eJSE International

Electronic Journal of Structural Engineering (2008)

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

S.A. Hsu

Coastal Studies Institute, Louisiana State University, Baton Rouge, Louisiana, USA

Email: sahsu@lsu.edu

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 3/60 or 5%, therefore from statistics (see, e.g., Spiegel, 1961) we have:

$$u_{3\,sec} = u_{1min} + 2\sigma_u \tag{1}$$

or

$$u_{3\,sec} = u_{1\,min}\left[1 + 2\frac{\sigma_u}{u_{1\,min}}\right] \tag{2}$$

where $u_{3\ sec}$ is the 3-second gust, $u_{1\ min}$ is the 1-minute sustained wind speed, and σ_u is the standard deviation of the $u_{1\ min}$.

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

$$\sigma_u = 2.5u_* \tag{3}$$

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

$$\frac{u_*}{u_{1\,min}} = \kappa p \tag{4}$$

where κ (= 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)

$$\frac{u_2}{u_1} = \left(\frac{Z_2}{Z_1}\right)^p \tag{5}$$

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:

$$u_{3\,sec} = u_{1\,min}(1 + 2p) \tag{6}$$

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_{max}) can be approximated by

$$u_{max} = u_{1\,min} + 3\sigma_u \tag{7}$$

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:

$$u_{max} = u_{1\,min}(1 + 3p) \tag{8}$$

Since, according to Panofsky and Dutton (1984),

$$p = \frac{1}{ln\frac{Z}{Z_0}} \tag{9}$$

then:

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

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/pdfpapers/108666.pdf) made measurements of u_{max}, $u_{3\,sec}$ and $u_{1\,min}$. Our results are provided in Tables 1 and 2 for $u_{3\,sec}$ and u_{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).

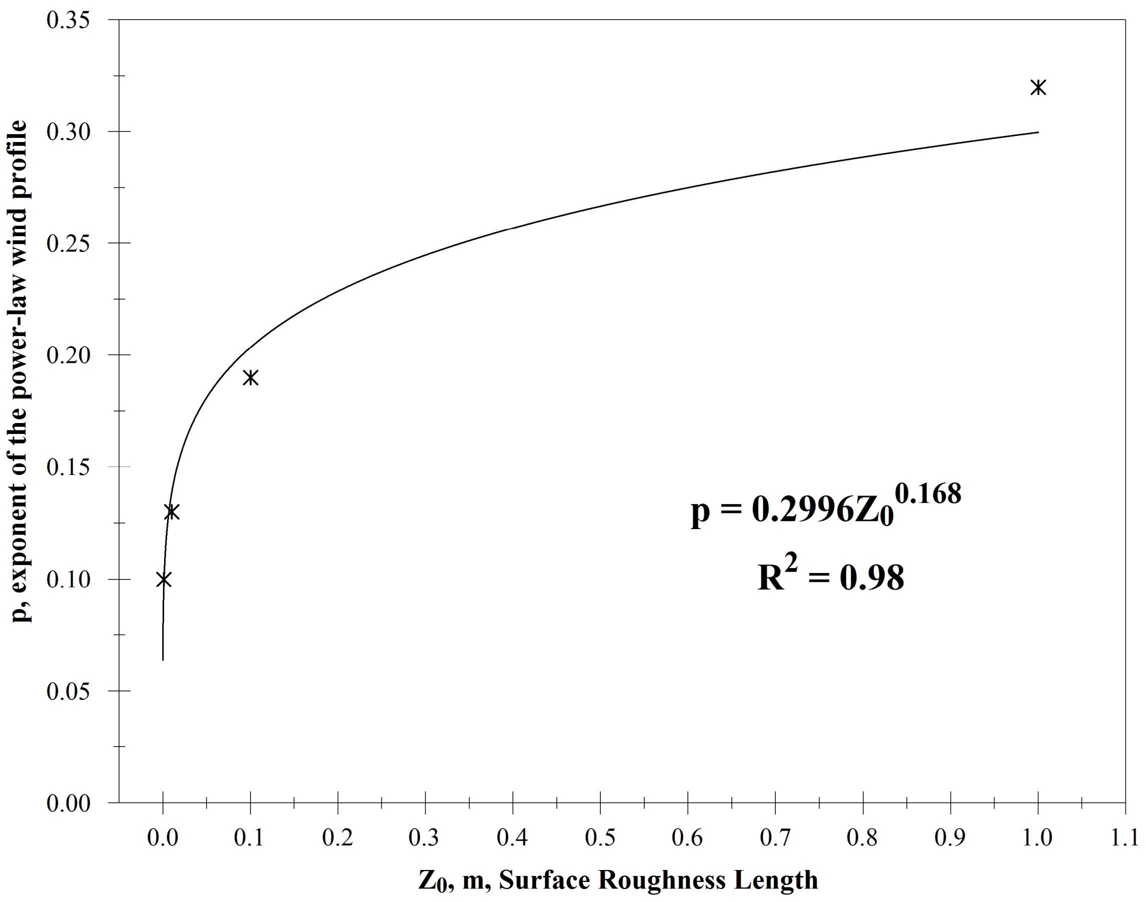

Figure 1. The relationship between Z_0 and p (data source: Justus, 1985, in neutral stability condition).

Table 1. A verification of Eq. (6).

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

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

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

Deployment Site	u_{max} measured m/s	u_{max} from Eq. (8)* m/s
Vacherie, LA	32.8	35.8
Slidell, LA	44.6	45.0
Bay St. Louis, MS	52.3	43.6
Anuhuac, TX	40.5	40.3
Winnie, TX	40.7	45.5
Port Arthur, TX	53.8	60.6
Orange, TX	42.1	42.3
Mean	43.8	44.7

*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). 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

Arya, S. P., Air Pollution Meteorology and Dispersion, Oxford University Press, 1999, p. 92.

Durst, C. S., "Wind Speeds Over Short Periods of Time", Meteorol. Mag., 89, 1960, p. 181 – 186.

Hsu, S. A., "Estimating Overwater Friction Velocity and Exponent of Power-Law Wind Profile from Gust Factor during Storms", J. Waterway, Port, Coastal and Ocean Engineer., ASCE, July/August 2003, p. 174 -177.

Hsu, S. A., Coastal Meteorology, Academic Press, 1988, p. 199-200.

Irwin, J. A., "A Theoretical Variation of the Wind Profile Power-Law Exponent as a Function of Surface Roughness and Stability", Atmos. Environ., Vol. 13, 1979, pp. 191-194.

Justus, C. G., "Wind Energy", in Handbook of Applied Meteorology, D. D. Houghton (Ed.), Chapter 33, John Wiley & Sons, N.Y., 1985, pp. 915-944.

Krayer, W. R. and Marshall, R. D., "Gust Factors Applied to Hurricane Winds", Bull. Am. Meteorol. Soc., 74(5), 1992, p. 613 – 617.

Panofsky, H. A. and Dutton, J. A., Atmospheric Turbulence, John Wiley & Sons, 1984.

Spiegel, M. R., Statistics, Schaum Pub. Co., 1961.

Vickery, P. J. and Skerlj, P. F., "Hurricane Gust Factors Revisited", J. Structural Engineering - ASCE, Vol. 131, No. 5, May 2005, pp. 825-832.