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Gust durations, gust factors and gust response factors in wind codes and standards

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Abstract. This paper discusses the appropriate duration for basic gust wind speeds in wind loading codes and standards, and in wind engineering generally. Although various proposed definitions are discussed, the 'moving average' gust duration has been widely accepted internationally. The commonly-specified gust duration of 3-seconds, however, is shown to have a significant effect on the high-frequency end of the spectrum of turbulence, and may not be ideally suited for wind engineering purposes. The effective gust durations measured by commonly-used anemometer types are discussed; these are typically considerably shorter than the 'standard' duration of 3 seconds. Using stationary random process theory, the paper gives expected peak factors, g_u, as a function of the non-dimensional parameter (T/τ), where T is the sample, or reference, time, and τ is the gust duration, and a non-dimensional mean wind speed, $\bar{U}.T/L_u$, where $\bar{U}$ is a mean wind speed, and L_u is the integral length scale of turbulence. The commonly-used Durst relationship, relating gusts of various durations, is shown to correspond to a particular value of turbulence intensity I_u, of 16.5%, and is therefore applicable to particular terrain and height situations, and hence should not be applied universally. The effective frontal areas associated with peak gusts of various durations are discussed; this indicates that a gust of 3 seconds has an equivalent frontal area equal to that of a tall building. Finally a generalized gust response factor format, accounting for fluctuating and resonant along-wind loading of structures, applicable to any code is presented.

Keywords: anemometer; codes; gust duration; gust response factor; peak factor; wind load

1. Introduction

Many national wind codes and standards are based on a maximum gust wind speed, with a defined gust duration. Traditionally a '*3-second*' gust has been adopted by several codes and standards, including, for example, ASCE 7 since 1995 (American Society of Civil Engineers, 2010). On the other hand the Australian/New Zealand Standard (Standards Australia 2011) has recently redefined its gust duration as *0.2 seconds*. Related to this is the use of standardized wind

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speed – duration relationships, such as the 'Durst curve', by various groups to convert between wind speeds of various durations.

The use of 3-seconds as a gust duration in the past largely arose as a result of *ad-hoc* decisions made by code and standard committees, based loosely on perceived anemometer response characteristics, without a lot of deep consideration, or logic, behind its adoption. The '3-second gust' is a name that was formerly applied to measured analogue gust speeds, which we now know is inappropriate, as discussed in the following sections. However, the '3-second gust' has now become firmly established, following its adoption by the World Meteorological Organization (WMO), and most national meteorological agencies, based on a moving average definition (WMO 2008).

This paper will discuss the definition of 'gust duration', the response characteristics of typical anemometers, the effective frontal areas associated with typical gust durations, and standard peak factors and gust factor curves. It also proposes a 'generalized' form of gust response factor, or gust loading factor, which can be applied to any wind code or standard with the use of appropriate peak factors. The paper is primarily concerned with synoptic winds, including tropical cyclones and typhoons.

2. Anemometer response and gust duration

2.1 Anemometer response characteristics

Assessment of the effective gust duration of gust wind speeds measured routinely by national meteorological agencies in past recordings of gust wind speeds, requires knowledge of the response characteristics of the measuring instrument. In many cases cup anemometers were used, and continue to be used, as the principal wind-measuring instrument by national meteorological agencies. The response characteristics of this instrument can be reasonably well described by a first-order system model, with a distance constant, *D*, so that the transfer function for response to turbulence treated as a random function, such as turbulent wind speeds, can be written

$$|H_1(n)|^2 = \frac{1}{1+\left(\frac{2\pi nD}{\overline{U}}\right)^2} \tag{1}$$

where *n* is frequency and $\overline{U}$ is the mean wind speed .

This instrument responds to a step change in wind speed exponentially so that it reaches 63% of its final value in a time equal to ($D/\overline{U}$).

The Dines pressure-tube/float type of anemometer was used for most of the 20th Century in several jurisdictions (generally in the British Commonwealth countries). The dynamic response of this instrument is complex, and has only recently been fully understood (Miller *et al.* 2013). For a long time the Dines anemometer was assumed to produce a gust that had a duration of about 3 seconds, (e.g., Whittingham 1964), but this has since been found to be incorrect, based on the equivalent moving average definition (see next section), and the effective gust duration is much shorter.

