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Research Article

# Energy Efficient Diffuser Design For Dawt

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**Abstract**

In recent years, the need for renewable energies keeps on increasing. Thus, there is a need to improve the methods forharnessing the renewable energy such as wind. Wind is also sustainable, Eco friendly and zero cost energy. One such improvement is Diffuser augmented type is a class of horizontal axis Wind Turbine. The design optimization of Diffuser augmented wind turbine is discussed in this work. Along with the flangeless diffuser, the diffuser in diffuser type, flanged diffuser considered and optimized by placing of blades to maximize the velocity thereby maximize the power output. The Computational Fluid Dynamic analysis employed in the simulating flow by using Fluent of ANSYS Software. The wind inlet velocity of 5m/s and the values are compared to get optimized model to achieve good power output. From the results, the flanged Diffuser outperformed and optimized blade location was 0.135 m from the entry of diffuser and thereby a significant increase in power output determined.

**Keyword:**Renewable Energy, Wind turbine, optimization, computational Fluid Dynamic analysis, Diffuser.

## 1. Introduction

DAWT is a kind of horizontal axis class of wind turbine where blades of a rotor mounted within the Diffuser to convert the wind energy to electrical power. The arrangement of blades in DAWT, highly influences in power output. That is the blades arrangement is responsible boost up wind speed which supply by diffuser. The limitation as well as a influencing factor Betz’s law by which as it is open wind turbine the maximum of 16 parts of wind energy out of 27 parts supplied by diffuser can be converted into useful work that is 59 percentage. The working phenomenon (Refer figure 1) includes that the diffuser duct provided for augmenting cross section by making the drastic pressure drop at behind the blades. Such pressure drop attracts the more flow of winds across the blade. In combination of more flow and diffuser inherent property the flow velocity increases significantly. The bare turbine model is improved and released Vortex 7 which outperformed well when compared with equal diameter of the rotor [1].

Later it was proved that the low cost energy can be produced and DAWT can be designed to work on a lower cut wind velocity and also same power out can be obtained by reducing the size of the turbine by modifying the influencing parameters to obtain same wind density. It was found that noise influencing factor in the DAWT is yaw. The yaw is usually referredin aerodynamic as misalignment between turbine pointing direction and wind direction. It is often noticed that the noise is fluctuating when wind flows accordingly, it meant that if allowed the degree of freedom the turbine align yaw as itself [2]. The figure 2 compares the conventional bare wind turbine to DAWT size reduction from the conventional wind turbine. Size reduction gives noise reduction, less hazards flying birds, mechanically lower the load and increase the life with the same output. Some of the intangible benefits like transportation savings, installation and maintenance costs, life-time improvements etc.This piece of research aimed to focus on duct design. Because [3] reported that by use of duct, one can overcome the bets limitation of energy conversion, reduces the acoustic pollutions (by reduction of blade tip noise) and free the turbine from the attack of debris. But also the duct provides safe guard to blades from breakages [4]. [5] Explained that wind turbine operates with shroud is best solution. [6] Suggested nozzle shaped duct as well as brim shroud diffuser.

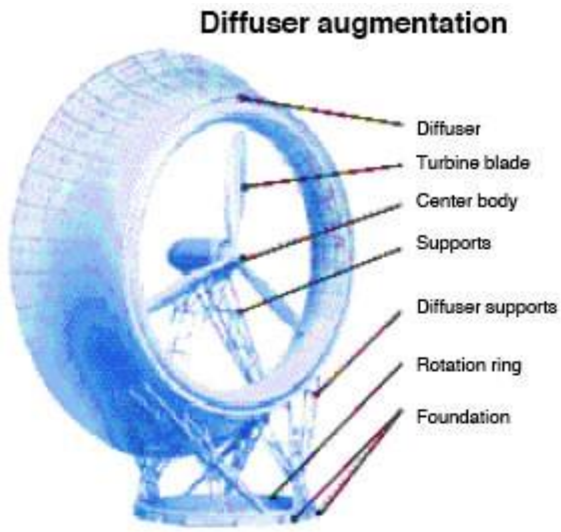
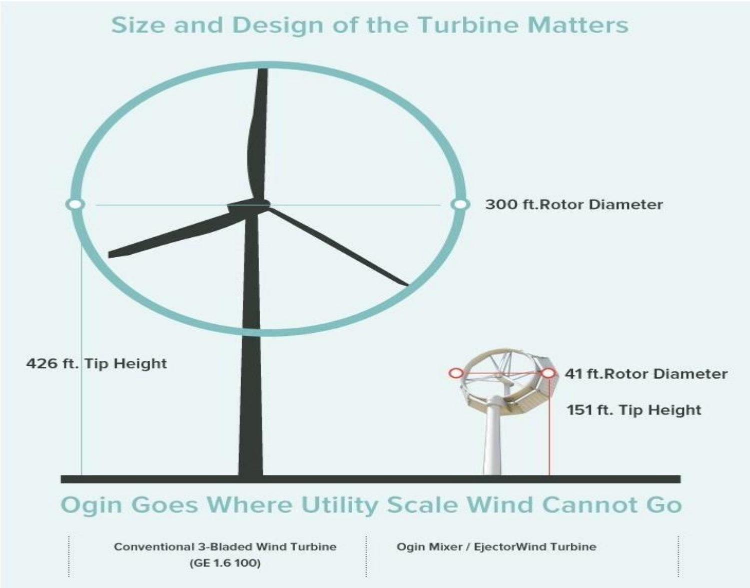



**Figure 1: General Construction features of DWAT [1]**

Inwhichthearearatiowas1.67(Ae/Ai=1.67)andlengthofthediffuser(L=0.289m)was0.289meterforbrimshrouddiffuserandthearearatiowas1.19(Ae/Ai=1.19)andlength of the diffuser (L=0.408m ) was 0.408 meter for nozzle shaped duct. The nozzle shaped ductwas56%higherefficientthanbrimshrouddiffuserduetoinconvergentportionactas collector[7].

