Computational Technique Adopted to Study Vortex Formation in Industrial Wind Turbines

Dhanish Ahamed, Chinni Maadesh, Harish Adishwar, Ayshwarya Mahadevan, and Aravind Seeni

Abstract Problems in wind engineering are addressed using computational techniques, or computational wind engineering (CWE). Although Computational Fluid Dynamics (CFD) is just one component of CWE, it has up to now been used as a main tool. The vortex formation in wind turbines has to be studied certainly in order to avoid the formation of induced drag and methods that are required to minimize the effects of vorticity. The boundary layer formation analysis and vortex formation analysis in the blades of industrial wind turbines are solved using numerical techniques. To achieve the necessary flow characteristics, such as vortex generation and boundary layer creation in the wind turbine blades during flow separation, the lift-to-drag ratio, pressure coefficient, variation of lift with respect to the angle of attack, variation of drag with respect to the angle of attack, and intensity of induced drag brought on by vortex formation are studied using CFD. It also encloses the control and minimizing techniques of vorticity generation and boundary layer formation.

Keywords CFD · Vorticity · Boundary layer · HAWT · Three-blade turbine

Abbreviation

v	Tangential velocity (m/s)
ɼ	Strength of vortex filament (m^2/s)
ω	Angular velocity of fluid particle (rad/s)
r	Radial distance between elemental vortex filament and point in space
l	Total length of the vortex filament

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S. G. Rajasekharan et al. (eds.), *Proceedings of the 9th National Conference on Wind Engineering*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-99-4183-4_11

1 Introduction

Humanity has known for ages how useful wind power can be in daily life, from sailboats to windmills. Developing and designing vertical axis wind turbines have been the subject of several research projects. Among the few investigations, two were emphasized here and categorized as computational studies and experimental studies. Due to population increase and the expansion of economies, the world's energy demand is anticipated to more than quadruple by 2060. Lift-based Darrieus VAWT design is more frequently utilized since it has larger power coefficients [1]. Darrieus VAWTs typically fall into one of two categories based on blade configuration: both straight and curved blades. Straight line blades, in particularly the H-rotor types, have gained popularity because of how easily they can be produced. On employing VAWT, maximum power coefficient can be achieved, but on the other hand, construction, operation, and cost of manufacturing are crucial considerations when choosing VAWTs as in [2] for power production. Power generation expenses will be decreased by raising the power coefficient of VAWTs and HAWTs.

2 Problem Statement

The present analysis incorporates the formation of vorticity in the wind turbines and the intensity of vortices in the tip and the root of the blades. Unlike the aircrafts, the vortex in the wind turbine blade is of different structures and it is an important aspect of study the vortex structure in the blades. The airfoils chosen are S833, S834, and S835 of the NREL series. Also, vorticity formation due to the upstream flow or the wind speed is analyzed and an insight on ways to reduce the vortices is given. The turbulence analysis is included in the paper and the corresponding results are provided.

3 Methodology

The paper is expected to exhibit the study of vortex formation in the wind turbines. Initially, the blade is designed with S833, S834, and S835 airfoils separately and the simulation is done with four different wind speeds, and the vortices' formations are obtained. The turbulence models are taken and analyzed [3]. These airfoils are made with the intention of having a constrained maximum lift and a minimal sensitivity to leading-edge roughness [4]. In the past, an analysis for this type of wind turbine was performed where the analysis was performed for HAWT with a NACA airfoil. However, in this study, the HAWT blade type is chosen and S833, S834, and S835 airfoils are picked, and they are then given an aerodynamic analysis [5]. The vortex formations in the wind turbine is a function of wind speed which is why the analysis involves choosing different wind speeds in order to provide the best airfoil for wind turbines.

4 Code QBlade

The turbulence analysis and vorticity formation were simulated in QBlade. It is a wind turbine design and simulation software. QBlade is a software that helps to design wind turbine and maximizes all the key relations between blade twist, chord, section airfoil performance, turbine control, power, and load curves in a clear and understandable manner.

5 Theory

For quantitatively predicting liquid and gas flows in many industrial applications, Computational Fluid Dynamics (CFD) is a potent tool. Air flows around wind turbines to produce renewable energy by turning the turbine blades, which is an obvious application of CFD in wind energy.

