Aerodynamic Analysis of S Series Wind Turbine Airfoils by using X Foil Technique

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Abstract-In order to attain supreme energy from wind turbine economically, blade profile enactment must be acquired. For extracting extreme power from wind, it is necessary to develop rotor models of wind turbine which have high rotation rates and power coefficients. Maximum power can also be haul out by using suitable airfoils at root and tip sections of wind turbine blades. In this research four different S-series airfoils have been selected to study their behavior for maximum power extraction from wind. The wind conditions during the research were ascertained from the wind speeds over Kallar Kahar Pakistan. In order to study the wind turbine operation, the extremely important parameters are lift and drag forces. Therefore an endeavor to study lift force and drag force at various sections of wind turbine blade is shown in current research. In order to acquire the utmost power from wind turbine, highest value of sliding ratio is prerequisite. At various wind speeds, performance of several blade profiles was analyzed and for every wind speed, the appropriate blade profile is ascertained grounded on the utmost sliding ratio. For every airfoil, prime angle of attack is resolute at numerous wind speeds.

Keywords-Airfoils, Angle of Attack, Sliding Ratio, Wind Speed, Tip Speed Ratio, Reynolds Number

I. INTRODUCTION

One of the crucial inputs for the development of any country is energy. State of development of a country can be described by a mutual factor which is energy supply per unit capita. Pakistan is a third world country with 188 million population [i]. Energy supply per capita of Pakistan is 0.48 tons of oil equivalent (TOE) annually in association to world's average of 1.90 TOE [ii]. Unfortunately the energy production for the last decade is static, whilst for next five years,annual growthrate in demand is estimated 7.4 %. Almost 68 % inhabitants of Pakistan resides in rural regions while 37 % has no electricity facility. Their life standard can be enhanced by facilitating least amount of electricity.

At present, Pakistan has 22812 MW installed electrical generation capacity, 67 % of which comes from fossil fuels, 29.7 % from hydel resources and the rest from nuclear energy [iii-iv]. Hydroelectricity is cheaper and has less pollution effects but gradual decrease in its contribution is being observed from 70% in 1960s to 33% currently [v]. Electricity prices and air pollution has been increased due to this trend.

Environment corrosion, fossil fuels expenses and huge gap between demand and supply are the factors which necessitate reliable, environment friendly and cost effective energy resources. Now a days, world focus on development of renewable energy resources has been increased [vi]. Wind energy has supreme future scenarios among the entire sorts of sustainable and renewable energy resources. Furthermore, wind energy has attract the world as it originates all over the world and it is valuable renewable energy because it has no effect on greenhouse due to any radiation [vii]. World's capacity of wind power generation has touched to 282,275 MW at the end of 2013 [viii]. Wind is a low density power source. Maximum conversion of wind energy efficiency into mechanical energy leads to make it economically feasible. For achieving this goal, rotor aerodynamics is the key factor.

Syed et al was used two dimensional CFD RANS equations for S809 and S826 wind turbine blade airfoils at low Reynolds number and 11 m/s [ix]. Hoogedoorn et al had also been carried out two dimensional CFD RANS computations for NACA 0008 and NACA 0012 at high Reynolds numbers [x]. Wang et al was applied URANS approach on NACA 0012 air foil at free stream velocity 14 m/s [xi]. The literature indicates that high wind speed range is the main focus of most researchers but no one emphasis on range of low wind speed.

Pakistan is now focusing on renewable energy resources. Alternative energy development board (AEDB) Pakistan has made short and long term policies. Main aim of short term policy is to produce 650 MW of wind power in near future and to enter this power into national grid [xii]. Major aims of long term policy includes to make sure 10 percentage share of renewable energy in total power production of Pakistan at the end of 2015 and to produce 9.7 GW electricity from wind and solar energy at the end of 2030 [xii].

Main objective of this research is to find the most suitable HAWT wind turbine airfoil for the wind conditions of Sardhi, Kallar Kahar, Pakistan at Latitude 32.70° N and Longitude 72.73° E [xiii]. At 50m height, Kallar Kahar has 293W/m^2 total wind power density which makes it an exceptional site for wind power generation prospects according to international wind power classification [xiii]. Profili software is used for determination of aerodynamic load on selected airfoils.

II. CONTEMPORARY RESEARCH

In order to enhance wind turbine efficiency, highest power produced by wind turbine is required. In current research, wind flow is analyzed around blades of wind turbine to determine power. National Renewable Energy Laboratory developed blade profiles are selected for current research. When associating different airfoils, drag and lift coefficients for every airfoil are determined at various angles of attack. Drag and lift forces are measured by dimensionless drag and lift coefficients and depend upon airfoil shape and α (angle of attack). Equations 1 and 2 can express lift and drag forces calculations [xiv] as

$$L = (½)\rho A V^2 C_L \quad (1)$$

$$D = (½)\rho A V^2 C_D \quad (2)$$

Equation 3 can expresssliding ratio [15] as

$$\varepsilon = L/D = C_L / C_D \quad (3)$$

III. METHODOLOGY

Cross sections of wind turbine blades use profiles of airfoils to produce mechanical power. Determination of blade dimensions depends upon the airfoil characteristics, maximum required power and strength. Well tested airfoil families have been used to design modern horizontal axis wind turbines. Thin airfoil is used to design blade tip for high sliding ratio and for structural support, thick airfoil is used for root area. Air foil characteristics should be determined before the discussion of wind turbine power production [xv]. NREL generated, 2D S-series profiles are used for aerodynamic simulations with the help of RANS equations. Performances of blades are tested at selected range of winds as mentioned in Pakistan metrological department report for Sardhi Kallar Kahar, Pakistan [xiii] and for each wind speed, appropriate profile will be determined on the basis of maximum power produce by wind turbine blade. For optimum blade shape, Wilson et al has calculated the power coefficient C_P for turbines by considering the drag and finite number of blades [xv]. The results fit accessible records within 0.5% accuracy for sliding ratio from twenty five to infinity, tip speed ratios from four to twenty and one to three number of blades (B) [xv].