## 2. MATERIALS AND METHODS

Understandingtheexactphenomenonhelpstoimproveitsperformancethefigure3illustratestheworkingphenomenonofDAWT.Inordertoincreasethepoweroutputofthe DAWT, the diffuser maintains the low pressure must be at the back side of theturbine.Thepositionofvorticesformedisinfluencinginaccelerationanddecelerationofthewind in the DAWT, if vortices position is inside the diffuser which decelerated the wind,which already augmented by the diffuser will lead to low power at output of DAWT. This canbeavoided by avoiding flow separation inside the diffuser and allow the vertices forms as far away from the diffuser and at the back side.




**54Figure 2: Comparing Conventional bare wind turbine and DAWT [5]**

The combined effects allow the flow of wind through DAWT increase. The wind velocity decides the wind power generation, so check thepossibilitytoaugmentthewindvelocity.Asthewindenergydensityisconcentratedin DAWT the miniaturization waspossible.

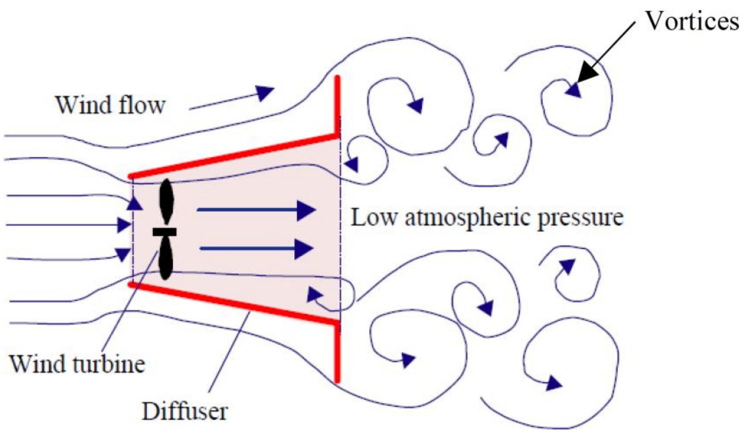



**Figure 3: Principle of DAWT [8]**

## 3. MATHEMATICALMODEL

The one dimensional model developed to understand the behavior and optimizethe parameters. The fundamental mathematical assumptions and some basic relations were derived from the earlier models of [9-13]. In the control volume the analysis assumes a control volume the ambient flow velocity of wind is $U_{\infty}$. Similarly, wind speed at section 1-4are:inletofdiffuser$U_1$,beforeapproachingblades$U_2$,afterpassingoverblades$U_3$and exitofthediffuser$U_4$.Thevelocityofthewindatthefreestreamregionorinletofdiffuser aresame$U_{\infty}=U_1$, withinthecontrolvolume

- Number of blades notlimited
- Anon-rotatingwake isconsidered
- Wind flow is in a uniquedirection
- Flow is steady andfrictionless
- The trust is uniform over therotor
- The wind inside the Control volume is inviscid andhomogeneous.

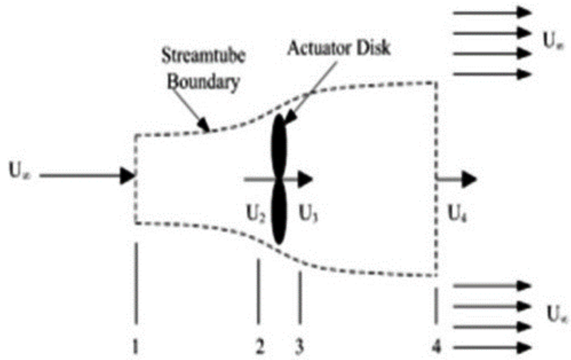



**Figure 4: Modelling of DAWT**

$$F_\tau = m^{\cdot}(U_1 - U_4) \quad (1)$$

- Here the mass flow rate of the wind is $m^{\cdot}$ ,$U_1$, and $U_4$ are wind velocity at entry and the exit of the diffuser respectively. The equation (1) reveals that the velocity status that exit velocity of the wind is less than theinlet velocity of the wind. According to continuity equation for the same air density p and respective area of the Section $A_1$ and $A_4$,the mass flow rateis

$$m^{\cdot} = \rho A_1 U_1 = \rho A_4 U_4 \quad (2)$$

If there is no moving part between section 1 and 2 as well as section 3 and 4. Hence there is no work done, onlyflow energy,Hence the energy equation between section 1 and 2 is

$$P_1 + \frac{1}{2}\rho U_1^2 = P_2 + \frac{1}{2}\rho U_2^2 \quad (3)$$

The energy equation between section 3 and 4 is

$$P_3 + \frac{1}{2}\rho U_3^2 = P_4 + \frac{1}{2}\rho U_4^2 \quad (4)$$

The change of area before and after rotor (Section 2 and Section 3) is almost neglected as rotor blade requires uniform clearance with diffuser, hence ($A_2$=$A_3$). Due to pressure differencetheworkdonehappens.Soitismathematicallystatethatthethrustdevelopedat rotor

$$F_\tau = A_2P_2 - A_3P_3 = A(P_2 - P_3) = \frac{1}{2}\rho A_2(U_1^2 - U_4^2) \quad (5)$$

