# Analysis of Different Geometrical Impacts on Wind Turbine Blades

**N. Aravindhan, Chidambaranathan Bibin, S. Murali, M. Marimuthu, Siddi Harsha Vardhan, and Santhosh Varma**

**Abstract** Renewable power production is getting advancement as an alternative to conventional type power generation. The design of wind turbine blades getting advanced to be efficient, further it needs to exhibit lightweight, durability, high fatigue strength, damage tolerance, the potential of recycling, and stiffness. A lot of efforts were made to upsurge the effectiveness of the wind turbine blades like adding triplets at the edges, biplane blades, blades with moving surfaces. In this work, we tried three different methods for validating the performance of the blades by inducing a hole near the tip of the blades, a material reduction in the tip of the blades with the standard profile of NACA 4415. The results indicated that the standard profile performed better compared to the modified profiles as the velocity at the tip decreases and the pressure on the tip of the blades increased drastically.

**Keywords** Wind turbine blades · Triplets · Biplane · Hole · Material reduction

## 1 Introduction

The minimal effort, proficiency, consistency, and wide accessibility, wind energy has arisen as perhaps the most remarkable sustainable power source lately. In the performance of wind turbines, blades are a vital part. An optimal design of small-scale blades can easily outperform a shape that can outperform the unoptimized large-scale blades [1]. Ansal Muhammed et al. studied the performance of wind turbine blades made of various materials, including the AW 106 Epoxy/E-Glass fiber/nano clay Composite. They examined the viability of using nanocomposites in wind turbine blades at different working conditions [2]. Blades made by hand lay-up, which includes mixing various percentages of Montmorillonite nano clay into an AW 106 Epoxy/E-Glass fiber composite, are stronger. A comparative analysis of the proposed four materials blades suggests that the composite with 1% Montmorillonite

---

N. Aravindhan (✉) · C. Bibin · S. Murali · M. Marimuthu · S. H. Vardhan · S. Varma
Department of Mechanical Engineering, RMK College of Engineering and Technology, Puduvoyal, Tiruvallur 601206, India
e-mail: aravindhn25389@gmail.com

V. Edwin Geo and F. Aloui (eds.), *Energy and Exergy for Sustainable and Clean Environment, Volume 2*, Green Energy and Technology,
https://doi.org/10.1007/978-981-16-8274-2_4

had exhibited higher tensile stress with optimum hardness comparing other compositions [3]. The researchers investigated the properties of regular fiber-supported polymer composites in wind turbines, with different approaches and different compositions. They identified that the normal fiber built compositions are exciting good mechanical properties and will be biodegradable [4].

## 2 Different Shaped Edges for Improving the Performance of Wind Turbine

Pengfei Li et al. made a mathematical investigation of lightning connection to wind turbine edge. They proposed a technique that exploits electrostatic recreation to inspect the conception of the line lightning connection qualities of wind turbine sharp edges [5]. The lightning association normal for a turbine cutting edge and a descending pioneer is examined utilizing a three-dimensional electromagnetic recreation dependent on the limited component measure. Our recreations show that the weakest territory for lightning strikes on a breeze turbine cutting edge is inside 6 m of the tip, with the initial 1 m being especially helpless as shown in Fig. 1 [6].

Shi-Zheng et al. generated a high-devotion dimensional decrease model of composite breeze sharp edge by the variational asymptotic multistage strategy. The thermoplastic variational articulation of a three-dimensional composite breeze cutting edge was developed by utilizing the construction's intrinsic little boundaries, the thermoplastic energy utilitarian was then asymptotically extended to a succession

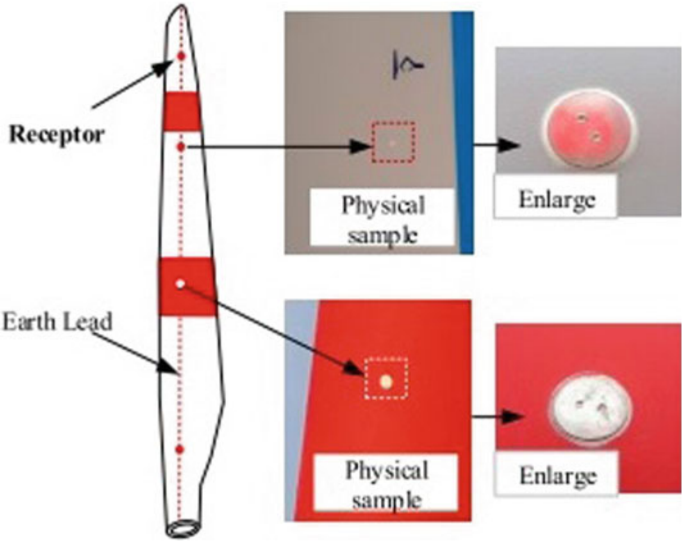


**Fig. 1** Enlargement of receptors for improving the blade efficiency [6]

of 2D energies. The proposed setup generated the robust movement of blades and the loads are disturbed in all segments [7].

