Comparison and Selection of Airfoils for Small Wind Turbine between NACA and NREL's S series Airfoil Families

Md. Robiul Islam[1], Labid Bin Bashar[2], Dip Kumar Saha[3], NazmusSowad Rafi[4]

Lecturer[1, 3], Student[2, 4]

Department of Mechatronics Engineering

Rajshahi University of Engineering & Technology Rajshahi, Bangladesh

Corresponding author's email id: *-robiulislamme07@gmail.com*

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Abstract

This paper presents comparative study different airfoils from NACA and NREL Airfoil families focusing on their suitability for small wind turbine. In this point of view, four criteria of comparison have been taken into account. The criteria are: maximum glide ratio at lower and higher Reynolds number, difference between angle of attack between lower and higher Reynolds number and percentage deviation of maximum glide ratio from stall point. XFOIL analysis with the help of Qblade software results in data necessary for comparing two families of airfoil which finally show that NACA airfoils have better average performance criteria whereas NREL airfoils have better stability criteria.

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

INTRODUCTION

Worldwide interest for energy has increased worry on the point of greenhouse effects initiated by fossil igniting and excessive fuel consumption. This has led to global warming and has brought about the increasing use of the renewable energy resources provided by biomass, sun, wave and wind. Over the last thirty five years, wind energy has become an outstanding part of the answer to these issues, and therefore the design, implementation and enforcement of wind energy producer is not limited to small-scale, experimental basis rather has entered into a completely trendy and mature industrial sector [1].

Wind turbine is a device or machine that produces energy by somewhat obstructing wind speed employing the theory kinetic energy of wind. It is required to study about the techniques that can ensure the maximization of wind energy out of available resources. Therefore, a couple of theories have been emerged about how precisely wind energy can be achieved. One of the finest trials is the modelling of horizontal axis wind turbine whose conducts mostly relies on blade aerodynamics and structure [2].

A wind turbine is formed of different parts and accessories. The most significant component of wind turbine is its rotor blade. The geometry of blade must be such that it would rotate in an expected wind speed. Airfoil is a geometric section of blade which determines the efficiency of rotor blades. 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 bring corresponding design to expected level [3].

There are obviously several engineering needs moving into the choice of a wind turbine airfoil. These embody primary needs associated with aerodynamic performance, structural strength and stiffness, manufacturability, and maintainability. Needs related to alternative rotor characteristics like electromagnetic interference, acoustic noise generation, and aesthetic look are typically assumed to be of secondary importance. The usual assumption, traditionally established in airplane lifting surface theory, is that high lift and low drag are fascinating for an airfoil which the lift-to-drag ratio (often abbreviated as L/D) may be an important thought. This point of discussion is not similar to that of airfoils of aircraft wing. General analysis of rotor performance shows that the first issue is that the product of the chord and also the lift coefficient, or C_{CL}. Thus, once different characteristics like tip-speed quantitative relation and diameter are held constant, operational at a better lift constant can allow the employment of narrower blades. Generally, this may not end in lower viscous power losses, since viscous torsion is controlled additionally by the L/D quantitative relation of the airfoil than the particular amount of lift [4].

The early NACA airfoil series, the 4-digit, 5-digit, and changed 4-/5-digit, were generated employing analytical equations that describe the camber (curvature) of the mean-line (geometric centreline) of the airfoil section moreover because of the section's thickness distribution along the length of the airfoil. Later families, as well as the 6-Series, are more sophisticated shapes derived exploiting theoretical instead of geometrical ways. Before the National advisory Committee for aeronautics (NACA) developed these series, airfoil design was rather discretionary with nothing to guide the designer except past expertise with legendary shapes and experimentation with modifications to those shapes [5].

