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Design and Development of New Airfoil for Small Horizontal Axis Wind Turbine Blade at Low Wind Speed

Manoj Kumar Chaudhary[1], K.B. Gavali[2], Sagar Gadakh[3], Meet Mehta[4]

[1-4]*Mechanical Engineering, Trinity Academy of Engineering, Pune, India*

ABSTRACT

Low aerodynamic airfoil performance is a frequent issue for small horizontal axis wind turbines operating in low-speed winds. This research work developed three high aerodynamic performances (MKC-Series) airfoil using the X-Foil programme, which were designed and optimized for small horizontal axis wind turbine blades with a Reynolds number of 100,000 to 300,000. Using BEM theory and blade geometry optimization, Matlab programme was created. Blade pitch angles of 0° and 30° were used in the laboratory study of rotor performance in an open wind tunnel were tested Laboratory. When applied to the blade geometry of wind turbine rotors with a 0.4 m diameter, an optimized design method based on BEM Theory is described using new airfoil (MKC series). The 3D printing additive manufacturing process was used to create the experimentally optimized wind turbine rotor blades. It was found that the MKC-Series airfoils performed better than the SG6043 airfoil at Low wind speed.

Keywords: ***Airfoil, Blade, Power Performance, Reynolds Number, Tip Speed Ratio***

1. INTRODUCTION

The environment in which people live and work is closely related to energy, which is essential for both social and economic progress. Technology applications are increasingly using wind energy, a clean, sustainable source of energy. HAWT turbine start wind speed was 4.2 m/s. The optimized blade can be used on top of structures or beside roads since it can reduce starting speed without the aid of an outside force [1-3]. The comparative analysis of maximizing the distribution of chord and twist angles on the blades [4-5]. An investigated how to raise the annual energy output of small wind turbines. Winglets geometry affects blade performances, increasing the winglets curvature radius and cant angle can boost the power coefficient; on average, the winglet geometry improved the power coefficient by 10.5% in comparison to the case without a winglet [6-10]. An optimized a tip speed ratio (TSR) of for 2 kW wind turbine. In order to correlate the solidity, power coefficient, TSR, and pitch angle of constant chord untwisted turbines, a theoretical analysis using BEMT and lifting-line-based wake theory. For application in the low Reynolds number region of 38,000 to 205,000, which SWTs optimized for HAWT at low Reynolds number airfoil [11-13]. An examined thin airfoils from the SG60XX family (SG6040 to SG6043), which are suitable for usage in tiny wind turbine blades with Re values between 1×10^5 and 5×10^5, how the airfoil section affected the effects along the blades. The compact wind turbine blades should be optimized in multiple dimensions. Such designs promise low-cost production of sophisticated three-dimensional (3D) blade shapes as well as a wide range of design possibilities for blades for different uses, such as quick-start blades for low-wind settings or, in particular, quiet blades for mounting on buildings [14-16].

2. DESIGN METHODOLOGY

2.1 Design and optimization of a low Reynolds number airfoil through X-Foil.

The tool for airfoil analysis and blade shape optimization at low Reynolds numbers in this work was X Foil version v0.963, 64 bit, and Matlab. A number of existing low-wind HAWT airfoils have been simulated and examined using X-Foil's airfoil procedures. By changing the thickness and camber settings of the base airfoil in X Foil, new airfoils with Reynolds numbers between 100,000 and 300,000 and an AOA between 0° and 15° were created, with a step size of 1° being taken into consideration for simulation the low Reynolds numbers were the characteristics used to create the new airfoil. In this case, 251 coordinate points were taken into consideration for the examination of aerodynamic properties utilizing the X-Foil software for novel airfoil design and optimization. Following their development, three new airfoil bearing the designations MKC7-6, MKC8-6, and MKC9-6 were created. Sections 3 and 4 compare the aerodynamic performance of these new airfoil with that of the SG6043 airfoil. In order to create 3-bladed, 0.4 m rotor radius, 0.12 m root radius wind turbine rotors for wind applications 3 to 6 m/s, the BEMT was applied to the MKC-Series airfoil. The hub and blade were created via 3D printing. To make the 3-blade rotor lightweight, PLA material was used in manufacturing.

