Proceedings of the 1st International Conference on Emerging Trends in Energy Conservation - ETEC
Tehran, Tehran, Iran, 20-21 November 2011

Theoretical Aerodynamic analysis of six airfoils for use on small wind turbines

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ABSTRACT

In this paper theoretical analysis of six airfoils, the AG24, AG35, AG455ct, CAL1215j, CAL2263m and CAL4041l has been done. The analysis performed in this study are intended to provide theoretical predictions for power coefficient by used of MATLAB software based on experimental measurements at low Reynolds number. The results show that the airfoil appropriate to the design is AG35Airfoil.

Key words: Aerodynamic analysis, Airfoil, power coefficient, small wind turbine, MATLAB code.

1. INTRODUCTION

1.1. POWER

Small vertical wind turbines can produce electrical energy in the border between 5 kilowatts to 20 kilowatts. So the goal of this research is to design a vertical axis wind turbine produces electrical energy between 5 kW and 20 kW [1].

1.2. RATED WIND SPEED

By the average speed for the area to be set up by the design rated wind speed can be calculated from the equation:

$$V_{rated} = (1.5{\sim}2) * \bar{V}_{annual} \tag{1}$$

1.3. POWER COEFFICIENT (C_P)

Power coefficient, C_P, is obtained by below equation:

$$C_p = \frac{P}{P_{wind}} \tag{2}$$

The amount of power, P that can be absorbed by a wind turbine can be found from:

$$P_{wind} = 0.5 * \rho * A * U^3 * Cp \tag{3}$$

$$A = 2 * \pi * r * L \tag{4}$$

1.4. NUMBER OF BLADES (B)

The appropriate number of blades can be selected from the below table.

Tip Speed Ratio (λ)	1	2	3	4	≥۵
Number of blades (B)	8-24	6-12	3-6	3-4	1-3

Table 1: Choose the appropriate number of blades

1.5. SOLIDITY (σ)

The solidity, σ, states a relation between the blade area and the turbine swept area and has different definitions for different types of turbines. For a horizontal axis wind turbines (HAWT), it is defined as:

$$\sigma = \frac{B * c}{2 * \pi * r} \tag{5}$$

Where B is the number of blades, c is the chord length, and R is the radius of the turbine. For a vertical axis wind turbines (VAWT), the solidity is defined as:

$$\sigma = \frac{B * c}{R} \tag{6}$$

1.6. AXIAL INDUCTION FACTOR (a)

The rotor speed wind flow upstream of some of the flow velocity is lower, so the base can be quickly computed stream that passes through the rotor to axial induction factor (7) the relationship is defined as:

$$a = \frac{V_{rated} - U}{V_{rated}} \tag{7}$$

1.7. LINEAR SPEED CAUSED DURING BLADE (V_Θ)

Blade rotational speed of the rotor speed multiplied by the radius of a rotor angle can be obtained:

$$V_\theta = r.\omega \tag{8}$$

1.8. TIP SPEED RATIO (λ)

This parameter is equal to the speed ratio of linear velocity from blade speed during free flow effectively. This factor has an impact on power production.

$$\lambda = \frac{V_\theta}{U} \tag{9}$$

2. AIRFOIL

In Figure 1, aerodynamic characteristic of six airfoils AG24, AG35, CAL1215j, CAL2663m and CAL4041 are shown. It should be noted that there was no experimental data to draw a diagram of the airfoil AG455ct. Also in figure 2, these six airfoils are compared with together. To draw these charts, we used experimental data [2].

