Valeology: International Journal of Medical Anthropology and Bioethics
(ISSN 2995-4924) VOLUME 02 ISSUE 04, 2024

STUDY THE EFFECT OF AIR CHANNELS ON THE AERODYNAMIC FORCES OF WIND TURBINE AIRFOILS (EXPERIMENTAL STUDY)

Hussein K. Mohammad[1], Mohsin I. Abdullrazzaq[2]
[1, 2] Iraq, Salah al-din, Tikrit University, College of Science, Department of Physics
[1]hussein.h.Mohammed@tu.edu.iq

Abstract:

In this research, an experimental comparison was presented to study the effect of air channels on the aerodynamic properties of the asymmetric NACA2412 airfoil, before and after the adenium air channels, the airfoil data was imported and designed by AutoCAD with the work of two models, the first regular and the other a model containing air channels along the airfoil, the design models were then sent in the form of STL files to the printing press to be printed, and to conduct the tests were Use a low-velocity educational wind tunnel. The experimental tests were conducted at three velocities (3.8, 5.1, 6.1) m/s. The lift and drag coefficients were calculated at several different angles of attack under the same conditions and the results were compared to show the effect of channeled on airfoil performance. The results showed that the lift and drag coefficients increase with increasing angle of inclination of the airfoil, and this study also found that channeled leads to a deterioration in aerodynamic performance, especially a decrease in lift and increased drag and thus a decrease in the dynamic efficiency of the channeled airfoil.

Keywords: *lift coefficient, drag coefficient, aerodynamics, airfoil, low-velocity wind tunnel.*

Introduction

Symbols and terminology

q	Dynamic Compression
F_L	Lift force
F_D	Drag force
C_L	Lift coefficient

C_D	Drag coefficient
A_s	Airfoils area
v	Wind velocity
ρ	Air density
c	Airfoil chord
b	Airfoil extension
α	Angle Of Attack

Introduction

Wind turbines have been in use since the tenth century [1], in our current societies the airfoil

demand for energy has begun to grow exponentially and the depletion of fossil energy has led to the spotlight on renewable energy, which has also led to a significant increase in the importance and scale of the use of wind energy [2-3[. At the same time, the structural requirements for blades are much higher than those of conventional small turbines [4]. Common attempts to improve the efficiency of wind turbines have emerged, but current research is based on original mathematical formulas. for the nineteenth century [5-6[. Scientific challenges to the design of airfoils that combine structural strength with effective aerodynamic performance have become an obstacle to the development of large wind turbines, the shape of the airfoils used to build wind turbine blades determines the aerodynamic efficiency of these turbines, and therefore the amount of energy extracted from the wind [7]. From this aspect, the aerodynamic properties have a significant impact on the efficiency of these turbines, even when the blades are longer than 45 meters, the dynamic behavior of the airfoil must also be taken into account [8]. In this study, the characteristics of the pavilion are determined experimentally by an educational wind tunnel. Wind tunnel tests areexpensive, and in studies of large wind tunnels on air airfoils, they are particularly difficult when optical techniques are used [9-10]. Trying to improve the blade design in our current study is a primary goal of the research. In the last Hussain and other authors made a dimple on the surface of Naca 4415 into forms internal and external; after conducting tests using a wind tunnel, they found the airfoil with internal dimples provides better performance in lifting and somewhat less resistance in drag [11]. After that Mushtak and his friends came up with another idea by making a hexagonal dimple on the surface of the airfoil, by comparing the result with ordinary airfoil they found better performance for the airfoil had hexagonal dimples [12]. Later, other authors experimented with the effect of the serrated flap on the performance of the NACA0012 airfoil at different heights Note that the flap reduces the back vortex of the airfoil and improves its dynamic performance at a certain altitude [13].

Aerodynamics

Aerodynamics is the scientific field that explains the movement of air about objects, that is, it involves the study of any object that travels through the air or vice versa. The principles of aerodynamics also define the flight mechanisms and movement of wind turbine blades, among many other applications. For these mechanisms to function effectively, for example in the movement of wind turbine blades, the upward lift force must exceed the downward force of gravity [14].

