Hydrodynamics Simulation for Air Flow Past Over an SD 2030 Airfoil Using Two Dimensional Model

Dhafer A Hamzah¹, Naseer H Hamza¹, Mohamed F Al-Dawody¹ and Khaled Al-Farhany¹

¹Department of Mechanical Engineering, University of Al-Qadisiyah, Al-Qadisiyah, Iraq
dhafer.hamzah@qu.edu.iq

Abstract. In the old new present work cares with change of Reynolds number effect on the hydrodynamic characteristics. The different pitch angle is taken to analysis drag, lift, and pressure coefficients. The goal of these parameters is to understand the nature of the flow over the upper surface of the airfoil since the long laminar boundary layer and transition region have a light point for aerodynamics performance assessment. The results indicated that the improvement in performance is parallel in path with the increasing length of the laminar flow region.

1. Introduction
Any understanding and development of an airfoil behavior must pass through a study of basic hydrodynamic characteristics. The development in the experimental devices and numerical techniques can give results that are more accurate in fields of aeronautical and astronautically engineering. (Rhie and Chow 1983) have been using an ordinary grid system instead of staggered grid. Also in there study, they used k-ε model without separation infinite volume element technique. They concluded without separation that, the results give a good agreement with experimental results. Hard efforts made by (Selig, Donovan et al. 1989) to present the drag and lift coefficient at low speed by using strain gauge and Pitot tube with different profile of airfoil sections. Different series achieved by (Selig, Guglielmo et al. 1995) at low different Reynolds numbers and the attached angle to cover all types of airfoil sections. It has been used to investigate the drag and lift parameters. (Wolfe and & Ochs 1997) concern on the appropriate model of CFD analysis for wind turbine airfoil and fluid flow field to determine the aerodynamic characteristics. Because of global warming, the researchers focus on wind energy. Three-dimensional flow around wind blade has been studied by (Johansen and Sørensen 2002). They studied the effect of different flap wise in moment and force production. They concluded that the tangential and normal forces in a standard tip have steeper gradient than in the two-tapered tip. (Simao Ferreira, van Kuik et al. 2008) care about the dynamic stall phenomena happen in vertical axis wind turbine by using a particle image velocimetry (PIV). They found a real effect on the power and load at different tip speed ratios and azimuth angles of blade sections. (Dai, Gardiner et al. 2011) studied different hydrodynamic models to design a Darrieus turbine in marine conditions and compare their results with available experimental results. They found that at higher solidity and low tidal turbine cascade, the momentum and vortex models were less accurate at higher attack angles with unsteady factors. (Kim, Yoon et al. 2012) investigate the hydrodynamic performance of turbulent flow past over a wavy leading edge with different amplitude and length. The result showed that there is a considerable loss value in lift force. (Dunne and McKeon 2013) concern on dynamic separation which
happens in the vertical axis in wind turbines. The numerical dynamic decomposition model and experimental study achieved in there study at different pitch up and pitch down keeping the flow attached not separation. (P. B. Makwana and makadiya 2014) they analyzed the effect of slotted leading edge of NACA 0012 airfoil on the separation phenomena. They found that with 15%C leading edge slot maximum lift occurs at 17°. (Rahimi, Medjroubi et al. 2014) they evaluate the different turbulent models in different types of airfoil with different mesh strategies. They found a good agreement between k-ε SST and kkl-ω models, also the results show kkl-ω model gives better results comparing with RNG unsteady model. (Bianchini, Ferrara et al. 2015) showed the effect of pitch angle on the performance of Darrieus wind turbine. The results confirmed that the lift force increasing with proper pitch angle at medium and high solidity ranges. (Li, Maeda et al. 2015) study the effect of solidity of wind turbine by change of blades number. The results show that the performance of wind turbine decrease with increase the solidity, also the high performance depends on upstream region for azimuth angles. (Zaheer, Munir et al. 2015) they using different S series of airfoil to determine the sliding ratio at different attack angles. Moreover, they found the prime attack angle to every type of presented airfoil. (Bedon, De Betta et al. 2016) they used algorithm loop to create a new shape profile for Darrieus wind turbine. They used the URANS CFD model to verified their results for aerodynamic factors. The study concluded that the new profile could be used carefully with two or more wind speed in turbine design. (Dhert, Ashuri et al. 2017) they added more parameters in CFD to get more accurate results for the wind design by coupling technique for torque gradient coefficients. They found that the torque increasing by 22% for the present design depending on mesh generation and number of variables. A detailed study achieved by (Rezaeia, Kalkman et al. 2017) using unsteady Reynolds-average Navier-Stocks URANS to predict laminar transition to turbulent as well as shed vorticity. The study showed that the optimum pitch angle at -2 with tip speed ratio 4. (Zhang, Gillebaart et al. 2017) reduce the error of the results of wind turbine blades by using non-rotating model. A good agreement observed with RANS numerical model for different types of airfoil section. Also, the vortices structure created in mid distance a long span. (Hashem and Mohamed 2018) predicted the power coefficient for 24 new airfoil and effect of wind lens on the performance. The study showed that S1046 airfoil type have the best performance at tip speed ratio from 2-7, also the maximum power coefficient equal to 0.3463 (Urszula Golyska 2018). From above survey, there is a lack in effect of Reynolds in the hydrodynamic characteristics such as pressure coefficient and vorticies distribution. In the present work, a viewpoint will be light in fundamental hydrodynamic performance.

2. Problem description and mesh generation
In the present work, smooth SD 2030 is taken as a model for a 2-dimensional study. The chord length is 0.305 m, the Reynolds numbers of airflow are between 4x10^4 and 30x10^4 as laminar flow. The pitch angle changes from 0o to 12o. The rectangular mesh will be taken a number of cells between 30x10^4 and 85x10^4 as refinement increases around the effect region. The width and the length of the 2D domain are 0.8 m x 0.4 m respectively as shown in Fig.1.