5.1 Vorticity

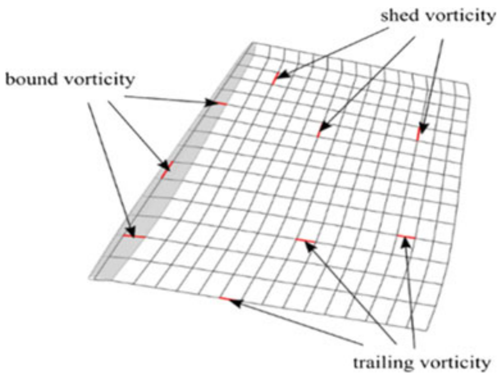
The vortex flow is that type of flow in which the fluid particles take a rotational motion during its flow separation from the fluid–solid interaction. Free vortex flow and forced vortex flow are the two types of vortex flows, whereas in forced vortex flow, the fluid particles rotate in its own axis by means of the external torque applied to the fluid flow. Tangential velocity acting on the fluid,

$$v = \omega r. \tag{1}$$

The analysis is based on the formation of vortices in the wind turbine which replicates the number of vortex filaments that has formed during the flow separation in the wind turbine blades. The vortices are developed is formed in the downstream of the blades which induces a velocity at some points by Biot–Savart law.

$$\mathrm{d}\vec{v} = \frac{\Gamma}{4\pi}\frac{\overrightarrow{d_l}\, X\vec{r}}{r^3} \tag{2}$$

Fig. 1 LLFVW model



By integrating the above expression, the velocity relation is obtained

$$v = \frac{\Gamma}{4\pi} \int_{-\infty}^{\infty} \frac{\sin \vartheta}{r^2} \mathrm{d}l \tag{3}$$

The Lifting Line Free Vortex Wake technique may be used in QBlade to mimic the aerodynamic forces operating on a rotor (LLFVW). The FVW approach used in this study solves for the turbine wake. The FVW model is derived from Lagrangian method (Fig. 1).

6 Results and Discussions

In this analysis, geometric models of the airfoils have been created and vortex formations in the wind turbines are simulated for three different turbine blade geometries. According to the author's knowledge, it is found theoretically that the number of vortex filaments formed across the wake of the blade is inversely proportional to the wind speed.

6.1 Geometric Model

The below given figure shows the blade design of the airfoils S833, S834, and S835:

1. S833 (Fig. 2).

Fig. 2 S833 blade

Fig. 3 S834 blade

Fig. 4 S835 blade

2. S834 (Fig. 3).

3. S835 (Fig. 4).

6.2 Vortex Simulations

The vortex simulations for four different wind speeds are shown:

(1) *Airfoil: S833 speed of wind in* m/s

1. *Speed of wind*: 10 (Fig. 5).
2. *Speed of wind*: 12 (Fig. 6).
3. *Speed of wind*: 14 (Fig. 7).
4. *Speed of wind*: 16 (Fig. 8).

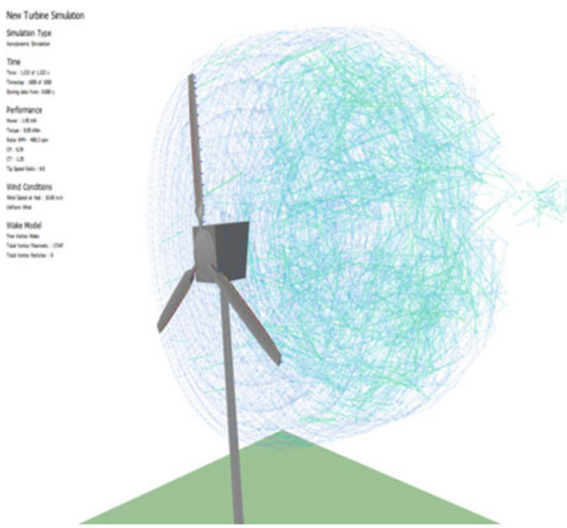


Fig. 5 Vortex formation of S833 (10)