2.2 Definition of gust duration

Although several ways to define a ‘gust duration’ have been proposed, the most universally-accepted way is by an *equivalent moving average*. This definition has been adopted internationally by ESDU 83045 (ESDU International 1983), the World Meteorological Organization (WMO 1988) and by the International Organization for Standardization (ISO 2009). In practice, this is easily implemented in the digital processing of automatic weather systems.

In the frequency domain, the transfer function for a simple moving average ‘filter’ can be written as

$$\left|H_2(n)\right|^2 = \left(\frac{\sin(n\pi\tau)}{n\pi\tau}\right)^2 \tag{2}$$

where τ is the moving average time.

The WMO (Beljaars 1987) originally suggested a value of τ of 2 to 5 seconds, obtained by digital filtering, as being an appropriate one for national meteorological services to record maximum gusts on a consistent basis around the world. In fact, a value of τ equal to 3 seconds has been widely adopted – i.e., a digital moving average extending for 3 seconds is commonly applied to sampled data from automatic weather stations. Note that, when τ is equal to 3 seconds, the right-hand-side of Eq. (1) takes a value of zero for *n* equal to (1/3) Hertz, and the half-power point is approximately 0.15 Hertz, frequencies that are well within the energy-containing range of atmospheric turbulence, and that are significant for wind pressures on structures.

2.3 Equivalent gust durations of various anemometer types

The effective gust duration of historical recorded gust data from analogue instrumentation systems in the pre-digital era was simply a function of the anemometer response.

Cook (1985) stated that, in the U.K.: ‘both Dines and cup anemometers record(ed) … fluctuating gusts down to about 1 second duration’, although a definition of ‘duration’ was not given. Kwon and Kareem (2014) included the effect of the chart recorder in an analysis of the equivalent averaging time of the F420C cup anemometer-recorder system of the National Weather Service of the United States, used prior to the introduction of automatic digital systems, and concluded that the equivalent averaging time of the analogue system was about 1 second.

Equivalent gust durations, τ_{equiv}, based on the equivalent moving average definition, for analogue response of various anemometers, as a function of mean wind speed, are shown in Table 1. These were determined by matching the gust factors obtained using a standard wind turbulence spectrum (Eq. (3)), with the known transfer functions for the anemometers, with those obtained using Eq. (2) with the appropriate moving average time, τ_{equiv}.

It will be noted from Table 1 that the equivalent moving average time, τ_{equiv}, is approximately twice the value of the time constant ($D/\bar{U}$) for a cup anemometer. An impression of the relationship between the transfer function for the cup anemometer in Eq. (1) and the moving average filter (‘sinc’ function) of Eq. (2), can be obtained by Fig. 1, in which Eq. (1) has been plotted for ($D/\bar{U}$) equal to 0.1 seconds, together with Eq. (2) with τ equal to 0.2 seconds. It can be seen that the areas under the two transfer functions are approximately equal to each other when $\tau = 2(D/\bar{U})$.

Table 1 Equivalent gust durations for various anemometer types

Anemometer	$\overline{U}$ (m/s)	τ_{equiv} (sec)
cup (D = 6 m)	25	0.5
cup (D = 6 m)	40	0.3
cup (D = 13 m)	25	1.2
cup (D = 13 m)	40	0.7
Dines	25	0.5
Dines (high-speed version)	40	0.3