Aerodynamic Forces

The aerodynamic forces created on a particle are due to two main sources, the distribution of pressures and stress generated by the wind on the surface of the body. When an airfoil-shaped object is positioned at an angle of attack in the velocity field, an aerodynamic force is generated. According to the blade theory the resultant aerodynamic force R on any airfoil, will consist of the lift and drag components that depend on the characteristic parameters of the flow field, such as velocity, pressure, temperature, and density. Lift force F_L is directed to the top and operates perpendicular to the relative wind direction. The drag force F_D that resists the movement of air is the axial component parallel to the relative wind direction. Suppose the total force is determined in the direction of the hypotenuse and the perpendicular direction of the hypotenuse. In that case, the

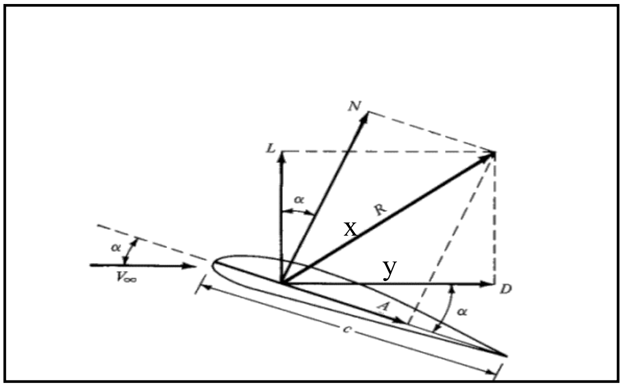

Figure 1. shows the forces acting on the airfoil [16]**.**

components in question are called the vertical force F_N and the axial force F_A[15-16] , as shown in Figure (1).

Using trigonometric identities and the principles of force and weight, numerical equations of lift and drag forces in aerodynamics can be derived.

To find the numerical value of the lift acting on an airfoil in certain units, this equation (1) can be used.

$$F_L = N\cos\alpha - A\sin\alpha \qquad (1)$$

The same way to find the numerical value of the drag acting on the airfoil, through relation (2).

$$F_D = N\sin\alpha + A\cos\alpha \qquad (2)$$

Since the lift and drag force on the airfoils are proportional to its area As (m^2) and to the indicated dynamic pressure q Considering that ρ is the density of air, and is the velocity of free current respectively, in free current, away from the body the dimensional quantity called free dynamic pressure is determined. The dynamic pressure, denoted by q, is expressed by the airfoil equation [17]:

$$q = \frac{1}{2}\rho v^2 \qquad (3)$$

where ρ (kg/m^3) is the density of the air, and v (m/s) is the velocity of the air.

It is most common to give drag and lift in the form of dimensionless transactions, which can calculate the coefficients of lift and drag C_L and C_D, as follows:

$$C_L = \frac{F_L}{\frac{1}{2}\rho v^2} \qquad (4)$$

$$C_D = \frac{F_D}{\frac{1}{2}\rho v^2} \qquad (5)$$

Airfoil NACA 2412

The numbers for the airfoil, NACA 2412, describe its characteristics, meaning that the maximum of 2% falls 40% (0.4 chords) from the front edge and with a maximum thickness of 12% of the chord, four-digit sequential airfoils by default have a maximum thickness of 30% of the chord (0.3 chords) from the front edge. The data used to create a two-dimensional profile was imported from theAirfoil Tool website [18]. With this data imported into AutoCAD, he was trusted to create a three-dimensional model. A sample of the airfoils was designed by representing the channels with air channels with a diameter of (0.2 cm) and the distance between each two channels of 1.5 cm, with a second sample design without making any other changes to send the designs in the form of STL files to the printing press. Figures (2) and (3) show the samples designed in both three-dimensional and two-dimensional displays, and Figure (4) shows the airfoil samples during printing.