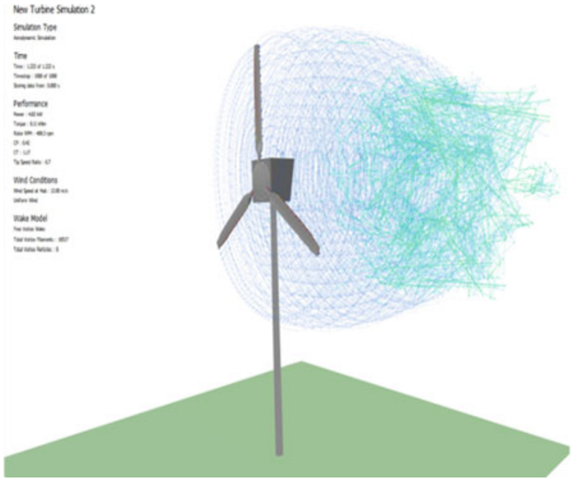


Fig. 6 Vortex formation of S833 (12)

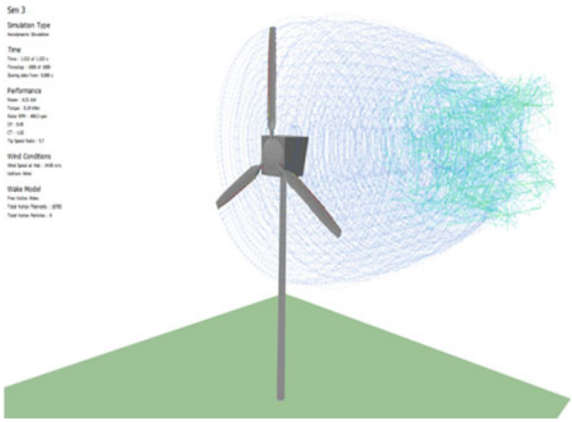


Fig. 7 Vortex formation of S833 (14)

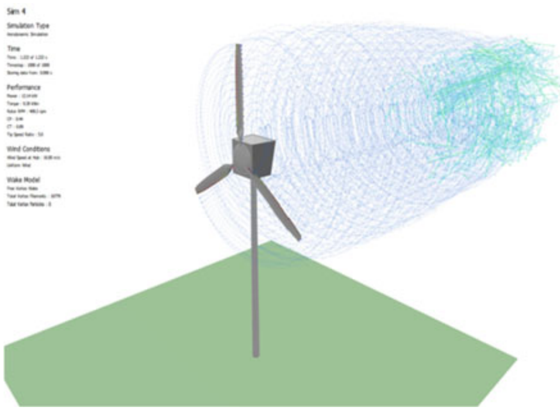


Fig. 8 Vortex formation of S833 (16)

6.3 Turbulence Graphs

The graphs of blade length versus circulation, time versus induced velocity, and time versus vortex filaments for S833 are given below (Figs. 9, 10 and 11):

(2) *Airfoil: S834*

1. *Speed of wind*: 10 (Fig. 12).
2. *Speed of wind*: 12 (Fig. 13).
3. *Speed of wind*: 14 (Fig. 14).
4. *Speed of wind*: 16 (Fig. 15).