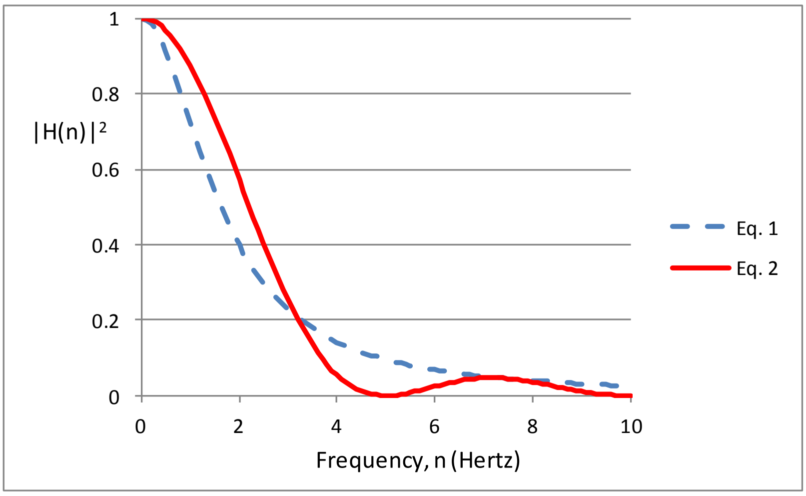

Fig. 1 Comparison of Eq. (1) for $(D/\overline{U})$ equal to 0.1 seconds, with Eq. (2) for τ equal to 0.2 seconds

Miller (2007) proposed an effective gust duration equal to the reciprocal of the half-power frequency i.e., the frequency at which the transfer function takes a value of 0.5. For a cup anemometer, from Eq. (1), this gives an effective gust time equal to $2\pi(D/\overline{U})$ – i.e., more than six times the time-constant, and about three times the equivalent moving average time, τ_{equiv}. This definition, while giving values reasonably consistent with the traditional '3-second' gust, would be difficult to apply to the Dines anemometer, which has a double peak in its transfer function (Miller *et al.* 2013), and would clearly be inconsistent with the WMO moving average definition.

Table 1, and the work of Kwon and Kareem, suggest that anemometer gust data recorded at high wind speeds relevant to design of structures, in the pre-digital era, generally had equivalent moving averaging times of 1 second or less – i.e., significantly lower than the assumed 'standard' gust duration of 3 seconds, as currently adopted by meteorological agencies. Thus, current '3-second' gusts produced by digital systems need correction (upwards) to be compatible with earlier archived data produced by analogue recordings.

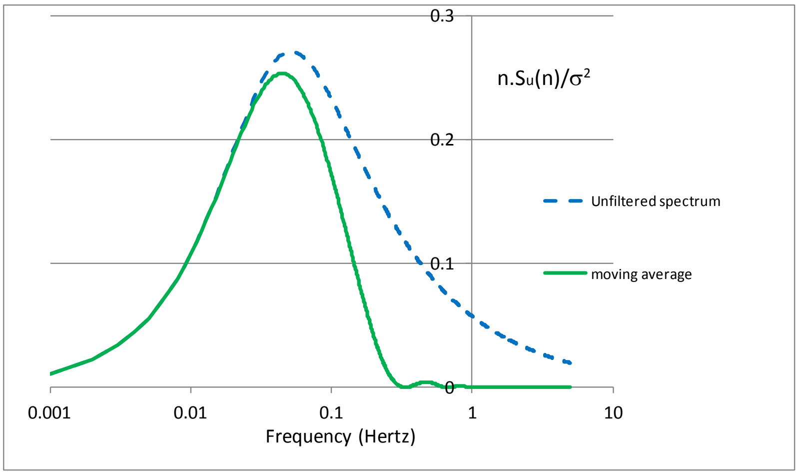

Fig. 2 Effect of a moving average filter with an averaging time, τ, of 3 seconds on the wind spectrum, at a typical design wind speed

3. The '3-second' gust and the spectrum of turbulence

The effect of moving average filters can be illustrated by applying the filter transfer function of Eq. (2) to a typical spectral density of wind turbulence. This has been done in Fig. 1, with the averaging time, τ, equal to 3 seconds. The spectral density chosen was the von Karman form given in Eq. (3), with the integral length scale, L_u, of 85 metres. This value is the length scale used in Australian Standard AS/NZS 1170.2 (Standards Australia 2011) for a height above ground of 10 metres.

$$\frac{n.S_u(n)}{\sigma_u^{\ 2}} = \frac{4\left(\dfrac{nL_u}{\bar{U}}\right)}{\left[1+70.8\left(\dfrac{nL_u}{\bar{U}}\right)^2\right]^{5/6}} \tag{3}$$

From Fig. 2, it is clear that the effect of a moving-average filter with the value of τ equal to 3 seconds on the high frequency end of the wind spectrum is severe. A large proportion of the high-frequency end of the spectrum is truncated. This has a significant effect on the peak factors and gust factors, as discussed in a later section.