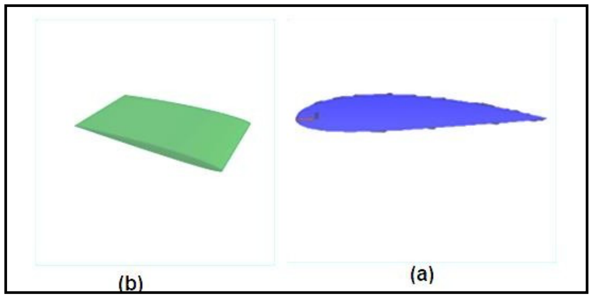

Figure 2. The cross-section (a) in two-dimensional (b) three-dimensional ordinary NACA 2412 airfoil.

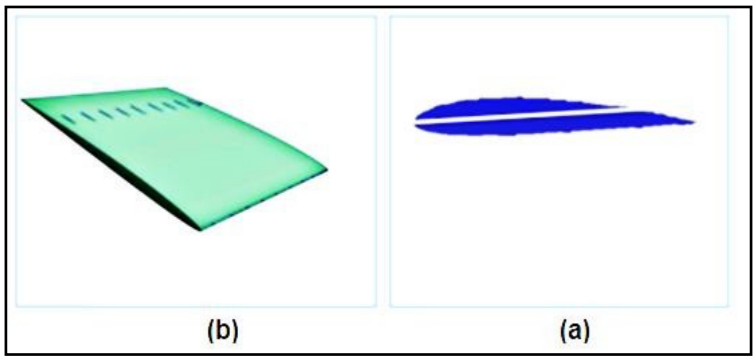

Figure 3. The cross-section (a) Two-dimensional (b) three-dimensional, channeled NACA 2412 airfoil.

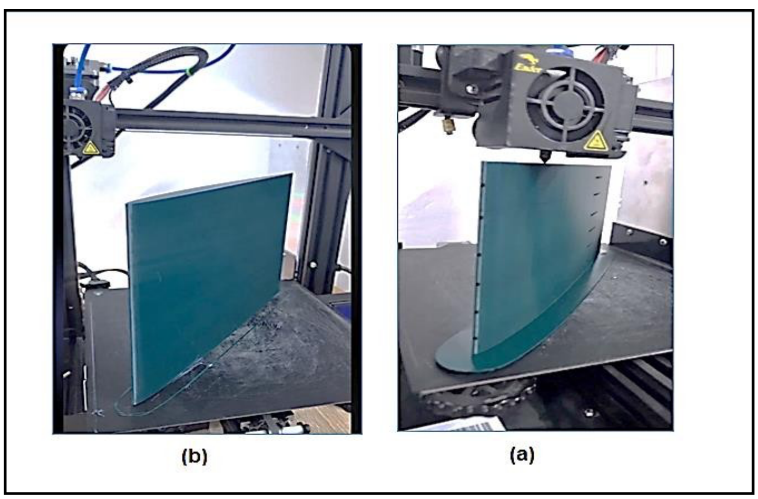

Figure 4. (a) Channeled airfoil, (b) Ordinary airfoil, after printing.

The surface of these samples was not smooth enough, which could generate more swirls that could cause further disruption. To overcome this issue, sandpaper was used to soften the surfaces of the airfoils.

Experimental setup and measurements

Wind Tunnel Our wind tunnel was used for measurements of aerodynamic forces. Wind tunnel specifications: Test section with an area of (2500 cm^2) and a flow speed of up to (7 m/s), figure (5) shows this wind tunnel. These specifications were used to provide the appropriate environment for measuring meters. Therefore, the testing area was built inside the wind tunnel, In its measurements, it relies on a force balance equipped with load cell technology to obtain experimental data.

Figure 5. The wind tunnel.

In addition, this wind tunnel is equipped with metal gratings, as shown in the figure (6), with plastic tubes with a diameter of 1 cm and a length of 9 cm as a champer section for the air coming from the outside through the gratings to obtain a linear airflow as much as possible in the test section, the figure (7) showing that.

