POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)
URL: http://dergipark.org.tr/politeknik

CFD analysis of a NACA 0009 aerofoil at a low reynolds number

NACA 0009 profilli bir kanadın düşük bir reynolds sayısında had analizi

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Bu makaleye şu şekilde atıfta bulunabilirsiniz(To cite to this article): Gorgulu Y. F., Ozgur M. A. ve Kose R., "CFD analysis of a NACA 0009 aerofoil at a low reynolds number", ***Politeknik Dergisi***, 24(3): 1237-1242, (2021).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.877391

CFD Analysis of a NACA 0009 Aerofoil at a Low Reynolds Number

Highlights

- *Using Ansys version 15.0, three-dimensional simulations of NACA 0009 aerofoil has been carried out.*
- *Four different angles of attack were used at the constant Reynolds Number and aerodynamic performance was measured in the light of the data received.*
- *In the analysis in addition to the lift coefficient, drag coefficient and L/D ratios, velocity profiles and streamlines are visualised in order to explain the events taking place.*

Graphical Abstract

It would be more consistent to look at the L/D ratio in determining the aerodynamic performance, as well as the lift and drag coefficients. The best aerodynamic performance in the study is 5 ° of attack angle, and the L / D ratio is 10.03.

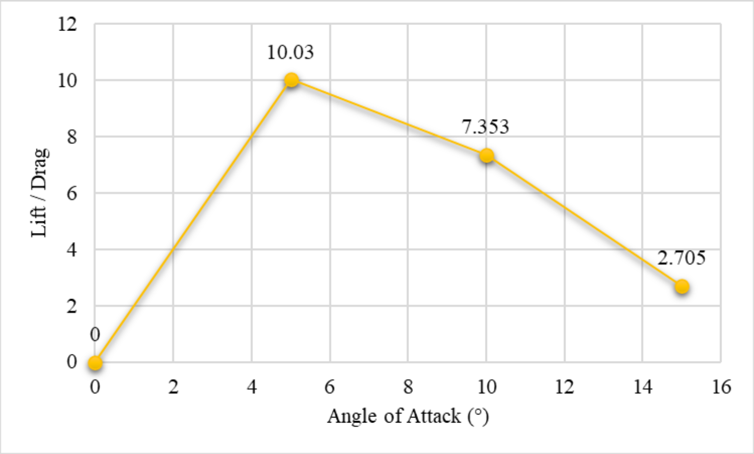

Figure 11. Lift/Drag (L/D) at 0°, 5°, 10°, 15° angles of attack.

Aim

The aim of the study is to match the aerodynamic performance data obtained from the simulation with the literature data and finding the ideal working conditions of the blade.

NACA 0009, the four-digit NACA aerofoil has been chosen as the model for simulations using Ansys 15.0. The geometry has been created, a mesh has been generated, simulations done and evaluated results.

Originality

Four different angles of attack were evaluated in a fixed reynolds number. Data such as lift, drag, L/D were monitored and visual graphs were created and evaluated to prove them.

Findings

Lift and drag coefficients can be misleading in aerodynamic performance comparisons when evaluated individually. While the lift and drag coefficients indicated different angles of attack as the best performance, the best performance was a different angle of attack when looking at the L/D ratio.

Conclusion

Based on the lift and drag coefficients from the simulations, the results indicate different angles of attack. However, with a L/D ratio of 10.03, a different angle of attack prevailed.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

CFD Analysis of a Naca 0009 Aerofoil at a Low Reynolds Number

Araştırma Makalesi / Research Article

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(Geliş/Received : 09.02.2021 ; Kabul/Accepted : 15.03.2021 ; Erken Görünüm/Early View : 29.03.2021)

