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Pedestrian level wind assessment and directionality

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Abstract

The effects of varying wind direction probability on pedestrian level wind assessment are discussed, using the Melbourne area wind climate as an example. Contours of limiting velocity ratios, (i.e. the ratio of acceptable gust wind gust speed at 2 metres height to the hourly mean speed at 300 metres height), are plotted as a function of wind direction. Outer and inner contours of the velocity ratio are plotted; the difference between the two is the assumption with respect to directional probability. It is shown that these form limits which can conveniently be used to determine the acceptability of a given location with respect to the defined gust criterion, and avoid the complexity of carrying out a full integration to obtain the combined probability of limiting wind speeds being exceeded at a given point *from any direction.*

Examples of use of the limits are given for some generic locations in a suburban situation (TC3), and also for a case typical of one near the base of a tall building in the Melbourne CBD. A possible intermediate 'central' contour is also discussed.

Introduction

Melbourne (1978a) described procedures developed at Monash University to assess the ground level wind environment. These procedures have been almost universally adopted for commercial wind-tunnel assessments for planning applications in all of Australia. In a separate paper, Melbourne (1978b) also discussed the gust speeds for acceptable conditions for various activities such as fast walking, strolling, sitting etc. However, these will not be discussed in detail in the present paper; the values of 3s gust speed currently specified for the various activities, exceeded for no more than 0.1% of the time, will be taken as a 'given'.

The method proposed by Melbourne (1978a) utilised polar plots of the *square* of the velocity ratio (i.e. the ratio of acceptable wind speed at two metres height to the hourly mean speed at a height of 300 metres), on the basis that pressure is more important than velocity when considering the mechanical effects of wind on humans. However, we have chosen to plot velocity ratios since thermal effects are directly related to velocity, and the current limiting criteria are expressed in terms of velocity in metres per second.

Velocity ratio contours for Melbourne

Contours of limiting velocity ratios (i.e. the ratio of acceptable wind gust speed at 2 metres height to the hourly mean speed at 300 metres height) are plotted as a function of wind direction. Two sets of contours are plotted:

1) An *outer* limit which incorporates the directional probability. This effectively ignores the possibility that wind can blow from sectors other than the given sector, when calculating the limiting ratio for that sector; it is therefore an *unconservative* limit,

2) An *inner* limit which assumes 100% probability of the wind blowing within a given direction sector. This assumes that the wind always blows from the given sector when calculating the limiting ratio for that sector; it is therefore a *conservative* limit.

Figure 1 shows the acceptable velocity ratios in Melbourne for the walking criterion (i.e. the gust at a given location with a probability of exceedence of 0.1% should not exceed 16 m/s). The limiting contours were obtained by processing 10-minute mean wind speeds recorded at 10m height at Melbourne Airport (Tullamarine), every 3 hours between 1970 and 2010. The 10-minute average wind speeds at the airport, assumed to be Terrain Category 2 according to AS/NZS 1170.2 (Standards Australia, 2011), were converted to equivalent hourly means at a height of 300 metres in Terrain Category 3.

For each 22.5° direction sector, a Weibull probability distribution was fitted to the data and the values for each direction sector, corresponding to the 0.1% exceedence probability, were calculated. These values then formed the denominators for the values on the contour plot. As discussed above, the outer limit incorporates the directional probability of each direction sector, thus reducing the hourly wind speed for the 0.1% exceedence probability and giving a higher value for the acceptable velocity ratio on the contour plots.

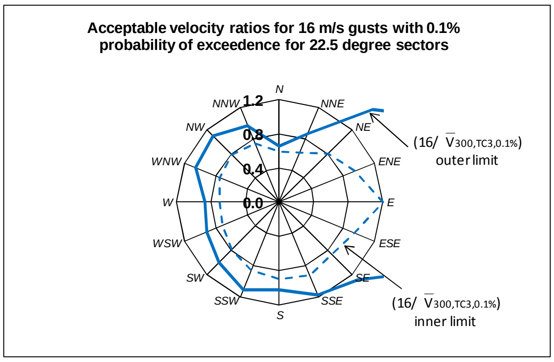

Figure 1. Acceptable velocity ratios for walking (16m/s gust)

Figure 2 shows a similar figure to Figure 1 but based on the 'short-term stationary' gust limit of 13 m/s.

