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A Comparison Study of Airfoils Used in H-Rotor Darrieus Wind Turbine

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Abstract-A Vertical Axis Wind Turbines (VAWTs) is considered one of the promising type of turbines. Although the full life cycle of VAWTs shows that it has advantageous on a cost basis or material basis over Horizontal Axis Wind Turbines HAWTs. VAWTs are easy to connect generator/gears, lower fatigue, and easier blade control if required and compact design. Darrieus turbine is one of the most important types of VAWTs since it reaches to an approximate level of horizontal axis wind turbines. The main disadvantages are that the Darrieus turbines are not a self-starting turbine and its performance is low comparing to the horizontal axis. In order to improve the Darrieus performance and its execution, it needs to check the efficiency of the H-rotor Darrieus turbine. In this project, ANSYS is used to compare between different types of airfoils to check which one gives a precise result. This experiment will be carried out by two-dimensional Computational Fluid Dynamics to the aerodynamic investigation for 15 different types of symmetric and non-symmetric airfoils. Through the test, if attack angle is increased, the C_l/C_d ratio increases as well. The C_l/C_d ratio is representing the performance factor of an accurate result and shape of air foils. There are four family types of airfoils that give a smoother result than the rest of airfoils, and the results indicated that AH93W215 has the highest possible efficiency with the wider operating range compared with other four-airfoil sections. This study expresses the idea of using AH93W215 airfoil instead of the conventional NACA 00XX for the H-rotor Darrieus turbine since it has a better performance and precise results.

Keywords- *CFD, Airfoil, Darrieus Turbine, Wind Turbine*

I. INTRODUCTION

In recent years, the price of fossil fuels is increasing every day. Most countries concern about the environmental consequences of greenhouse gas emissions, therefore those countries have started to use renewable energy sources for power generation such as wind, solar, wave…etc. Wind is one of the most important sources of renewable energy, it consists of wings that transfer the wind to mechanical energy by hitting the wings [1]. Overall, using wind to produce energy has few effects on the environment compared to other energy sources, as know that it has been working for thousands of years of wind turbines. Wind turbines don’t contaminate the water or air, and they don’t need water for cooling. In addition, wind turbines minimize the amount of electricity generation of fossil fuels, which outcome in carbon dioxide emissions and lower total air contamination. The wind turbine blade power maximizing can be performed through selecting airfoil shape having a maximum lift to drag ratio (C_l/C_d) [2].

There are many projects related to Darrieus turbine have been studied through this project to compare, improve, develop the study of the H-rotor Darrieus turbine. The following revisions are some examples used to investigate the H-rotor Darrieus turbine, most of them have advantages and disadvantages that helped to improve this study.

M.H. Mohamed [3] investigated in a H-rotor Darrieus turbine to get better design and performance in transformation the wind to energy for obtaining a higher efficiency. In order to reach this aim, the two-dimensional Computational Fluid in the aerodynamic study carried out for 20 different airfoils.

Şahin and Acir [4] studied an experimental and numerical analysis drag and lift performances from NACA 0015 airfoil through measuring the strengths every two degrees from 0° to 20° in various attack angle in low Reynolds numbers (Re).

Ravi et al. [5] studied 3×10^6 Reynolds numbers for NACA 4412 airfoil profile. They used two different numerical models who were Spalart Allmaras, and k-epsilon investigated transmission from laminar flow to turbulence flow. Experimental results were compared with Numerical results. They indicated when the rises Reynolds number; two numerical models gave similar results.

Lianbing et al. [6] used FLUENT programs to examine the execution of wind turbine in NACA 0012 airfoil where Spalart Allmaras turbulence model for numerical solutions were used by Lianbing et al. from an airfoil at 3×10^6 Reynolds number for stall angle and drag and lift performance.

Hashem and Mohamed [7] studied aerodynamic performance to improve the generator power and increase the output power coefficient Cp by using 24 new airfoils as the sectional profiles of the Darrieus turbine.

Villalpando et al. [8] represents in this paper a NACA 63-415 airfoil profile. They saw that SA (Spalart Allmaras) when using a different model of disturbance in the FLUENT model gives the better results. Therefore, they achieved aerodynamics from the airfoil at high and low angles of attack.

