Design & Fluid Flow Analysis of Monolithic Wind Turbine Blade Constructed using NACA 4424, NACA 4421 & NACA 4418 Airfoils

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Abstract— The world vision for the sustainable power source assets and its usage is expanding step by step. Thus, scientists in the territory of sustainable power source assets additionally expanded particularly in the range of wind turbines. By 2030 each significant nation of the world is a dream to use wind energy by 35% for their electrical needs. Many sorts of difficulties are confronted in the development of wind power units, for example, topology, geology, building challenges, and so on. Keeping in mind the end goal to accomplish the world vision for wind energy and to give power even to remote territories, this paper goes for building up the monolithic wind turbine blade which can be introduced in the remote zones of the world including inhabitable islands, places and in remote ranges with less population density. The modeling of monolithic wind turbine blade is done in Solidworks Part Design and the fluid flow analysis is done in Solidworks Flow Simulation.

Key words: Airfoil, Blade, CFD, Drag Coefficient, Lift Coefficient, FEA, Simulation, Wind Mill

I. INTRODUCTION

As of late, there is an exceptional ascent in the requirement for the improvement of sustainable power source advances because of the debilitating non-sustainable power sources. Therefore, every nation has its own particular commitments to the advancement of sustainable power source advances. In the territory of wind turbines, many sorts of research are occurring in the strategies to expand the efficiency and for the optimized design to introduce in practically all aspects of the world. The real complexities confronted in the wind turbine fabricating are the complexities in the design of geometry of the blade, the span of the wind turbine and determination of right topology in which they should be introduced. So the improvement and the examination for the better wind turbine blade assumes a fundamental part in the advancement of safe and better wind turbine.

In this paper the procedure for the design of the monolithic wind turbine blade and analysis it's in the real working conditions of the are detailed. The new design of monolithic wind turbine blade is done by using three standard Airfoil profiles in a single wind turbine blade design. NACA 4424, NACA 4421 and NACA 4418 are the standard profiles used in the design of the monolithic wind turbine blade in this paper.

The monolithic wind turbine blade workings are similar to the wings of an aircraft. The lift on the wind turbine blade is caused due to the pressure difference on two sides of the blade. This lift force makes the wind turbine blade to rotate. A horizontal axis monolithic wind turbine blade is designed in this paper.

II. AIRFOIL DETAILS AND CHARACTERISTICS

The details and performance characteristics of the NACA 4424, NACA 4421 and NACA 4418 airfoils are shown in Table 1.

Details	NACA 4424	NACA 4421	NACA 4418
Thickness	24.0%	21.0%	18.0%
Camber	4.0%	4.0%	4.0%
Trailing edge angle	27.0^o	31.3^o	27.0^o
Lower flatness	3.2%	4.6%	5.9%
Leading edge radius	5.6%	4.8%	4.0%
Efficiency	36.1	34.9	33.2
Max C_L	2.255	1.285	1.187
Max C_L angle	15.0	15.0	14.0
Max L/D	95.628	86.297	79.747
Max L/D angle	-0.5	-0.5	-0.5
Max L/D C_L	0.521	0.504	0.488
Stall angle	-0.5	-0.5	-0.5
Zero-lift angle	-5.0	-4.5	-4.0

Table 1:

III. GEOMETRY OF MONOLITHIC WIND TURBINE BLADE

The isometric view of the monolithic wind turbine blade designed in Solidworks Part Design is shown in Figure 1 and the wireframe model is shown in Figure 2.