Bhupinder Singh et al. generated a wind turbine sharp edge idea for inducing a low rotational velocity at variable rates with various turning points utilizing Q-Blade programming. The edge component energy model was utilized to assess the lift, drag, just as pressing factor coefficients of air profiles utilizing QBlade programming. Two optimal profiles were identified for the conditions on which the NACA0012 performed better comparing the NACA008, due to the expanded harmony thickness [8]. Suresh et al. formulated a little even pivot wind turbine for rustic applications with low wind speeds. They proposed that the force coefficient (Cp) fluctuated for all aerofoils chosen comparable to the Tip Speed Proportion (k).

As shown in Fig. 2, Mohammad et al. [9] attempted mechanical recycling and reusing of life-ended wind turbine blades. They used 3D printing to regenerate the model and reuse the useful constituents of scrap cutting edges in a Melded Fiber Manufacture (FFF) measure to improve the piece edges' mechanical properties.

Nachtane et al. developed another hydrofoil idea for marine current turbines and led a hydrodynamic execution test on it. They formulated a numerical investigation on another hydrofoil for marine flow turbines that were fabricated and tried under submerged conditions. The XFLR5 code and QBlade, an Edge Component Energy solver with a sharp edge configuration include, is utilized to assemble the turbine edge. The performance is simulated in CFD and the results indicated that the proposed edge is capable of an undeniable degree of execution [10].

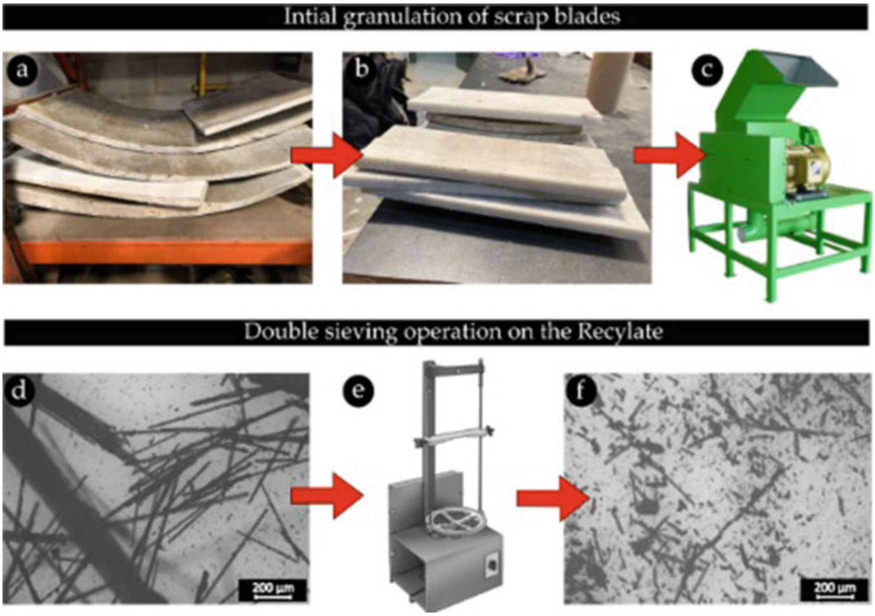


Fig. 2 Recycling of wind turbine blades [9]

Ajay et al. reviewed the wind turbine analysis of blades for improving the theoretical and numerical efficiency of blades. The optimal modification of the angle of attack will improve the aerodynamic efficiency. They analyzed the various loading forces under dynamic operating conditions on a wind turbine are presented. The power and efficiency of small-scale wind turbines are evaluated under different velocities [2].

Roadman et al. proposed the thermoplastic composite breeze turbine edges. The edges are made as joining of thermoplastic sap made breeze turbine cutting edges. The fabrication complexity is taken over by thermoplastic resin. It overcame the conventional welding methodology to join two edges with a greater exhibition of strength to weight ratio [11].

Xin Shen designed a little wind turbine with adaptable cutting edges. They mathematically examined the acceptability of transforming bladed turbine. The flexible edges have improved the efficiency of the turbine considerably [12]. The Composite rotor cutting edge aeroelastic was developed recently. In which the composite edge with a run-of-the-mill profile with a high degree of angle of blades for a parametric demonstrating measure [13].

Schubel et al. analyzed the mathematical performance of rotor-cutting edge yield for a little flat pivot wind turbine. It explores the presentation of two kinds of level hub wind turbine edges, one of which was displayed utilizing the sharp edge component force hypothesis for improving the performance of wind turbine blades [14].

Raj Oak et al. the adaptable breeze turbine sharp edges streamlines the flow and aeroelastic properties under incidental insecure inflows. The aeroelastic model is dependent on the mathematically cutting edge component energy framework. The streamlined and Aeroelastic properties of the NREL 5WM adaptable breeze turbine edge are concentrated under intermittent temperamental inflow the results show that as the cutting edge passes by the pinnacle, the Breeze shear prompts huge varieties in the fold diversion and yaw second, while the Pinnacle shadow impact makes intense changes in the, push energy, and yield strength [15].

## 3 Innovative Blade Shapes for Improving the Efficiency

Salimipour et al. proposed a moving surface of a seaward wind turbine fan which improves mathematically as shown in Fig. 3. The blade segmented as a stream control gadget, the surface has thrived with a streaming surface. The impacts of position and speed of the moving surface on the stream attributes were researched to accomplish the best mechanical effectiveness of the airfoil at each approach. A computational liquid elements method was utilized to reproduce the stream. 30, 62, 131, and 152% increment in proficiency, separately [16].

