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Optimum Geometrical Shape Parameters for Conical Diffusers in Ducted Wind Turbines

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Abstract: Encasing of wind turbines in ducts to increase wind energy extraction has been under study for several decades. Ducts are meant to accelerate the wind speed past the wind turbine rotor enclosed in the duct. The most common duct used in wind turbines is a diffuser. Wind speed augmentation in diffusers depends on the geometrical shape parameters of the diffuser, mainly the diffuser expansion angle (θ) and the non-dimensional length $(\frac{L}{D})$. This paper addresses wind speed augmentation by empty conical diffusers. It presents the dependence of the wind speed augmentation on the diffuser geometrical shape parameters and the optimum geometrical shape parameters for maximum wind speed augmentation. It is shown that for a given $\frac{L}{D}$, wind speed augmentation increases with θ up to the maximum wind speed augmentation and starts to decrease. Each $\frac{L}{D}$ has a unique θ which gives the maximum wind speed augmentation. It has also been shown that the maximum wind speed augmentation increases with $\frac{L}{D}$. For $0.5 \leq \frac{L}{D} \leq 3$ wind speed increased from 1.48 m/s to 1.55 m/s.

Keywords: Wind Energy, Wind Speed Augmentation, Diffuser Geometrical Shape Parameters

1. Introduction

Renewable energy has been the source of energy for hundreds of years. The last decade has seen a rapid growth in renewable energy technologies with a global power capacity exceeding 1 470 GW in 2012, with wind energy accounting for 39%, followed by hydropower and solar photo voltaics, each accounting for approximately 26% each [1]. It follows that wind energy added more renewable energy capacity than any other renewable energy technology.

For any power plant to generate electricity, it needs fuel, for a wind power plant, that fuel is wind [2]. However, many locations especially in-land regions, are characterized by low wind speeds which are not useful in wind power generation in relation to the current wind turbine system design. The encasing of wind turbines in a duct or "shroud" to optimise energy extraction has been seen as a novel way to exploit low wind speeds for wind power generation. This technology dates back to the 1950s, when it was recognized that a shroud augmented wind turbine can produce up to twice the power of an unshrouded turbine of the same diameter [3]. Research work in this field has taken a number of approaches in studying the effects of diffusers and other wind concentrating devices [4].

The most common duct used to encase wind turbines to optimise energy extraction is a diffuser. Air flow behaviour and performance of a diffuser depends on geometrical shape and flow parameters [5]. Geometrical shape parameters comprise the non-dimensional length $(\frac{L}{D})$, the ratio (A_r) of the inlet and outlet cross-sectional areas of the diffuser and the diffuser expansion angle (θ). Flow parameters determine flow conditions such as turbulence intensity, inlet swirl, boundary layer thickness, Reynolds' number and inlet velocity profile.

The impact of the geometrical parameters on diffuser performance has led many researchers to investigate the effect of these parameters on diffuser performance. Djebedjian [6] found out that, the pressure recovery coefficient (C_{pr}), depends on $\frac{L}{D}$ and the expansion angle (θ). Matsushima et al [7] in their work, "Characteristics of a highly efficient propeller type small wind turbine with diffuser", investigated the effect the diffuser shape had on the wind speed and concluded that the wind speed inside the diffuser is greatly influenced by the length (L) and divergent angle (θ) of the diffuser, and maximum speed increased 1.76 times with the selection of the appropriate diffuser shape. Chaker et al. [8] found out that the ratio of the free stream velocity and wind velocity recorded in the inlet section of an empty diffuser $\left(\frac{V}{V_o}\right)$ increases linearly with the expansion angle (θ) and reaches a maximum at 10^o. Sarway et al. [9] experimentally found out that the wind speed in the diffuser was greatly influenced by the expansion angle (θ), flange height, hub ratio, centre body length and inlet shroud length.

Geometrical shape parameters are key in the performance and behaviour of diffusers. The present study experimentally investigated the dependence of wind speed augmentation $\left(\frac{V_x}{V_o}\right)$ on the geometrical shape parameters of empty conical diffusers and determined the optimum diffuser geometrical shape parameters which give the maximum wind speed augmentation at the throat of the conical diffuser. These optimum values are critical in the design and construction of diffuser augmented wind trubines.