NREL airfoil families are relatively insensitive to relative roughness effects which end up in somewhat lower annual energy losses. Additionally, the airfoils square measure typically modulated to a thicker body which can end in surprising performance criteria. If it's stall-regulated turbine, additional performance improvement is got by using blade tip airfoils with low GR, scoop that associates regulation of highest power. This permits the utilization of 100 percent to fifteen a lot of sweptback rotor space for a given generator size. NREL's S-Series airfoils are available skinny and thick families. The skinny aerofoil families lend themselves to stall regulated wind turbines wherever performance losses to aerofoil change of state square measure vital. For variable-pitch and variable-speed turbines, aerofoil change of state isn't a serious drawback. Generally, a primary aerofoil is combined with root and tip airfoils. Most turbine blades have a circular section that attaches to the hub. This can be particularly vital for pitching blades. There’s then a transition from the circular portion to the basis aerofoil section that sometimes happens concerning the most chord. Between the circular section and also the root aerofoil section, the transition is faired. The fairing method ought to avoid concavities to forestall buckling. The first aerofoilsometimes happens in its original state round the seventy five percentradiuses and also the tip aerofoil is typically pure round the ninety five percent positions. Numerous interpolation ways square measure accustomed outline aerofoil shapes between the 3 pure airfoils. The tip aerofoil is additionally sometimes preserved bent the tip of the blade; however some allowances may be created to accommodate special tip shapes. The basis aerofoil usually has the best thickness quantitative relation (maximum thickness to chord quantitative relation) and also the thickness ratio gets smaller together approaches the tip. At the blade root, giant aerofoil thickness is required to regulate blade structural issues and toward the tip, diluting airfoils square are required to degrade drag and blade change of state losses [6-7].

In this paper, through some experiment, comparison between different NACA and NREL airfoils would be demonstrated. Each and every experiment would be based on certain criterion. Some examples of the criteria are: Glide ratio at Renumber of 1x10^5, glide ratio at Renumber of 3.3x10^5, C_L at maximum GR, stall point, percentage deviation of GR from maximum GR, difference of angle of attack etc.

METHODOLOGY

While coming up with a wind turbine, the typical wind speed is simply the primary parameter within the study, it is also necessary to think about the atmospheric pressure, air density, air consistency and also the dimensions of the generator. So, a constant that associates with these parameters is required to portray the airflow, the Reynolds number, hence termed as Re, can fulfill this case. Reynolds number for blade can be represented as follows [8]:

$$\mathrm{Re} = \frac{\rho v C}{T} \quad (1)$$

Where, ρ = Density of air, v = Velocity of air, C=Chord length of blade, T =Dynamic viscosity of air. Not only Re, but also Glide ratio (GR) is a significance performance identity of an airfoil. It is also called lift to drag ratio. It is expected to have higher lift to drag ratio, as it raises the rotor torque and put down the bending moments on the rotor blade for a definite lift value as well.

So, the glide ratio is given by the following equation [9]:

$$GR = \frac{L}{D} = \frac{C_L}{C_D} \quad (2)$$

Where L and Dare the lift and drag force for corresponding airfoil. C_L and C_D are coefficient of lift and drag force respectively.

So, the first tool for comparing among airfoils is maximum value of glide ratio at low Reynolds number. In this point of view, ten airfoils from NACA and NREL airfoil families each are taken and compared to see which one has more maximum GR at low Re. It is much significant for small wind turbine at low wind speed area because it gives a light outline about cut in speed of the corresponding wind turbine. Hence, fig 1(a) and 1(b) demonstrates lift to drag ratio at the range of angle of attack (or alpha) at Re of 1x10^5 for NACA and NREL airfoils respectively [10].These two curves predict how the airfoils would help generating power at lower wind resources. The figures also show that NACA 6409 airfoil has the highest maximum glide ratio among all airfoils here. But NREL airfoil curves are comparatively smoother and hold more or less unique shape. In this case, curves some of NACA airfoils possess ridges which may lead to noise and discontinuity in power generation for stall controlled wind turbine.

