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Effect of Surface Roughness on Aerodynamic Performance of Symmetric NACA 0012

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ABSTRACT

Roughness in a wind turbine blade surface has a large effect on its aerodynamic performance. The current research concentrates on the various effects of the surface roughness upon the aerodynamics of a symmetrical NACA 0012 airfoil. In this respect, six kinds of different grit sizes of sandpaper were used: P500, P1000, P1500, P2000, P2500, and P3000, to provide a range of roughened surfaces for the study. In this experiment, the lift and drag coefficients were measured at three angles of attack (5, 10, and 15 degrees), and at three flow speeds of (5, 10, and 15 m/s). It was realized that an increase in surface roughness significantly impairs the aerodynamic efficiency, depicted by a reduction in the lift coefficient and an augmenting coefficient of drag. These changes lead to a reduced lift-to-drag ratio and reflect the importance of smoothness of the surface of wind turbine blades to maintain optimal performance. Comparisons with previous studies corroborate these findings, proving that surface roughness generates increased turbulence and skin friction, causing deterrents in boundary layer development around the airfoil.

Keywords: Surface roughness, Aerodynamic performance, NACA0012 airfoil, Lift coefficient, Drag coefficient.

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تأثير خشونة السطح على الأداء الديناميكي الهوائي لجناح NACA 0012 المتماثل

حسين خضير محمد

قسم الفيزياء، كلية العلوم، جامعة تكريت، تكريت، العراق

الملخص

ان لخشونة سطح شفرة توربينات الرياح تأثير كبير على أدائها الديناميكي الهوائي. يركز البحث الحالي على تأثير خشونة السطح على الديناميكا الهوائية لجناح NACA 0012 المتماثل. وبهذا الصدد، تم استخدام ستة أنواع من أحجام مختلفة من ورق الزجاج P500, P1000, P1500, P2000, P2500, and P300 وذلك لتوفير مجموعة من الأسطح الخشنة المختلفة للدراسة. في هذه التجربة، تم قياس معاملات الرفع والسحب بثلاث زوايا هجوم (5, 10, and 15 degrees)، وبثلاث سرع تدفق مختلفة (5, 10, and 15 m/s). ولقد وجد أن زيادة الخشونة السطحية تضعف بشكل كبير الكفاءة الديناميكية الهوائية، التي يتضح من انخفاض معامل الرفع وزيادة معامل السحب. تؤدي هذه التغييرات إلى انخفاض نسبة الرفع إلى السحب وتعكس أهمية نعومة سطح شفرات توربينات الرياح للحفاظ على الأداء الأمثل. وهذه النتائج تتفق مع الدراسات السابقة، مما يثبت أن خشونة السطح تولد زيادة في الاضطراب والاحتكاك السطحي، وهذا بدوره يتسبب في إعاقة تطور الطبقة الحدودية حول الجناح.

1. INTRODUCTION

In the present global energy scenario, renewable sources of energy are of increasing importance, as many countries are trying to reduce greenhouse gas emissions and dependence on fossil fuels. Of these, it is wind energy that has gained a prime position among all other sources, given its sustainability, technological advancement, and decreasing costs. Wind turbines convert the kinetic energy of wind into electrical energy and thus form the core of this renewable energy revolution[1, 2]. More to the point, wind turbine blades are supposed to have good aerodynamic performance if such is intended to be efficient and effective[3-5]. Many studies investigated NACA 0012 airfoil to measure the lift and drag forces because of its efficiency in wind turbines applications [6-9]. Such surface roughness can have enormous impacts on the performance of wind turbine blades and may come from a range of sources, such as insect accumulation, erosion, and manufacturing defects. Surface roughness changes the flow of air over blades, which in turn shifts both lift and drag. Lift is the aerodynamic force acting perpendicular to the oncoming flow direction and bracing of the blade against gravity, while drag is the aerodynamic resistance force acting parallel to the flow direction. Lift coefficient C_L and drag coefficient C_D can be define as [10]:

$$C_L = \frac{F_L}{{}^{1}/_{2}\rho V_0{}^2 c} \quad \ldots (1)$$

$$C_D = \frac{F_D}{{}^{1}/_{2}\rho V_0{}^2 c} \quad \ldots (2)$$

Where ρ is the air density, c is the chord length, and V_o is the flow velocity. A useful measure for the efficiency of a wind turbine blade is its lift-to-drag ratio, C_L/C_D, where higher values mean better performance. Previous investigations have proven that the surface roughness can increase drag and reduce lift, which lowers the blades' overall aerodynamic efficiency. For instance, Dalili et al.[11] studied the impacts of ice, insects, and sand erosion on a wind turbine's performance and concluded that there is a linear relationship between surface roughness and power loss. Keegan et al.[12, 13] investigated the degradation effects of the leading edge surface caused by rain and hail,

