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# A Study Effect of Sistan Region Dust on the Aerodynamic Performance of Wind Turbine Blade

*It is very important to establish a wind farm in the windy areas due to the increased use of renewable energies. Sistan region is one of the windy regions in Iran but due to the dust in the wind of this area and adhesion property of this particles to the wind turbine blade, smoothness of the blade surface is somewhat lost which affects its aerodynamic performance. In this paper, the aerodynamic performance of wind turbine blade was numerically investigated considering the roughness height due to the sticking dust particles in the wind, change of the attack angle, and roughness height. It compared with the experimental results and the range of the optimum attack angle was proposed for turbine in the Sistan region.*

***Keywords***: *Dust, wind turbine, airfoil, lift coefficient, drag coefficient*

## 1. Introduction

All modern wind turbines producing electricity energy use the lift force generated by the blades for the rotor bouyancy. But the smoothness of blade surface has been affected in Sistan region and aerodynamic performance and lift coefficient of the blade has been changed due to the dust in the wind and adhesion property of this particles to the wind turbine blades. Since the use of vortex generation device is one of the ways to improve the aerodynamic performance of large turbines, Gao et al. [1] investigated numerically the effects of size of mentioned device on the aerodynamic performance improvements of wind turbine with DU97-W-300 airfoil in 2015. According to their results, drag force is more dependent on the studied parameters in the article than the lift force. They also plotted and analyzed the flow lines and vortices in the wake region. In 2015, Lee and Lim [2] done a numerical investigation on the aerodynamic performance of Darrieus-type vertical-axis wind turbine with NACA airfoils series. They examined various parameters such as chord length, helical angle, pitch angle, and rotor diameter. They investigated the flow in the vicinity of the blade and torque and power characteristics by changing the mentioned parameters and focused more on the optimized design of the blade which have the least interaction and disturbance with the environment. In 2014, Lee et al. [3] carried out a study with the title of "Lift correction model for local shear flow effect on wind turbine airfoils". They used the BEMT theory to calculate the loads acting on the turbine blade and examined the impact of idealized local shear flows on the aerodynamic characteristics around two-dimensional airfoil by using CFD Simulation. They also investigated the impact of angle of attack and chord length along with change in shear flow on the lift and drag coefficients.

In 2014, Yang et al. [4] anticipated the wind turbine aerodynamic performance using the obtained data from CFD method on the airfoils. They used azimuthally averaged velocity for defining angle of attack and calculating lift and drag coefficients by using the forces acting on the blade. To do this, they used the blade element momentum (BEM) theory and compared results of their study with the Shen's tip loss correction model and experimental data. In 2012, Yao et al. [5] done a two-dimensional numerical investigation on the NACA0018 airfoil aerodynamic performance of the wind turbine. They examined lift and drag coefficients under different turbulence models for this airfoil by changing the angle of attack and compared it with the available experimental results. They also evaluated change of the surface pressure and flow separation under different turbulence models by changing the angle of attack. In 2012, Sedaghat et al. [6] designed aerodynamic wind turbine with the horizontal axis in Semnan, Iran. They employed the BEM theory to calculate the coefficients of lift, drag, angle of relative wind, and angle of attack. Timmer [7] worked on the aerodynamic characteristics of wind turbine blade airfoils at high angles-of-attack in 2010. He found the maximum drag coefficient and also lift to the drag ratio in the particular circumstances of his problem solving and discovered that the airfoils lift to drag ratio with the leading edge separation is not related to the aspect ratio. In 2007, Mohammad Khalfallah et al.'s study [8] was the only work which carried out on the actual case of wind turbine under different conditions for 9 months in the Egypt with the title of "investigation of the effects of the dust on the wind turbine's performance". In 2009, another study done with the title of "the effect of dust on the wind turbine's airfoils performance" by Ren et al. [9] In this study, two-dimensional solving of the Navier-Stokes equations and turbulence model were investigated to study the flowing incompressible viscous fluid from two-dimensional airfoil of the wind turbine under clean surface conditions and rough surface. A numerical simulation was performed for the airfoil under clean conditions and changes of lift and drag coefficients under different heights of the roughness were measured. In 2010, Khosravi [10] done a study on the investigation of the vertical distribution of storm's dust in the Middle East using the NAAPS model in the Sistan, Iran. In this study, he presented the criterion to measure the amount of dust in the air during storms based on dust milligrams per cubic meter of mixture in the months of the year. Change of the lift, drag, momentum, and pressure coefficients were investigated for many types of NACA airfoils by Frank et al. [11] in 2001 and their changes diagrams were also presented. Douglas et al. [12] examined changes of the drag and lift coefficients based on three different roughness height for the NACA airfoils of 44, 24,230 series at different Reynolds numbers in 1982. They presented some relations to calculate drag and lift coefficients according to the different conditions as well as diagrams of the lift and drag coefficients based on the angle of attack and the lift coefficients, respectively for NACA sections. In 1999 Cristian Buck et al. [13] done some experiments to determine the drag and lift coefficients curves for airfoils of NACA and FFA_W3 sections and also drawn the obtained curves. Timmer [14] reviewed the NACA airfoils characteristics with 6-digit naming identifier for the large wind turbines in 2009. In this source, some diagrams were provided for the lift coefficient- attack angle and lift-drag coefficients for different airfoils.