Castelli et al. [9, 10] worked on improving a performance prediction modeling strategy out of CFD modelling by performed 2D and 3D analysis through a three-straight bladed VAWT in order.

Danao et al. [11] completed the investigation on the impact of stable and unstable wind in the VAWT performance and performed 2D CFD investigation of a VAWT.

Hamada et al. [12] and Howell et al. [13] used the commercial program ANSYS Fluent to utilize the three various subtypes of the k−ε turbulence model which are accessible. Also, they control and managed 2D and 3D emulation on straight bladed VAWT.

Hossain et al. [14] performed a comparison study of NACA 4412 and NACA 6409. Clearly, they expressed the comparison between the lift-to-drag ratio and the pressure distributions of these two airfoils with a laminar flow speed of about 1 m/sec. So, the result shows that the NACA 4412 aerofoil is more efficient than NACA 6409 aerofoil.

Ahmedov and Ebrahimi [15] discussed the force interaction among fluid flow and a rotating H-type Darrieus vertical axis wind turbine. They focused in this study to find the specification of the wind rotor's performance during the turbulent wind. They expressed a numerical investigation executed for several tip-velocity ratios accordingly; Darrius turbine performance advantages were obtained.

Lanzafame at el. [16] described the methodology to improve a two-dimensional CFD model of H-Darrieus Wind Turbines. The model was actualized in ANSYS Fluent solver to expect and optimize its geometry and the wind turbines performance. The results demonstrated that the good capabilities of the Transition SST turbulence model compared to the classical fully turbulent models. Clearly represents the results of the tests were executed in the two-dimensional model of the wind turbine.

McLaren et al. [17] represented that result after comparison them with the standard k - ω and k - ε models the k - ω SST model was the most precise results. They performed over a constant blade with airfoil section NACA 0015 at 360000 Reynolds number. They studied flow separation modeling capacities of the k - ω SST model to the test. The results for the lift and drag forces were obtained by three various turbulence models and were compared with experimental data.

Hossain et al [18] represented a comparison analysis of NACA 4412 and NACA 6409. The comparison was performed between the lift-to-drag ratio and the pressure distributions of these two airfoils, and the laminar flow velocity of 1 m/sec. It clearly shows that a NACA 6409 airfoil is less efficient than NACA 4412 airfoil.

Patel et al [19] performed in PYTHON (x,y) programming the analysis of Lift and Drag for NACA airfoils forces utilizing for a wind turbine blade NACA6412, NACA4412 and NACA0012 Airfoil profile. They completed the variation of analysis in the velocity and angle of attack through the three airfoils. The results clearly presented that the maximum lift forces obtained for the NACA4412 airfoil are the greatest result of airfoils under specified boundary conditions. The J-shape airfoil has been investigated in [23, 24] to check the performance of Darrieus turbine under this modified airfoil. In the same direction, Mohamed et al. [25] introduced a force analysis for several airfoils.

II. METHODOLOGY

This study used FLUENT programs numerical analyses. The numerical were conducted a wind velocity at 10 m/s (V), dynamic viscosity at $1.983 * 10^{-5}$ (μ), the chord length at 0.1 m2 (L) and the density of air at 1.225 kg/m^3 (ρ). Lift and drag coefficients for some airfoils at a different angle of attack between 0° and 12° were the measurement by using the Realizable k-epsilon turbulence model, and Advantages of the k-ε Realizable turbulence model over the standard k-ε turbulence model including flow separation, strong pressure gradients, improved performance inflows with recirculation, and the non-reliance on an assumed relationship between the strain rate tensor and the Reynolds stress tensor.

The transport equations for k and ε in the Realizable keε model are given as:

$$\frac{\partial}{\partial t}(\rho K) + \frac{\partial}{\partial x_j}(\rho k u_j) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M + S_k \quad (1)$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_j}(\rho\varepsilon u_j) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \rho C_1 S\varepsilon - \rho C_2 \frac{\varepsilon^2}{k+\sqrt{\nu\varepsilon}} + C_{1\varepsilon}\frac{\varepsilon}{k}C_3 C_b + S_\varepsilon$$

where:

$$C_1 = \max\left[0.43, \frac{\eta}{\eta+5}\right], \eta = S\frac{k}{\varepsilon} \text{ and } S = \sqrt{2S_{ij}S_{ij}}$$

Airfoils have different shape and size. Therefore, to assess the advantages and disadvantages of airfoils (lift and drag coefficients) the non–dimensional coefficients were used.