Chiu et al. developed a biplane wind turbine with sharp edges which improved underlying proficiency, streamlined execution, and diminished streamlined burdens. Interestingly, the impact of these factors on cutting-edge mass is evaluated for identifying the mass of biplane wind turbine edges. The weight reserve funds are generous,

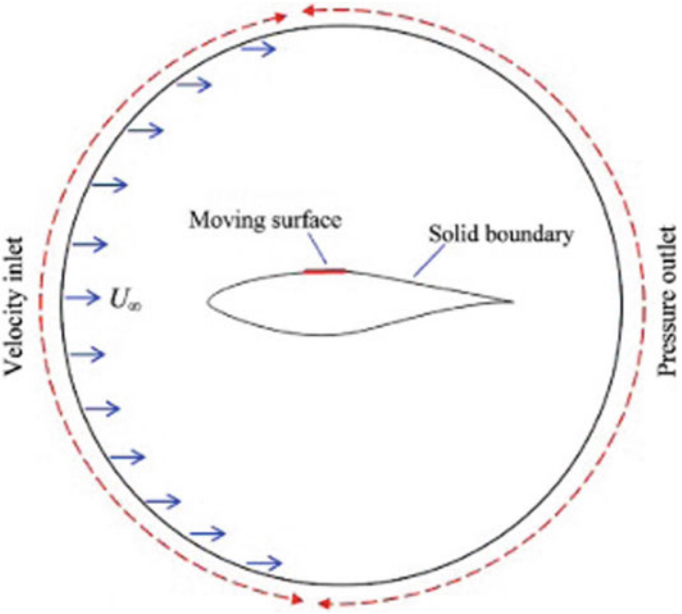


**Fig. 3** Moving surface blades [16]

with ideal biplane sharp edges being more than 45% lighter than a comparably streamlined monoplane edge. This is to a great extent because of the biplane cutting edges' better opposition than fold shrewd avoidance when contrasted with monoplane edges, considering altogether less fight cap material to be utilized. Biplane edges have additionally been demonstrated to be more impervious to consumption in Fig. 4 [17].

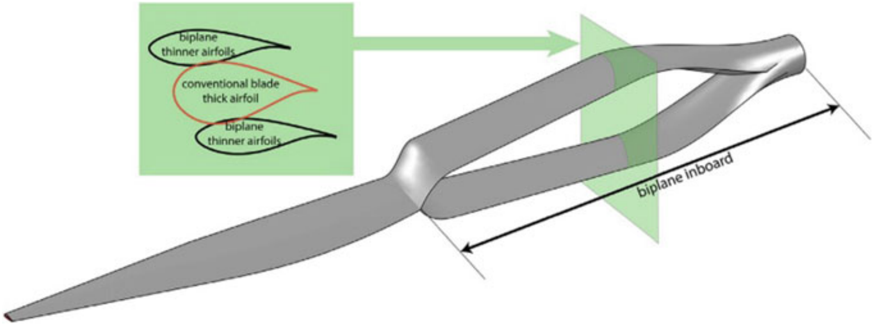


**Fig. 4** Blades with biplane edges [17]

## 4 Performance Analysis of Composite Blades to Improve Their Characteristics

Ganesh R Kalagi the investigated mechanical properties of common fiber built-up polymer composite materials for wind turbine edges. They reported the utilization of regular fiber-supported polymer composites as their properties, constituents, producing innovations, and imperfections. The best illustration of a sustainable power source is wind energy. In nature, the materials utilized in wind turbines are likewise non-biodegradable [17]. An adaptable multibody approach was utilized to advance the state of low-speed wind turbine edges.

Monteiro [18] performed a wind tunnel testing with a wind turbine blade of length 1.2 m and compared it with numerical results generated by Q Blade element momentum codes. The experiments were conducted at 2 X 2 m open chamber closed circuit for a wind speed of 3–8 m/s. They calculated the rotation of the shaft with varying tip speed ratios. The wind speed has a significant impact on the power coefficient as speed increases power coefficient decreases.

Imraan et al. [19] evaluated the performance of telescopic blade wind turbines with a prototype of chord length 0.6. Under different wind speeds, they have measured the performance of rotor speed, shaft twisting force, and thrust. The 20% of the extended step-change in the blade chord has resulted in a reduction of the power coefficient. But using telescopic blades has overcome the power losses for all blade extensions. The plotted correlations for both experimental and numerical results have acted as a gap for bridging the losses due to the step-change in the chord.

Usabiaga et al. [20] presented an automated procedure for principal stress and strain analysis on wind turbine blades at different locations. They performed a two-and-a-half dimensional aeroelastic analysis and identified the pressure distribution due to variations on wind turbine loading.

Le et al. [21] carried out wind tunnel experiments for predicting the behavior of wind turbines under abnormal conditions. They examined velocity measurements at multiple heights with the flow device capable of generating a gust of a non-stationary outflow. The experiments are carried out on a tall building model and compared with numerical results. They indicate that a multi-blade flow device is capable of generating the gust from present wind turbines with huge modifications to the present wind turbines.