4. Peak factors

For the conversion of wind tunnel data on building pressures, based on mean wind speeds, for use in codes or standards based on gust speeds, gust factors are required. In general, gust factors are a function of mean wind speeds and turbulence intensity as well as peak factors. The dependence on turbulence intensity means that gust factors vary with the height above ground and terrain. Peak factors are relatively insensitive to the siting however.

For calculation of the peak and gust factors associated with the various gust durations, random process theory can be applied using the transfer function of Eq. (2) with the wind spectrum of Eq. (3). Similar approaches, based on stationary random processes, were previously adopted by Davenport (1961), Greenway (1979) and Beljaars (1987).

The cycling rate or 'average frequency', ν, of the filtered process can be calculated from Eq. (4) as follows

$$\nu = \left\{ \frac{\int_o^\infty n^2 \cdot S_u(n) \cdot |H(n)|^2 dn}{\int_o^\infty S_u(n) \cdot |H(n)|^2 dn} \right\}^{1/2} \tag{4}$$

The expected, or average, peak factor, g_u, can then be calculated using the well-known formula for Gaussian random processes (Davenport 1964), with the assumption of independence of peaks

$$g_u = \sqrt{2\log_e \nu T} + \frac{0.577}{\sqrt{2\log_e \nu T}} \tag{5}$$

where T is the sample time.

Peak factors have been calculated from Eqs. (2), (3), (4) and (5), and are shown in Fig. 3. It should be noted that, as is normal practice, the peak factors have been rescaled to be applicable to the unfiltered process with a spectral density given by Eq. (3). Expected peak factors, g_u, are shown as a function of the non-dimensional parameter (T/τ), where T is the sample time, and τ is the gust duration, and a non-dimensional mean wind speed, $\bar{U}.T/L_u$, where L_u is the integral length scale of turbulence.

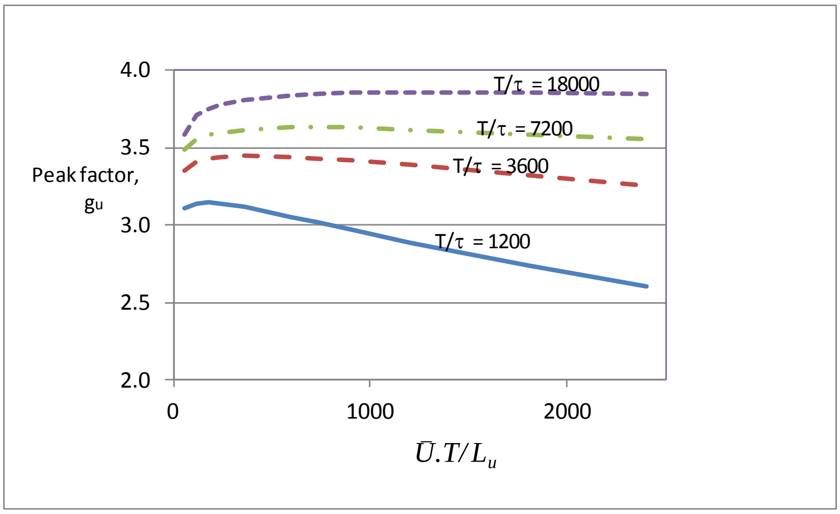

Fig. 3 Expected peak factors for various non-dimensional moving average times

It will be noted from Fig. 3 that for low values of T/τ, the peak factor becomes more sensitive to $\overline{U}.T/L_u$ – i.e., to the mean wind speed, $\overline{U}$. For high values of T/τ - i.e., for shorter gust durations, τ, the peak factor is nearly constant with varying mean wind speed.

Values of expected peak factors for various values of τ and T are summarized in Table 2 (for $\overline{U}$ = 20 m/s and L_u = 100 m).

