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Numerical Analysis of Wind Lens

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ABSTRACT: A recent development in the windmill technology is in the concept of so-called wind-lens turbine, or turbine with a shroud around the rotor [1]. This brim has the possibility of enhancing the power of a given rotor and a given free stream beyond the limit put by Betz theory by altering the velocity at the vicinity of the rotor. The essential concept here is the possibility of enhancing the free stream velocity at the rotor in order to extract much larger power by increased velocity at the rotor. This concept tries to go beyond the Betz limit of 59% on the limit for power extraction through the turbine.

A computational study have been carried out in order to assess the effect the obstruction around a wind rotor in the form of brim which happens to enhance the local velocity at the face of the rotor. Indeed, a parametric study considering the ratio of brim height to width of the diffuser. Navier-Stokes code, Fluent 6.3 as a solver with Gambit 2.2 for grid generation. For this study, only the brim structure is analyzed considering two-dimensional axisymmetric model.

KEYWORDS: Brimmed diffuser, rooftop wind turbine, overcoming Betz limit.

I. INTRODUCTION

Wind energy has gained a wide acceptance as a renewable source because of its ease of availability and improvement in the wind turbine technologies. However, there are limitations for extracting power from wind. These limitations include availability of gust at required pace throughout the day and year, diameter of the rotor and associated structural problems, safety and maintenance, etc. According to Betz, under ideal conditions, a maximum of 59% of wind energy can be extracted from a given stream tube. This limit is known as Betz limit.

According to Betz theory, power extractable from finite wind stream is given by:

$$P_{\max} = \frac{16}{27} \frac{\rho}{2} V_1^3 \frac{\pi D^2}{4} \text{ (watt)} \quad (1)$$

Where D is the Diameter of the rotor

V is the wind velocity

Equation(1) shows that increasing diameter twice will increase power by four fold. However larger the diameter, more will be the structural and balancing problems associated with it. Hence there is a limitation on the maximum diameter. The other way to increase power output is to increase the wind velocity through the rotor. It is evident from the above equation that twice the increase in wind velocity will increase the power output by eight times.

A shroud like structure placed around a wind turbine in order to increase mass flux through it and thereby increasing velocity of air locally. This concept was first introduced by Yuji Ohya of Kyushu university, Japan[1]. According to them, acclimation of shroud over a wind turbine enhanced its power output by almost 2-5 times. The shroud around the wind turbine concentrates the air flow on to the rotor and hence called as “wind lens” shown in Figure 1. They also have installed such power plants. According to their study, vortices induce additional flow through the rotor. This type of adaptation is suitable for a wind turbine of reasonable size as the structural design complexities are of a vital consideration. Wind lens on a larger turbine will lead to very high stresses being induced in the supporting tower.

The advantage of wind lens is reduction in cut-in speed of the wind turbine due to local increase in velocity. Thus making it very feasible option for rooftop installations and small scale power generation. On the other hand, the size of a wind rotor required to produce given amount of power reduces considerably because of wind lens. The other advantages include ease of installation, lower noise etc.

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Ohya attributes the efficacy of a brim to the suction created by the brim at location downstream of the rotor. A different argument, however, is put forth here for the increased velocity. It is argued here that it is the severe blockage created by the brim that makes the flow in front of the rotor to choose an alternative path of least resistance through the rotor. It was our curiosity to find out the variation of mass flow rate through the rotor area and also the effect of the height of the lip over mass flux and maximum velocity. For this purpose we have simulated a 2D model of the shroud considering the case to be axisymmetric. The variation in mass flow rate and maximum velocity were studied based on the ratio of brim height to diffuser width as a parameter.