ABSTRACT

Proper blade design, selection and use continue to gain importance with the developing technology, aviation and space industry. Many applications use wings such as aircraft (planes, helicopters, etc.), UAV (Unmanned Aerial Vehicle), wind turbines and so on. This study covers a NACA 0009 profiled wing with a 111 mm span and chord and its CFD analysis using Ansys version 15.0. Three-dimensional analysis has been done using Ansys Fluent. A geometry was created, this geometry was meshed properly, tighter especially close to the wings, and its analysis was completed using the k-w turbulence model. In total 2,078,272 nodes and 2,036,295 elements have been formed in the mesh. Four different angles of attack have been tested which are 0°, 5°, 10° and 15° at 37,000 Reynolds number. Generated mesh has an average skewness rate of 1.3 and an average orthogonal quality rate of 0.97. Velocity contours and streamlines have been compared to the literature. Lift and drag coefficients have been monitored. As the angle of attack increases, it is seen that shocks form at the trailing edge especially at 15° angle of attack and therefore aerodynamic performance of the NACA 0009 at different angles has been tested. With a L/D ratio of 10.03, the 5° angle of attack have been prevailed in comparisons.

Keywords: Aerodynamics, aerofoil, computational fluid dynamics, NACA.

NACA 0009 Profilli Bir Kanadin Düşük Bir Reynolds Sayisinda Had Analizi

ÖZET

Uygun kanat tasarımı, seçimi ve kullanımı gelişen teknoloji, havacılık ve uzay sanayi ile birlikte önem kazanmaya devam etmektedir. Hava araçları (uçaklar, helikopterler vb.), İHA (İnsansız Hava Aracı), rüzgâr türbinleri vb. gibi birçok uygulamada kanatlar kullanılmaktadır. Bu çalışma, 111 mm kord uzunluğuna ve kiriş uzunluğa sahip bir NACA 0009 profilli kanadı ve Ansys 15.0 sürümünü kullanarak HAD (Hesaplamalı Akışkanlar Dinamiği) analizini kapsamaktadır. Ansys Fluent kullanılarak üç boyutlu analiz yapılmıştır. Bir geometri oluşturulmuş, bu geometri uygun şekilde özellikle kanat yakınları sık olacak şekilde sayısal ağ oluşturulmuş ve k-w türbülans modeli kullanılarak analizi tamamlanmıştır. Sayısal ağda toplamda 2.078.272 düğüm noktası ve 2.036.295 eleman oluşturulmuştur. 37.000 Reynolds Sayısı altında 0°, 5°, 10° ve 15° olmak üzere dört farklı hücum açısı için test edilmiştir. Oluşturulan sayısal ağın ortalama çarpıklık oranı 1,3 ve ortalama ortogonal kalite oranı 0,97'dir. Hız kontürleri ve akım çizgileri literatürle karşılaştırılmıştır. Kaldırma ve sürükleme katsayıları kayıt altına alınmıştır. Hücum açısı arttıkça, özellikle 15° hücum açısında firar kenarında şokların oluştuğu görülmekte ve böylece NACA 0009'un farklı açılarda aerodinamik performansı test edilmiştir. 10,03'lük L/D oranı ile 5° hücum açısı kıyaslamaları galip tamamlamıştır.

Anahtar Kelimeler: Aerodinamik, hesaplamalı akışkanlar dinamiği, kanat, NACA.

1. INTRODUCTION

Wind turbines are used for generating electrical energy as a link. One of the most significant factors affecting the performance of wind turbines is wing aerodynamics. Blade cross-sectional geometry affects the entire blade's performance and thus the overall performance of the wind turbine. Some studies have shown that the appropriate selection of the wind turbine blade geometry reduces electrical energy generation costs [1]–[3]. It is an optimisation process between strength requirements, manufacturing difficulties and aerodynamic performance to achieve maximum performance from the chosen wind turbine. High lift/drag ratio and insensitivity to roughness are desired for aerodynamic performance. However, it might negatively influence strength, ease of manufacture, ease of repair, etc. properties especially in large-scale wind turbines.