The value of peak factor of 3.0 for 3-second gusts based on a 1-hour sample time, T, agrees with corresponding values given in ESDU 83045 (ESDU International 1983), and in ISO 4354 (ISO 2009). Note that the peak factor of 3.7 suggested by Deaves and Harris (1978), for T=3600 seconds, and adopted widely, is not appropriate for a 3-second gust under the moving average definition, although it was a reasonable value for use with peak gusts obtained by standard Dines anemometers, for which the gust duration, τ, is much shorter than 3 seconds (see Table 1) .

In the light of the above discussion, it is of interest to consider the peak factors used, or implied, in various major wind codes and standards. The Australian/New Zealand Standard, has now adopted a value of 3.4 for g_u, appropriate for τ equal to 0.2 seconds and T equal to 600 seconds in Table 2; this value has replaced the value of 3.7, from the Deaves and Harris (1978) model, in AS/NZS 1170.2.

ASCE 7 also uses a value of g_u of 3.4, although the nominal values of τ and T are 3 seconds and 3600 seconds, respectively. However, in the formulation of the 'gust effect factor' in ASCE 7, the factor 2 in the denominator has been replaced by 1.7, giving an effective peak factor of 2.9 (= 1.7×3.4/2). From Fig. 2, for T/τ equal to 1200, g_u of 2.9 is obtained for $\overline{U}.T/L_u$ of about 1000, a value which is obtained for $\overline{U}$ equal to 28 m/s when T is 3600 seconds and L_u is 100 m. Thus, the effective gust factor in ASCE 7 is consistent with the stated gust duration of 3 seconds, but would need revision if the gust duration is changed to 1 second, as proposed by Kwon and Kareem (2014). Gust effect factors and gust response factors are discussed later in this paper.

The 'peak velocity pressure' used in the Eurocode (British Standards Institution 2005) incorporates an implied peak factor of 3.5 (=7/2). T is 600 seconds in the Eurocode, and a peak factor of 3.5 is then obtained for an implied gust duration of about *0.1 seconds* ($T/\tau \cong$ 6000 in Fig. 3).

Table 2 Expected peak factors for various τ and T

Averaging time, τ (secs.)	Sample time, T (secs.)	T/τ	$\overline{U}.T/L_u$	g_u
3	3600	1200	720	3.0
3	600	200	120	2.5
1	3600	3600	720	3.4
1	600	600	120	2.9
0.2	3600	18000	720	3.8
0.2	600	3000	120	3.4

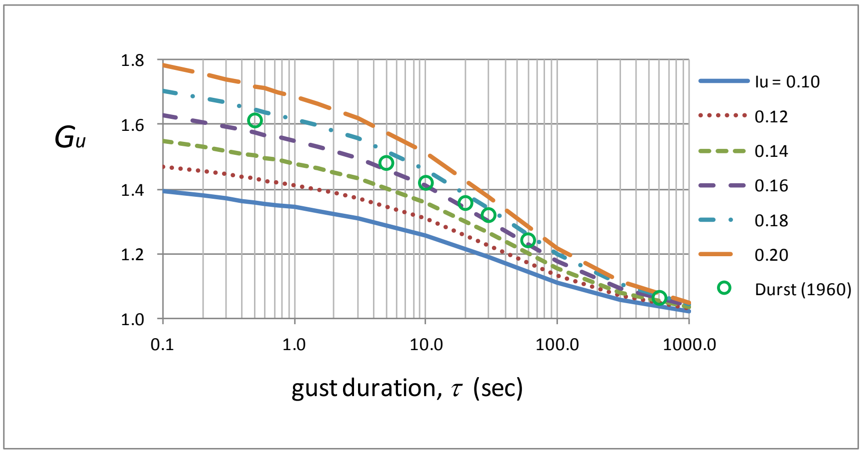

Fig. 4 Gust factors, G_u, as a function of turbulence intensity for $L_u/\overline{U}$ = 10 s, T = 3600 s

5. Gust factors for velocity

The expected gust factor, G_u, for the longitudinal velocity component, can be calculated from the peak factor, g_u, knowing the turbulence intensity

$$G_u = \frac{\hat{U}}{\overline{U}} = \frac{\overline{U} + \sigma_u}{\overline{U}} = 1 + g_u I_u \tag{6}$$

where σ_u is the standard deviation of the turbulent wind fluctuations, and I_u is the (unfiltered) longitudinal turbulence intensity (= $\sigma_u/\overline{U}$).