2. Materials and Method

Experiments were conducted to determine the dependence of the wind speed augmentation on the diffuser geometrical shape parameters for an empty conical diffuser. Wind speed augmentation is given by the wind speed ratio $\left(\frac{V_x}{V_o}\right)$, where, V_x is the wind velocity at an arbitrary axial position x of the diffuser and V_0 is the free wind velocity. The investigated geometrical shape parameters included the diffuser expansion angle (θ) and the non-dimensional length $\left(\frac{L}{D}\right)$. The thrust of the experiments was to determine how each of the parameters affect $\frac{V_x}{V_0}$ and determine optimum parameters for maximum wind speed augmentation $\left(\frac{V_x}{V_0}\right)_{max}$.

Figure 1 shows a diagram of a one-dimensional conical diffuser. L is the axial length of the diffuser, D is the diffuser inlet diameter and is equal to the throat of the diffuser (the narrowest part of the diffuser) and θ is the diffuser expansion angle. The diffuser has a cylindrical inlet shroud which funnels the wind into the diffuser. The shroud reduces the blockage effect at the throat. A smooth oval shape at the throat encourages the fluid to attach itself to the surfaces of the diffuser thus reducing early flow separation. The inlet shroud's length was given by d = 0.125D [10]. Figure 2 shows an image of a conical diffuser of $\frac{L}{D} = 2$.

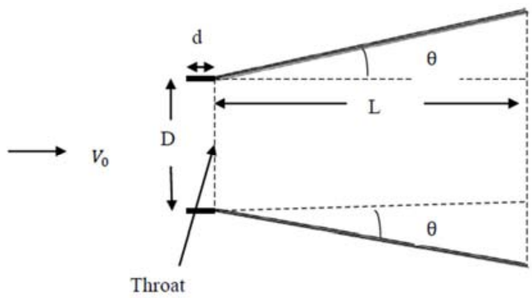


Figure 1. *A one-dimensional diagram of a conical diffuser.*

Figure 2. *Conical diffuser of L/D=2.*

The experiments were done in two parts, that is:

(a) The determination of the dependence of $\frac{V_x}{V_0}$ on the diffuser expansion angle for an empty conical diffuser.

(b) The determination of the dependence of $\frac{V_x}{V_0}$ on $\frac{L}{D}$ for an empty conical diffuser

To determine the dependence of $\frac{V_x}{V_0}$ on the expansion angle, empty conical diffusers of $\frac{L}{D}$ values ranging from 0.5 to 3 in step of 0.5 were constructed using a 0.5 mm thick aluminium metal sheet. For each $\frac{L}{D}$ value a number of diffusers at different expansion angles were constructed. The expansion angle was varied between $1^o \leq \theta \leq 24^o$. A small scale blower wind tunnel controlled by a frequency inverter was used to supply a constant wind speed (V_0) of 3 m/s. Figure 3 shows the experimental set up used in these experiments.

Figure 3. *Experimental setup for the wind speed augmentation measurement.*

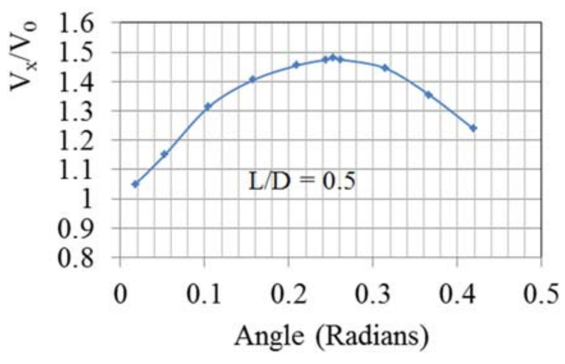
As can be seen in Fig. 3, this was an open type experiment. This was done to mimic the actual operating conditions of the diffuser when exposed to free wind. Thus free stream turbulence intensity was not considered. A diffuser was placed in front of the wind tunnel exit with its central axis coinciding with the central axis of the wind tunnel. An adjustable arm attached to the wind tunnel was used to hold the diffuser in position. The arm was made in such a way that it could be adjusted so as to place the diffuser at the desired position. An L-type pitot tube was used to measure the axial wind velocity, V_x, along the central axis of the diffuser.

