مجلة جامعة بني وليد للعلوم الإنسانية والتطبيقية
Bani Waleed University Journal of Humanities and Applied Sciences
تصدر عن جامعة بني وليد - ليبيا
Website: https://jhas-bwu.com/index.php/bwjhas/index

ISSN 3005-3900 | (190 -176) الصفحات | المجلد الحادي عشر _ العدد الخامس _ 2026

Validation and Comparative Aerodynamic Analysis of Airfoils at Different Reynolds Numbers Using XFLR5

Abdallah Ali Abuzrida
Department of Aeronautical Engineering, College of Civil Aviation-Misurata, Misurata, Libya.
abdullahabuzarida@misrataca.edu.ly

التحقق والتحليل المقارن للخصائص الإيروديناميكية للمقاطع الهوائية عند أعداد رينولدز مختلفة باستخدام برنامج XFLR5

عبدالله علي أبوزريدة
قسم هندسة الطيران، كلية الطيران المدني-مصراتة، مصراتة، ليبيا

Received: 08-06-2026	Accepted: 22-07-2026	Published: 28-07-2026

الملخص
تتأثر الخصائص الديناميكية الهوائية، مثل الرفع والسحب ونسبة الرفع إلى السحب ومعامل العزم، بشكل أساسي بسطح الجناح. ومن المهم معرفة كيفية استجابة أسطح الأجنحة للظروف المختلفة لتحسين تصميم الطائرات. تهدف هذه الدراسة إلى بحث قدرة محاكاة XFLR5 كأداة للتنبؤ بأداء أسطح الأجنحة، وكيف تؤثر التغيرات في شكل الجناح ورقم رينولدز على الرفع والسحب ونسبة الرفع إلى السحب ومعامل العزم. تم تمثيل التغير في أشكال أسطح الأجنحة بنوعين: NACA 2412 و Davis's smooth. تم التحقق من صحة نتائج المحاكاة عند رقم رينولدز Re = 100000 لنوعين مختلفين من أسطح الأجنحة بمقارنتها بقواعد بيانات Airfoil Tools. كانت نتائج المحاكاة مقبولة ودقيقة للغاية، بانحرافات عن المتوسط بلغت 2.22% و5.33%. أظهرت النتائج أن معامل الرفع إلى السحب لجناح ديفيس الأملس كان أعلى، خاصةً عند زوايا الهجوم من 0° إلى 6°، مقارنةً بالقيم التي انخفضت عن قيم جناح NACA2412. ووفقًا لمنحنيات معامل الرفع إلى السحب، يُظهر جناح NACA 2412 استقرارًا أكبر في الأداء من جناح ديفيس الأملس نظرًا لانخفاض معامل السحب فيه. في المقابل، يتميز جناح ديفيس الأملس بارتفاع كلٍ من الرفع والسحب، مما يؤدي إلى انخفاض كفاءته الديناميكية الهوائية. كما تُشير الدراسة إلى أن ارتفاع رقم رينولدز يُؤدي إلى زيادة الرفع وانخفاض السحب، مما يُحسّن الكفاءة الديناميكية الهوائية الإجمالية.

الكلمات الدالة: ديناميكا الهواء للجنيح ; برنامج XFLAR5؛ رقم رينولدز؛ هندسة الجنيح؛ الأداء الديناميكي الهوائي؛ نسبة الرفع إلى السحب..

Abstract
The aerodynamic characteristics, such as lift, drag, lift-to-drag ratio, and moment coefficient, are primarily affected by the airfoil. It is important to know how airfoils respond to diverse conditions to improve the design of an aircraft. This study aims to investigate the ability of XFLR5 simulation as a tool for airfoil performance predictions and how changes in airfoil shape and Reynolds number alter lift, drag, lift-to-drag, and moment coefficients. The change in airfoil

shapes is represented by two airfoils: NACA 2412 and Davis's smooth. The validation of simulation results was performed at Re = 100000 for two different airfoils by comparing them with the Airfoil Tools databases. The simulation results were acceptable and highly accurate, with deviations from the mean of 2.22% and 5.33%. The results illustrated that the lift-to-drag coefficient for the Daviss smooth airfoil had a higher value, especially for 0° to 6° of angles of attack, than the values decreased below the NACA2412 values. According to lift-to-drag coefficient curves, NACA 2412 shows more performance stability than Daviss smooth due to its lower value of drag coefficient. In contrast, the Daviss smooth airfoil has both high lift and high drag, therefore less aerodynamic efficiency. Also, the study shows that a high Reynolds number results in increased lift and decreased drag, which improves overall aerodynamic efficiency.

Keywords: Airfoil aerodynamics; XFLAR5; Reynolds number; Airfoil geometry; Aerodynamic performance; Lift-to-drag ratio.

Introduction

The performance and design of wind turbines, airplanes, and other aerodynamic structures are greatly influenced by airfoil aerodynamics. To maximize lift, reduce drag, and enhance overall aerodynamic efficiency, it is essential to understand the behavior of airfoils. Computational fluid dynamics (CFD) simulations and wind tunnel testing are two traditional, time-consuming, and costly techniques for evaluating airfoil performance [1].

Tools like XFLR5 are now often used in both industry and academia to streamline the analytical process. XFLR5 is a computational tool based on lifting-line theory, panel methods, and viscous analysis to predict airfoil and wing performance [2]. Key aerodynamic characteristics, including lift coefficients, drag coefficients, and moment coefficients at different angles of attack and Reynolds numbers, can be studied by engineers and researchers using the program [3]. Because of this, XFLR5 is a valuable tool for designing airfoils and wings in their initial stages, before proceeding to more complex CFD simulations or experimental verification.

The boundary layer thickens, and the aerodynamic properties begin to become non-linear with respect to the angle of attack as the angle of attack increases further. The Cl max, the airfoil's maximum lift coefficient, will soon be reached. Stalls occur as the angle of attack increases further, causing flow separation on the upper surface, a sudden decrease of lift, and a noticeable rise in drag [4].

Figure 1 illustrates the development of a thickening boundary layer, and the onset of flow separation will eventually limit the lift production on an airfoil and will also increase its drag, which is called “stall.”

However, as the angle of attack increases, the aerodynamic performance of the airfoil deteriorates because of flow separation, which causes loss of lift and an increase in drag. The lift-to-drag ratio also decreases. A major influence on boundary-layer development as well as separation characteristics is the Reynolds number and airfoil geometry. It is thus important to study their effect on aerodynamic performance. This should be done using reliable numerical tools such as XFLR5.