There are usually two techniques for the design of wing section geometry: the first is to make certain applications in the current standard geometry of the wing section and repeat this process until better performance is achieved. The second is to determine the distribution of the pressure coefficient that will generate the aerodynamic performance desired and then to obtain the geometry that provides this distribution [4].

Currently used NACA series aerofoils were developed for the wings of warplanes produced in the Second World War [5]. These blade sections are manufactured for aeroplanes and therefore it is not expected to perform the same performance in wind turbine blades. While

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aeroplanes are required to display preferable aerodynamic performance at high Reynolds Number values, for wind turbines it is desired to show high aerodynamic performance at low Reynolds Number values [6].

2. MATERIAL and METHOD

The blade section geometry has been obtained by adjusting the coordinates of the surface curves that characterise the regular NACA 0009 blade geometry. Computational Fluid Dynamics (CFD) has been used to analyse the aerodynamic properties of this wing sections (HAD)[7].

2.1. Blade Sections and Aerodynamic Properties

National Advisory Committee for Aeronautics (NACA) has standardized some aerofoils, which is called NACA aerofoils. Their geometries are characterised by a set of digits. There are four-digit, five-digit, 1-series and more kinds of NACA aerofoils. In this study, one of four-digit NACA profiles which is NACA 0009 is chosen and tested in the analysis. The last digits of the wing that are "00" show the wing does not have a camber and it is a symmetrical profile. The other digits "09" is the thickness to chord length ratio. The wing has a 9 percent thickness [8], [9]. Its shape is encoded within an equation. Symmetrical four-digit NACA aerofoil can be expressed as [10];

$$y_t = 5.t.c.\left[0.2969.\sqrt{\frac{x}{c}} + (-0.126).\frac{x}{c} + (-0.3516).\left(\frac{x}{c}\right)^2 + 0.2843.\left(\frac{x}{c}\right)^3 + (-0.1015).\left(\frac{x}{c}\right)^4\right] \quad (1)$$

Where:

"y_t " is the half-thickness of the aerofoil

"t" is the maximum thickness

"c" is the length of the chord

"x" is the position

Energy is generated by wind turbines from the power of the wind. The principle between the airflow acting on turbine blades and blades of an aircraft is similar to each other. However, the wind moves towards the blades of the turbine and the blades do not apply any extra force, so the thrust of the blades is exactly the opposite in the case of aircraft. Like aircraft blades, turbine blades are subjected to lift and drag forces that activate the blades, converting wind energy into the kinetic energy of the blades. As with aircraft wings, the lift and drag rely on the angle of attack of the turbine blade between the wind direction and the chord line of the blade. Aircraft are held in the air by pushing the wings or wings forward. In this case, an external source, via propellers or jet engines, pushes the wing forward. A lift force perpendicular to the movement of the wing and greater than the downward gravitational force on the wing, and thus keeping the aircraft in the air, is the product of the wing's motion in free stream.

The drag depends on the effective area of the wing facing directly to the airflow and also on the shape of the wing shape. The lift and drag are influenced by the angle of attack between the wing's direction of movement in the air and the blade's chord line. Figure 1. illustrates the forces acting on an aircraft aerofoil [11], [12].

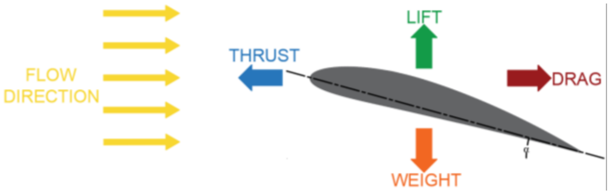

Figure 1. Forces acting on an aircraft aerofoil.

Drag is the force exerted by the wing against the movement of the fluid. The relative motion between wing and fluid often referred to as wind resistance or fluid resistance moves in the opposite direction. The opposite example shows the aerodynamic drag forces encountered when airspeed is increased by a wing or aircraft wing moving in the air with a constant angle of attack.