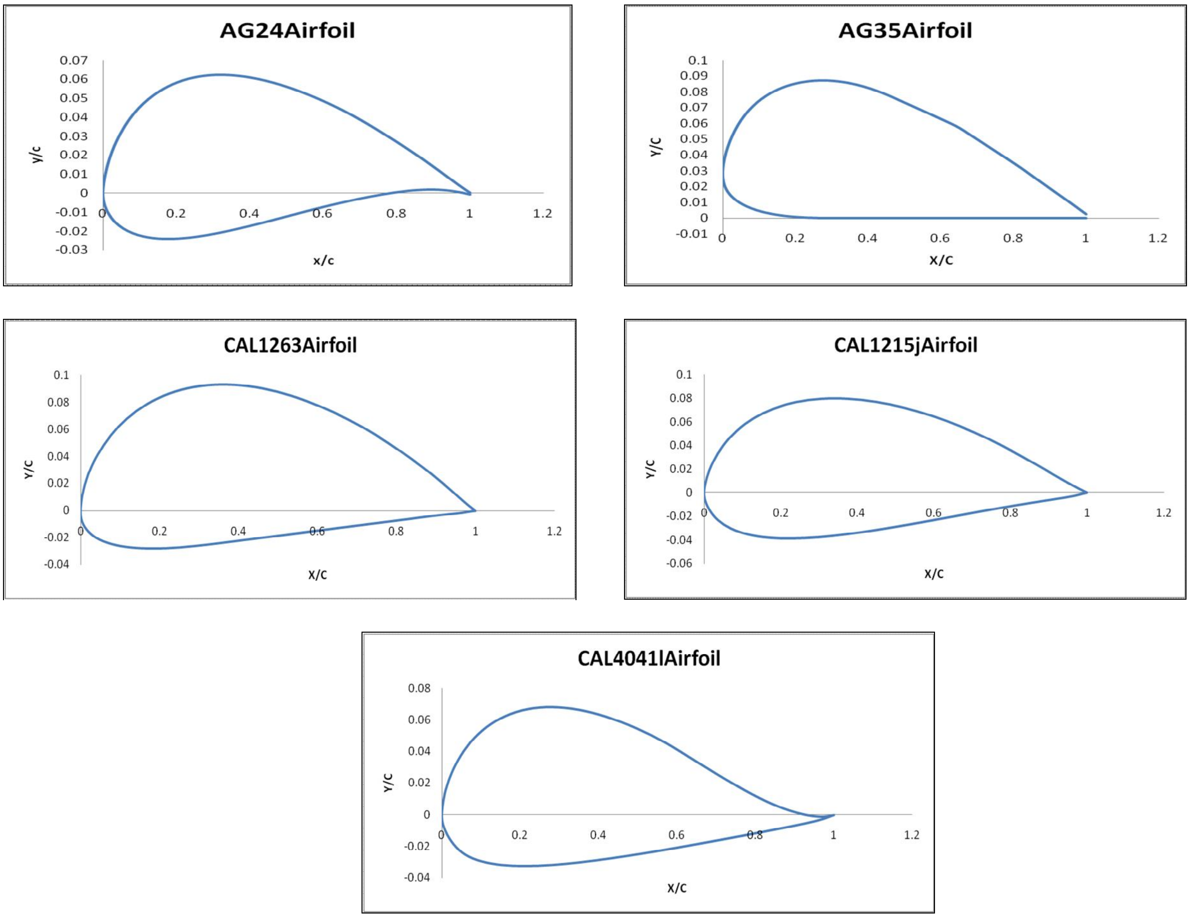


Fig 1: Low-Speed Airfoils

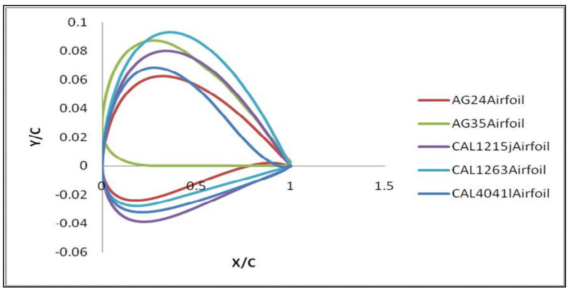


Fig 2: Comparison of low-Speed Airfoil

2.1. DRAG COEFFICIENT VERSES ANGLE OF ATTACK

Below experimental charts show change C_d and α by changing Reynolds number. It is noticed that the maximum value for each of the C_d and α occurred when the value of the Reynolds number is low and the minimum value for each of the C_d and α occurred when the value of the Reynolds number is high.