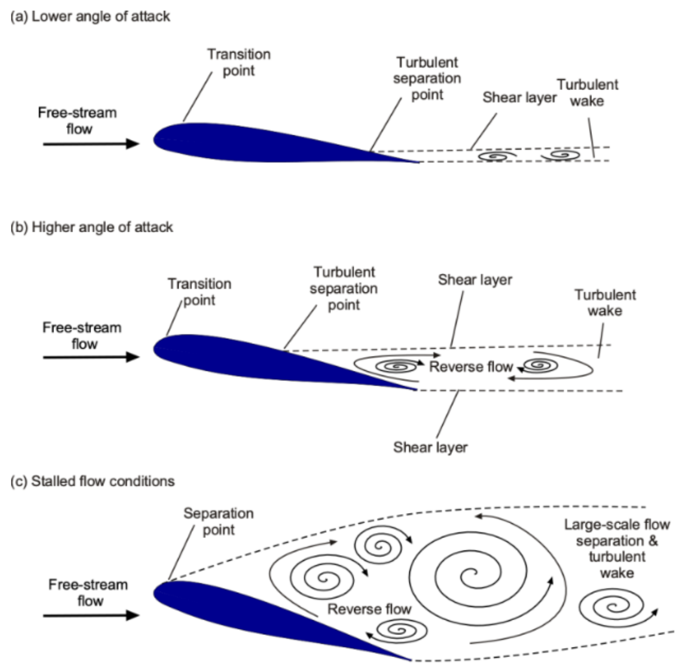

Figure (1). Development of boundary layer thickness with increasing the angle of attack (AoA) [4].

Therefore, studying the change in characteristics such as Reynolds number and airfoil geometry on airfoil performance is very important to know the effectiveness of the airfoil by determining the factors affecting airfoil efficiency, such as lift and drag coefficients, and the ratio of lift to drag.

This study is focused on evaluating the ability of the XFLR5 simulation using the panel method technique to predict 2D aerodynamics over an airfoil at a given angle of attack, and the Reynolds number will be considered in this study. The simulation will be conducted for two main reasons: the first is to achieve accuracy between XFLR5 and the airfoil tools' database results, and the other is to study the effect of changing the characteristics of an airfoil, such as the shape of an airfoil and Reynolds number, on the airfoil's performance. Two airfoils were selected for this study to achieve accuracy, mainly 4-digit airfoils. The numerical solution is conducted for NACA 0012 and 4412 airfoils. The tested airfoils are oriented at different angles of attack and will also be tested at a constant Reynolds number (Re = 100000). The validation results were obtained for these airfoils by comparing the simulation results from the XFLR software and the airfoil tools' database results. After achieving acceptable results, the comparison will be conducted between two popular airfoils, which are NACA 2412 and Daviss Smooth. These results will indicate the effect of changing the shape of the airfoil and the Reynolds number on airfoil performance.

The simulation method helps designers to predict the airflow behaviors on an airfoil model under different conditions, observe the airflow separation patterns, and measure all the parameters which effect on an airfoil's performance, reducing the dependency on expensive experimental methods such as wind tunnel testing.

Previous study

The use of XFLR5 for airfoil aerodynamic analysis and performance optimization has been explored in several studies. All of these studies demonstrate how well XFLR5 works as a tool for initial aerodynamic study in a variety of applications, especially in wind turbines, light aircraft, and UAVs.

Daniel (2020) showed how airfoil selection affects aerodynamic efficiency in UAV design by doing a performance analysis of an asymmetrical airfoil for subsonic flight using XFLR5 software. According to the study, computational tools are crucial for maximizing lift and reducing drag for improved flying performance [5]. Similarly, Periyasamy et al. (2023) used a combination of CFD and XFLR5 simulations to study the aerodynamics of an Active Aeroelastic Wing (AAW). Their results demonstrated that a flexible trailing edge improves lift characteristics while lowering reliance on the control surface [6].

Rimi et al. (2023) employed dimensional parametric analysis to optimize the Selig S3014's airfoil aerodynamic performance. They found changes that increased the airfoil's lift-to-drag ratio and made it more appropriate for a range of aerospace applications using XFLR5 [7]. Airfoil performance for tiny wind turbines running at low wind speeds was investigated by Le Quang Sang et al. (2023) in another study. Their findings showed that utilizing XFLR5 to rebuild the S1010 airfoil resulted in increased aerodynamic efficiency, especially for applications involving renewable energy [8].

There are many studies that have demonstrated XFLR5's reliability in predicting aerodynamic performance. Guzelbey et al. (2018) confirmed that the XFLR5 provides accurate estimates for preliminary airfoil analysis by comparing its lift coefficient (Cl) predictions with experimental wind tunnel data [9]. Communier et al. (2017) additionally confirmed this result by showing that XFLR5 estimates and wind tunnel measurements had a good correlation, especially for airfoils with low Reynolds numbers [10]. The application of XFLR5 in realistic aerodynamic design is supported by these validation studies.

Although XFLR5 is generally used to predict aerodynamic two-dimensional properties of aircraft, it is not used to validate its predicted results before being used for comparative aerodynamic testing. Moreover, previous investigations were to a large extent focused on either the effect of Reynolds number alone or the effect of the geometry of the airfoil in isolation, with only a limited number of studies exploring their combined effects in the same numerical framework. In addition, there are not many studies directly comparing NACA 2412 with Daviss smooth airfoils with the same Reynolds number. Therefore, there is a need for a validated calculation study of the combined effect of Reynolds number and aerodynamic geometry on lift, drag, lift-to-drag ratio, and roll-over inertia to provide a more reliable assessment of the aerodynamic performance of the aerodynamic form of the aircraft.