In this study, the effect of wind turbine blade's roughness on the change of lift and drag coefficients is investigated with several hundred kilowatt power for large wind turbine installed in Loutak region, Zabol. To do this, lift and drag coefficients are calculated by using derived formulas and diagrams from experimental studies in the literature, then NACA63 airfoil, which is half of the wind turbine blade's section installed in Sistan, is numerically simulated. Next, the drag and lift coefficients are calculated in a numerical fashion by applying wind conditions of Sistan region and blade surface roughness height on the mentioned airfoil and are compared with the experimental results.

## 2. Problem Theory

Blade surface smoothness becomes low due to the striking dust particles to the blade and the blade becomes rough. The end result of existing roughness is the increase of aerodynamic drag on the blade and the decrease of maximum lift coefficient. Increase of the drag coefficient reduces the energy conversion coefficient in all wind power and the lower lift coefficient maximum reduces the output power maximum of a given wind turbine in its wind speed rate. Here, the roughness expresses with the $k/c$ parameter which is made with regard to the Rayleigh distribution.

### 2.1. Effect of roughness on the lift force

The lift coefficient depends on the Reynolds number and angle of attack and it has affected by changing these two parameters. In this paper, we study the effect of changing the angle of attack in terms of change in the roughness heights. Changes of lift force in terms of change of attack angle consist of three areas: 1. linear range 2. shear rounded range 3. lag range. We study the last two areas.

In the shear rounded range, the lift coefficient calculates through the following formula:

$$C_l = C_{l,opt} + \frac{dC_l}{d\alpha}(\alpha - \alpha_{opt}) - bW^2 \frac{Y}{|Y|} \qquad \alpha_{cf} \prec \alpha \prec \alpha_{st} \tag{1}$$

$C_{l,opt}$ represents the optimum coefficient, $dC_1/d\alpha$ slope of the lift curve, $\alpha_{opt}$ optimum angle of attack, Y dimensionless parameter which is a fraction equation of the expected angle of attack between the symmetry angle and stall angle. W also represents the dimensionless parameter and is a fraction equation which shows the ratio of the expected angle of attack between $\alpha_{cf}$ and stall angle and the b coefficient measures in the stall angle. Angles of attack of $0.7C_{l,\max}, C_{l,\max}$ show with $\alpha_{cf}, \alpha_{st}$ ,respectively. In the lag area, the equations for calculating the lift coefficient express as follows:

$$\begin{aligned}
C_l &= C_{l,opt} + (C_{l,\max} - C_{l,opt} - S_1 z)\frac{Y}{|Y|} && z \prec \alpha_m - \alpha_{st} \\
C_l &= C_{l,opt}(C_{l,st} - C_{l,opt})\frac{Y}{|Y|} && \alpha_m - \alpha_{st} \prec z \prec \alpha_{fp} - \alpha_{st} \\
C_l &= C_{l,opt} + 1.1\sin(\pi|Y|(\alpha_{st} - \alpha_{opt})) && \alpha_{fp} - \alpha_{st} \prec z
\end{aligned} \tag{2}$$