To determine the dependence of $\frac{V_x}{V_o}$ on $\frac{L}{D}$, six diffusers of different $\frac{L}{D}$ values were constructed. The $\frac{L}{D}$ values range was as described above. All the diffusers were of equal diffuser expansion angle of 5.5°. The diffuser expansion angle of 5.5° gave the maximum wind speed augmentation when $\frac{L}{D}$ = 2. This value was obtained in experiments explained above and results given in Section 3. The choice of 5.5° was based on its corresponding optimum $\frac{L}{D}$ value ($\frac{L}{D}$ = 2) which was close to the median of the $\frac{L}{D}$ values under study. This enabled a better observation of the dependence of $\frac{V_x}{V_o}$ on $\frac{L}{D}$ throughout all the $\frac{L}{D}$ values under study. The experimental set up and procedure for the experiments was similar to the one shown in Figure 3. In all cases the wind speed augmentation $\left(\frac{V_x}{V_o}\right)$ was calculated by dividing V_x by V_0.

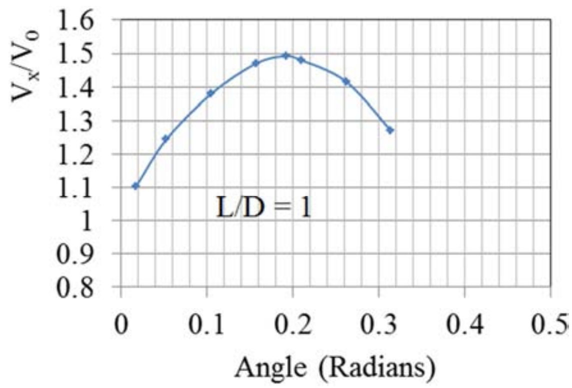
3. Results and Discussion

3.1. Dependence of $\frac{V_x}{V_o}$ on the Diffuser Expansion Angle

$\frac{V_x}{V_o}$ was calculated from the axial wind speed (V_x) in the diffuser and the free wind speed (V_o). Figure 4 shows the variation of $\frac{V_x}{V_o}$ with diffuser expansion angle for various $\frac{L}{D}$ values. It was observed that $\frac{V_x}{V_o}$ varies with the diffuser expansion angle. With reference to Figure 4, for a given $\frac{L}{D}$, it can be observed that $\frac{V_x}{V_o}$ increases with the diffuser expansion angle up to a maximum and then decreases.



(a)



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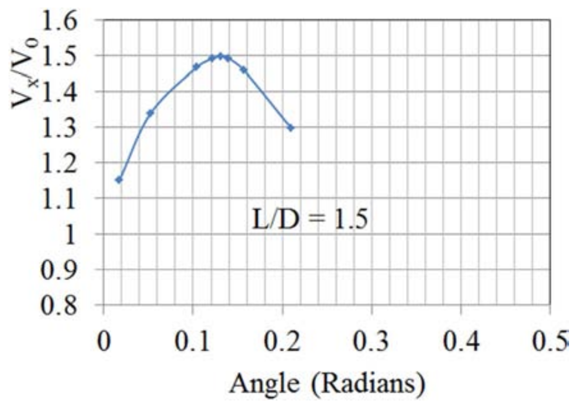

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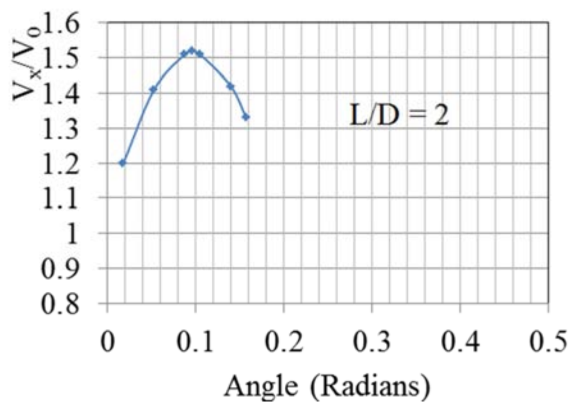