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researching that the gelcoat of the leading edge could be eroded by rain and hail, increasing the roughness. Walid Chakroun et al.[14] worked on the effects of surface roughness on the performance of the NACA 0012 airfoil, showing from the research that with an increase in roughness, lift is reduced, and drag increases due to skin friction. These studies underline the fact that understanding and mitigating the effects of surface roughness on aerodynamic performance is very important. The overall objective of the paper is to systematically investigate the effect of surface roughness on the aerodynamic performance of a symmetric NACA 0012 airfoil. The overview provided in this paper will, therefore, relate to how surface roughness, at different angles of attack and flow speeds, affects lift, drag, and the general lift-to-drag ratio. The results of this study will provide valuable insight to improve the design of wind turbine blades and other aerodynamic structures, and their maintenance.

2. EXPERIMENTAL METHOD

2.1. Materials and airfoil preparation

This work uses the NACA 0012 airfoil. It was selected for its symmetric profile and high usage in aerodynamics. Data from this airfoil was taken from Airfoil Tools website and inserted into the ANSYS software application to make a 2D model, which later was extruded to form the 3D shape as shown in Figure 1. The airfoil model was 3D printed at Western Michigan University; it was of a chord length of (14 cm) and span of (10 cm). The surface of the printed airfoil was left rough to capture the realistic conditions in the field. In this experiment, to depict different magnitudes of surface roughness, six different grit sizes of sandpaper—P500, P1000, P1500, P2000, P2500, and P3000—were used to treat the airfoil. A different degree of roughness is attributed to every grit size; the coarser the grit, the lower the number, and the finer, the higher. The aerodynamic tests were then conducted after treating the airfoil with these different grit sizes of sandpaper.

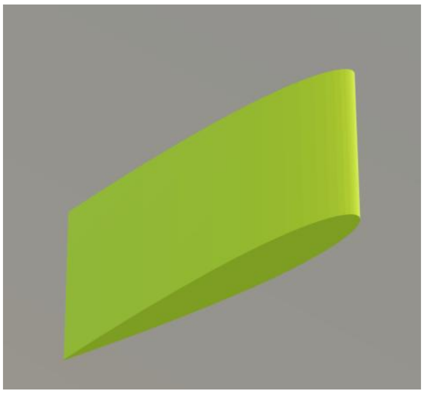

Fig. 1: 3D graph of NACA 0012 airfoil.

2.2. Wind tunnel testing

The aerodynamic performance of the airfoil was tested in a wind tunnel located in the fluid dynamics laboratory in the mechanical engineering department at Western Michigan University. It can generate an airflow that has controlled speed, and for this study, flow speeds were set at (5, 10, and 15 m/s). The setup for the wind tunnel is shown in Figure 2.

Fig. 2: Wind tunnel used in the study.

2.3. Measurement of Aerodynamic Forces

The airfoil lift and drag forces were measured with a specially made force balance, as illustrated in Figure 3. The force balance measures the forces acting on the airfoil due to flow incidents upon it at various angles of attack (AOA) (5°, 10°, and 15°) and at flow speeds (5, 10 and 15 m/s). Each test was conducted three times to ensure accuracy and the repeatability of results.

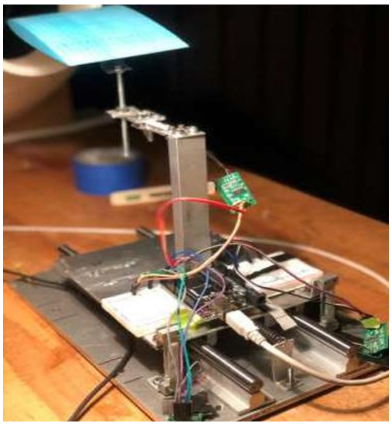

Fig. 3: Force balance setup for measuring lift and drag forces.

3. RESULTS AND DISCUSSION

3.1. Lift coefficient (C_L)

The lift coefficient (C_L) was measured for each grit size of sandpaper at three different angles of attack (5, 10, and 15 degrees) and three different flow speeds (5, 10, and 15 m/s). The results are summarized in Table 1 and visually represented in Figure 4.