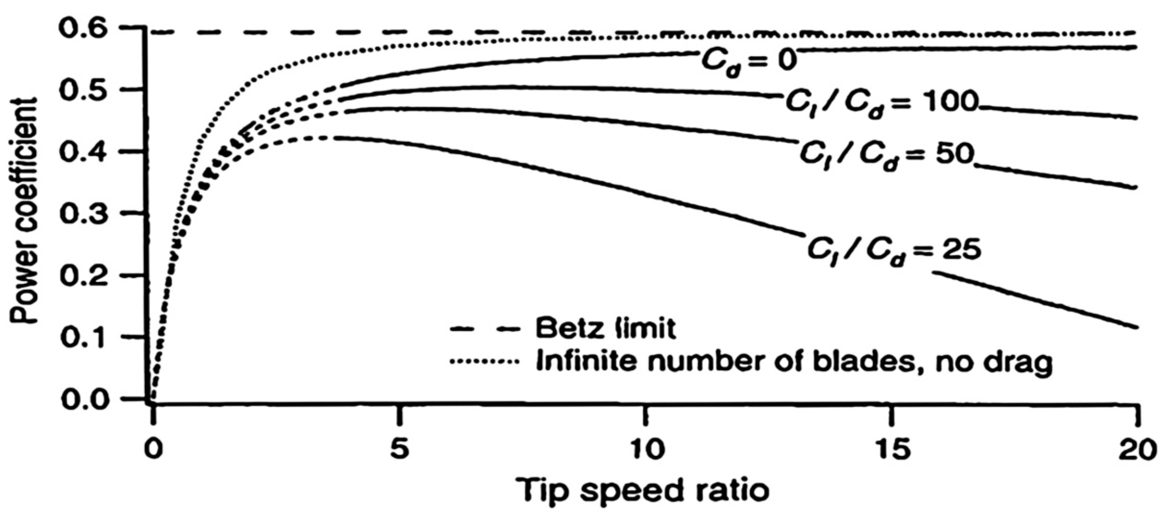


Fig. 1. Power coefficient of three bladed wind turbine rotor as a function of sliding ratio [15].

For three bladed wind turbine rotor, the sliding ratio effect on power coefficient is presented in Fig. 1. It is clear in figure that as the airfoil drag increases then reduction in power occurs significantly. Equation 4 can express power coefficient as [xv]

$$C_P = (16/27) * \lambda / ((\lambda + (1.32 + ((\lambda - 8)/20)^2)/B^2)) - (0.57 \lambda^2 / (\varepsilon * (\lambda + (1/2B))) \quad (4)$$

TABLE I
SELECTED RANGE OF REYNOLDS NUMBER FOR CURRENT RESEARCH AT VARIOUS WIND SPEEDS AT 50 M ALTITUDE AND ONE METER WING CHORD

No.	Wind Speed (m/s)	Reynolds Number
1	5	341000
2	6	409000
3	7	477000
4	8	546000
5	9	614000
6	10	682000
7	11	750000

Round off values of Reynolds number have been taken and best suited altitude 50 m, for Sardhi Kallar Kahar Pakistan [xiii] has been taken with one meter wing chord. For this research, C_L and C_D are measured at selected range of wind speeds [xiii]. Following S series profiles are used in the current study for simulation purpose, as shown in table II.