For two dimensions solution, the non–dimensional coefficients were given as below:

Lift coefficient: $C_l = \frac{2L}{\rho V^2 c}$

Drag coefficient: $C_d = \frac{2D}{\rho V^2 c}$

A. Mesh Independent Study:

This study ensures that the mesh independence study these have converged to a steady value otherwise, that would have a different result even if the simulation runs for additional iterations. The idea of guaranteeing that the values have arrived a steady solution means that the choices on one repeatable value. By following this idea, then the results will have more confidence information.

Mesh independence studied on NACA 0015 at a different number of divisions to test the best number of divisions and the results compared with results of the experimental analysis from Şahin and Acir work [4]. As shown in the fig. (1) below, it has reached a converged to a steady value of 350 to 500. Additionally, the error ratio calculated by

$$\frac{Theoretical\ value - Experimental\ value}{Theoretical\ value} * 100$$

The following table shows the results of 10 different steady values. The result is clearly shown that at 500 is the lowest error ratio that means the best result as shown below.

TABLE I. ERROR RATIO FOR MESH INDEPENDENT STUDY

No of div	CL	CL EXP	Error
50	0.19588	0.335	-71.0231
100	0.22537	0.335	-48.6445
150	0.28068	0.335	-19.353
200	0.30701	0.335	-9.11697
250	0.314	0.335	-6.6879
300	0.33317	0.335	-0.54927
350	0.35365	0.335	5.273576
400	0.36158	0.335	7.35107
450	0.35233	0.335	4.918684
500	0.33511	0.335	0.032825

B. Validation

III. Model validation is a continual effort to ensure that the tools meet all design requirements and that computed results provide a high level of accuracy and performance. After the mesh independence studies, numerical turbulence model validation is the second step in the CFD process. For complex simulations, various individual models are verified and validated, which can play a major impact in simulation results. These studies might be an experimental investigation or a proven theory. Therefore, the process is to compare results and check the reliability.

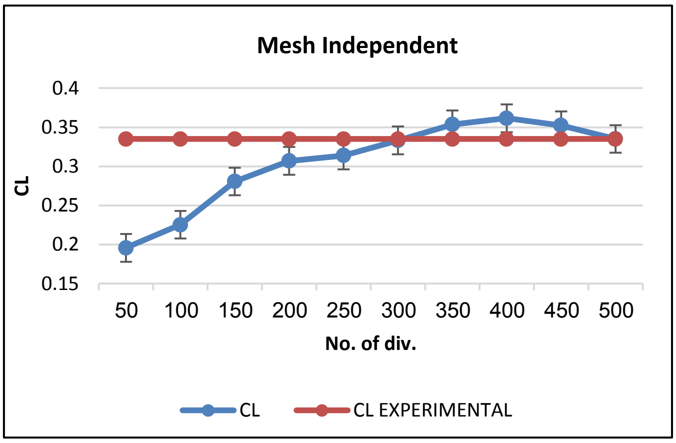

Figure 1. Mesh Independent Study

The validation has been gained by comparison between some models results and published experimental results [4]. These results provide a great agreement achieved between present CFD for the target function, C_l and experiments if utilize the realizable k-ε turbulence model. The outcome of the CFD simulation can be seen in Figure (2).

Shih et al. [20] developed a realizable k-ε turbulence model has always been retained in this study. Usually, it is recommended the realizable k-ε model for rotating bodies.

