Gust Occurrence in Simulated Non-Stationary Winds

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ABSTRACT: Significant difficulty is experienced when trying to relate peak gust intensity of a downburst to an apparent mean wind speed. Much of this difficulty stems from trying to properly characterize the so-called "non-turbulent" component of the wind. For short duration, high intensity events, conventional methods of using large period means cloak the true non-stationary nature of the event.

An investigation is presented of peak gust intensity in varied duration non-stationary winds, in which the non-turbulent component of the event is fully controlled. A typical downburst was simulated repeatedly using a technique that utilizes a parametric analytical model of the downburst's non-turbulent winds, and an amplitude modulated Gaussian stochastic process for the turbulent component. The peak gust strength of each event was expressed as a Gust Factor in relation to the largest non-turbulent speed. The properties of the simulated downburst Gust Factors are compared to those of stationary events of varied duration.

A parametric study in which the non-turbulent component of the wind was simulated using a sine wave, relatable to a downburst through the use of a "Storm Period" (SP) parameter, was conducted. A range of SP and turbulence amplitude modulation factors were used, and the properties of the Gust Factors are discussed.

KEYWORDS: Gust Factor, Downburst, Non-stationary, Peak Factor.

1 INTRODUCTION

In recent times we have seen the first studies that address Gust Factors for non-stationary wind events such as downbursts (e.g. [1]). Researchers have used a variety of moving average periods to smooth full-scale data and estimate the apparent “mean”, or “non-turbulent” speeds in the events for determining the Gust Factors. The Gust factors have been related to the moving average periods used.

The averaging period used in this approach takes on a somewhat different meaning to that for conventional gust factors (and peak factors) [2]. As the mean speed for the stationary event is assumed to be constant, any averaging period that is reasonably large in comparison to the duration of fluctuations will yield the same mean. As such, the averaging period also defines the size of the wind gust sampling wind.

When applied to the analysis of a downburst, a small averaging period may provide an accurate representation of the non-turbulent component of the wind event, or the local turbulence intensity. A given averaging period may be applicable to events with a range of durations. However, the range of times over which the largest wind speeds occur is likely to be a function of the event duration. Therefore describing downburst Gust Factors on the basis of the downburst duration or other parameters of the storm may be a more appropriate method, and is more consistent with the conventional Gust Factor description.
Further, the non-stationary nature of the events mean that the assumptions that lead to the use of the Type 1 Extreme Value Distribution (EVD) for stationary events may be invalid and not be applicable to downburst gust speeds. Provided the covariance function satisfies appropriate conditions, the maximum of a stationary Gaussian random process over either discrete time or continuous time, suitably standardized, converges to an EVD (Type 1) as the size of the interval under consideration becomes large [3,4]. To simulate downburst wind speeds, a number of assumptions have been made. Although the turbulence has been modeled utilizing a stationary process, the mean of the wind speed is not constant and the variance of the turbulence is proportional to this varying mean. As the peak speed is going to occur most often in the vicinity of the peak non-turbulent speed, where the apparent “mean”, and hence variance, are relatively locally constant, the primary concern is that the time frame is short so it is unlikely that the asymptotic distribution will be reasonable. The sampling frame can exacerbate this, as it may allow only a small number of observations of the wind speed.

2 WIND SPEED TIME HISTORY SIMULATION AND GUST ANALYSIS

The first part of the study involved simulating the distribution of G for a “typical” downburst scenario. The method of simulating downburst winds used in this study is described in detail in Chay et al [5]. The wind speed, \( U(x,y,z,t) \), occurring at any point in space \((x,y,z)\) and time \(t\) within a downburst can be thought of as the sum of two vector components:

\[
U(x,y,z,t) = \bar{U}(x,y,z,t) + u'(x,y,z,t)
\]  

where \( \bar{U}(x,y,z,t) \) is the “non-turbulent” wind velocity at a given location within the storm and \( u'(x,y,z,t) \) is the turbulent fluctuation. An analytical method was used to simulate the non-turbulent component of the winds. The turbulent component was simulated using an Auto-Regressive Moving Average (ARMA). The ARMA process, based on the Kaimal Spectrum [6] process was used to produce a Gaussian turbulence time-history \( \kappa(x,y,z,t) \) with a variance of one, and a mean of zero. While there is recent evidence that the power spectrum of downburst turbulence is different to that of boundary layer winds [7], this assumption is not believed to compromise the trends observed in the current study. The Gaussian time history is then amplitude modulated to an appropriate intensity using the equation

\[
u'(x,y,z,t) = a(x,y,z,t)\kappa(x,y,z,t)
\]

where \( a(x,y,z,t) = I_u^* \bar{U}(x,y,z,t) \) and \( I_u^* \) is the desired turbulence intensity. 200 storms were generated as test cases, with maximum non-turbulent speeds \( (\bar{U}_{MAX}) \) of 46.7m/s at observation height (including a translational speed of the storm of \( U_{Trans} = 10\text{m/s} \)), \( I_u^* = 0.1 \) and a radius to maximum wind speed \( r_T = 1500\text{m} \). An interval of \( \delta t = 0.2\text{s} \) was used for the ARMA process.