TABLE II
SELECTED S SERIES AIRFOILS

No.	S series airfoils
1	818
2	825
3	826
4	828

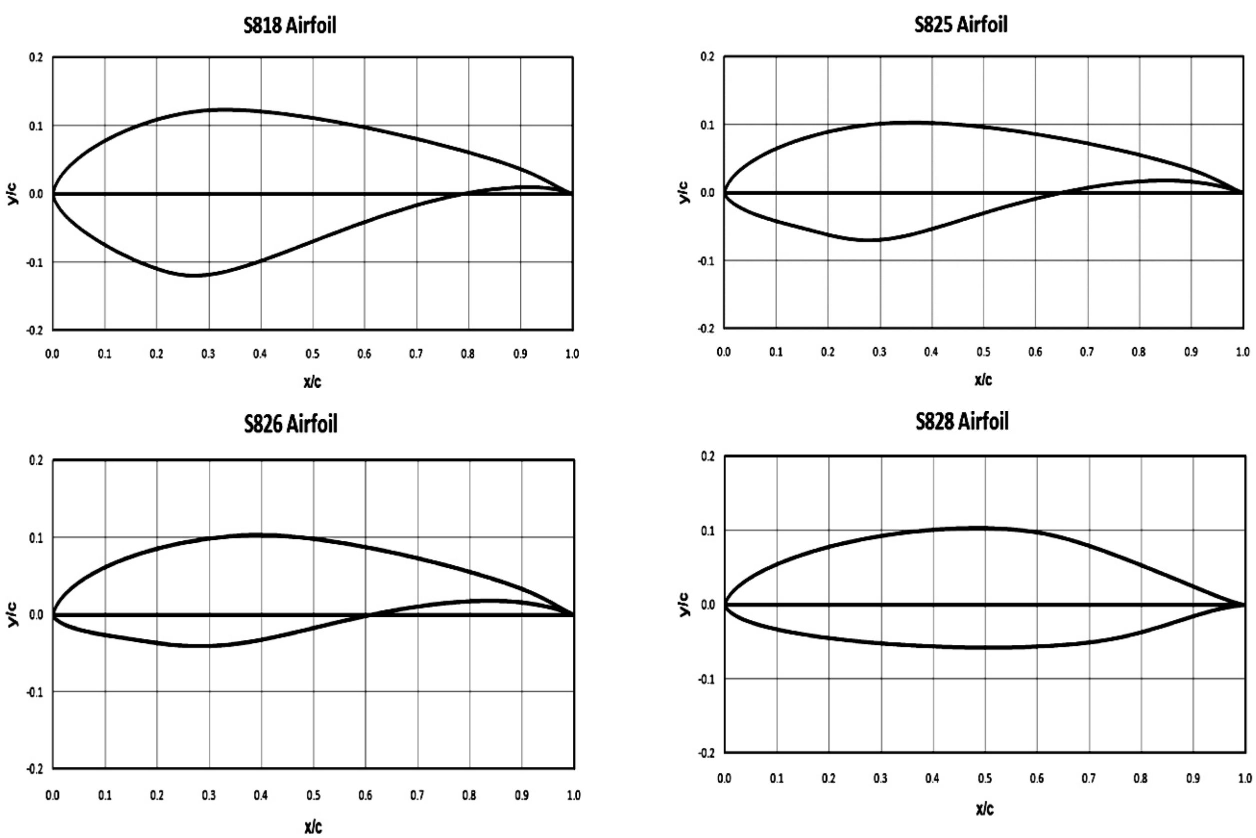


Fig. 2. Selected range of S series airfoils

Flow field simulation of these airfoils has been done by using Profili software package. Effect of forces on surrounding boundary and surfaces is also determined by Profili. Note that due to low velocity range, there is always a subsonic flow in current research. Selected range of angle of attack is from -5° to 13°. Polars of selected airfoils have been determined within boundary conditions as a function of Reynolds number with a step difference of 0.5. Flow considerations around boundaries and surfaces of airfoils are also observed. Basically X-Foil technique is used in Profili. For data acquisition, linear interpolation and extrapolation techniques are also used. Trapezoidal and elliptical wings are also designed by using selected range of airfoils. Number of ribs for half wing is taken 10 while lower and upper skin thicknesses are taken 1.50 mm each and chord length is taken 1 meter. Thickness of airfoil at root and tip sections of wind turbine blade can be increased or decreased by considering rotor design. Normally root region of blade is made thicker for structural support [xvi].

IV. Results and Discussion

At various wind flow velocities, airfoil simulations were carried out. The velocity range, tabulated in table I, is selected for this research because wind speed in Kallar Kahar region lies within this array. Angle of attack range for simulation is taken from -5° to 13° which lies within the standard operative range of wind turbine design. Main goal of this research is to locate the suitable angle of attack at which wind turbine blades can develop maximum power based on highest value of sliding ratio. Trailing edge angle, maximum thickness, thickness distribution, leading edge radius and mean camber line of airfoil, as shown in Fig. 3, are the factors which affect the aerodynamic performance of that airfoil.

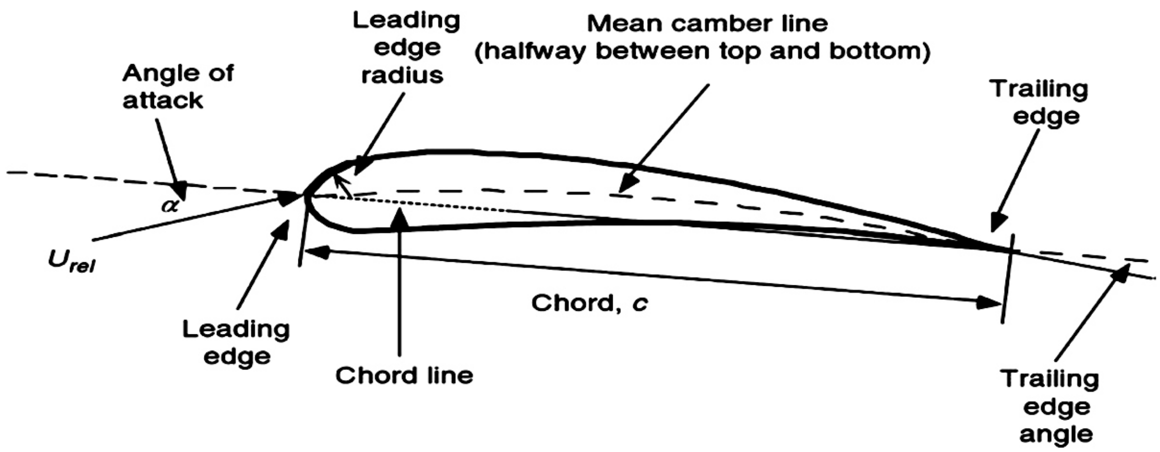


Fig. 3. Basic terms of airfoil [xv]

Figures 4a to 4g, represent the sliding ratio results of selected S-series airfoils against angle of attack at defined range of velocities. It has been observed for all airfoils that sliding ratio value increases with the increase of wind speed. For a constant velocity, data shows that as angle of attack increases then sliding ratio first increases and after reaching to a peak value, it starts decreasing to low values for all airfoils. All airfoils have different angle of attack for maximum value of sliding ratio. If cambered airfoil is used then the possibility of increasing the lift coefficient and decreasing the drag coefficient is enhanced at low angle of attack. Due to highest camber, S818, S825 and S826 have high values of sliding ratio while S828 has low values of sliding ratio among selected airfoils. S818, S825 and S826 are almost symmetric airfoils and due to this symmetry, the pressure difference between the suction surface and pressure surface remains trivial at zero angle of attack. In order to find the best angle of attack for all profiles, combined effect of sliding ratio value curves of each airfoil for all wind speeds is shown in Figures 5a to 5d.