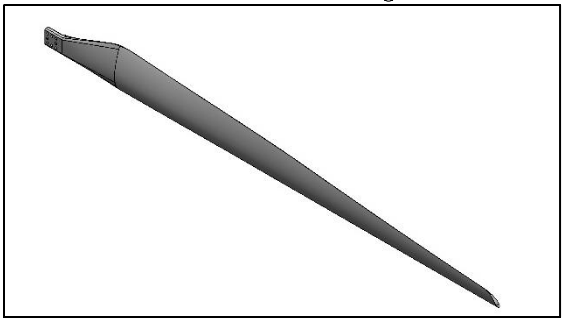


Fig. 1: Isometric view of Monolithic Wind Turbine Blade

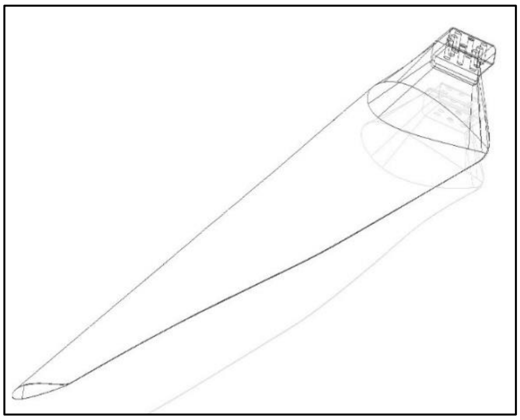


Fig. 2: Wireframe model of Monolithic Wind Turbine Blade

IV. METHODOLOGY

The model which is created in Solidworks Part Design is analyzed in Solidworks Flow Simulation. The CFD analysis procedure follows the following steps:

A. *Grid generation:*

Structured cartesian immersed – body mesh which consists of solid cells, fluid cells, and partial cells are used in the generation of grids for the model. The solid cells and fluid cells contain solid and fluid respectively. The partial cells contain both solid and fluid. Cuboid shaped cells are used in the meshing. The respective cells count of monolithic wind turbine blade is shown in Table 2.

Model	Fluid cells	Solid cells	Partial cells	Total cells
Monolithic Wind Turbine Blade	349307	4603	3475	357385

Table 2:

B. *Flow conditions:*

The different initial flow conditions and boundary flow conditions for wind turbine blade is shown in Table 3.

Parameters	Wind Turbine Blade
Solver	Eulerian Finite Difference (EFD)
Turbulence model	**k – ε**
Velocity (m/s)	20
Humidity	50%
Angle of attack (degree)	15°
Initial pressure (Pa)	101325
Initial temperature(K)	293.20

Table 3:

C. *The meshing of the model:*

The model is meshed along with the global domain in the Grid generation step only. Finite element meshing is used in the meshing of the monolithic wind turbine blade. The mesh generated on the model is shown in Figure 3.

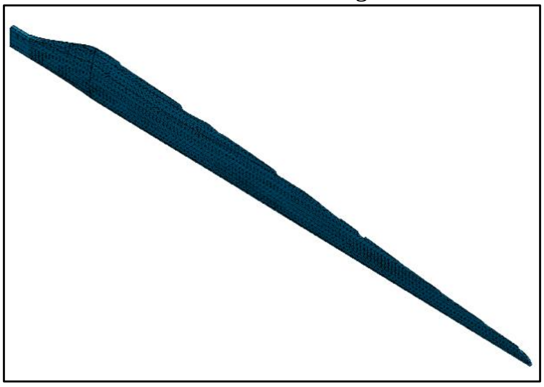


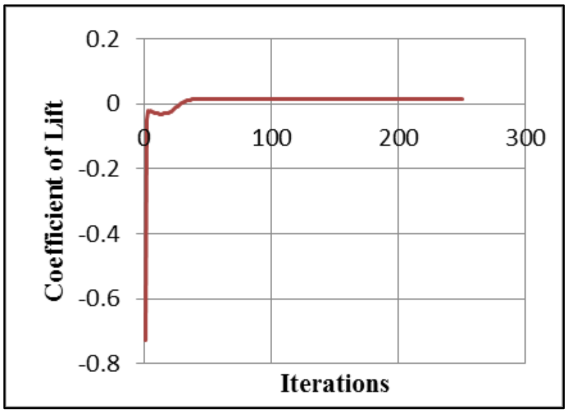
Fig. 3: Monolithic Wind Turbine blade mesh

