

Computational Flow Analysis of Straight Converging-Diverging, Vertical Flanged Diffusers for a Small Wind Turbine

Haribhau G. Phakatkar, Rushikesh V. Godse, Sandip A. Kale, Mahasidha R. Birajdar

Abstract: *Small wind turbines used for community are not till appreciated by the people till date because of non satisfactory performance as they operate in low wind regions. The wind turbines covered with diffuser can improve the power output of the wind turbine. This paper focuses on the straight converging, diverging vertical flanged diffusers for small wind turbine and its computational analysis for selected variables. These computational experiments are carried out for wind turbine of 3000 mm diameter. During the analysis, diffuser diameter at the throat, flange inclination, throat distance from the exit and the distance of the rotor from the throat are kept constant. The four variables such as inlet diameter, exit diameter, flange height and entry to throat distance are considered at three levels. For these four variable and three levels nine cases are formed by Taguchi methods and CFD analysis of these nine cases is carried out to obtain the best combination. During the computational analysis wind speed is considered as 6.5 m/s in all cases. Based on the wind velocity obtained in the diffuser predicted power output is calculated and it is observed that 1.72 to 2.15 times increase in power output is possible for the considered cases.*

Index Terms: *Computational fluid dynamics, Diffuser augmented wind turbine, small wind turbine, wind speed.*

I. INTRODUCTION

Wind power is the most accepted renewable energy source by many countries across the world [1]. On-shore and off-shore large wind turbines installed at various windy regions across the world are successfully producing the electricity and fulfilling the growing electricity needs of human beings [2]. But, the micro and mini wind turbines suitable for small community, installed in low wind regions are still not believed because of unacceptable performance [3]. Generally, these micro and mini wind turbines are also categorized as small wind turbines. The performance of these micro and mini wind turbines can be improved by covering them by a diffuser and accelerating the approach wind velocity at the rotor plane [4, 5].

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As the solar prices are declining and within the acceptance of the average community population, only a few researchers are working to develop the cost effective and efficient wind turbines for these community. Now, it has become possible to develop the micro and mini wind turbines in various countries because of reach of technological advancement in manufacturing and material science. Ultimately, The mechanical system design and development of the wind turbine is possible at low cost and at the local level also. The generator availability at local level is still a significant issue, but can be solved because of global online market. Diffuser augmented wind turbine has the potential to attract the researchers and people and contributing towards the sustainable development using wind as a renewable energy source.

As stated earlier the small wind turbines covered with diffuser increases open wind velocity when enters through the diffuser. As the wind power output is proportional to cube of wind velocity, the slight increase in wind velocity at the rotor plane has the ability to increase power output significantly [6, 7]. The geometric parameters which decide the acceleration of wind flow at rotor plane are [3, 7],

- Shape of the diffuser,
- Wind turbine diameter,
- Diffuser diameter at entry,
- Diffuser diameter at throat,
- Diffuser diameter at exit,
- Flange height,
- Flange inclination
- Overall length of the diffuser,
- Throat distance from entry and exit
- Position of the rotor with respect to diffuser throat

This work is focused on study of computational flow analysis of straight conical shaped convergent and divergent shaped diffuser with vertical flange for a wind turbine rotor diameter of 3000 mm. The computational flow analysis for selected variables are carried out in this research work. Though, some works are carried out for straight shaped and curved diffuser for small wind turbines this basic study is important to get an insight of the basic straight shape and effect of selected variables on wind flow through the

diffuser.

II. METHODOLOGY

In this paper research work is carried out for straight conical shaped convergent and divergent shaped diffuser with vertical flange for a wind turbine of rotor diameter 3000 mm. The basic geometrical parameters are shown in Fig. 1. From the geometric parameters listed in the previous section, the parameters fixed for this study are shown in Table I,

Table I: Details of Fixed parameters

Parameter	Details
Wind turbine diameter (D)	3000 mm
Diffuser diameter at throat (D_2)	3080 mm
Flange inclination (θ)	Zero – Vertical flange
Throat distance from exit (L_2)	750 mm
Distance of the rotor from throat	Zero - Rotor at throat

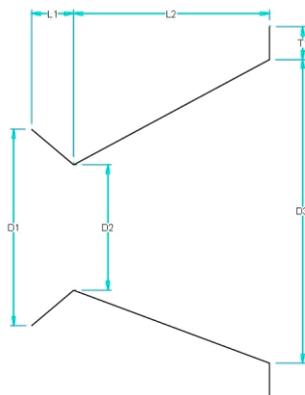


Fig. 1. Basic geometrical parameters of the diffuser

Four variables are considered at three value levels as shown in Table II. All values presented in the table are in mm.