It has been observed that at similar operating angle of attack, sliding ratio value increases with the increase in wind speed. In figure 6, appropriate range of angle of attack for designated airfoils is revealed. It is determined that to attain maximum power from a wind turbine, 6° to 10° is the appropriate range of AOA. For S 828, the best angle of attack with respect to its high sliding ratio value lies from 6° to 7° because its maximum thickness remains from 40% to 50% of the chord length. While for S 818, S 825 and S 826, range of appropriate angle of attack is from 6° to 10° because all of them are symmetric airfoils and their maximum thickness befalls from 20% to 40% of the chord length. The appropriate values of angle of attack as displayed in figure 6, can be utilized to establish a 3D blade profile that comprises of different airfoils and each airfoil has a twist angle equal to its appropriate angle of attack. At each wind speed, best airfoil can also be chosen by considering the maximum sliding ratio effect at appropriate angle of attack.

Average wind speed in Sardhi, Kallar Kahar Pakistan at 50 meter height is approximately 7 m/s [xiii]. Data in figure 6 shows that S 825 and S 826 have maximum value at 7 m/s and so that they are able to produce maximum power at this speed. So it has been recommended to use these airfoils for wind turbine blades which operate at this wind speed in selected site. Results also display that suitable airfoil in selected conditions changes with the variation of angle of attack. For example, at 7 m/s and 7° angle of attack, appropriate airfoil is S 825 while at same speed and 10°, appropriate airfoil is S 818.

It is observed from data in figures 4-6, there is a prominent influence of angle of attack on determining of appropriate airfoil and there is no effect of wind speed in the selection of suitable profile. There should be required a broad study to find appropriate airfoil at each value of angle of attack.