A turbine blade's angle of attack is the angle between the apparent or relative wind direction and the mean line of the blade. In the case of an aircraft, the angle is between the wing's direction of movement and the wing's chord line.

The airflow over an aerofoil is steady and laminar at very low angles of attack, and there is probably little turbulence at the trailing edge of the aerofoil. Separation of the flow occurs at the trailing edge. As the angle of attack rises, the area of the wind turbine blade facing directly to the wind is also increased. That increases the lift but at the same time however, with the increase in the cross-sectional area the drag is also raised.

Generally, the maximum lift occurs when the angle of attack is about 15 degrees, but for specially constructed blades this can differ. The separation point moves over 15 degrees to the leading edge of the wing and laminar flow over the wing fades and transforms into a turbulent flow. The increased turbulence causes the lift to deteriorate rapidly while significantly increasing drag, leading to a stall. Thus, it is significant to find the critical point where the lift hits a maximum while the drag hits a minimum magnitude [11].

For this case, NACA 0009 profiled aerofoil has been chosen which is a symmetrical aerofoil and do not own a camber. It has a 111 mm chord and 111 mm span length.

2.2. Computational Fluid Dynamics (CFD)

In the numerical analysis, the model of the aerofoil, flow domain, mesh generation and boundary conditions are included. A symmetrical aerofoil with a defined shape feature is NACA 0009. This study consists of a three-dimensional model of the aerofoil and also a fluid domain. The model aerofoil, as assumed in the experimental study model, with a chord length of 111 mm, a sharp and a closed trailing edge. The coordinates providing the shape feature needed are extracted from an aerofoil online database [13]. The outline of the aerofoil is shown by a total of 200 points. The points are exported into ANSYS [14]. Then, the fluid domain is sketched using Design Modeler. To collect precise data from the analyses, a dense mesh is needed especially close to the aerofoil geometry [15].

The fluid domain's geometrical dimensions are given in Figure 2.

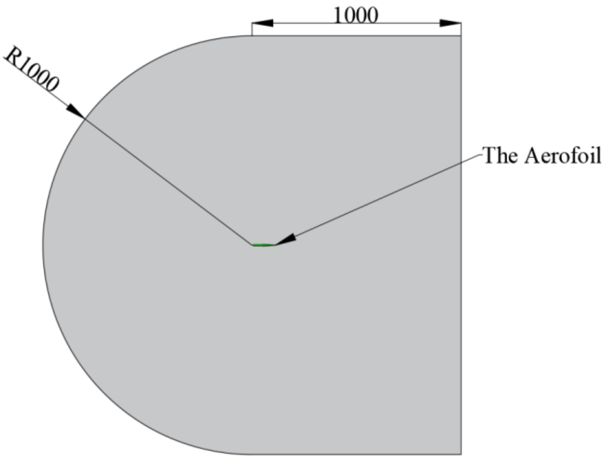

Figure 2. The dimensions of the created fluid domain.

Therefore, the body of influence geometry is created to improve the data quality. This geometry can be seen in Figure 4. After meshing the fluid domain and the aerofoil itself, the quality of the mesh is desired to be good enough to receive an exact outcome. Figure 3. demonstrates the mesh structure for both the aerofoil and the fluid domain.

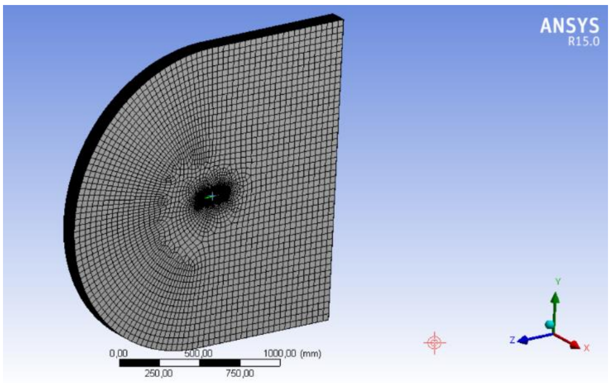

Figure 3. The created fluid domain and the mesh structure.