The equation of continuity at section 2 is

$$m = \rho A_2 U_2 \tag{6}$$

$$F = \frac{1m}{2U_2}(U_1^2 - U_4^2) \tag{7}$$

That is $pA_2=m^{\cdot}/U_2$

Nowweequatingthrustequationthat

$$m = (U_1 - U_4) = \frac{1m}{2U^2}(U_1^2 - U_4^2)$$

We get that

$$U_2 = \frac{1}{2}(U_1 - U_4) \tag{8}$$

Theequation8revealsthataverageofinletandexitvelocityofthecontrolvolumeisrotor planevelocity. Due to power generation certain velocity to be expended that fraction of velocity is termed as axial induction Factor $a_{ij}$it is some occasion termed as interference) factor

$$a_u = \frac{U_1 - U_2}{U_1} \tag{9}$$

From equation 9 it can be obtained that

$$U_2 = U_1 (1 - a_u) \tag{10}$$

And

Hence Power produced by turbine $P_T$

$$P_\tau = F_\tau U_2 \tag{11}$$

Substituting the $F_T$value from equation 5, equation 10 subsequently, the equation 13 will be obtained.

$$P_\tau = \frac{1}{2}\rho A_2 (U_1^2 - U_4^2) U_2$$

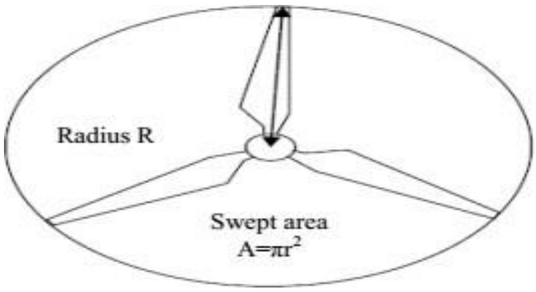
$$P_\tau = \frac{1}{2}\rho A_2 U_2 (U_1 - U_4)(U_1 + U_4) = \frac{1}{2}\rho A_2 {U_1}^3 4A a_u (1 - a_u)^2$$

Here after we consider only Rotor area $A_2$ is replaced by A and velocity is ambient wind velocity only so $U_2$ is replaced by U.

$$P_\tau = \frac{1}{2}\rho A U^3 4 a_u (1 - a_u)^2 n \tag{13}$$

where the control volume, $A_2$ is replaced with A (*refer Figure 5)*, the rotor area, and the free stream velocity $U_1$ is replaced by U.

**Figure 5: Swept area of DWAT**




The following term is called power coefficient

$P_c = 4a_u\,(1 - a_u)^2$ (14)

Substituting in this in equation 13 we get

$$P_c = \frac{P_\tau}{\frac{1}{2}\rho A U^3}$$

Maximum possible coefficient value can be obtained by

$$= 4\left(\frac{\delta P_c}{\delta a_u} - 3a^2\right)$$

Therefore the $a_u$=1/2

Then the $P_{cmax}$ will be.

$P_{cmax}$= 0.5926 (15)

We know that general kinetic energy equation

$$E = \frac{1}{2} m U^2 \quad (16)$$

HereUisvelocityasstatedabove.Fromtheenergyequation,thepowerisenergyflowper unittime.Sothechangeinpowercanbewrittenas

$$P_T = \frac{dE}{dt} = \frac{U_2 dm}{2dt}$$
(17)

In which the term dm/dt is mass flow rate. The same can be written as

$$\frac{d_m}{d_t} = \rho A \frac{dx}{dt} \quad (18)$$

In the above equation dx/dt meant velocity U. That is U=dx/dt. So dm/dt= p.A.UThe power is

$$P_T = \frac{1}{2}\rho A U^3$$
(19)

The maximum possible value of Power Coefficient (refer equation 15)

The maximum available power can be mathematically expressed as $P_{TA}=P_T P_{Cmax}$

That is

$$P_{TA} = \frac{1}{2}\rho P_{cmax} A U^3 \tag{20}$$

## 4. PROPOSEDDESIGN

The diffuser function is basically affected by its expansion angle and length. In this designaunitlengthofdiffuseisconsidered.Theproportionatedimensionsderivedfromthe standard design to obtain the marginal results. Three different diffuser designs are proposed to augment the wind speed and thereby improving the DAWT output. [8] examined and declared that 1.7 times wind speed can be augmented by altering above saiddimensions. [14]examinedbysimulationandconfirmedthatresults.Thesuccessfuldimensionswere preferredinthisinvestigationlikethelengthofthediffuser,exitdiameterandflangeheight.

### 4.1. FlangelessDiffuser

Theflangelessdiffusernameitselfimpliedthattherenoflangeprovision.Thedesignis illustratedinthefigure6.Thesamesizeofflangeddiffuserisconsideredforcomparative study.That is the diffuser is a meter long, and its entrance diameter is 0.4 meter and expansion angle is $\alpha$ is12$^{o}$.

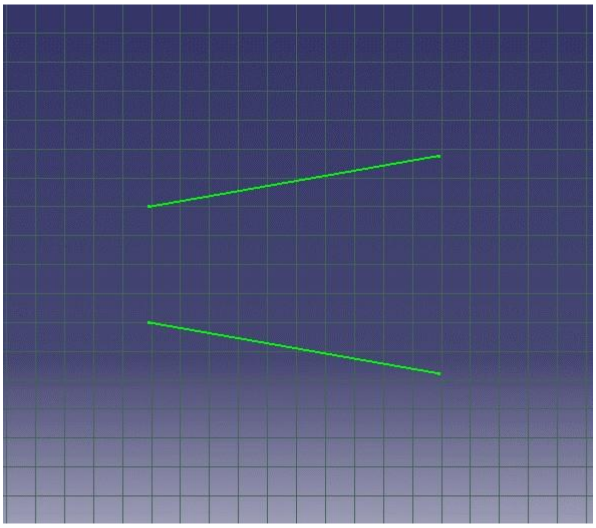


**Figure 6: Flangeless Diffuser**

### 4.2. Flangeless Diffuser inDiffuser

Theflangelessdiffuserindiffusertypeproposeddesignisillustratedinthefigure7.The nameflangelessimpliedthatthereisnoflangeprovidedhere.Thenamediffuserindiffuser self-explainedthattheiraxisareunique.Hencethenecessarydimensionsare:asabovesaid lengthofthediffuser(majororouterdiffuser)isunitmeter.Thediameterandlengthofthe innerdiffuseris50%oftheouterdiffuser.Soasderivedabovetheouterdiffuserdiameter atentranceis0.4meter,ifsotheinnerdiffuserentrancediameteris0.2meterandsimilarly theinnerdiffuserlengthis0.5meter(50%ofonemeter).Heretheinnerdiffuserservesasa splitter.Thepurposeofthesplitteristoavoidthecollapseofthepressurefieldbyshifting itsvortexfrominsideofthediffuser.Hencethesplitterdiffuserkeepsthevortexawaythe diffuserthatisonitsbacksideofmaindiffuserandalsoavoidingtheflowseparationinside thediffuser.Heretheexpansionangleis$\alpha$s12$^{o}$fordiffuser,andexpansionangleis$\alpha_1$for splitter is8$^{o}$.