Guo et al. [22] developed vertical axis wind turbine blades with an inclined pitch axis. The blade performance was measured under low speeds wind tunnel. They identified that the inclination of 8° produced maximum power coefficients at a wind speed of 7.28–9.16 m/s. Beyond the fold angle of 8° in any direction the maximum coefficient of power decreases. The blade pitch angle influences the power output more comparing the blade diameter and rotor area.

## 5 Role of Profiles on Wind Turbine Blades

Hirahara et al. [23] developed a unique small-scale turbine with a 500 mm rotor diameter for functioning in the urban environment. They used the National Aeronautics and Space Administration (NACA) 2404 cross-sectional profile for turbine blades. They visualized the airflow around the turbine with particle flow velocimetry. They have shown better performance when operating under the range of wind speed 8 m/s to 12 m/s.

The three blades setup is proved to be more efficient with high rotational speed for small-scale wind turbines even at a speed range of 2.5–3.5 m/s. Pambudi et al. [24] developed a nozzle lens to improve the rotational speed of the rotor. And it's evident that from the experimental results the larger diameter lens increased the wind speed which in turn increased the power output also.

## 6 Proposed Modification on Wind Turbine Blades

The three models have been integrated and analyzed for better performance. The NACA 4415 non-twisted profile is selected due to its ability to exhibit a high speed ratio at low speeds and three models proposed are described as follows.

Model 1:Standard NACA 4415 Profile

Model 2:Standard NACA 4415 Profile with the hole at the tip

Model 3:Standard NACA 4415 Profile with material reduction at the tip

## 7 Results and Discussion

### *7.1 Performance of Standard National Advisory Committee for Aeronautics (NACA) 4415*

The performance of standard NACA 4415 is shown in Fig. 5. We have chosen to plot the velocity contour of NACA 4415 at a wind speed of 12 m/s. The results interpolated that the velocity at the tip reduces drastically within the range of 6–9 m/s. The power coefficient will not be as expected due to the reduction in the tip speed ratio. The results are intercepted in the following Fig. 6.

Though the velocity contour profile has been equivalent on the blade throughout the tip shows the major change. It creates a lot of effects as the tip acts as the major source for deciding the Power coefficient value. The pressure analysis of sure NACA 4415 was performed under the pressure of 101.325 Pa. The results interpolated that the pressure at the tip increases drastically within the range of 25–43 Pa. The power

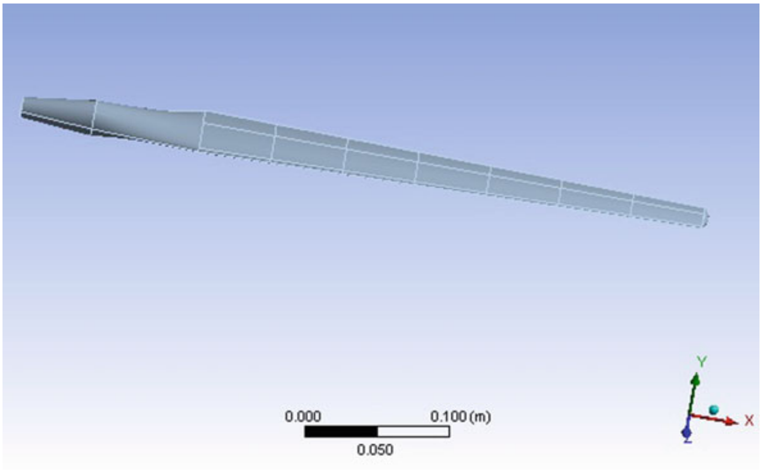
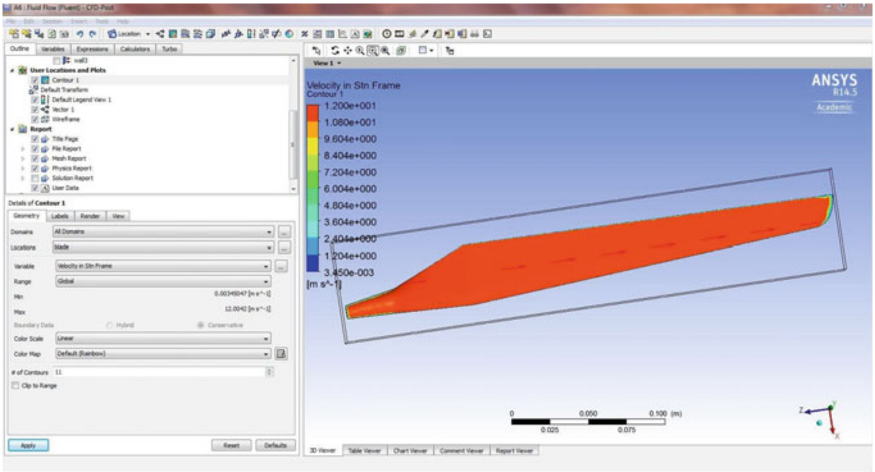