Ansys recommends that the maximum skewness ratio should be less than 0.95 for the mesh to be of sufficient quality. It is claimed that the average skewness ratio between 0-0.25 is excellent, between 0.25-0.50 is very good, between 0.50-0.80 is good, acceptable between 0.80-0.94, bad between 0.95-0.97 and unacceptable in the range of 0.98-1.00 [16]. In this case, the maximum skewness ratio is 0.91 which is much smaller than 0.95

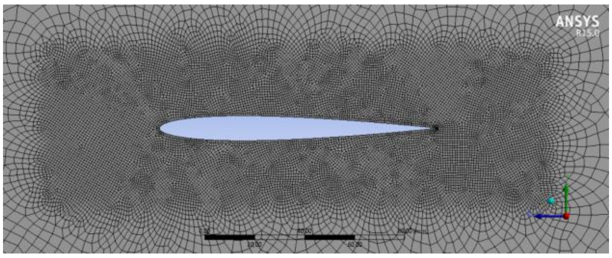

Figure 4. The mesh distribution around the aerofoil.

and the average ratio is 0.13. It can be said that from the scale it is a perfect quality mesh. Orthogonal quality is another parameter that can measure the quality of the mesh. It is recommended the minimum orthogonal quality rate should be smaller than 0.1. It also meets the requirements with a minimum orthogonal quality rate of 0.17. Also, a rate of average orthogonal quality rate betwixt 0.95-1.00 is considered as perfect quality. In the simulation, the mesh has an average orthogonal quality of 0.97. The average orthogonal quality likewise has a spectrum of quality levels. The range of 0.95-1.00 is excellent, 0.70-0.95 is very good, 0.20-0.69 is good, 0.10-0.20 is acceptable, 0.001-0.10 is bad and lastly 0-0.001 is considered as unacceptable. The skewness and the orthogonal quality rates are shown in Figure 5 [16].

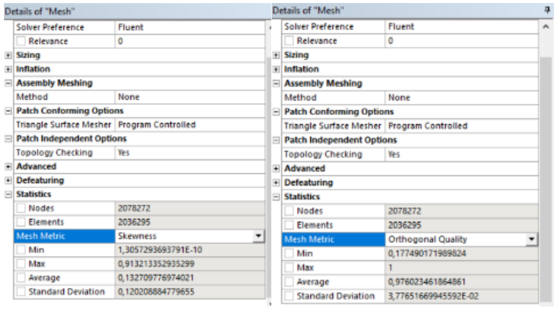

Figure 5. Skewness and orthogonal quality rates of the generated mesh.

Ansys contains many turbulence models such as Spalart-Allmaras, k-w, k-ε and so so on [17]. Some articles about turbulence models suggest standard k-w turbulence model for aerodynamics and turbomachinery applications [18]–[22]. It is also preferred in low Reynolds Numbered applications [16]. Therefore standard k-w turbulence model has been used in the analysis. Due to computer and its features used in the CFD analysis, the node and element numbers restricted around 2 millions. When used higher numbers, the computer memory lacks of running and completing analyses. Aerodynamic performance has been measured with simulations on NACA 0009. Based on the data obtained, the aerodynamic properties of this blade were examined with the CFD analysis using Ansys Fluent and then the lift and drag coefficient values were calculated. The static pressure value at the upper part of the wing section is smaller than the static pressure value at the lower part. Thus, a lift force occurs due to the pressure difference. The greater the difference between the pressures, the greater the lift force. In the colored screenshots given in Figure 6, the blue regions show the places where the velocity value is low and the velocity is higher in the red, yellow or green regions compared to the blue regions. For example, in the velocity contour of the NACA 0009 wing section at 15° angle of attack, the maximum velocity value in the red regions increases to approximately 7,6 m/s, while this value decreases to 0 m/s in the blue regions due to separations and boundary layer.