Methodology

This section will explain the XFLR5 software, airfoil geometry (models), governing aerodynamic parameters, the numerical method of XFLR5, analysis parameters, and the Validation and Comparison Procedure

XFLAR5 software

XFLR5 is a numerical software primarily used for airfoil analysis but can also be used for wings and complete aircraft at low Reynolds numbers [11][12]. To perform 2D airfoil analysis, XFLR5 uses the XFOIL aerodynamic solver, which combines a linear-vorticity panel method with a viscous boundary-layer formulation [2][11]. The airfoil surface is discretized into panels by the panel method to compute the inviscid pressure distribution with reasonable accuracy. The boundary layer viscously interacts with the inviscid flow on the airfoil surface [2]. This method allows approximate estimation of lift coefficient (Cl), drag coefficient (Cd), lift-drag ratio (Cl/Cd), and pitching moment coefficient (Cm) with a much lower computational cost than conventional CFD methods. Therefore, the XFLR5 software is a useful tool for preliminary aerodynamic design [11][13]. XFLR5's viscous analysis predicts the boundary layer development over the airfoil surface. Moreover, it estimates the skin-friction drag, pressure drag, and limited prediction of the flow separation [14]. Moreover, the software predicts the laminar-to-turbulent boundary-layer transition using the e^n transition method, in which the transition location is calculated from the amplification of Tollmien-Schlichting disturbances through the critical amplification factor (Ncrit) [14]. As boundary layer transition is a key factor in flow separation, drag, and aerodynamic efficiency at low Reynolds numbers, a reliable prediction of transition will make aerodynamic simulations more trustworthy than a purely inviscid panel method [2]. However, XFLR5 doesn’t solve the full Navier–Stokes equations but uses a coupled viscous–inviscid approach. Therefore, prediction accuracy drops for extensive flow separation or deep stall [13]. Consequently, before using XFLR5 for comparative aerodynamic investigations, it is advisable to validate the numerical results against a trustworthy aerodynamic database or experimental data [11].

a. Airfoil models

The shape of the airfoil has a crucial influence on airfoil performance. The main parameters that affect airfoil shape are chord line, camber line, thickness, angle of attack (AoA), and aspect ratio (AR). Figure 2 illustrates these parameters [16].

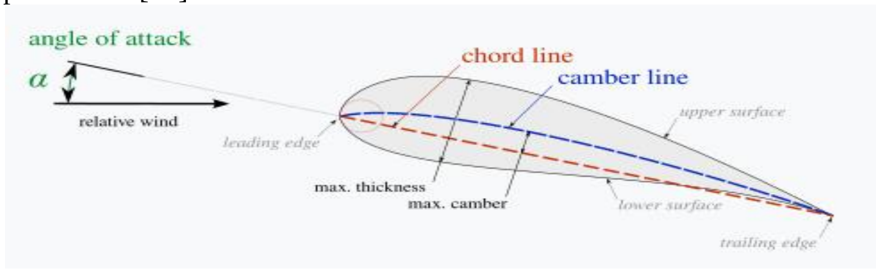

Figure 2. Main parameters to describe the airfoil shape [16]

i. Airfoil selection

This study considered four airfoil models. The NACA 0012 and NACA 4412 airfoils were selected to validate XFLR5 numeric predictions against the Airfoil Tools database. As a result, the NACA 2412 and Daviss Smooth airfoils were chosen for comparative aerodynamic analysis due to their differing geometric characteristics and aerodynamic behaviour in low-Reynolds-number operating conditions.

The NACA 0012 airfoil shown in Figure 3 is symmetrical, the 00 indicating that it has no camber. The 12 indicates that the airfoil has a 12% thickness to chord length ratio; it is 12% as thick as it is long [17].

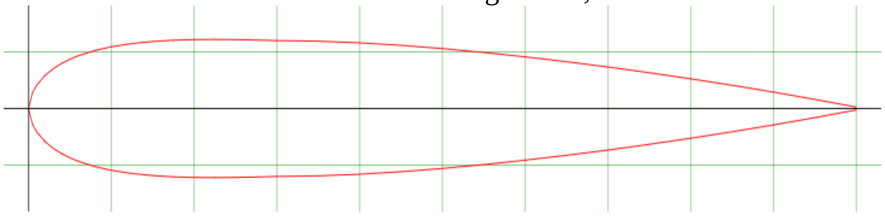

Figure 3. NACA 0012 airfoil [18]

The NACA 4412 airfoil shown in Figure 4 has a maximum camber of 4% located 40% (0.4 chords) from the leading edge with a maximum thickness of 12% of the chord [17].

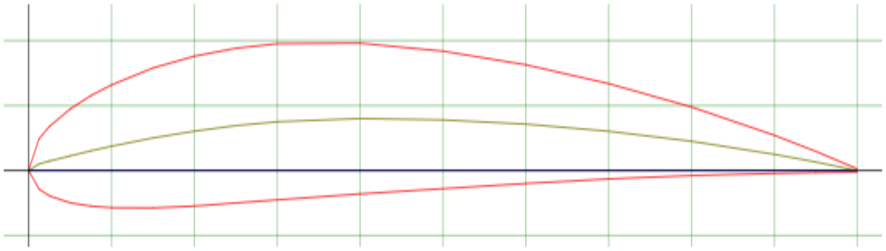

Figure 4. NACA 4412 airfoil [18]

The selected airfoils for comparison results will be two airfoils, which are NACA 2412 and Davis smooth (Davissm). The explanation about these two airfoils is as follows:

NACA 2412 and Davis Smooth (Davissm) are two airfoil types with unique designs and aerodynamic capabilities tailored to meet specific aviation needs. The NACA 2412 airfoil, developed by the National Advisory Committee for Aeronautics (NACA) in the United States, features a moderate camber and a cross-sectional shape that provides a high lift coefficient at low to medium angles of attack, as shown in Figure 5 [17].

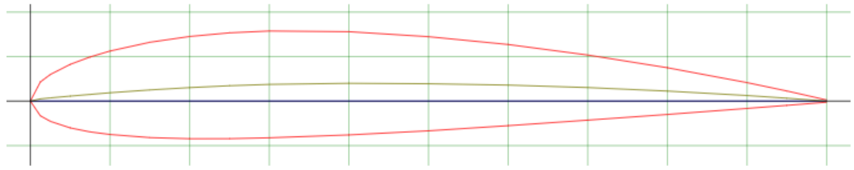

Figure 5. NACA 2412 airfoil [18]

This design reduces drag and enhances flight efficiency, making it well-suited for small and medium-sized aircraft. It is commonly used in light sport and civil aircraft, such as the Cessna 172, one of the world's most popular training aircraft. The NACA 2412's moderate thickness and simple camber offer good stability and reliable performance at low to medium altitudes, making it ideal for aircraft operating at moderate speeds and requiring ease of control.

The Davis Smoothed airfoil, on the other hand, is a more streamlined design, featuring reduced turbulence along the airfoil edges to achieve greater stability and control at nearly all flight speeds, as shown in Figure 6 [17].