Table II: Details of Variable parameters

Parameter	Level 1	Level 2	Level 3
Inlet diameter (D_1)	3160	3215	3295
Exit diameter at throat (D_3)	3558	3638	3718
Flange Height (T_1)	200	240	280
Entry -Throat distance (L_1)	190	200	210

For the selected four variable and three levels nine experiments are decided using Taguchi Method as shown in Table III. The experiments for selected combinations are possible using physical set-up in the wind tunnel and computational experiments using Computational Fluid Dynamics (CFD). The availability of wind tunnel along with manufacturing of diffuser prototypes is very costly and time consuming concern. Hence, this research work is carried out using Computational Fluid Dynamics analysis of the selected nine combinations.

Table III: Combinations selected for CFD Analysis

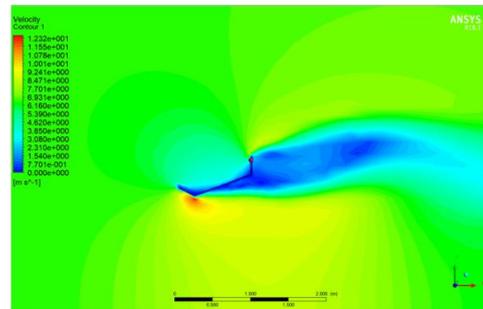
Case	D_1	D_3	T_1	L_1
Case 1	3160	3558	200	190
Case 2	3160	3638	240	200
Case 3	3160	3718	280	210
Case 4	3215	3558	240	210
Case 5	3215	3638	280	190
Case 6	3215	3718	200	200
Case 7	3295	3558	280	200
Case 8	3295	3638	200	210
Case 9	3295	3718	240	190

III. CFD ANALYSIS & RESULTS

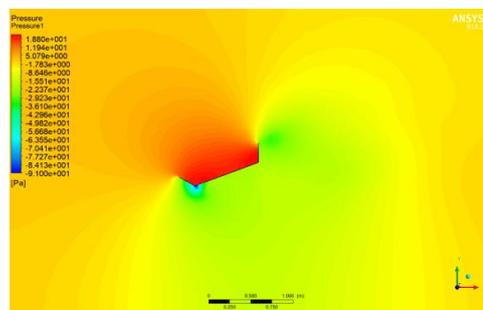
Larger wind turbines are designed at the rated wind speed of 13 to 18 m/s. Smaller wind turbines are installed and operated in low wind regions. As per IEC standard rated wind speed for small turbines is determined by multiplying the annual average speed by the factor 1.4 [2]. The annual average wind speed at which small wind turbines are operated is very low [3, 7]. Considering the practical feasibility the wind speed selected for computational analysis in this research work is 6.5 m/s.

A. Case 1: $D_1=3160$, $D_3=3558$, $T_1=200$, $L_1=190$

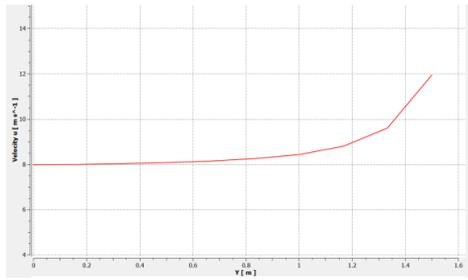
The computational results for fixed parameters listed in Table I and variables for Case I as per Table III, are plotted in Fig. 2. Fig. 2 (a) and 2 (b) represents the velocity counter and pressure counters respectively for Case 1. Fig. 2 (c) represents the velocity distribution at rotor plane considered at the throat, starting from the diffuser axis to throat diameter. Fig. 2 (d) is the plot of the velocity streamline for Case 1.



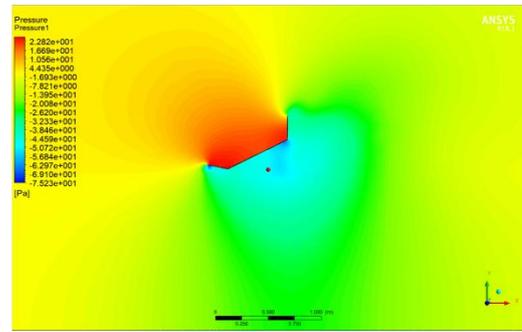
(a)



(b)

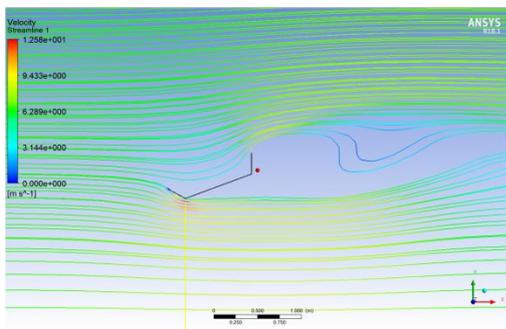


(c)



(b)

From the results in Fig 2 (c), it is observed that, the input wind velocity of 6.5 m/s is increased to 8 m/s at throat plane and for approximately 0.8 m from diffuser center it is about constant, up to 1.17 m distance it changes considerably and after that it changes drastically.