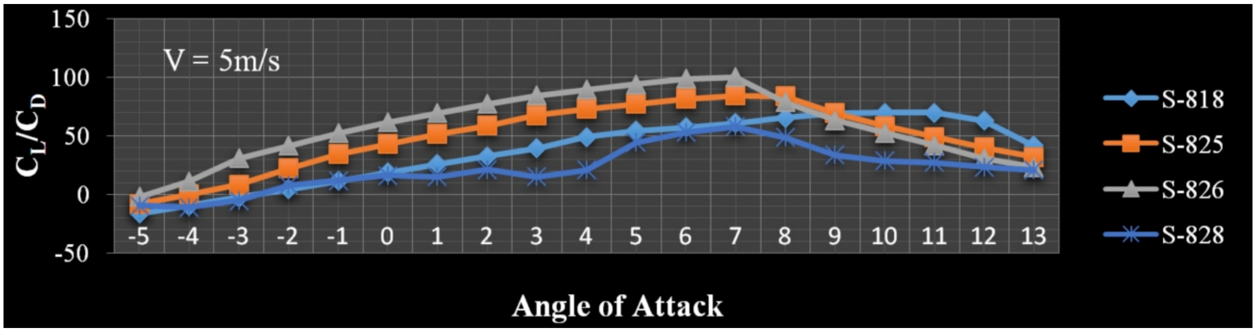


Fig. 4a. Values of sliding ratio at 5 m/s

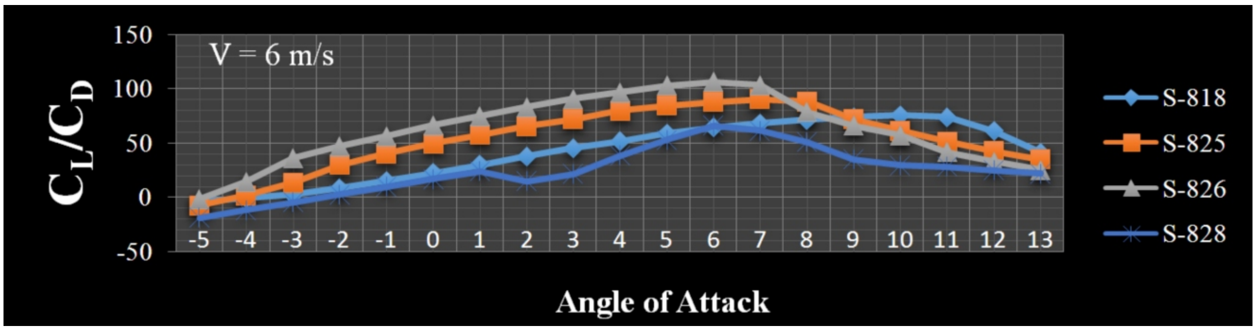


Fig. 4b. Values of sliding ratio at 6 m/s

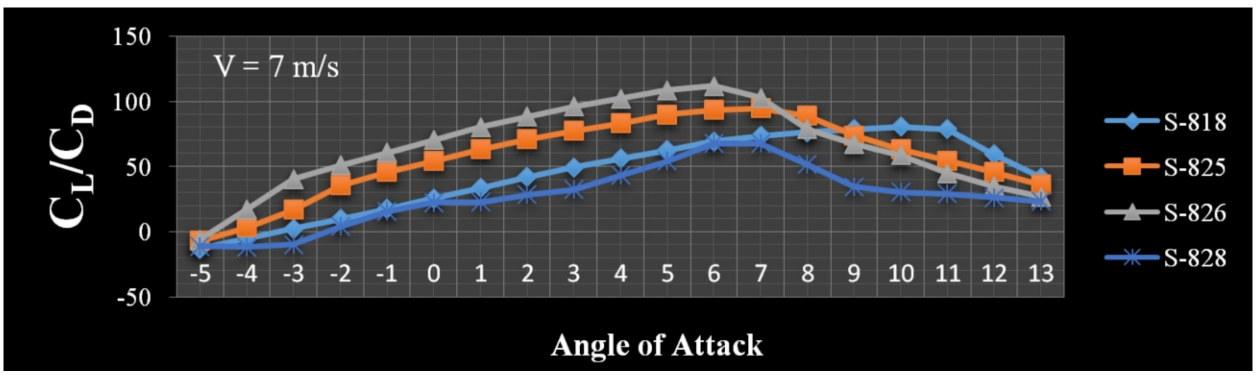


Fig. 4c. Values of sliding ratio at 7 m/s

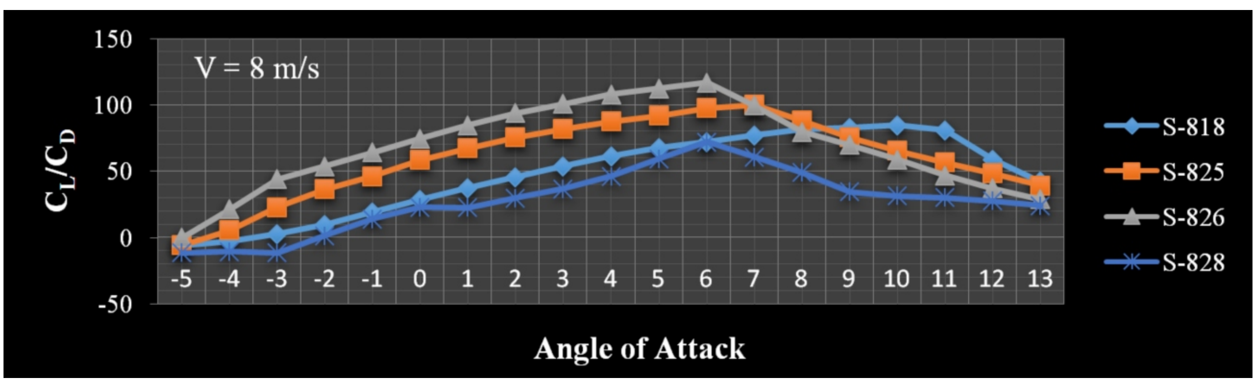


Fig. 4d. Values of sliding ratio at 8 m/s

