August 27-31, 2023
FLORENCE - ITALY
ICWE 16
16th International Conference on Wind Engineering

# Aspect Ratio Effects on Peak Wind Loads of Low-to-High Rise Buildings using CDF mapping

Timothy John Acosta [1*], Jin Wang [1], Gregory A. Kopp [1]

*[1]Boundary Layer Wind Tunnel Laboratory, Faculty of Engineering, University of Western Ontario, London, ON, N6A 5B9, Canada, *tacosta@uwo.ca*

**SUMMARY:**
The current code-based design procedures for determining wind loads on high-rise buildings follow the assumption that the building pressures follow a Gaussian process. However, the problem arises for low-rise buildings wherein non-Gaussian behavior is dominantly observed. To address this concern, this paper proposes a framework for determining the non-Gaussian peak factor for the windward wall as a function of a critical non-dimensional building geometry parameter. First, the study used two aerodynamic databases to characterize buildings' windward wall-averaged statistical characteristics. The results show that a general relationship between the peak distribution and the non-dimensional parameter H/B can be established for windward walls. To determine the non-Gaussian peak factors, a translation method via CDF mapping was used, and the applicability of target standard marginal distributions was examined. The Weibull distribution was then found to be the best target marginal distribution compared to peak factors generated using the Lieblein BLUE method. A model for non-Gaussian peak factors was then proposed as a function of H/B. The model's results compared to the peak wind factors evaluated using the Lieblein BLUE method showed good agreement.

*Keywords: translation, peak, factor, non-Gaussian*

## 1. INTRODUCTION

The current code-based design procedure for determining wind loads on high-rise buildings is founded on the quasi-steady theory of Davenport (1977), which uses a Gaussian distribution assumption in the fluctuation of large-scale freestream turbulence. However, when considering low-rise buildings, strongly non-Gaussian fluctuations can be observed in the windward wall due to horse-shoe vortex shedding and in flow-separated regions (Ginger and Letchford, 1993) Furthermore, building surfaces such as the roof, side walls, and leeward walls also experienced highly non-Gaussian behavior due to flow separation or vortex shedding (Solari, 1993).

To systematically understand the statistics and building aerodynamics, Wang and Kopp (2021b) examined the gust effect factor model using an extensive database obtained by the University of Western Ontario (UWO). They observed that the non-Gaussian behavior due to horseshoe vortex shedding is dominant in buildings with a H/B < 1.0, which they subsequently classified as low-rise buildings. For H/B values, the upstream flow tends to move around the sides of the building, wherein the effect of the horseshoe vortex is less observed on the statistics of the windward wall. With a H/B > 4, the windward walls approach a Gaussian distribution. Due to these statistics such as the kurtosis and skewness are dependent on the non-dimensional parameter H/B, Wang and

Kopp (2021b) suggest that a peak factor model based on this parameter may be investigated. The analysis of a translation function dependent on the different building configurations can only be done with an extensive systematic aerodynamic database that has not been available before. This paper then investigates using standard marginal distributions as a translation function specifically for the area-averaged pressures of the windward wall by utilizing an extensive building aerodynamic database in order to develop a model for determining peak factors for non-Gaussian behavior as a function of non-dimensional building geometry parameters.

## 2. METHODOLOGY FOR DETERMINING PEAK FACTORS

### 2.1. Building configurations

The datasets used in this paper are from Ho et al. (2005), for low-rise buildings, and Wang and Kopp (2021a) for mid to high-rise buildings. Specifically, 28 building configurations from Ho et al. (2005) with a roof slope less than 10º and 30 buildings configurations from Wang and Kopp (2021b) were used in this paper.

### 2.2. Statistics of windward wall and roof surfaces

For the analysis, a kurtosis range from 2.5-3.5 and a skewness range of -0.5 – 0.5 would imply a Gaussian distribution to a mildly non-Gaussian distribution (Kumar and Stathopoulos, 2000). Figure 1 gives the order statistics with their corresponding H/B. The monotonic region approximated by Winterstein and MacKenzie (2011), in which a Hermite Polynomial Model (HPM) translation function exists, is also plotted for discussion.