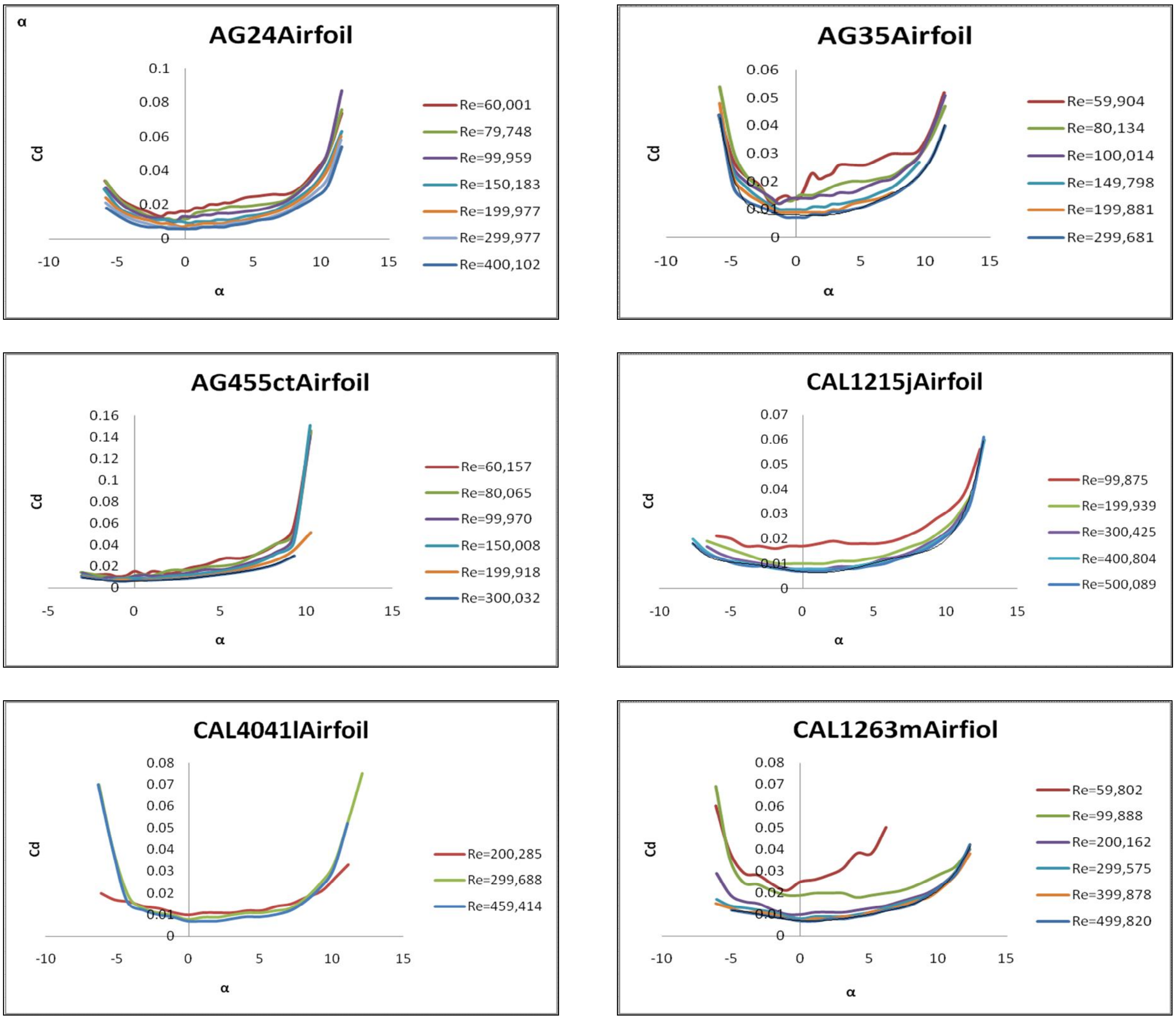
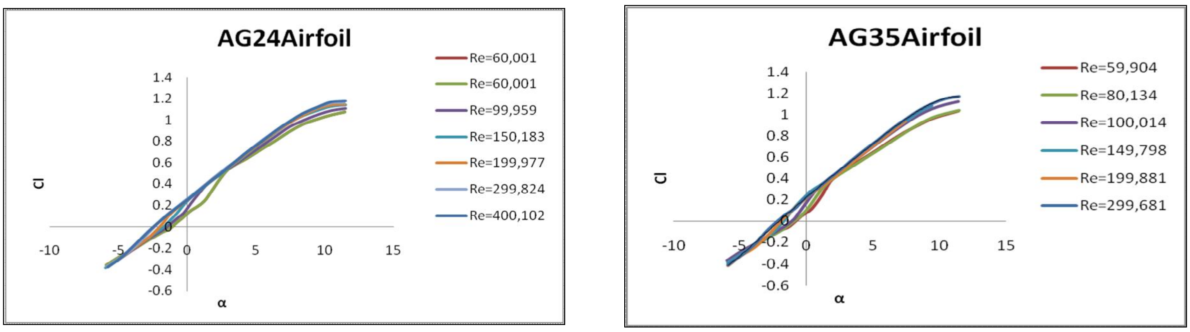


Fig 2: Drag coefficient verses angle of attack

2.2. LIFT COEFFICIENT VERSES ANGLE OF ATTACK

Below experimental charts show change C_l and α by changing Reynolds number. It is noticed that the maximum value for each of the C_l and α occurred when the value of the Reynolds number is high and the minimum value for each of the C_l and α occurred when the value of the Reynolds number is low.



