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Research Article

Study Of Leading Edge Protuberances For Low Speed Horizontal Axis Wind Turbines

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ARTICLE INFO **ABSTRACT**

As fossil fuel reserves deplete at an ever increasing rate, renewable energy sources have become a serious alternative for power generation. Of these, Solar and Wind energy have shown a lot of promise. Wind energy is commercially and operationally the most viable renewable energy resource and is emerging as one of the largest source. While conventional wind power generation is confined to windy regions, newer blade designs are making low wind power generation increasingly effective. Wind energy will witness abundant opportunities in the developing economies such as India, where the power supply situation and infrastructure development efforts provide a huge market for active investment. Presently, Wind energy harnessing methods are limited to Horizontal Axis Wind turbines (HAWT) and Vertical axis wind turbines (VAWT).
Present workdeals with the effect of protuberances on leading edge of HAWTblade. Plain static blades incorporating the Selig/Giguere SG6043 wind turbine aero foilprofile with a uniform chord length is selected for the purpose. The protuberances are modeled as sinusoids. The amplitudes and wavelengths of the sinusoids are taken to be linear function of chord length and subsequently, the equations of the sinusoids are obtained. Five static blade models are considered for the analysis. The one free of any protuberance was taken as the baseline modeland the remaining four incorporatedsinusoidal protuberances of varying amplitude and wavelength.
Experiments were performed for varying angle of attacks to obtain lift/drag coefficients. Results indicate that the blades incorporating sinusoidal protuberances perform better in the stall regionas compared to the baseline model.This suggest that protuberant blades maybe be put to use in suitable low Reynolds number applications.

Keywords: Renewable energy, Horizontal axis wind turbine, Protuberances, Lift to Drag ratio.

INTRODUCTION

India is a rapidly growing economy which needs energy to meet its growth objectives in a sustainable manner. The Indian economy faces significant challenges in terms of meeting its energy needs in the coming decade. The increasing energy requirements coupled with a slower than expected increase in domestic fuel production has meant that the extent of imports in energy mix is growing rapidly. India is among the top five Green-house-gas (GHG) emitters globally.With in the renewable energies, wind is considered as one of the most promising green energy sources due to its eco-friendliness and worldwide availability. In the development history for the use of wind power over time, it evolves from driving ships ,pumping water of windmills, and finally to generating electricity for general uses.Today,the use of wind turbine for electricity generation is the most common application and a lot of researches focus on the blade design.

LITERATURE SURVEY

Development of tubercles on leading edges of wind turbines was inspired from the humpback whales flippers to enhance mobility or flexibility of wind turbines. P.watts et al [1] developed an efficient panel method simulation applicable to blade that move immersed in a fluid at large Reynolds They compared blades with leading edges tubercles versus without tubercles at range attack 10° and concluded that blade with tubercles

gave better results compared to without tubercles with increment of lift, reduction in drag induction and lift to drag ratio was 4.8%,10.9% and 17.6% respectively. If the angle of attack is zero then there is no use of tubercles. If the angle of attack is greater than 15°, then there is a great potential gain by using tubercles. The force of a control surface may also increase.
Johari.H et al [2] developed airfoils with leading edge sinusoidal protuberances in water tunnel. Lift and drag and pitching moment were compared between leading edges with sinusoidal protuberances and baseline foil with smooth leading edge. The amplitude and wavelength of sinusoidal protuberances were 2.5 to 12% and 25 & 50% of the mean chord length respectively. Modified foils caused a reduction in lift co-efficient at the angle of attack. The foils with sinusoidal protuberances have greater drag and lift co-efficient in pre-stall & post-stall regimes respectively. The wavelength of sinusoidal protuberances & leading edge radius played a minor role on the force and moment co-efficient. The sinusoidal protuberances wavelength played major role in the flow separation
Guerrero et al [3] investigated the application of a sinusoidal leading edge to the design of micro air vehicles (MAVs) and concluded that both the amplitude and wavelength of these protuberances play important roles for low aspect ratio blades.
Smaller wind turbines performing at less wind speed generally faces difficulties like low performances due to bubbles on laminar separation on blades. But Ronit K Singh et al [4] developed a lower Re airfoils which is working at lower wind speed to improve overall performance of the turbine. They designed a 2-bladed rotor with lighter material and compared parameter like instantaneous 2-blade rotor airfoils with base line rotor airfoil.
Maskoud et al [5] investigated the impact protuberances on both leading and trailing edge of NACA 634-021 aerodynamic performances by using K-Ɛ model in the PHOPENICS software and compared to wavy-aerofoils standard NACA 634-021.
Guo-yan et al [6] conducted experiment for the 3D static models to obtain the lift and drag co-efficients They concluded that the protuberant blades with smaller amplitudes posses better performances at the stall region as compared with baseline model

