercomparison run.

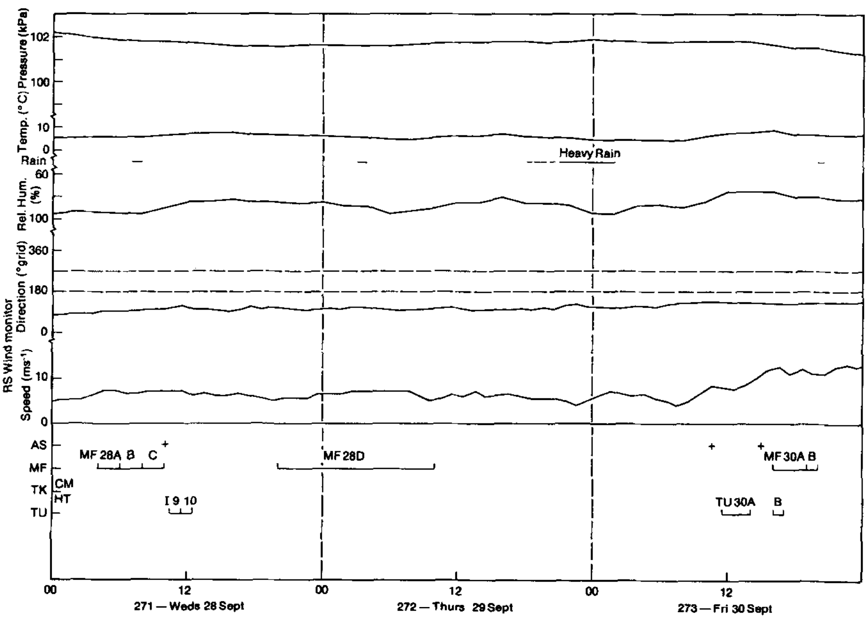


Fig. 8b.

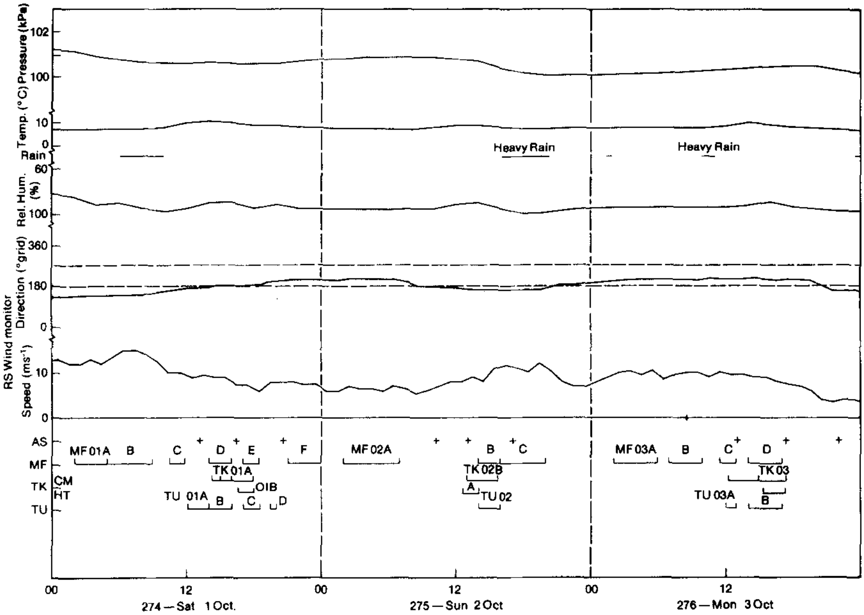

Pressure (kPa)
Temp. (°C)
Rain
Rel. Hum. (%)
RS Wind monitor
Direction (°grid)
Speed (ms⁻¹)
Heavy Rain
Heavy Rain
AS
MF
TK
TU
MF01A B C D E F
MF02A B C
MF03A B C D
TK01A
TK02B
TK03
CM
HT
TU 01A B C D
OIB
A
TU02
TU 03A
B
00 12 00 12 00 12
274 — Sat 1 Oct.
275 — Sun 2 Oct
276 — Mon 3 Oct

Fig. 8c.