The parameter z is the difference between the expected angle of attack and the stall attack angle. For $S_1$, We have:

$$S_1 = -0.43 + n/10, n = 0,1,2,4 \tag{3}$$

$$C_{l,st} = 0.6C_{l,\max} \tag{4}$$

$$\alpha_m = \alpha_{st} + (C_{l,\max} - C_{l,st})/S_1 \tag{5}$$

$$\alpha_{fp} = \alpha_{opt} + 1/2\sin^{-1}((C_{l,st} - C_{l,opt})/1.1) \tag{6}$$

### 2.1. Effect of roughness on the drag force

The aerodynamic drag force increases as a result of striking wind dust particles to the turbine blade in which they stick to the blade surface and create roughness. The performed XRD analysis on the soil sample of Sistan region indicates that a small percentage of dust particles have a diameter of 4000 microns which stick to the blade surface. It is assumed that the roughness height is 4000 mm in this stage. We know that two types of inhibitions make due to the roughness:

1. Aerodynamic inhibition which measures by the drag coefficient (Cd).
2. Inhibition due to the friction which measures by parietal friction coefficient (Cf).

The following formula is used for drag coefficient:

$$\left\{\begin{array}{l} X < 1 : prestall \\ C_d = C_{d,\min} + \delta C_d \\ \delta C_d = a_0 + a_1 X + \ldots + a_{10} X^{10} \\ C_{d,\min}(\mathrm{Re} = 6*10^6) = (1 + p_i) C_{d,\min}(smooth) \\ C_{d,\min} = C_{d,\min}(\mathrm{Re} = 6*10^6)\left(\dfrac{6*10^6}{\mathrm{Re}}\right)^{0.11} \\ p_i = 1.0935 + 0.1418\log(\dfrac{k}{c}) \\ C_{d,\min}(smooth) = 0.004 + 0.00016Th \end{array}\right\} \tag{7}$$

$$\left\{\begin{array}{l} X > 1, Y > 1 : poststall \\ C_d = C_{d,\min} + \delta C_d + o.3275z \\ \delta C_d = a_0 + a_1 X + \ldots + a_{10} X^{10} \\ C_{d,\min}(\mathrm{Re} = 6*10^6) = (1 + p_i) C_{d,\min}(smooth) \\ C_{d,\min} = C_{d,\min}(\mathrm{Re} = 6*10^6)\left(\dfrac{6*10^6}{\mathrm{Re}}\right)^{0.11} \\ p_i = 1.0935 + 0.1418\log(\dfrac{k}{c}) \\ C_{d,\min}(smooth) = 0.004 + 0.00016Th \end{array}\right\} \tag{8}$$

Note that x is a dimensionless parameter which depends on the different lift coefficients. Also, $a_0 - a_{10}$ coefficients read from the related tables and Th represents the percentage of airfoil thickness to the chord length [8].

$$X = \frac{\left(C_L - C_{L,opt}\right)}{\left(C_{L,\max} - C_{L,opt}\right)} \tag{9}$$

### 3. Discussion

Here, using the presented theory in the previous section and the selected roughness, the lift and drag coefficients calculate for NACA63 airfoil which is half of the large wind turbine blade section with several hundred kilowatt power installed in the Loutak region, Sistan. A number of expressed parameters in the equations are the same for all roughness and angles of attack and they are only a function of the airfoil type:

$$S_1 = -0.33, \alpha_0 = -1.25, \frac{dC_l}{d\alpha} = 0.101,$$
$$C_{l,opt} = 0.1, \delta\alpha = 2.25, \alpha_{opt} = -0.2599$$

It should be noted that selection of the roughness values is done according to the available data in the literature which obtained through experiments and use of wind tunnel. Theoretical analysis results give in Table1. From Table1, it can be seen that the maximum lift coefficient is for a condition in which $\alpha_{st} \prec \alpha \prec \alpha_{fp}$ (it is true for the least coefficient of roughness). In other word, it is in the shear rounded range and the maximum lift coefficient in the same angle of attack is also in the least roughness, which is not so unexpected.

In the available graphs, the amount of lift coefficient equals to about 1 at 10 degrees angle of attack for without roughness condition, so-called smoothness of the blade for the NACA 63 sections [15]; it can be observed that the amount of lift coefficient reduces approximately 50 percent with making 0.011 roughness, which is the highest value in this study.