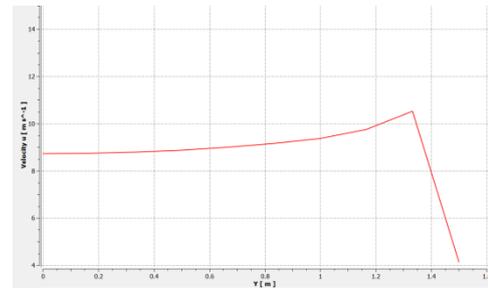


(d)

Fig. 2. Computational results for Case 1

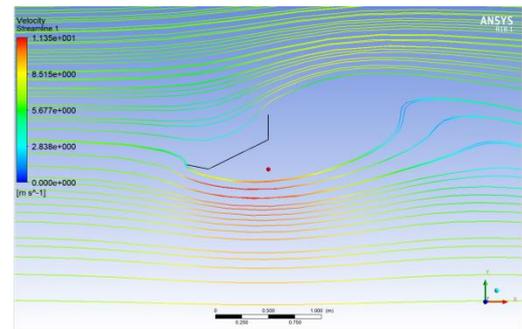
B. Case 2: $D_1=3160$, $D_3=3638$, $T_1=240$, $L_1=200$

The computational results for Case 2 are plotted in Fig. 3. Fig. 3 (a) and 3 (b) represents the velocity counter and pressure counters respectively for Case 2. Fig. 3 (c) represents the velocity distribution at rotor plane, starting from the diffuser axis to throat diameter. Fig. 3 (d) is the plot of the velocity streamline for Case 2.



(c)

From the Fig 3 (c), it is observed that, the input wind velocity 6.5 m/s is increased to 8.4 m/s at throat plane and for approximately 0.9 m from diffuser center it is about constant, up to 1.35 m distance it changes considerably and after that it changes drastically.

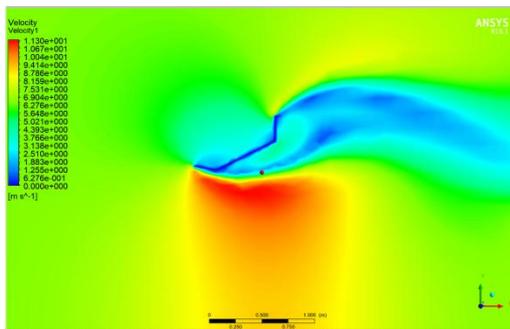


(d)

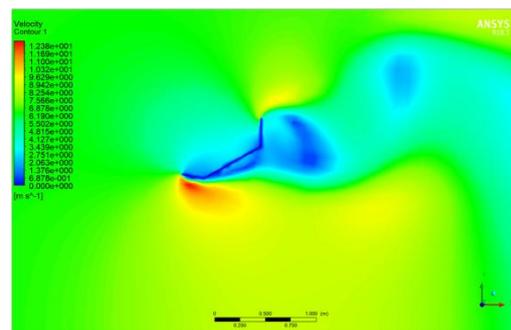
Fig. 3. Computational results for Case 2

C. Case 3: $D_1=3160$, $D_3=3718$, $T_1=280$, $L_1=210$

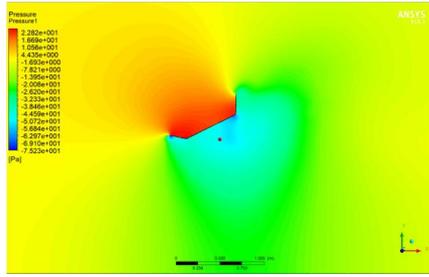
The computational results for Case 3 are plotted in Fig. 4. Fig. 4 (a) and 4 (b) represents the velocity counter and pressure counters respectively for Case 3. Fig. 4 (c) represents the velocity distribution at rotor plane, starting from the diffuser axis to throat diameter. Fig. 4 (d) is the plot of the velocity streamline for Case 3.



