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Importance of approach flow conditions on gust factor

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SUMMARY:
The "Durst curve" is widely used to estimate gust factor which relates gust wind speeds between different averaging periods. Gust factor is a function of mean wind speed, turbulence intensity, integral length scale and observation period for the mean wind speed. Durst curve is applicable for a specific wind condition and therefore does not vary with the aforementioned parameters. On the other hand, ESDU provides a detailed approach to calculate gust factor for different wind characteristics. The ESDU approach is computationally demanding, which possess challenges for mass use. In this study, an adjustment to the Durst curve is proposed that is applicable for different wind conditions at different scales. The adjusted Durst curve is then compared with full-scale and wind tunnel data as well as the ESDU approach. It is evident from the comparison that the adjusted Durst curve would be a good alternative to the ESDU approach for easier adaptation with much less computation than ESDU as well as to implement in the wind loading standards.

Keywords: gust factor, Durst curve, wind conditions

1. INTRODUCTION

The gust factor (G) is usually defined as the ratio of gust wind speed of duration τ (e.g., a 3-second gust) to the mean speed of the observation period T (e.g., T = 10 minutes or one hour). The gust factor is used throughout wind engineering. For example, it is used to compare wind load coefficients between building codes that normalized by mean speed and those that normalized by gust speed. Using gust factor, peak wind loads which includes the dynamic loading effects due to gustiness can be estimated from mean wind loads (Davenport, 1964; Solari and Kareem, 1998). It is well-established that the gust factor is a function of the turbulence intensity. For example, Holmes et al. (2014) provides an equation of the form

$$G = 1 + gI_u \quad (1)$$

where g is the peak factor, given as 2.5 (Holmes et al., 2014, assuming τ = 3s and T = 10 minutes), and I_u is the turbulence intensity, the ratio of the standard deviation to the mean, σ_u/U_{mean}.

ESDU (ESDU 83045, 1983) provides a detailed method for calculating G for different wind turbulence conditions. This method integrates the spectrum between T and τ (with appropriate low pass and high pass filters) to determine σ_u, and uses Davenport's cycling rate to calculate the peak factor.

A relationship of G for different values of τ is provided by Durst (1960) for T = 1 hour. The American structural loading standard, ASCE 7-22 (2021) has adopted the Durst curve for calculating gust factor in extratropical winds. As noted by Holmes et al. (2014), the Durst curve is strictly valid for open country terrain (I_u close to 17%, roughly matching Exposure C in ASCE 7). However, in addition to turbulence intensity, $G(\tau, T)$ also depends on mean wind speed (U) and integral length scale $({}^xL_u)$, and observation period (T), none of which are addressed by Durst curve.

To our knowledge, the ESDU approach is the most comprehensive method to obtain gust factor curves. While many engineering firms have implemented the detailed mathematical programming to develop in-house tools, this approach is not always possible in wind loading standards. Therefore, this study provides an adjustable Durst curve to account for all of these parameters.

2. THE DURST CURVE

In order to extract the wind conditions pertaining to the Durst curve, the ESDU gust factor curve was matched with the Durst curve. Using U = 16 m/s for T_0 = 1 hour, I_u = 17% and ${}^xL_u$ = 160 m, a good match was found (Figure 1). We also individually varied U, I_u and ${}^xL_u$ to demonstrate the effect of these parameters on gust factor which can also be seen in Figure 1. Gust factors for τ = 10 s for different wind conditions are shown in the figure with green dashed lines for comparison. It is evident from Figure 1 that different wind conditions result in different gust factors which can be significant for larger deviations from the Durst conditions.