It should be clear from the preceding discussion that if all the points plotted on the polar plots for a particular location – that is the velocity ratios for all directions – fall *inside* the inner dashed contour, then the location is clearly acceptable with respect to that criterion. On the other hand, if any velocity ratios plotted fall outside the outer 'solid' contour, then the location is clearly unacceptable with respect to the criterion, as the contribution from a single direction is sufficient to produce gusts that exceed the value of the criterion. If all, or some, points fall between the two limits, but none fall outside the outer contour, there is some doubt about the acceptability, or otherwise, of the location, and strictly, a full integration to determine the actual wind gust speed satisfying the 0.1% probability limit, should be undertaken, taking into account all wind directions.

It should be noted that the current practice is to utilise only the outer limit as a basis for acceptability.

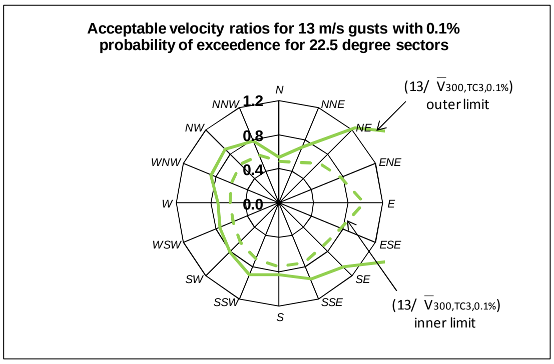

Figure 2. Acceptable velocity ratios for short-term stationary activities (13m/s gust)

Generic examples

Fully-shielded location in a suburban area

Firstly we will consider the velocity ratio associated with a fully-shielded location in a suburban area (Terrain Category 3), as determined from AS/NZS 1170.2: 2011 and AS 1170.2-1989, and using peak factors determined by Holmes *et al*. (2014). The ratio of the expected 3-second average gust at 2 metres height in TC 3 to the hourly mean at 300m in the same terrain can then be determined by:

$$\frac{V_{3s,2m,TC3}}{\bar{V}_{60\,\min,\,300m,TC3}} = \frac{V_{3s,2m,TC3}}{\hat{V}_{0.2s,2m,TC3}} \cdot \frac{\hat{V}_{0.2s,2m,TC3}}{\hat{V}_{0.2s,300m,TC3}} \cdot \frac{\hat{V}_{0.2s,300m,TC3}}{\bar{V}_{60\,\min,\,300m,TC3}} =$$

$$\frac{1+3.0(0.271)}{1+3.8(0.271)} \cdot \frac{0.83}{1.29} \cdot [1 + 3.8(0.121)] = 0.839$$

Full shielding is then accounted for by multiplying by the lowest shielding multiplier, M_s, of 0.7 in AS/NZS 1170.2, giving a final ratio of $0.839 \times 0.7 = 0.587$.

This ratio is plotted with the contours for the 'walking' criterion in Figure 3. Since the points all fall inside the inner (dashed) contour, a full integration would produce an expected maximum 3s gust of less than 16 m/s, within an hourly mean wind with an exceedence probability of 0.1%, and the hypothetical location can therefore be regarded as clearly acceptable for walking.

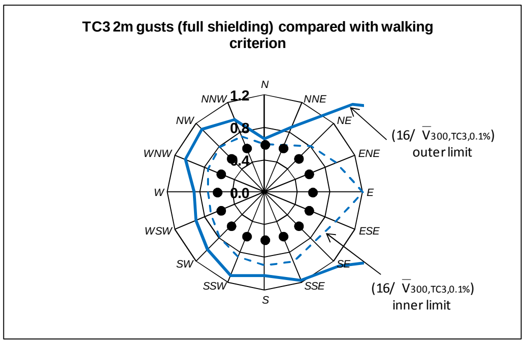

Figure 3. Velocity ratios for a hypothetical 'fully-shielded' suburban location compared with the 'walking' criterion

Figure 4 shows the comparison of the velocity ratio for this location with the contours calculated for the 'short-term stationary' criterion of Figure 2. In this case, the velocity ratio points fall outside the inner contour for several directions, but except for the north direction, fall within the outer contour.