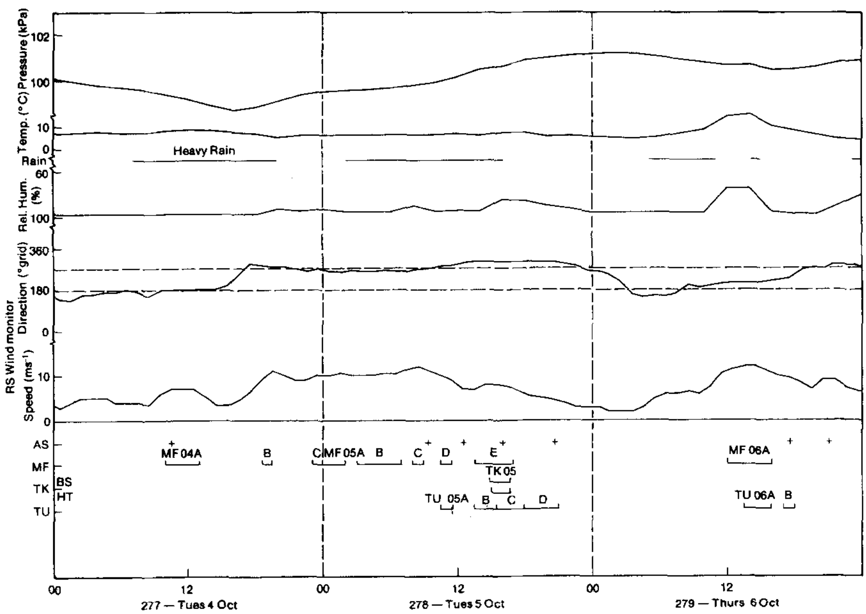
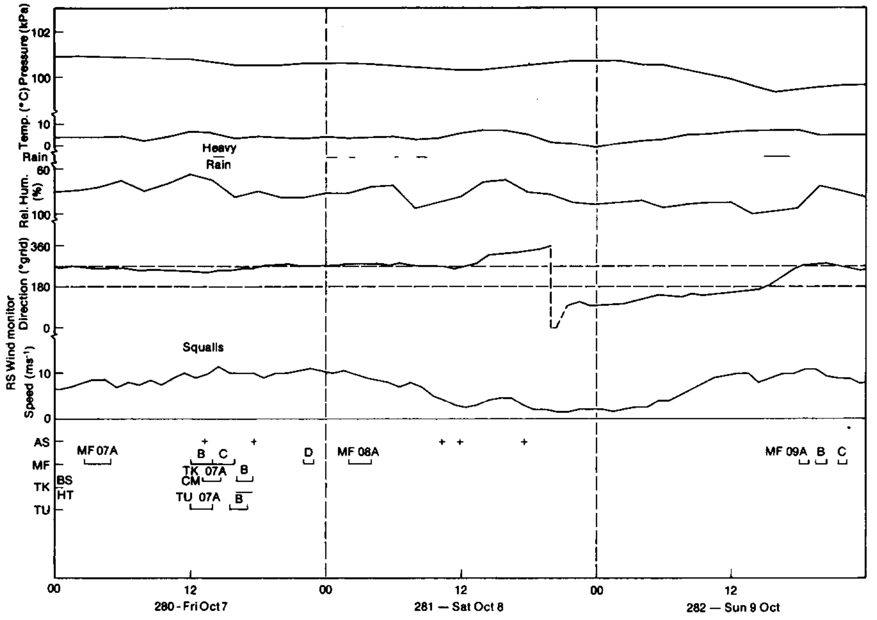
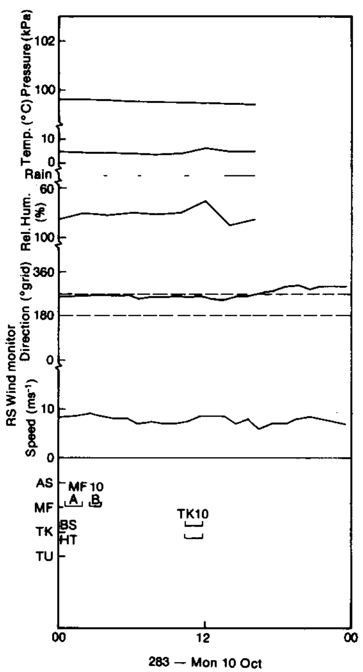