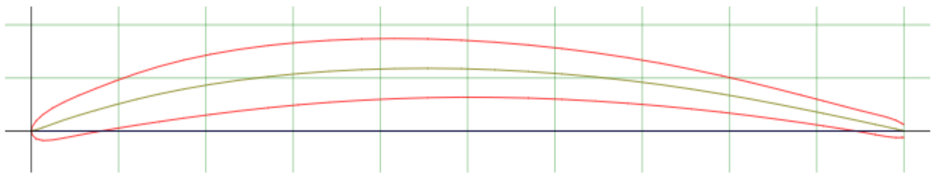

Figure 6. Davis Smooth airfoil [18]

b. Governing Aerodynamic Parameters (Cl, Cd, Cl/Cd, Cm, Re)

Airfoil aerodynamic performance is measured with four dimensionless parameters, namely, lift coefficient (Cl), drag coefficient (Cd), lift-to-drag ratio (Cl/Cd), and pitching moment coefficient (Cm). The aerodynamic coefficients are dimensionless aerodynamic forces and moments (lift, drag, rolling moment). In the present study, the Reynolds number and the airfoil geometry influence the aerodynamic performance with the use of these parameters.

i. Lift Coefficient (Cl)

The lift coefficient (Cl) is the lift generated by an airfoil divided by the dynamic pressure of the freestream and the reference area. A higher value of Cl implies it can lift a bigger weight under the same flow conditions. It is described as [19].

$$C_l = \frac{L}{\frac{1}{2}\rho V^2 S} \text{ .... (1)}$$

ii. Drag Coefficient (Cd)

The drag coefficient (Cd) is a coefficient that helps quantify drag on an airfoil. The drag coefficient refers to the resistance experienced by the airfoil as it moves through the fluid and is mainly used to check aerodynamic efficiency. Lower Cd values mean less air resistance. The drag coefficient is expressed as [19]:

$$C_d = \frac{D}{\frac{1}{2}\rho V^2 S} \text{ .... (2)}$$

iii. Lift-to-Drag Ratio (Cl/Cd)

The lift-to-drag ratio (Cl/Cd) is perhaps the most important indicator of aerodynamic efficiency, as it measures the lift generated for a given drag force. Having a large Cl/Cd value means that the airfoil has more lift and less drag. So, the airfoil has good aerodynamic characteristics. It is computed as follows:

$$\frac{C_l}{C_d} \text{ .... (3)}$$

iv. ***Pitching Moment Coefficient (Cm)***

The pitching moment coefficient (Cm) is the aerodynamic pitching moment that acts about a particular reference point, usually taken to be the quarter-chord aerodynamic center in airfoil studies. The Cm value gives information about the longitudinal stability of the airfoil. A negative pitching moment corresponds to a tendency to nose down. The pitching moment coefficient is defined as [19]:

$$C_m = \frac{M}{\frac{1}{2}\rho V^2 S c} \dots\dots\dots\dots\dots\dots(4)$$

v. ***Reynolds number (Re)***

The Reynolds number is the ratio of inertial forces to viscous forces. The Reynolds number is a dimensionless number used to categorize the fluid systems in which the effect of viscosity is important in controlling the velocities or the flow pattern of a fluid. The Reynolds number is expressed as [19]:

$$R_e = \frac{\rho V c}{\mu} \dots\dots\dots\dots\dots\dots\dots\dots (5)$$

Table 1 illustrates the terminology of the aerodynamic parameter variables used in this study.

Table (1). Terminology of the aerodynamic parameter variables

Symbol	Description	Unit
Cl	Lift coefficient	--
Cd	Drag coefficient	--
Cm	Pitching moment coefficient	--
Cl/Cd	Lift-to-drag ratio	--
L	Lift force	N
D	Drag force	N
M	Pitching moment about the reference point	N.m
ρ	Air density	kg/m^3
V	Freestream velocity	m/s
S	Reference area	m^2
c	Airfoil chord length	m
$q = \frac{1}{2}\rho V^2$	Dynamic pressure	Pa
Re	Reynolds number	--
μ	Dynamic viscosity of air	Pa.s or (kg/m.s)
ϑ	Kinematic viscosity of air	m^2/s
α	Angle of attack	degree (°)

c. Numerical Method of XFLR5

The method used in the XFLR5 simulation is the Panel Method.

- Panel Method

It is a numerical technique used in computational fluid dynamics (CFD) to analyze the aerodynamic characteristics of airfoils, wings, and other surfaces immersed in a fluid flow. It is often used for the analysis of inviscid (non-viscous), compressible or incompressible flows, and is based on potential flow theory, which assumes the fluid has no viscosity and the flow is irrotational [11].

How does the Panel Method work?

The surface of the airfoil or wing is divided into a series of small, flat panels (Figure 7), usually in the form of straight-line segments. The idea is to approximate the continuous surface of the object with discrete sections, each of which can be treated independently. These panels are often defined as source panels or vortex panels [11].

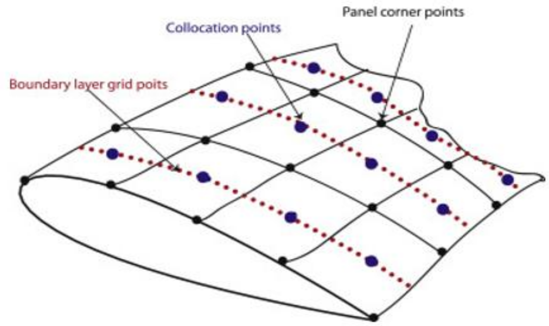

Figure 7. The surface of the airfoil or wing is divided into a series of small, flat panels [11]

Analysis parameters

The analysis parameters of this study are set as follows:

Note: standard conditions for air are at constant pressure and temperature, 1 atm, and 15 °C, respectively.