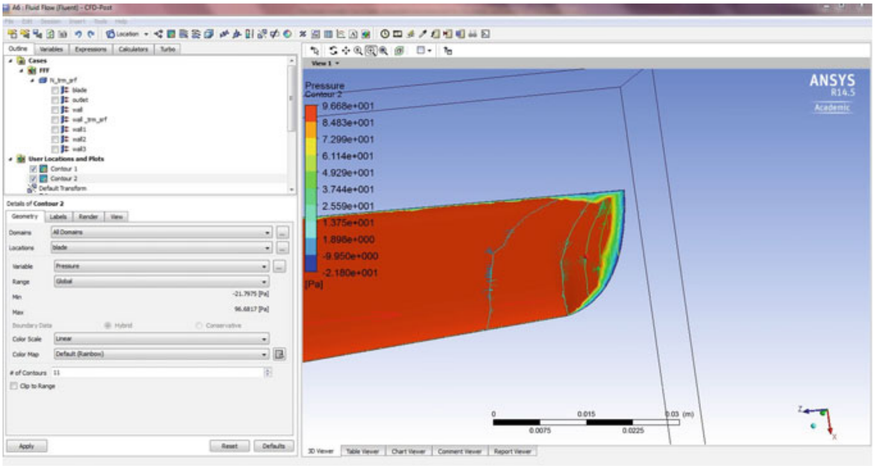
**Fig. 5** NACA 4415 profile



Domains: All Domains
Locations: blade
Variable: Velocity in Stn Frame
Range: Global
Min: 0.00345047 [m s^-1]
Max: 12.0042 [m s^-1]
Boundary Data: ○ Hybrid ● Conservative
Color Scale: Linear
Color Map: Default (Rainbow)
# of Contours: 11
☐ Clip to Range

**Fig. 6** NACA 4415 velocity contour profile

coefficient will not be as expected due to the reduction in the tip speed ratio. The results are intercepted in the following Fig. 7.



Details of **Contour 2**

Geometry | Labels | Render | View

Domains: All Domains
Locations: blade
Variable: Pressure
Range: Global
Min: -21.7975 [Pa]
Max: 96.6817 [Pa]
Boundary Data: ● Hybrid ○ Conservative
Color Scale: Linear
Color Map: Default (Rainbow)
# of Contours: 11
☐ Clip to Range

**Fig. 7** Pressure contour profile of standard NACA 4415

## *7.2 Standard NACA 4415 Profile with the Hole at the Tip*

A hole is made behind the tip of the blade for reducing the material on that tip. As same as the standard model we analyzed the velocity contour of NACA 4415 Profile with the hole at the tip under wind speed of 12 m/s. The velocity analysis of NACA 4415 was performed under wind speed of 12 m/s. The results interpolated that the velocity at the tip reduces drastically within the range of 3–7 m/s. The power coefficient will not be as expected due to the reduction in the tip speed ratio. The results are intercepted in the following Fig. 8. The hole at the tip on the blade for a reduction on a velocity on the blade. Though the velocity contour profile has been equivalent on the blade throughout the tip shows the major change. It creates a lot of effects as the tip acts as the major source for deciding the Power coefficient value. The pressure analysis of sure NACA 4415 Profile with the hole at the tip performed under the pressure of 101.325 Pa. The results interpolated that the pressure at the tip increases drastically within the range of 25–80 Pa. The power coefficient will not be as expected due to the reduction in the tip speed ratio. The results are intercepted in the following Fig. 9.

## *7.3 Standard NACA 4415 Profile with Material Reduction at the Tip*

As a part of our new approach, we tried to have a material reduction at the tip, and its velocity contour of NACA 4415 Profile with material reduction at the tip is analyzed under the same constraints as shown in Fig. 10. The results interpolated

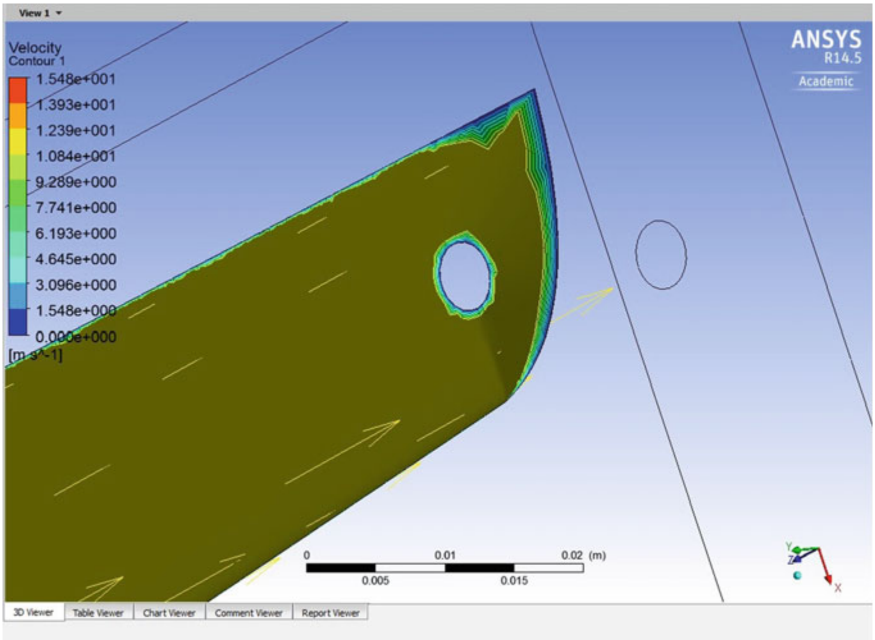
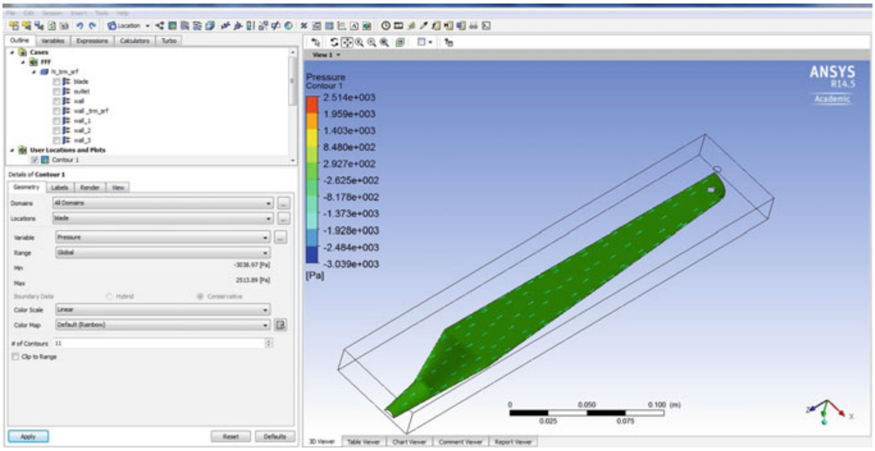