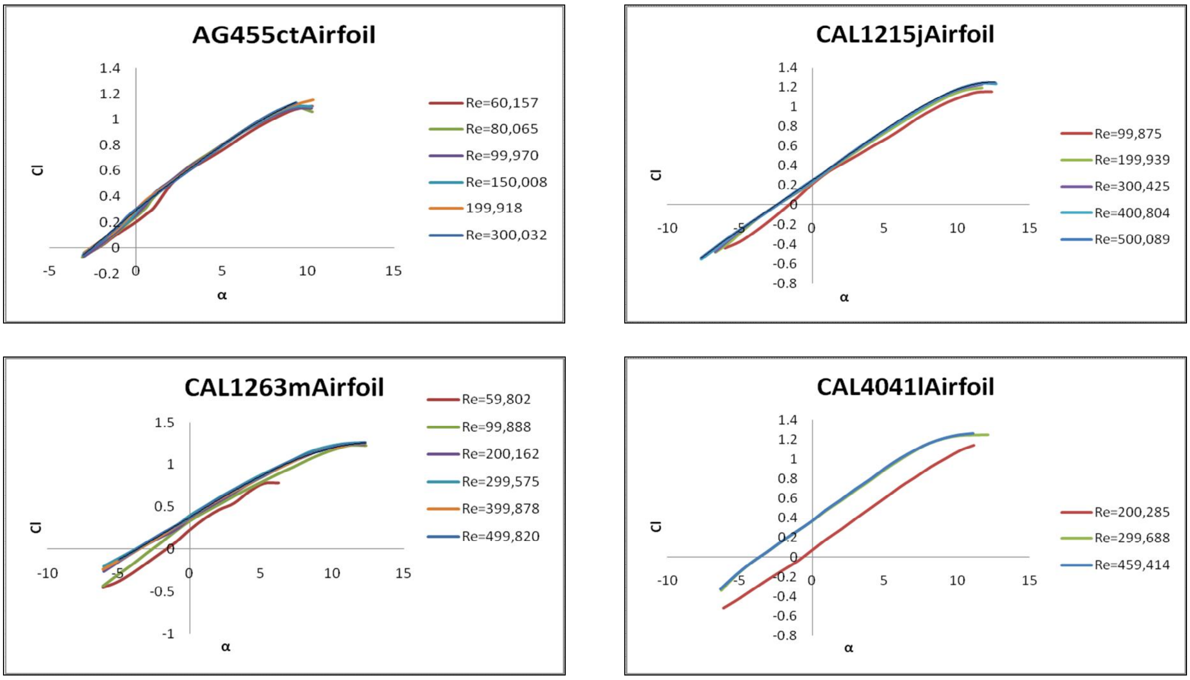
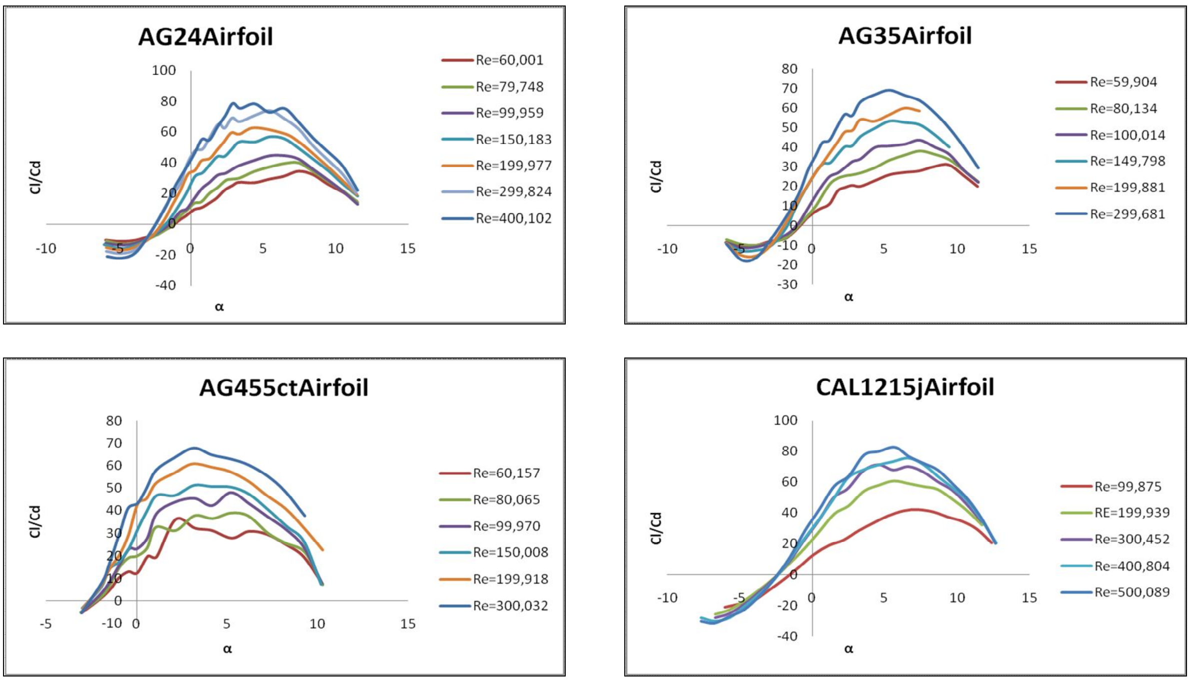


