Validating Wind Profile Equations during Tropical Storm Debby in 2012

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Abstract

Comparisons of logarithmic and power-law wind profiles are made for offshore conditions during Tropical Storm Debby in 2012 over the Gulf of Mexico. It is found that both laws are validated up to 122m and that the power law is as good as the log law statistically. For practical applications, the exponent of power law can be determined from the gust factor measurement available routinely from National Data Buoy Center (NDBC) buoys.

Index terms— logarithmic wind profile, power-law wind profile, gust factor, tropical storm debby.

1 Introduction

n the atmospheric boundary layer, vertical distribution of the wind speed (under strong wind conditions so that the thermal effects may be neglected, see Hsu, 2003) can be formulated according to the logarithmic wind profile (e.g. Panofsky and Dutton, 1984) as:$U_z = (U^*/k)\ \mathrm{Ln}\ ((Z-d)/Z_0)$**(1)**

Where U_z is the wind speed at height Z, U* is the friction velocity, k (=0.4) is the von Karman constant, d is the displacement height, and Z_0 is the roughness length.

Note that when Z is much larger than d, Eq. (1) may be reduced to $U_z = (U^*/k)\ \mathrm{Ln}\ (Z/Z_0)$ (2)

Note also that, for offshore conditions, Z_o can vary with wave characteristics since the sea state is mobile depending on the wind speed, duration and fetch (Hsu, 1988).

Because the log-law requires several parameters including U*, d, and Z_0, the power-law wind profile has been widely used instead in the engineering community (e.g. Irwin, 2006) that:$U_2/U_1 = (Z_2/Z_1)^p$ (3) For $Z_2 > Z_1$

Where U_2 and U_1 are the wind speed at Z_2 and Z_1, respectively, and p is the exponent, which is related to the gust factor, G, via following formulation (see Hsu, that,$G = 1 + 2p$**(4)**

The purpose of this study is to validate windprofile equations, whether it is logarithmic or power, for over water applications.

2 II.

3 Methods

In order to compare Equations (**??**) and (3) statistically, they are rearranged as follows: From Equation (2), we have $\mathrm{Ln}\ Z = \mathrm{Ln}\ Z_0 + (k/U^*)\ U_z$ (5) This equation has a least-square linear regression form such that$Y = A + B X$**(6)**

Where $Y = \mathrm{Ln}\ Z$, $A = \mathrm{Ln}\ Z_0$ or $Z_0 = e^A$, $X = U_z$, and $B = k/U^*$.

If the anemometer is located at 10 m, one can normalize the wind speed at higher elevation by NDBC measurements so that Equation (3) becomes $U_z/U_{10} = (Z/10)^p$ (7) Where U_{10} is the wind speed at 10 m, which is routinely available from Buoy 42040.

4 III.

5 Validating Wind Profile Equations

When Tropical Storm Debby in 2012 was over the Gulf of Mexico (www.nhc.noaa.gov), there were 3 meteorological stations, which measured wind speed at 3 different heights ranging between 10 and 122m above the sea surface. These data are available online from NDBC (http //www. ndbc.noaa.gov). Since these 3 stations were close-by, their data are listed in Table 1. Using the mean value for each height as listed in the Table, Figures 1 and 2 provide the analyses for the logarithmic and the powerlaw wind profiles, respectively. Since the coefficient of determination, R 2 , values are very high, both profiles are verified. For operational applications off shore, it is found that the power-law is as good as the log-law. This finding is very important because over vast ocean, only one level measurement of wind speed from few buoys or ships is available. I

6 Vertical Variation of the Gust Factor

Vertical variation of the gust factor for offshore conditions has been studied by Hsu (2012). Our results during Debby are shown in Figs. **??** and 4. It is found that for operational applications, the gust factor does not decease with height between 10 and 160 m as compared to that over land as shown in Fig. **??** near land-falling Hurricanes Frances and Jeanne in 2004 (based on Merceret, 2009) and Fig. **??** for Typhoon Muifa in 2012 (based on An et al.,2012).

In addition, according to Hsu (2012), the mean overwater gust factor between 5 and 160 m during Tropical Storm Lee in 2011 is 1.273 with the standard deviation of 0.11 so that the coefficient of variation, which is the ratio of standard deviation and the mean, is 8.6% (which is within the 10% composite error margin in the field measurements for the wind speed). This means that p=0.137 is a good value to use for offshore conditions. Comparison of this p value with the powerlaw analysis shown in Fig. **??** (where p=0.142) indicates that P = 0.14 should be useful for practical applications. Furthermore, by substituting this p (=0.142) value from fig. **??** into Eq.4, we have G=1+2*0.142=1.284, which is in good agreement with the normally quoted G value of 1.30. In other words, the common use of 30% gust factor for offshore applications receives further support from this study.

7 Conclusions

On the basis of foregoing analyses and discussions, following conclusions can be drawn:

? A comparison between logarithmic and power-law wind profiles is made for offshore conditions (up to 122m or 400ft from the sea surface). It is found that, although the log law has more theoretical support, statistical analyses. Therefore, the powerlaw is recommended for operational applications since it involves only one unknown parameter, which is the exponent. ? The exponent of the power-law wind profile can be determined from the gust factor which is routinely available from NDBC measurements. It is also found the gust factor does not vary with the altitude statistically within 160m or 525ft from the sea surface. This finding, which is contrary to the common belief for onshore conditions, is very important for wind loading analyses for offshore structures as well as search and rescue mission planning during storms at sea.

the power-law is as good as the log-law based on [1]

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Figure 1: Figure 1 :

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Figure 2: Table 1 :

	Year	month	day	hour UTC	min	wind direction	U122m m/s	U54.9m m/s	U10m m/s
	2012	6	25	19	30	340	13	10	8
	2012	6	25	18	30	340	14	11	9
	2012	6	25	16	30	350	15	12	11
	2012	6	25	6	30	360	18	16	12
	2012	6	25	4	30	360	19	18	14
Year 2014	2012	6 6 6	25	3 0	30	10 360	19 24 22	18 22	14 16
	2012		25	23	30	360		20	16
	2012		24		30				
2	2012	6 6	24	20	30	360 360	19 19	17 16	14 13
	2012		24	19	30				
XIV Issue I Version I ( ) Volume							18.2	16	12.7
Global Journal of Researches in Engineering		U 0.4 0.6 z 1 1.2 /U 1.4 1.6 10 0.8 0.2 0					y = 0.997x 0.141		
							R^2 = 0.998		
		0		2	4	6 8 Z/10	10	12	14

[Note: © 2014 Global Journals Inc. (US) E Figure 2 : Power-law wind profile over the Gulf of Mexico during Tropical Storm Debby in 2012 mean IV.]

Figure 3:

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