V. RESULTS

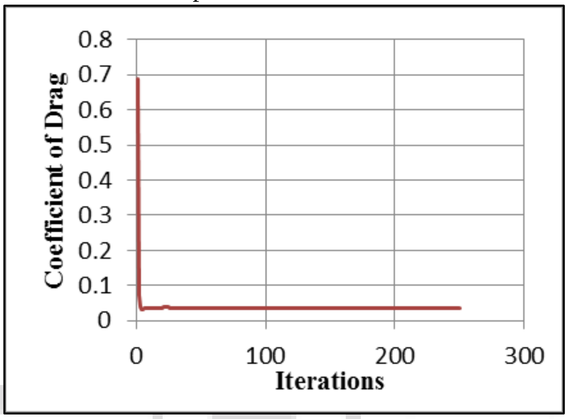
The CFD analysis on the monolithic wind turbine blade gives the results such as drag coefficient, lift coefficient, drag forces and lift forces. The values of different results are plotted against iterations and are shown in graphs as follows:

A. *Monolithic Wind Turbine Blade:*

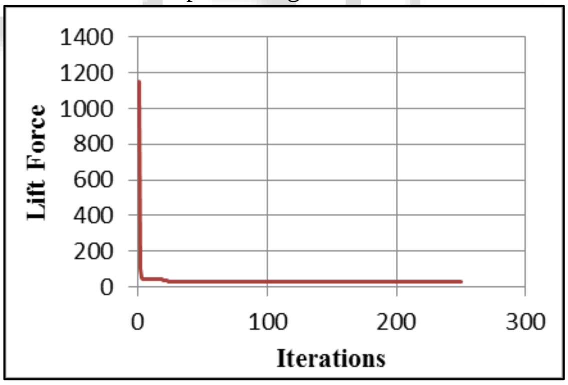
The monolithic wind turbine blade designed operates only at subsonic speeds. The vector plots are given below for different iterations.



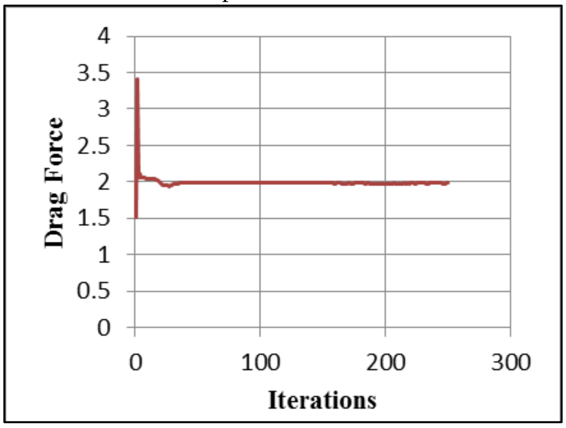
Graph 1: Lift coefficient



Graph 2: Drag coefficient



Graph 3: Lift force



Graph 4: Drag force

Name	Unit	Value
Lift coefficient (C_L)	No units	0.0131363
Drag coefficient (C_D)	No units	0.0356459
C_L/C_D	No units	0.3685233
Lift Force	N	31.430
Drag Force	N	1.980

Table 4: gives the average values for all iterations.

In the Figure 4 surface pressure distribution is shown and initial velocity contours at 7th iteration and final velocity contours at 250th iteration are shown in Figure 5 and Figure 6.