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Table 1: Lift Coefficient (C_L) for Different Grit Sizes, Angles of Attack, and Flow Speeds.

Grit Size	Flow Speed (m/s)	Angle of Attack (degrees)	CL
P500	5	5	0.268
P500	5	10	0.451
P500	5	15	0.643
P500	10	5	0.282
P500	10	10	0.482
P500	10	15	0.710
P500	15	5	0.305
P500	15	10	0.511
P500	15	15	0.723
P1000	5	5	0.238
P1000	5	10	0.403
P1000	5	15	0.552
P1000	10	5	0.254
P1000	10	10	0.435
P1000	10	15	0.603
P1000	15	5	0.262
P1000	15	10	0.452
P1000	15	15	0.628
P1500	5	5	0.200
P1500	5	10	0.335
P1500	5	15	0.464
P1500	10	5	0.215
P1500	10	10	0.386
P1500	10	15	0.505
P1500	15	5	0.225
P1500	15	10	0.371
P1500	15	15	0.523
P2000	5	5	0.268
P2000	5	10	0.244
P2000	5	15	0.555
P2000	10	5	0.278
P2000	10	10	0.398
P2000	10	15	0.555
P2000	15	5	0.315
P2000	15	10	0.416
P2000	15	15	0.585
P2500	5	5	0.333
P2500	5	10	0.561
P2500	5	15	0.555
P2500	10	5	0.315
P2500	10	10	0.561
P2500	10	15	0.555
P2500	15	5	0.346
P2500	15	10	0.583
P2500	15	15	0.585
P3000	5	5	0.305
P3000	5	10	0.523
P3000	5	15	0.585
P3000	10	5	0.315
P3000	10	10	0.583
P3000	10	15	0.585
P3000	15	5	0.723
P3000	15	10	0.778
P3000	15	15	0.829

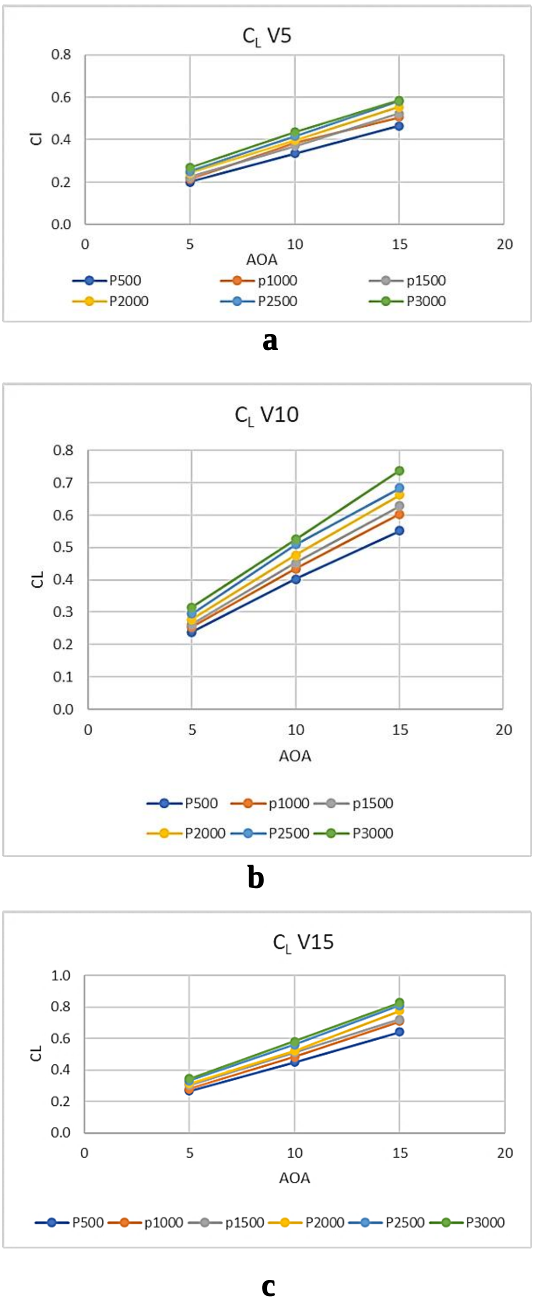

Fig. 4: Lift Coefficient (C_L) for Different Grit Sizes at Various Angles of Attack and Flow Speed: (a) 5 m/s, (b) 10 m/s, (c) 15 m/s.

