Estimating 3-second and maximum instantaneous gusts from 1-minute sustained wind speeds during a hurricane

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ABSTRACT: Formulas for estimating 3-second and maximum instantaneous gusts from 1-minute sustained mean wind speeds are derived for operational applications. These formulas are verified by measurements recorded during Hurricanes Katrina and Rita.

Keywords: Peak wind, hurricane gusts, and roughness length

1 INTRODUCTION

In the event of a hurricane structural engineers need to be able to answer the following question: What are the 3-second (normally defined as ‘peak’) and the maximum instantaneous gust values if 1-minute sustained or mean wind speed is available, for example, from the National Hurricane Center (NHC) Advisories? It is the purpose of this brief study to help provide an accurate answer. References to contributors to hurricane gust factor analysis can be found elsewhere, e.g., Durst (1960), Krayer and Marshall (1992), Hsu (2003), and Vickery and Skerlj (2005).

2 FORMULAS

For 3-second gust over a one minute period, the probability is \( \frac{3}{60} \) or 5%, therefore from statistics (see, e.g., Spiegel, 1961) we have:

\[
\begin{align*}
\bar{u}_{3,sec} &= \bar{u}_{1, min} + 3\sigma_u \\
\text{or} \\
\bar{u}_{3,sec} &= \bar{u}_{1, min} \left[ 1 + 2\frac{\sigma_u}{\bar{u}_{1, min}} \right]
\end{align*}
\]  

(1)

where \( \bar{u}_{3,sec} \) is the 3-second gust, \( \bar{u}_{1, min} \) is the 1-minute sustained wind speed, and \( \sigma_u \) is the standard deviation of the \( \bar{u}_{1, min} \).

In most cases the hurricane gust factor (e.g., \( \bar{u}_{3,sec} / \bar{u}_{1, min} \)) can be described using models developed for standard neutral boundary layer flow conditions (Vickery and Skerlj, 2005) and according to Arya (1999, p. 92)

\[
\sigma_u = 2.5u_w
\]  

(3)

where \( u_w \) is the friction velocity. Furthermore, according to Hsu (1988, p. 200),

\[
\frac{u_w}{\bar{u}_{1, min}} = \kappa p
\]  

(4)

where \( \kappa (= 0.4) \) is the von Karman constant and \( p \) is the exponent of the power-law wind profile such that (see, e.g., Hsu, 1988, p. 99)

\[
\frac{u_z}{u_1} = \left( \frac{Z_2}{Z_1} \right)^p
\]  

(5)

where \( u_1 \) and \( u_2 \) are the wind speeds at heights \( Z_1 \) and \( Z_2 \), respectively.

Now, by substituting Eqs. (3) and (4) into (2), one gets:

\[
\bar{u}_{3,sec} = \bar{u}_{1, min} (1 + 2p)
\]  

(6)

Eq. (6) is the formula for estimating the 3-second gust from a 1-minute sustained speed.
Analogous to Eq. (1), the maximum instantaneous gust ($u_{\text{max}}$) can be approximated by

$$u_{\text{max}} = u_{1\text{min}} + 3\sigma_u$$  \hspace{1cm} (7)

The second term on the right-hand side represents the 3 standard deviation (or $1 - 0.9973 = 0.0027$) or within the top 1% probability. Substituting Eqs. (3) and (4) into (7), we have:

$$u_{\text{max}} = u_{1\text{min}} (1 + 3p)$$  \hspace{1cm} (8)

Since, according to Panofsky and Dutton (1984),

$$p = \frac{1}{ln\left(\frac{Z}{Z_0}\right)}$$  \hspace{1cm} (9)

then:

$$u_{\text{max}} = u_{1\text{min}} \left[1 + \frac{3}{ln\left(\frac{Z}{Z_0}\right)}\right]$$  \hspace{1cm} (10)

where $Z_0$ is the roughness length. Note that Eq. (10) is the same as that proposed by Panofsky and Dutton (1984, p. 377).

