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# Investigations on Airfoils for Small Wind Turbine Blades for Rajshahi Weather Condition

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## Abstract

*This paper focuses on study of different airfoils and detecting their suitability in Rajshahi region in terms of wind speed and Reynolds number. As a consequence of increasing demand of renewable energy, it is now a matter of attention to extract enough power from such a site what was unthinkable earlier. Using a sequential analysis of several airfoils, it results in a couple of such airfoils whose performance and stability are most fitted for our study area. The last step is Coefficient of power calculation using Qblade software which gives validation of how airfoils have been investigated step wise. So, out of more or less 150 primarily selected airfoils based on previous works, it reaches 11 airfoils through six hierarchical elimination criteria. The future scope of this work is making sample prototype of small blade based on results of current effort to check the feasibility of the method of investigation.* .

Keywords: Airfoil, glide ratio, coefficient of lift, coefficient of drag, angle of attack

## 1. Introduction

Due to rapid depletion of fossil fuels and global warming concerns, demand of renewable energy sources are increasing day by day. It is estimated that, in some sectors, dominance of fossil fuel will last till 2050 [1]. So, different types of renewable energy sources such as biomass, wind energy, hydro energy and solar energy are well enough to take over the markets of fossil fuel in future [4]. Being one of the most favorable renewable energy sources, wind energy addresses energy deficit by ensuring zero $CO_2$ emission having good cost combativeness as against other energy sources in such locations where wind resources are well available [2,3].

Wind turbine generates power by partially stopping wind energy using the kinetic energy of wind. It can be named with different title based on type of form of output power [6]. Maximizing the extracted kinetic energy out of wind resources is a matter of investigation by technologists from the beginning of emergence of wind turbine. Therefore, many ideas have been evolved about how well wind energy can be extracted. One of the successful attempts is the developing horizontal axis wind turbine whose performance mostly depends upon blade aerodynamics and structure [4].

In many applications, small wind turbine is most fitted technology in respect of medium or large wind turbine. Specially, off-grid electrification and water pumping practices are precise examples of cause of small wind turbine implementation [5]. So, how would one recognize a wind turbine as small wind turbine (SWT)? International Electrotechnical Commission (IEC) has prescribed small wind turbine as one with swept area less or equal to 200 $m^2$ having rated power up to 50KW [7].

One of the most basic tools for designing a wind turbine blade is either design or selection of airfoil. Either designing new airfoil or selecting existing one from catalog usually depends on the type of applications the blade should be used for. In many practices, designing completely new airfoil gives advantage over only selecting one from the catalog. Selection of an airfoil without systematic modifications may not fit design specifications and requirements. In that case some modifications in the selected airfoil brings corresponding design to expected level [8]. Over the years, varieties of airfoils have been designed by different scientists and institutions for dedicated use in wind turbine blades. Among them, Airfoils from NACA are of older categories.

They have some limitations in performance criteria. They suffers from annual energy losses. Also, they are affected by leading edge contamination and are not appropriate for varying Reynolds's numbers. NREL airfoil families are comparatively insensitive to relative roughness effects which results in somewhat lower annual energy losses [9]. Delft University of Technology in Netherlands introduced Delft airfoil families. Their design goal was to maintain surface roughness insensitivity and convenient structural design. Consequently, their airfoils are comparatively thicker [10]. Other airfoil families are Risø airfoils by Risø National Laboratory in Denmark [11], CAS-W1 by the Chinese Academy of Sciences [12], MH airfoils by German scientist Dr.Martin Hepperle [13], Althaus AH, Wortmann FX, Selig Giguere SG [14] etc.

Our objective of this work is to investigate through various airfoils whether compatible with the weather region of Rajshahi based on air density, Reynolds's number, and average wind speed of the study area. In this point of view, we have considered some criteria based on which the relative acceptability of airfoil for Rajshahi region can be specified. For analyzing airfoil performance Qblade, a simulation software for wind turbine has been used. Airfoils that contribute to acquiring maximum coefficient of power has been prioritized giving less importance to structural design of the blade as our focus is on small wind turbine having less average wind speed.