Pressure (kPa)
Temp. (°C)
Rain
Rel. Hum. (%)
RS Wind monitor
Direction (°grid)
Speed (ms⁻¹)
Heavy Rain
AS
MF
TK
TU
MF04A B C MF05A B C D E
MF 06A
TK05
BS
HT
TU 05A B C D
TU 06A B
00 12 00 12 00 12
277 — Tues 4 Oct
278 — Tues 5 Oct
279 — Thurs 6 Oct

Fig. 8d.



Pressure (kPa)
102
100
Temp. (°C)
10
0
Rain
Heavy Rain
Rel. Hum. (%)
60
100
RS Wind monitor
Direction (°grid)
360
180
0
Squalls
Speed (ms⁻¹)
10
0
AS
MF
TK
TU
MF 07A
B C
D
MF 08A
TK 07A
CM
B
BS
HT
TU 07A
B
MF 09A B C
00
12
00
12
00
12
280 - Fri Oct 7
281 — Sat Oct 8
282 — Sun 9 Oct

Fig. 8e.



Pressure (kPa)
102
100
Temp. (°C)
10
0
Rain
Rel. Hum. (%)
60
100
RS Wind monitor
Direction (°grid)
360
180
0
Speed (ms⁻¹)
10
0
AS
MF
TK
TU
MF 10
A B
BS
HT
TK10
00
12
00
283 — Mon 10 Oct

Fig. 8f.

TABLE IV

Designated TALA Kite Profile (TK) runs for Askervein '83

Date	Run No.	Duration	ϕ_{RS}[a]	Ri_{10}	Locations	Comments
1 Oct. (a)	TK01–A	1500–1600	180°	−0.0142	Coast[b]	6 Standard Kites (BRE)
(b)	TK01–B	1630–1730	180°	+0.0104	Coast[b]	6 Standard Kites (BRE) – data from 4 kites avail. 1420–1810
		1630–1800	180°		Aprox. midway between HT & CP	Single kite (CAN) with data normalized wrt 10 m winds at HT
2 Oct. (a)	TK02–A	1230–1400	165°	−0.0128	Near HT	Single Kite (CAN).
(b)	TK02–B	1330–1530	165°	−0.0017	Coast[b]	6 Standard Kites (BRE), Data available 1300–1550
3 Oct.	TK03	1500–1700	205°	−0.0040	Coast[b]	6 Standard Kites (BRE)
		1515–1715	205°		On downwind hillside	Single Kite (CAN)
5 Oct.	TK05	1445–1645	305°	−0.0105	ASW85	Single Kite (CAN)
		1515–1645	305°		Between HT & CP	Single Kite (CAN)
7 Oct. (a)	TK07–A	1300–1400	240°	+0.0013	Coast[b]	4 Standard Kites (BRE) – variable winds. Data also available 1400–1430
(b)	TK07–B	1615–1730	260°	+0.0011	ASW85	Single Kite (CAN)
		1615–1730	260°		Between HT & CP	Single Kite (CAN)
10 Oct.	TK10	1015–1145	260°	+0.0003	ASW85	Single Kite (CAN)
		1015–1145	260°		Between HT & CP	Single Kite (CAN) – no HT normalizing data.

[a] Based on windmonitor strip chart (°grid).
[b] Coastal Machair Site kite profiles combined with RS tower data to give single upstream profile.

The MF and TU runs can be collected together in groups based on the RS wind direction; this has been done in Tables VII and VIII. For the MF runs (Table VII), the direction group ranges are $\pm 5°$ while for the turbulence runs, a $\pm 10°$ range has been used, since there are fewer runs available.