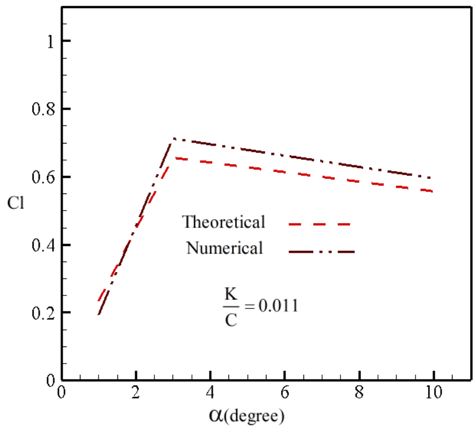


**Figure 1.** Comparison of numerical and theoretical study of lift coefficient changes in terms of angle of attack changes with roughness of 0.011

Using obtained results of NACA 63 airfoil modeling and applying roughness and change of attack angle, some results obtain with good approximation by the theory. It can be seen from Figure 1, changes of the lift coefficient and angle of attack are very close together both theoretically and numerically and have error about 4 percent. Also, Figures 2 and 3 showed an error rate about 3% and 2% for 0.000458 and 0.000083 roughness, respectively. Since turbine detects the wind direction through the installed device on the Nusselt part and hub and blade have the ability of rotation, so the angle of attack would surely be constant and possibly low because increasing angle of attack creates vortex, separation of flow, and positive pressure gradient and it has negative effect on the lift coefficient and lift force and also lifting performance of the airfoil. Thus, with reference to the forms and procedure of lift coefficient changes and by considering available roughness due to the sticking dust particles to the turbine's blade, it can be seen that the best value of the angle of attack is in a condition in which we have the maximum lift coefficient, so the range of attack angle is between 3 to 6 degrees of the optimum value.

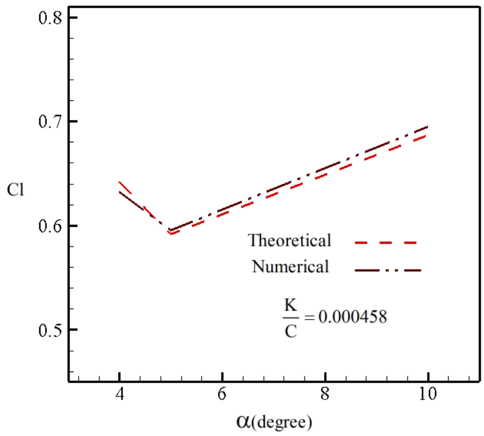


**Figure 2.** Comparison of numerical and theoretical study of lift coefficient changes in terms of attack angle change with 0.000458 roughness

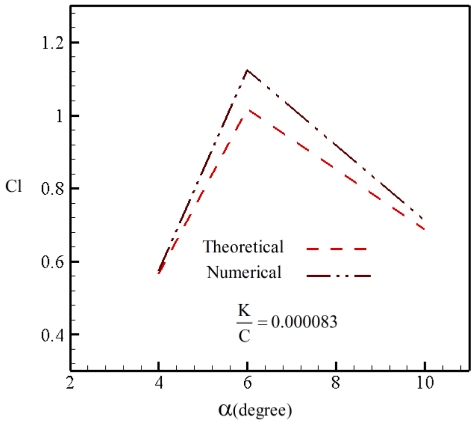


**Figure 3.** Comparison of numerical and theoretical study of lift coefficient changes in terms of attack angle change with 0.000083 roughness.

**Table 1.** Effect of changing the angle of attack and the roughness height on the lift coefficient for NACA 63 airfoils.