2.2 Airfoil design and optimization

lift coefficient and lift-to-drag ratio performance for several airfoil suitable for low Re applications served as the foundation for the novel airfoil design and optimization in the current work. A variety of existing low speed HAWT airfoils were tested using X-Foil. The highest lift coefficient and maximum lift-to-drag ratio based on t/c at Re ranged from 100,000 to 300,000. These variations are shown in Figure 1. According to Figure 1, the maximum lift coefficient and lift-to-drag ratio values for each Re were found at t/c ratios of roughly 1.16 to 1.6. However, the lift and lift-to-drag ratios decline outside of this t/c range. Additionally, it has been found that as the Reynolds number increased, the aerodynamic performance (lift, lift-to-drag ratio), improved. Re increases from 100,000 to 300,000 enhanced L/D by about 10% to 25%.

Table 1 and Figure 1 describe the geometrical characteristics and profiles of these airfoils. In comparison to the base airfoil, the new MKC-Series airfoils feature a slightly higher camber and thinner design.

Table 1 Optimization of thickness and camber quantities for SG6043 and MKC-Series airfoils

Airfoil	**Thickness (% c)**	**Camber (% c)**
SG6043	10.01	5.5
MKC7-6	7	6
MKC8-6	8	6
MKC9-6	9	6

2.3 Comparison of MKC-Series airfoil with base airfoil, (SG6043) for small wind turbines at low Re.

Fig. 3 shows the maximum lift coefficient performance data for basic and MKC-Series airfoils at Re=100,000 to 300,000. Figure 3 (a–c) shows that at Re=100,000–300,000, the new MKC-Series airfoil has a maximum lift coefficient of 3%–5% as compared to the base airfoil. Maximum lift coefficients for the MKC7-6, MKC8-6, MKC9-6, and SG6043 were 1.65, 1.66, 1.68, and 1.7 at Re=100,000.

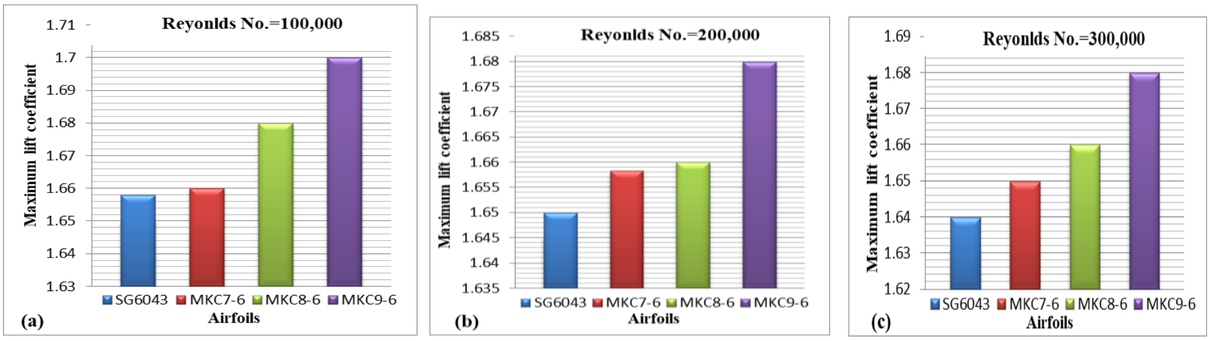

Fig. 3: Maximum lift coefficient of MKC-Series and SG6043 airfoil at different Re (a) Re=100,000 (b) Re=200,000 (c) Re=300,000

2.4 Airfoil analysis and fabrications

X-Foil and Cura 4.1.0 were used to analyse and optimize the airfoil numerically, with a t/c range of 0.8 to 1.6. The study and constructed model of the MKC-Series and SG6043 airfoil at Re=100,000. 2D-airfoil model as shown in Figure 4. PLA material was used in a 3D printer to create four airfoil. Each airfoil has a chord length of 0.05 m, a span length of 0.02 m, and a camber of 6% c. In comparison to the basic airfoil, the MKC-Series airfoil trailing edges have the roughest surface. 160 minutes

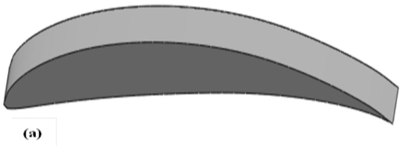

Fig 4: 2D-airfoil model Airfoil model in XFOIL software

3. Fabrications and Experimentation work

3.1 Fabrication of small wind turbine rotor blade

Printing PLA filaments with nozzle temperature set to 205 °C, bed temperature of 60 °C, and a print speed of 50 mm/s produced the optimized horizontal axis wind turbine blade structures in Table 2. Blade was constructed utilizing the MKC9-6 airfoil. The proposed airfoil blade model was imported into the X-Foil programme to have a circular tip for improved aerodynamic performance. The rotor has a 0.4 m diameter.