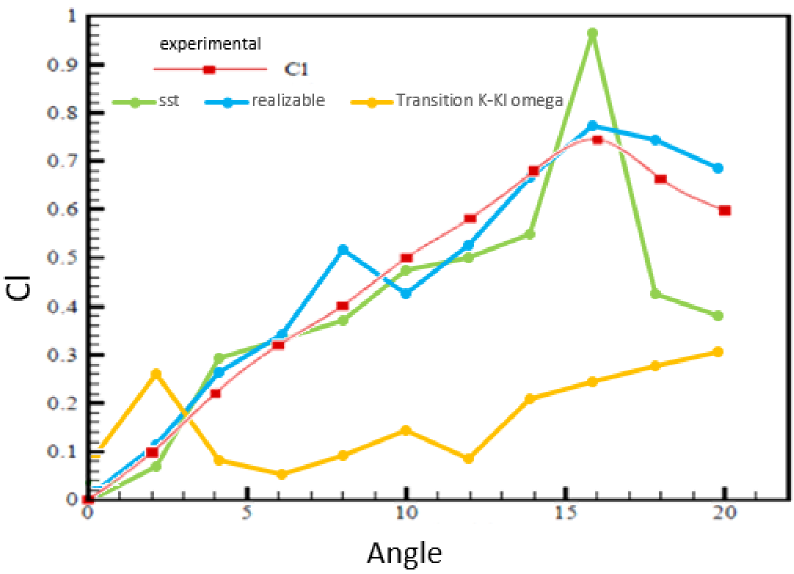

Figure 2. Validation by comparison between the Experimental and numerical results

IV. RESULTS

The best performance (C_l/C_d) for some of the wings was examined as shown in the figures below. Also, the best C_l/C_d evaluation performance was achieved at about 8 degrees. There are different types of aerofoil's family discussing in this paper as describe below;

A. NACA FAMILY

In this family, the best C_l /C_d ratio is NACA 63415 as shown in Figure. 3. Also, the contours for velocity and pressure are presented in Figures 4 and 5.

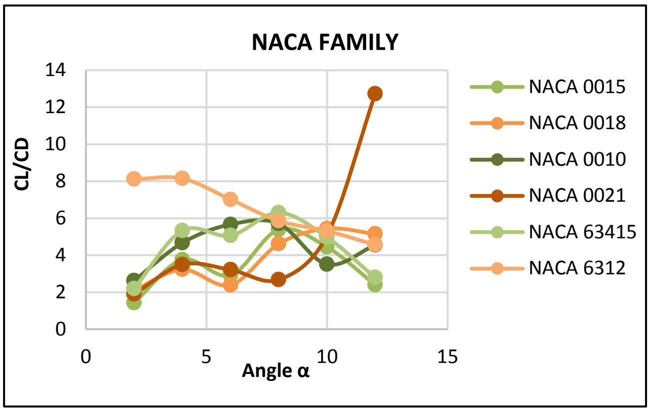

Figure 3. Ratio of Cl/Cd for various attack angle of NACA family

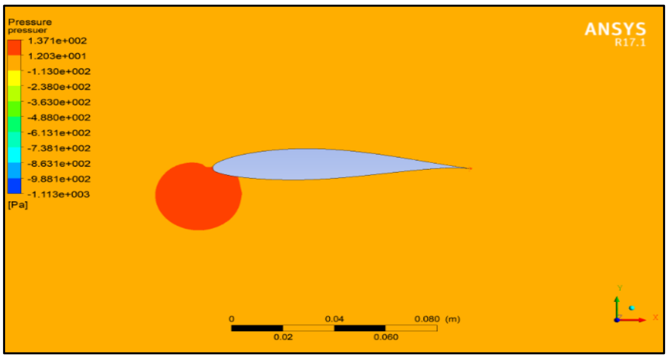

Figure 4. Pressure contour for NACA 63415

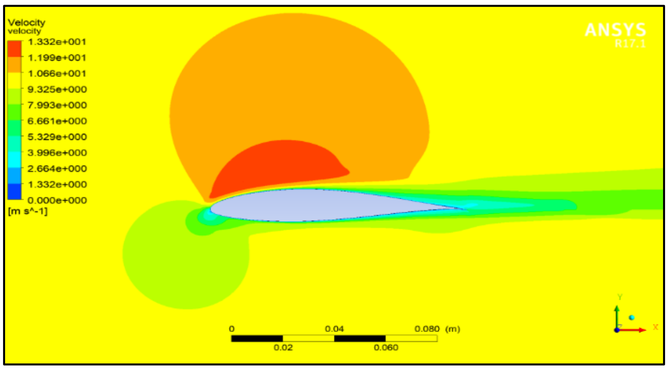

Figure 5. Velocity contour for NACA 63415

B. AH FAMILY

In this family, the best C_l/C_d ratio is AH93W215 as shown in Fig. 6. Also, the best contour for velocity and pressure in Fig. 7, 8.