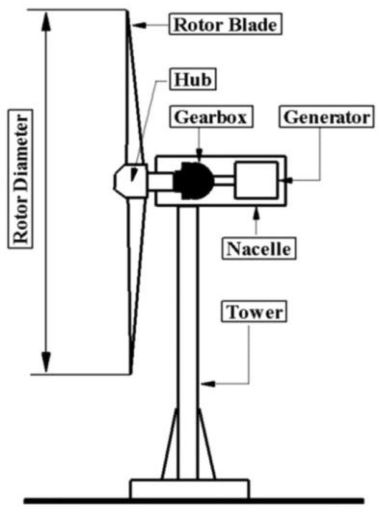


Fig. 1. Configurations of HAWT

EXPERIMENTAL STUDIES

The first step of the design process is to decide on the optimum airfoil profile for the static blades. The SG6043 airfoil has a thickness of 10% of the overall chord length and was designed for small horizontal axis wind turbines with a mean output between 1 and 5 kW. Another important parameter to select before progressing with the design of the static blades is the chord length of the airfoil. A chord length (C) of 150 mm was selected based on the test volume of the open-circuit wind tunnel facility on campus. The next parameter to determine was the overall length of the blade. As we chose to study low aspect ratio blades, we went ahead with an aspect ratio of 2. Consequently, the overall length of the blade was calculated to be 300 mm.
The next step is to determine the optimal values of the amplitude and wavelength. For studying the effect of leading edge protuberances on SG6043 airfoils have chosen two amplitudes and two wavelengths. The amplitudes chosen are 0.015C (A-1) & 0.085 C (A-2) and wave lengths chosen for static blades are 0.15C (W-1) & 0.065C (W-2) .
The same set of amplitude and frequency relations are adopted for the design and testing of the static blades. As there are two amplitudes and two wavelengths options available, we can design 4 separate static blades. The four models incorporating these protuberances are given by the following table.

TABLE 1. STATIC MODELS DESCRIPTION

Static Model	Amplitude-Wavelength Combination
SM – 1	A - 1 x W - 1
SM – 2	A - 1 x W - 2
SM – 3	A - 2 x W - 1
SM – 4	A - 2 x W - 2

The baseline static model developed using Computer aided modelling software Unigraphics (NX 8.0) and numerical study was conducted by using MATLAB (R2015a). The front, top and isometric view of SM-1 are as shown below.

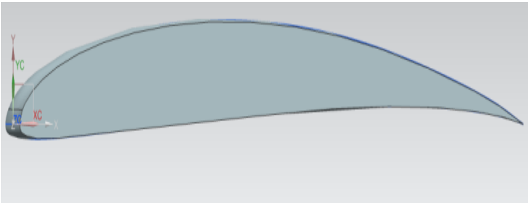
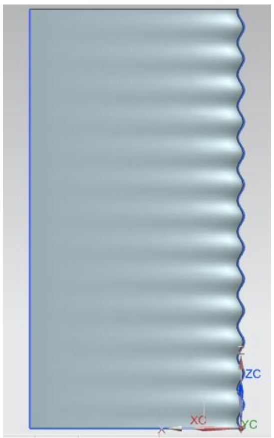


Fig 2 (a). Front view of SM-1



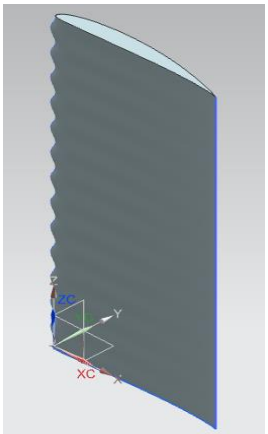


Fig 2 (b). Top view of SM-1 Fig 2(c). Isometric view of SM-1

The fabrication of these four static blades was done by 3-D printing usingAcrylonitrile Butadiene Styrene (ABS) material.
A six-degree strain balance was used to obtain the lift and drag forces during the experimentation of the static blades.The Six component balance -WBAL–00106- manufactured by Sunshine measurements is suitable for use in a wind tunnel having a 600mm x 600mm test section and a maximum speed upto 50m/sec.The outputs from the Strain gauge mounted on the strain elements are amplified by appropriately designed amplifiers. The system consists of three major parts which are:

i. Balance Mechanisms: This has a mechanical load transfer mechanism to strain gauged elements along with pitching and yawing mechanism. This mechanism includes Balance calibration attachment.
ii. Strain Gauge Instrumentation Amplifiers: These are six in number for the six strain gauged elements.
iii. Microcontroller Based measurement system: This is microcontroller based system which is used for measuring outputs from the strain gauge amplifiers, communication to PC and to store the measured values.