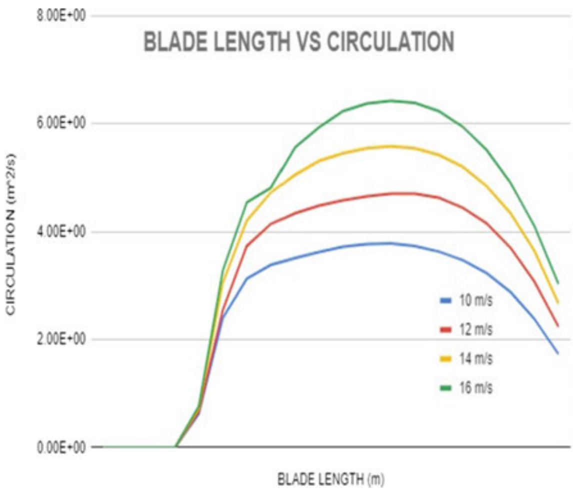


Fig. 9 Plot of blade length versus circulation

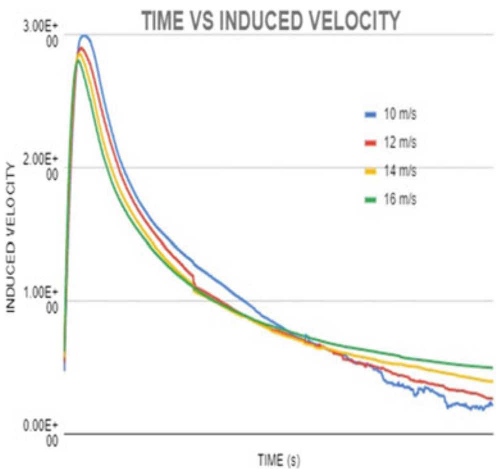


Fig. 10 Plot of time versus induced velocity

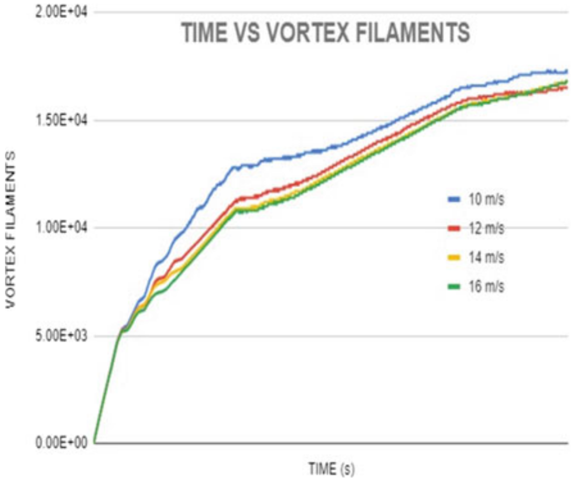


Fig. 11 Plot of time versus vortex filaments

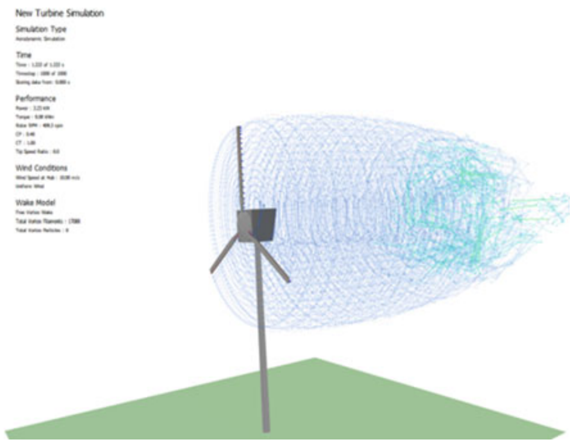


Fig. 12 Vortex formation of S834 (10)

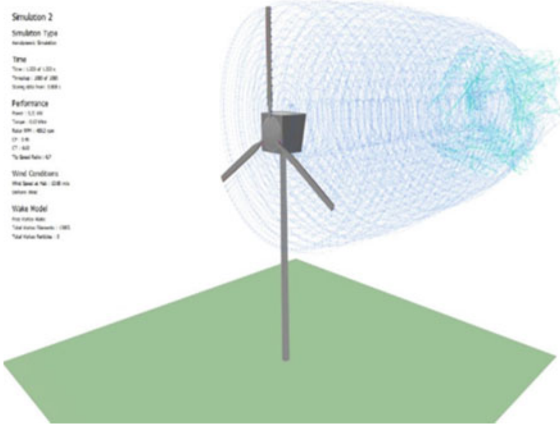


Fig. 13 Vortex formation of S834 (12)

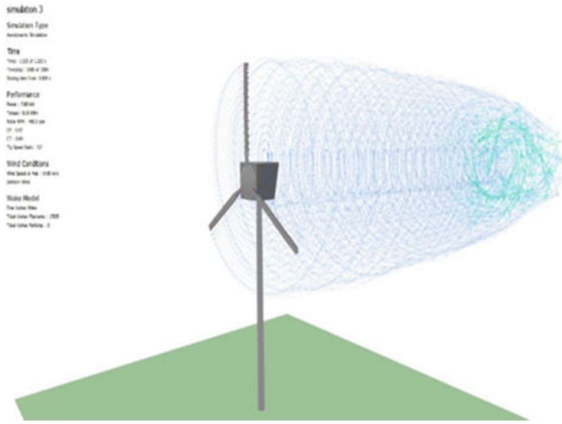


Fig. 14 Vortex formation of S834 (14)