## 2. Method

### A. Area under Study

Before investigating through various airfoils, it is necessary to find parameters that represents the area under study. Our investigation of airfoils is on the region of Rajshahi, Bangladesh. The first and foremost parameter that denotes wind profile of any is average wind speed of that region. In this case, table I shows the monthly average wind speed of Rajshahi. The wind speed data has been provided by "Regional Weather Office, Rajshahi". There are other parameters characterizing air flow of that region such as air density, dynamic viscosity of air, atmospheric pressure, dimensions of rotor blades etc. These parameters can be linked to one another by bringing another parameter called Reynolds number or shortly Re. Reynolds number for blade can be represented as follows:

$$\mathrm{Re} = \frac{\rho v C}{T} \tag{1}$$

Where, $\rho$ = Density of air, $v$ = Velocity of air, $C$ = Chord length of blade, T = Dynamic viscosity of air. Calculating Reynolds number for Rajshahi region gives value $1.5\text{x}10^5$ which satisfy the conditions for laminar flow.

Table 1. Average Wind Speed of Rajshahi in 2018

| Month | Average Speed in m/s (At 10m height) | Average Speed in m/s (At 2m height) |
|---|---|---|
| January | 8.46 | 2.17 |
| February | 7.64 | 2.32 |
| March | 12.31 | 4.12 |
| April | 14.54 | 6.50 |
| May | 15.13 | 6.33 |
| June | 13.36 | 4.5 |
| July | 14.71 | 6.03 |
| August | 13.04 | 4.5 |
| September | 11.07 | 3.76 |
| October | 5.94 | 2.82 |
| November | 4.23 | 1.88 |
| December | 8.61 | 2.17 |

### B. Initialization for Simulation

The inquiry of airfoils was executed through the software Qblade which provides for both of the capabilities called XFOIL and XFLR5 [18]. Initially, airfoil data files were imported from UIUC Airfoil Coordinates Database [16] and the National Renewable Energy Laboratory USA (NREL) [17]. From the databases, 150 airfoils were selected. High lift airfoil, low Reynolds number airfoil were prioritized while airfoils for general aviation were avoided. Before analyzing each airfoil, some parameters were chosen. At first, Re was inserted. In this case, the value was given as per calculation done for Rajshahi region. Mach number, another parameter for XFOIL direct analysis [18] was defined as zero in this case because velocity of rotor blade is much lower than that of sound [15, 19]. The value of NCrit has been taken as 9 which is default for general wind turbine

## C. Criteria under Investigations

All the airfoils have been examined according to six different criteria. First one is justifying the capability of airfoil data by checking the convergence of the data to the XFOIL direct analysis program. This means that XFOIL program could not calculate any coefficients for those airfoils having failure in convergence and then gives garbage values as output [15].

Second measure of the study is maximum glide ratio GR at Re $1.5x10^{5}$ which is calculated Re for Rajshahi region. GR is the ratio of coefficient of lift to coefficient of drag.

$$GR = \frac{C_L}{C_D} \tag{2}$$

Where, $C_L$ is coefficient of lift force and $C_D$ is Coefficient of drag force. The airfoils which have passed the first criteria are selected to find maximum GR. Then the mean of max-GR is calculated. The airfoils failed to exceed mean max-GR and 0.9 coefficient of lift force at max-GR, the third criteria are not considered as qualified for being evaluation further. Fourth one is difference of angle of attack at max-GR between Re $1.1x10^{5}$ and $3.3x10^{5}$. This criterion is important to detect instability in wind turbine operation. Fifth measure for study is percentage difference of GR from max-GR at interval of 0.5 degree angle of attack. This indicates level the stability maximum glide ratio of the airfoil. It is preferred not to have percentage more than 5% [15].

Finally, the coefficient of power has been calculated for those airfoils which have satisfactory value in third, fourth and fifth criteria. This final criterion may be called feedback criterion which certifies the effect of previous criteria, most important criteria among all. In this case, a common blade has been assumed based on which airfoil can be investigated. In this stage, some of the parameter should be assumed. Here, tip speed ratio has been taken as 5.5. Further, it has been considered that the rotor of corresponding wind turbine designed for the Rajshahi region has three blade having 1m length of each length.

## 3. Result

At the first stage, 43 airfoils have been discarded because of some internal flaw in running the program resulting in some garbage values. Figure 1 shows an airfoil failed to satisfy this criterion. Then, mean value of maximum GR has been calculated as 51. 16 Out of 107 airfoils that could pass the first stage, 51 of them have turned out that they could not cross the average value. Figure 2 partially demonstrates those airfoils. Then comes the third criterion. 16 airfoils are such that they are have lower drag coefficient but cease to possess higher lift coefficient. Figure 3 graphically shows such type of airfoils.