II. COMPUTATIONAL METHOD

Since the free stream velocity considered is very low for this study, 2D incompressible model has been employed for the analysis. Pre-processor gambit was used to generate grid for the analysis. The brimmed diffuser structure is shown in Figure 2. The farfield conditions used are as shown in Figure 3. Simple quadrilateral elements were employed in the mesh scheme. The farfield distances were fixed upon by means of grid dependence studies [2]. First grid point was located at a distance of 0.0005m from the body corresponding to a y^+ value of approximately 5. Same grid was slightly modified so as to accommodate variation in the brim height. A fine mesh was propagated around the brimmed diffuser in order to resolve the flow features over it, as shown in Figure 4.

This wind lens was designed for a rotor of diameter 2.5m with 0.4m diffuser width. To make the analysis simple only the shroud is considered. The height of the brim varies as a parameter. Ratio of brim height to diffuser width is the parameter considered for this study, shown in Figure 2. This ratio has been varied from 0 to 1 in increments of 0.2.

$$\text{Ratio } r = \frac{a}{b} \quad (2)$$

Where a = brim height
 b = diffuser width.

Fluent 6.3 was used as CFD solver for the analysis with Spalarat-Almaras one equation turbulence model and axisymmetric conditions. Spalarat-Almaras is a simple yet accurate model for analysis of turbulent flows. In order to treat the derivatives, second order upwind scheme has been used.



Figure 1: Wind lens

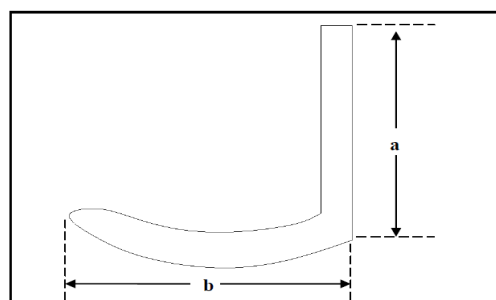


Figure 2: Shape of brimmed diffuser

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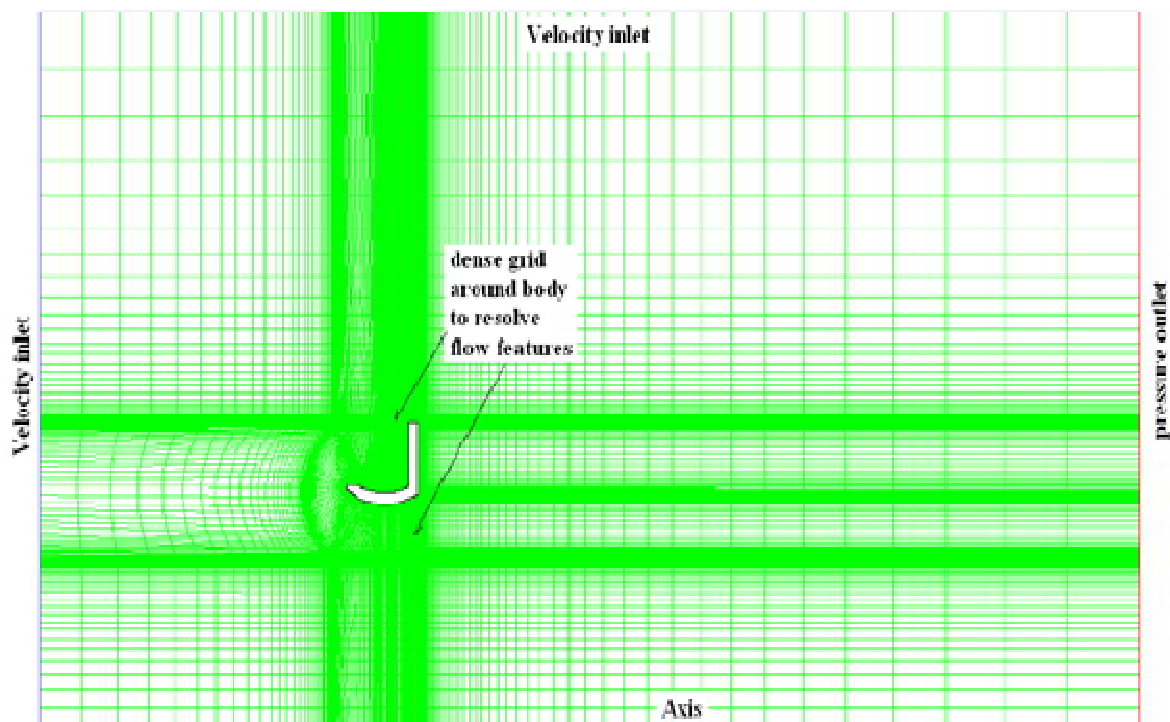