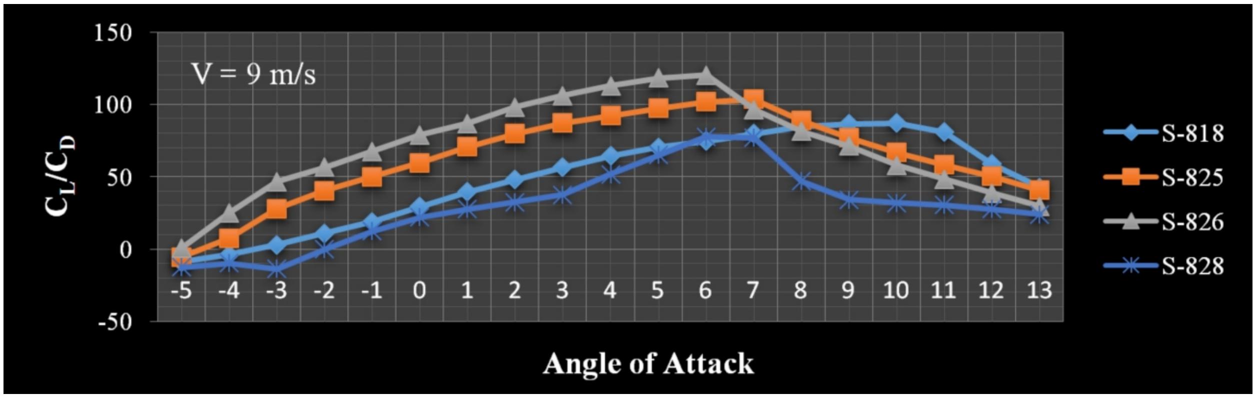


Fig. 4e. Values of sliding ratio at 9 m/s

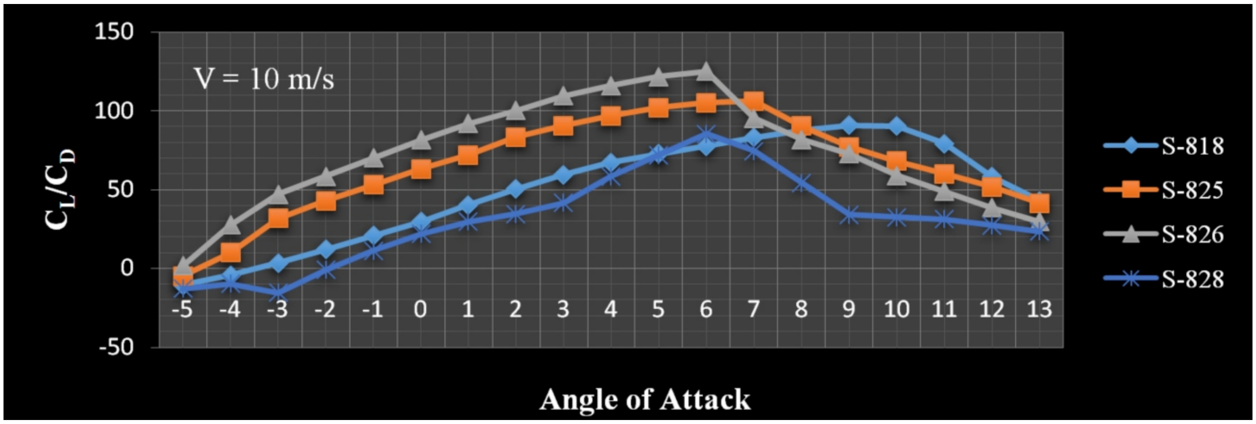


Fig. 4f. Values of sliding ratio at 10 m/s

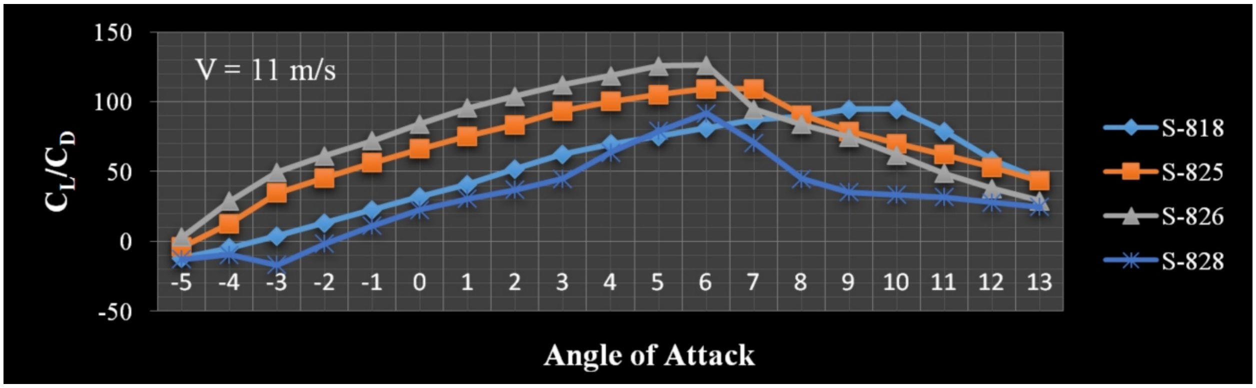
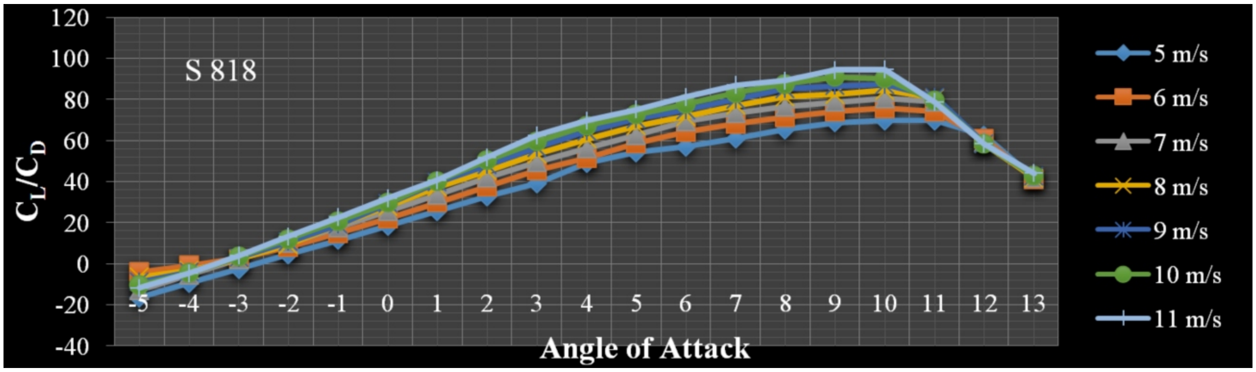
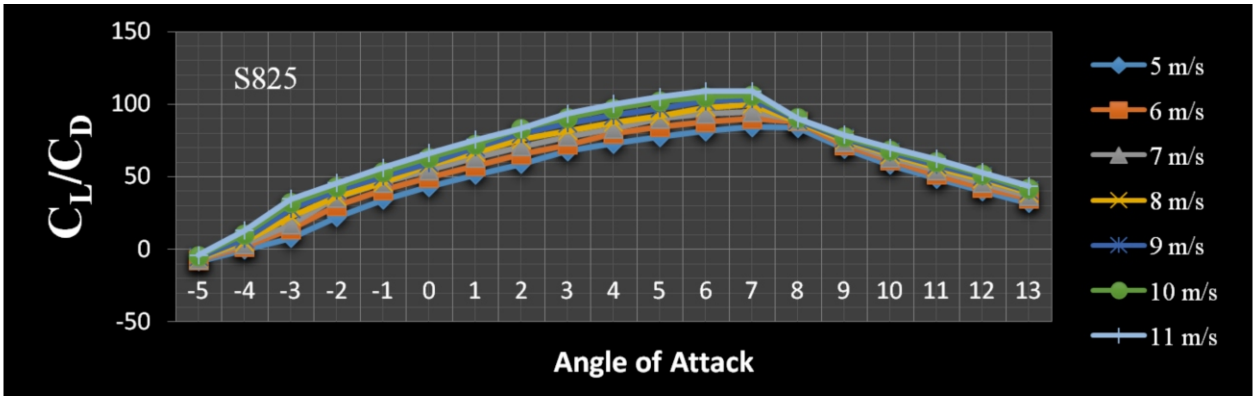


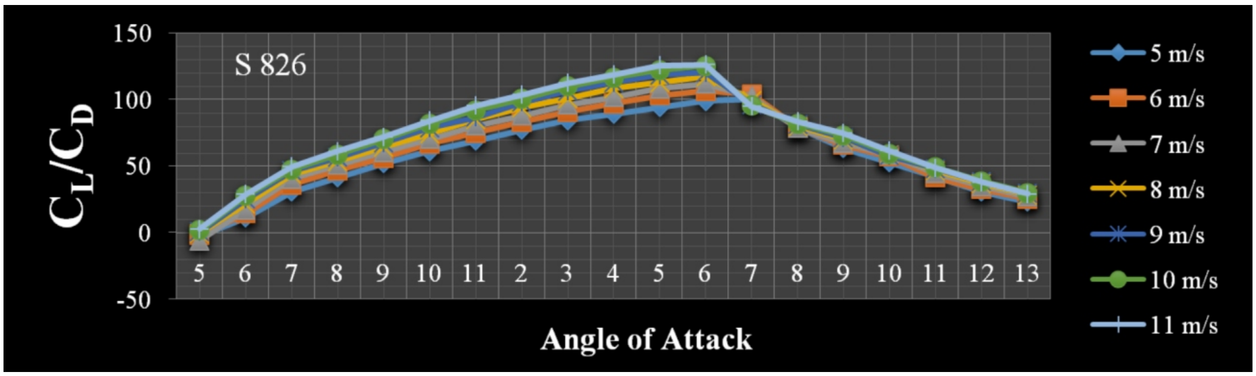
Fig. 4g. Values of sliding ratio at 11 m/s



