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IMPROVEMENT IN DESIGN OF SMALL SCALE WIND TURBINES BY INCORPORATION OF TUBERCLES

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ABSTRACT

Alternative sources of naturally available energies such as wind power will meet part of power generation deficit of hydro and thermal power plants due to failure of monsoons and unavailability of coal respectively. Small wind turbines have become viable sources of power which can be used for domestic needs. But not much attention has been given to the design of the small wind turbine blades. The shape of the wind turbine blade decides the effective utilization of available wind power and it is especially important for small wind turbines as they operate at lower wind speeds. This project aims to develop a new wind turbine blade that is more efficient than conventional ones by incorporating tubercles along the blades of the wind turbine, similar to those on a hump back whale to produce more lift force with a slight design modification. Initially a blade of existing wind turbine is modeled and CFD analysis is carried out on it. A number of cases of modified designs varying both the size of the tubercles and number of tubercles are simulated. These modified designs of the wind turbine blades are compared with existing design to find the optimum tubercle number and sizes.

INTRODUCTION

Wind energy is one of the greatest future prospects among the different types of renewable and energy technologies. Wind energy is becoming more interesting throughout the world because it is found everywhere and it is useful renewable energy while it does not affect greenhouse due to any radiation. The efficiency of wind energy applications are becoming more vital these days because the use of wind energy applications have rapidly increased in the world, especially in the past decade. Moreover, wind energy is a low density source of power i.e the power obtainable per unit area of occupation of machinery is comparatively lower compared to conventional power generators such as thermal power. For a wind turbine, rotor design is still based on Blade Element Momentum theory (BEM). Nevertheless, the point has been reached where conventional dynamic modelling of a wind turbine rotor cannot be improved upon without modelling the flow of the fluid medium in which it works. Hence performing CFD is gaining more momentum these days. In order to increase the efficiency of the wind turbine, the maximum power developed by the wind turbine is desired. For this the wind turbine must be capable of converting the maximum amount of wind power available to it into mechanical power. Lift force developed can be used as a measure of this power generated.

Tubercles are leading-edge rounded protuberances that alter the flow field around an airfoil. It has been reported that tubercles on the humpback whale (Megaptera novaeangliae) flipper act as lift enhancing objects, allowing the flow to remain attached for a larger range of attack angles, thus delaying stall and increasing CL max. This is considered an important characteristic for the humpback whale, which must perform tight turning maneuvers as part of its feeding ecology. Such an adaptation has enabled the energy expenditure required to achieve a given lift coefficient to be lower, since the maximum lift coefficient for a given swimming speed would be higher. According to several researchers, the mechanism responsible for the improvement in performance is the generation of streamwise vortices, which enhance momentum exchange within the boundary layer. Such a passive modification to the leading edge of a foil delays stall and enables a higher maximum lift coefficient can be explored for use in wind turbine applications.

2. METHOD OF ANALYSIS

For this study, a wind turbine blade with S823 at root and S822 at tip is modelled in Solidworks. The wind turbine blade has a radius of 3m as suggested by the NREL, is modelled as shown in Fig 1 a. and taken for analysis. Spherical tubercles are taken along the span of the wind turbine blade from the tip. Initially a tubercle of 10% chord length near the tip is chosen and three adjacent sizes i.e 100 mm, 125 mm, 150 mm, 200 mm. were taken up and also. In order to account for the varying number of tubercles, 15, 19, 24 number of tubercles models for each of the above said sizes were modelled.

The computational domain considered in the CFD analysis is described as follows. The wind turbine blade model is taken and placed in a domain of radius of 2 times the radius of the blade and length of the domain equaling 10 times the radius of the wind turbine blade. The domain was made by subtracting the actual wind turbine blade from the formed domain. The computational domain was meshed by ICEM with a mixed three dimensional mesh. Since most of the cells of the domain won't interfere with the calculation of lift force, tetrahedral elements were created of larger size in regions far away from the blade and the mesh was made to become finer near the tips of the blades as shown in Fig 1 b. Generally tetrahedral elements were used to mesh the domain and hexahedral elements were used in the boundary layer region to capture the field variables more accurately. The surface mesh element sizes are controlled to obtain fine mesh elements close to the blades as shown in Fig 1 c. A high concentration of grid points were taken in the region of the tubercles and near the tip of the blade to accurately capture the wing shape. The mesh grows in size from the rotor surface. Different mesh configurations starting from coarse to fine are taken and analyzed for grid sensitivity analysis. The flow is taken as flowing in the negative z direction with a wind speed of 10 ms^{-1}. The SST k-ω method was taken as the turbulence model as suggested by Sørenson et. all (2002) as the k ε model fails to predict the turbulence behavior accurately (Crespo et al., 1985). The wall of the blade was considered to be a no slip wall. The inlet was taken as a velocity inlet with 10 ms^{-1} velocity in negative z direction and the outlet was considered as a pressure outlet equaling atmospheric pressure.