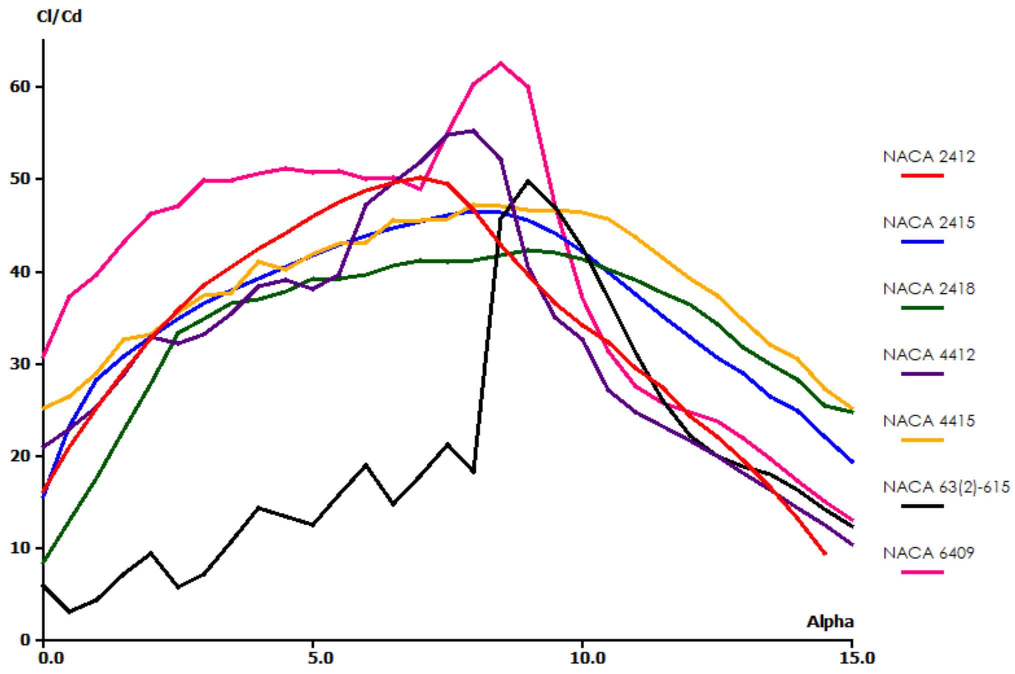

Figure 1(a):- Glide ratio Vs. Angle of Attack at Reynolds number of 1x10^5 for NACA

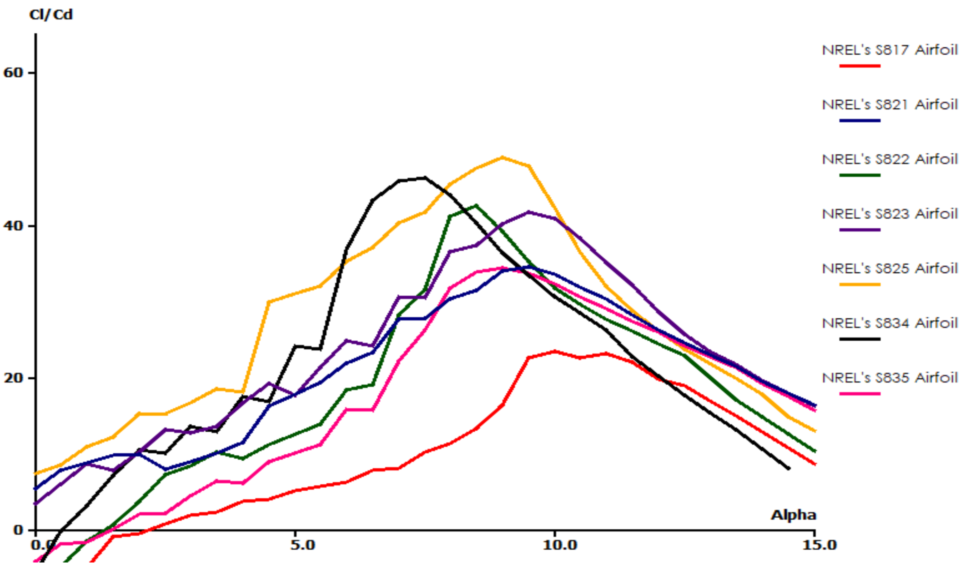

Figure1 (b):- Glide ratio Vs. Angle of Attack at Reynolds number of 1x10^5 for NREL airfoils.