6. Summary

The Askervein experiments have produced what we feel is an excellent set of full-scale data on the nature of atmospheric boundary-layer flow over an isolated, moderately low hill. Almost all of the data are for essentially neutrally-stable conditions. Periods for the study of mean wind and turbulence characteristics induced by the hill have been identified for a number of basic wind directions and, while the spatial extent of the data sets is often not as large as we would have liked (an almost foregone conclusion in experiments of this type!), we believe that the results obtained will be extremely useful

TABLE V

Designated turbulence (TU) runs for Askervein '83

Date	Run number	Time (BST)	Duration (hr)	Mean wind at RS[a]	RS profile data[b]		Ri[c]	$z/\mathscr{L}$[d]
					u_* (m s^{-1})	z_0 (m)		
September 1983								
Sun 25	TU25	1600–1700	1.0	210/5.5	0.37	0.024	−0.0083	−0.029
Mon26	TU26	1000–1400	4.0	220/7.0	0.49	0.026	−0.0116	–
Fri 30	TU30–A	1130–1300	1.5	135/7.8	0.54	0.030	+0.0005	−0.005
	–B	1600–1700	1.0	130/13.0	0.85	0.028	+0.0051	–
October 1983								
Sat 01	TU01–A	1200–1400	2.0	170/9.2	0.63	0.023	−0.0228	−0.030
	–B	1400–1600	2.0	180/9.0	0.55	0.013	−0.0205	−0.026
	–C	1700–1830	1.5	185/7.5	0.49	0.022	+0.0103	+0.001
	–D	1930–2000	0.5	200/7.5	0.49	0.017	+0.0205	+0.008
Sun 02	TU02	1400–1600	2.0	165/10.0	0.69	0.029	−0.0026	–
Mon03	TU03–A	1200–1300	1.0	210/9.8	0.63	0.022	−0.0038	−0.015
	–B	1400–1700	3.0	210/8.9	0.57	0.020	−0.0074	−0.004
Wed05	TU05–A	1030–1130	1.0	285/9.5	0.64	0.020	−0.0011	−0.016
	–B	1330–1530	2.0	305/7.8	0.51	0.014	−0.0073	−0.012
	–C	1530–1700	1.5	300/7.5	0.45	0.009	−0.0118	−0.016
	–D	1800–2100	3.0	300/5.0	0.38	0.039	+0.0461	–
Thu 06	TU06–A	1430–1600	1.5	212/11.0	0.75	0.021	+0.0002	–
	–B	1700–1800	1.0	228/9.2	0.64	0.024	+0.0011	
Fri 07	TU07–A	1200–1400	2.0	240/9.0	0.63	0.027	+0.0004	–
	–B	1530–1700	1.5	260/10.0	0.66	0.022	+0.0009	−0.008

[a] From AES wind monitor at Δz = 10 m (°grid/m s^{-1}).
[b] From lowest ~10 m of profiles.
[c] Based on temperature and velocity differences (4.9–16.9 m) on RS 17 m tower.
[d] Ratio of height (10 m) to Monin–Obukhov length ($\mathscr{L}$) from sonic anemometer at Δz = 10 m at RS.

for validating and improving theories and the physical and mathematical models and techniques which are currently being developed for flows of this type.

The present paper is intended to provide a basic overview of the Askervein Hill Project and to provide some of the background information for a series of scientific papers using results from the project. These will include details of mean wind speed variations at fixed heights (3 m, 10 m) above the terrain and profile data from RS, HT, and CP coupled with numerical model and wind-tunnel simulation comparisons. Topography-induced spatial variations of various turbulence characteristics will also be discussed in detail in these subsequent papers.