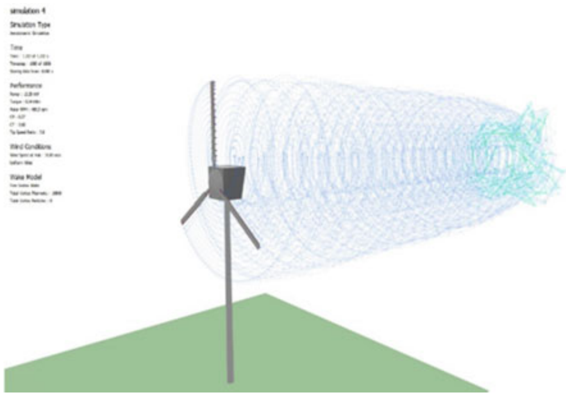


Fig. 15 Vortex formation of S834 (16)

6.4 Turbulence Graphs

The graphs of blade length versus circulation, time versus induced velocity and time versus vortex filaments for S834 are given below (Figs. 16, 17 and 18):

(3) *Airfoil: S835*

1. *Speed of wind*: 10 (Fig. 19).
2. *Speed of wind*: 12 (Fig. 20).
3. *Speed of wind*: 14 (Fig. 21).
4. *Speed of wind*: 16 (Fig. 22).

