CODIFICATION OF TOPOGRAPHICAL EFFECTS

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Introduction

Wind loading codes account for the effects of topography in many different ways. Some allow for an increase of speed of up to 20%, others have a more precisely defined 'escarpment rule' - the remainder either caution that topographical effects can be significant or ignore them altogether. However the last ten years have seen a great flurry of measurements of wind flow over hills, and it is now obvious that the allowance for speedup in loading codes is inadequate. It is not entirely obvious how to improve this situation, but this paper discusses some recent progress.

Loading codes should always be based on realistic physical models, and most studies of wind flow over hills have been interpreted in terms of the theory due to Jackson and Hunt (1975). In general this theory gives surprisingly good agreement with numerical, full-scale and wind-tunnel measurements, so as the flow structure proposed by the theory is quite simple it would seem to be the obvious starting point for development of design rules. The basic idea is that the flow has two discrete regions - a thin 'inner layer' next to the surface in which changes in shear stress are significant, and a much thicker 'outer layer' in which they are not important so that the velocity perturbation there can be predicted from potential theory. The pressure gradient generated by this outer flow also acts on the inner layer, where the velocities are much lower and therefore much more susceptible to pressure gradients. The induced changes in speed near the surface can thus be a large fraction of the incident speeds at the same height.

Maximum Speedup

There are several ways of quantifying this speed change. The ratio most favoured in the literature is the 'fractional speedup';

$$S = \{u(x, \Delta z) - U_o(\Delta z)\} / U_o(\Delta z)$$

where u is the speed at a *local* height of Δz above the surface. In regions where the pressure gradient is small (as at hill crests) one might expect the flow to be logarithmic close to the surface - that is, to be nearly in local equilibrium - which case S reduces to a constant. In practice this does seem to be the case, and this property of tending to a constant near the surface is the reason for the popularity of S as a speed-up parameter. One alternative is the 'nondimensional speedup'

$$\Delta u \frac{h}{L} = \{u(x, \Delta z) - U_o(\Delta z)\} / U_o(L)$$

where L is the hill length. This ratio is based on the scaling for the outer layer and is therefore independent of the method used for turbulence closure in the inner layer. However the problem is that actually *both* the above measures are relevant, but they apply in different regions of the flow. This can quite clearly be seen in Figure 1 (taken from Jackson, 1979) which is a numerical simulation of flow over a rounded ridge.

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For $Z = \Delta z/L > 0.05$ the curves for different values of surface roughness z_0 collapse to a single curve for Δu, whereas near the surface the profiles are obviously all logarithmic with intercepts governed by z_0 and therefore would collapse to a single curve for S. The height at which the changeover in flow structure occurs depends on the height of the inner layer, l, predicted by Jackson and Hunt (JH) from

$$l/z_0 \ln(l/z_0) = 0.32\ L/z_0. \qquad (1)$$

There has been considerable argument over this length. This particular formula predicts some measurements quite well (Bradley, 1980) but is often found to overpredict the apparent inner layer thickness (Taylor *et al*, 1982). In Figure 1 the Δu curves peak at heights almost exactly half those given by this method. In practice the depth l can be quite large. For $L \sim 1$km and z_0 in the range 1 - 1000mm the length l varies from 30m to 75m, so clearly the inner layer is often deep enough to immerse structures completely. It therefore seems sensible to start a design rule for ***maximum*** speedup based on the constant-value property for S near the surface. Taylor and Lee (1985) have quite recently proposed the following near-surface values for fractional speedup;

$$S_{max} = \begin{cases} 2.0\ h/L & \text{for 2-D ridges} \\ 0.8\ h/L & \text{for 2-D escarpments} \\ 1.6\ h/L & \text{for 3-D axisymmetric hills,} \end{cases} \qquad (2)$$

where here L is taken as the horizontal distance in which the hill falls to half its peak height h. Again there are several possible definitions of hill length, but this one seems to be winning in the literature. The numerical coefficients here have been selected by Taylor and Lee as average values of speedup obtained from measurements and numerical predictions.

