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AERODYNAMIC ANALYSIS OF MORPHING BLADE FOR HORIZONTAL AXIS WIND TURBINE

Abhilasha Rathod, Nalin Raut, Sai Patil, Kajol Kamble, Shailendra Shisode
Department of Mechanical Engineering, MIT-College of Engineering, Pune, India

ABSTRACT

With increasing emphasis on renewable sources of energy, wind energy has turned into a major form of energy. Wind turbines are used worldwide to harness the wind energy. Conventional wind turbines have limitations due to their rigid structures. Morphing can be used as a technique to improve the performance of the wind turbine. The paper involves the aerodynamic analysis of the morphing wind turbine blade. Morphing enables the turbine blades to adapt with varying wind velocity. Here we are considering only the effects of morphed trailing edge of the wind turbine blade. The aerodynamic efficiency and the power output vary for various morphing angles of the turbine blade.

Key words: HAWT, Morphing, Computational fluid dynamics.

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1. INTRODUCTION

Wind energy as a renewable source has seen substantial growth in the past few decades. The wind turbine has many advantages that make it an attractive energy source, especially in parts of the world where the transmission infrastructure is not fully developed. Wind turbines can be easily installed and do not generate any harmful emissions in the process.

Wind turbines are primarily categorized as Horizontal axis wind turbine (HAWT) and Vertical axis wind turbine (VAWT). A horizontal axis machine has its blades rotating about an axis parallel to the ground whereas VAWT has its axis of rotation perpendicular to the ground.

Morphing technologies are currently receiving significant interest from the wind turbine community because of their potential high aerodynamic efficiency, simple construction and low weight. Morphing is derived from ‘Metamorphosis’ which means to change shape, appearance or form. The purpose of this paper is to study the effects of morphing the trailing edge of the wind turbine and analyze the power output.

2. THEORETICAL ASPECTS

Wind turbines extract energy from the wind by leveraging the aerodynamic principals of lift and drag. Lift and drag forces move the turbine blades which convert kinetic wind energy to rotational energy. The rotational energy can then be transformed into electrical energy. The rate of energy extracted from the wind is governed by Equation (1), where P is the power, T is the torque, and ω is the angular velocity of the turbine blades.

$$P = T\omega \tag{1}$$

Lift and drag forces are measured as a function of the angle of attack, α. The angle of attack is defined as the angle between the chord line c of the airfoil and the direction of the wind, as shown in Fig 2. It is generally ideal to choose the airfoil that has the greatest lift-to-drag ratio, since there will be the least amount of thrust required to maintain altitude. The objective of turbine blade design is also to maximize the lift force on the blade and reduce drag so that the force on the blade that acts in the tangential direction is maximized. Lift acts in the direction normal to the fluid flow, which is not necessarily acting in the tangential direction once the turbine blades begin to spin. In most wind turbine designs, only the lift force on a blade creates a tangential force in the correct direction, while the drag force creates a small tangential force in the opposite direction. Other than the tangential force, another force, called thrust, is also comprised of lift and drag and acts normal to the plane of rotation. In air turbine design, it is crucial to reduce the thrust on the turbine blades because it wastes energy and it requires a stronger blade to withstand its loading. [1]

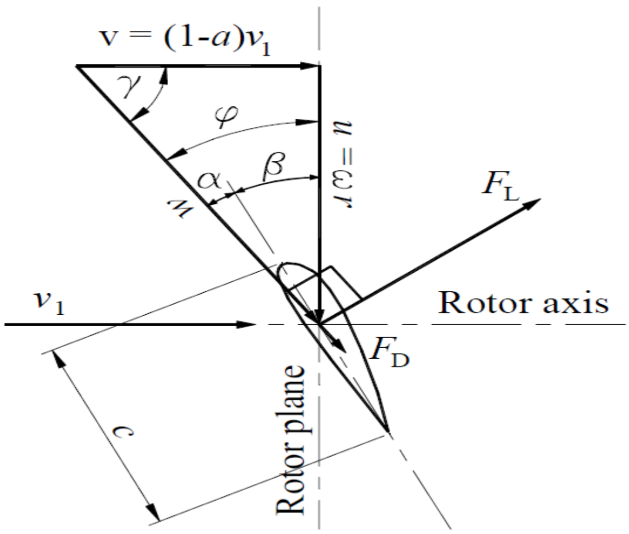


Figure 2 The Angle of Attack and Chord Line of an Airfoil [3]