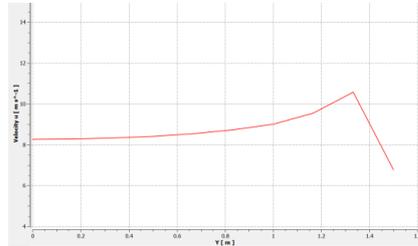
(a)



(a)

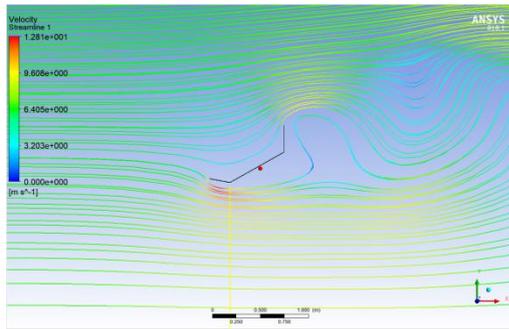


(b)



(c)

From the Fig 4 (c), it is observed that, the input wind velocity is increased to 8.12 m/s at throat plane and for approximately 0.9 m from diffuser center it is about constant, up to 1.2 m distance it changes considerably and after that it changes drastically.

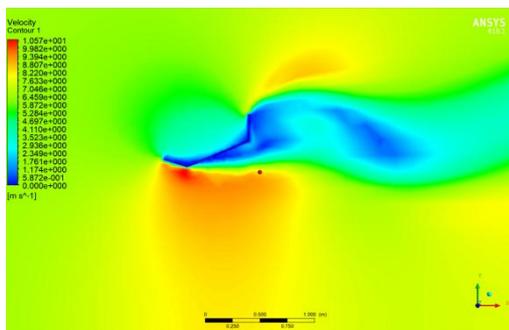


(d)

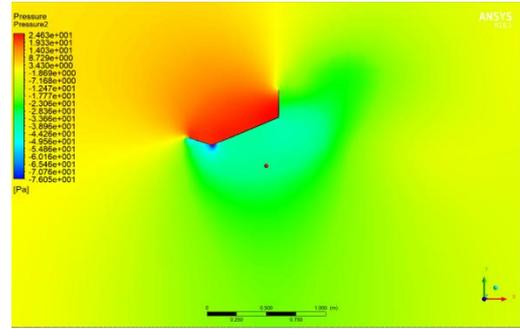
Fig. 4. Computational results for Case 3

D. Case 4: $D_1=3215$, $D_3=3558$, $T_1=240$, $L_1=210$

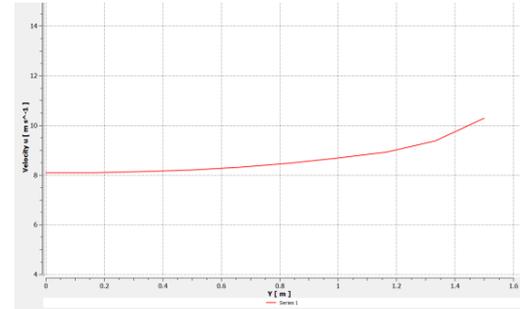
Fig. 5 (a) and 5 (b), 5 (d) represents the velocity counter, pressure counters and velocity streamline respectively for Case 4. Fig. 5 (c) represents the velocity distribution at rotor plane, starting from the diffuser axis to throat diameter.



(a)

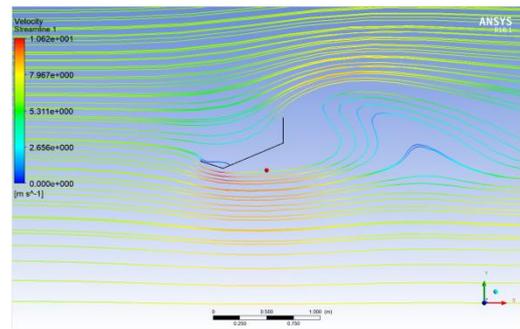


(b)



(c)

From the Fig 5 (c), it is observed that, the wind velocity at throat plane is increased to 8.05 m/s and for approximately 1 m from diffuser center it is about constant, 0.4 to 1 m distance changes up to 8.4 m/s, after it up to 1.3 m distance it changes considerably and after that it changes drastically.

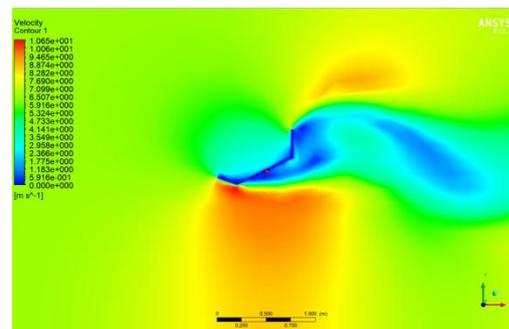


(d)