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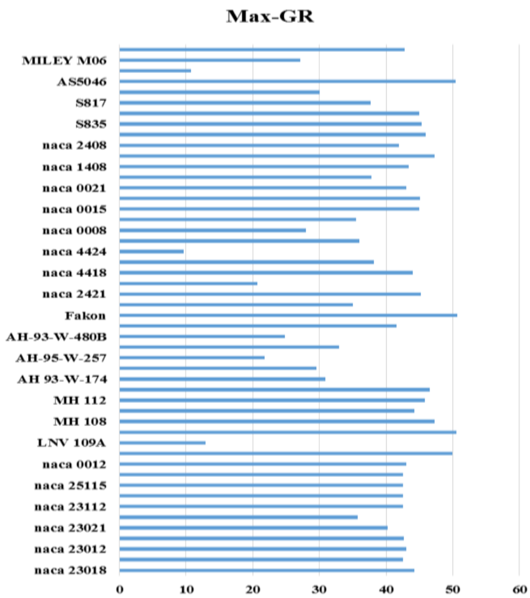


Fig. 1 Airfoils failed to exceed mean value of Maximum GR

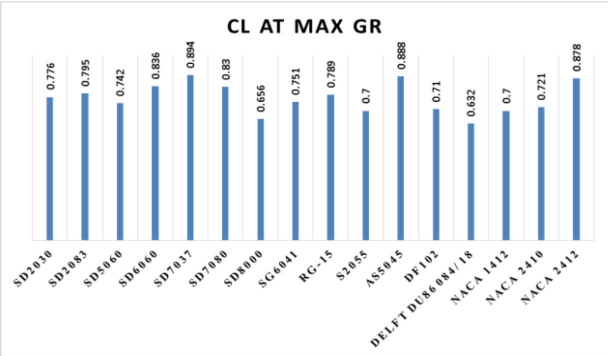


Fig. 2 Airfoils failed to achieve at least 0.9 coefficient of lift force

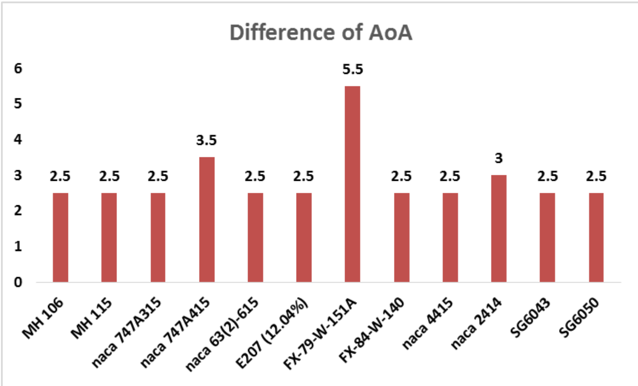


Fig. 3 Airfoils with more than $2^0$ Difference of Angle of Attack

Then, rest of the airfoils have been taken to check the difference between angle of attack at max-GR for Reynolds number of $1.1x10^5$ and $3.3x10^5$. In this stage, it has been observed that 12 of the airfoils have difference of angle of attack more than $2^0$. It indicates that if blade is designed with those airfoils, it may produce instability in aerodynamic behavior of wind turbine [15]. Figure 4 shows airfoils that could not pass the fourth criterion.

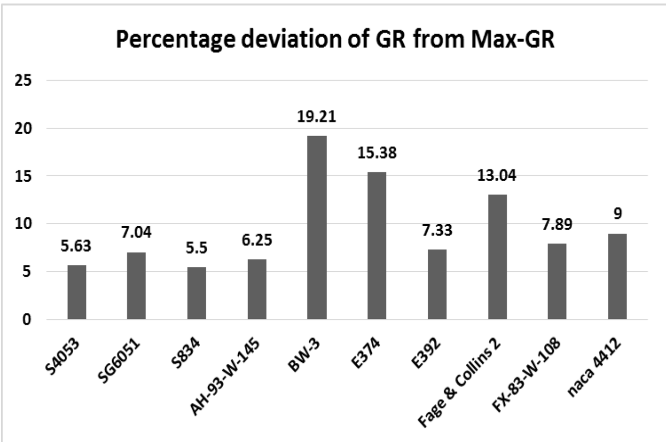


Fig. 4: Airfoils failed to achieve fifth criterion

After that, maximum percentage deviation of glide ratio from maximum glide ratio at $0.5^0$ angle of attack at both side of the peak has been calculated for the airfoils which pass the fourth criterion. Here, 10 of the airfoils score more than 5% deviation which signifies not enough stability in Max-GR position. Fig. 5 visualize such kind of airfoils.