The flow condition for the experimentation purpose depends predominantly on three parameters. The first being the target Reynolds number of the experiment and then the average chord length of each static blade and lastly the mean room temperature while conducting the experiments. The first two parameters are interconnected and the chord length of the static blade plays as the critical dimension for the calculation for the Reynolds number. The target Reynolds number for the experiments is 100,000.
The mean room temperature during the experiments plays a vital in determining the air density. This in turn affects the dynamic viscosity and hence the Reynolds number. An average room temperature of 30°Celsius was measured.

TABLE 2. FLOW VISUALISATION PARAMETERS

Experimental Reynolds Number	$\mathbf{1 \times 10^5}$
Dynamic Viscosity	$\mathbf{1.601 \times 10^{-5}}$
Free Stream Velocity	$\mathbf{16.01\ m/s}$
Density of Air at 20°C	$\mathbf{1.1644\ kg/m^3}$

RESULTS AND DISCUSSIONS

The graphs below illustrate comparatively the performance curves of all the five blades. The performance parameters used for this is:
a) Coefficient of Lift
b) Coefficient of Drag
c) Lift to Drag Ratio
All of these parameters are plotted for the five static blades against angle of attack from -10° to +26° with increments of 2°.

COEFFICIENT OF LIFT

It is clear from the Coefficient of Lift performance graph shown in figure 3, that the SM – 1 Blade model performs better than the baseline model, in terms of lift generation. This is in conformation that the protuberance act as vortex generators and improve the performance of the static blades. Additionally, we observe that both the blades SM-1 and SM-3 perform better than the baseline up until a relatively high angle of attack of 10°. This is a positive result. Beyond about 14°, SM-1, SM-2 and SM-3 perform better than the baseline model, which supports its use for suitable applications.

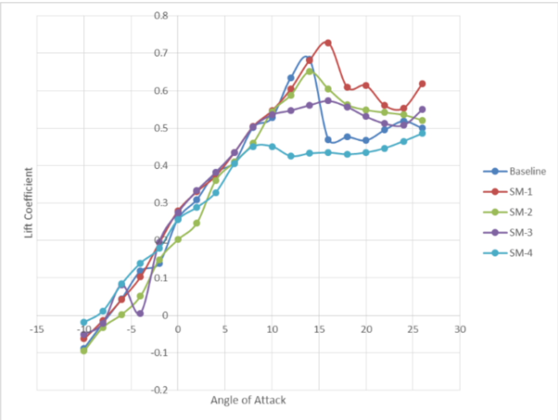


Fig 3. Coefficient of Lift vs Angle of attack

COEFFICIENT OF DRAG

It is observed that for higher amplitude and lower wavelength blade, that is, for the SM-4 model; the drag coefficient is the lowest. This may be due to the large gaps between the protuberances that allow the passage of air flow with minimal resistance. We also observe that the low amplitude and low wavelength model, that is, SM-2 also does a good job at maintain a minimal drag coefficient. Beyond 10 degrees angle of attack, SM-3 tends to generate much higher drag when compared with the other static blades.

LIFT TO DRAG RATIO

The Lift vs Drag Ratio parameter gives a holistic reflection of the performance of the blade. The graph clearly indicates that the low amplitude and high wavelength blade, that is, SM-1 model performs the best. Again, both the models SM-2 and SM-3 perform consistently better than the baseline blade till about 10° angle of attack.

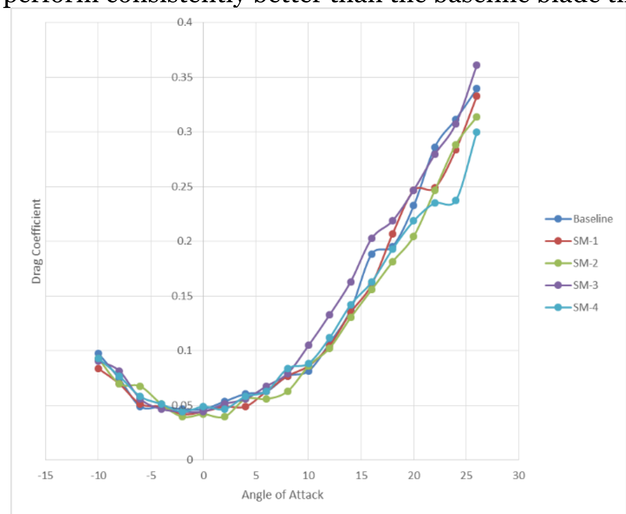


Fig 4. Co-efficient of Drag vs Angle of attack.

