MRU Cardington Technical Note No. 18

Pershore Sonic/Probe Intercomparison

by

W P Hopwood

August 1993

Met. Office Research Unit
RAF Cardington
Shortstown
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Note

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Abstract

Intercomparisons between a Cardington turbulence probe and a Kaijo-Denki sonic anemometer were carried out during the inhomogeneous terain experiment at Pershore in Worcestershire during 1991. The results of which show that using the probe inclinometers as accelerometers can correct for the transverse vibration of the balloon tether cable.

1 Introduction

An important consideration when conducting field experiments is the performance of the instruments that are used. In mast based trials the important influences on the accuracy of the outputted data are dominated by the response of the sensor used and the flow regime around the instrument. However, when we move to a tethered balloon as an instrument platform, there are additional considerations. The very nature of the balloon allows it to be in motion in the same range of frequencies as we wish to measure. On top of this there are the various vibrational modes that exist on the tether cable when instruments are placed upon it. Various processing algorithms were developed by Lapworth and Mason (1988) to correct for the most common instrumental motions. Grant (1991), in his intercomparison, showed that for certain circumstances the probe velocities deduced from the Lapworth and Mason (1988) algorithims did not reflect the entire motion of the probes. It is the intention of this study to further the work done by Grant (1991) in isolating the causes of error in the probe system and to quantify a correction algorithim suggested by Lapworth (1993; private communication).

2 Experimental and Results

For periods during the Pershore detachment of 1991 a turbulence probe was attached to the balloon cable at the same height as a mast borne sonic anemometer. This enabled an intercomparison of the two instruments to be carried out. The site itself was situated on a disused airfield with a fetch of short cut grass for up to 1km upwind (see Hopwood, 1993 for detail description). The turbulence probe was identical in design to that described in Lapworth and Mason (1988) and it was compared against a Kaijo-Denki Dat 300 sonic anemometer-thermometer that used a TR61A directional head. The sonic was mounted, together with an Ophir hygrometer, on a 16m strumech mast. The common sonic/ophir mount could be rotated so as to point into the mean wind so as to minimise errors due to transducer shadowing effects (Wyngaard and Zhang, 1985; Grant and Watkins, 1989). The sonic anemometer and the probe were separated by a horizontal distance of about 60m. The data was recorded at a rate of 4Hz, with the analogue outputs from the sonic/ophir being logged via a turbulence probe A/D converter connected by cable into the turbulence probe ground station. The statistics were calculated after the detrending and rotation of the horizontal wind components into a coordinate frame based upon the mean wind. The probe data was further rotated to force the mean of the vertical wind component to zero over the 33-min averaging period employed. During the intercomparisons the conditions were generally slightly unstable with moderate winds.

The comparison between the probe and sonic measured windspeed is shown in Figure 1. There is good agreement with a root mean square difference of $0.18ms^{-1}$ and no significant systematic difference. As an aside, this result is within the accuracy quoted by Lapworth and Mason (1988). If we now compare the streamwise component of the stress as in Figure 2 then the obvious thing to note first is that there is a lot more scatter than for windspeed, as would be expected for a second order moment. Considering the work done by Dyer et al. (1982) then the rms differences, δ for sensors separated by a horizontal distance y can be estimated from,

$$\delta^2 = 2\epsilon^2 F(y/L_y)$$

where ϵ is the relative error in the (co-)variance and $F(y/L_y) = 1 - r_y$ and r_y is the correlation. For flux measurements this would lead to an approximate rms difference of 20% and the observed scatter is consistant with this estimate with a rms difference of 19%. The other noteworthy thing from Figure 2 is that the probe measured stress systematically exceeds the sonic measured stress by about 20%. One explaination is a levelling error created when mounting the sonic anemometer. Grant and Watkins (1989) report that an inclination of approximately 2° leads to an error of about 10-15% in the streamwise component of the stress. For the data presented here the inclination, equivalent to the 'angle of attack' $arctan(w/u)$, is 2.6° which leads to an error in the region of that observed. Another possibility is that the sonic transducers are experiencing a shadowing effect because the sonic was not correctly aligned into the mean wind. Wyngaard and Zhang (1985) show that transducer-shadow effects could lead to about a 20% underestimate in the streamwise stress component for the worst case. However the sonic was kept to within 5° of the mean wind direction on the intercomparison runs so any shadowing errors would be minimal.