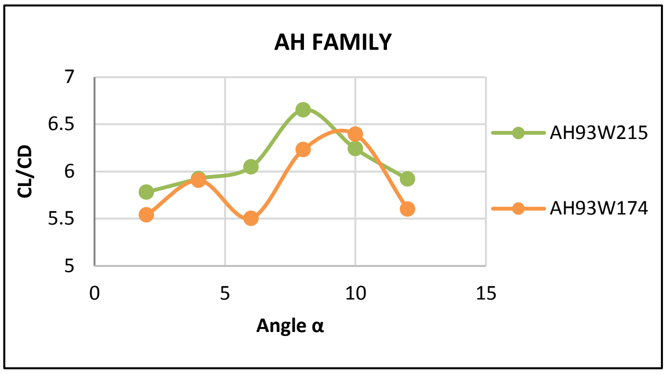

Figure 6. Ratio of Cl/Cd for various attack angle of AH FAMILY

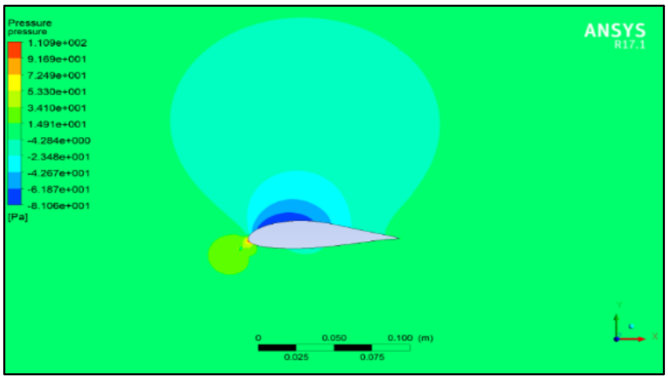

Figure 7. Velocity contour for AH93W215

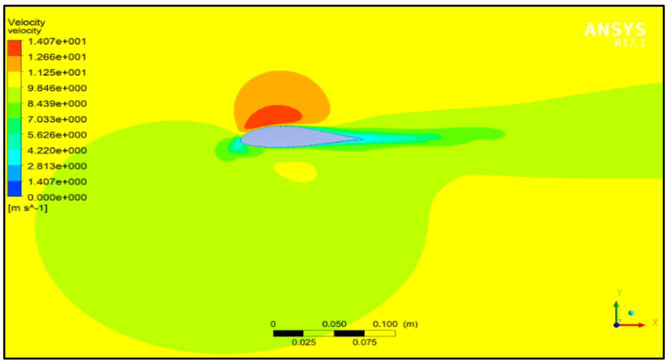

Figure 8. Pressure contour for AH93W215

C. FX FAMILY

In this family, the best C_l/C_d ratio is FX71L150 as shown in Fig. 9. The contours for velocity and pressure are presented in Figures 10 and 11.