The trends of reducing the lift coefficient with increasing surface roughness, for all flow speeds and angles of attack tried, are shown in Table 1 and Figure 4. Physics Behind the Trend Because surface roughness alters the development of the boundary layer, it will influence the flow characteristics at the stern. An increase in surface roughness causes more turbulence in the boundary layer, which means there will be an increase in skin friction and, hence, energy loss. This has the effect of reducing the effective lift that can be generated by an airfoil. The results show similarity for all the three different velocities as seen in Figure 4.

3.2. Drag coefficient (C_D)

The drag coefficient (C_D) was measured for each grit size of sandpaper at three different angles of attack (5, 10, and 15 degrees) and three different flow speeds (5, 10, and 15 m/s). The results are summarized in Table 2 and visually represented in Figure 5.

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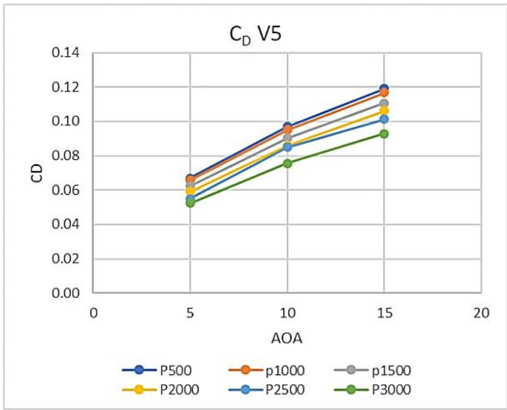
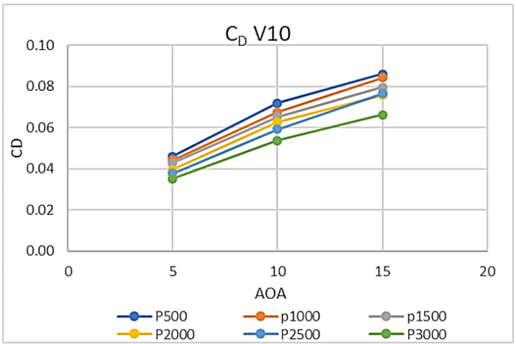
Table 2: Drag Coefficient (C_D) for Different Grit Sizes, Angles of Attack, and Flow Speeds.

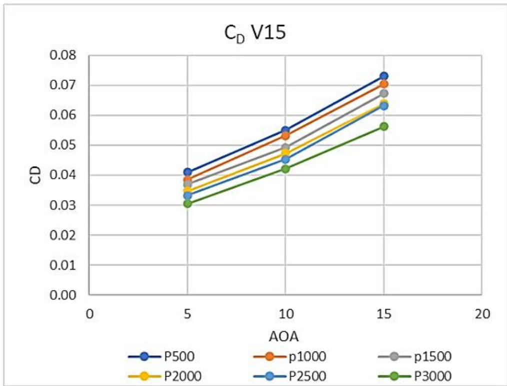
Grit Size	Flow Speed (m/s)	Angle of Attack (degrees)	CD
P500	5	5	0.041
P500	5	10	0.055
P500	5	15	0.073
P500	10	5	0.039
P500	10	10	0.053
P500	10	15	0.070
P500	15	5	0.037
P500	15	10	0.049
P500	15	15	0.067
P1000	5	5	0.046
P1000	5	10	0.072
P1000	5	15	0.086
P1000	10	5	0.044
P1000	10	10	0.068
P1000	10	15	0.084
P1000	15	5	0.043
P1000	15	10	0.065
P1000	15	15	0.080
P1500	5	5	0.067
P1500	5	10	0.097
P1500	5	15	0.119
P1500	10	5	0.066
P1500	10	10	0.095
P1500	10	15	0.117
P1500	15	5	0.062
P1500	15	10	0.090
P1500	15	15	0.111
P2000	5	5	0.046
P2000	5	10	0.072
P2000	5	15	0.119
P2000	10	5	0.040
P2000	10	10	0.068
P2000	10	15	0.117
P2000	15	5	0.035
P2000	15	10	0.059
P2000	15	15	0.106
P2500	5	5	0.035
P2500	5	10	0.054
P2500	5	15	0.106
P2500	10	5	0.038
P2500	10	10	0.063
P2500	10	15	0.106
P2500	15	5	0.033
P2500	15	10	0.059
P2500	15	15	0.101
P3000	5	5	0.030
P3000	5	10	0.054
P3000	5	15	0.093
P3000	10	5	0.030
P3000	10	10	0.042
P3000	10	15	0.076
P3000	15	5	0.030
P3000	15	10	0.042
P3000	15	15	0.076



a



b



c

Fig. 5: Drag Coefficient (C_D) for Different Grit Sizes at Various Angles of Attack and Flow Speed: (a) 5 m/s, (b) 10 m/s, (c) 15 m/s.