Again, the second criterion for comparing among airfoils is maximum value of glide ratio at higher Reynolds number. Higher value of maximum lift to drag ratio at this point is desired because it signifies peak value of power generation of wind turbine. Hence, fig 2(a) and 2(b) demonstrates lift to drag ratio at the range of angle of attack at Re of 3.3x10^5 for NACA and NREL airfoils respectively [10]. In these figures apart from the values of maximum GR, curves of NACA airfoils are comparatively smoother than that of NREL airfoils.

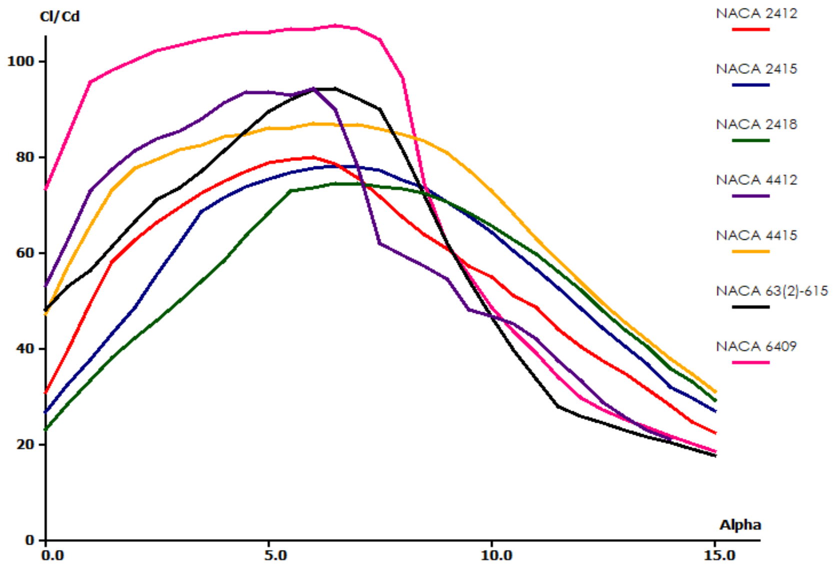

Fig. 2(a): Glide ratio Vs. Angle of Attack at Reynolds number of 3.3x10^5 for NACA.

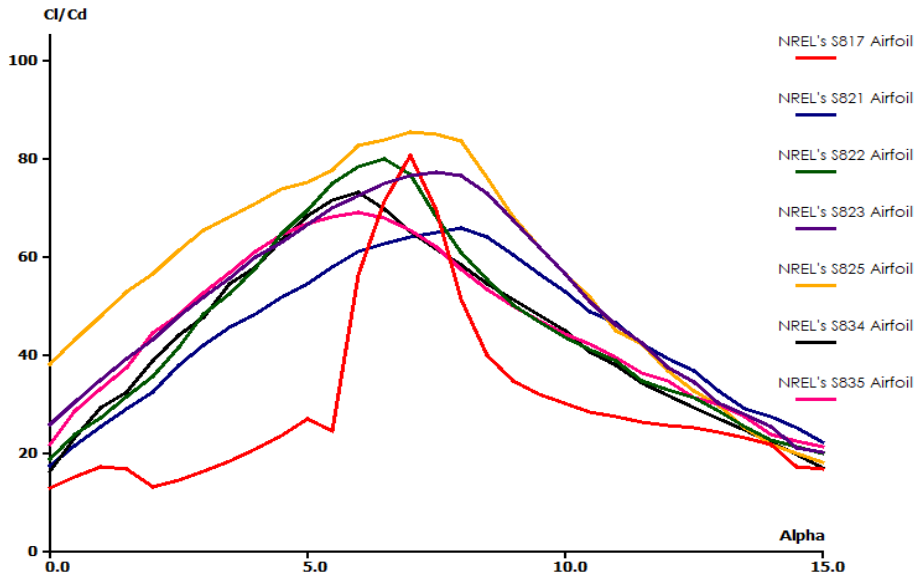

Fig. 2(b): Glide ratio Vs. Angle of Attack at Reynolds number of 3.3x10^5 for NREL airfoils.