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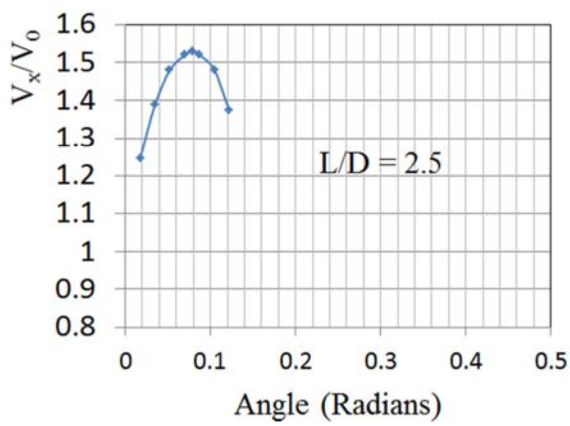

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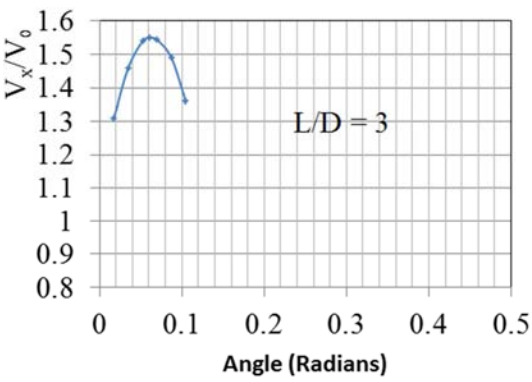

(f)

Figure 4. *Variation of* $\frac{V_x}{V_o}$ *with diffuser expansion angle for various* $\frac{L}{D}$ *values.*

For all the considered values of $\frac{L}{D}$, it was found out that the maximum wind speed augmentation $\left(\frac{V_x}{V_o}\right)_{max}$ increased with $\frac{L}{D}$. From $\frac{L}{D} = 0.5$ to $\frac{L}{D} = 3$, $\left(\frac{V_x}{V_o}\right)_{max}$ increased by 4.7%. The wind speed increased from 1.48 m/s to 1.55 m/s for the range of $\frac{L}{D}$ values considered. Table 1 shows the $\left(\frac{V_x}{V_o}\right)_{max}$ with $\frac{L}{D}$ and the corresponding optimum diffuser expansion angle.

Table 1. *Maximum wind speed augmentation for various* $\frac{L}{D}$ *values and the corresponding optimum angles.*

$\frac{L}{D}$ (± 0.1)	$\left(\frac{V_x}{V_o}\right)_{max}$ (± 0.01)	**Optimum diffuser expansion angle (θ)**	
		(radians) (± 0.008722)	**(°)** (± 0.5)
0.5	1.48	0.252944	14.5
1	1.49	0.191889	11
1.5	1.50	0.130833	7.5
2	1.52	0.095944	5.5
2.5	1.53	0.078500	4.5
3	1.55	0.061056	3.5

With reference to Figure 4 and Table 1 it was observed that each $\frac{L}{D}$ has its own specific optimum expansion angle which gives $\left(\frac{V_x}{V_o}\right)_{max}$. This implies that there is no a unique diffuser expansion angle for $\left(\frac{V_x}{V_o}\right)_{max}$ rather each $\frac{L}{D}$ has its own specific optimum diffuser expansion angle. Comparing all the graphs in Fig. 4 it is also observed that the optimum diffuser expansion angle decreases with the increase of $\frac{L}{D}$. This is summarized in Table 1. These findings concur with [11] who also found out that in diffusers, $\frac{V_x}{V_o}$ increases with the diffuser expansion angle to a peak value after which it decrease, $\left(\frac{V_x}{V_o}\right)_{max}$ increases with increase in $\frac{L}{D}$ and the diffuser optimum expansion angle decreases with increase in $\frac{L}{D}$. Barbosa et al. [12] obtained that $\left(\frac{V_x}{V_o}\right)_{max} = 1.51\ m/s$ at $\theta = 5^o$ with $\frac{L}{D} = 2.3$ and [13] obtained $\left(\frac{V_x}{V_o}\right)_{max} = 1.34\ m/s$ at $\theta = 4^o$ with $\frac{L}{D} = 1.5$. Therefore the results presented in this work are comparable with what has been found by other researchers.