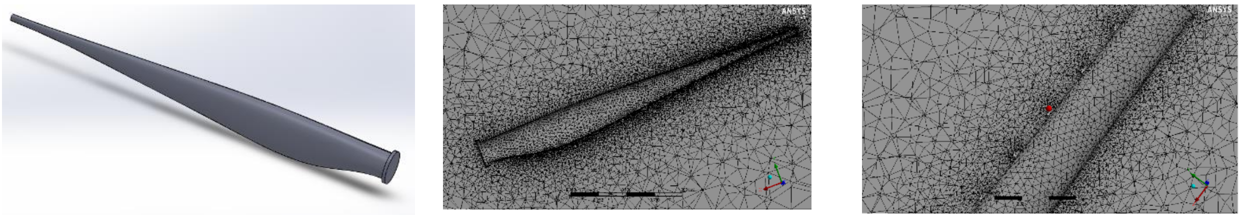


Fig 1 (a) Blade Model (b) Meshed blade (c) Prismatic elements

In order to eliminate numerical error in the calculation, a grid sensitive analysis was performed by taking different grids with increasing number of cells. The number of cells were increased by reducing the size of the cells on the face of the blade surface in a progressive manner. Here the value of lift force was monitored when converged results were obtained as it is the value of interest in this study. It can be seen from Fig 2 that as the grid cells number increases the slowly the lift force becomes less and less dependent on it. Finally in a mesh containing 9.4 million cells, the lift force became independent of the number of cells. This mesh will be used in the upcoming analysis to measure the lift forces of blades with varied tubercle sizes and numbers

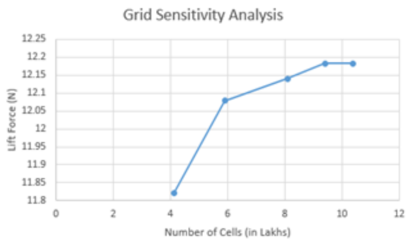


Fig 2 Grid Sensitivity Analysis

RESULTS AND DISCUSSION

The analysis was carried out to find explicitly the lift force generated by each of the blades. A complete analysis of all possible combinations of the chosen number of tubercles and size of the tubercles were carried out. This was done as such, so as to find the trend of the lift force generation as a function of both the size and number of tubercles. The convergence criteria was given as 10^{-5} for the residuals and 10^{-3} for the k and ω parameters. Once the results had converged the lift force was calculated for the blade surface and the calculated results are plotted in the table below.

Table 1 Lift Force for various Tubercle size and numbers

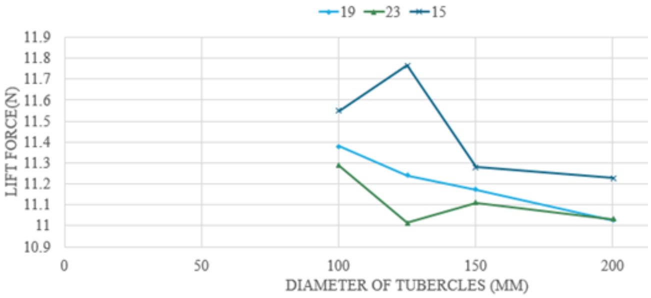
Number of Tubercles	Size of Tubercles			
	100 mm	125 mm	150 mm	200 mm
15	11.547 N	11.765 N	11.279 N	11.227 N
19	11.287 N	11.240 N	11.171 N	11.026 N
23	11.317 N	11.013 N	11.111 N	11.031 N

(i) Variation due to Size

First the results are taken such that the number of tubercles are kept constant and size of the tubercles are varied. These results generally show a trend that as the size increases the increase in lift decreases. This may be due to the fact that the vortices created near the blade tips are adversely affected by the increasing sizes. Fig 3 shows the lift force of blade with 15 tubercles of different sizes. Similarly it also shows lift force of blade with 19 and 23 tubercles respectively with different tubercle sizes. It can be seen clearly from these results that 150 mm and 200 mm tubercle models generate far lower lift than 100 mm and 125 mm tubercle models. From this trend we can understand that tubercle size extension beyond 125 mm generally leads to decreased generation of lift force. Also we can see from the results that 125 mm model produced the maximum of 6% rise in lift force from a no tubercle model. Hence the 100 and 125 mm tubercle models can be taken into account for further studies so that the tubercle size can be optimized even further.

(i) Variation due to Tubercle Numbers: Now the same results are plotted on a common graph by taking the size of the tubercle constant at a time and taking number of tubercles as the independent variable. This plot gives us a better understanding of how the lift force varies with respect to number of tubercles. From Figure 4 it can be observed that as the number of tubercles increases the lift force decreases progressively. It can be observed that the same trend is followed in all the tubercle sizes. Hence it can be safe to assume that of the three models tested, the 15 tubercle model showed the most improvement in lift characteristics.

These results also point out the incomplete nature of the tests. As can be seen from figure 3 the actual size of the tubercles can be more refined to get better results. More tubercle sizes around the 100 mm to 125 mm must be tested and also sizes below 100 mm to find the optimum value of the tubercle for the blade. Also as seen in Fig 4 the optimum value of number of tubercles has also not been found yet as the value of lift has shown a steady decrease from 15 tubercle model.



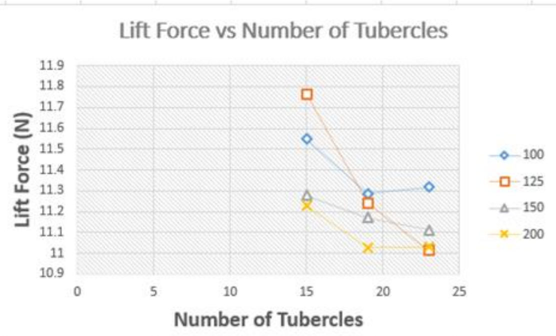


Fig 3. Lift Force vs Diameter of Tubercles **Fig 4. Lift Force vs. Number of Tubercles**

CONCLUSION & FUTURE WORK

The CFD analysis has shown that tubercles indeed help in generating higher lift force than models without tubercles. Also the trend of the current analysis has shown that the lift force generated decreases with increase in number of tubercles and also with size of tubercles. At present for this particular model 15 tubercle model seems to be the best suited. But models incorporating lesser than 15 tubercles must be modeled and simulated to find the optimum number of tubercles. Also the tubercles sizes at present are discrete values of 100 mm, 125 mm etc. Those must be refined to find the best suited size of tubercle.

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