Fig 3: Lift coefficient verses angle of attack

2.3. THE RATIO BETWEEN DRAG COEFFICIENT AND LIFT COEFFICIENT VERSES ANGLE OF ATTACK

The following experimental charts show each change of C_l/C_d and α by changing Reynolds number.



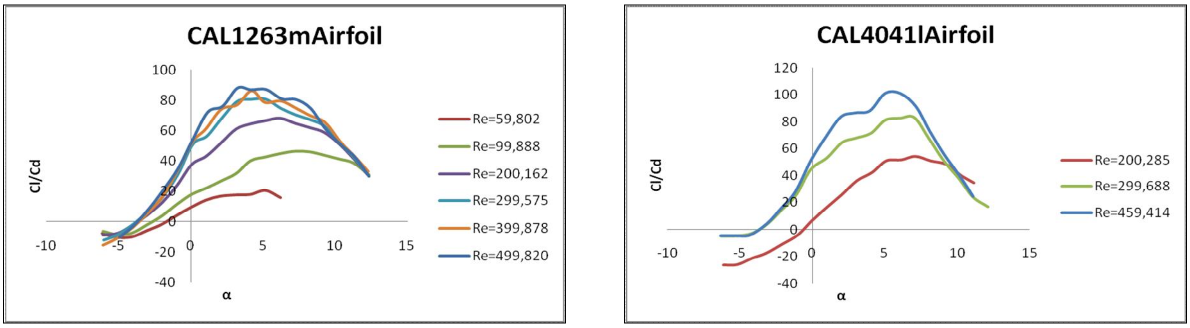


Fig 4: The ratio between drag coefficient and lift coefficient verses angle of attack

2.4. DRAG COEFFICIENT VERSES LIFT COEFFICIENT

Below experimental charts show change C_l and C_d by changing Reynolds number. It is noticed that the maximum value for each of the C_l and C_d occurred when the value of the Reynolds number is high and the minimum value for each of the C_l and α when the value of the Reynolds number is low.