Figure 5 shows the variation of the optimum diffuser expansion angle with $\frac{L}{D}$.

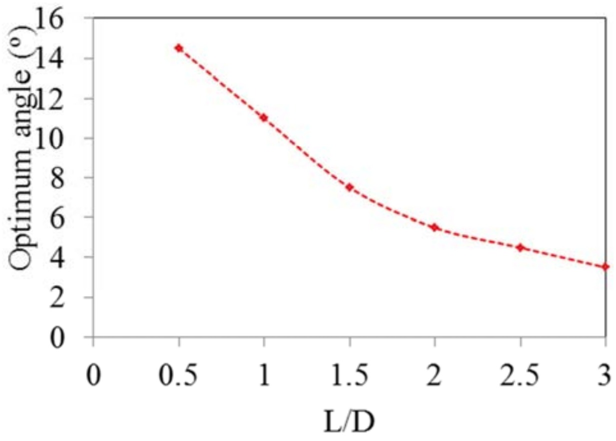

Figure 5. *Variation of the optimum diffuser expansion angle with* $\frac{L}{D}$.

From Figure 5 it is observed that diffusers with small $\frac{L}{D}$ values have large optimum diffuser expansion angles. It is shown in Table 1 that $\frac{L}{D} = 0.5$ has 14.5° as its optimum diffuser expansion angle while $\frac{L}{D} = 3$ corresponds to 3.5°.

3.2. Dependence of $\frac{V_x}{V_o}$ *on* $\frac{L}{D}$ *for an Empty Conical Diffuser*

Figure 6 shows the variation of $\frac{V_x}{V_o}$ with $\frac{L}{D}$ at an optimum diffuser expansion angle of 5.5^o. 5.5° was the expansion angle used in the experiment for all $\frac{L}{D}$ values. With reference to Figure 5, it can be seen that $\frac{V_x}{V_o}$ increases with increase in $\frac{L}{D}$ to 1.52 m/s which corresponds to $\left(\frac{V_x}{V_o}\right)_{max}$ at $\frac{L}{D} = 2$. This implies that for a given diffuser expansion angle $\frac{V_x}{V_o}$ increases with $\frac{L}{D}$ up to $\left(\frac{V_x}{V_o}\right)_{max}$ of that expansion angle and starts to decrease. Jafari et al. [14], also found out that there is an optimum $\frac{L}{D}$ to achieve optimum performance in diffusers.

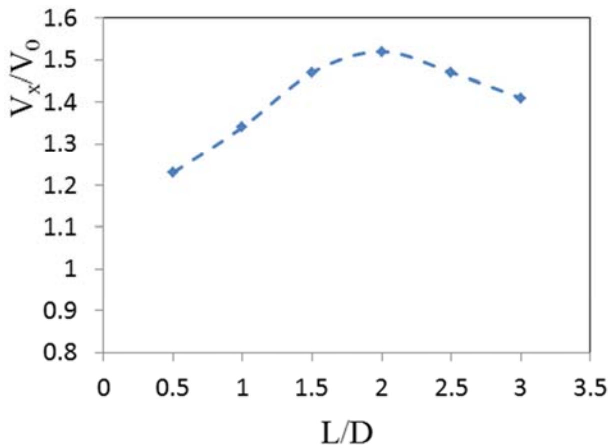

Figure 6. *Variation of* $\frac{V_x}{V_o}$ *with* $\frac{L}{D}$ *at* $\theta = 5.5^o$.