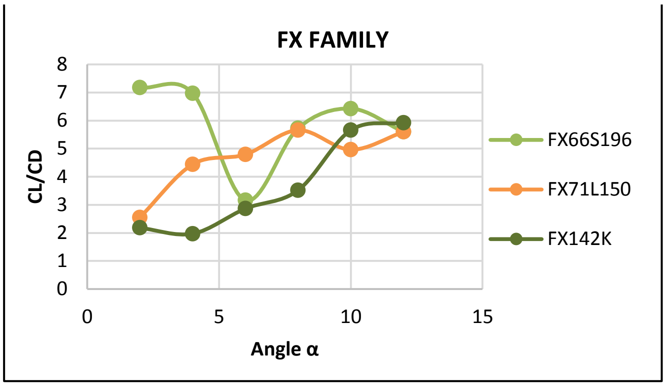

Figure 9. Ratio of Cl/Cd for various attack angle of FX FAMILY

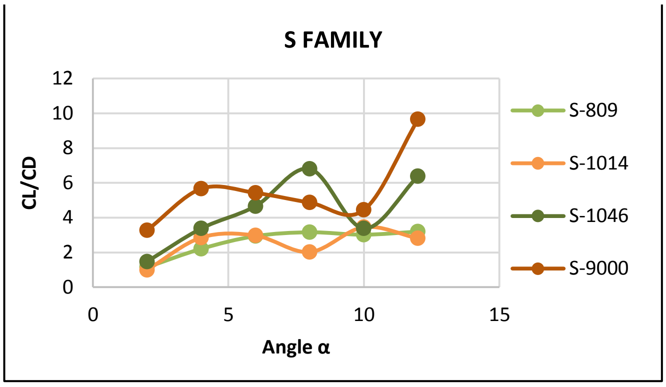

Figure 12. Ratio of Cl/Cd for various attack angle of S FAMILY

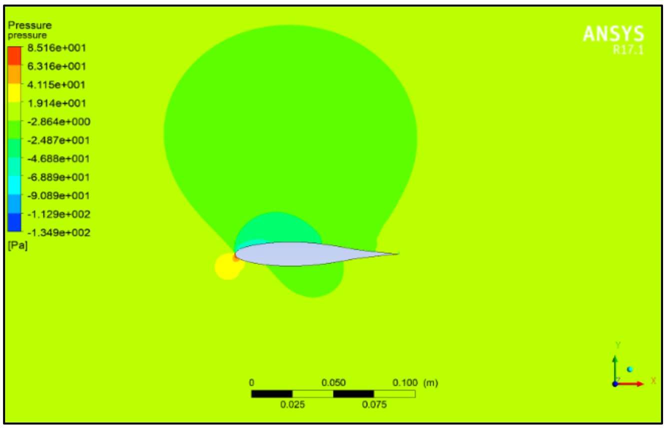

Figure 10. Pressure contour for FX71L150

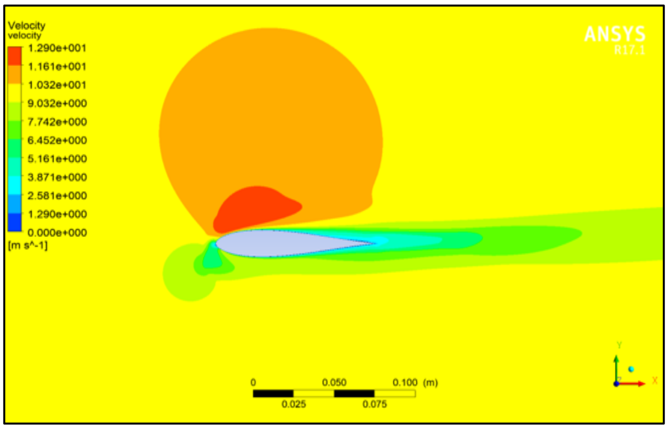

Figure 13. Velocity contour for S-1046

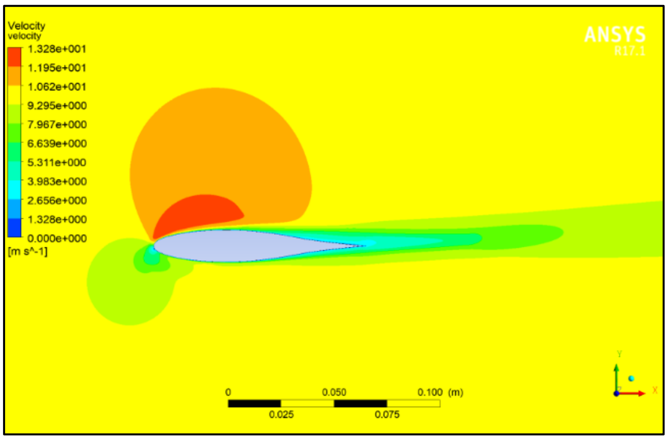

Figure 11. Velocity contour for FX71L150

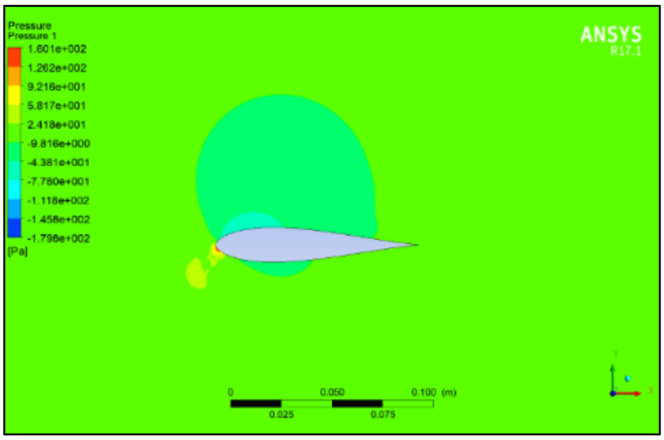

Figure 14. Pressure contour for S-1046

D. S FAMILY

In this family, the best C_l/C_d ratio is S-1046 as shown in Fig. 12. The contours for velocity and pressure are in Fig. 13, 14.

As shows the lift and drag ratio performance of airfoil's families with regular surface without dimples for different attack angles from 2 to 12.

Clearly, after reviewing all figures, it appears that figure 1, 2, 3 and 4 are those for airfoil's families with the regular surface, coefficient of drag (C_d) increases as the angle of attack goes on increasing. Moreover, the increase in the angle of attack, the value of the coefficient of lift (C_l) increases, but the value of the coefficient of lift to drag ratio is suddenly decreasing and goes on decreasing as per increase in angles of attack after arriving for some points. The condition at which value of the coefficient of lift starts reducing is known to be stalling condition. The following Figure 15 presents the best curve of airfoil that used in this test.

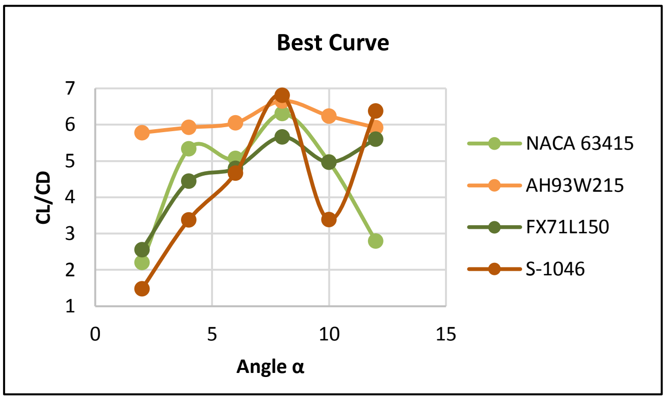

Figure 15. Ratio of Cl/Cd for various attack angle of best Airfoils