3 VERIFICATION

During Hurricanes Katrina and Rita in 2005, Giammanco et al. (available online at http://ams.confex.com/ams/pdfs/108666.pdf) made measurements of $u_{\text{max}}$, $u_{3\text{sec}}$ and $u_{1\text{min}}$. Our results are provided in Tables 1 and 2 for $u_{3\text{sec}}$ and $u_{\text{max}}$, respectively. It can be seen from the mean that for operational applications, our proposed formulas are useful.

In order for the engineers to have a better estimation of $p$ from $Z_0$, Figure 1 is provided. For example, for a city environment where $Z_0 = 1$ m, $p = 0.30$. The relationship of $Z_0$ to various terrain types is available in Table 6.2 of Panofsky and Dutton (1984, p. 123) as well as Table 33.5 of Justus (1985, p. 925).

![Figure 1](image.png)

Figure 1. The relationship between $Z_0$ and $p$ (data source: Justus, 1985, in neutral stability condition).
Table 1. A verification of Eq. (6).

<table>
<thead>
<tr>
<th>Deployment Site</th>
<th>$u_{3\text{sec}}$ measured</th>
<th>$u_{3\text{sec}}$ from Eq. (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacherie, LA</td>
<td>31.4</td>
<td>32.1</td>
</tr>
<tr>
<td>Slidell, LA</td>
<td>38.5</td>
<td>40.3</td>
</tr>
<tr>
<td>Bay St. Louis, MS</td>
<td>47.1</td>
<td>39.1</td>
</tr>
<tr>
<td>Anuhuac, TX</td>
<td>37.9</td>
<td>36.1</td>
</tr>
<tr>
<td>Winnie, TX</td>
<td>38.6</td>
<td>40.8</td>
</tr>
<tr>
<td>Port Arthur, TX</td>
<td>51.9</td>
<td>54.3</td>
</tr>
<tr>
<td>Orange, TX</td>
<td>39.3</td>
<td>38.0</td>
</tr>
<tr>
<td>Mean</td>
<td>40.7</td>
<td>40.1</td>
</tr>
</tbody>
</table>

where $p = 0.15$ for the rural environment is used based on Irwin (1979).

Table 2. A verification of Eq. (8).

<table>
<thead>
<tr>
<th>Deployment Site</th>
<th>$u_{\text{max}}$ measured</th>
<th>$u_{\text{max}}$ from Eq. (8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacherie, LA</td>
<td>32.8</td>
<td>35.8</td>
</tr>
<tr>
<td>Slidell, LA</td>
<td>44.6</td>
<td>45.0</td>
</tr>
<tr>
<td>Bay St. Louis, MS</td>
<td>52.3</td>
<td>43.6</td>
</tr>
<tr>
<td>Anuhuac, TX</td>
<td>40.5</td>
<td>40.3</td>
</tr>
<tr>
<td>Winnie, TX</td>
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<td>Port Arthur, TX</td>
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<td>Orange, TX</td>
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<td>42.3</td>
</tr>
<tr>
<td>Mean</td>
<td>43.8</td>
<td>44.7</td>
</tr>
</tbody>
</table>

where $p = 0.15$ for the rural environment is used based on Irwin (1979).

4 CONCLUSIONS

On the basis of statistical and meteorological considerations, Eqs. (6) and (8) are proposed and verified for 3-second and maximum wind gust estimations from 1-minute sustained wind speed data. Under neutral stability conditions over the rural environment, the value of the 3-second gust over a 1-minute period is 1.3, which further supports the statement by Landsea (see [http://www.aoml.noaa.gov/hrd/tcfaq/D4.html](http://www.aoml.noaa.gov/hrd/tcfaq/D4.html)). The maximum instantaneous gust over a 1-minute period is approximately 1.45. For a better estimation of $p$ from $Z_0$, Figure 1 is provided, where the value of $Z_0$ may be found in the literature.

REFERENCES