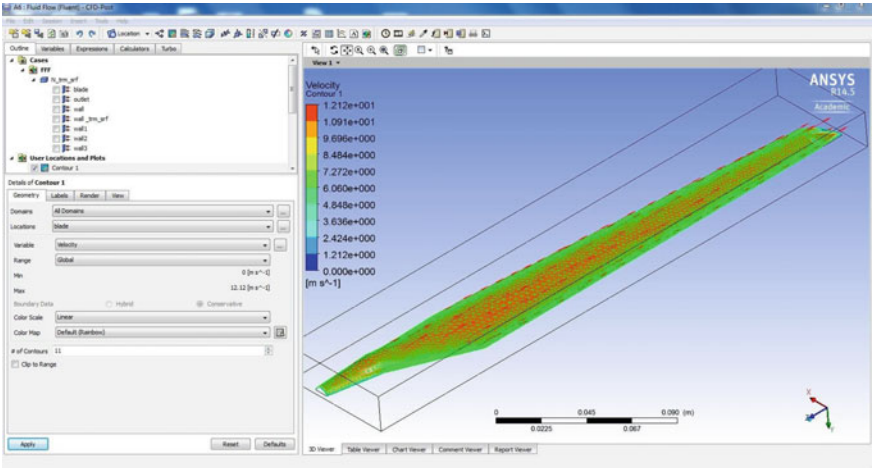
**Fig. 8** Blade with the hole at the tip



Details of **Contour 1**

Domains: All Domains
Locations: blade
Variable: Pressure
Range: Global
Min: -3038.97 [Pa]
Max: 2513.89 [Pa]
Boundary Data: ○ Hybrid ● Conservative
Color Scale: Linear
Color Map: Default (Rainbow)
# of Contours: 11
☐ Clip to Range

**Fig. 9** Pressure contour profile of NACA 4415



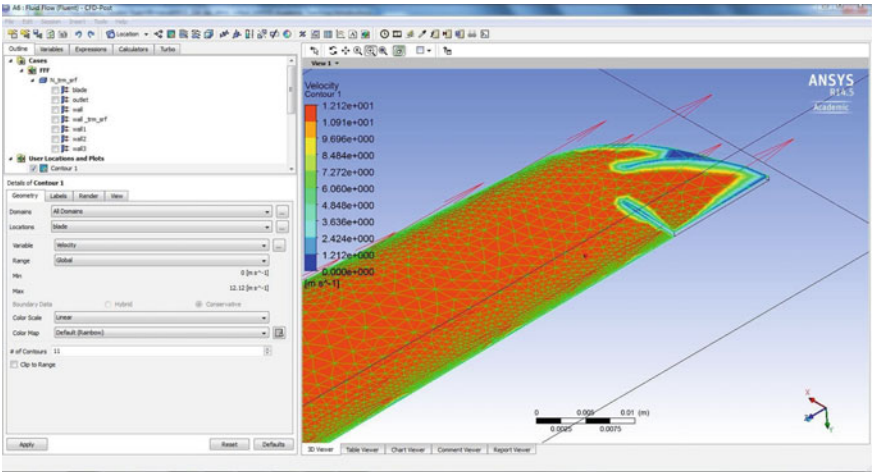
A6 : Fluid Flow (Fluent) - CFD-Post

Details of Contour 1

Domains: All Domains
Locations: blade
Variable: Velocity
Range: Global
Min: 0 [m s^-1]
Max: 12.12 [m s^-1]
Boundary Data: ○ Hybrid ● Conservative
Color Scale: Linear
Color Map: Default (Rainbow)
# of Contours: 11
☐ Clip to Range

**Fig. 10** Velocity contour analysis for model 3

that the velocity at the tip reduces drastically within the range of 3–8 m/s. The power coefficient will not be as expected due to the reduction in the tip speed ratio. The pressure analysis of sure NACA 4415 Profile with the material removed at the tip performed under the pressure of 46–96 Pa as shown in Fig. 11. The results interpolated that the pressure at the tip increases drastically within the range of Pascal in Fig. 12. The power coefficient will not be as expected due to the reduction in the tip speed ratio. The results are intercepted in the following Fig. 13.