The lift and drag forces on an airfoil are proportional to their respective coefficients, C_L-coefficient of lift and C_D- coefficient of drag, Figure 3 shows how the lift and drag forces are transformed into torque T and thrust Th forces, which are required to determine the power created by the turbine.

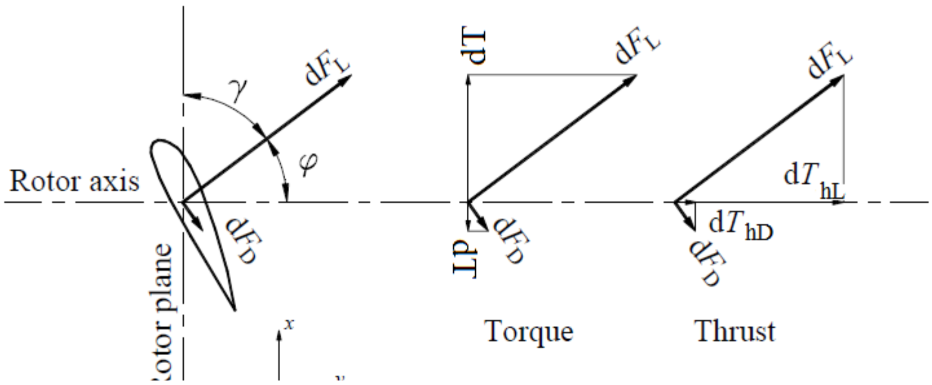


Figure 3 Transformation of Lift and Drag into Torque and Thrust

3. BLADE DESIGN AND MORPHING

Here we consider a small horizontal axis wind turbine, with blade length of 1.0 m. The wind turbine rotor has 3 blades and a tip speed ratio of 4. A local survey of wind speed suggests an average wind speed of 5m/s. The airfoil selected is NACA 4412 [3] for study. Angle of attack at maximum glide ratio (C_L/C_D) for the design wind speed (5 m/s) is optimum at 7 degrees as shown in Figure 4.

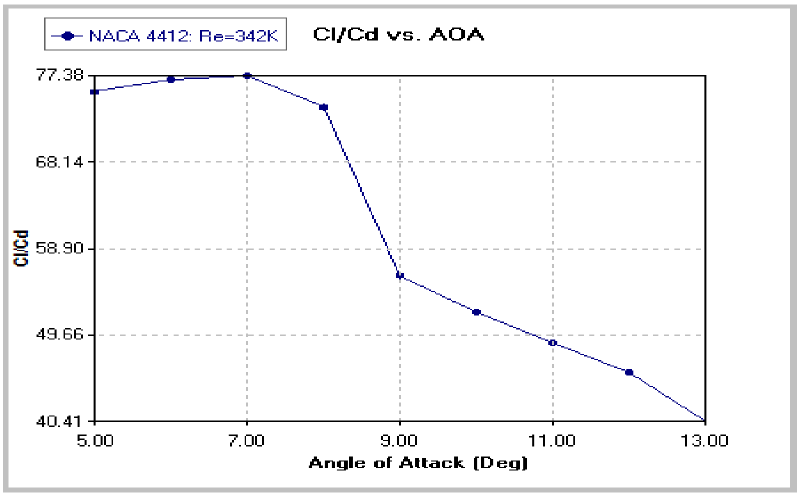


Figure 4 Angle of attack vs. C_L/C_D (Glide ratio) at 5 m/s.