Fig. 5. Computational results for Case 4

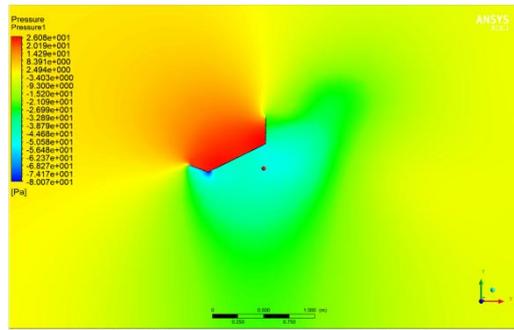
E. Case 5: $D_1=3215$, $D_3=3638$, $T_1=280$, $L_1=190$

Fig. 6 (a) and 6 (b), 6 (d) represents the velocity counter, pressure counters and velocity streamline respectively for Case 5. Fig. 6 (c) represents the velocity distribution at rotor plane, starting from the diffuser axis to throat diameter.

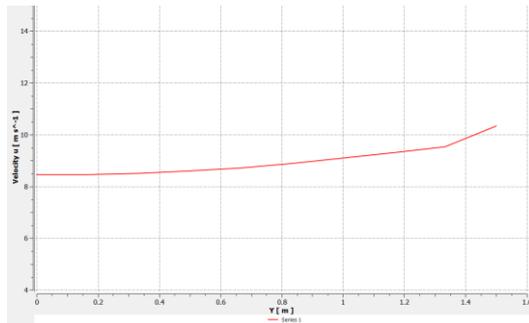


(a)



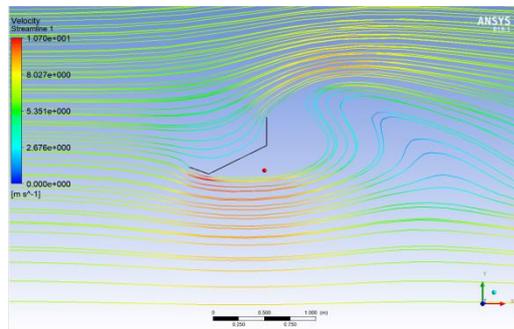


(b)



(c)

From the Fig 6 (c), it is observed that, the wind velocity at throat plane is increased to 8.25 m/s and for approximately 1 m from diffuser center it is about constant, after this distance, it changes slowly but considerably.

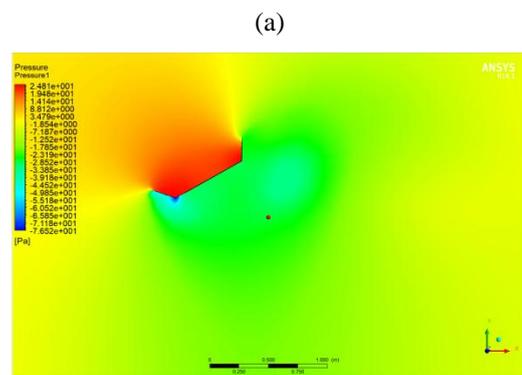


(d)

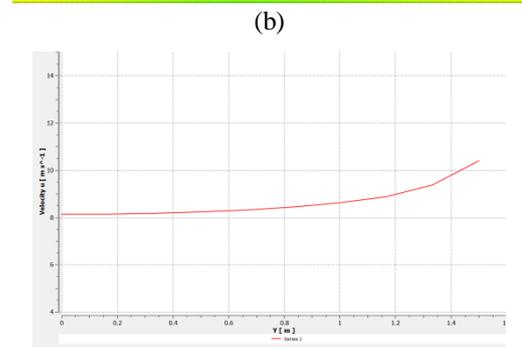
Fig. 6. Computational results for Case 5

F. Case 6: $D_1=3215, D_3=3718, T_1=200, L_1=200$

Fig. 7 (a) and 7 (b), 7 (d) represents the velocity counter, pressure counters and velocity streamline respectively for Case 6. Fig. 7 (c) represents the velocity distribution at rotor plane, starting from the diffuser axis to throat diameter.



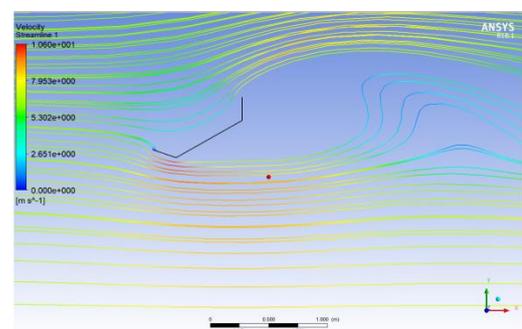
(a)



(b)

(c)

From the results Fig 7 (c), it is observed that the wind velocity at throat plane is increased to 8.05 m/s and for approximately 1 m from diffuser center it is about constant, up to 1.35 m distance it changes considerably and after that it changes drastically.