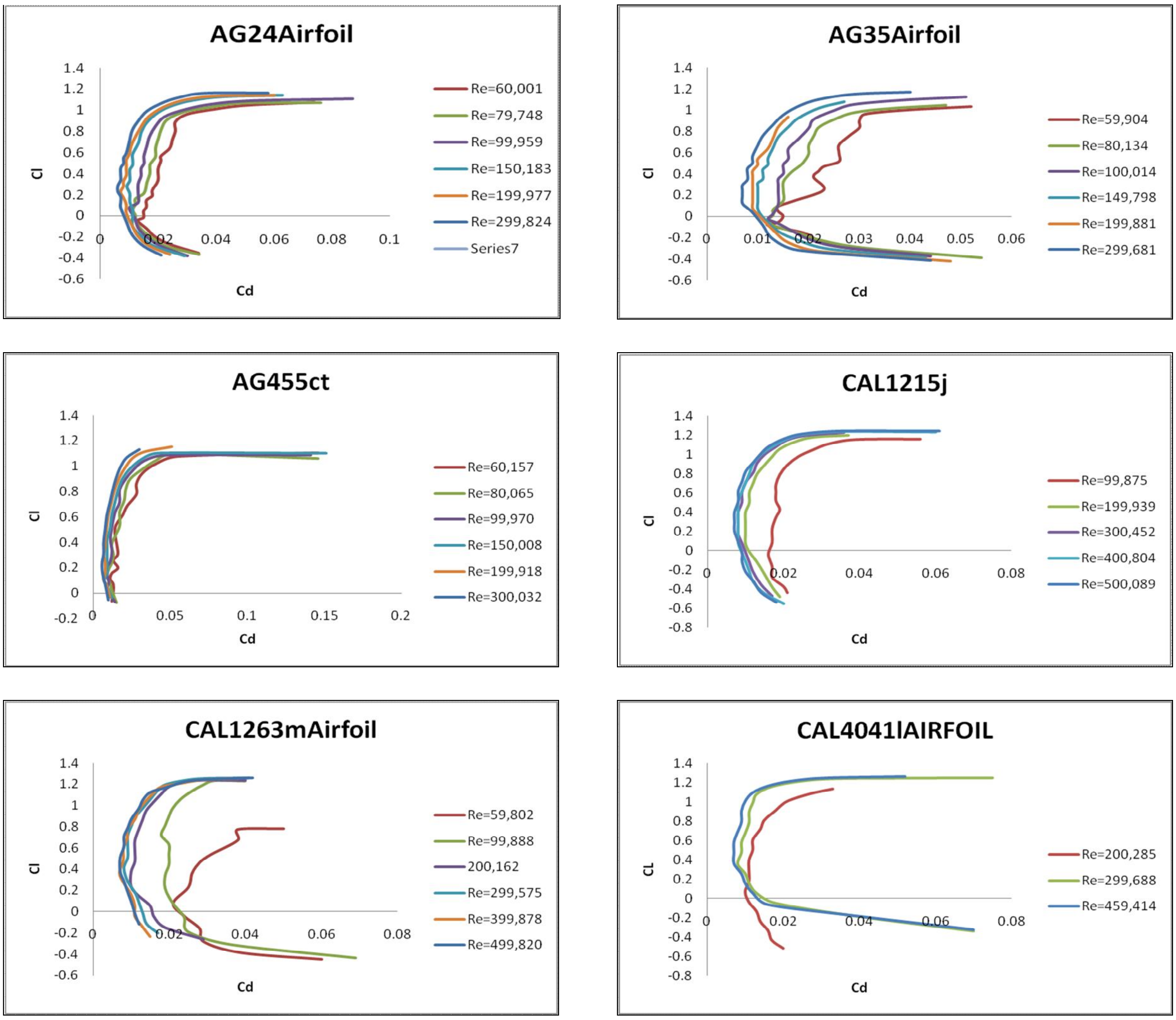


Fig 5: Drag coefficient verses lift coefficient

2.5. TIP SPEED RATIO, λ VERSES POWER COEFFICIENT, C_P

At this section, based on experimental data and experimental figures presented above, using a MATLAB code, the following figures are obtained. In the below figures, L is the blade length and D is the diameter of blade.