Figure 1. Mesh generation with refinement at 0° pitch angle.
3. The governing equations

The well-known governing equations of conservation of mass and momentum can be expressed in the perpendicular coordinates as:

\[
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i} (\rho u_i) = 0
\]

\[
\frac{\partial \rho u_j}{\partial t} + \frac{\partial}{\partial x_i} (\rho u_i u_j) + \frac{\partial p}{\partial x_i} = \frac{\partial}{\partial x_j}(\tau_{ij} + \tau_{ij}^v) + S, i = 1, 2, 3
\]

where \(u_i\), velocity vector normalized by some velocity scale \((U)\), \(t\) is the time normalized by the convective time scale, \(p\) is the pressure normalized by the dynamic pressure \((\rho U^2)\), and \(\rho\) is the fluid density. \(F_x\) and \(F_y\) forces acting in \(x, y\)-direction respectively. \(A\) is the projection area of the airfoil section.

4. Results and discussion

For airfoil performance assessment the characteristics of flow should be calculated as lift, drag and pressure coefficients. Figure 2 shows the development of lift factor against pitch angles with constant Reynolds number. The low Reynolds number 5x10^4 has the lowest values of lift coefficient, this is normal due to low speed which leads to low dynamic pressure for lifting the airfoil section. In spite of some values at low pitch angles near lift values of relatively high Reynolds number 10x10^4. This behavior due to the viscous force for laminar flow, which is dominant in leading-edge for both Reynolds number. The lift force is continuously increasing at higher Reynolds numbers. This is due to the effect of viscous forces and their role in determining the lift force. The flow zones over the entire airfoil are mainly determined by the value of Reynolds number which indicates whether it is laminar, transitional or turbulent flow.

Figure 3 shows that the drag coefficient decreasing when the lift coefficient and pitch angle increasing.
The drastic decrease in the drag coefficient found at \( Re = 5 \times 10^4 \) and \( 30 \times 10^4 \) is due to the formation of a Laminar Separation Bubble at that angle of attack. Laminar separation, transition, and turbulent reattachment near the leading edge of airfoils. The crucial issue in the flow zones is the moving from laminar to turbulent zones which is so-called transition region developing as Reynold number approaches its critical value. Sometimes the drag increases at relatively low lift coefficients and in such situations laminar separation bubbles are used to give an indication about that especially at low Reynold numbers (AREN A et. al.1980).

For more persuasion about the performance of the airfoil pressure coefficient present for some cases to demonstrate the negative upper pressure and positive lower pressure which causes the Coanda effect. Fig.4a shows the pressure factor with the airfoil profile for the upper and lower surface at \( 30 \times 10^4 \) and 0-degree pitch angle. Fig.4b shows the optimum case with high Reynolds number \( 30 \times 10^4 \) and 12-degree pitch angle.

![Figure 3. Drag coefficient versus pitch angle.](image)

![Figure 4a. Pressure coefficient at Re=30x10^4](image)

![Figure 4b. Pressure coefficient at Re=30x10^4](image)
The substantiality interprets all the above behavior verified by a streamline contour, which shows the awake due to separation in boundary layer. An appropriate illustration of the airfoil performance at this certain range of Reynold number, i.e., \((5 \times 10^4 < Re < 30 \times 10^4)\) can be done here by the presence of a laminar separation bubble (LSB) at some values of \(\alpha\). It can be seen that the drag increase at moderate lift coefficients is caused by LSB as shown in figure 5. When an adverse pressure induced by the growth of laminar boundary layer, but it may separate it. It is remarked that the laminar stage does not longer exist because of instabilities it soon transmits to the turbulent shear flow. In the turbulence zone, the instabilities tend to absorb momentum from the outside stream throughout the shear layer itself down to the airfoil surface. In case of strong transport of momentum, the turbulent boundary layer again attaches the outer surface and in such a way it closes the separation bubble.

Also, there is a type of laminar separation followed by reattachment to the airfoil surface is a leading-edge vortex (LEV). This LEV is formed by separation at the sharp leading edge of an airfoil during the downstroke of the flapping cycle. The separation rolls up on top of the wing and forms a vortex near the leading edge. The flow outside the vortex is able to reattach to the airfoil surface.

Figure 5a. Streamlines distribution with velocity contours at 0° and different Reynolds number.
Figure 5b. Streamlines distribution with velocity contours at 2° and different Reynolds number

Re=5*10^4

Re=10*10^4

Re=15*10^4

Re=20*10^4

Re=25*10^4

Re=30*10^4
Figure 5c. Streamlines distribution with velocity contours at 4 different Reynolds number:

- $Re = 5 \times 10^4$
- $Re = 10 \times 10^4$
- $Re = 15 \times 10^4$
- $Re = 20 \times 10^4$
- $Re = 25 \times 10^4$
- $Re = 30 \times 10^4$
Figure 5d. Streamlines distribution with velocity contours at 12 different Reynolds number
5. Conclusions

- The increasing in pitch angle leads to increase lift and drag coefficient. Since the velocity for upper streamlines is more than the lower, so a negative pressure will be happening at the upper surface.
- Not always the increase in pitch angle leads to an increase in performance, these depend on the length of the laminar boundary layer and transition region.
- The lower Reynolds number has a clear separation region, while at relatively high Reynolds number the reattachment for streamlines will be verified.
- The pitch angle makes the upper region of the maximum velocity decreasing with increasing it.
- More efforts should be achieved to approximate the simulation and experimental work.

6. References

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