The average of the normalised cospectra of the streamwise component of the stress from the sonic and probe data is shown in Figure 3. The cospectral shapes are in fair agreement except at wavelengths greater than 0.03, where the probe cospectra are systematically larger in magnitude than those from the sonic anemometer. This was also reported by Grant (1991) in his intercomparison and is due to the fact that the probe velocities calculated from the cable catenary do not reflect the entire motion of the probe. One such source of probe motion is the transverse vibration of the tether cable corresponding to the normal modes of a weighted string. It produces accelerations of the probes in a 'side-to-side' manner, perpendicular to the direction the probe is pointing. The effect occurs at wavelengths of 10-15m (i.e. a period of 2-3 seconds) which unfortunately overlaps with the 'real' turbulence generated motions of the probe. This overlap leads to contamination of the inclinometer data such that until recently they could not be used to deduce the high frequency motion of the probe. Recent advances in processing (Lapworth, 1993; private communication) have allowed the inclinometers to be used as accelerometers so allowing the 'sideways' motion of the probes to be estimated and then corrected. The application of this correction to the intercomparison data can be seen to decrease the systematic errors in the stress cospectra, see Figure 4.

Grant (1991) also described a similar difference betweeen the probe and sonic vertical velocity spectra in the same frequency band. This difference does not appear in this study as can be seen in Figure 5. In fact the vertical velocity spectra are in quite close agreement up to frequencies where the probes lack of response becomes an issue. This apparent contradiction in intercomparison results does have a plausible explanation. In Grant (1991), it was suggested that the difference between the probe and sonic vertical velocity spectra was related to the changing orientation of the balloon tether cable, due to errors in the wind vector determined from the Gill anemometers. These errors were thought to be caused by flow distortion induced by the probe body and be more acute as the probe was tilted backwards along the direction of the mean wind. This mechanism would account for the fact that the total vertical velocity variance was not seriously affected although spectrum derived dissipation estimates would have been systematically high. Work conducted at Cardington (Brettle, 1993; private communication), where probes were mounted on masts fitted with mounts that could be tilted to various angles, showed the same sort of effects as those described by Grant (1991) when the probes were tilted beyond about 30°. In the present study the probe was tilted to a maximum extent of 20° so reasonable agreement between the probe and sonic vertical velocity spectra is to be expected.

3 Conclusions

The results of this study are consistant with those found by Grant (1991).In addition they appear to show that using the data from the inclinometers to derive the probe transverse accelerations can be used to take into account the transverse probe motions. The result of applying this correction is to reduce the systematic error in the stress cospectra.

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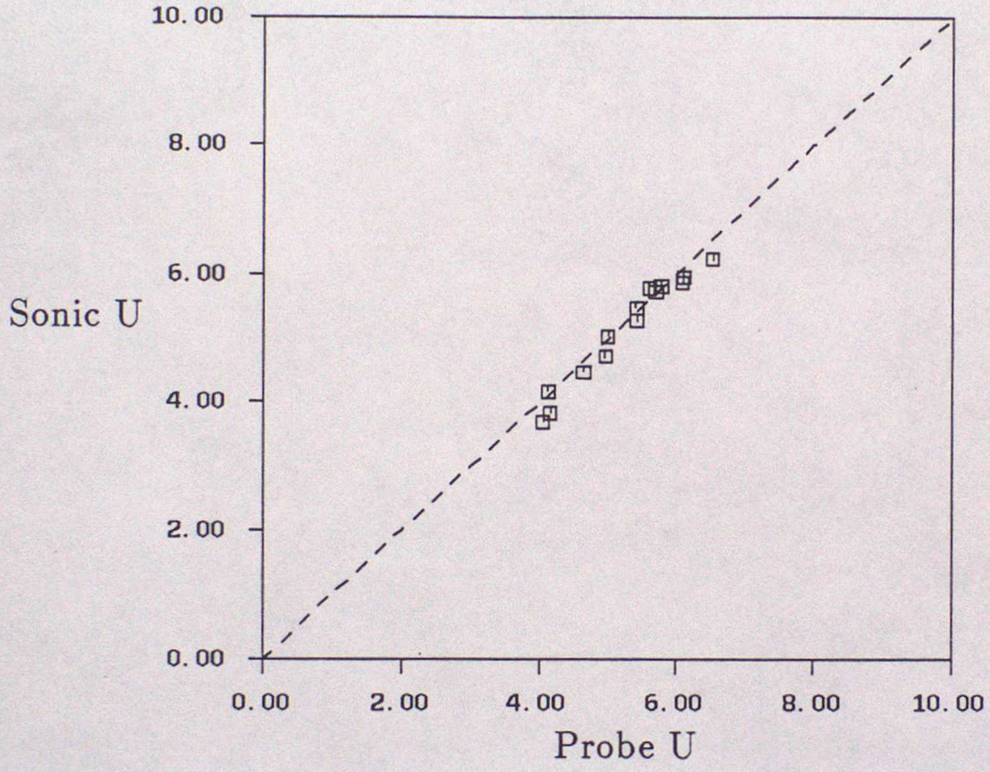
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Figure 1