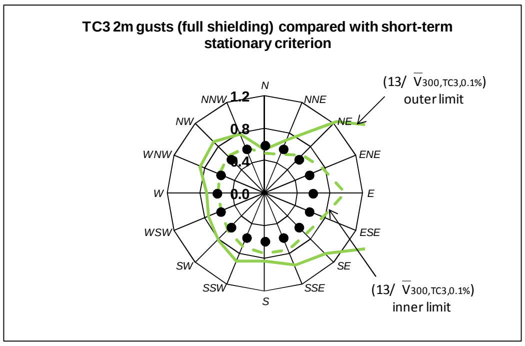

Figure 4. Velocity ratios for a hypothetical 'fully-shielded' suburban location compared with the 'short-term stationary' criterion

The 3-s gust, from any wind direction, with an expected probability of exceedence of 0.1% can easily be calculated from the probability distribution of the all-direction 10-minute mean wind speeds at 10 m height at Melbourne Airport. An analysis of the latter data for 1970-2010 gave a Weibull shape factor of 1.92, and a scale factor is 6.25 m/s. Hence, the 10-minute mean wind speed at 10 m height in TC 2, with 0.1% probability of exceedence, is:

$$6.25 \times [log_e 1000]^{1/1.92} = 17.1 \text{ m/s}$$

The ratio of the expected unshielded 3-second average gust at 2 metres height in TC 3 to the 10-minute mean at 10m in TC2 is given by:

$$\frac{V_{3s,2m,TC3}}{\bar{V}_{10\,\min,\,10m,TC2}} = \frac{V_{3s,2m,TC3}}{\hat{V}_{0.2s,2m,TC3}} \cdot \frac{\hat{V}_{0.2s,2m,TC3}}{\hat{V}_{0.2s,10m,TC2}} \cdot \frac{\hat{V}_{0.2s,10m,TC2}}{\bar{V}_{10\,\min,\,10m,TC2}} =$$

$$\frac{1+3.0(0.271)}{1+3.8(0.271)} \cdot \frac{0.83}{1.0} \cdot [1 + 3.4(0.183)] = 1.203$$

Applying a shielding multiplier of 0.7, this factor becomes of $1.203 \times 0.7 = 0.842$.

Hence the expected maximum 3 sec gust at 2 m height in a shielded situation in TC3, with a probability of exceedence of 0.1%, is: $17.1 \times 0.842 = \underline{14.4}$ m/s

As expected from Figures 3 and 4, since 13 < 14.4 < 16 m/s, this location satisfies the 'walking' criterion, but fails the 'short-term stationary' criterion. Several points outside the inner contour, and one outside the outer contour (for the north wind direction), in Figure 4 are sufficient to produce the latter result.

Partially- and un-shielded locations in a suburban area

Using a similar approach to the preceding example for partially-shielded (M_s=0.85) and unshielded (M_s=1.0) locations in Terrain Category 3, 3-sec all-direction gusts with 0.1% exceedence probabilities of 17.5 m/s and 20.6 m/s respectively, are obtained. In both cases, the walking criterion is exceeded as a result of several points being outside the inner contour, as shown in Figures 5 and 6.

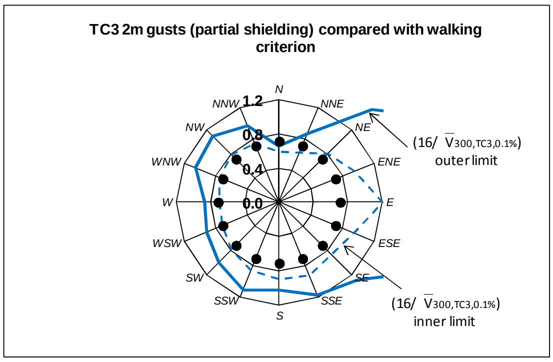

Figure 5. Velocity ratios for a hypothetical 'partially-shielded' suburban location compared with the contours for the 'walking' criterion

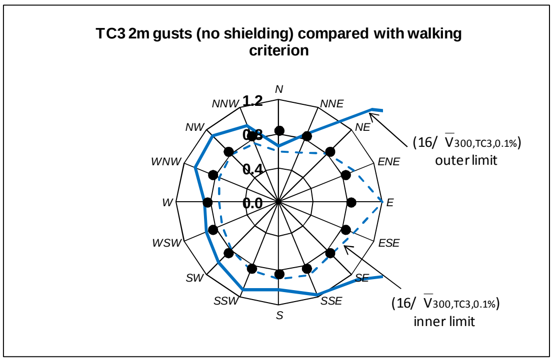

Figure 6. Velocity ratios for a hypothetical unshielded suburban location compared with the contours for the 'walking' criterion

An example from a typical building study

For an example more typical of one near the base of a real building, we have chosen one with plausible velocity ratios for a building exposed to northerly and westerly winds at the north side of the Melbourne CBD. We have labelled this case as 'Station S'. The velocity ratios ($V_{3s,\ 2m}/\ \overline{V}_{60\ min,\ 300m,\ TC3}$) for this station, assumed to have been obtained from a wind-tunnel test, are shown in Table 1 for sixteen direction sectors.