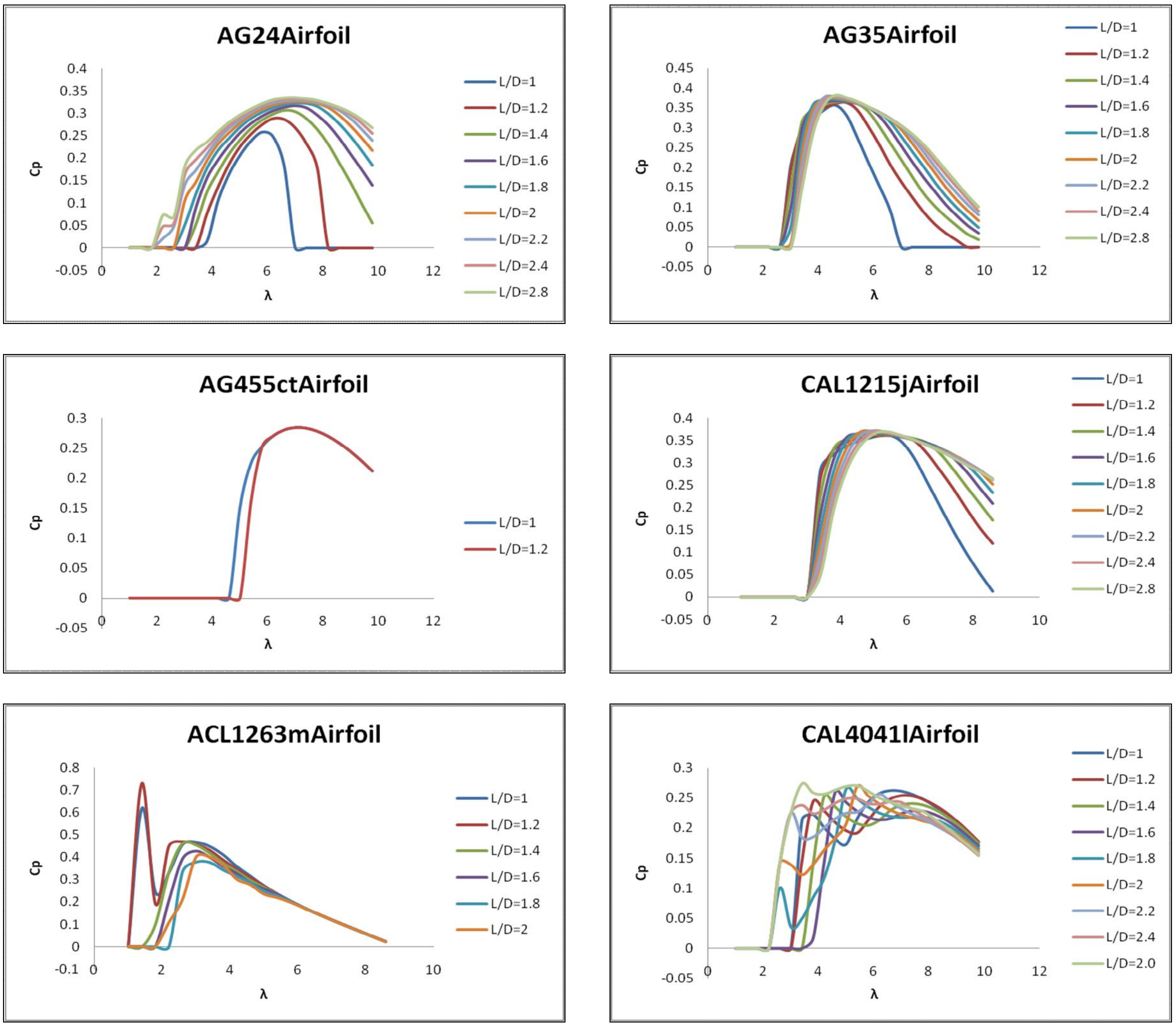
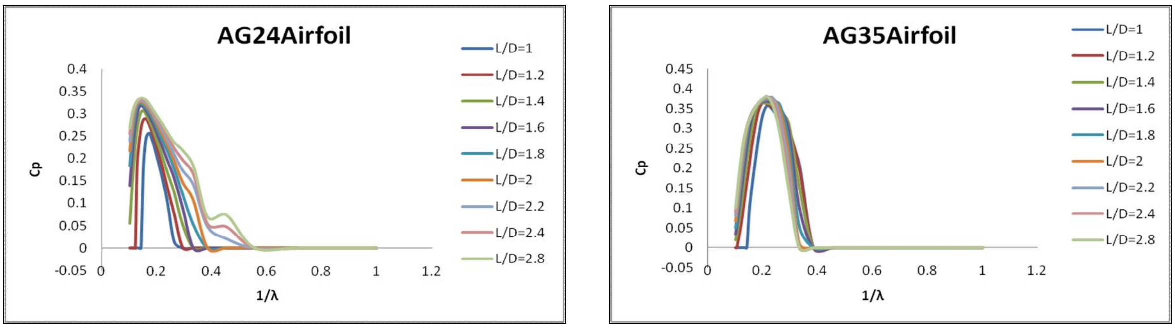