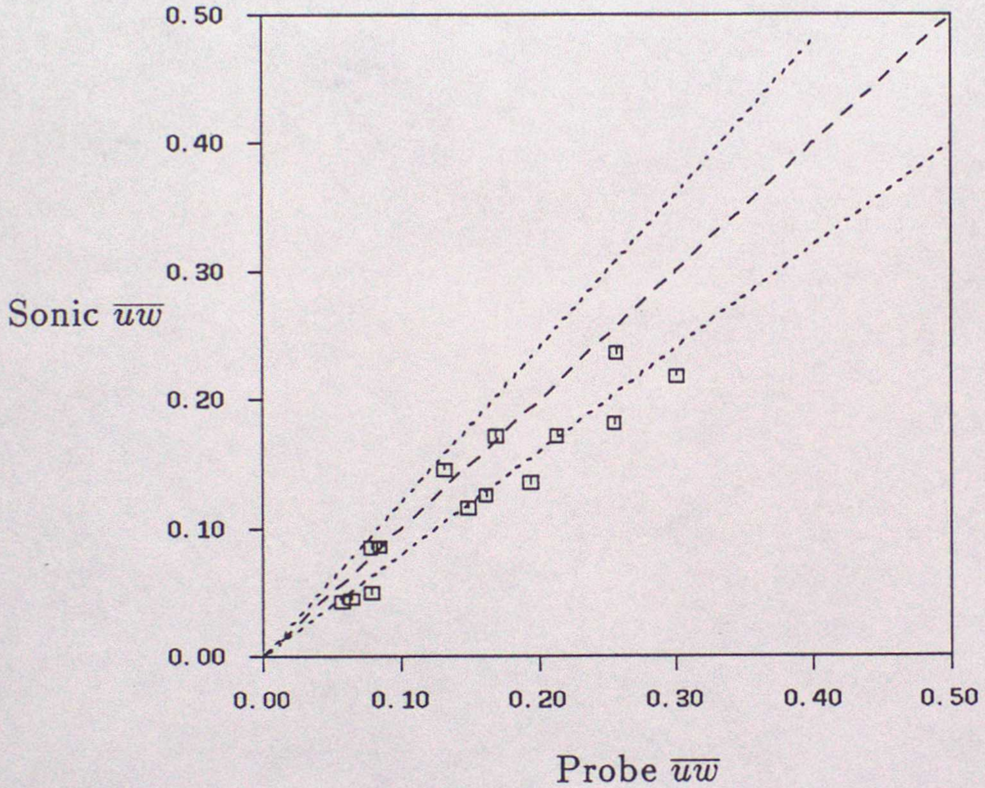
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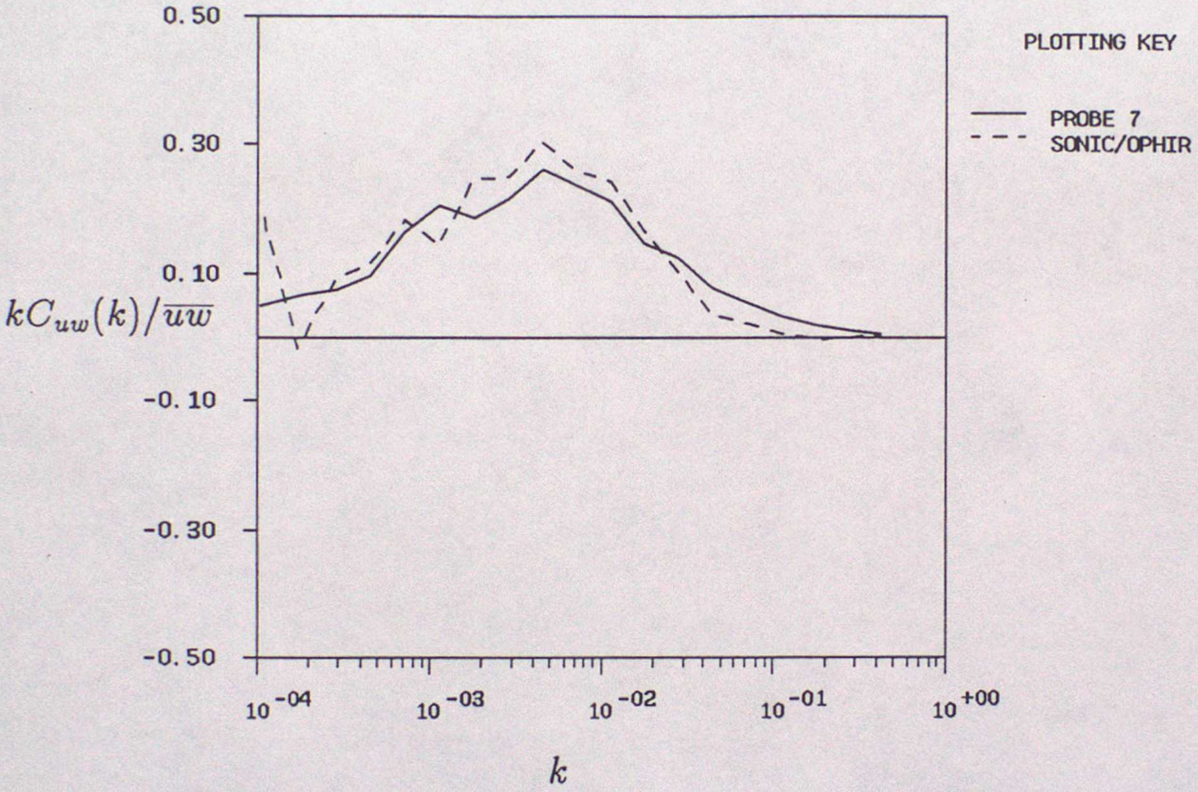