Table 2. Details of optimized blade geometry data information

Position	0	0.015	0.02	0.05	0.072	0.088	0.104	0.12	0.136	0.152	0.168	0.184	0.193	0.2
Chord, c (m)	0.012	0.012	0.012	0.042	0.035	0.029	0.026	0.022	0.019	0.018	0.016	0.015	0.014	0.002
Twist angle(deg.)	0	0	0	19.4	14.3	10.8	8.33	6.52	5.08	3.94	3.01	2.24	1.59	0
Airfoil	Circular	Circular	Circular	MKC9-6	MKC9-6	MKC9-6	MKC9-6	MKC9-6	MKC9-6	MKC9-6	MKC9-6	MKC9-6	MKC9-6	Circular

3.2 Wind tunnel tests

The experiments were conducted in an open wind tunnel in the fluid mechanics laboratory at the Trinity Academy of Engineering Pune (India) affiliated to the SPPU University. Figure 5 Fabrications of experiments on the proposed airfoil at various AOAs and wind speeds in a low-speed wind tunnel inside the test section.

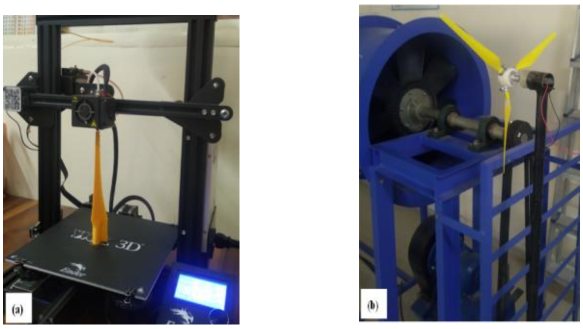

Fig. 5: Fabrication and testing of blade (a) Blade fabrication (b) Wind Tunnel test setup

4. Results and Discussions

This section presents the findings of the numerical and experimental research for all situations. Rotor blade pitch angles range from 0° to 45° in experimental wind turbine rotor instances with wind speeds ranging from the cut-in speed (3 m/s) to the rated wind speed (6 m/s).

4.1 Lift performance of MKC-Series airfoils and SG6043 base airfoil

Figures 6 (a-c), show the lift coefficient performance curves of the SG6043 and MKC-Series airfoils at Re=100,000–300,000. In the X Foil software, the examination of the fundamental SG6043 and MKC-Series airfoils is carried out by adjusting the AOA from 0° to 15° and the Re from 100,000 to 300,000. The MKC7-6, MKC8-6, MKC9-6, and SG6043 airfoils stall at AOAs of 12°, 13°, 14°, and 14°, respectively, with lift coefficients of 1.65, 1.66, 1.69, and 1.68 at a Reynolds number of 100,000, according to analysis results. The MKC7-6, MKC8-6, MKC9-6, and SG6043 airfoils stall at AOAs of 13°, 14°, 16°, and 15°, respectively, with lift coefficients of 1.63, 1.66, 1.67, and 1.65 at Re=200,000, according to analysis results. With lift coefficients of 1.64, 1.65, 1.66, and 1.64 at Re=300,000, the MKC7-6, MKC8-6, MKC9-6, and SG6043 airfoils also stall at AOAs of 14°, 16°, 15°, and 14°, respectively. When AOA approaches the stall angle, the flow becomes unstable on the suction side of the airfoil. The numerical results of the MKC9-6 airfoil drag performance when Re is varied from 100,000 to 300,000 are displayed in Figure 6(d) and taken from Figure 6(d).

According to the simulation results, the drag coefficient is observed to be 0.012, 0.045, and 0.075 for AOAs of 6^{o}, 12^{o}, and 15^{o} at Re=300,000, while the Cd of the MKC9-6 airfoil is observed to be 0.021, 0.015, and 0.012 at Re=100000, 200000, and 300000 for AOA=6^{o}. Additionally, it has been found that when the Reynolds number increased, the drag coefficient decreased. As Re increased from 100,000 to 300,000, Cd fell by roughly 5% to 15%.