TABLE VI

Weather conditions during the main observation period, Askervein '83

Sunday, 25 Sept.	High cloud with SW winds. Cloud level dropped to 100 m in late afternoon.
Monday, 26	Very low cloud with visibility often less than 1 km. Light SW winds. Clouds lifted temporarily on several occasions.
Tuesday, 27	Very foggy in morning with light SW winds. The fog cleared at about 1300 hr and the afternoon was relatively warm and sunny with the cloud level at about 300 m with occasional clear patches.
Wednesday, 28	Cool E winds which steadily increased during the afternoon. 7/8 middle cloud with low cloud over the higher hill tops.
Thursday, 29	Cool E to SE winds with showers. High 8/8 middle cloud with low cloud over the higher hill tops. Cloud level lifted during day.
Friday, 30 Sept.	9/10 middle cloud and low cloud over hill tops. SE winds gradually strengthened to gale force in evening. Occasional sunny periods.
Saturday, 1 Oct.	Winds slowly decreased during the morning and backed to the south. Low cloud and showers continued in morning. More westerly winds in afternoon with 7/8 middle cloud and low cloud over hill tops. Showers became infrequent in afternoon.
Sunday, 2	SW winds and scattered cloud at about 1000 m with patches of sunshine. A front came through at about 16.30 bringing continual rain and poor visibility.
Monday, 3	7/8 low cloud at 300 m but lower near high ground. Moderate SW winds strengthened during the middle of the day and then decreased in afternoon. A long heavy shower occurred between 10 and 11.00 hr, followed by occasional sunny intervals.
Tuesday, 4	Dense low cloud down to 200 m with long periods of heavy rain. Light S winds reduced to near calm conditions in late afternoon. Westerly wind change at about 17.00 hr.
Wednesday, 5	7/8 low cloud at 300 m with periodic heavy showers from cumulus clouds. Strong winds from NNW gradually decreased during the afternoon. Became fine and calm by evening.
Thursday, 6	Persistent heavy rain and strong SW winds with low cloud base at about 100 m.
Friday, 7	Westerly winds with broken cloud and periodic high cumulus clouds. Short but heavy showers with periods of sunshine. Cooler temperatures.
Saturday, 8	Showers in morning with heavy cloud and light NNW winds but cleared in afternoon with calm, sunny conditions.
Sunday, 9	Cloudy with light winds in morning but light winds and mist from the south set in during the afternoon.
Monday, 10	SW to W winds and cumulus clouds brought heavy showers and sunny periods.

TABLE VII

Directional groups for MF runs; Askervein '82 and '83

Nominal direction	No. of runs	No. of hours	Run numbers
(a) *Askervein '82*			
120	1	2	2.25
155	1	2	2.01b
165	2	5	2.27, 2.01a
180	2	5	1.22, 2.28
200	1	2	2.02
230	3	6	1.23a, 2.29a, 2.29b
245	1	2	1.23b
Totals	11	24	
(b) *Askervein '83*			
100	4	20	MF28–A, 28–B, 28–C, 28–D^S
135	3	13	MF30–A, 30–B, 01–A
145	1	4	MF01–B
165	2	6	MF02–B, 02–C
170	1	1.5	MF01–C
180	4	11.5	MF26–A^S, 01–D^U, 01–E, 04–A
210	8	26	MF25, 26–B, 01–F, 02–A^S, 03–A, 03–B, 03–C, 03–D
220	2	7	MF26–C, 26–D
240	3	6	MF27–A, 27–B, 07–B^3
265	10	17	MF04–C, 05–A, 05–B, 05–C, 07–A^3, 07–C^3, 07–D^3, 09–C^3, 10–A^3, 10–B^3
280	5	6	MF04–B, 05–D, 08^3, 09–A^3, 09–B^3
305	1	3.5	MF05–E
Totals	44	121.5	

$( )^U \Rightarrow Ri < -0.015$ (slightly unstable)
$( )^S \Rightarrow Ri > 0.015$ (slightly stable)
} Ri values obtained from 17 m tower at RS

[3] Runs with anemometers at 3 m level.

TABLE VIII

Directional groups for TU runs, Askervein '83

Nominal direction ($\pm 10°$ or less)	No. of runs	No. of hours	Run numbers
135	2	2.5	TU30–A, 30–B
175	4	7.5	TU01–A, 01–B, 01–C, 02
215	7	12.0	TU25, 26, 01–D, 03–A, 03–B, 06–A, 06–B
250	2	3.5	TU07–A, 07–B
300	4	7.5	TU05–A, 05–B, 05–C, 05–D
Totals	19	33.0	

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