It is important to ensure that the airfoil to be used in designing wind turbine blade must not incur any instability in operation. Specially, in case of pitch controlled wind turbine, it is necessary to keep angle of attack more or less constant to uphold the operability in the fullest sense. Henceforth the third criteria describes difference of angle of attack at maximum GR between Re 1x10^5 and 3.3x10^5. The lower the value of difference of angle of attack, higher is the possibility of sable operation of the wind turbine [10]. Fig 3(a) and 3(b) illustrate such phenomenon in form of bar graph.

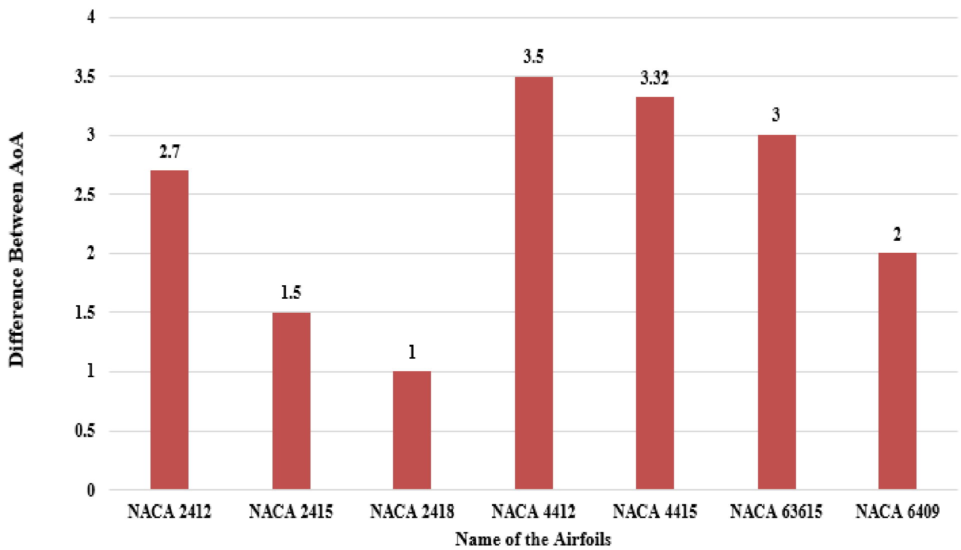