Parameters	Value	Units	Notes
Reynolds number (Re)	100000	No unit	For validation cases
Reynolds number (Re)	50000, 100000	No unit	For comparison cases
Density of air (ρ)	1.225	kg/m^3	Density of air at standard conditions
Kinematic viscosity (ϑ)	1.5×10^{-5}	m^2/s	Kinematic viscosity of air at standard conditions
Chord	1	m	Length of airfoil
Span	1	m	Width of airfoil
Area (S)	1	m^2	Area of airfoil per unit span length
Number of panels	100	No unit	The number of panels is constant for all cases
Mass	1	kg	/
Angle of Attack (AoA)	0 to 16	Degree	Change the angle of attack by 0.5 degrees

Figure 8 illustrates the number of panels distributed around the airfoil surface; this distribution is based on the (Global Panel Refinement) variables. As seen in Figure 9, the panel distribution was almost uniform around the airfoil; the distribution for panels begins from (TE), and the panel points are discretized by equal space on the upper and lower surfaces; the number of panels concentrates more on (LE) to get a more accurate foil surface and to improve the results around this region.

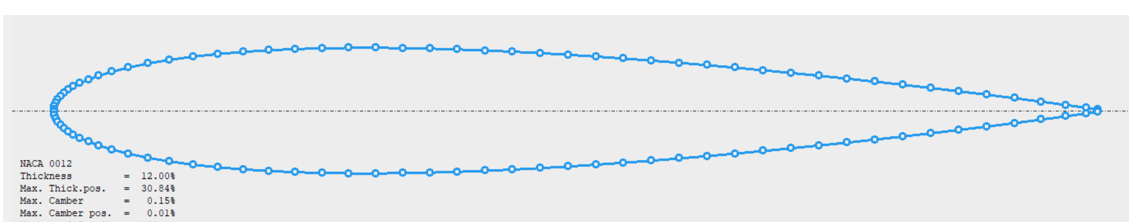

Figure 8. The panel point distribution around the airfoil surface

Validation and Comparison Procedure
The evaluation procedure will be conducted for three different types of airfoils, which are NACA 0012 and NACA 4412 airfoils at a Reynolds number value equal to 100000. The validation will be conducted only on the Cl/Cd ratio. The validation will be represented in the average approach percentage between the XFLR5 results (simulation results) and the Airfoil Tools results (exact results). The approach percentage is defined as follows:

$$Approach\ percentage = \frac{|exact\ value - simulation\ value|}{exact\ value} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The comparison will be conducted between two airfoils, NACA 2412 and Davis Smooth airfoils, at three different values of Reynolds number: 50000 and 100000. Comparison points between airfoils are Cl, Cd, Cl/Cd, and Cm.

Result and discussion
The results will be divided into two main sections, which are validation results and comparison results.

4.1 Validation results
The obtained validation results will represent the average approach percentage between the XFLR5 results (simulation results) and the Airfoil Tools results (exact results).

4.1.1 Validation result for NACA 0012 airfoil
Figure 9 illustrates the approach results between the XFLR5 simulation result and the Airfoil Tools results for the NACA 0012 airfoil. The average approach percentage in this case was too close, by 2.22%, to the exact results.

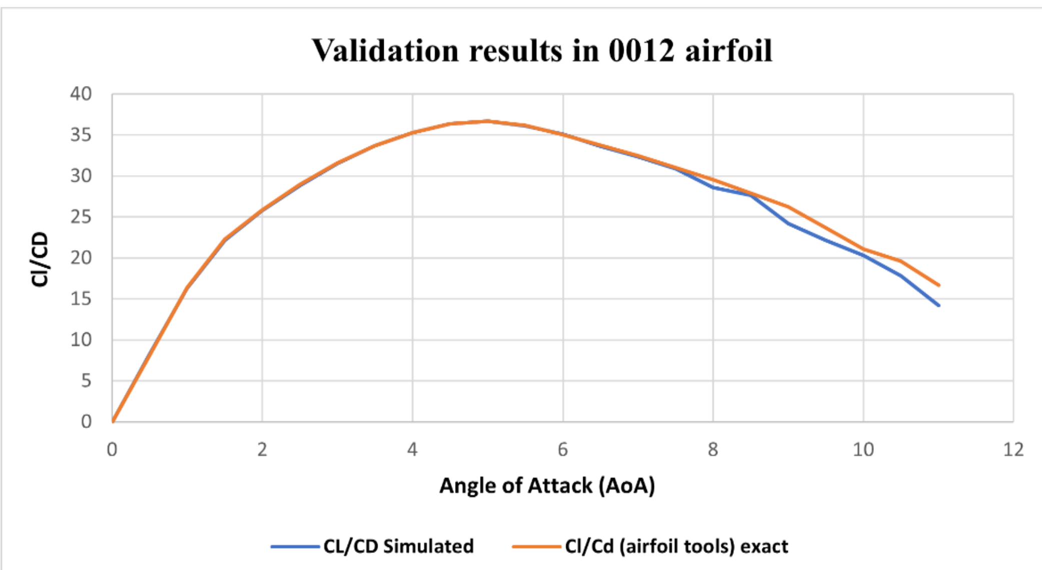

Figure 9. Validation results in 0012 Airfoil, CL/CD Vs. AoA

4.2.2 Validation result for NACA 4412 airfoil
Figure 10 illustrates the approach results between the XFLR5 simulation results and the Airfoil Tools results for the NACA 4412 airfoil. The average approach percentage in this case was too close, by 5.3289% from the exact results.

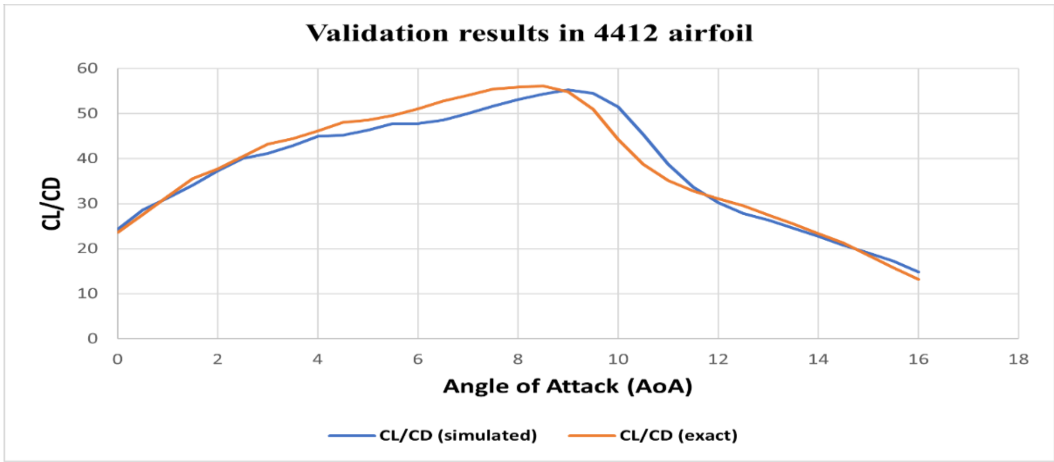

Figure 10. Validation results in 4412 Airfoil, CL/CD Vs. AoA

Note: As shown by the results of validation, the range of the Angle of Attack (AoA) is from 0° to 11° in two cases because the results of Airfoil Tools have a range from 0° to 11° as well.