Figure 3: Mesh scheme and boundary conditions for flow analysis of brimmed diffuser

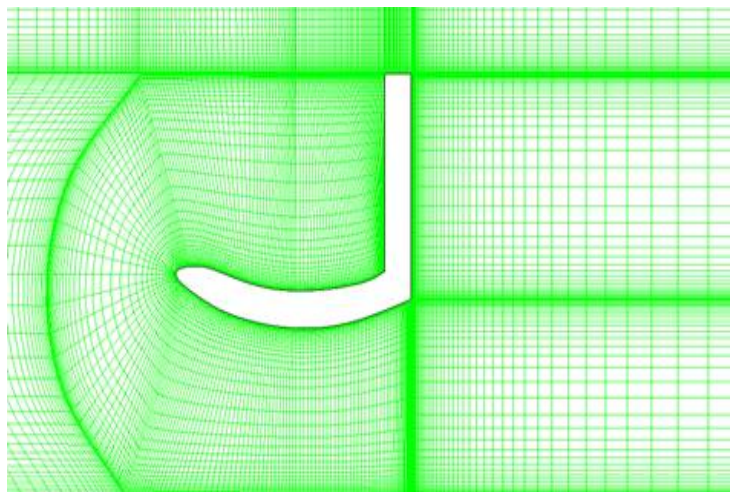


Figure 4: Mesh around brimmed diffuser

III. RESULTS

Both mass flow rate and peak velocity are found to increase with the increase in the brim height. Because of the obstruction to the flow path, flow separation is seen; and vortices are induced. With increase in brim height the strength of the vortices also increases and is evident from Figure 5 to Figure 10. Also the feeding tube diameter increases with increase in brim height as seen from Figure 11. Superimposed velocity profiles for all brim heights considered are

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shown in Figure 12. A sharp increase in both maximum velocity and mass flow rate has been observed till about ratio of 0.6 and further increase in ratio results in slight increase of the maximum velocity and mass flow rates, as shown in Figure 13 and Figure 14. The maximum velocity obtained is about 5.93 m/s for ratio of 1; the value is almost twice the free stream velocity.