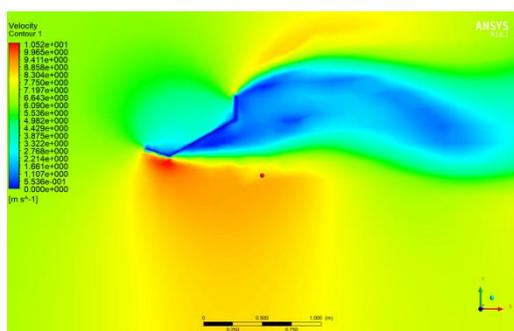


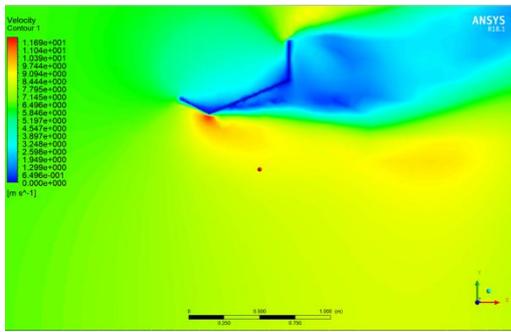
(d)

Fig. 7. Computational results for Case 6

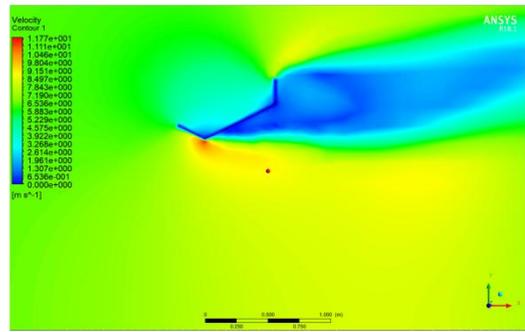
G. Case 7: $D_1=3295, D_3=3558, T_1=280, L_1=200$

Fig. 8 (a) and 8 (b), 8 (d) represents the velocity counter, pressure counters and velocity streamline respectively for Case 7. Fig. 8 (c) represents the velocity distribution at rotor plane, starting from the diffuser axis to throat diameter.

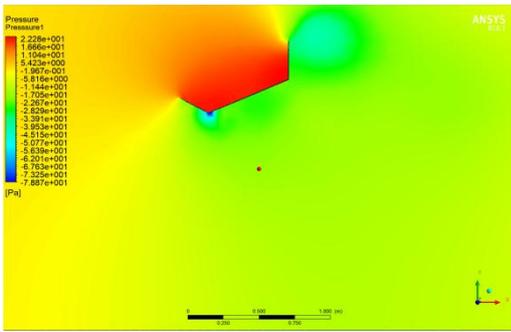




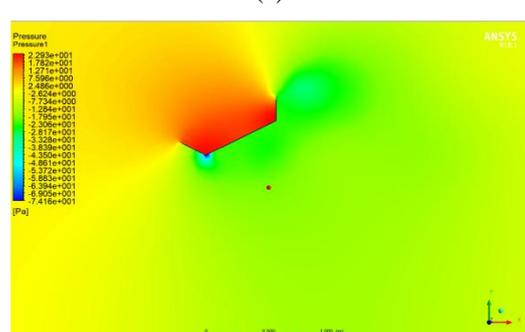
(a)



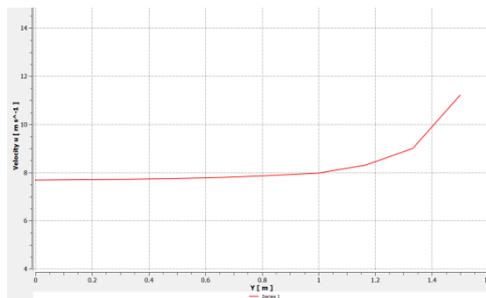
(a)



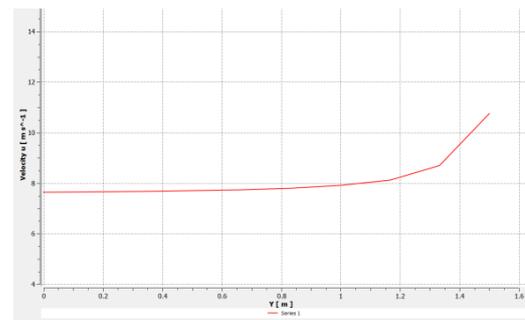
(b)



(b)