4.2 Comparison Results

The comparison results were conducted between the NACA 2414 and Daviss Smooth airfoils at three different values of Reynolds number at 50000, 100000, and 200000. The comparison will be represented in Cl vs. AoA, CD vs. AoA, Cl/CD vs. AoA, and Cm vs. AoA graphs. The range of the Angle of Attack is between 0° and 11°

4.2.1 Lift Coefficient (CL) at Re =50000

The graph in Figure 11 shows that both airfoils gain lift as the angle of attack increases. The NACA 2412 airfoil rises gradually and achieves a higher lift coefficient, while the Daviss Smooth airfoil increases steeply, but it drops suddenly, almost at an angle of attack of 6.25 degrees, and then rises again. As seen from the graph, the NACA 2412 had a steady rise of lift coefficient, while the Daviss smooth had no steady rise of lift coefficient at the lower Reynolds number.

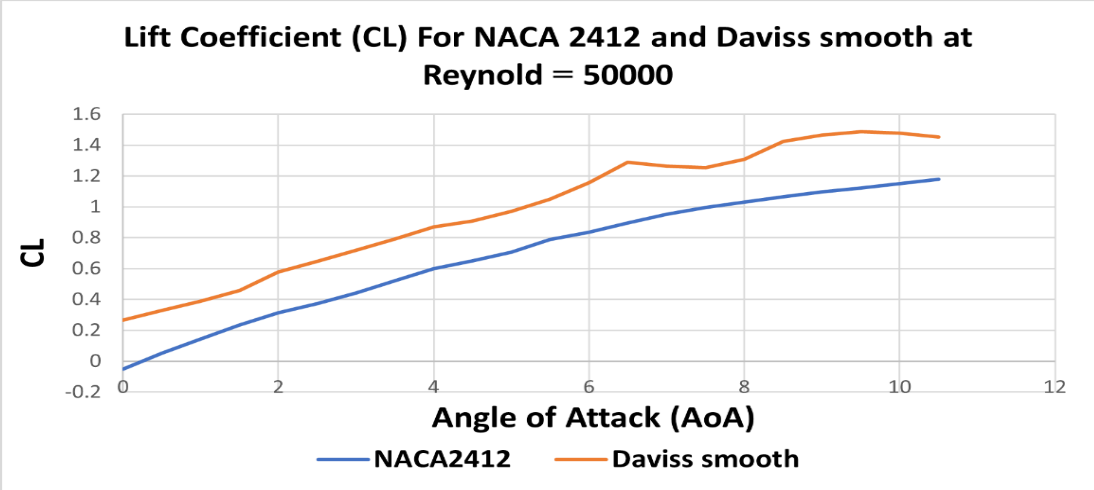

Figure 11. Comparison results in NACA 2412 and Daviss Smooth Airfoil CL Vs AoA at Re = 50000

4.2.2 Lift Coefficient (CL) at Re =100000

The graph in Figure 12 illustrates that both airfoils gain lift as the angle of attack increases. The NACA 2412 airfoil rises more gradually than the first case, while the Daviss Smooth airfoil increases more than the NACA 2412, and the lift coefficient curve becomes more stable than the first case, but it stalls faster than the other. As seen from the graph, the lift coefficient of Daviss Smooth improved, and the difference in lift coefficient between the two airfoils increased.

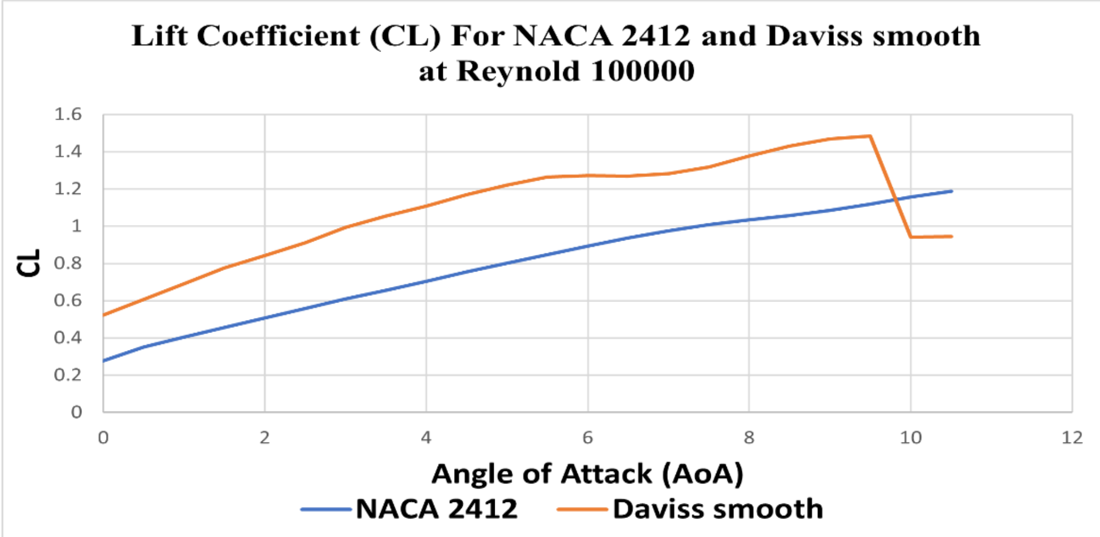

Figure 12. Comparison Results in NACA 2412 And Daviss Smooth Airfoil CL Vs AoA at Re = 100000

4.2.3 Drag Coefficient (CD) at Re = 50000

The graph, as shown in Figure 13, illustrates that the CD curve for the NACA 2412 airfoil has lower values with an increase in the AoA from 0° to 8°. While the CD curve of Daviss Smooth has higher values for the whole curve length, the best region of the CD curve is limited from 5.5° to 6.25° approximately. NACA 2412 airfoil demonstrated more stability than Davis Smooth and was more efficient at a lower Reynolds number.