This linear dependence of speedup on slope originally emerged from the JH theory and appears to be maintained right up to hill slopes at which separation begins (about 0.4 for ridges). Obviously once separation begins speedup does not continue to increase indefinitely with slope, and Taylor and Lee suggest an upper limit of 1.2 for S_{max}.

Spatial Variation of Speedup

A similar proposal for speedup has been made by BRE (1984) as;

$$S = 2\ s\ h/L \qquad (3)$$

where s is a 'speed increment coefficient' with a maximum value of 1.0 which takes account of positions other than that of maximum speedup. Here L is the *total* length of the slope, so this formula predicts only half the speedup of Taylor and Lee and is therefore too low. (Note that the working formula as given in the BRE document omits the h/L factor.) However the general formulation of this expression is a good one, but much more research is needed regarding the distribution of s for different hill shapes (the BRE reference uses some early wind-tunnel results).

The decrease in speedup with height (included in the s factor) is not easy to predict because different length scales are important at different heights from the ground. It seems clear that the flow near the hill crest is affected most by the 'sharpness' of the crest (hence the definition of L used by Taylor and Lee), but higher up the local topographical detail becomes less significant and the speed changes are more likely to be controlled by, say, the overall hill volume. This hypothesis is tested in Figure 2, where the outer flows from several numerical experiments are plotted using a length scale L_v which gives each hill the same volume as the Witch of Agnesi, as follows:

Hill	Shape	Cross-sectional area	L_v
Witch	$(1 + x/L)^2$	$\pi h L$	L
cosine	$(1 + \cos \pi x/L)/2$	h L	L/π
Gaussian	$\exp(-(x/L)^2)$	$h L \sqrt{\pi}$	$L/\sqrt{\pi}$
triangular	$(1 \pm x/L)$	h L	$L/\sqrt{\pi}$

Here S_{max} is the limiting value of S near the surface at the crest, and the ratio S/S_{max} is plotted against height directly above the crest using the vertical scale $\Delta z/L_v$ in each case. This can be seen to produce a reasonably good collapse of the data to a single curve given approximately by -

$$S/S_{max} = (1 + 1.2 \Delta z/L_v)^{-2} \quad (4)$$

The general form of this expression is suggested by the exact solution for the Witch of Agnesi in the outer region. A construction which is reasonably accurate at all heights is then;

$$S/S_{max} = \begin{cases} 1.0 & \text{for } \Delta z/l < 0.5 \\ \text{eqn (4)} & \text{for } \Delta z/l > 0.5 \end{cases} \quad (5)$$

where l is given by equation (1). Although the JH theory would suggest that Δu and not S would be the appropriate ratio for heights well above the surface, a code version would be confusing if more than one speedup were defined. Unfortunately it seems likely that it will then be necessary to use more than one definition of hill length, as shown above, but again more study of this point is needed.

There are several projects under way on full-scale and model-scale measurements of wind flow over hills. The Kettles Hill experiment carried out by the Canadian Atmospheric Environment Service is a good example (Taylor, *et al*, 1983, Teunissen *et al*, 1982). The results show very good agreement between full-scale measurements and numerical and wind-tunnel simulations. A similar experiment on a much grander scale is now under way at Askervien, and again preliminary AES wind-tunnel results show good agreement. It therefore seems likely that within even one more year there will be much more information available about the parameters discussed above (though it is perhaps equally probable that these experiments will raise more questions than they answer).