| $\frac{k}{c}$ | $C_l$ | $C_{l,\max}$ | $C_{l,st}$ | $\alpha_m$ | $b$ | $\alpha_{fp}$ | $\alpha_{st}$ | $\alpha_{cf}$ | $\alpha$ | $z$ | $Y$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.011 | .2318 | .3025 | .184 | 3.636 | .2272 | 3.995 | 1.9299 | .847 | 1 | .9299- | .5755 |
| 0.011 | .6557 | .3025 | .184 | 3.636 | .2272 | 3.995 | 1.9299 | .847 | 3 | 1.07 | 1.4887 |
| 0.011 | .5576 | .3025 | .184 | 3.636 | .2272 | 3.995 | 1.9299 | .847 | 10 | 8.07 | 4.685 |
| .000458 | .6416 | .506 | .291 | 5.929 | .226 | 6 | 4.7398 | 2.257 | 4 | .7398- | .852 |
| .000458 | .5919 | .506 | .291 | 5.929 | .226 | 6 | 4.7398 | 2.257 | 5 | .2602 | 1.052 |
| .000458 | .687 | .506 | .291 | 5.929 | .226 | 6 | 4.7398 | 2.257 | 10 | 5.26 | 2.052 |
| .000083 | .5657 | .528 | .3022 | 5.546 | .2275 | 6.23 | 5.036 | 2.409 | 4 | -.5164 | .8043 |
| .000083 | 1.0176 | .528 | .3022 | 5.546 | .2275 | 6.23 | 5.036 | 2.409 | 6 | 1.4836 | 1.182 |
| .000083 | .6877 | .528 | .3022 | 5.546 | .2275 | 6.23 | 5.036 | 2.409 | 10 | 5.484 | 1.94 |

**Table 2.** Effect of changing the angle of attack and the roughness height on the drag coefficient for NACA 63 airfoil.

| $Th$ | $\frac{k}{c}$ | $\alpha$ | $X$ | $Y$ | $z$ | $pi$ | $C_{d,\min}$ | $\delta C_d$ | $C_d$ |
|---|---|---|---|---|---|---|---|---|---|
| 0.16 | 0.011 | 1 | 0.65086 | - | - | 0.81577 | 0.01034 | 0.00838 | 0.01872 |
| 0.16 | 0.011 | 10 | 2.2598 | 0.46853 | 0.80701 | 0.81577 | 0.01034 | 3.46 | 3.49 |
| 0.16 | 0.000458 | 10 | 1.45 | 0.58203 | -0.7398 | 0.62 | 0.0113 | 3.04 | 2.81 |

The calculation results of drag force for NACA 63 airfoil can be seen in Table 2. Assuming that roughness do not exist, we have:

$$C_{f,L} = \frac{0.074}{\left(9.29*10^5\right)^{1/5}} 4.7384*10^{-3} \tag{10}$$

$$D = 0.0361\rho_{air}U^2bl\left[\mathrm{Re}\right]^{-1/5} = 12.008 \tag{11}$$

In the above formula, b, the maximum width of blade, equals to 4.5 m and L, the length of blade, is 22.9m. It can be observed from done XRD analysis on the soil sample of Sistan region that large number of constituents of initial soil sample is quartz and the rest combinations are called feldspar which is quartz or silica, varied or combined with another material. 7.9 percent of the sample contains particles with a diameter of about 4750 microns which is approximately 4.7 mm, then the roughness height assumes to be the same as the particle diameter, $4000\mu m$ . Therefore, to calculate the drag coefficient, we must first calculate the height of boundary layer at the end of blade. By comparing the height of boundary layer and height of roughness, the considered area is determined to study $C_f$ , we have:

$$\frac{L}{e} = \frac{22.9}{4*10^{-3}} = 5725 \rightarrow C_f = 0.0055 \tag{12}$$

$$D = \frac{1}{2}\rho U^2blC_f = 14.29 \tag{13}$$

The results of the calculations indicate that the roughness has a little effect on the drag coefficient.

## 4. Conclusion

This paper investigated the lift coefficient due to the change in angle of attack and studied numerically change of the roughness, then compared it with the experimental results. As a result, the optimum angle of attack was proposed for the lift coefficient in which this value was determined from 3-6 degrees considering different roughness height.

Regarding that turbine detects the wind direction and blade and Nusselt are rotatable, we can obtain the optimal lift coefficient and optimal amount of lift force in different conditions by adjusting the angle of attack. The results confirm that the force drag is increased considering roughness about 17%.