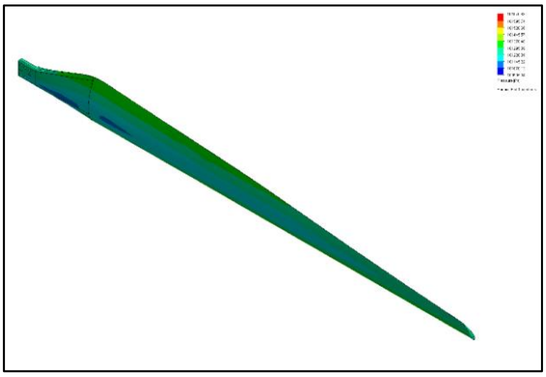


Fig. 4: Surface Pressure Distribution

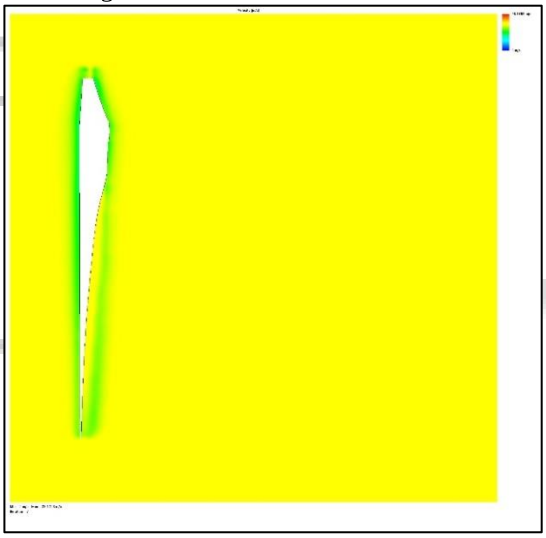


Fig. 5: Velocity Contour at 7th iteration

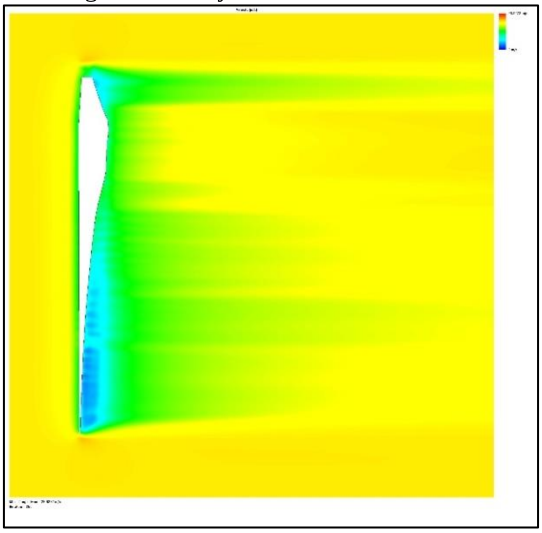


Fig. 6: Velocity Contour at 250th iteration

The cut plots show the variation of pressure and velocity along profile curves of the monolithic wind turbine blade.

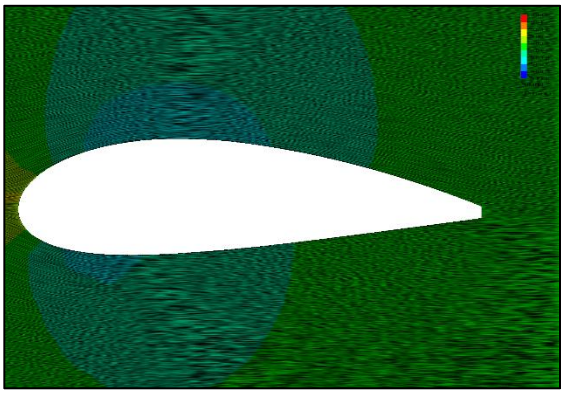


Fig. 7: Pressure cut plot

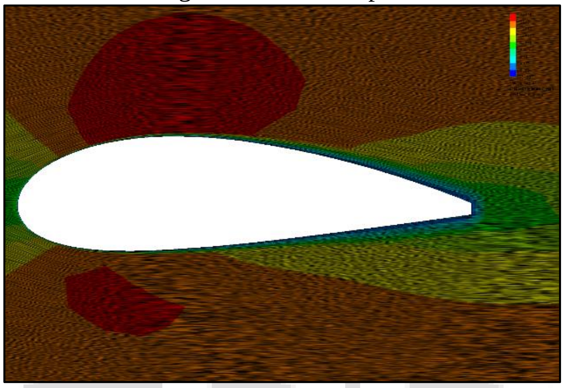


Fig. 8: Velocity cut plot

Figure 7 shows the pressure variation and Figure 8 shows the velocity variation along the profile curves of the monolithic wind turbine blade.