Figure 2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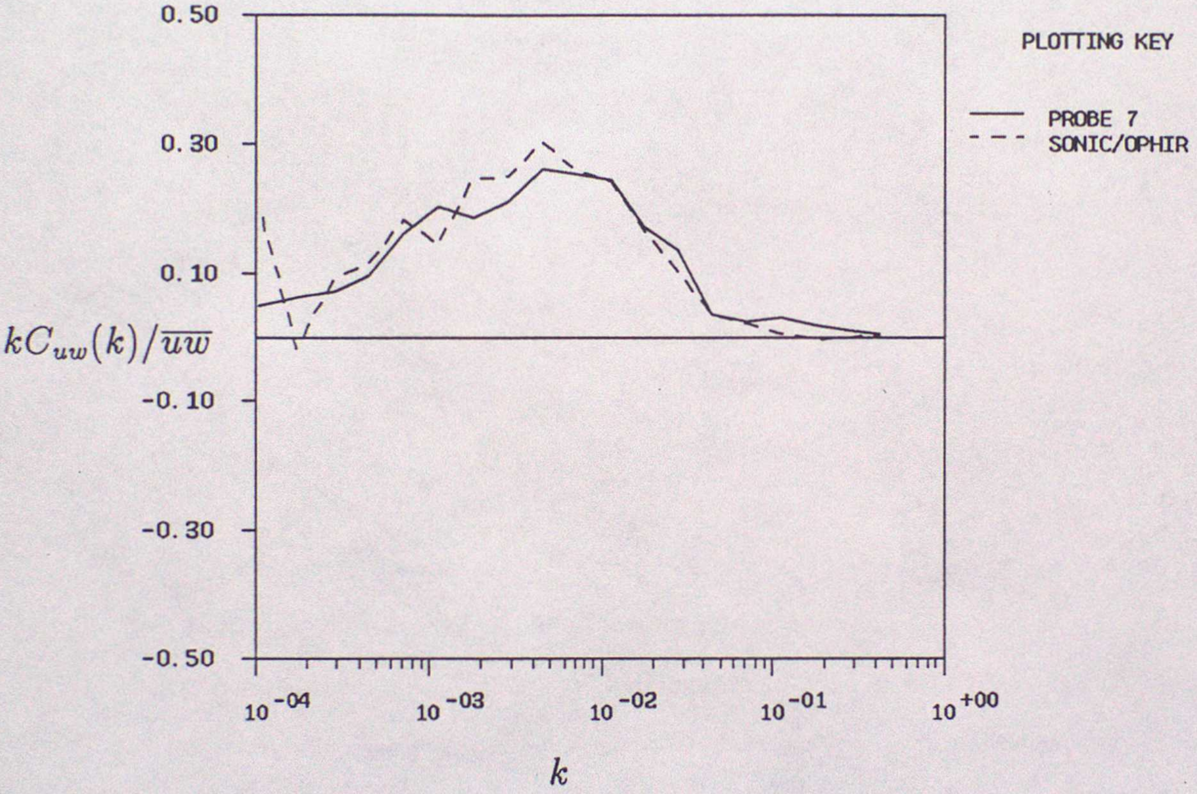
PLOTTING KEY
PROBE 7
SONIC/OPHIR