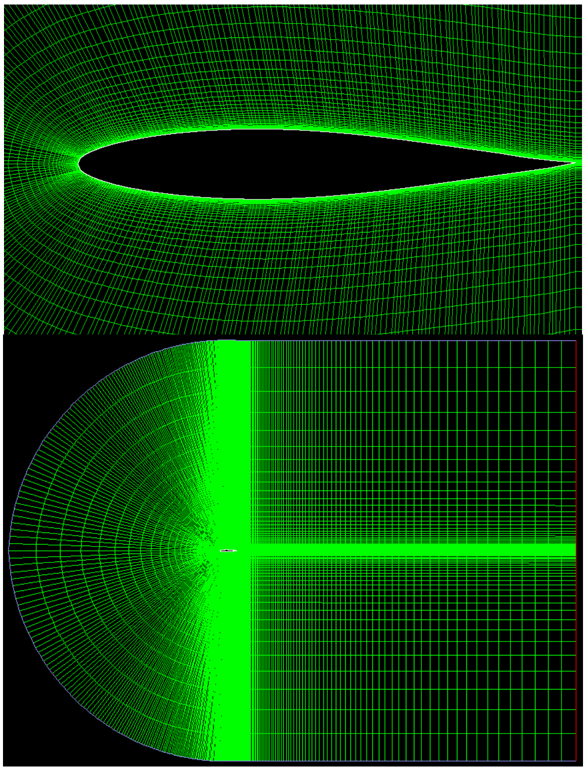

**Figure 4.** Schematic of the NACA 63 airfoil and its mesh.

**References**


[1] Gao L., Zhang H., Liu Y., Han S., *Effects of vortex generators on a blunt trailing-edge airfoil for wind turbines*, Renewable Energy, Vol.76, pp.303-311, 2015.

[2] Lee Y.T., Lim H.C., *Numerical study of the aerodynamic performance of a 500 W Darrieus-type vertical-axis wind turbine*, Renewable Energy, Vol.83, pp. 407-415, 2015.

[3] Lee K.S., Chung C.H., Baek J. H., *Lift correction model for local shear flow effect on wind turbine airfoils,* Renewable Energy, Vol.65, pp 275-280, 2014.

[4] Yang H., Shen W., Xu H., Hong Z., Liu C., *Prediction of the wind turbine performance by using BEM with airfoil data extracted from CFD*, Renewable Energy, Vol. 70, pp 107-115, 2014.

[5] Yao J., Yuan W., Wang J., Xie J., Zhou H., Peng M., Sun Y., *Numerical Simulation of Aerodynamic performance for two dimensional wind turbine airfoils,* Procedia Engineering, Vol. 31, pp 80-86, 2012.

[6] Sedaghat A., Mirhosseini M., *Aerodynamic design of a 300kW horizontal axis wind turbine for province of Semnan,* Energy conversion and management, Vol 63, pp 87-94, 2012
[7] Timmer W.A., *Aerodynamic characteristics of wind turbine blade airfoils at high angles-of-attack*, The Science of Making Torque from Wind, 2010.
[8] Khalfallah G., Koliub M., *Effect of dust on the performance of wind turbine,* Desalination, pp 209-220, 2007.
[9] Ren N., Ou J., *Dust effect on the performance of wind turbine airfoil,* J. Electromagnetic Analysis & Applications, Vol. 1, pp 102-107, 2009.
[10] Kousravi M., *Investigation of the vertical distribution of storm dust in the Middle East using the NAAPS model: Sistan. Iran*, Proceedings of the International Congress of the Islamic World Geographers, Zahedan, Iran, 2010.
[11] Bertagnolio F., Sorensen N., Jeppe J., Fuglsang P., *Wind turbine airfoil catalogue,* Riso National Laboratory, 2001.
[12] Douglas E., Thompson B.S., *The effect of blade roughness on the wind turbine performance*, Texas, 1982.
[13] Bak Ch., Fuglsang P., Niels N.S., Madsen H.A., *Airfoil characteristics for wind turbine*, Riso National Laboratory, 1999.
[14] Timmer W.A., *An overview of NACA 6-digit airfoil series characteristics with reference to airfoils for large wind turbine blades,* AIAA Aerospace Sciences Meeting, Florida, 2009.
[15] Fuglsang P., Ioannis A., Dahl S.C., Madsen Aa.H., *Wind tunnel test of the FFA-W3-241,FFA-W3-301 and NACA 63-430 airfoils,* Riso National Laboratory, 1998.

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