References

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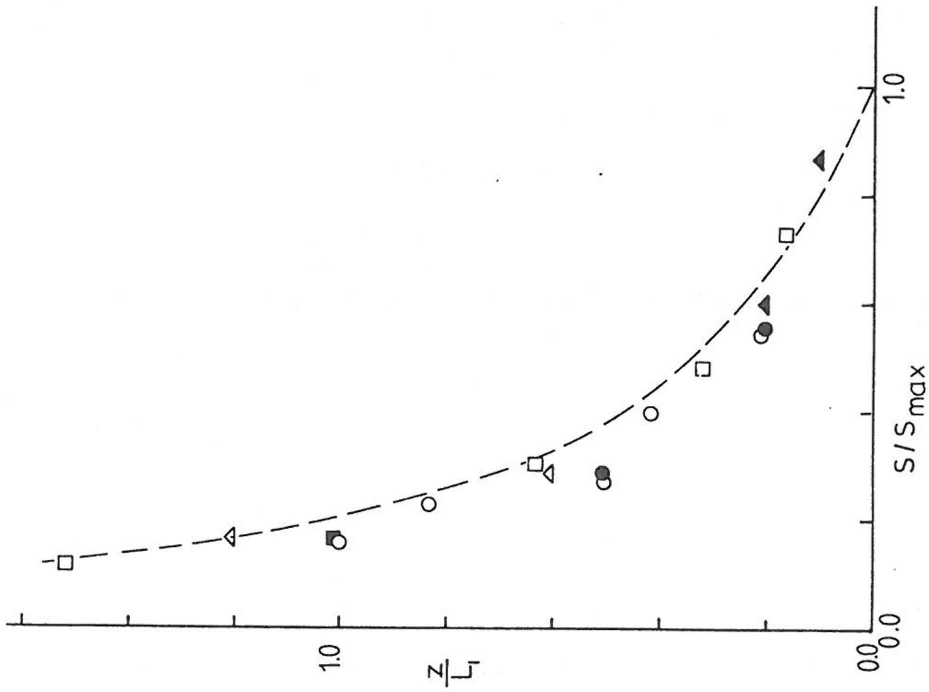

Figure 2 Change of speedup with scaled height above crest.
(Deaves - o Fig 3, ∆ Fig 6 ;
Jackson - □ Fig 2.23, ● ▲ Fig 2.20)

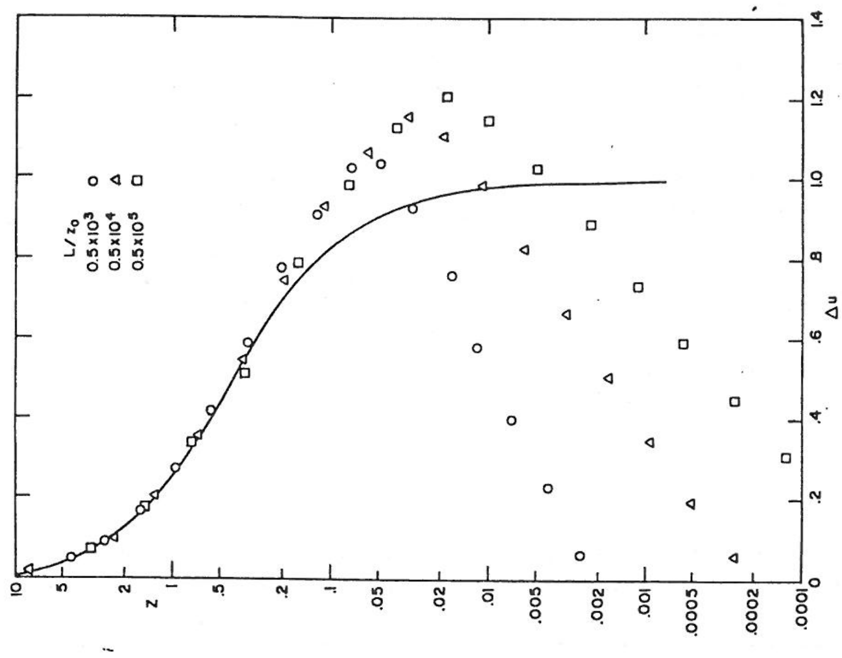

Figure 1 Nondimensional speedup over Witch of Agnesi
($^h/L$ = 0.3, using Taylor numerical model)