Figure 9 shows the trajectories of the fluid particles along the profile curves of the monolithic wind turbine blade. These fluid particles trajectories are called Streamlines.

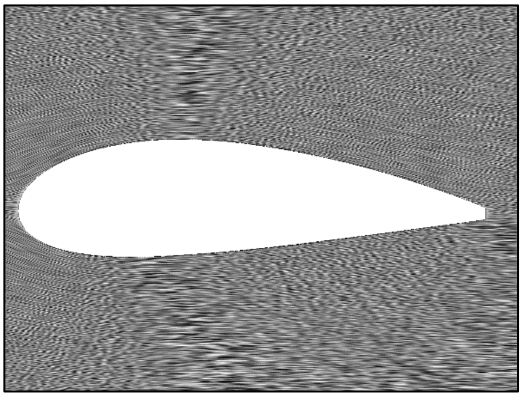


Fig. 9: Streamlines

B. *Interpretation of Results:*

It can be seen from Table 4 that the values of Lift coefficient (C_L), Drag coefficient (C_D), and the ratio of lift coefficient to the drag coefficient (C_L/C_D) have positive values. From this, we can interpret that the design is successful and can be coupled with the windmills or the wind turbine.

VI. CONCLUSION

With the help of Solidworks Flow Simulation solver, the model is tested under real working conditions with air as working fluid and the aerodynamic coefficients are calculated. From the study we can observe that:

The values of Lift coefficient (C_L), Drag coefficient (C_D), and the ratio of lift coefficient to the drag coefficient (C_L/C_D) are positive values. This shows that model is successful and ready to use in real conditions.

The values of Lift coefficient, $C_L = 0.0131363$ which is positive. This implies that a lift force is acting on the blade which causes the blade to translate its position. Therefore, if it is coupled to the shaft of the hub of the wind turbine it causes rotation which is responsible for the rotation of the coupled generator.

Since the model is analyzed 293 K, 20 m/s and Humidity ratio 50%, it can also be used in regions where low temperatures exist and can also be used at sea shores or ocean shores where the humidity is high. The model can withstand high wind velocities.

From the above observations, we conclude that the objectives of the project to design the monolithic wind turbine blade which can operate and can be installed in various topological and geological conditions are fulfilled. The model designed using three standard airfoils NACA 4424, NACA 4421 and NACA 4418 in a single wind turbine blade is successfully working under real operating conditions.

REFERENCES

[1] John M Obrecht, “METHOD AND SYSTEM FOR IMPROVING WIND FARM POWE PRODUCTION EFFICIENCY,” United States Patent, Patent N0.: US 20140234103 A1.
[2] Soren Sorensen, Martin Ansbjerg, “Plant Power Optimization,” United States Patent, Patent N0.: US 20120133138 A1.
[3] Wolf, Kevin, Thomas, Robert, Nasson, “Vertical and Geographical Placements of Arrays of Vertical- Axis Wind- Turbines,” World Intellectual and Property Organization, International Publication Number: WO 2017/070225 Al.
[4] Wolf, Kevin, Thomas, Robert, Nasson, “Vertical and Geographical Placements of Arrays of Vertical- Axis Wind- Turbines,” United States Patent, Patent N0.: US 20170107975 A1.
[5] Gjerlov, Christian, Graugaard, Jesper, “A Wind Turbine,” European Patent Specification, Patent N0.: EP 2 249 029 B1.
[6] Jonathan C. Berg, Brian R. Resor, Joshua A. Paquette, and Jonathan R. White, “SMART Wind Turbine Rotor: Design and Field Test,” Sandia National Laboratories.
[7] HERONEMUS, William, E. HERONEMUS, Phyllis R., “OFFSHORE WIND TURBINE,” European Patent Specification, Patent N0.: EP 1483 502 B1

