2.5 Patterns of mean wind and turbulence inside a square porous windbreak

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1 Introduction

Networks of intersecting or parallel windbreaks are common in horticulture, but any quantitative understanding of their aerodynamics, and so the mechanism by which they impact the microclimate about them, remains to be developed. Strong pressure gradients, full 3-dimensionality, and the generation of large vortices interacting with those naturally occurring in the surface layer, render this a challenging problem.

Here we present wind measurements in a square plot, surrounded by a single porous fence (Fig. 1). Tracer gas dispersion experiments with a source lying within the fence are reported in paper **P1.21**, and paper **9.8** covers the simpler situation where the source (visible in Fig. 1) emitted into undisturbed surface-layer winds.

Figure 1: Windbreak, Elleslie, Alberta.

2 Experimental configuration

We set up a porous plastic windbreak fence (height $h = 1.25m$, resistance coefficient $k_r = 2.4$) in the form of a square (side-length $D = 20m$, so that $D/h = 16$) on otherwise undisturbed land (sparse stubble, $z_0 \sim 0.02m$); Argete and Wilson (1989) had earlier reported the microclimatic (equivalent temperature) disturbance induced by this same configuration. Cup anemometers (height $z = h/2$) and a single 3-d sonic (CSAT3) probed conditions in the plot, while instruments on a tower standing outside the shelter provided mean wind direction β, vertical profiles of the mean wind $U_0(z)$ and temperature $T_0(z)$, and reference velocity statistics (second CSAT3 at $z = 2.0m$). Data are 15 min means.

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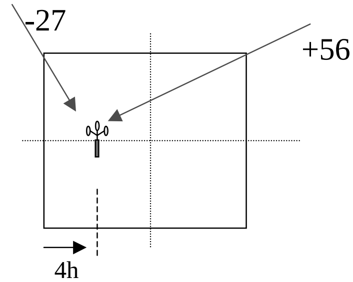

Figure 2: Anemometer at "side" position ($x/h = -4, y/h = 0$) in the plot, and ("reduced") wind directions β_r implying "corner flow" relative to that position, for which $-90 \leq \beta_r \leq 90^o$. Not to scale.

Let ($x = y = 0$) define the centre of the plot, and ($x/h = -8, y/h = 8$) its NW corner (etc). For an anemometer at plot centre, a wind direction of -45^o (or 45^o) implies the NW (or NE) corner lies upstream. It is evident that, by symmetry, one may introduce a "reduced" mean wind direction spanning $0 \leq \beta_r \leq 45$ and that a mean wind from any other sector is equivalent to a mean wind direction in this sector. Similarly for "side" positions (Fig. 2), symmetry implies that $-90 \leq \beta_r \leq 90$, where -90 is a wind from the south.

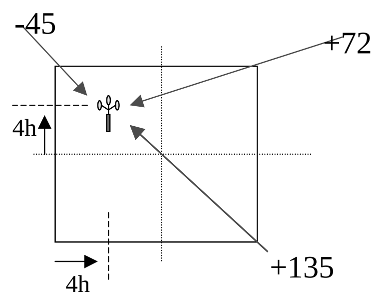

Figure 3: Anemometer at a "corner" position in the plot, and "corner flow" relative to that position, for which $-45 \leq \beta_r \leq 135^o$.

3 Results

When the mean wind blew at nearly normal incidence across the fence to any particular anemometer in the shelter, good fractional wind reduction was recorded (Figs. 4, 5, 6). Its numerical value was approximately that expected in the near lee of a long, straight, isolated

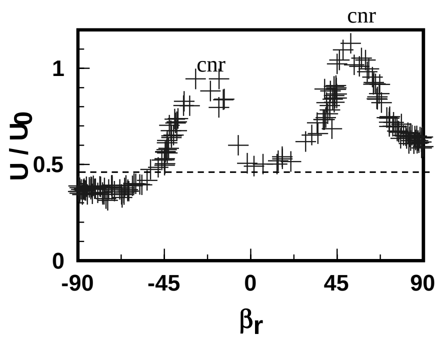

Figure 4: Mean windspeed at side position versus reduced mean wind direction β_r. The dashed line is the windspeed expected on the basis of eqn(1) for a long straight fence with $k_r = 2.4$.

fence (Wilson *et al.*, 1990):

$$\frac{\Delta U}{U_0} \equiv \frac{U_0(z) - U(x,z)}{U_0(z)} = \frac{k_r}{(1+2k_r)^{1.8}} \qquad (1)$$

$\Delta U/U_0$ was not very sensitive to stability (Figs. 4, 5 include all 15-min periods with $L \geq 10m$, and all cups indicating $U \geq 1m\ s^{-1}$.), but very sensitive to mean wind direction: when the wind blew over any corner of the plot in order to reach the anemometer, there was no reduction in mean speed (eg. at side positions, no wind reduction for the special angles $\beta_r = -27, +56^o$). Fig. (7), representing all runs for which all $U \geq 1m/s$, indicates that significant mean vertical velocities occur in the plot. Velocity standard deviations were altered by up to a factor of two (not shown).

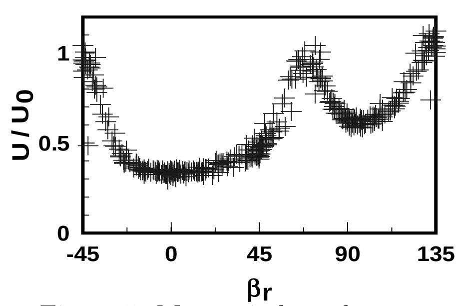

Figure 5: Mean windspeed at corner position.

4 Implication

This well-defined shelter flow is severely disturbed, so that observations at any one location could not be considered representative. To "feed" 3d velocity statistics to a dispersion model for a source in this flow would necessitate either fitting empirical functions to the data,

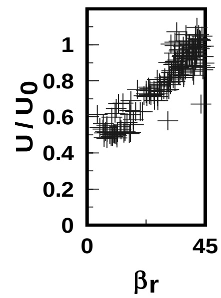

Figure 6: Mean windspeed at centre position versus reduced mean wind direction β_r.

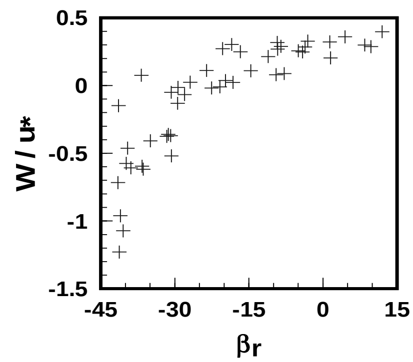

Figure 7: Mean vertical velocity at corner position.

or computing solutions of Reynolds-averaged Navier-Stokes equations. The former approach is unlikely to prove easily generalizable for other $(h/z_0, D/h, k_r)$ etc., while the latter, though more "profound", may not be very plausible - if recent simulations by Wilson and Yee (2002), for an array of parallel windbreaks, are indicative.

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References

Argete, J.C., & Wilson, J.D. 1989. The microclimate in the centre of small square sheltered plots. *Agric. Forest Meteorol.*, **48**, 185–199.

Wilson, J.D., & Yee, E. 2002. Calculation of Winds Disturbed by an Array of Fences. *Agric. Forest Meteorol.*, **in press**.

Wilson, J.D., Swaters, G.E., & Ustina, F. 1990. A perturbation analysis of turbulent flow through a porous barrier. *Quart. J. Royal Meteorol. Soc.*, **116**, 989–1004.