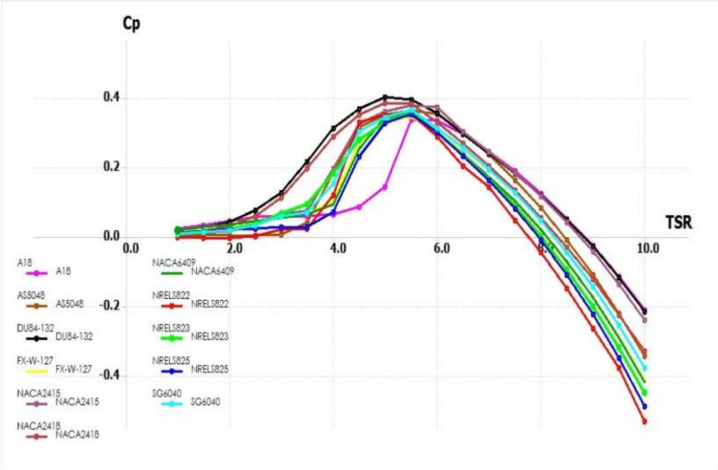


Fig. 5: Coefficient of Power vs. Tip speed Ratio curve

Finally, 11 airfoils enter into coefficient of performance test passing all of the above criteria. These airfoils are NREL's S822, S823 and S825, DELFT DU84 132, A18, AS5048, SG6040, Fx-84-W-127, NACA 6409, NACA 2415 and NACA 2418. Table II demonstrates the overall performance of these airfoils. It clearly shows that DELFT DU84 132 has the highest efficiency securing 0.4 coefficient of power or shortly $C_P$. All other airfoils have close value to one another everyone acquiring more than 0.3 $C_P$.

Table 2. Evaluation of All Criteria for Finally Selected Airfoils

| Name of Airfoil | Max GR | $C_L$ at Max-GR | Difference of AoA | Percentage deviation of GR (%) | $C_P$ |
|---|---|---|---|---|---|
| S822 | 58.55 | 0.973 | 2 | 2.77 | 0.355 |
| S823 | 53.81 | 1.16 | 2 | 1.50 | 0.36 |
| S825 | 60.78 | 1.42 | 2 | 2.59 | 0.355 |
| DU84-132 | 64.11 | 0.93 | 1.5 | 3.1 | 0.40 |
| A18 | 76.85 | 0.95 | 2 | 3.95 | 0.34 |
| AS5048 | 51.73 | 0.94 | 2 | 3.05 | 0.36 |
| SG6040 | 64.04 | 1.2 | 0.5 | 1.88 | 0.36 |
| FX-84-W127 | 70 | 1.23 | 2 | 2.57 | 0.34 |
| NACA 6409 | 75.3 | 1.4 | 2 | 3.2 | 0.34 |
| NACA 2415 | 57.64 | 0.98 | 1.5 | 0.95 | 0.375 |
| NACA 2418 | 52.62 | 1.05 | 1 | 0.7 | 0.38 |

## 4. Discussion

After testing 150 airfoils through hierarchical six step analysis, the results show which airfoil to use for designing small blade for the weather area of Rajshahi or areas with same wind features. For example, the airfoil DELFT DU84 132 fits most perfectly to our application specifications. It has higher maximum glide ratio of 64.24 having $C_L$ more than 0.9. It may provide good aerodynamic stability to the blade. It also ensures max-GR stability having percentage deviation as less than 5%. Lastly, efficiency of the blade designed with this airfoil conceptually indicates the best choice specific to our application. Figure 6 shows the XFOIL generated polar curve. There is a scope in future to study more about that. The airfoils that could not show good performance in fourth and fifth criteria might show better performance to extract more power. In addition to that, validation of the method of investigation would be effective if prototype could have been made.

## 5. Conclusion

The main concept of the investigation methodology has been taken from the work of selecting airfoils by Fuentes et al. [15]. The area specific airfoil study is inspired by the work of Tarhan et al. [20]. It is really a quicker way of investigating airfoils as well as giving quite better intuition of performance and stability of the blade. Qblade has been used in this work because it provides both XFOIL and XFLR5 programs to analyze airfoils. Moreover, it is a dedicated software for designing and analyzing wind turbine blades. Thus it has helped finding coefficient of power in a very short period of time and deciding better airfoils.