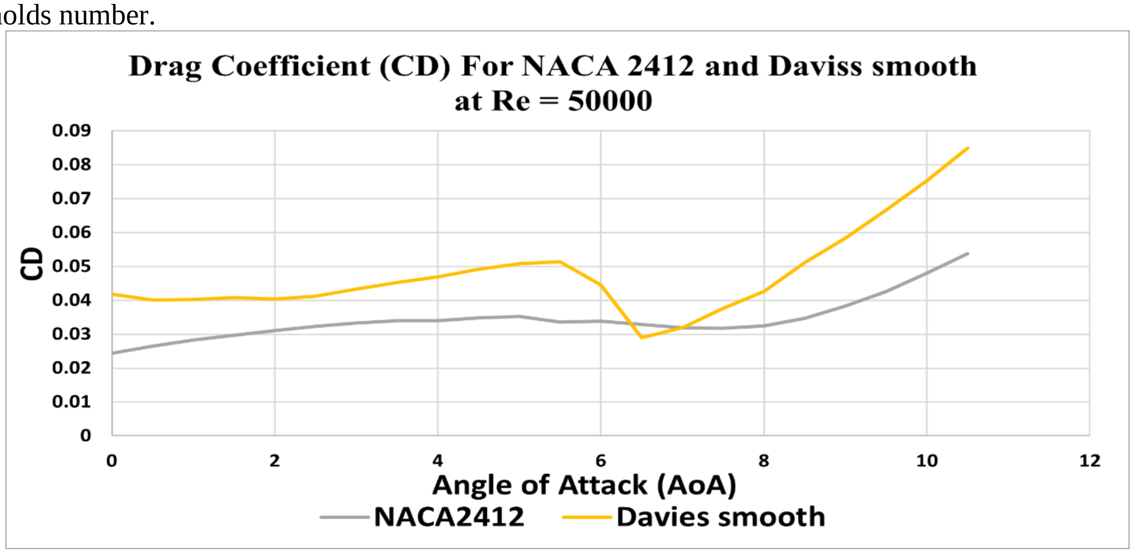

Figure 13. Comparison Results in NACA 2412 and Daviss Smooth Airfoil CD Vs AoA at Re = 50000

4.2.4 Drag Coefficient (CD) at Re = 100000

The graph, as shown in Figure 14, illustrates that the CD curve for Daviss's smooth airfoil improved compared with the previous case; it appeared to decrease in CD curve values from 0° to 6°, but it was not more efficient than the NACA 2412 airfoil due to it being lower in the CD curve, as well as improving more than the previous case. Both airfoils were improved with an increase in Reynolds number.

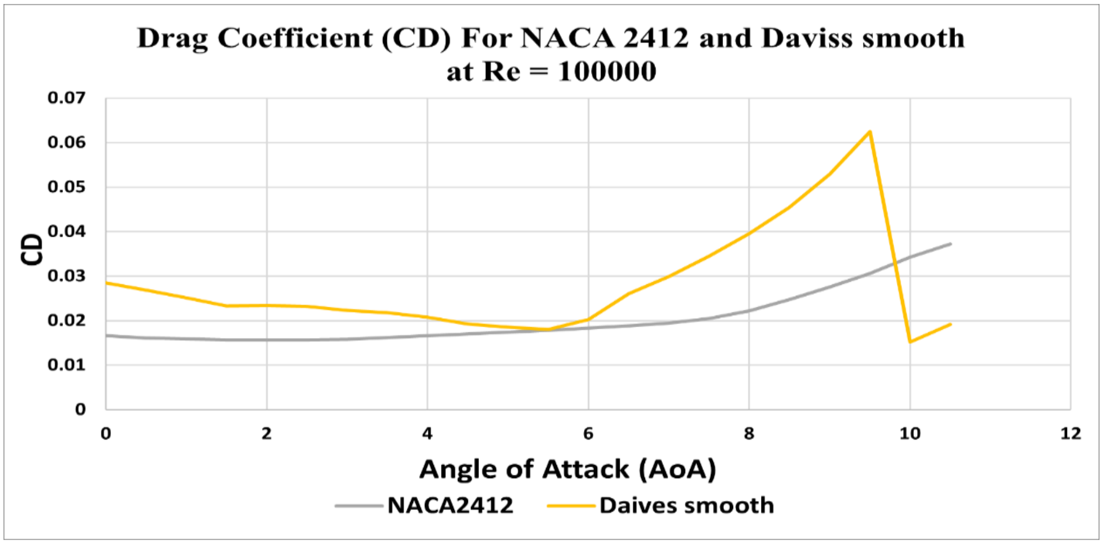

Figure 14. Comparison Results in NACA 2412 and Daviss Smooth Airfoil CD Vs AoA at Re = 100000

4.2.5 Lift to Drag Ratio (CL/CD) at Re = 50000

The graph, as shown in Figure 15, illustrates the (CL/CD) curves for NACA 2412 and Daviss Smooth at Re = 50000. Daviss Smooth airfoil demonstrated better performance than NACA 2412, especially at low AoA, and at 6° to 8° was the best performance of Davis Smooth airfoil. The advantage of NACA 2412 was the stability of performance, which increased gradually with increased AoA.