Taking into account all of the above, the wind turbine rotor is designed as per BEM principles stated in John J. McCosker's dissertation [2]. The CAD of the designed blade and rotor are shown below (Figure 5)

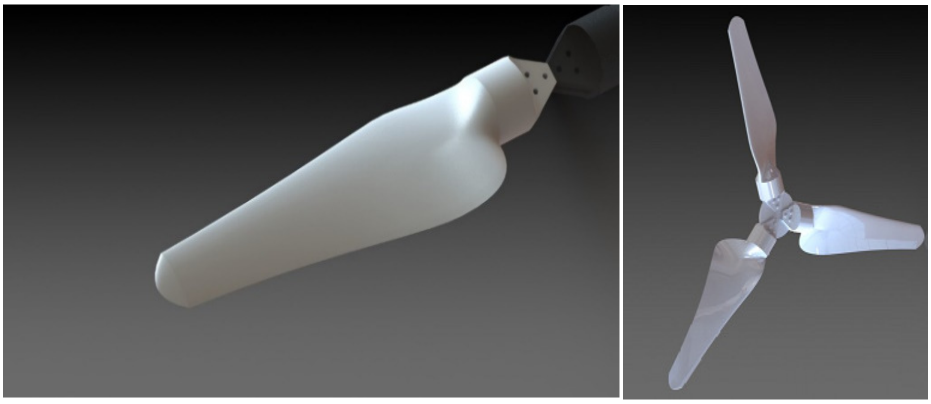


Figure 5 CAD model of blade and rotor

To morph the above designed blade, we choose blade span ranging from 0.5m to 0.8m of the blade length starting at the root of the blade. We do so because the power generated due to this span of the blade is considerably high. The morphing of trailing edge in an airfoil is shown in Figure 6.

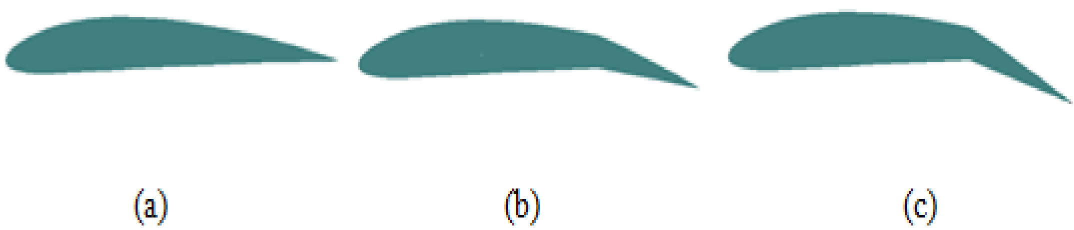


Figure 6 Morphing of blade cross-section: 0°Morphing angle (a), 10°Morphing angle (b) and 20° Morphing angle(c)

4. 2 DIMENSIONAL FLOW ANALYSIS

We use Visual Foil 2-Dimensional flow simulation software to acquire the values of C_L and C_D. A cross-section at 0.6m from the root of the blade length is considered for the 2D analysis. We use these values to calculate the Torque and Axial thrust exerted on the blade. The Power generated (Proportional to torque exerted) and axial thrust is plotted against different wind velocities as seen in Figure 7 and Figure8.