**FlangedDiffuser**

Thediffuserwithflangedesignisshowninthefigure8.Assaidabovethelengthofthe diffuserisunitmeter.Theotherproportionatedimensionsaretheentrancediameteris400mm or 0.4 meter. The flange height is 200 mm or 0.2 meter. The expansion angle is $\alpha$ is $12^{o}$ and flange height is 0.2 meter.

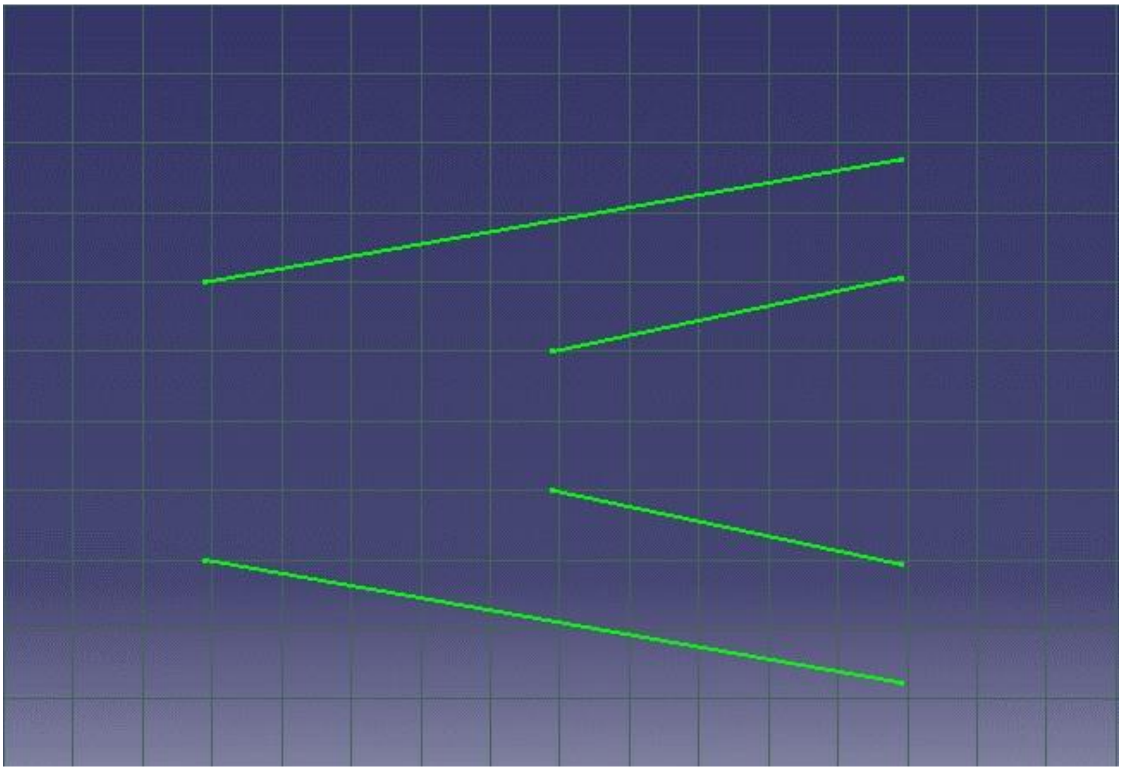


**Figure 7: Flangeless Diffuser in Diffuser**

## 4.3. BOUNDARYCONDITIONS

Figure9showsthesampleinvestigationofdefiningboundaryconditionforflangeddif- fuser.Theanalysisisconsideredaxisymmetric.Thehalfconeangleis$\varphi$heretheflangeheight h is 0.2 meter the rear end diameter is 0.5D that is 0.2meter. The air inlet heights that is slip height 9.5D. The inlet located from one side of control volume is 5D and 8.5Dbefore theoppositesideofthecontrolvolume.Thewindflowassumedhereunidirectionalthatis xdirection.

## 4.4. FLANGELESSDIFFUSER

The flangeless diffuser in diffuser case is considered here for dynamic analysis in the ANSYS Fluent 15.O. the velocity contours magnitudes were investigated. The uniform wind speed of 5 meter per second is considered. The figure 10 demonstrates the results of the velocity distribution of flangeless diffuser in diffuser case. The maximum velocity could be augmented up to 7.28 meter per second in this proposed flangeless diffuser in diffuser case.