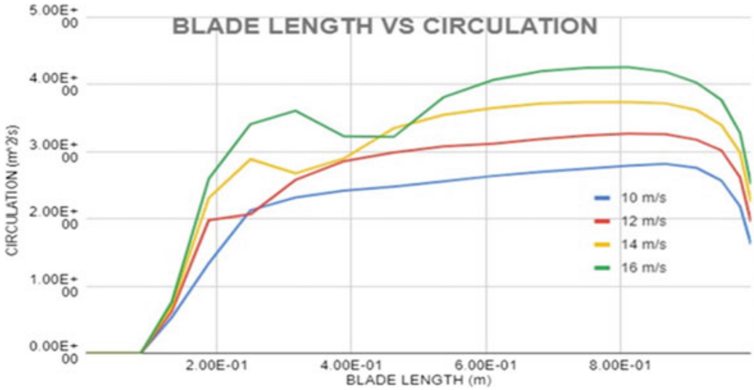


Fig. 16 Plot of blade length versus circulation

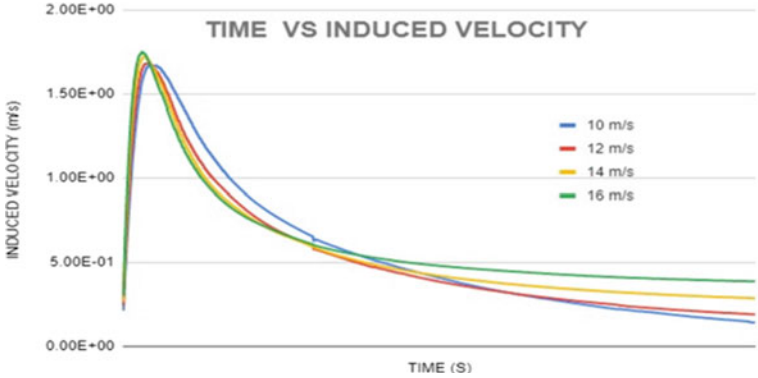


Fig. 17 Plot of time versus induced velocity

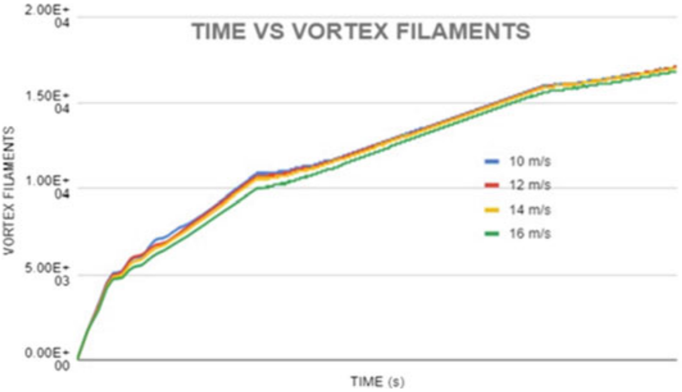


Fig. 18 Plot of time versus vortex filaments

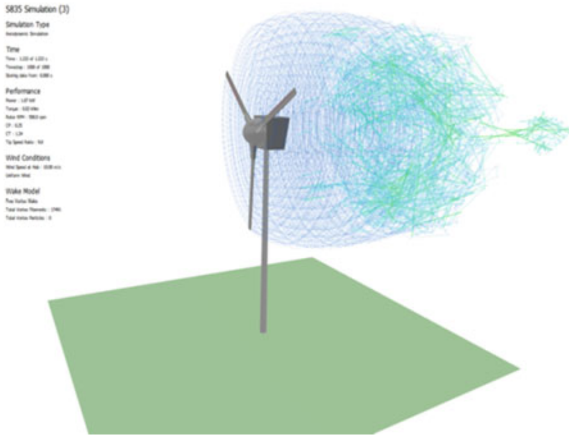


Fig. 19 Vortex formation of S835 (10)

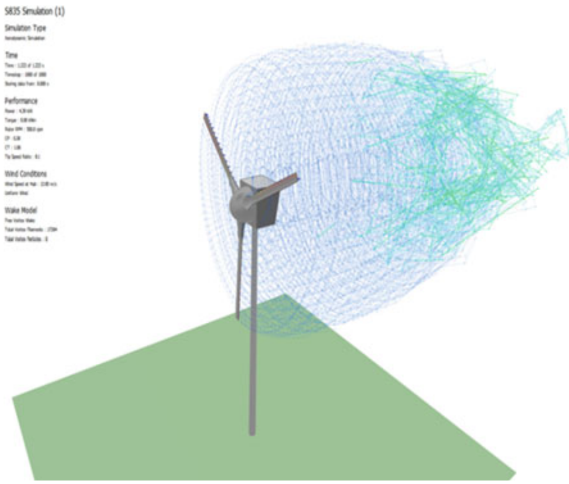


Fig. 20 Vortex formation of S835 (12)

6.5 Turbulence Graphs

The graphs of blade length versus circulation, time versus induced velocity, and time versus vortex filaments for S835 are given below (Figs. 23, 24 and 25):

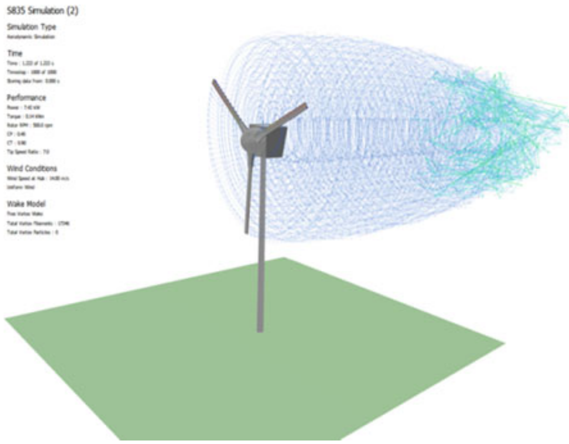


Fig. 21 Vortex formation of S835 (14)

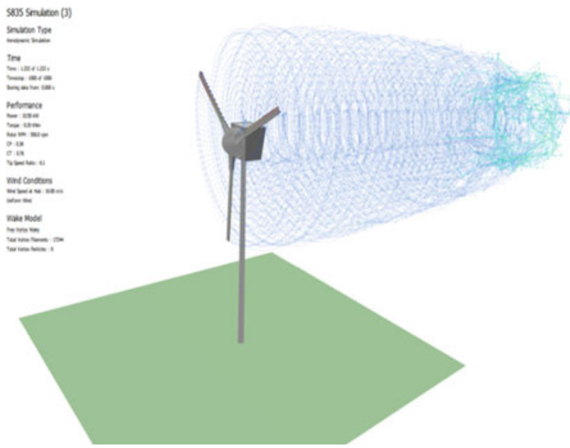


Fig. 22 Vortex formation of S835 (16)