The dependency of gust factors on turbulence intensity is illustrated in Fig. 4 for $L_u/\overline{U}$ = 10 seconds.

A gust factor curve attributed to Durst (1960) is also shown in Fig. 4. This curve has been adopted by ASCE 7 as a 'universal' gust factor curve at the standard site conditions (open country, 10 metres height), for several editions of that Standard. Except for the gust duration of 0.5 seconds, the Durst data was derived from measurements made in the late 1920s at the airship port at Cardington, U.K., at a height of 50 feet (about 15 metres), not at the standard height of 10 metres. Fig. 3 shows that the Durst curve is consistent with a turbulence intensity of 0.165 – a reasonable value for a height of 15 metres above the open terrain of Cardington.

Furthermore, a recent re-assessment of the original Cardington data by Miller (2011) showed that the analysis by Durst was based on a relatively small sub-set of the complete data set (reported by Giblett 1932), and that use of the full data set leads to average gust factors that are up to 5% higher than those given by the Durst 'curve'. Miller (2011) found a lower turbulence intensity (0.133) than the value of 0.165 discussed above, and shown in Fig. 3. However, the former value is based on the 5-second 'block-averaged' data of Giblett (1932); this averaging process acts a significant low-pass filter (see Fig. 1) and unless corrected, would produce an artificially low value of turbulence intensity.

The above discussion, and the paper of Miller (2011) shows that the 'Durst curve', and the data that it is based on, are primarily of historical interest, and that a more rational basis should be used for gust factors in codes and standards such as ASCE 7.

6. Effective frontal area

A consideration in defining a maximum gust duration for a wind code or standard, is the effective frontal area over which a gust can be considered to act. Using an expression for aerodynamic admittance proposed by Vickery (1968) and given in Eq. (7), and a moving average filter, effective, or equivalent, frontal areas for a τ-second gust can be derived by matching the calculated expected peak factors, for a range of mean wind speeds.

$$|H(n)|^2 = \frac{1}{\left[1+\left(\frac{2n\sqrt{A}}{\bar{U}}\right)^{4/3}\right]^2} \tag{7}$$

This process results in a relationship between equivalent frontal area for a 3-second gust (i.e., τ = 3 s) and (hourly) mean wind speed shown in Fig. 5.

Fig. 5 shows that the equivalent frontal area varies considerably with mean wind speed. However, at a typical design hourly mean wind speed of 30 m/s, a 3-second gust has an equivalent frontal area of 3200 square metres – equivalent to that for a tall building 100 metres tall and 32 metres wide. Thus a code based on a 3-second gust (based on the moving average definition) with quasi-steady shape factors, should include a 'gust effect factor' greater than 1.0 to *increase* the effective pressure, when applied to small buildings, or other structures with small frontal areas. Furthermore, the gust response factor (or dynamic response factor) used to estimate dynamic response for tall structures, should be adjusted to allow for the 'built-in' correlation effects associated with a 3-second gust.

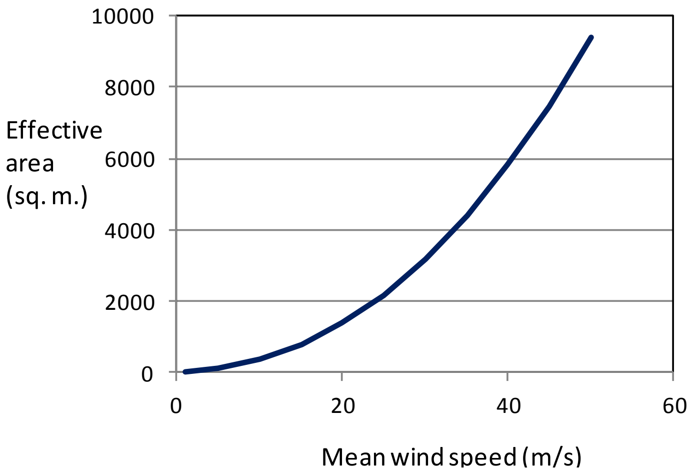

Fig. 5 Equivalent frontal area for a 3-second gust (for L_u = 85 m)