These velocity ratios are plotted with the contours for the walking criterion in Figure 7. It may be seen from this figure that all the velocity ratios fall within the outer contour, but several are outside the inner contour. An assessment, based on the outer contour, would have therefore given a positive acceptance with respect to the walking gust criterion of 16 m/s.

However, a full integration to obtain the 3-s gust wind speed at Station S with a total probability of exceedence of 0.001 (0.1%) gave a value of 17.6 m/s. This was determined from the Weibull distributions of wind speed for each sector, with the scale factors adjusted for the velocity ratios. The contributions to the probability of exceedence from the sixteen direction sectors are shown in Table 1. The contributions from NNE clockwise to WSW are negligible.

Thus, the 3-s gust speed at pedestrian level at Station S with a total probability of exceedence of 0.1% is 17.6 m/s – i.e. it is greater than the criterion value of 16 m/s. This is a result of some values being outside the *inner* contour in Figure 7, and indicates that use of the outer contour alone can give incorrect results, in cases such as this one.

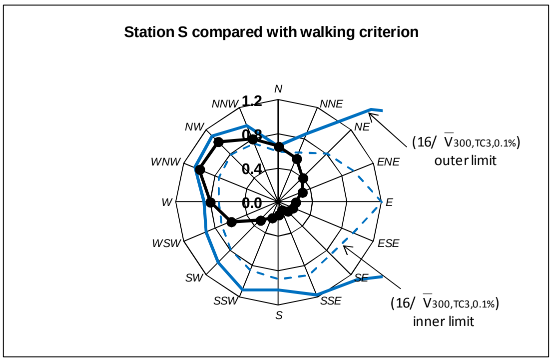

Figure 7. Velocity ratios for 'Station S' compared with the contours for the 'walking' criterion

Table 1. Velocity ratios for 'Station S', and full integration giving a combined probability exceedence of 0.1%

Dirn.	$V_{3s,\ 2m}$ / $\overline{V}_{60min,300m}$	Prob > 17.6 m/s
N	0.65	0.00026
NNE	0.55	0.00000
NE	0.40	0.00000
ENE	0.30	0.00000
E	0.20	0.00000
ESE	0.18	0.00000
SE	0.15	0.00000
SSE	0.10	0.00000
S	0.15	0.00000
SSW	0.20	0.00000
SW	0.30	0.00000
WSW	0.60	0.00000
W	0.80	0.00015
WNW	1.00	0.00032
NW	1.00	0.00022
NNW	0.80	0.00004
total		**0.00100**

An intermediate 'central' contour

To avoid the complexity of having two limiting contours for each criterion which give conservative and unconservative limits respectively, it should be possible to specify an intermediate or 'central' contour for each criterion, that would fall between the two limits, and for practical purposes provide a suitable limit that would, to a good approximation, reproduce the results of a full integration.

Several ways could be devised, but one possibility is shown for the Melbourne area, and the walking criterion, in Figure 8. This is based on a similar procedure to that used to derive the outer contours, but instead directional probability for each sector is doubled. This is equivalent to the 'outer' limit with a probability of exceedence of the wind speed of 0.05%, instead of 0.1%, for each direction sector. This idea is not dissimilar to that used by Melbourne (1984) to derive directional wind speeds and multipliers for AS/NZS 1170.2 – i.e. a version of the 'sector' method' for directionality.