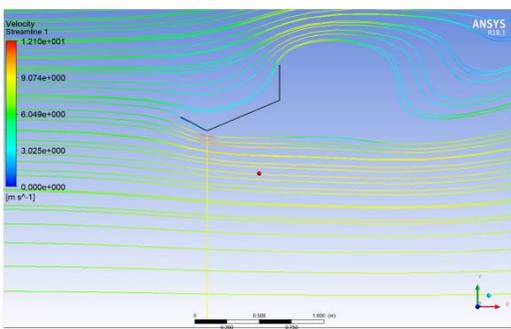
(c)



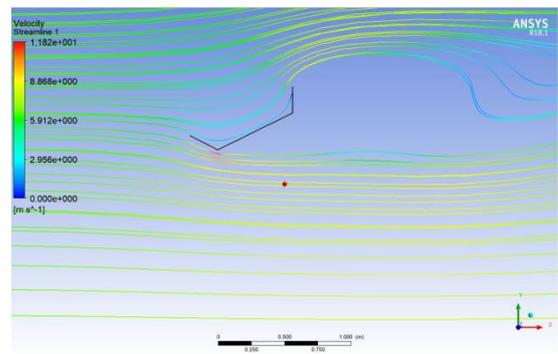
(c)

From the results Fig 8 (c), it is observed that the wind velocity at throat plane is increased to 7.85 m/s and for approximately 1.1 m from diffuser center it is about constant, and after that it changes drastically.

From the results Fig 9 (c), it is observed that the wind velocity at throat plane is increased to 7.8 m/s and for approximately 1.2 m from diffuser center it is about constant, and after that it changes drastically.



(d)



(d)

Fig. 8. Computational results for Case 7

Fig. 9. Computational results for Case 8

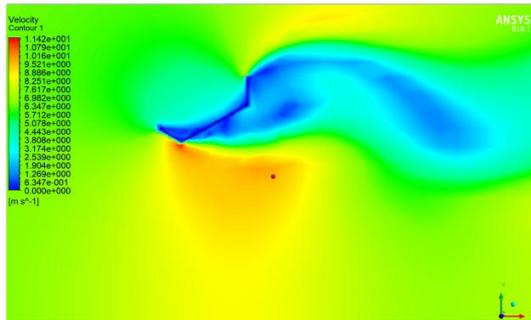
H. Case 8: $D_1=3295$, $D_3=3638$, $T_1=200$, $L_1=210$

Fig. 9 (a) and 9 (b), 9 (d) represents the velocity counter, pressure counters and velocity streamline respectively for Case 8. Fig. 9 (c) represents the velocity distribution at rotor plane, starting from the diffuser axis to throat diameter.

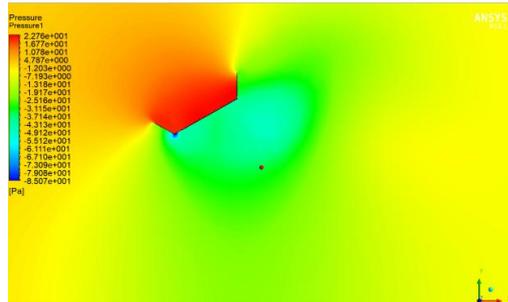
I. Case 9: $D_1=3295$, $D_3=3718$, $T_1=240$, $L_1=190$

Fig. 10 (a) and 10 (b), 10 (d) represents the velocity counter, pressure counters and velocity streamline respectively for Case 9. Fig. 10 (c) represents

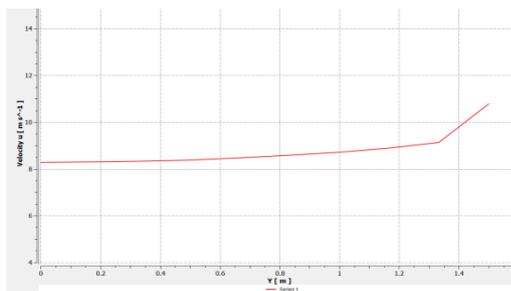
the velocity distribution at rotor plane, starting from the diffuser axis to throat diameter.



(a)

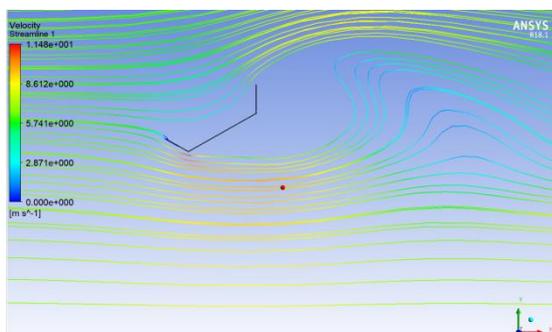


(b)



(c)

From the results Fig 10. (c), it is observed that the wind velocity at throat plane is increased to 8.12 m/s and for approximately 1 m from diffuser center it is about constant, up to 1.3 m distance it changes considerably and after that it changes drastically.