Fig.3 (a): Difference of Angle of Attack at maximum Glide Ratio for NACA

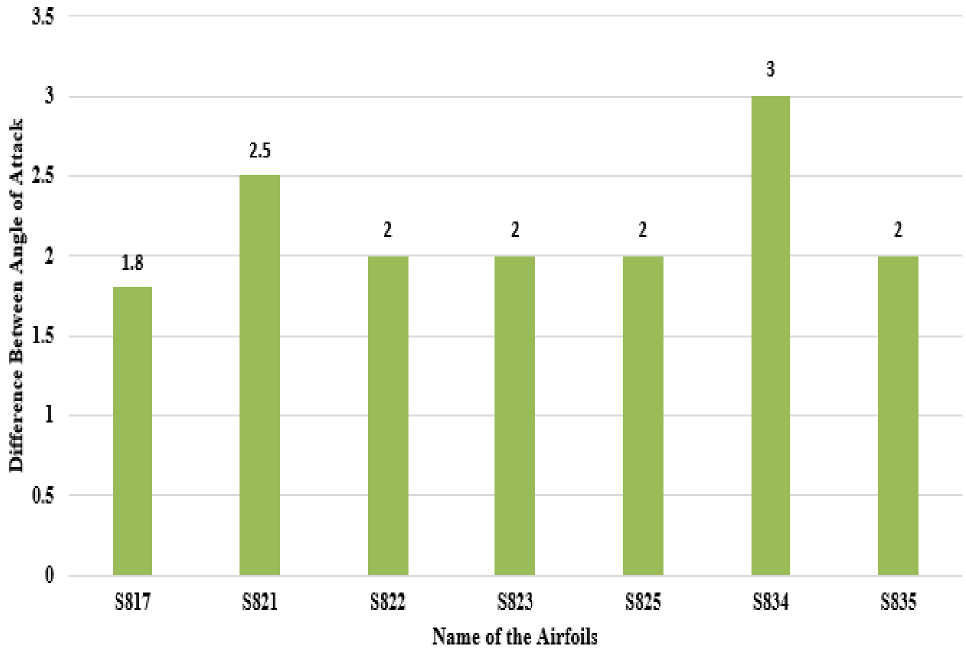

Fig.3(b): Difference of Angle of Attack at maximum Glide Ratio for NREL airfoils.

Finally, percentage deviation of maximum GR from both side of stall point is the fourth point of comparison. The range of angle of attack from stall point is 0.5 degree. More deviation means more instability factor of the corresponding wind turbine. Fig 4(a) and 4(b) illustrate such phenomenon in form of bar graph.

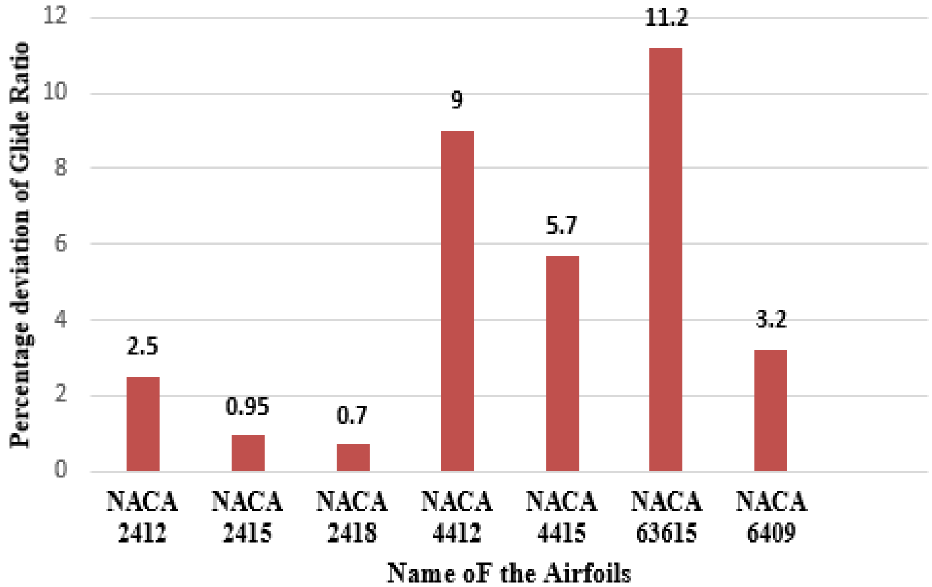

Fig.4 (a): percentage deviation of maximum GR from both side of stall point for NACA