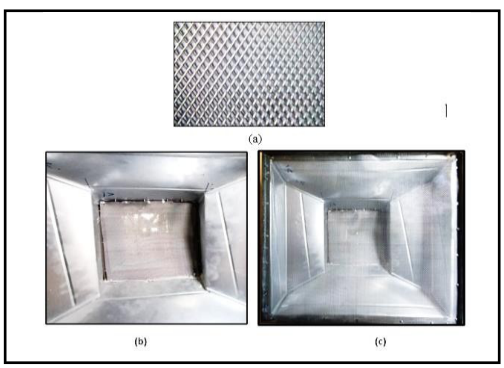

Figure 6. (a) The metal mesh used, (b) The first mesh grating (c) The second mesh grating.

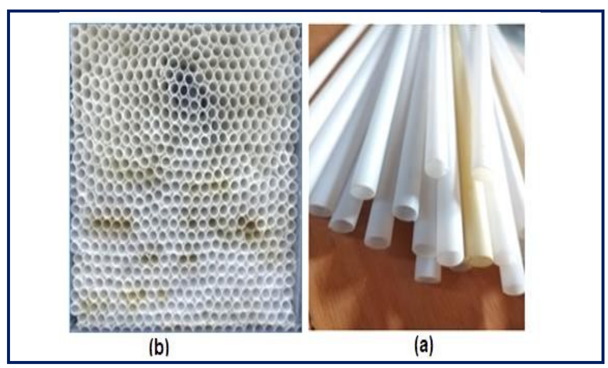

Figure 7. (a) Piping used, (b) interface of tempering section.

Forces Testing Step

In the airfoils test, a prefabricated wind tunnel, which is used to determine the lift and drag forces of the airfoil at different angles of attack, is used in Figure (5) during the test process.

Figure 8. The wind tunnel image during the airfoils test.

The test steps to obtain the data are as follows:

1. Fix the airfoils on the scale in the wind tunnel, so that the airfoils do not move forward and backward.
2. Adjust the angle of attack of the airfoil at a certain angle, in this study, the tests were at (0, 3, 6, 9, 12, 15, 18, 21) degrees down to the angle of the collapse of the airfoil.
3. Turn on the fan so that air flows through the airfoil. Lift and drag forces are measured at three wind velocities before changing to the other angle.
4. The value of the numerical gauges is monitored on the computer and the results of the lift value and drag value are recorded at each angle of attack during different air velocities, and then the results are calculated and compared for the two airfoils.

Results

Aerodynamic performance is directly related to the results of aerodynamic force. This section is dedicated to force results. Lift and drag forces were measured by the wind tunnel. Three flow velocities were calculated, i.e. the results of 3.86m/s, 5.1m/s, and 6.1m/s will be studied.

First case: wind velocity (3.86 m/s)

The first comparison of the characteristics of the aerodynamic forces between the two airfoils is made at a wind velocity of 3.86 m/s, Figure (9) shows that the lift coefficient increases with the increase in the angle of attack of the airfoil, and even the critical angle, at all angles there was a decrease in the lift coefficient of the channeled airfoil by a percentage of the lift coefficient of the normal airfoil. Figure (10) indicates that the drag coefficient shows an increase when compared with the normal airfoil, in addition to that it rises with increasing angle of attack. Figure (11) shows the experimental comparison The latter is due to the aerodynamic efficiency of the airfoils, so it is clear that these channels hurt the efficiency of these airfoils.