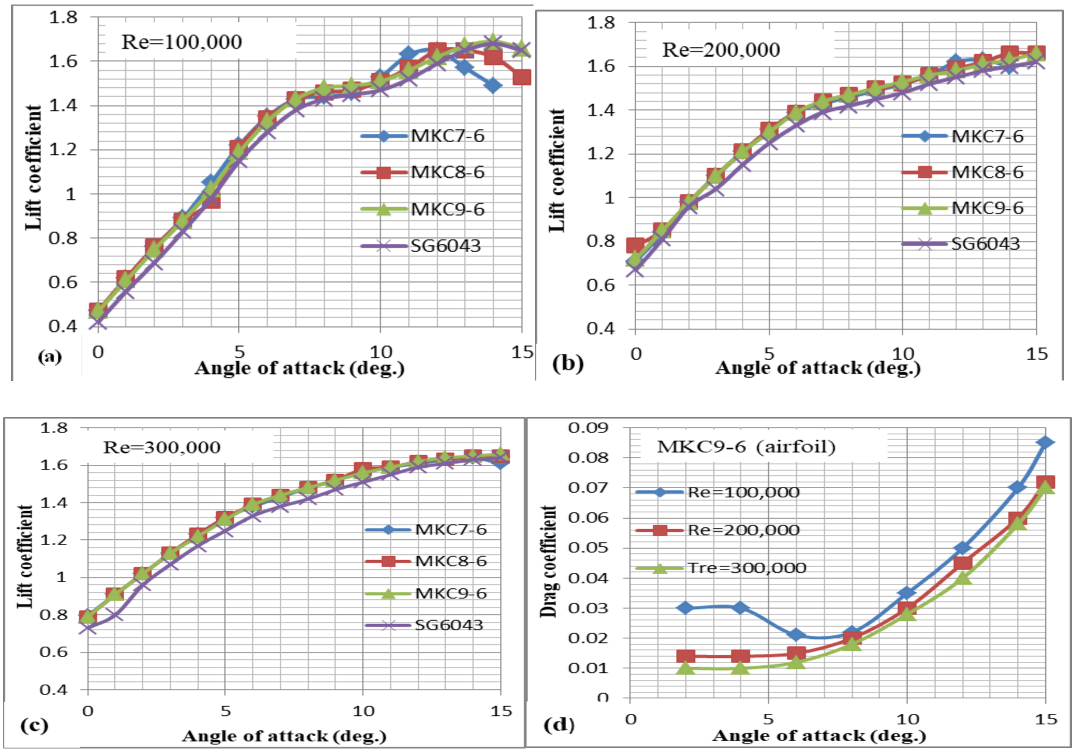

Fig. 6: Lift and drag performance versus AOA of SG6043 and MKC-series airfoil (a) Re=100,000 (b) Re=100,000 (c) Re=300,000 (d) MKC9-6 airfoil at Re=100,000 to 300,00

5. Conclusions

In this study, three innovative airfoils (MKC-Series) for tiny horizontal axis wind turbine applications were created, manufactured, and tested for aerodynamic performance in the low Reynolds number range of 100,000 to 300,000. The thickness to camber ratio was used to optimise and design the MKC-Series airfoil from the SG6043 base airfoil. With the highest combination of lift coefficient, lift-to-drag ratio, and lowest value of drag coefficient, the MKC-Series airfoils demonstrated good aerodynamic performance. The MKC7-6, MKC8-6, MKC9-6 and SG6043 airfoils had maximum lift-to-drag ratios of 71.6, 70.89, 68.9 and 66.6 respectively and maximum lift coefficient 1.65, 1.66, 1.69 and 1.68 respectively at AOA=7o for low Re=100,000. The MKC7-6, MKC8-6 and MKC9-6 airfoil had 3.94 %, 6.66 % and 3.83 % maximum L/D ratio as Compared to the SG6043 airfoil at

Re=200,000 for optimum AOA=4o to 5° respectively. The MKC7-6, MKC8-6 and MKC9-6 airfoil had 9.73 %, 6.35% and 5.08 % maximum L/D ratio as Compared to the SG6043 airfoil at Re=300,000 for optimum AOA=4° to 5° respectively. For the design and development of small horizontal axis wind turbine rotors at low wind speeds and low Reynolds number applications, the MKC-Series airfoil and blade geometry optimization are appropriate.

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