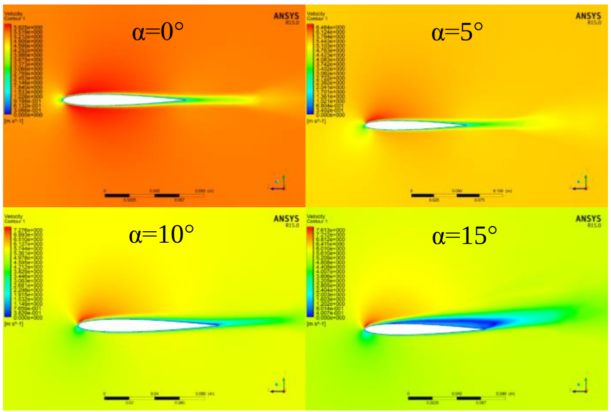

Figure 6. Velocity contours at 0°, 5°, 10°, 15° angles of attack.

Different velocities at various points around the wing cross-section cause a varying pressure distribution at every point around the body according to the Bernoulli equation. When the wing section is curved, the area on the upper surface is increased and the speed of the air passing over the section is increased by increasing this area. By increasing the air velocity, the pressure is further reduced according to the Bernoulli equation. Thus, the pressure difference between the lower surface and the upper surface increases and consequently the lift force is increased [7].

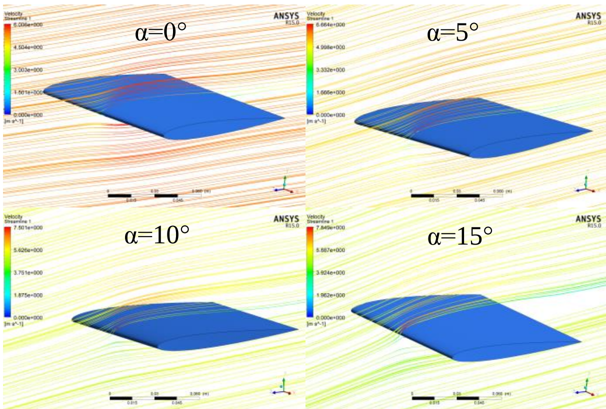

Figure 7. Streamlines at 0°, 5°, 10°, 15° angles of attack.

As it can be seen from Figure 7., a free airstream hits the leading edge and then a shock is formed. At 0° angle of attack, velocity streamlines are symmetrical and uniform. At 5° angle of attack, separations start to be observed at the trailing edge. As the angle of attack is escalated, the separations are dramatically increased. At 15°, separations make a peak and it can be said that drag force also raised steadily.

3. DISCUSSION

In this study, simulations were designed according to angles of attack in the range of 0-15° with intervals of 5° and tests were carried out under the experimental condition with a free airflow velocity of 5 m/s. The evaluation of lift and drag forces independently of each other was found to give the best results for two different angles of attack. However, for the NACA 0009 profiled wing, the angle of attack with the best aerodynamic performance is 5°. Evaluations of lift and drag forces alone may achieve incorrect results. Therefore, it is thought that comparing with the L/D ratio will give more accurate results. In the literature, there are similar studies about NACA aerofoils including NACA 0009. It can be stated all parameters evaluated in the analysis, lift and drag coefficients, L/D ratios, streamlines resemble the analysis has been done [23]–[30]. This study is discriminated from meshing methods, mesh quality and aerofoil dimensions. Even though some are worked on different NACA aerofoils, they follow a similar trend especially symmetrical aerofoils. The results are consistent with other studies in the literature, and more different studies can be done with lower ranges of angles of attack and different flow velocities.

4. CONCLUSION

Increasing aerodynamic performance in the wing section is achieved by increasing the lift force generated around the wing section and reducing the drag force. The lift force is increased by giving the wing section a hump, but this also causes the drag force to increase. This situation is observed when a non-symmetrical wing, which has a larger camber compared to the symmetrical ones.