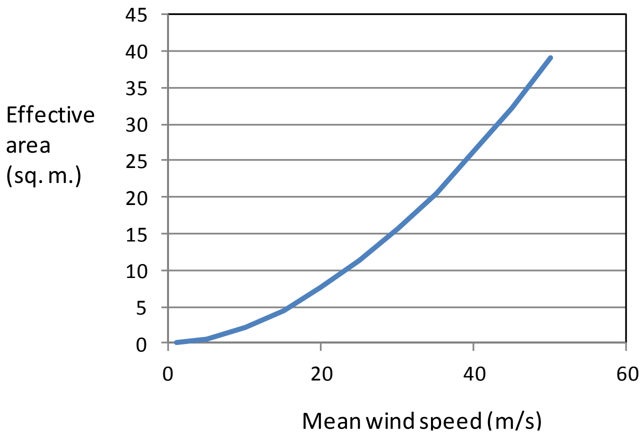

Fig. 6 Equivalent frontal area for a 0.2-second gust (for L_u = 85 m)

Fig. 6 shows the equivalent frontal area for a *0.2 second* moving average gust. The equivalent area at a mean wind speed of 30 m/s is only about 16 square metres – about the area of a small building. Thus, a gust duration of this size can be used in codes or standards with quasi-steady shape factors, with no special gust effect factors for small buildings.

7. Generalized gust response factors for buildings

7.1 Gust response and dynamic response factors

Gust response factors, or 'gust loading factors', for tall buildings (accounting for along-wind loading, including resonant dynamic contributions) have evolved since the 1960s, through the work of Vickery (1966), Davenport (1967), and subsequently by Simiu (1980), Solari (1993), and several others. The format and notation have been adopted in many wind loading codes and standards. A more recent development has been the introduction of the 'dynamic response factor' format for use with codes and standards based on gust speeds (e.g., Holmes 2002, Standards Australia 2011, ISO 2009).

In its original format, the gust response/loading factor, based on a mean wind speed, took a general form similar to the following

$$G_r = 1 + 2I_u\sqrt{{g_B}^2 B + {g_R}^2 R} \tag{8}$$

where the notation G_r has been used for the gust response, or loading, factor to distinguish it from the gust factor for velocity, G_u, of Eq. (6). B and R contain terms for calculation of the background fluctuating, and resonant dynamic components, respectively.

7.2 Generalized form for any code format

The form of Eq. (8) was originally developed for use with a mean wind speed, averaged over 10 minutes to 1 hour. A 'generalized' gust response factor form that is applicable to any code or standard, including those based on peak gust wind speeds, is as follows

$$G_r = \frac{1 + 2I_u\sqrt{{g_B}^2 B + {g_R}^2 R}}{1 + 2g_u I_u} \tag{9}$$

The denominator in Eq. (9) is included to convert the wind loading calculated by the code or standard, to an equivalent mean loading to which the numerator, similar to the gust loading factor of Eq. (8), is applied. Eq. (9) reverts to Eq. (8) when g_u is taken as zero.

Note that the factor '2' in both Eqs. (8) and (9) results from the linearization of the pressure–velocity relation – i.e., it arises from the fundamental physics, and should not be treated as an adjustable parameter.

Usually when Eq. (9) has been adopted by codes based on gust speeds, the same peak factor, g_B, appears in both numerator and denominator, and is taken as the peak factor for velocity, g_u. However, in general, *different* values should be adopted for these values, unless the code or standard is based on a short gust duration, such as 0.1 or 0.2 seconds.

Appropriate values of g_B and g_u should be adopted depending on the reference time, T, for specifying peak values, and on the gust averaging time, τ, that has been adopted for the general loading specifications of the code or standard. T should be a time over which the fluctuations of velocity and loading can be considered statistically stationary – e.g., for large scale extra-tropical synoptic systems, taking T equal to 10 minutes to 1 hour may be appropriate; the former is the recommended averaging time by the WMO. For tropical cyclones (including hurricanes and typhoons), T equal to ten minutes is more suitable. For thunderstorm winds, a time as low as 1 minute might be appropriate.