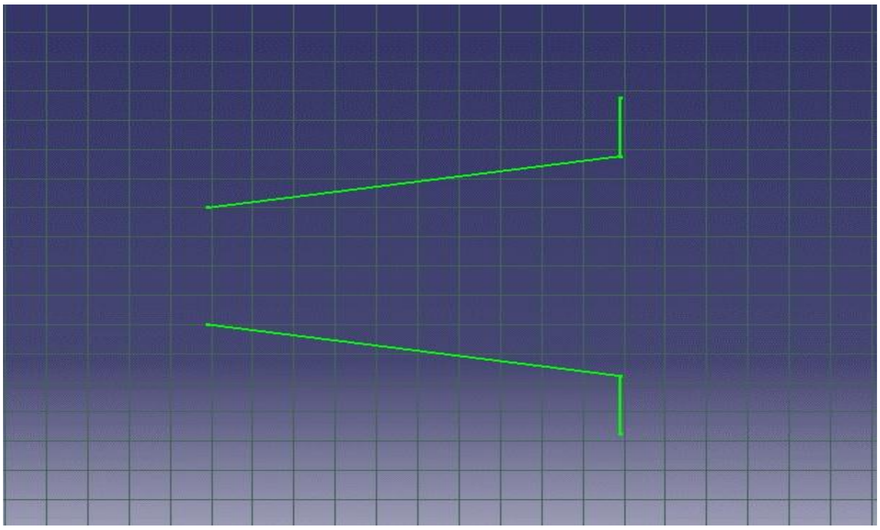


**Figure 8: Flanged Diffuser**

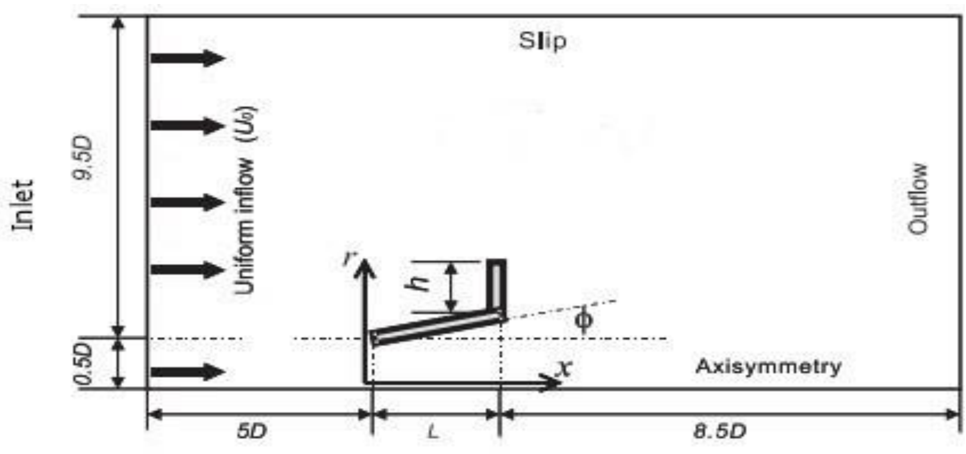



**Figure 9: Flanged diffuser standard Boundary conditions**

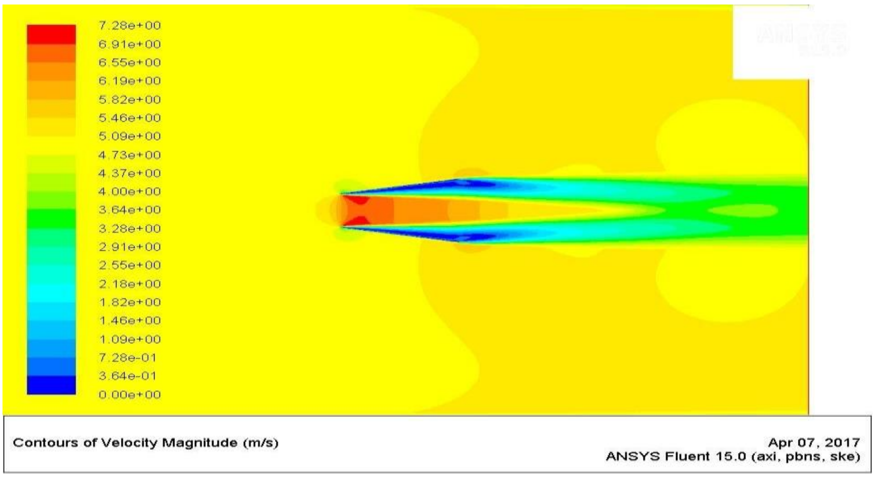



**Figure 10: Velocity distribution Results of dynamic analysis on Flangeless Diffuser**

## 4.5. DYNAMIC ANALYSIS ON FLANGELESS DIFFUSER IN DIFFUSER

**CASE**

The flangeless diffuser in diffuser case is considered here for dynamic analysis in the ANSYS Fluent 15.O. the velocity contours magnitudes were investigated. The uniform wind speed of 5 meters per second is considered. The figure 11 demonstrates the results of the velocity distribution of flangeless diffuser in diffuser case. The maximum velocity could be augmented up to 6. 70 meters per second in this proposed flangeless diffuser in diffuser case.

### 4.6. DYNAMIC ANALYSIS ON FLANGED DIFFUSERCASE

InthisanalysistheflangeddiffusercaseisconsideredfordynamicanalysisintheANSYS Fluent 15.O. The uniform wind speed of 5 meter per second is considered. The figure 12 exhibits the velocity distribution result of dynamic analysis on flanged diffuser for defined boundaryconditions.Itisnoticethatthemaximumaugmentedwindspeedis8.02meter per second.