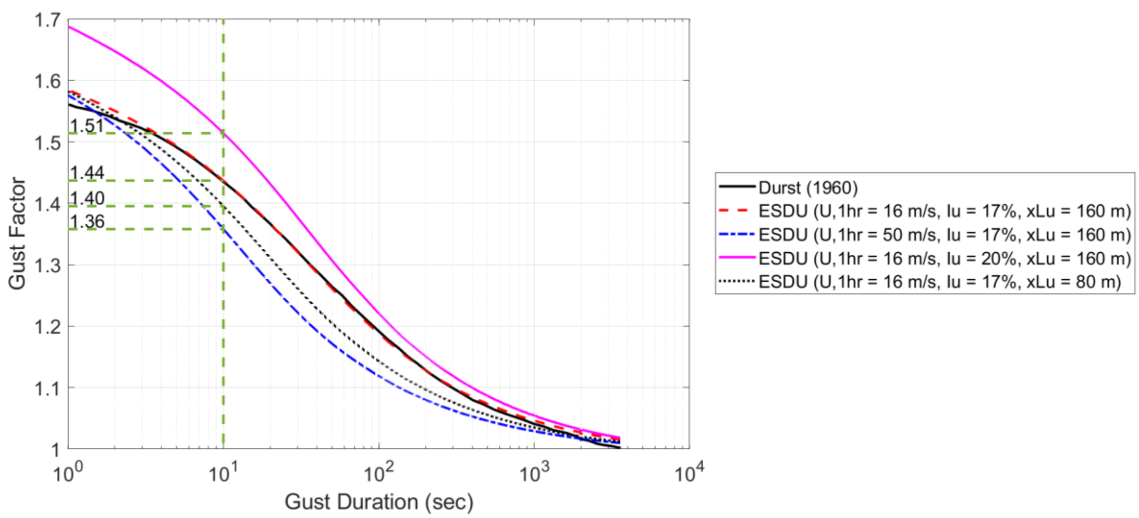

Figure 1. Gust factor curves for different wind conditions.

We propose the following adjustments (Eqs. (2 to 4) to the Durst curve to better represent variations of U, I_u and ${}^xL_u$:

$$GF_{360}(\tau) = (GF_{Durst}(\tau) - 1) \times \left(\frac{Iu_{obs}}{Iu_{Durst}}\right) + 1 \tag{2}$$

$$GF_{adj}(\tau) = {GF_{360}(\tau)}\Big/{GF_{360}(\tau = T)} \tag{3}$$

$$\tau_{adj} = \tau_{Durst} \times \left(\frac{{}^{x}L_{u,obs} / {}^{x}L_{u,Durst}}{U_{obs} / U_{Durst}} \right) \qquad (4)$$

where, GF_{360} represents gust factors for up-to a duration of 360 integral length scales (i.e., 3600 s for the Durst curve), GF_{Durst} is the gust factor from the Durst curve, Iu_{obs} is the observed turbulence intensity, Iu_{Durst} is the estimated turbulence intensity for the Durst curve (0.17), GF_{adj} is the adjusted gust factor (Eq. 3 is responsible for the additional adjustment when T is less than the duration of 360 integral length scales), τ_{adj} is the adjusted gust duration, τ_{Durst} is the gust duration from the Durst curve, ${}^{x}L_{u,obs}$ is the observed longitudinal integral length scale, ${}^{x}L_{u,Durst}$ is the longitudinal integral length scale from the Durst curve match (160 m), U_{obs} is the observed mean wind speed over a period of T and U_{Durst} is the mean hourly wind speed from the Durst curve match (16 m/s).

Values provided in Table 1 for Iu_{Durst}, ${}^{x}L_{u,Durst}$ and U_{Durst} should be used as constants in Eqs. 2 and 3. For standard exposures, Iu_{obs}, ${}^{x}L_{u,obs}$ and U_{obs} can be obtained from wind loading standards, such as Table C2-1 in ASCE/SEI 49-21 (2021). However, Table C2-1 is for a specific wind speed (20 m/s) at a reference height (10 m). For other conditions, detailed instructions for calculating U, I_u and ${}^{x}L_u$ are given in Section 2.3 of ASCE/SEI 49-21 (2021).

Table 1. Durst curve parameters

U_{Durst}	Iu_{Durst}	${}^{x}L_{u,Durst}$
16 m/s	17%	160 m

It should be noted that there is a significant variation among standards for ${}^{x}L_u$. Figure 2 compares ${}^{x}L_u$'s from different standards at different heights. Depending on the standard, ${}^{x}L_u$ can be between 150 m to 410 m at a height of 100 m from the ground. The full paper will examine some field observations, but these also show considerable variability. As gust factor varies with ${}^{x}L_u$, more streamlined estimation of ${}^{x}L_u$ among various standards and consensus among researchers are necessary for more accurate calculation of gust factors. Further research based on full-scale data is thus highly encouraged to obtain better insights on ${}^{x}L_u$.