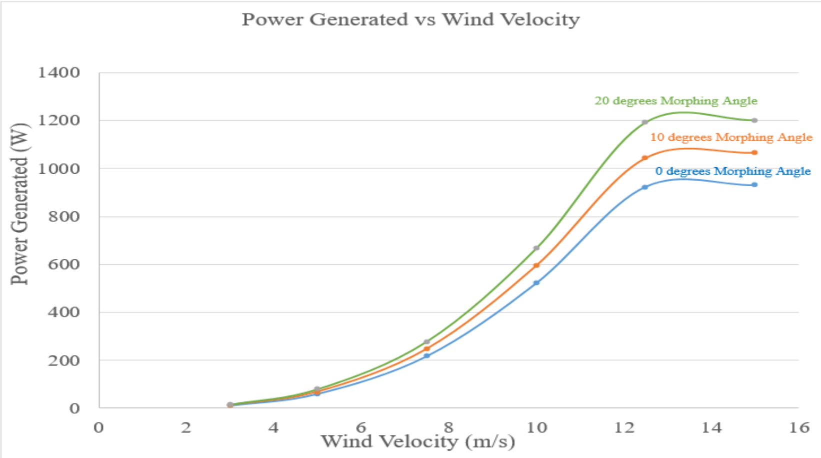


Figure 7 Power generated vs. Wind velocity

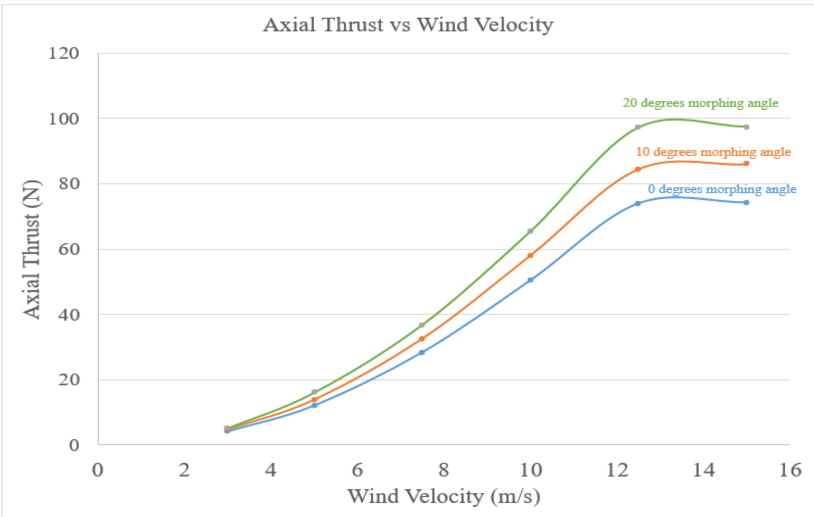


Figure 8 Axial Thrust vs. Wind velocity

5. 3 D COMPUTATIONAL FLUID DYNAMICS SIMULATION

In the previous section VisualFoil has been used to analyse blade segments. However, we must not forget that it is a 2-dimensional analysis software. To simulate three dimensional (actual) conditions we analysed the blade using Star CCM+ at different morphing angles. Polyhedral mesh is used with 2 prism layers at the boundaries and 4 prism layers at the face [4]. The flow is assumed to be steady and turbulent having constant density. The turbulent model used is turbulent kinetic energy and emissivity model or simply known as K-ε (K-Epsilon) turbulence model. Velocity magnitude contour plot, pressure contour plot at 5m/s wind speed and at different morphing angles have been shown below for the blade span ranging from 0.55m to 0.65m of the blade length. The values for Lift and Drag forces have been acquired to further compare with the values acquired from the wind tunnel test.