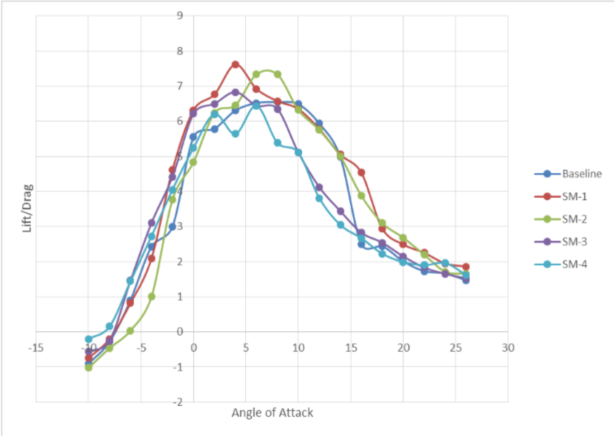


Fig 5. Lift to Drag Ratio vs Angle of attack

FLOW VISUALISATION OF THE STATIC BLADES MODELS

The flow visualisation of the static blade models was carried out at the same blow type open circuit wind tunnel as the one used for the load measurement. The static blade models were mounted onto the strain gauge which was also used to vary the angle of attack of these blades. The smoke was generated using an electric hot wire and paraffin wax as the melting medium as shown in figure 6.

Fig 6. Complete Hot wire Smoke Visualization Set-up

The flow visualisation for the blade model was conducted from -5 to 25 degrees with increments of 5 and is illustrated below.

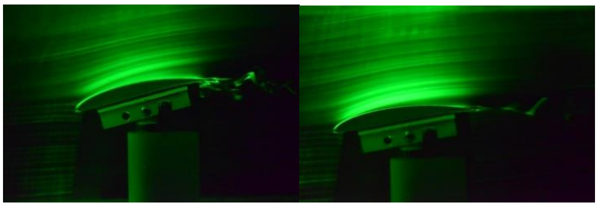


Fig 7(a). -10° and -5° SM-1.

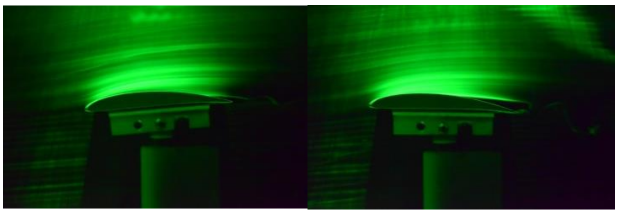


Fig 7 (b). 0° and 5° SM-1.

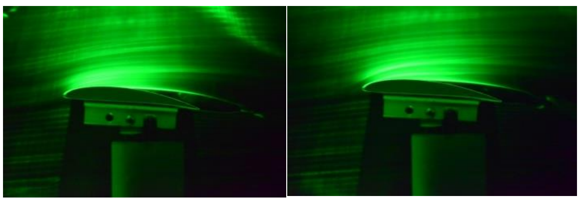


Fig 7 (c). 10° and 15° SM-1.

Fig 7 (d). 20° and 25° SM-1.

Fig 7. Flow visualisation studies for various angle of attacks for SM-1.

CONCLUSION

The tubercle like structures was modelled as sinusoidal protuberances. A set of four such sinusoids were obtained based on the combination between a set of two amplitudes and two wavelengths. The equations of these curves were calculated, plotted and coordinate files were generated on MATLAB. As the first part of the project, the intention was to study the effect of these tubercles on static blade models. Using the coordinate files of the protuberance sinusoids, four static blade models incorporating these curves were designed on the modelling software NX 8.

The static blade models were fabricated for both the flow visualisation purpose and lift and drag co-efficient computation purpose. It was conducted using 3-D printing technique along with suitable surface finishing methods to avoid any discrepancies during the time of the experiments. It is the clear from the experimental results conducted on the static blades that 3 of the models consistently perform better than the baseline model. This suggests that they maybe put to use in suitable low Reynolds number applications.

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