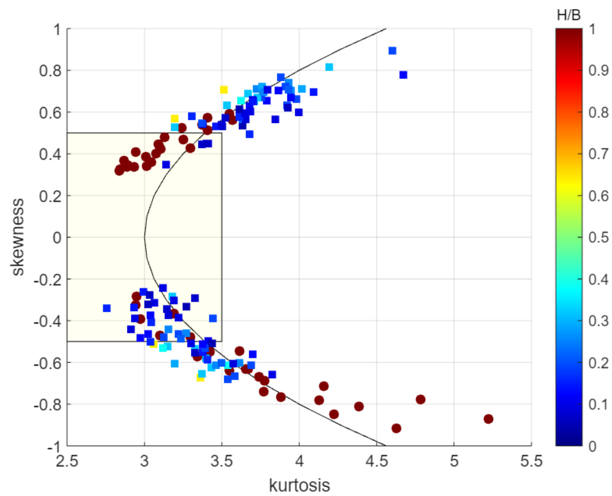


**Figure 1.** Skewness and kurtosis with corresponding H/B parameters of all building configurations and the monotonic region for HPM.

In figure 1, the region bounded by the light-yellow color is the zone that is characterized as Gaussian to mildly non-Gaussian (Kumar and Stathopoulos, 2000). It can be observed that, unlike point pressure taps, there are a significant number of data points outside the monotonic region that do not permit an HPM translation. This shows the limitation of HPM translation as compared to CDF mapping for area-averaged surfaces.

## 2.3. Translation Process

Grigoriu (1984) proposed a method to relate the standard Gaussian process u(t) to a standard non-Gaussian process x(t) through a memoryless monotonic translation function, where g( ) is a translation function of the standard Gaussian value u. The CDF of the peak of u within a reference duration t can be computed by $F_{U_{PK}}(x,t)$. (Rice, 1945) and wherein the zero-up crossing rate, $v_o$, can be determined by calculating the spectral ratio (Sadek and Simiu, 2002). In CDF mapping, the translation function can be acquired by equating the CDF of the target marginal distribution $F_X(\cdot)$ to the CDF of the underlying standard normal distribution Φ(·) (Grigoriu, 1995). The equivalent non-Gaussian peak factor is computed as follows:

$$x_{pk} = F_X^{-1}\left(\Phi\left(\sqrt{2\ln\frac{v_o T}{\ln(1/p)}}\right)\right) \tag{1}$$

Given that there is an observed relationship between the building surface pressure fluctuations as a function of non-dimensional building aspect ratios (Wang and Kopp, 2021b), an empirical relationship for the parameters ( $\theta_1(H/B), \theta_2(H/B)$ ) of a target marginal distribution ($F_X(x|\theta_1, \theta_2)$) can be fitted.

## 2.4. Peak factor using the proposed translation method

This paper applies the translation model to Solari and Kareem's (1998) model with no filter functions and then compared the results to a measured peak factor (Wang and Kopp 2021b). The non-Gaussian peak $g_{png}$ is approximated using the following expression:

$$g_{png} = F_x^{-1}\left(\left(\left\{1.175 + 2\ln\left[\tilde{T}\sqrt{\frac{Q_1}{Q_0}}\right]\right\}^{0.5} \middle| \theta_1(H/B), \theta_2(H/B)\right)\right) \tag{2}$$

In this paper, it should be noted that the distribution parameters as a function of H/B were not yet fitted into an empirical model. The linear fitting of the parameters as a function of H/B will be developed in the future work with the corresponding error quantification. Figure 2 shows the results of the model when compared to the measured peak factor.

## 3. SUMMARY OF RESULTS

The paper examined the use of translation theory in developing a peak factor model as a function of H/B for windward wall area-averaged pressures. The investigation of the statistics area-averaged pressures of the extensive database reveals that CDF mapping would be more appropriate than an HPM framework due to the existence of kurtosis and skewness pairs outside of the monotonic region for HPM. The results also agree with Wang and Kopp (2021b), wherein the behavior of the windward walls is in the mildly non-Gaussian region for a H/B < 1.0. The dataset was then fitted into target marginal distributions wherein the Weibull distribution was found to be the best in predicting the positive tail of the datasets. This serves as the distribution basis for using a translation model for windward walls. Finally, the proposed translation model with distribution parameters as a function of H/B was applied to a peak factor model derived using a Gaussian assumption. The results show similar results when compared to the empirical peak. Future work is recommended to explore mixed distributions for the central portion of the database and the tails of the dataset.