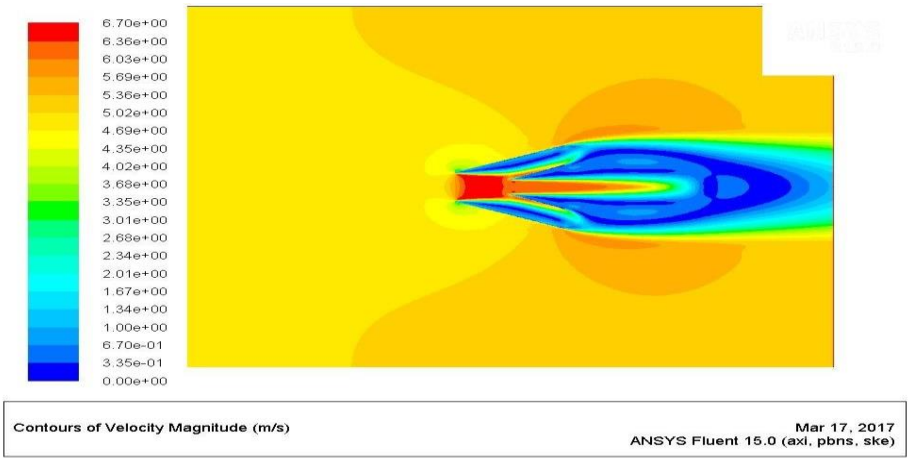



**Figure 11: Velocity distribution Results of dynamic analysis on Flangeless Diffuser in Diffuser case**

## 5. RESULTS ANDDISCUSSIONS

### *5.1.* FLANGELESSDIFFUSER

Table 1: Results of this Research

| Proposed Diffuser | Maximum augmented wind speed (m/s) | Percent of wind speed Augmented | Power output Augmentation interms of No diffuser case (P) | Best Blade Location from entrance | Comments |
|---|---|---|---|---|---|
| Flangeless Diffuser | 7.26 | If abbreviations are used in the text they should be defined in the text at first use, and a list of abbreviations shouldbe provided. | Results should be clear and concise. | Title page text... | |
| Flanged Diffuser | 8.02 | 60.34% | 3.53 P | 0.135 | Almost all layer of wing augmented so Safe and storng Safe and storng |

Thevelocityprofileisdepictedinthefigure13for,thecaseofflangelessdiffuserthelow pressure regions are it was ensured that the maximum velocity of 7.26 meter per second augmentedbymeansofflangelessdiffuser.Thewindexpandedonthroughthediffuserwith theexpenseofpressuredropthevelocityisaugmented.In the figure 14 it is clear that the velocity gets dropped after a certain distance in the normal direction. The normal distance is equally spitted in seven parts and analyzed the details of the study result depicted in the figure 15. It should be noticed in the figure 15 thatthegreenanddarkbluecoloredgraphwhichshowthestatus2/7and3/7partofthe vertical distance. It shows the augmentation profile of wind from the entry to exit. The maximumwindspeedaugmentationfromassumed5meterpersecondis7.260meterper second. This implied that the flangeless diffuser augmented wind speed by45.20%. Thebladelocation'sdistanceis0.165metertoutilizethehighspeedwing.Theproblem issuddenlyfallenofvelocityafter0.16meterdistancefromtheentrance.The accelerationis not found similar for all layers of wind below with respect to height except 2/7 and 3/7 distance from the axis.

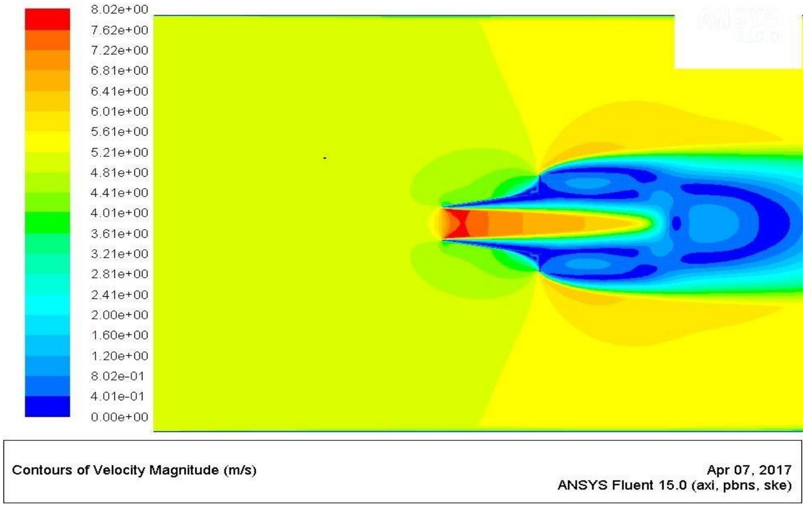



**Figure 12: Velocity distribution Results of dynamic analysis on Flanged diffuser case**

## *5.2.* FLANGELESS DIFFUSER IN DIFFUSERCASE

Thevelocitydistributionofflangelessdiffuserindiffuserisshowninthefigure15.The innerdiffuserandouterdiffuservelocitydistributionprofilesshowclearlyinthefigure16. Theaxiallyvelocityaugmentationisfoundgood. Buttheinnerdiffuserreducedthesizeof thediffuserandhencethenetaugmentationisdiminishedthantheflangelessdiffusercase. The velocity augmentation region continues at inner diffuser. The maximum wind speed observed that 6.696 meter per second. That is 33.99% wind speed is augmented by this flangeless diffuser and diffusersetup.Thefigure16showsthatthevelocityaugmentedbybothdiffusers.Thedottedlinesshow thevelocityaugmentationwithrespecttodifferentlayersinnormaldirections.Similarly,the solid lines show the splitter diffuser augmentation. As expected the splitter continuously augment the wingthroughout its length,