fig 6: Tip speed ratio, λ, verses power coefficient, c_p



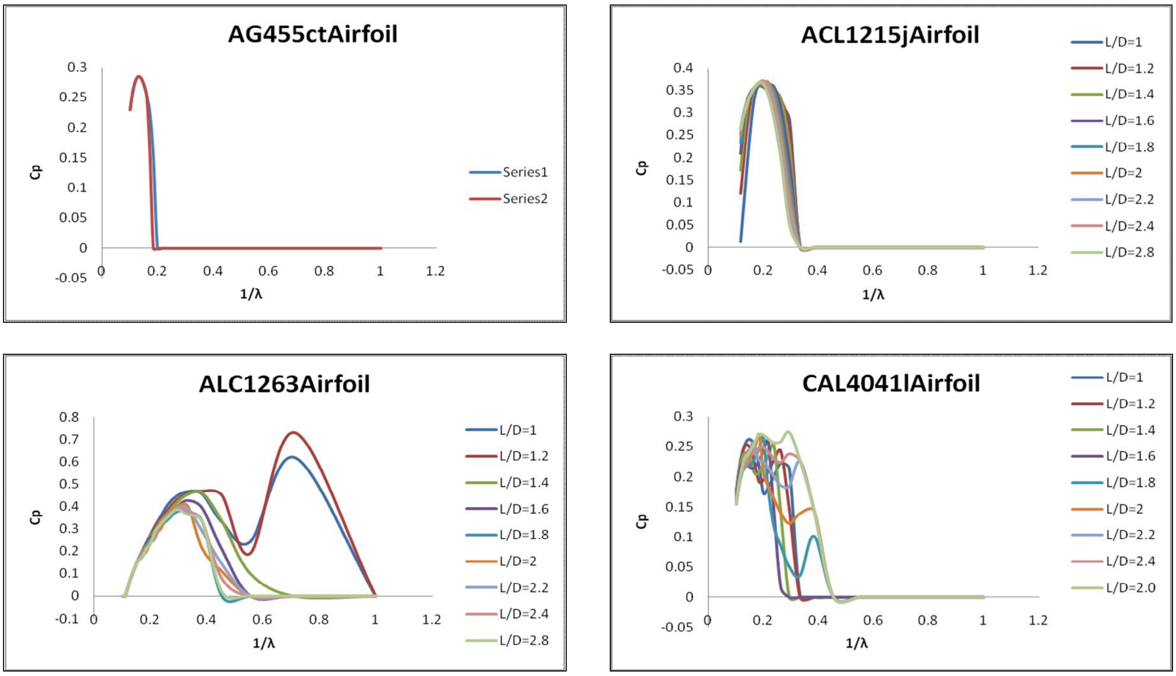


fig 6: 1/λ verses power coefficient, c_p

Table 2: Aerodynamic characteristics for six airfoil type

Airfoil type	**solidity**	**Power coefficient, Cp**	**Tip speed ratio, λ**	**1/λ**
AG24	0.04	0.32	6	0.2
AG35	0.06	0.4	5	0.22
AG455ct	0.05	0.29	7	0.19
CAL1215j	0.06	0.35	4.5	0.2
CAL2663m	0.13	0.7	1.5	0.8
CALl40411	0.05	0.27	3	0.25

From the above table has been selected the maximum value for the Power coefficient, Cp. Depending on the results, the airfoil appropriate to the design is AG35Airfoil. Although CAL2663m airfoil has a better power coefficient compare to AG35 airfoil, but its manufacturing cost is higher than AG35 because it has higher solidity. Therefore the airfoil appropriate to the design is AG35Airfoil.

3. CONCLUSION

In this paper theoretical analysis of six airfoils, the AG24, AG35, AG455ct, CAL1215j, CAL2263m and CAL4041l has been done. The analysis performed in this study are intended to provide theoretical predictions for power coefficient by used of MATLAB software based on experimental measurements at low Reynolds number. The results show that the airfoil appropriate to the design is AG35Airfoil.

REFERENCE

[1] James F. Manwell, Jon G. McGowan, Anthony L. Rogers, 'Wind Energy Explained: Theory, Design and Application', John Wiley & Sons, p.11, 2002.
[2] Michael S. Selig, Bryan D. Mc Granahan, and Benjamin A. Broughton, 'Summary of Low-Speed Airfoil Data', 2011.