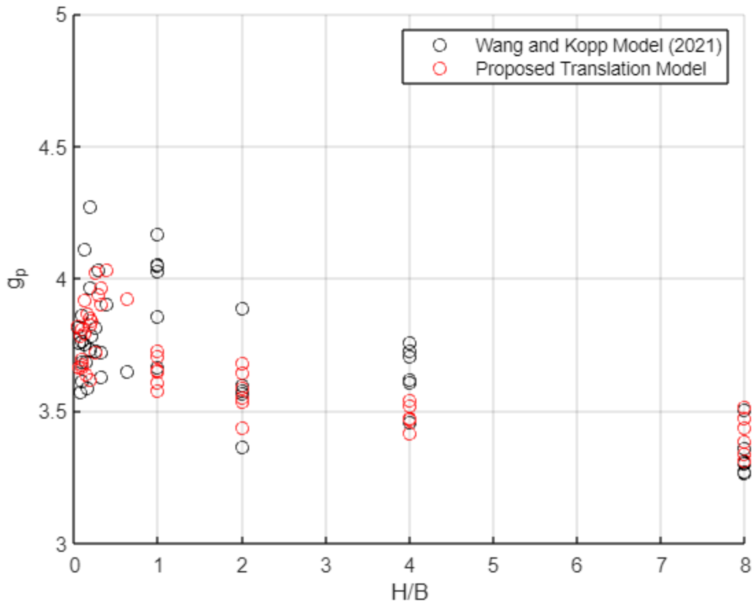


**Figure 2.** Proposed translation model peak factor versus measured peak factor

**REFERENCES**

Davenport, A.G., 1977. Wind Loads on Low Rise Buildings: Final Report of Phases I and II. Part I: Text and Figures.

Ginger, J. D., and C. W. Letchford. "Characteristics of large pressures in regions of flow separation." Journal of Wind Engineering and Industrial Aerodynamics 49, no. 1-3 (1993): 301-310.

Solari, G., 1993. Gust buffeting. I: peak wind velocity and equivalent pressure. J. Struct. Eng. 119 (2), 365–382.

Solari, G., Kareem, A., 1998. On the formulation of ASCE7-95 gust effect factor. J. Wind Eng. Ind. Aerod. 77, 673–684.

Wang, J. and Kopp, G.A., 2021a. Comparisons of Aerodynamic Data with the Main Wind Force–Resisting System Provisions of ASCE 7-16. II: Mid-and High-Rise Buildings. Journal of Structural Engineering, 147(3), p.04020348.

Wang, J. and Kopp, G.A., 2021b. Gust effect factors for windward walls of rigid buildings with various aspect ratios. Journal of Wind Engineering and Industrial Aerodynamics, 212, p.104603.

Ho, TCE, Surry, D., Morrish, D. and Kopp, G.A., 2005. The UWO contribution to the NIST aerodynamic database for wind loads on low buildings: Part 1. Archiving format and basic aerodynamic data. Journal of Wind Engineering and Industrial Aerodynamics, 93(1), pp.1-30.

Kumar, K.S. and Stathopoulos, T., 2000. Wind loads on low building roofs: a stochastic perspective. Journal of structural engineering, 126(8), pp.944-956.

Winterstein, S.R. and MacKenzie, C.A., 2011, January. Extremes of nonlinear vibration: models based on moments, L-moments, and maximum entropy. In International Conference on Offshore Mechanics and Arctic Engineering (Vol. 44342, pp. 617-626).

Grigoriu, M., 1984. Crossings of non-Gaussian translation processes. Journal of Engineering Mechanics, 110(4), pp.610-620.

Rice, SO, 1945. Mathematical analysis of random noise. The Bell System Technical Journal, 24(1), pp.46-156.

Sadek, F. and Simiu, E., 2002. Peak non-Gaussian wind effects for database-assisted low-rise building design. Journal of Engineering Mechanics, 128(5), pp.530-539.