## 11. References


[1] P. E. Brockway, A. Owen, L. I. Brand-Correa, and L. Hardt, **"**Estimation of Global Final-Stage Energy-Return-on-Investment for Fossil Fuels with Comparison to Renewable Energy Sources", *Nature Energy*, Vol. 4, pp. 612–621, 2019.
[2] A. M. Eltamaly and H. M. Farh, "Maximum power extraction from Wind Energy System Based on Fuzzy Logic Control", *Electric Power Systems Research*, Vol. 97, pp. 144–150, 2013
[3] W. J. Zhu, W. Z. Shen and J. N. Sørensen, "Low- Noise Airfoil and Wind Turbine Design" in *Wind Turbines - Design, Control and Applications*, A. G. Aissaoui, A. Tahour, Eds. Croatia: Intech, 2016, Ch. 3, pp. 55-72. Accessed on: July, 21, 2019.[online]. Available: http://dx.doi.org/10.5772/63335
[4] T.J Ajoko and T. Jhon, "Horizontal Axial Wind Turbine Blade Design Using Ansys Fluent", *Journal of Multidisciplinary Engineering Science Studies (JMESS*), Vol. 2, 797-803, 2016.
[5] O. Probst, J. Martínez, J. Elizondo and O. Monroy, (April 4th 2011). "Small Wind Turbine Technology" in *Wind Turbines*, I. Al-Bahadly, Ed. IntechOpen, 2011, ch. 5, pp. 107-135. Accessed on: July, 21, 2019 [online]. Available from: https://www.intechopen.com/books/wind-turbines/small-wind-turbine-technology.
[6] S. Ravikumar, V. Jaswanthvenkatram, Y.J.N.V. Sai kumar and S.Md. Sohaib, "Design and Analysis of Wind Turbine Blade Hub using Aluminium Alloy AA 6061-T6", *IOP Conference Series: Materials Science and Engineering* ,Vol. 197 Paper No.1, pp. 1-8, 2017.
[7] Commission, I. E. IEC 61400 - 2 Wind turbines –Part 2: Small wind turbines, 3rd ed. IEC, Geneva, 2013. (Standards and Reports).
[8] R. Eppler, Airfoil Design and Data, *Springer-Veriag Beriin Heidelberg*, 1st ed., pp. 1-2, 1989.
[9] J. L. Tangier and D. M. Somers, NREL Airfoil Families for HAWTs, NREL, Colorado, USA, 1995. (Reports)
[10] W.A. Timmer, and R.P.J.O.M. van Rooij (November 01, 2003). "Summary of the Delft University Wind Turbine Dedicated Airfoils", *Journal of Solar Energy Engineering*, vol. 125(4), pp. 488-496, 2013.
[11] P. Fuglsang, and C. Bak, "Development of the Risø wind turbine airfoils", *Wind Energy*, Vol. *7*, pp. 145-162, 2004.
[12] X. Li, K. Yang, L. Zhang, and J. Bai, "Experimental study of Reynolds number effects on performance of thick CAS wind turbine airfoils", *Journal of Renewable and Sustainable Energy*, vol. 9, pp. 063309(2-19), 2017.
[13] "*Aerodynamic Design of a Windmill*," Accessed on: 30 July. 2019. [Online]. Available: http://www.mh-aerotools.de/airfoils/windmill.htm.
[14] "*Camberline : Newsletter of the UIUC Low-Speed Airfoil Tests,"* Dec. 5, 1997. Accessed on: 30 July 2019. [Online]. Available: https://m-selig.ae.illinois.edu/uiuc_lsat/lsat_5bulletin.html.
[15] V.S. Fuentes , C. Troya, G. Moreno, and J. Molina, "Airfoil Selection Methodology for Small Wind Turbines", *International Journal of Renewable Energy Research,* Vol. 6, No. 4, pp. 1410-1415, 2016.
[16] "*UIUC Airfoil Coordinates Database*," Accessed on: 25 July. 2019. [Online]. Available: https://m-selig.ae.illinois.edu/ads/coord_database.html
[17] "*Wind Turbine Airfoil Families*," Accessed on: 25 July. 2019. [Online]. Available: https://wind.nrel.gov/airfoils/AirfoilFamilies.html
[18] D. Marten, "QBlade Short Manual: v0.8," Accessed on: 20 July, 2019. [Online]. Available: http://www.q-blade.org/#downloads
[19] C. Yan, and C.L. Archer, "Assessing Compressibility Effects on the Performance of Large Horizontal-Axis Wind Turbines", *Applied Energy*, Vol.212, pp. 33-45, 2017
[20] C.Tarhan and İ. Yilmaz, "Investigation of Small Wind Turbine Airfoils for Kayseri Weather Conditions", *International Journal of Fuels Fire and Combustion*, Vol.4, pp. 42-43, 2016