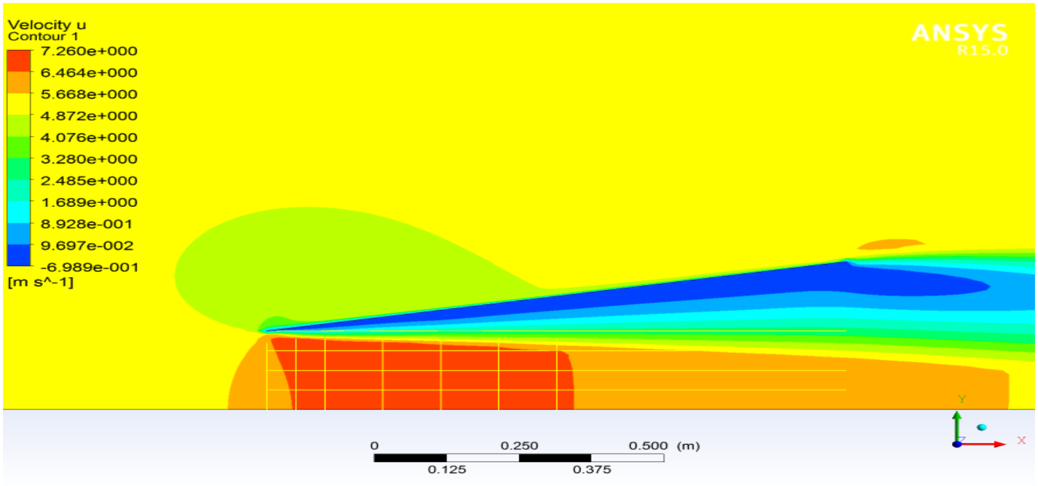



**Figure 13: The Results of Linear Velocity distribution for flangeless diffuser case**

Thiscasetobeenrichedbysuitableanalysisinfuturestudies.At0.135-meterdistancefrom theentranceistheoptimallocationofthebladeinthiscasetoutilizeaugmentedmaximum the velocity to convert the wind power to mechanical power. The wind blow at all layers, are get augmented in terms of velocity well. The pattern of all layers found uniform. The splitterdiffuserisalsosupportedwelltoaugmentthevelocityofwind.Ultimatelyalllayers the wind blowis augmented in terms of velocity. But sudden fall of velocity after 0.135 meter is noticed for alllayers.

## *5.3.* Linear Velocity results on FlangedDiffuser

Thefigure17showsthevelocitydistributionofflangeddiffusercase.Thevelocityaugmentation is found gradually improved as well higher than the flangeless diffuser as well asflangelessdiffuserindiffusercases.Themaximumvelocityof8.017meterpersecondis observed.Thatisamaximumof60.34%windspeedisaugmentedbymeansofthisflanged diffuser.Theuniformpatternisachievedforboththeflangediffuserheightsonlyextremelayers likeexcept10/12,11/12and12/12augmentationisgraduallyimproved.Theflangeddiffuser ensuredtheproperwindspeedaugmentationthantheflangelessdiffuseraswellasflangelessdiffuserindiffuserc ases.