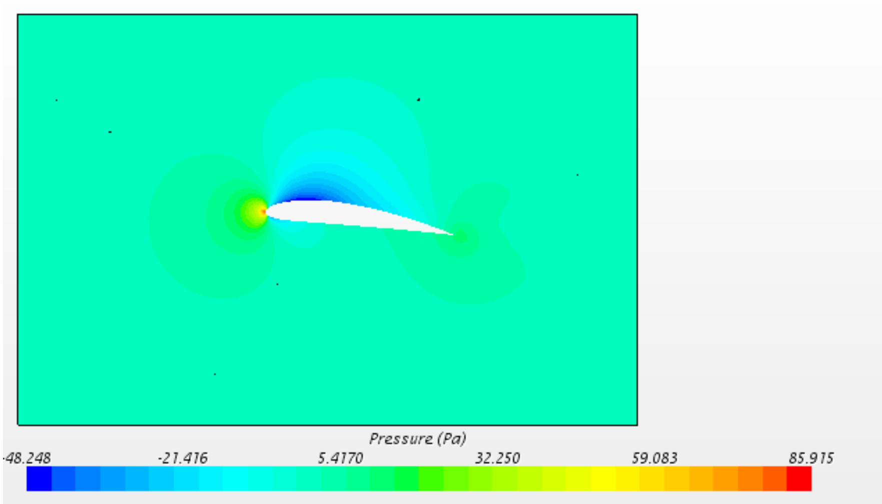


Figure 9 Pressure contour at Morphing angle of 0°

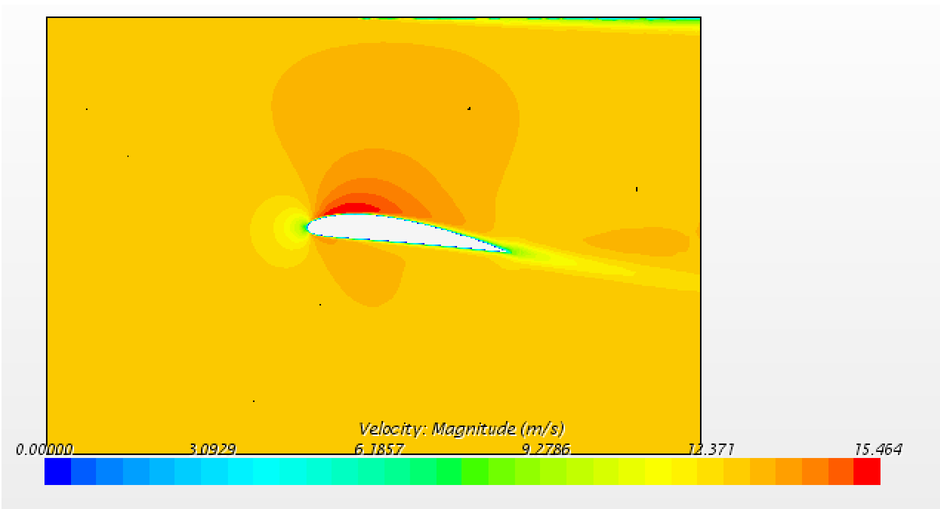


Figure 10 Velocity contour at Morphing angle of 0°

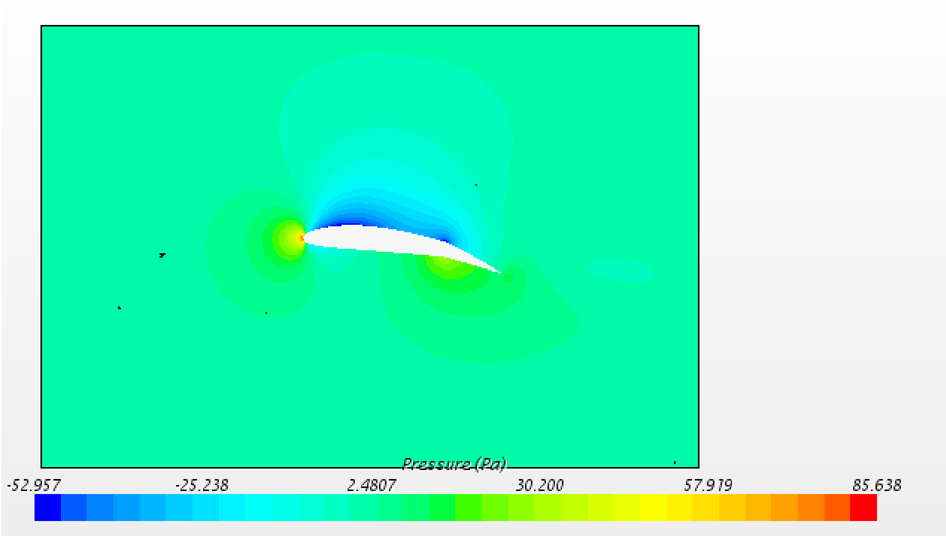


Figure 11 Pressure contour at Morphing angle of 10°

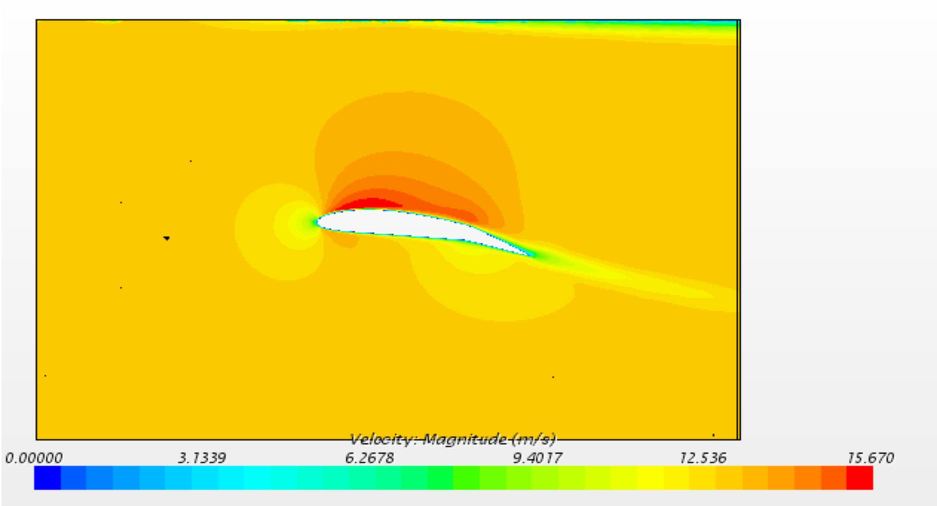


Figure 12 Velocity contour at Morphing angle of 10°

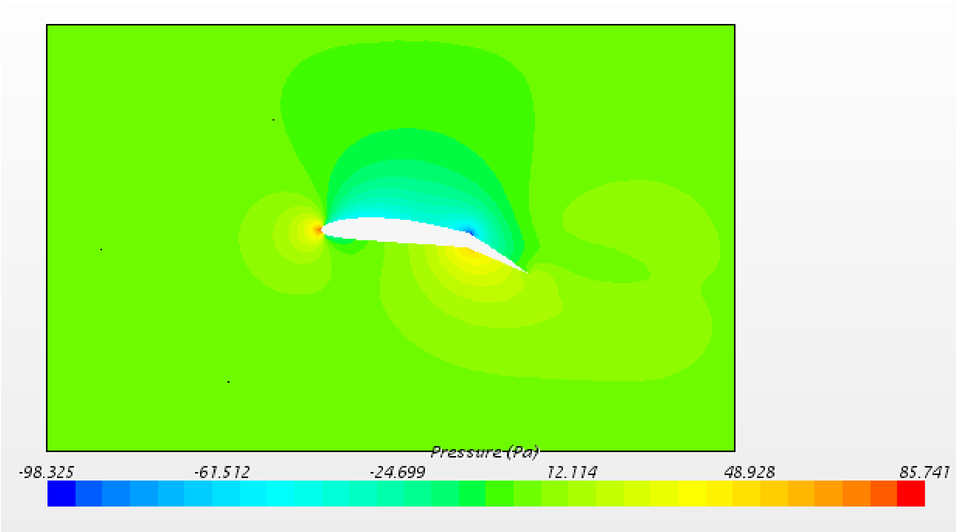


Figure 13 Pressure contour at Morphing angle of 20°

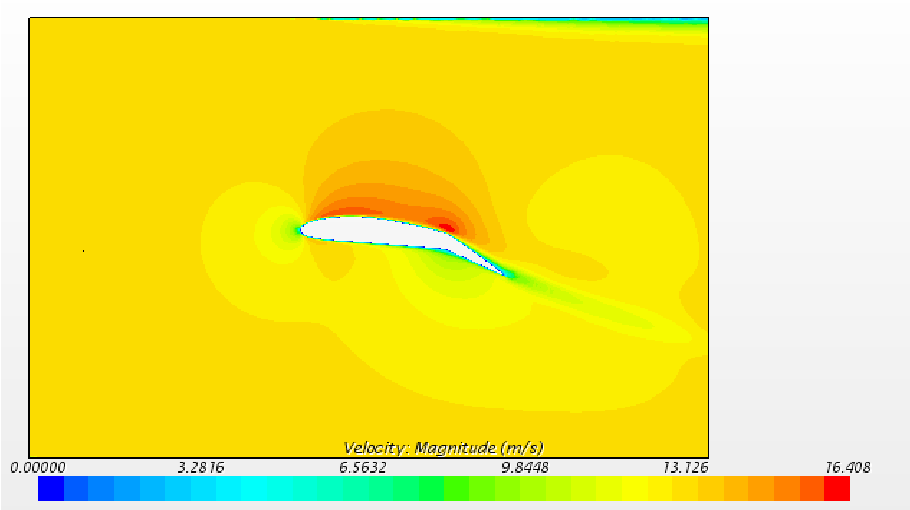


Figure 14 Velocity contour at Morphing angle of 20°

6. PROTOTYPING AND VALIDATION

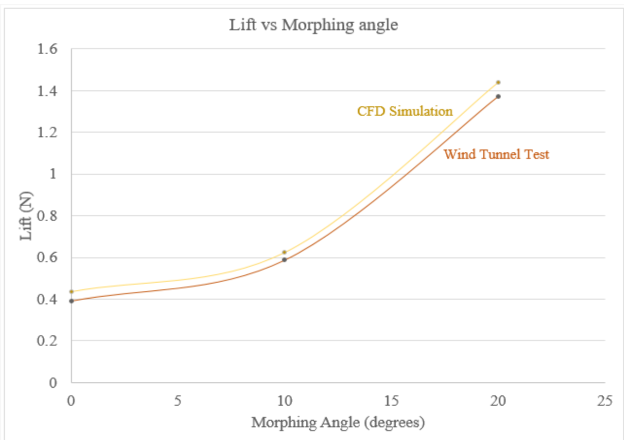