Examples of appropriate values of g_B and g_u, for various values of T and τ, are shown in Table 3. The values in Table 3 are valid for typical design wind speeds, and are derived from Table 2. It will be noted that when the averaging time τ, and reference time, T, are the same, the value of g_u is taken as zero, so that the denominator in Eq. (9) becomes 1.0, and that equation reverts to the original gust loading factor of Eq. (8). When a short gust duration factor is chosen (say 0.2 seconds or less, as in the Australian/New Zealand Standard, AS/NZS 1170.2), g_B and g_u can take the same value, but that value is dependent on the chosen value of reference time T. In this case, all the reduction for the large frontal area of a building is incorporated in the 'background factor, B, and a 'size factor' in the resonant term.

When a moving-average gust time, τ, of 3-seconds is adopted, g_u should be less than g_B, since only the denominator is used to correct the basic gust loading derived from the code to an equivalent mean loading, averaged over the chosen reference period, T. Once that has been done the allowance for gusting and dynamic effects is achieved by the numerator, as in Eq. (8).

7.3 Example of a non-resonant structure

Note that for small, stiff, non-resonant structures, the term R in Eq. (9) is negligible and B becomes 1.0. In that case, a value of g_u less than g_B will give a value of G_r greater than 1.0.

Table 3 Appropriate peak factors for G_r, for various τ and T

Averaging time, τ (secs.)	Sample (reference) time, T (secs.)	g_B	g_u
3600	3600	3.8	0.0
600	600	3.4	0.0
3	3600	3.8	3.0
3	600	3.4	2.5
0.2	3600	3.8	3.8
0.2	600	3.4	3.4

For example, for $\tau = 3$ sec., $T = 3600$ sec., and $I_u = 0.20$,

$$G_r = \frac{1 + 2(0.2)\sqrt{3.8^2(1.0) + 0}}{1 + 2(3.0)(0.20)} = \frac{2.52}{2.2} \cong 1.15$$

This demonstrates that a value of gust response factor around 1.15 is an appropriate one for small structures in rural areas, in a code or standard based on a gust duration of 3 seconds, and in fact a value of 1.14 has been adopted by the AAHSTO (American) Standard for Highway Signs (AAHSTO 2013).

8. Conclusions

A moving-average definition of gust duration has been adopted universally by meteorological agencies for modern automatic weather stations, with a 3-second average being the recommended value of the WMO, and is the most common gust quoted by these agencies. However, earlier analogue data recorded directly from anemometers generally had an equivalent gust duration of less than 1 second. Hence, these earlier data would require correction to a 3-second gust format.

Calculation of expected gust factors shows that the commonly-used ‘Durst curve’ applies to a particular longitudinal turbulence intensity (about 16.5%), and it should not be applied generally as a ‘universal’ curve.

The paper has shown that the filtering effect of a 3-second moving average truncates a large part of the turbulent wind spectrum at typical design wind speeds, and the equivalent spatial filter has a frontal area about that of a large tall building (i.e., 3200 m^2 at a mean wind speed of 30 m/s). Hence, if this gust duration is used as a basis of a loading code or standard, it is clear that a ‘gust effect’ factor greater than 1.0 should be applied for small buildings and other small structures, and a value of around 1.15 is shown to be appropriate for structures in rural areas.

It has been noted that the Australian/New Zealand Standard AS/NZS 1170.2:2011 (Standards Australia 2011) has adopted a peak moving-average gust duration of 0.2 seconds as its basis. This is partly due to the short gust duration that is associated with the Dines pressure-tube anemometer used up to about 1990 in Australia (see Miller *et al*. 2013, and Table 1), but also due the small frontal area associated with this gust at design wind speeds – about 16 m^2 at a mean wind speed of 30 m/s, equivalent to the frontal area of a small building (Holmes and Ginger 2012, and Fig. 6). The latter property avoids the need for a 'gust effect' factor for small buildings (i.e., the implied value of that factor is 1.0). For large buildings, the filtering effect of a large frontal area is incorporated through the 'background factor', *B*, term in the 'dynamic response factor' calculation, using an equation similar to Eq. (9).

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