It clearly shows that the airfoil AH93W215 is the best compared with other airfoils which have chosen the best performance as NACA 63415, S-1046 and FX71L150. This is due to its constant value along the operating range of the angle of attack. Therefore, the AH93W215 airfoil for the H-rotor Darrieus turbine is better than NACA 0021 that used before which normally used before.

V. CONCLUSION

Electricity consumption will increase the share of global energy demand during the next years. Wind energy plays a major rule in producing energy. This study will discuss the important of vertical turbines (Darrieus Turbines). The main idea is to obtain a higher efficiency by improving the performance factor Cl/Cd ratio an H-rotor Darrieus turbine for wind-energy conversion. In this paper, there are 15 different (symmetric and non-symmetric) airfoils investigated during the test in order to come up with a clear, accurate and precise result.

The test worked on many experimental and Numerical results compared to the realizable k-ε turbulence model can be used analysis. All turbines with different airfoil configurations are evaluated by CFD. The investigation of the best performance factor C_l/C_d ratio of H-rotor Darrieus turbine consisting of (symmetric and non-symmetric) airfoils has been obtained by using numerical simulations. In this study, the FLUENT was utilized for numerical calculations.

Also, lift and drag performances of several airfoils were calculated. The result has been numerically investigating the influence of multi airfoil effect on the aerodynamic performance of wind turbine blade by CFD. Also, the optimum airfoil performance was measured for the airfoils which used for the operating range of the angle of attack. Moreover, the results indicated that the AH93W215 airfoil for the H-rotor Darrieus turbine is the best.

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