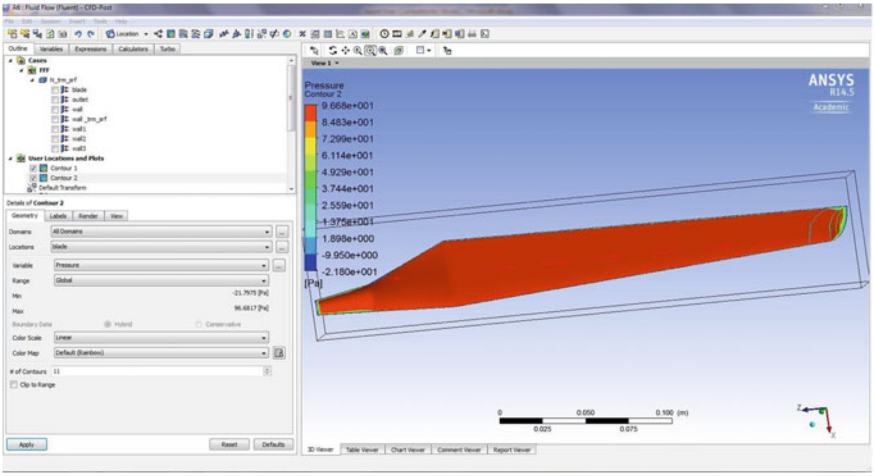


A6 : Fluid Flow (Fluent) - CFD-Post

Details of Contour 1

Domains: All Domains
Locations: blade
Variable: Velocity
Range: Global
Min: 0 [m s^-1]
Max: 12.12 [m s^-1]
Boundary Data: ○ Hybrid ● Conservative
Color Scale: Linear
Color Map: Default (Rainbow)
# of Contours: 11
☐ Clip to Range

**Fig. 11** Velocity contour NACA 4415 profile with material reduction at the tip



Details of Contour 2
Domains: All Domains
Locations: blade
Variable: Pressure
Range: Global
Min: -21.7975 [Pa]
Max: 96.6817 [Pa]
Boundary Data: ● Hybrid ○ Conservative
Color Scale: Linear
Color Map: Default (Rainbow)
# of Contours: 11
☐ Clip to Range

**Fig. 12** Pressure contour profile at the tip

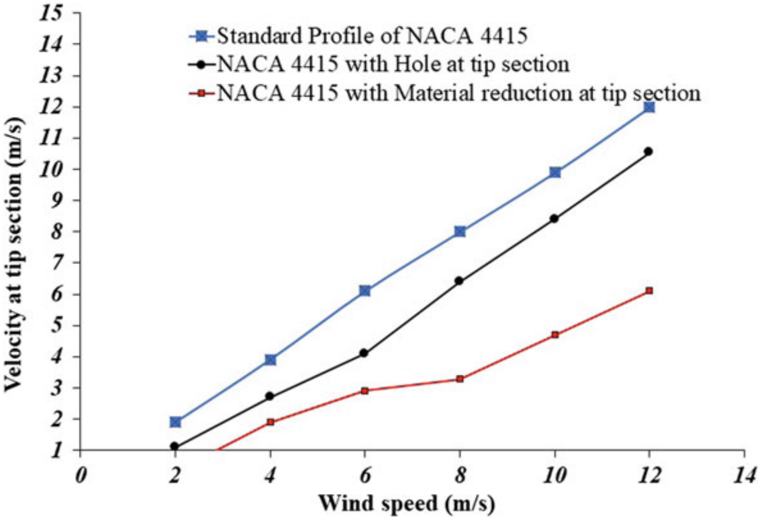


**Fig. 13** Comparative performance of NACA 4415 various profiles

The material reduction at the tip on the blade for a reduction on pressure on the blade. Though the pressure contour profile has been equivalent on the blade throughout the tip shows the major change. It creates a lot of effects as the tip acts as the major source for deciding the Power coefficient value.

## 8 Conclusion

For improving the concert of wind turbine researchers have tried a lot of pioneering approaches have employed but still, the standard forms of turbines are efficient and existing on practical usages. In this work, we tried two different approaches apart from the conventional behavior but it performed considerably low than the present turbines as shown in Fig. 13. The results indicate the velocity deceleration on modifications 1 and 2 comparing the standard profile this is mainly due to the pressure increase on the tip of the blades due to hole and material reduction on the surface of the blades.