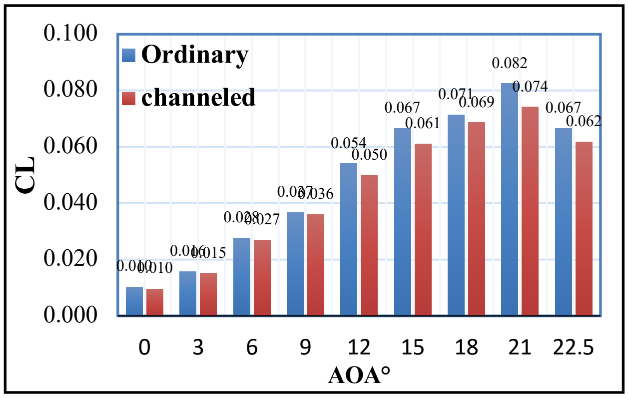

Figure 9. Comparison of the lift coefficient the two airfoils Ordinary and channeled

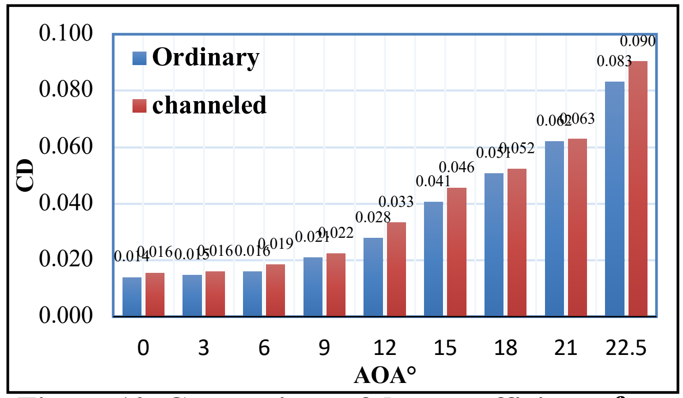

Figure 10. Comparison of drag coefficient of the for the two airfoils Ordinary and channeled

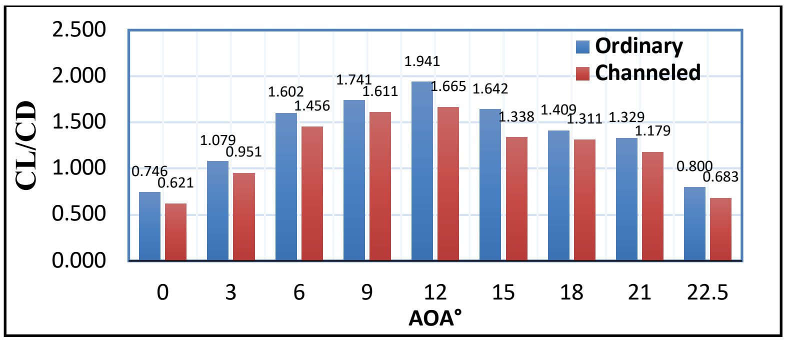

Figure 11. Comparison of the C_L/C_D ratio of common and channeled airfoils

Second case: wind velocity (5.1m/s)

In this case, the results of the second comparison were presented at a wind velocity of 5.1m/s. From Figure (12) it is also clear that the lift coefficient increases with the increasing angle of attack of the airfoils up to the critical angle, and that this angle increases with increasing wind velocity. A decrease in the airfoil's lift coefficient is seen at each angle relative to a channeled airfoil when compared with a common airfoil. Figure (13) indicates that the drag coefficient shows an increase when compared with the common airfoil, in addition to that it rises with increasing angle of attack and this value rises with increasing wind velocity. Figure (14) shows the recent experimental comparison of the aerodynamic efficiency of the two airfoils, so it is clear that these channels hurt the efficiency of these airfoils.

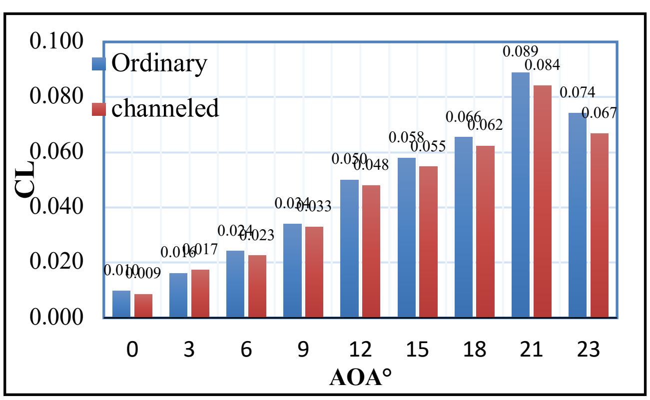

Figure 12. Comparison of the lift coefficient the two airfoils Ordinary and channeled