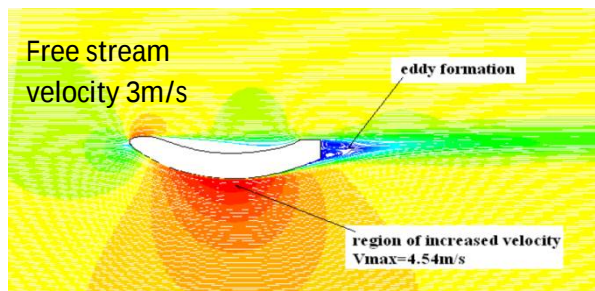


Figure 5: Pathlines around the diffuser
for ratio $r=0$

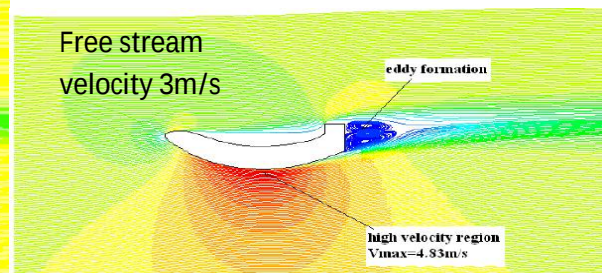


Figure 6: Pathlines around the diffuser
for ratio $r=0.2$

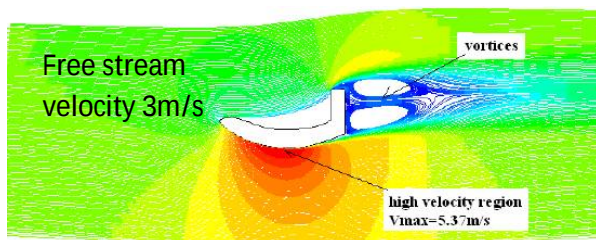


Figure 7: Pathlines around the diffuser
for ratio $r=0.4$

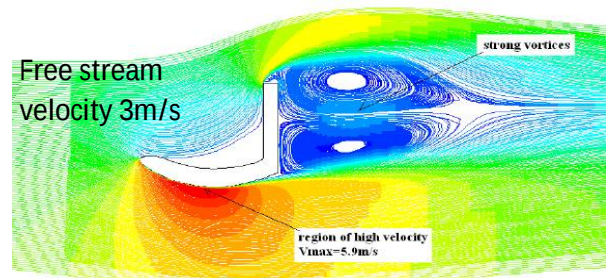


Figure 8: Pathlines around the diffuser
for ratio $r=0.6$

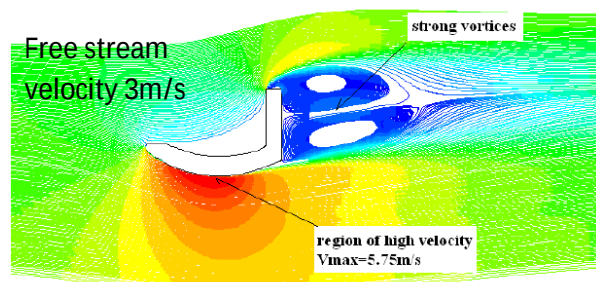


Figure 9: Pathlines around the diffuser
for ratio $r=0.8$

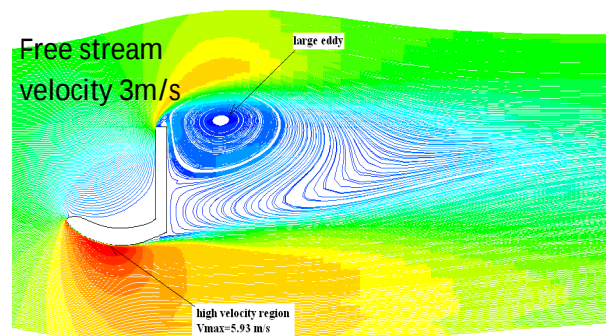


Figure 10: Pathlines around the diffuser
for ratio $r=1$

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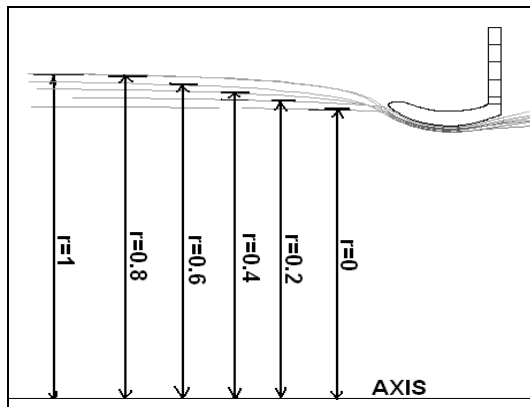


Figure 11: Feeding stream tube diameter.