For validation, a portion of blade is manufactured for wind tunnel testing [5][6][7]. The portion is the span of blade similar to the one used in CFD simulation i.e. 0.55 m to 0.65 m of the blade. The test is carried out at 5m/s. The material used for manufacturing the blade portion is teak wood and wire saw machine is used. The values are used to plot Lift and Drag forces for both CFD Simulation and Wind Tunnel test (Figure 17 and Figure 18).

(a) (b) (c)

Figure 15 Blade segments at 0° morphing angle (a), 10° morphing angle (b) and 20° morphing angle (c)

The wind tunnel has a test section of 0.35m×0.35m×0.45m dimensions and maximum achievable speed of 20m/s

Figure 16 Wind tunnel testing setup



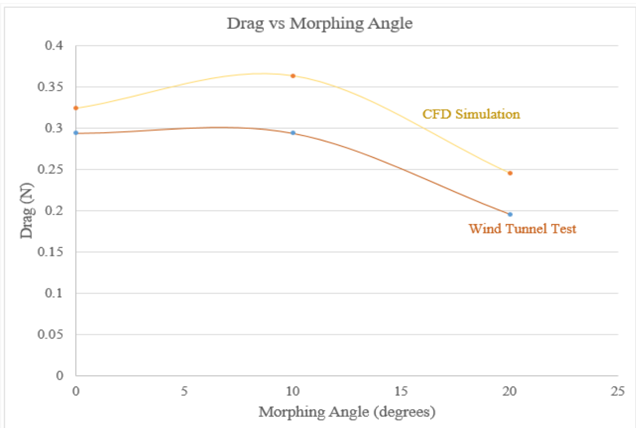


Figure 17 Lift force vs. Morphing Angle **Figure 18** Drag force vs. Morphing Angle

7. CONCLUSION

The 2-Dimensional analysis at different wind speeds and morphing angles shows that power increases as morphing angle is increased. This might lead us to conclude that morphing is suitable for all speeds. However greater morphing angle at higher wind speeds induces more thrust (Axial force). Therefore, morphing for low wind speeds is safe option. Further, the results from 3 Dimensional CFD analyses follow the same trend as 2-Dimensional Visual foil analysis but give us more realistic results. The wind tunnel testing validates CFD results and hence prove that morphing considerably.

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