Table 2 and Figure 5 show that with an increase in surface roughness, drag coefficient also increases. This trend is held for all test angles of attack and flow speeds. The increase in drag can only be attributed to the rise in skin friction from surface roughness. A major fraction of the extra drag may come from the direct interference with the boundary layer provided by the projecting roughness elements, offering increased resistance to the flow. The results show similarity for all the three different velocities as seen in Figure 5.

3.3. Lift-to-Drag Ratio (C_L/C_D)

The lift-to-drag ratio (C_L/C_D) is a critical measure of aerodynamic efficiency. The C_L/C_D was calculated for each grit size of sandpaper at three different angles of attack (5, 10, and 15 degrees) and three different flow speeds (5, 10, and 15 m/s). The results are summarized in Figures 6, 7, and 8.

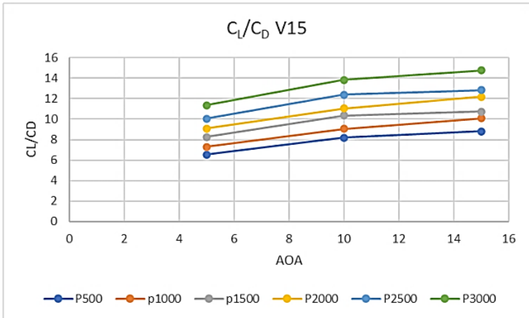


Fig. 6: Lift-to-Drag Ratio (C_L/C_D) for Different Grit Sizes at 15 m/s.

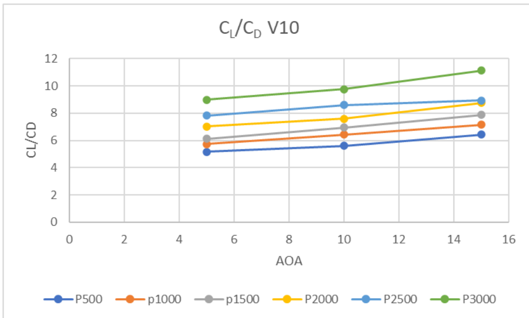


Fig. 7: Lift-to-Drag Ratio (C_L/C_D) for Different Grit Sizes at 10 m/s.

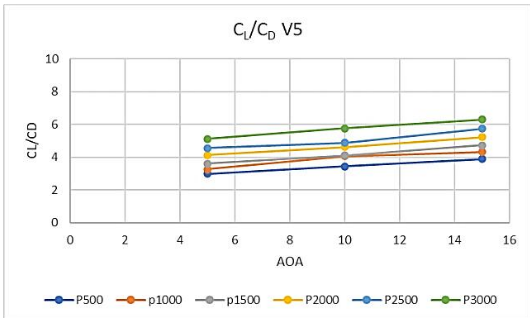


Fig. 8: Lift-to-Drag Ratio (C_L/C_D) for Different Grit Sizes at 5 m/s.

Figures 6, 7, and 8 demonstrate that the lift-to-drag ratio decreases as the surface roughness increases. This trend is consistent across all angles of attack and flow speeds tested. The decrease in

C_L/C_D ratio can be explained by the combined effects of reduced lift and increased drag caused by surface roughness. The roughness elements increase turbulence within the boundary layer, leading to higher skin friction and energy losses, which reduce the overall aerodynamic efficiency of the airfoil. The results show similarity for all the three different velocities as seen in Figures 6, 7, and 8.

3.4. Discussion

The results show that there is strong dependence of surface roughness on the aerodynamic performance of a NACA 0012 airfoil. With the increase in surface roughness, there will be a decrease in C_L and an increase in C_D, hence lower C_L/C_D. This relationship is more exaggerated at higher angles of attack. Physically, the trends have to do with the effect of surface roughness on the boundary layer development. The surface roughness greatly enhances turbulence in the boundary layer, directly enhancing skin friction with it and, therefore, energy losses. Net effects could be a decrease in effective lift actually generated by the airfoil and increased drag forces, hence a lower overall aerodynamic efficiency as measured by the lift-to-drag ratio, C_L/C_D. These results agreed with the previous findings that an increase in surface roughness must always increase the turbulence and skin friction which reduced the efficiency in aerodynamics, as in (3, 5).