A parametric study was then performed in which the downburst event duration of turbulence intensity was varied. In this part of the study, the non-turbulent component was simulated using a simple sine wave, whose period was equal to the Storm Period \( (SP) \).

\[
SP = \frac{4r_T}{U_{Trans}}
\]  

This waveform represents the ideal case of the winds an object would experience when passing through the primary axis of motion of an event, which is the worst case for structural loading, and provides a good representation of the \( \bar{U}(x,y,z,t) \) generated by the analytical model for this scenario. For simplicity, the translation component was not added to the magnitude of the sine wave, and only the first half of each full wave was considered, as previous studies have indicated
that it is the initial peak in the storm that is critical for structural response [8]. Trends observed using this idealized technique will still be applicable for more generalized cases.

In this study, Gust Factor (G) is defined as the ratio of the largest gust speed at any time in the event (\(U_{\text{MAX}}\)) divided by \(\bar{U}_{\text{MAX}}\), or \(G = U_{\text{MAX}} / \bar{U}_{\text{MAX}}\). The peak factors (g) represent the number of standard deviations by which the largest gust at any time in the event exceeds the largest non-turbulent speed occurring in the event.

\[
g = \frac{U_{\text{MAX}} - \bar{U}_{\text{MAX}}}{I_u \bar{U}_{\text{MAX}}} \tag{4}
\]

Hence, the relationship between G and g is such that \(G = 1 + g I_u^*\).

3 INVESTIGATION OF GUST OCCURRENCE IN THE SIMULATED DOWNBURSTS

In order to examine gust likelihood for a “typical” downburst event, G and g were calculated for the 200 simulated events using definitions discussed above. G ranged in magnitude between 1.157 and 1.382, with a median value of 1.244 (g ranged between 1.574 and 3.812, with a median value of 2.443). The G and g distributions appear to be slightly right skew. The G values compare favorably Choi and Hidayat’s [1] observations for gust durations of 0.25s and averaging periods in the order of 30s to 60s, although the simulated values appear to be slightly lower.

The distribution of g for the simulated downburst was compared to simulated stationary events of varying duration, with the same turbulence structure as the unit variance Gaussian process used to generate the downburst wind speed fluctuating component. Despite the downburst having a total duration of approximately 10min, the peak factors were significantly lower than the 10min stationary process (4.384 max., 2.845 min., 3.519 med.), and were most similar to the 30 second process (4.095 max., 2.491 min., 1.500 med.).

The effect of varying the duration of storms was also considered. The non-turbulent winds of the downburst were likened to a sine wave using the approach described above. Event periods between 60s and 1200s were considered. Figure 1 clearly demonstrates that an increase in storm period results in an increase in the strength of the Gust Factors.

![Figure 1. Gust Factors for the varying Storm Periods.](image)

To investigate the suitability of applying a Type 1 distribution to the simulated downburst data, G and g were plotted using Gringorten’s reduced variate [9]. While the Type 1 distribution may provide an adequately accurate level of agreement with the simulated data (more so for the larger Storm Periods), the distribution was not entirely linear. From both a theoretical and empirical point of view, a different, more generalized probability distribution may be more suitable for analyzing extreme values for downbursts.
A series of tests were also conducted in which the $I_u^*$ varied between 0.05 and 0.20. Storm Period was set to 600s, $\delta t=0.2s$ for the ARMA process, and $\bar{U}_\text{MAX}=46.7\text{m/s}$. The larger fluctuations associated with the higher $I_u^*$ yielded higher gust factors. A weak upward trend in $g$ as the $I_u^*$ increased was also apparent. The trend was more evident at lower levels of cumulative probability, and as the cumulative probability increased, the peak factors converged to similar values. The standard deviation ($\sigma_t$) of the time from $\bar{U}_\text{MAX}$ to time of $U_{\text{MAX}}$ was calculated for each series of tests. As $I_u^*$ increased, $\sigma_t$ increased, meaning that the range of times over which the peak speeds occurred increased as turbulence intensity increased. As fluctuation intensity increases the additive component of $\bar{U}(x,y,z,t)$ to the total gust speed is less significant. However, as $u'(x,y,z,t)$ is amplitude modulated in direct proportion to this variation, the process will not behave like a stationary process unless $\bar{U}(x,y,z,t)$ becomes constant. To investigate this relationship further a test case was simulated in which $I_u^*$ was unrealistically large (2.0). The results matched the trends described above.

4 CONCLUSIONS

A number of trends were observed regarding the wind speed extremes in the simulated downbursts. Gust and Peak factors are substantially lower in the simulated downburst than in a statistically stationary event with the same duration and same turbulence structure. Increasing the duration of the downburst event (largely by assuming a different physical size or translational speed) increases the magnitude of $G$ during the downburst. There is a clear relationship that is dependent on the duration of the storm. Also, more generalized probability distributions may be more appropriate than the Type 1 distribution for analyzing extreme values in non-stationary wind events. Finally, when $I_u^*$ increased, the magnitude of $G$ increased, and in general, so did the magnitude of the $g$.

While moving averages provide a convenient way to describe $\bar{U}(x,y,z,t)$ of a downburst event, adopting this averaging period as the primary basis for describing Gust Factor relationships in downbursts may fail to accurately characterize their behavior. The results of this study indicate that Gust Factor distribution are influenced by a number of characteristics of the event in question, which should not be excluded from such an analysis.

REFERENCES