Higher lift force, higher torque at the same wind speed and therefore greater power will be obtained in the wind turbine blades. Higher drag force causes a decrease in the tangential force that provides torque in wind turbines and also an increase in axial force that pushes the blades backward, which does not contribute to power generation. The lift coefficient varying according to the angle of attack is given in Figure 8. The lift has an increasing trend until the angle of attack reaches 10°. At this point the lift coefficient makes a peak and after that the lift value plummets to 0.661.

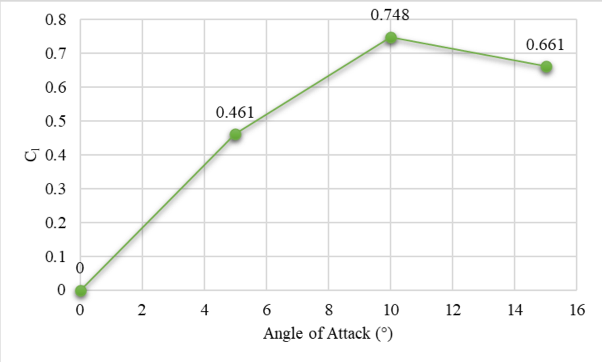

Figure 8. Lift coefficient values at 0°, 5°, 10°, 15° angles of attack.

Drag force is the force that is undesired in all applications such as wind turbines, aircraft and so on. It is wanted to be as low as possible. When looked into Figure 9., drag steadily climb upwards as the angle of attack rises. At 15° angle of attack, the drag coefficient reaches its highest figure which is 0.24439.

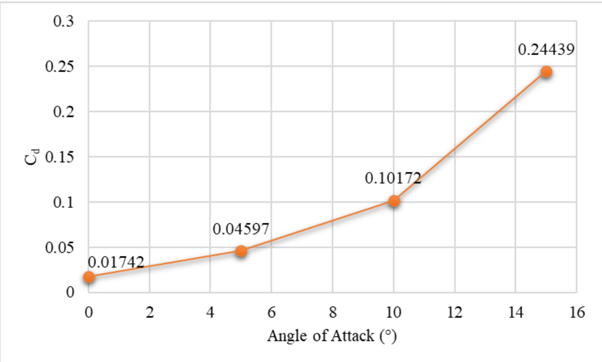

Figure 9. Drag coefficient values at 0°, 5°, 10°, 15° angles of attack.

The lift is desired to be at the maximum value and the drag is desired to be at the minimum value. While the lift coefficient hits its maximum value at 10° with 0.748, the drag coefficient hits minimum at 0° angle of attack with a value of 0.01742. Looking at these figures, it cannot be decided which angle of attack has the most convenient potential. Accordingly, the ratio of lift to drag is needed to be calculated. Figure 11. depicts the lift to drag ratio (L/D). From this line plot, it can be seen 5° angle of attack gives the most useful results with a ratio of 10.03.

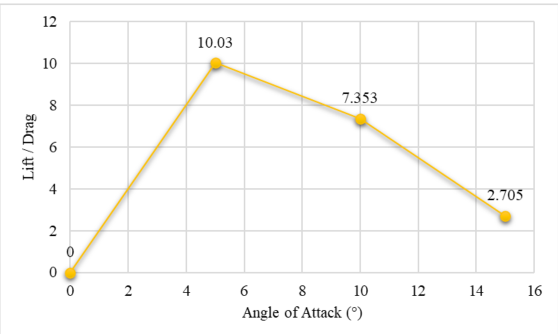

Figure 11. Lift/Drag (L/D) at 0°, 5°, 10°, 15° angles of attack.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Yasin Furkan GÖRGÜLÜ: Completed the simulations, evaluations and wrote the manuscript.

Mustafa Arif ÖZGÜR: Supported to correct formal errors.

Ramazan KÖSE: Supported to correct formal errors.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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