## References

1. Tummala A, Velamati RK, Sinha DK, Indraja V, Krishna VH (2016) A review on small scale wind turbines. Renew Sustain Energy Rev 56:1351–1371. https://doi.org/10.1016/j.rser.2015.12.027
2. Ajay V, Venkateshwarlu B, Vishnu Vardhan T (2018) A review on fabrication and performance evaluation of small wind turbine blades. Int J Mech Eng Technol 9:240–265
3. Ansal Muhammed K, Ramesh Kannan C, Stalin B, Ravichandran M (2020) Experimental investigation on AW 106 Epoxy/E-Glass fiber/nano clay composite for wind turbine blade. Mater Today Proc 21:202–205. https://doi.org/10.1016/j.matpr.2019.04.221
4. Mishnaevsky L, Branner K, Petersen HN, Beauson J, McGugan M, Sørensen BF (2017) Materials for wind turbine blades: an overview. Materials (Basel) 10:1–24. https://doi.org/10.3390/ma10111285
5. Bibin C, Seenikannan P (2013) Experimental analysis of energy recovery from an internal combustion engine exhaust using rankine cycle. Adv Mater Res 768:158–163. https://doi.org/10.4028/www.scientific.net/AMR.768.158
6. Li P, Lv D, Li C, Yue X, Cao H (2019) Optimized design of wind turbine blade receptors based on electrostatic field theory. Electron 8:1–13. https://doi.org/10.3390/electronics8121418
7. Aravindhan N, Chidambaranathan B, Rokesh D, Jagadesh D, Pravin S, Ramkumar N (2020) Performance of statistical control tools in identifying the defect on plunger-a review. In: IOP conference series: materials science and engineering vol 906. https://doi.org/10.1088/1757-899X/906/1/012012
8. CEA (2020) Installed Capacity (in Mw) 29:4991–4999
9. Rahimizadeh A, Kalman J, Henri R, Fayazbakhsh K, Lessard L (2019) Recycled glass fiber composites fromwind turbine waste for 3D printing feedstock: effects of fiber content and interface on mechanical performance. Materials (Basel) 12. https://doi.org/10.3390/MA12233929
10. Nachtane M, Tarfaoui M, Saifaoui D, Rouway M (2019) Hydrodynamic performance evaluation of a new hydrofoil design for marine current turbines. Mater Today Proc 30:889–898. https://doi.org/10.1016/j.matpr.2020.04.346
11. Murray RE, Roadman J, Beach R (2019) Fusion joining of thermoplastic composite wind turbine blades: lap-shear bond characterization. Renew Energy 140:501–512. https://doi.org/10.1016/j.renene.2019.03.085
12. Shen X, Yang H, Chen J, Zhu X, Du Z (2016) Aerodynamic shape optimization of non-straight small wind turbine blades. Energ Convers Manag 119:266–278. https://doi.org/10.1016/j.enconman.2016.04.008
13. Jia L, Hao J, Hall J, Nejadkhaki HK, Wang G, Yan Y, Sun M (2021) A reinforcement learning based blade twist angle distribution searching method for optimizing wind turbine energy power. Energy 215:119148. https://doi.org/10.1016/j.energy.2020.119148

14. Schubel PJ, Crossley RJ (2012) Wind turbine blade design. Energies 5:3425–3449. https://doi.org/10.3390/en5093425
15. Ageze MB, Hu Y, Wu H (2017) Wind turbine aeroelastic modeling: basics and cutting edge trends. Int J Aerosp Eng https://doi.org/10.1155/2017/5263897
16. Salimipour E, Yazdani S (2020) Improvement of aerodynamic performance of an offshore wind turbine blade by moving surface mechanism. Ocean Eng 195:106710. https://doi.org/10.1016/j.oceaneng.2019.106710
17. Chiu PK, Roth-Johnson P, Wirz RE (2020) Optimal structural design of biplane wind turbine blades. Renew Energ 147:2440–2452. https://doi.org/10.1016/j.renene.2019.08.143
18. Monteiro JP, Silvestre MR, Piggott H, André JC (2013) Journal of Wind engineering wind tunnel testing of a horizontal axis wind turbine rotor and comparison with simulations from two blade element momentum codes. Jnl Wind Eng Ind Aerodyn 123:99–106. https://doi.org/10.1016/j.jweia.2013.09.008
19. Imraan M, Sharma RN, Flay RGJ (2013) Wind tunnel testing of a wind turbine with telescopic blades: the influence of blade extension. Energy 53:22–32. https://doi.org/10.1016/j.energy.2013.03.008
20. Usabiaga H, Vandepitte D (2018) An efficient procedure for the calculation of the stress distribution in a wind turbine blade under aerodynamic loads. 172:42–54. https://doi.org/10.1016/j.jweia.2017.11.003
21. Le V, Caracoglia L (2019) Generation and characterization of a non-stationary flow field in a small-scale wind tunnel using a multi-blade flow device. J Wind Eng Ind Aerodyn 186:1–16. https://doi.org/10.1016/j.jweia.2018.12.017
22. Guo J, Zeng P, Lei L (2019) Performance of a straight-bladed vertical axis wind turbine with inclined pitch axes by wind tunnel experiments. Energy 174:553–561. https://doi.org/10.1016/j.energy.2019.02.177
23. Hirahara H, Hossain MZ, Kawahashi M, Nonomura Y (2005) Testing basic performance of a very small wind turbine designed for multi-purposes. Renew Energ 30:1279–1297. https://doi.org/10.1016/j.renene.2004.10.009
24. Pambudi NA, Pristiandaru DL, Wijayanto DS, Sriwardani N, Rahman N, Bugis H, Wahyudi BD, Sudibyo C, Karno MW (2017) Experimental investigation of wind turbine using nozzle-lens at low wind speed condition. Energ Procedia 105:1063–1069. https://doi.org/10.1016/j.egypro.2017.03.459