4. Conclusions

The study has illustrated that wind speed augmentation $\left(\frac{V_x}{V_o}\right)$ in conical diffusers increases with diffuser expansion angle up to the optimum diffuser expansion angle which gives $\left(\frac{V_x}{V_o}\right)_{max}$ and starts to decrease. Each $\frac{L}{D}$ has a unique optimum diffuser expansion angle for maximum wind speed augmentation. It is therefore imperative to always give the ratio $\frac{L}{D}$ used whenever a diffuser expansion angle (θ) is given. It has also been shown that $\left(\frac{V_x}{V_o}\right)_{max}$ increases with $\frac{L}{D}$. For the examined diffusers, that is, $0.5 \leq \frac{L}{D} \leq 3$ the increment of $\left(\frac{V_x}{V_o}\right)_{max}$ was found to be 4.7%. Optimum geometrical shape parameters for conical diffuser design were determined. These optimum diffuser geometrical parameters are important in the design and construction of the conical diffuser augmented wind turbine (DAWT) system. A conical diffuser at $\frac{L}{D} = 3$ gains 4.7% wind speed as compared to that at $\frac{L}{D} = 0.5$. However large structures cost more and might not effectively make use of the prevailing wind since they cannot quickly respond to wind direction changes because of increased inertia. As a result the intended gain in wind speed might not be achieved. Therefore one has to strike a balance between increase in wind speed and response of the system to the prevailing wind.

References

[1] REN21. Renewables Global Status Report. (Paris: REN21 Secretariat), 2013.

[2] J. Roeth, Wind resource assessment handbook final report. NYSERDA Report 10-30. New York, 2010.

[3] G. M. Lilley and W. J. Rainbird, "A preliminary report on the design and performance of ducted windmills," Technical report. C/T119, The British Electrical and Allied Industries *R*esearch Association, Great Britain, 1957.

[4] S. J. Watson, D. G. Infield, J. P. Barton, and S. J. Wylie, "Modelling of the performance of a building-mounte ducted wind turbine," Journal of Physics: Conference Series, vol. 75, no. 1, Article ID 012001, 2007.

[5] F. M. White, "Fluid dynamics," 7th edition. MacGraw-Hill, Newyork, 2009.

[6] B. Djebedjian, "Diffuser optimization using computational fluid dynamics and Micro- genetic algorithms," Mansoura Engineering Journal, Vol. 28, no. 4, 2003.

[7] T. Matsushima, S. Takagi, and S. Muroyama, "Characteristics of a highly efficient propeller type small wind turbine with a diffuser," Renewable Energy, Vol. 31, 2006, pp. 1343–1354.

[8] R. Chaker, M. Kardous, F. Aloui, and S. B. Nasrallah, "Relationship between open angle and aerodynamic performances of a DAWT," The Fourth International Renewable Energy Congress, Sousse, Tunisia, December 20-22, 2012.

[9] M. M. Sarwar, N. Nawshin, M. A. Imam, and M. Mashud, "A new approach to improve the performance of an existing small wind turbine using diffuser," International Journal of Engineering & Applied Sciences (IJEAS) Vol. 4, no. 1, 2012, pp. 31-42.

[10] R. A. Kishore, "Small-scale Wind Portable Turbine (SWEPT)". MSc thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, 2013.

[11] F. Owis, M. T. S. Badaway, K. A. Abed, H. E. Fawaz and A. Elfeky, "Numerical investigation of loaded and unloaded diffuser equipped with a flange" International Journal of Scientific and Engineering Research, Vol. 6, No. 11, 2015, pp. 312-341.

[12] D. L. M. Barbosa, J. R. P. Vaz, S. W. O. Figueirido, M. E. Silva and A. L. A. Mesquita, "An investigation of a mathematical model for the internal velocity profile of conical diffusers applied to DAWTs" Anais da Academia Brasileira de Ciencias, Vol. 87, No. 2, 2015, pp. 1133-1148.

[13] S. H. Chang, Q. H. Lim and K. H. Lin, "Design of a wind energy capturing device for a vehicle" 2014 Fifth international Conference on Intelligent Systems, Modelling and Simulation, 27-29 Jan. 2014, pp. 435-440.

[14] S. A. H. Jafari and B. Kosasih, "Flow analysis of shrouded small wind turbine with a simple frustrum diffuser with computational fluid dynamics simulations" Jornal of Wind Engineering and Industrial Aerodynamics, Vol. 125, 2014, pp. 102-110.