(d)

Fig. 10. Computational results for Case 9

IV. RESULTS AND DISCUSSION

This section presents a comparison of open wind speed and accelerated wind speed in the diffuser. Table IV presents minimum output velocity at the central axis of wind turbine based on Fig. 2 (c) to Fig. 10 (c). Theoretically, the bare wind turbine can produce 371 W power at 6.5 m/s velocity. Using the values of increased wind velocities and assuming other parameters and efficiencies, theoretically, the power output is calculated and presented in the Table IV. These results are also plotted in the Fig. 11 and gives a clear visual presentation of the power output for various cases of different diffuser dimensions.

Table IV: Velocity at throat and respective theoretical power for different cases

Case	$V_{\text{output min}}$	P_{Output}
Case 1	8.00	691
Case 2	8.40	800
Case 3	8.12	723
Case 4	8.05	704
Case 5	8.25	758
Case 6	8.05	704
Case 7	7.85	653
Case 8	7.80	641
Case 9	8.12	723

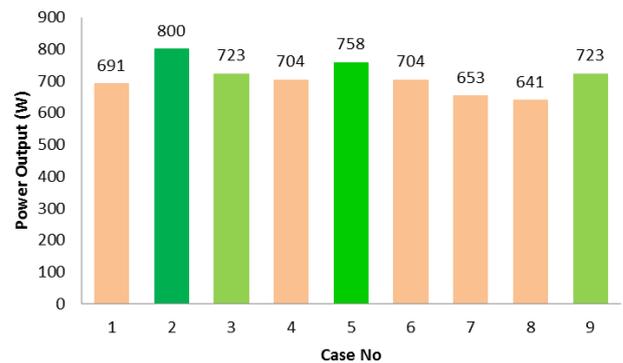


Fig. 11. Power output for different diffuser Cases

V. CONCLUSION

On the basis of computation fluid analysis results for the nine cases under considerations following conclusions are drawn.

- Case 2 found most efficient and wind velocity increases from 6.5 m/s to 8.4 m/s. It is predicted the power output increases from 371 W of to 800 W, which is 2.15 times that of the bare wind turbine for Case 2 diffuser.
- Case 5 diffuser are found as moderate performance, delivering diffuser.
- Cases 1, 3, 4, 6 and 9 are in between of Case 5 and Case 7 & 8.
- Case 7 and Case 8 found as low performing diffusers and found 1.72 times increase in power output.

REFERENCES

1. Sandip A. Kale, Swanand R. Kulkarni, Suraj D. Shrivagi and Ganesh P. Bharambe, Materials for



- Small Wind Turbine Blades, Chapter 3 in Renewable Energy and Sustainable Development, 2015, ISBN: 978-1-63463-429-8, pp.43-54.
2. Mahasidha Birajdar , S. A. Kale, S.N. Sapali, “Effects of Design Parameters on Aerodynamic Performance of New Profile Small Wind Turbine Blades”, ASME 2015 International Mechanical Engineering Congress and Exposition, Houston, Texas, USA, November 13-19, 2015, ISBN: 978-0-7918-5747-2, pp. V07BT09A049; 8 pages
 3. S. A. Kale, S.N. Sapali, “Development and Field Testing of an Inclined Flanged Compact Diffuser for a Micro Wind Turbine”, ASME 2014 International Mechanical Engineering Congress and Exposition, Montreal, Canada, November 14-20, 2014, ISBN: 978-0-7918-4952-1 , pp. V06BT07A070; 6 pages
 4. Yuji Ohya, Takashi Karasudani, Akira Sakurai, Ken-ichi Abe, Masahero Inoue, “ Development of shrouded wind turbine with a flanged diffuser” Journal of wind engineering and industrial aerodynamics, Vol. 96, 2008, pp. 524-539.
 5. Yuji Ohya, Takashi Karasudani “A Shrouded wind turbine generating high output power with wind lens technology”, Energies, 2010, pp. 634-649.
 6. Swanand Kulkarni, S. A. Kale, Prakash Dabeer, Suresh M Sawant, “Comprehensive Evaluation of Some Innovative Wind Turbines”, ASME 2015 International Mechanical Engineering Congress and Exposition, Houston, Texas, USA, November 13-19, 2015, ISBN: 978-0-7918-5757-1, pp. V014T06A006; 11 pages
 7. Kale S. A., Yogesh Gunjal, Sachin Jadhav, Ajinkya Tanksale, “CFD Analysis for Optimization of Diffuser for a Micro Wind Turbine”, IEEE Xplore Digital Library, ISBN: 978-1-4673-6149-1, DOI 10.1109/ICEETS.2013.6533392, pp. 257-260, 2013