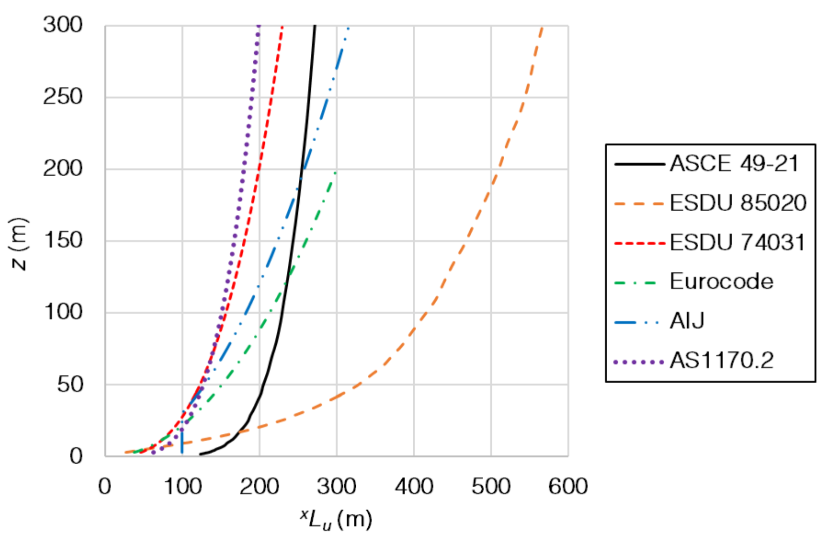

Figure 2. Integral length scales of turbulence from different standards

3. COMPARISON WITH ESDU, FULL-SCALE AND WIND TUNNEL DATA

In Figure 3, the adjusted Durst curve is compared with full-scale and wind tunnel data as well as ESDU approach based on von Karman spectra. Details of these boundary layers will be provided in the full paper and presentation, along with comparison with additional full-scale data. The gust factors in the data points were calculated directly from the data using a moving average of duration τ.

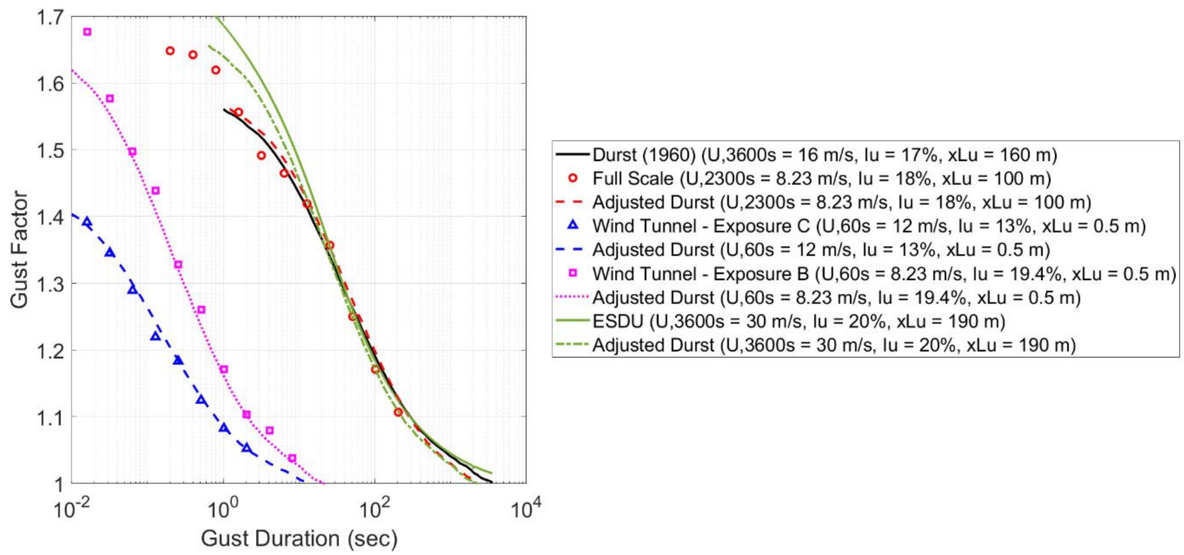

Figure 3. Comparison of adjusted Durst curves with ESDU, full-sale and wind tunnel data.

4. CONCLUSIONS

The importance of turbulence intensity, observation duration, wind speed and length scale in determining gust factor are illustrated using the ESDU method and incorporated into an adjustment to the Durst curve. The adjusted Durst curve compares favourably with gust factors calculated from full-scale data, wind tunnel data and ESDU approach. Wind loading standards can be used for the velocity profile information needed to use the adjusted Durst curve. However, there is a significant scatter among different wind loading standards, especially for integral length scales. A weak understanding of the integral length scale of turbulence is the biggest source of uncertainty in the gust factors estimates.

REFERENCES

ASCE 7-22, 2021. Minimum Design Loads and Associated Criteria for Buildings and Other Structures. American Society of Civil Engineers. https://doi.org/10.1061/9780784415788

ASCE/SEI 49-21, 2021. Wind Tunnel Testing for Building and Other Structures, Standards. American Society of Civil Engineers.

Davenport, A.G., 1964. Gust loading factors. J. Struct. Div. ASCE 5255.ST3, 11–34.

Durst, C.S., 1960. Wind speeds over short periods of time. Meteorol. Mag. 89, 181–186.

ESDU 83045, 1983. Strong winds in the atmospheric boundary layer. Part 2: Discreet gust speeds (No. Engineering Science Data Unit Number 83045).

Holmes, J.D., Allsop, A.C., Ginger, J.D., 2014. Gust durations, gust factors and gust response factors in wind codes and standards. Wind Struct. 19, 339–352. https://doi.org/10.12989/was.2014.19.3.339

Solari, G., Kareem, A., 1998. On the formulation of ASCE7-95 gust effect factor. J. Wind Eng. Ind. Aerodyn. 77–78, 673–684. https://doi.org/10.1016/S0167-6105(98)00182-2