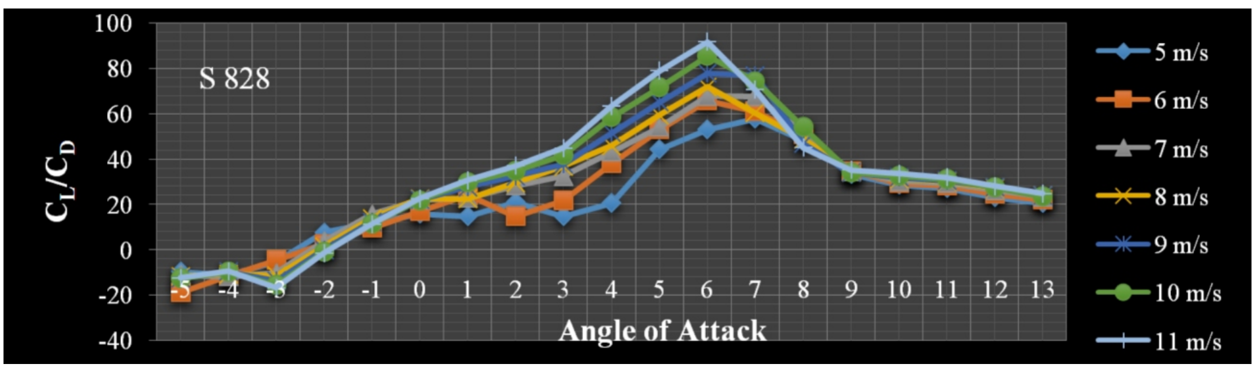
(a) S818



(b) S825



(c) S826



(d) S828

Fig. 5. Values of sliding ratio for each selected airfoil at various wind speeds

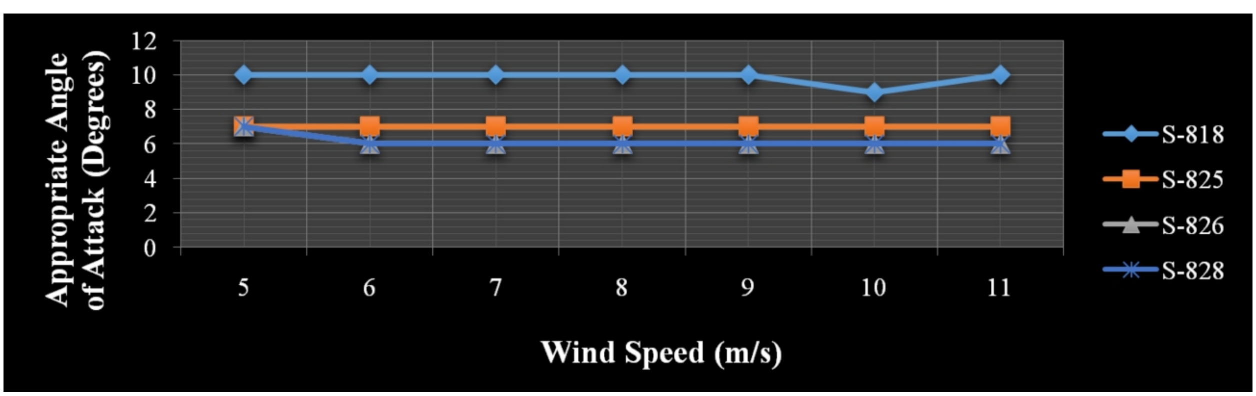


Fig. 6. Appropriate angle of attack for selected airfoils at various wind speeds

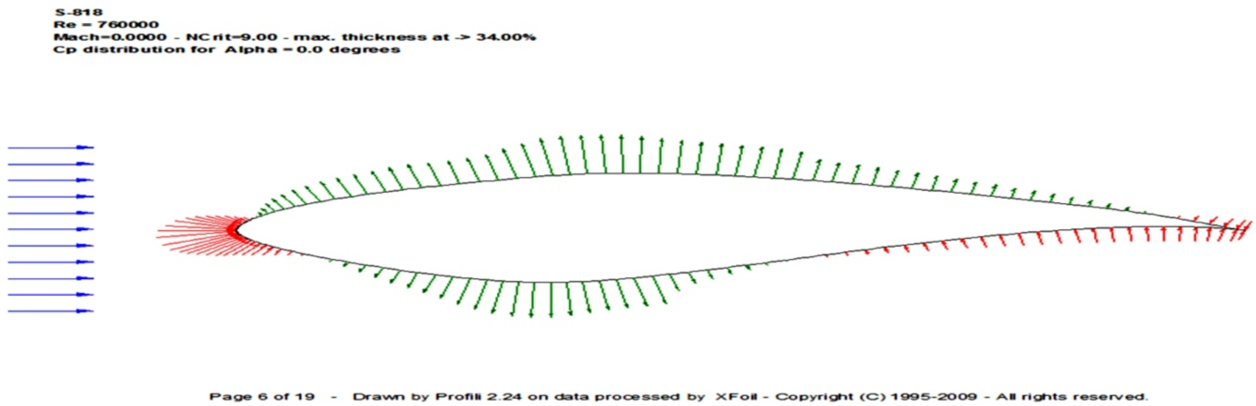


Fig. 7. C_p distribution for S 818 at 0^o angle of attack and 11 m/s

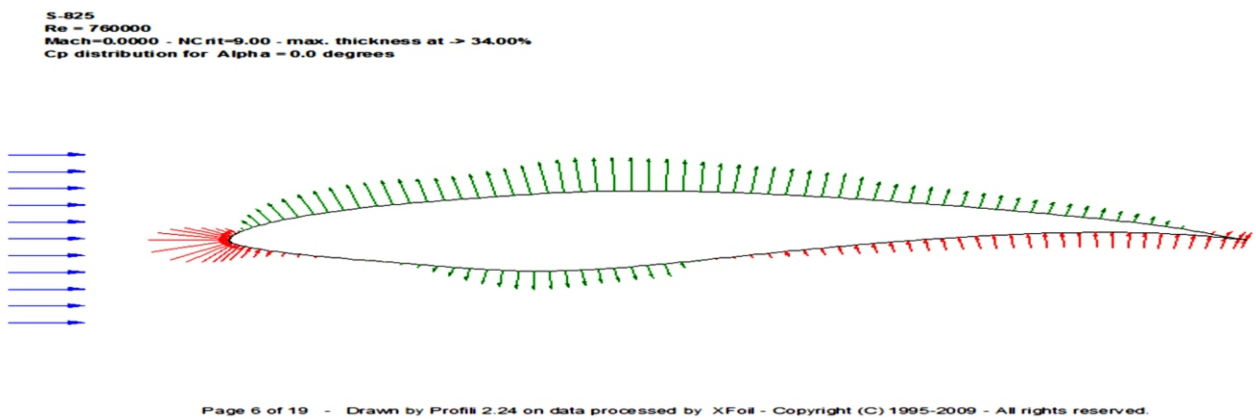


Fig. 8. C_p distribution for S 825 at 0^o angle of attack and 11 m/s

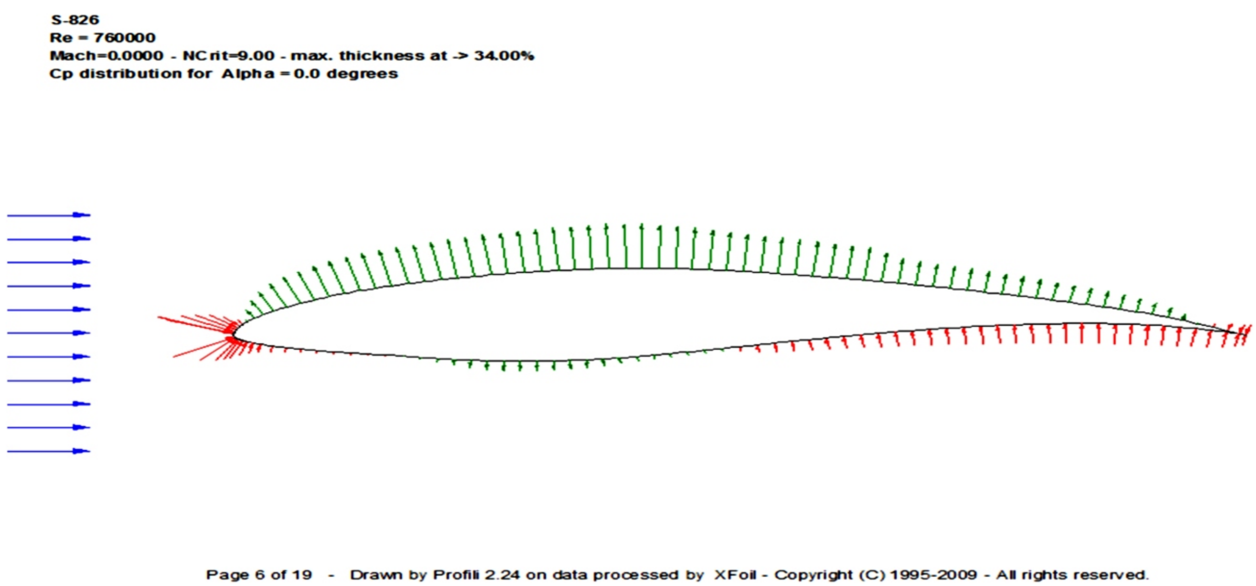


Fig. 9. C_p distribution for S 826 at 0^o angle of attack and 11 m/s

C_P distribution over S 818, S 825 and S 826 airfoils are shown in figures 7, 8 and 9. From all three figures, results show that there is a positive lift force on the lower surface of all profiles because pressure distribution is positive here. But at 2-4% of chord length in middle region, negative lift value occurs. Pressure rise is observed from minimum to maximum at trailing edge. This region is defined as adverse pressure gradient. Pressure adjacent the trailing edge is linked to profile thickness. Pressure is somewhat positive for thick airfoils but $C_P$is zero for infinitely thin airfoils. Stagnation point (C_P = 1) ensues nearby leading edge and at this region flow velocity is zero.

As shown in Figures 7, 8 and 9, as air flow starts to accelerate over the profile, data shows low values of pressure at that stage so C_P suddenly gets zero value and then to negative value. When flow decelerates, rise in pressure and drop in C_P values occurs. Due to these variations, rotation in airfoil occurs.

Note that pressure on upper surface is always less than the lower airfoil surface. Pressure coefficient turn into more negative value with the increase in wind speed.When flow reaches trailing edge, it decelerates on upper surface and combines with lower surface flow.

V. CONCLUSION

High efficiency of airfoil is directly related to high sliding ratio values. Data observation shows that selection of appropriate airfoil mainly depends on angle of attack. Choice of optimum profile does not depend upon the wind speed. Optimum range of angle of attack is from 6^o to 10^o for selected airfoils. At this range, maximum value of sliding ratio and maximum power from wind attains from all airfoils. It has been observed that sliding ratio value declines when angle of attack rises from appropriate range.

For extracting peak power from wind, airfoils whose thickness ranges from 20% to 40% of chord length, should be operated from 6^o to 10^o of angle of attack while those airfoils whose thickness occurs from 40% to 50% of chord length should be operated from 6^o to 7^o of angle of attack. Finally conclusion obtained from data is that most efficient airfoils from selected range are S 825 and S 826 and they are highly recommended for wind turbine working at selected range of wind speeds [13].

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