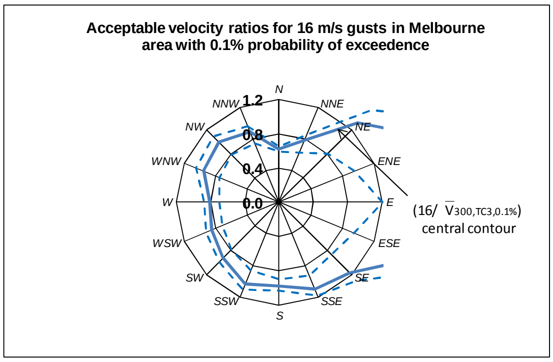

Figure 8. Possible intermediate ‘central’ contour for the Melbourne area for the 16 m/s walking criterion

The results from ‘Station S’, previously shown in Figure 7, are compared with the central contour in Figure 9. This shows that the contour is exceeded for the N, WNW and NW directions – i.e. the three largest contributors to the combined probability in Table 1. Thus, the crossings of the central contour indicate that the location does not meet the stated criterion when all directions are combined, even though there are no crossings of the outer contour (Figure 7). However, ideally, further ‘calibrations’ of such an approximate approach should be undertaken, using wind-tunnel data from real situations.

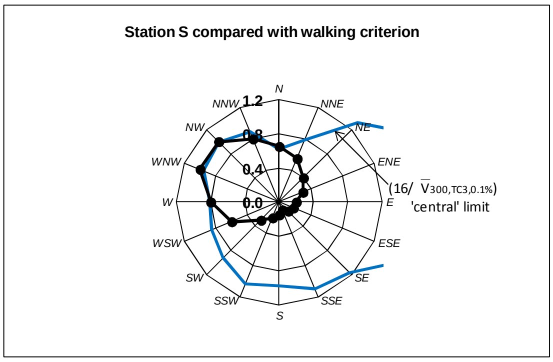

Figure 9. Velocity ratios for ‘Station S’ compared with the ‘central’ contour for the ‘walking’ criterion from Figure 8

Conclusions

The contour-crossing method developed by Melbourne (1978a) for pedestrian-level wind speeds in an urban development is a well-established, and convenient, method for carrying out such assessments, without the complexity of carrying out full integration over all direction sectors, for multiple locations of interest (e.g. Isyumov, 1978). The contour-crossing method has the practical advantage that wind-tunnel data need not be obtained for all direction sectors, for every location of interest, as is the case with the full-integration approach.

For the modifications to the method described in this paper, two contours have been defined – an ‘outer’ contour, which is similar to that used in current wind engineering practice, and a more conservative ‘inner’ contour. All velocity ratios falling within the *inner* contour guarantee that a full integration will show the location will satisfy the relevant criterion, when all wind directions are considered. However, all values falling within the *outer* contour is not a guarantee that the criterion will be satisfied when all directions are considered. That is, it is a necessary, but not *a sufficient*, condition for the criterion to be satisfied – a point also made by Melbourne (1978a).

These points have been illustrated with examples from the Melbourne area wind climate, including generic suburban situations with various levels of shielding, and a station typical of that at the base of a tall building exposed to northerly and westerly winds in the Melbourne CBD.

A possible ‘central’ contour has been proposed, lying between the outer and inner contours, and approximating better the rigorous full integration results.

The contour-crossing method is a ‘short-hand’ way of presenting data in a polar plot which shows clearly the critical directions. However, the full integration method gives the actual value of gust wind for the stated probability of exceedence, which correctly take accounts of all directions, and that method should be considered for critical locations near a building complex.

References

Holmes, J.D., Allsop, A.C. and Ginger, J.D. (2014) Gust durations, gust factors and gust response factors in wind codes and standards, *Wind and Structures*, Vol. 19, pp 339-352.

Isyumov, N. (1978) Studies of the pedestrian level wind environment at the Boundary Layer Wind Tunnel Laboratory of the University of Western Ontario, J*ournal of Industrial Aerodynamics*, Vol. 3, pp 187-200.

Melbourne, W.H. (1978a) Wind environment studies in Australia, J*ournal of Industrial Aerodynamics*, Vol. 3, pp 201-214.

Melbourne, W.H. (1978b) Criteria for environmental wind conditions, J*ournal of Industrial Aerodynamics*, Vol. 3, pp 241-249.

Melbourne, W.H. (1984) Designing for directionality, *Workshop on Wind Engineering and Industrial Aerodynamics*, Highett, Victoria, July 1984.

Standards Australia (1989) SAA Loading code. Part 2: Wind loads, Australian Standard AS 1170.2-1989.

Standards Australia (2011) Structural design actions. Part 2: Wind actions, Australian/New Zealand Standard AS/NZS 1170.2:2011.