4. CONCLUSIONS

The aerodynamic performance of the NACA 0012 airfoil is most strikingly influenced by surface roughness. It can be noted from the experimental results that an increased surface roughness contributes to a decrease in lift coefficients and an increase in drag coefficients, turning into a lowered lift-to-drag ratio. These findings therefore substantiate the need for smooth surfaces on wind turbine blades and other aerodynamic structures to ensure optimal performance. Other types of roughness, such as distributed or patterned, and future work could also be directed toward mitigating losses resulting from roughness. Long-term effects of surface roughness and possible strategies of maintenance in order to preserve the efficiency of aerodynamics could also be useful in applications.

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Author contribution: One author contributed in the study.

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Data availability: The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. The data include detailed experimental results on the aerodynamic performance of the NACA 0012 airfoil with varying surface roughness.

REFERENCES

1. Summerfield-Ryan O, Park S. The power of wind: The global wind energy industry's successes and failures. Ecological Economics. 2023;210:107841. https://doi.org/10.1016/j.ecolecon.2023.107841

2. Timmer W. Two-dimensional low-Reynolds number wind tunnel results for airfoil NACA 0018. Wind engineering. 2008;32(6):525-37. https://doi.org/10.1260/030952408787548848

3. Mahmood YH, IbrahIm AME, Kareem BA. Design and fabricate of tiny wind turbine in Tikrit-Iraq. Tikrit Journal of Pure Science.

2018;23(9):89-93. https://doi.org/10.25130/tjps.v23i9.817

4. Mahmood YH. Fabricated of Vertical Axis wind turbine (VAWT) and study the parameter. Tikrit Journal of Pure Science. 2019;24(7):99-103. https://doi.org/10.25130/tjps.v24i7.464

5. Mohammad H, Shrestha B, Kilchyk V. The effect of Flow Speed and Angle of Attack on the Aerodynamic Noise of NACA 0012 Airfoil. Tikrit Journal of Pure Science. 2023;28(6):42-50. https://doi.org/10.1115/1.4051409

6. Mohammad HK, Ibraheem L, Kilchyk V, Shrestha B. Experimental investigation of turbulence effects on aerodynamics noise of channeled naca 0012 airfoiL. Journal of Solar Energy Engineering. 2021;143(6):064503. https://doi.org/10.25130/tjps.v28i6.1418

7. Mohammad HK, Jalil S, Alden AYQ, Kilchyk V, Shrestha B. Experimental and Numerical Investigation of Channeling Effects on Noise and Aerodynamic Performance of NACA 0012 Aerofoil in Wind Turbine Applications. RE&PQJ. 2023;21(3). https://doi.org/10.24084/repqj21.328

8. Mohammad HK. Channeling Influence on Noise and Aerodynamic Performance of NACA 0012 Airfoil as a Possible Solution of Wind Turbines Noise: Western Michigan University; 2022.

9. Bohl DG, Koochesfahani MM. MTV measurements of the vortical field in the wake of an airfoil oscillating at high reduced frequency. Journal of Fluid Mechanics. 2009;620:63-88. https://doi.org/10.1017/S0022112008004734

10. Paterson RW, Vogt PG, Fink MR, Munch CL. Vortex noise of isolated airfoils. Journal of Aircraft. 1973;10(5):296-302. https://doi.org/10.2514/3.60229

11. Dalili N, Edrisy A, Carriveau R. A review of surface engineering issues critical to wind turbine performance. Renewable and Sustainable energy reviews. 2009;13(2):428-38. https://doi.org/10.1016/j.rser.2007.11.009

12. Keegan MH. Wind Turbine Blade Leading Edge Erosion: An investigation of rain droplet and hailstone impact induced damage mechanisms. 2014. https://doi.org/10.1088/0022-3727/46/38/383001

13. Keegan MH, Nash D, Stack M. On erosion issues associated with the leading edge of wind turbine blades. Journal of Physics D: Applied Physics. 2013;46(38):383001. https://doi.org./10.48730/3616-wk31

14. Chakroun W, Al-Mesri I, Al-Fahad S. Effect of surface roughness on the aerodynamic characteristics of a symmetrical airfoil. Wind Engineering. 2004;28(5):547-64. https://doi.org/10.1260/0309524043028136