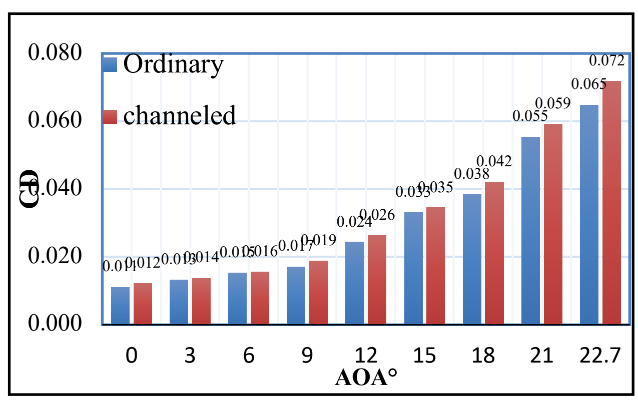

Figure 13. Comparison of drag coefficient of the for the two airfoils Ordinary and channeled

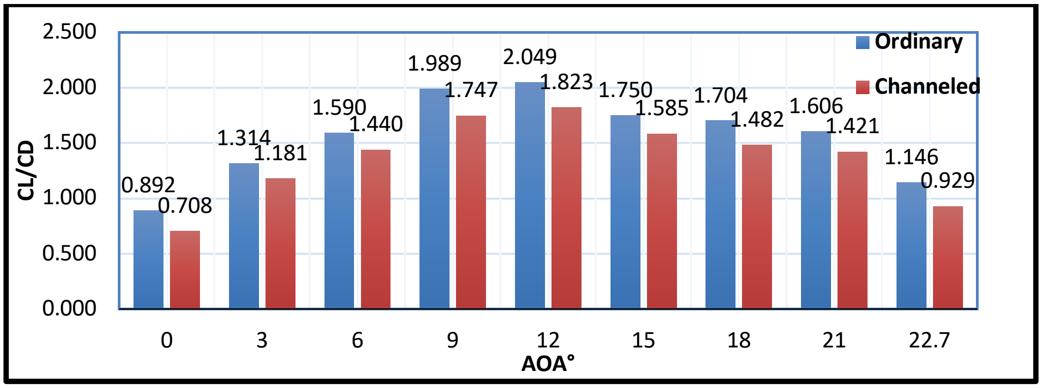

Figure 14. Comparison of the CL/CD ratio of common and channeled airfoils

Third case: wind velocity (6.1m/s)

The results showed that the lift coefficient decreases more for the channeled airfoil as the wind velocity increases when compared to the normal airfoil, as shown in Figure (15). The drag coefficient also appeared with higher values at all angles in this case, and from this, it is clear that the drag coefficient increases with increasing wind velocity and angle of attack, as shown in Figure (16). Figure (17) shows a comparison of the aerodynamic efficiency line of the two airfoils, which shows the negative effect of channels on the efficiency of the airfoil.

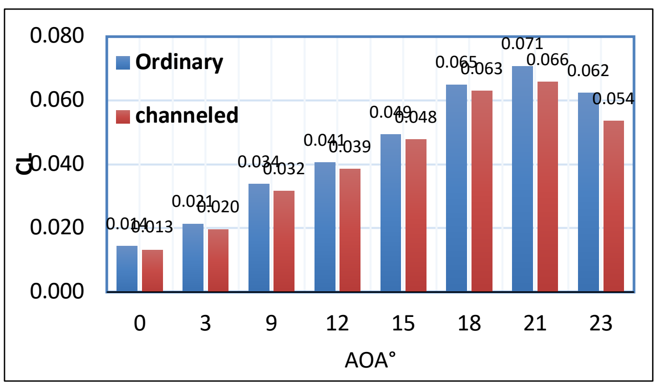

Figure 15. Comparison of the lift coefficient the two airfoils Ordinary and channeled