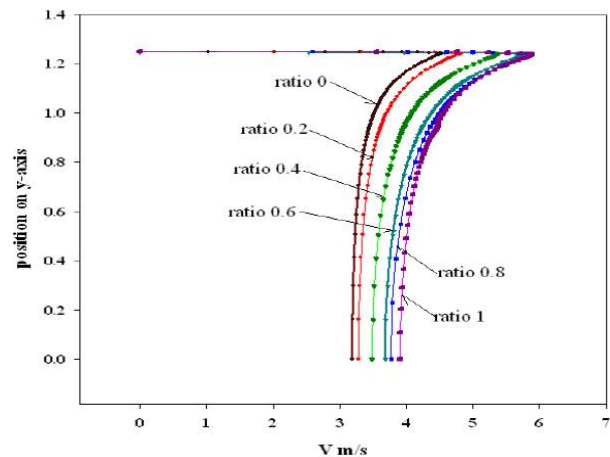


Figure 12: Superimposed velocity profiles

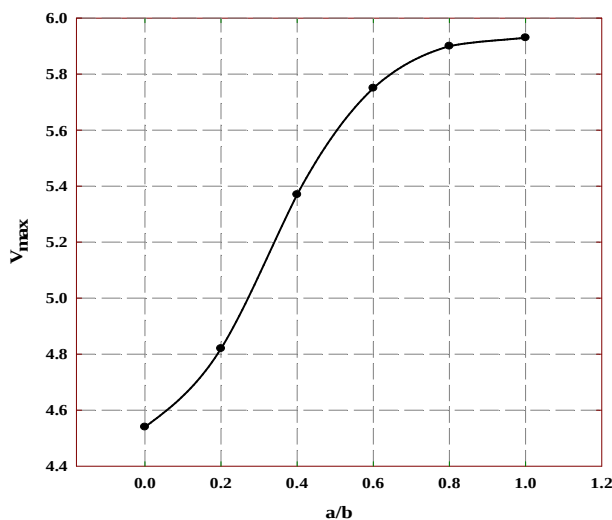


Figure 13: Variation of maximum velocity with ratio $r=a/b$

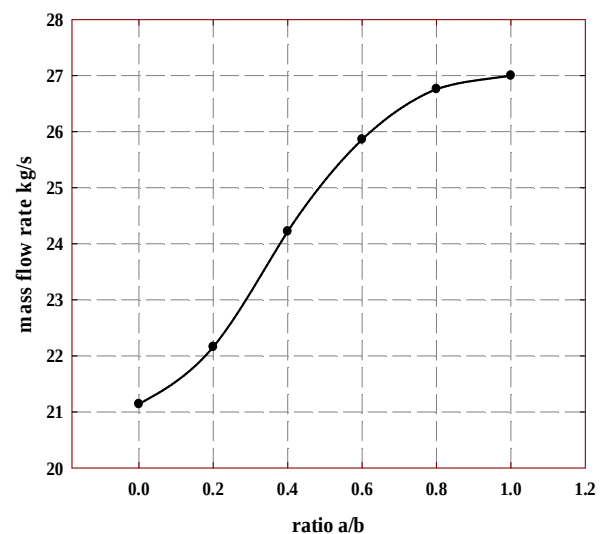


Figure 14: Variation of mass flow rate with ratio $r=a/b$

IV. CONCLUSION

Obstruction in the form of the brim increases flow through the diffuser and thus through the wind rotor. It is seen that for case with ratio of brim height to diffuser width of unity, the maximum velocity is almost twice that of the free stream and average velocity is 1.5 times that of free stream velocity. From Betz equation we can deduce that the output from given wind rotor can be 3.375 times more than that with no brimmed diffuser around the rotor. However, considering practical losses atleast 1.5 to 2 times increase in power output is expected; and is to be verified experimentally.

For given wind turbine diameter, increased power output can be obtained by adapting brimmed diffuser or necessary diameter of the wind turbine to generate required power can be reduced. The local increase in the wind velocity within

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the brimmed diffuser aids working of wind turbines at very low cut-in speeds of about 2 to 3 m/s. Thus making it a very viable option as a rooftop installation for power production in urban localities.

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