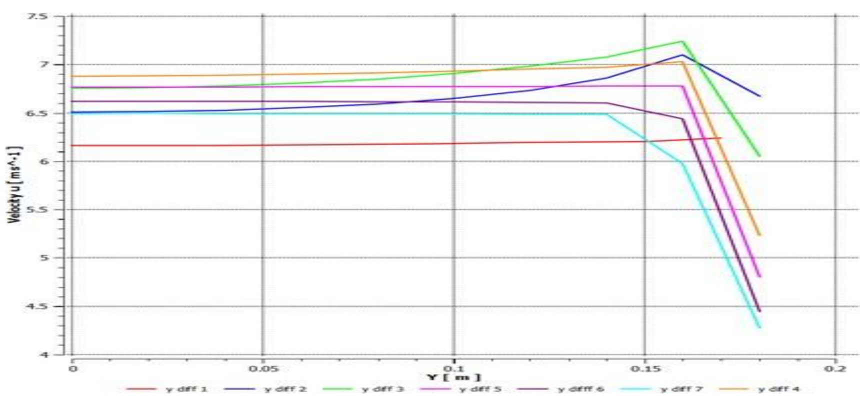



**Figure 14: Linear Velocity distribution along the normal direction for flangeless diffuser case.**

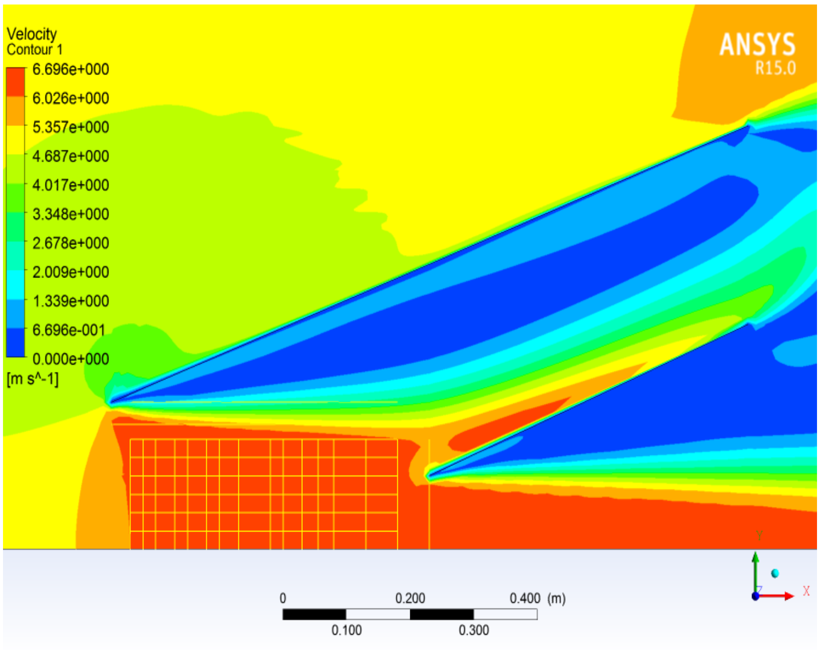



**Figure 15: Results of Linear Velocity distribution for flangeless diffuser in Diffuser**

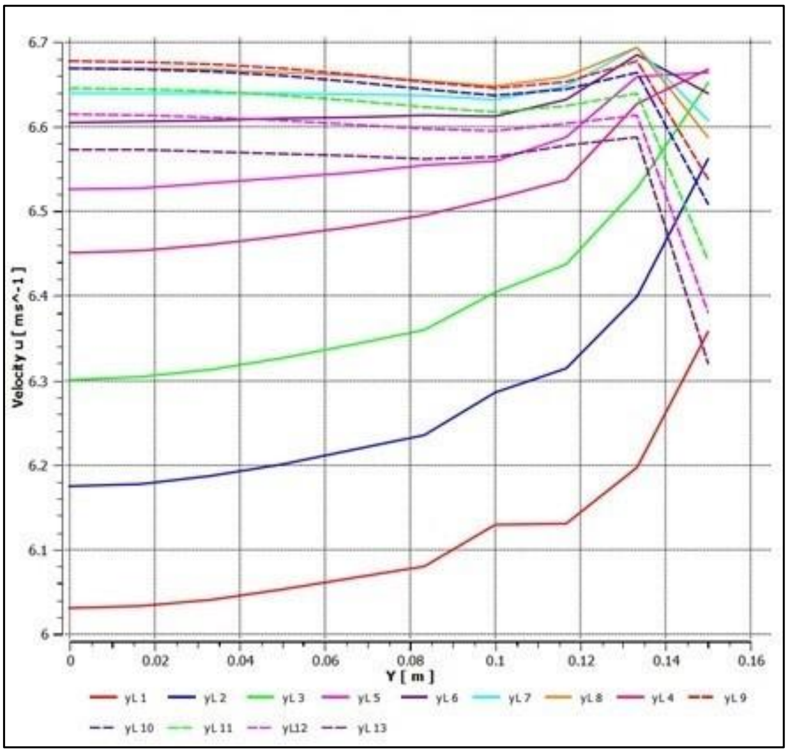



**Figure 16: Linear Velocity distribution along the normal direction for flangeless diffuser in diffuser case.**

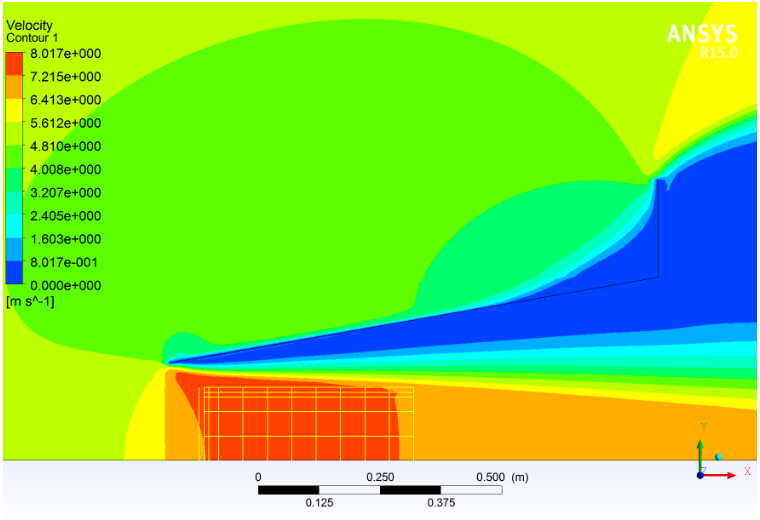



**Figure 17: Linear Velocity Distribution results on Flanged Diffuser case**

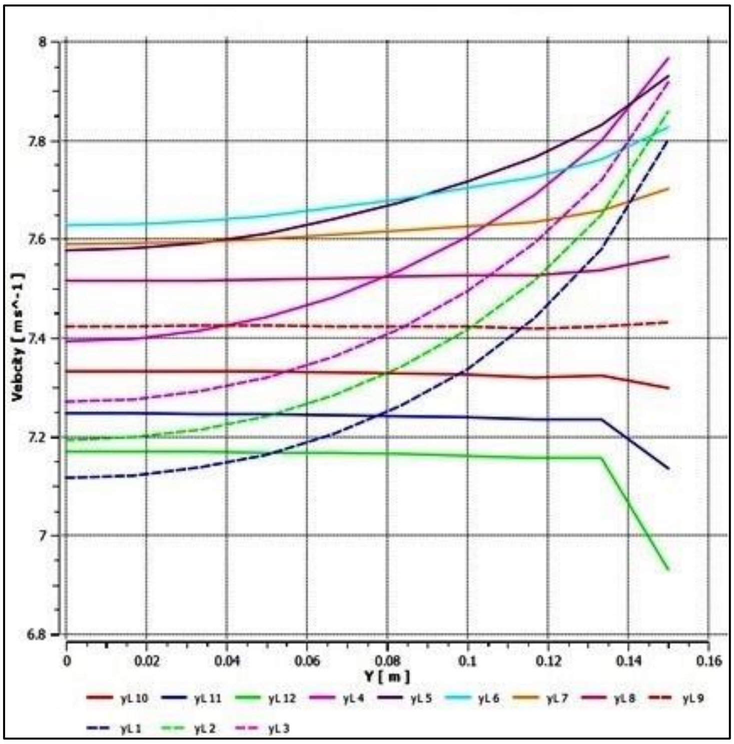



**Figure 18: Linear Velocity distribution along the normal direction for flanged diffuser case.**

Thenetwindspeedaugmentationalsofoundgood,safeandhigh comparingwithflangelessdiffusercases.Hencetheoptimalbladelocationforthiscaseis0.135 meter.

## 6. Conclusion

The DAWT is the miniaturization of a conventional bare wind turbine with the same output.Butthewindturbinesarelimitedwithbetslaw.Asitavoidsthesomanyaccidents andaddedadvantagesthisstudyisconsideredintheviewofenhancingthediffuserdesign. The conventional flangeless diffuser is considered in comparing the performance ofproposed designs. The flangeless diffuser in diffuser design and flanged diffuser designs are proposed. The experimentations numerically investigated the wind speedaugmentation.The results are classified and consolidated in the below tableIt is clear that the proposed designs are safe. For the further research planned that optimizingtheflangeheightfortheflangeddiffusertomaximizeitsperformance.Incaseof theflangelessdiffuserindiffusercase,itisplannedthattheparameterstobeoptimizedto maximize itsoutput.

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