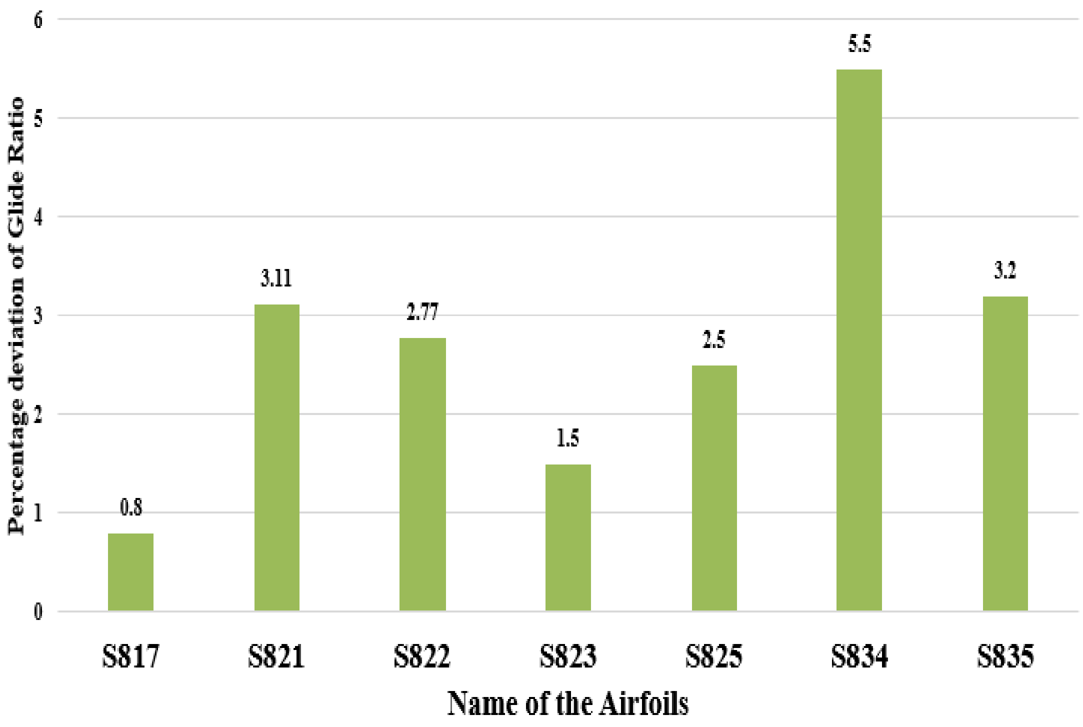

Fig.4 (b): percentage deviation of maximum GR from both side of stall point for NREL airfoils.

Comparison of average values of four criteria between selected NACA and NREL airfoils is mentioned bellow for proper selection of airfoils for small wind turbine for extraction of maximum wind energy.

Table 1: Comparison of average values of four criteria between selected NACA and NREL airfoils

Criteria	NACA	NREL
Average max. GR at low Re	46.4	41
Average max. GR at high Re	78	75
Average max. difference of angle of attack	2.44	2.18
Average percentdeviation of GR	4.78	2.75

RESULT

Average of maximum GR at Re of 1.0x10^5 for NACA airfoil is 46.5 whereas it is 41 for NREL airfoils. It means that NACA airfoil contribute more in low wind speed area. Again average maximum GR at Re of 3.3x10^5 for NACA airfoil is 78 and it is 75 for NREL which is close to that of NACA airfoils. It illustrates that both airfoil families are able to contribute peak power generation. Then NACA airfoils have 2.440 difference of angle of attack on average. On the other hand, it is 2.180 for NREL airfoils. Finally, NACA airfoil family have average of 4.78 % deviation of Maximum G_R from stall point whereas it is 2.75% for NREL airfoils. So, NREL airfoils are better suited in stability criteria than that of NACA airfoils.

DISCUSSION

The study was performed on Q-blade [11] software developed by Technical University of Berlin where XFOIL program with XFLR5 graphical user interface is available. Moreover, it is dedicated software for designing and analysing wind turbines. Before undergoing all the simulation, Mach number was considered as zero because motion of blade compared to speed of sound is almost insignificant. Furthermore, the value of Ncrit is important factor forfree flow turbulence and it helps to ascertain the transition location if no forced trip location is mentioned. A turbulent layer will generate more drag, but separate at higher airfoil angles of attack. In this work, value of Ncrit was taken as 9 which is a standard value for any general purpose wind tunnel.

CONCLUSION

Overall, a couple of airfoils were taken from both airfoil families. They were compared on the basis of some performance and stability criteria. Which airfoil family is better for small wind turbine, can be decided from the result of simulation. In performance criteria, NACA airfoils have rendered better results but things are opposite in case of stability criteria. In future, DELFT airfoils can be added in comparing between airfoils on far more criteria.

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