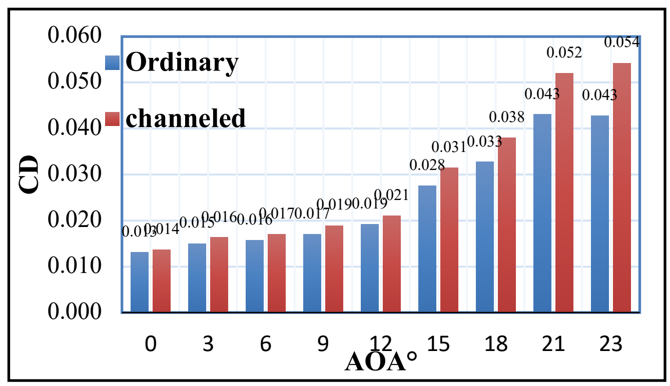

Figure 16. Comparison of drag coefficient of the for the two airfoils Ordinary and channeled

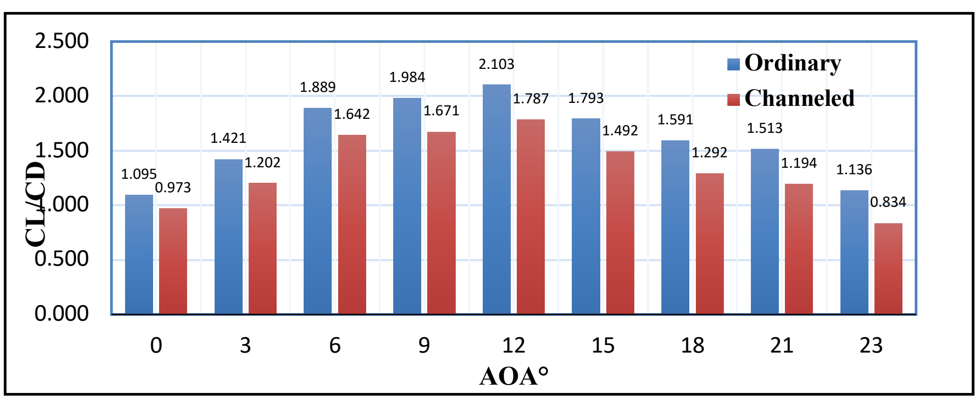

Figure 17. Comparison of the CL/CD ratio of common and channeled airfoils

Conclusions

All the above results showed that the presence of channels causes a decrease in the lift coefficients and an increase in the drag coefficient of the airfoil, which was punctured when compared with the normal airfoil. It can be said that the presence of channels leads to a reduction in the lift coefficient of the channeled airfoil and that the presence of channels has an inverse proportion to the lift coefficients. This decrease in the lift factor of the channeled airfoil can be replayed through the effect of channels on the airflow around the airfoil, as the channels obstruct the airflow around the airfoil, which leads to a decrease in the lift force resulting from the airfoil. The presence of channelsleads to increased turbulence of the airflow around the airfoil, as the channels cause the creation of Air vortices around the airfoil, which leads to the dispersion of the airflow energy around the airfoil.In addition, the channels change the airflow path around the airfoil, causing a deviation in the airflow around the airfoil, which leads to a decrease in the lift force around the airfoil. The presence of channels leads to an increase in drag coefficients, so the relationship between the presence of channels and the drag coefficient is directly proportional. The increase in drag coefficient can be explained by the effect of the channels on the airflow inside the airfoil, as the channels cause the creation of air vortices inside the airfoil, which leads to an increase in the drag force caused by the airfoil. The above factors combined led to a decrease in the coefficient of lift, an increase in thedrag coefficient, and thus a decrease in the aerodynamics of the airfoil.