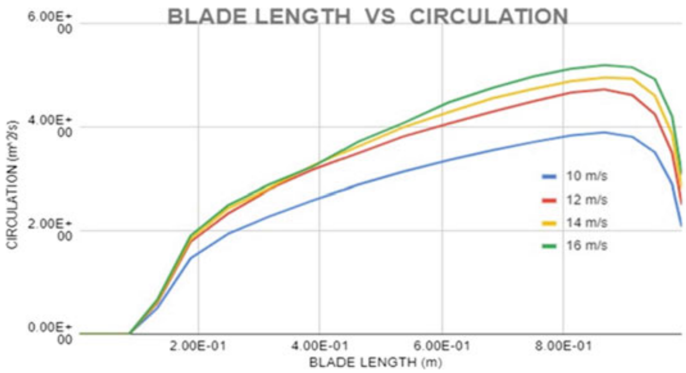


Fig. 23 Plot of blade length versus circulation

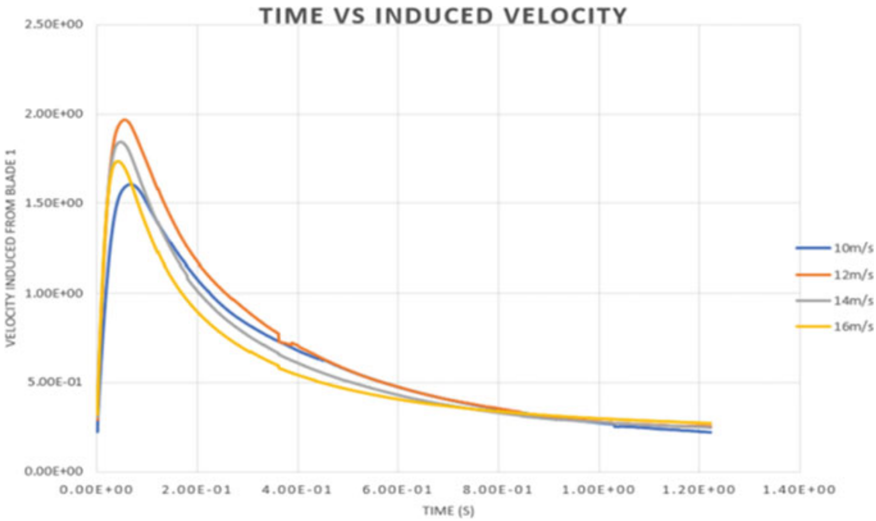


Fig. 24 Plot of time versus induced velocity

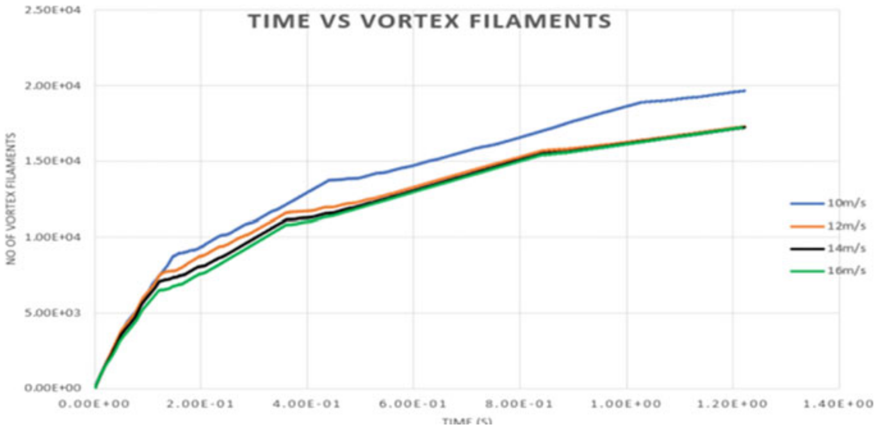


Fig. 25 Plot of time versus vortex filaments

7 Conclusion

The vorticity formation for the three airfoils has been obtained along with the graphs to study turbulence. The vortices formed during the working of a wind turbine affect the performance of it. Hence, it is essential to analyze and study ways to reduce them. From this analysis, it is found that distance between the wind turbine and the formation of vortex filaments is lesser at low wind speeds and formation of vortex filaments which is at high wind speeds is farther from the wind turbine. During the blade rotation, there is formation of vortices' downstream of wind turbine. By comparing the airfoils S833, S834, S835 based on the formation of vortex filaments, it is found that for S834 airfoil, the distance between the formation vortex filaments and wind turbine is more at low wind speeds, whereas for S833 and S835 airfoils, the distance is less at low wind speeds.

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