Figure 3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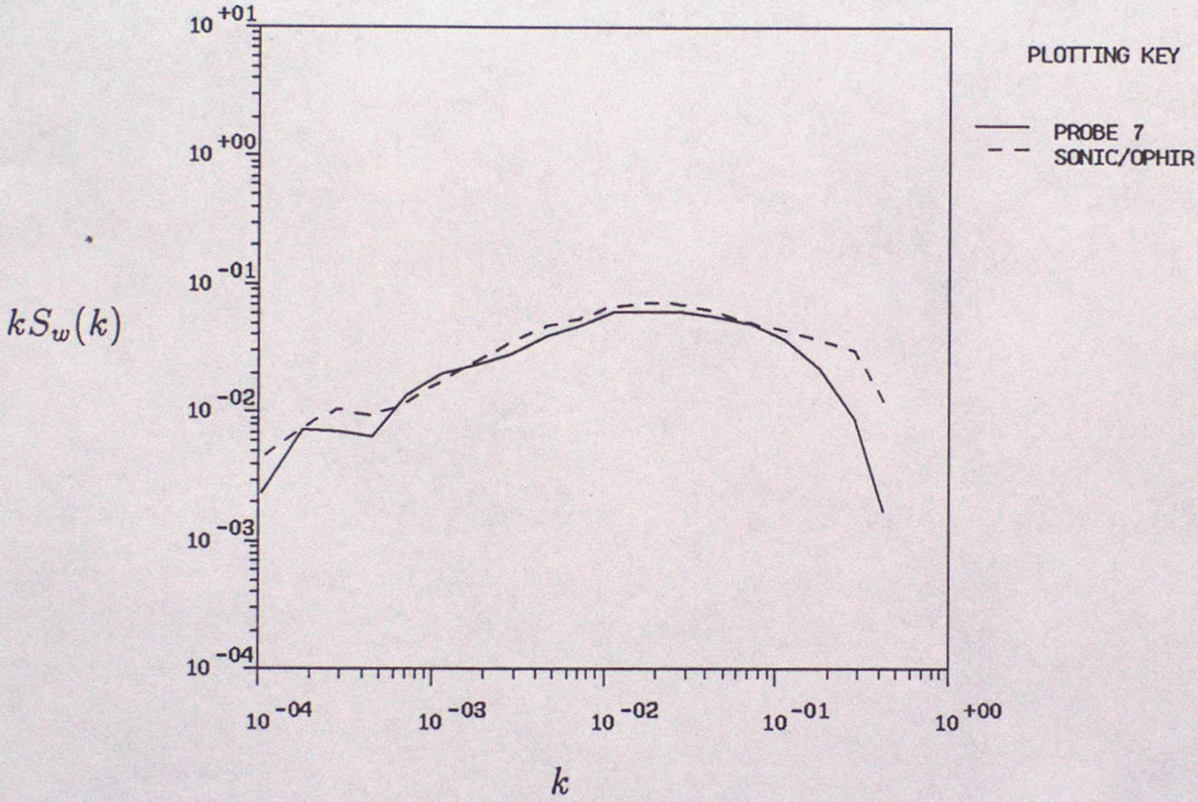
PLOTTING KEY
PROBE 7
SONIC/OPHIR

Figure 4



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PLOTTING KEY
PROBE 7
SONIC/OPHIR

Figure 5