Reference

1. D. A. Spera, “Wind turbine technology,” 1994.
2. H. M. Lee and Y. Wu, “An experimental study of stall delay on the blade of a horizontal-axis wind turbine using tomographic particle image velocimetry,” Journal of Wind Engineering and Industrial Aerodynamics, vol. 123, pp. 56–68, 2013, doi: https://doi.org/10.1016/j.jweia.2013.10.005.
3. D. B. Melo, J. Baltazar, and J. A. C. Falcão de Campos, “A numerical wake alignment method for horizontal axis wind turbines with the lifting line theory,” Journal of Wind Engineering and Industrial Aerodynamics, vol. 174, pp. 382–390, 2018, doi: https://doi.org/10.1016/j.jweia.2018.01.028.
4. J. Herrmann and G. Bangga, “Multi-objective optimization of a thick blade root airfoil to improve the energy production of large wind turbines,” Journal of Renewable and Sustainable Energy, vol. 11, no. 4, 2019.
5. A. N. Gorban’, A. M. Gorlov, and V. M. Silantyev, “Limits of the turbine efficiency for free fluid flow,” J. Energy Resour. Technol., vol. 123, no. 4, pp. 311–317, 2001.
6. V. L. Okulov and J. N. Sørensen, “An ideal wind turbine with a finite number of blades,” in Doklady Physics, Springer, 2008, pp. 337–342.
7. C. Tropea, A. L. Yarin, and J. F. Foss, Springer Handbook of experimental fluid mechanics, vol. 1. Springer, 2007.
8. M. Jureczko, M. Pawlak, and A. Mężyk, “Optimisation of wind turbine blades,” J Mater Process Technol, vol. 167, no. 2–3, pp. 463–471, Aug. 2005, doi: 10.1016/j.jmatprotec.2005.06.055.
9. I. Bayati, M. Belloli, L. Bernini, and A. Zasso, “Aerodynamic design methodology for wind tunnel tests of wind turbine rotors,” Journal of Wind Engineering and Industrial Aerodynamics, vol. 167, pp. 217–227, 2017.
10. B. Celis and H. H. Ubbens, “Design and construction of an open-circuit wind tunnel with specific measurement equipment for cycling,” Procedia Eng, vol. 147, pp. 98–103, 2016.

11. M. A. Hossain, M. N. Uddin, R. Mustak, and M. Mashud, “Experimental study of aerodynamic characteristics of airfoils using different shaped dimples,” The International Journal Of Engineering And Science (IJES), vol. 4, no. 1, pp. 13–17, 2015.

12. R. Mustak, M. H.-O.-R. Molla, and M. Mashud, “Improvement of aerodynamic characteristics of an airfoil by surface modification,” American Journal of Engineering Research (AJER), vol. 6, no. 3, pp. 7–14, 2017.

13. L. Chen, P. Yang, B. Zhang, and L. Chen, “Aerodynamic Enhancement of Vertical-Axis Wind Turbines Using Plain and Serrated Gurney Flaps,” Applied Sciences, vol. 13, no. 23, p. 12643, 2023.

14. “‘UNIVERSIDADE TECNOL´OGICA FEDERAL DO ... - UTFPR,’ [Online]. Available: http://repositorio.roca.utfpr.edu.br/jspui/bitstream/1/11813/1/CT_DAMEC_2018_2_44.pdf. [Accessed 14 Dec 2023]].”

15. J. F. Manwell, J. G. McGowan, and A. L. Rogers, “Aerodynamics of wind turbines,” Wind energy explained, vol. 2, pp. 91–155, 2009.

16. E. P. Rodríguez, “Aerodynamic analysis of the LAN1897 aerofoil,” 2019.

17. J. D. Anderson and M. L. Bowden, Introduction to flight, vol. 582. McGraw-Hill Higher Education New York, 2005.

18. “NACA 4 digit airfoil generator (NACA 2412 AIRFOIL).” Accessed: Feb. 24, 2024. [Online]. Available: http://airfoiltools.com/airfoil/naca4digit