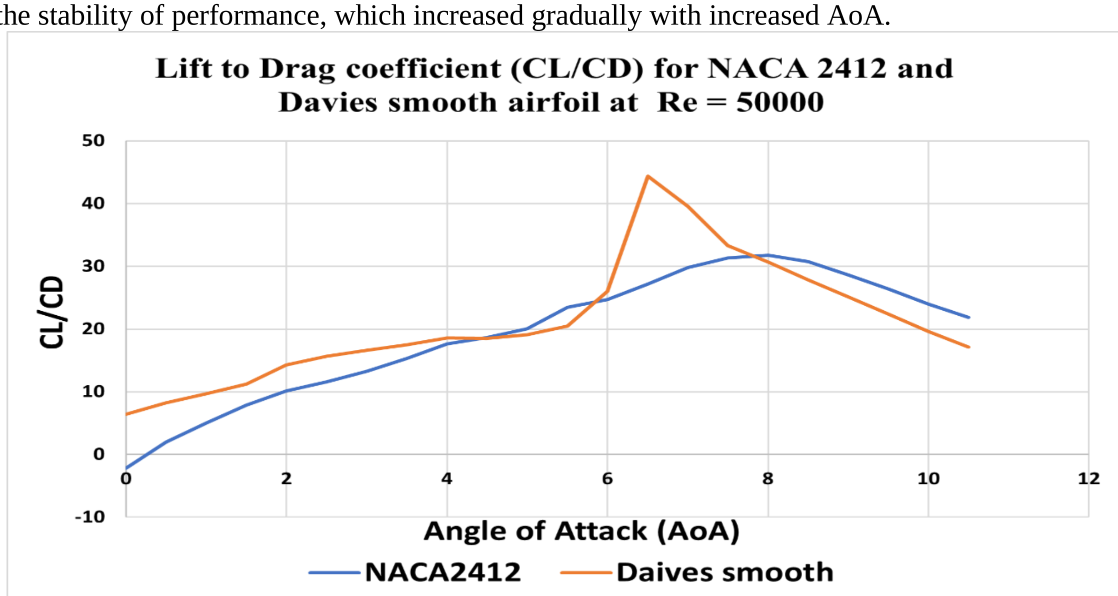

Figure 15. Comparison Results in NACA 2412 and Daviss Smooth Airfoil (CL/CD) Vs AoA at Re = 50000

4.2.6 Lift to Drag Ratio (CL/CD) at Re = 100000

The graph, as shown in Figure 16, illustrates that (CL/CD) curves for NACA 2412 and Daviss Smooth are at R = 100000. The CL/CD ratio curve has higher values for the Daviss Smooth airfoil, particularly in the range of approximately 0° to 5.5°, than for the NACA 2412 airfoil. In contrast, the NACA 2412 airfoil curve increases gradually and steadily better than the Daviss Smooth airfoil. Compared with the previous case, the CL/CD ratio values increased in both airfoils when the Reynolds number increased.

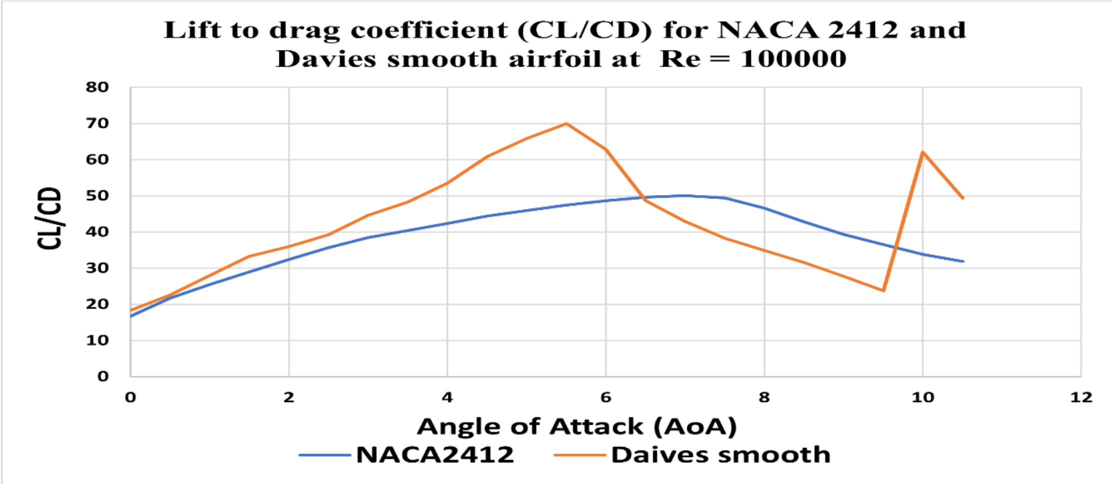

Figure 16. Comparison Results in NACA 2412 And Daviss Smooth Airfoil (CL/CD) Vs AoA at Re = 100000

4.2.7 Moment Coefficient (Cm) at Re = 50000

The graph in Figure 17 illustrates the moment coefficient (CM) for the NACA 2412 and Daviss Smooth airfoils at a Reynolds number of 50000 across angles of attack from 0 to 10.5 degrees. The NACA 2412 maintains a relatively stable moment coefficient near zero, indicating better aerodynamic balance. In contrast, the Daviss Smooth airfoil shows significant fluctuations with a negative moment coefficient, suggesting a tendency for nose-down pitching moments as the angle of attack increases. Overall, the NACA 2412 demonstrates greater aerodynamic stability than the Daviss Smooth airfoil at this Reynolds number.

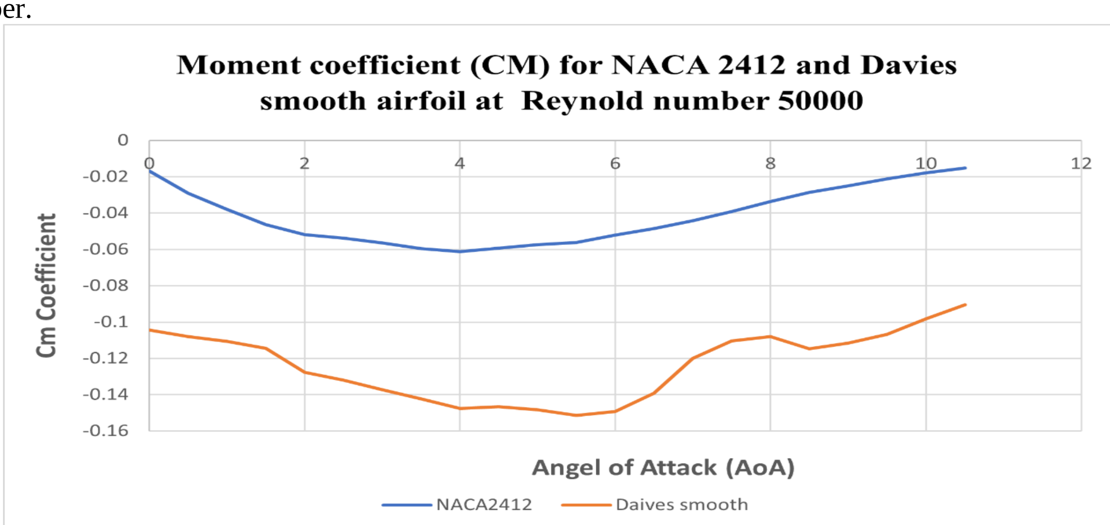

Figure 17. Comparison Results in NACA 2412 and Daviss Smooth Airfoil (CM) vs AoA at Reynold number 50000

4.2.8 Moment Coefficient (Cm) at Re = 100000

The graph in Figure 18 illustrates the moment coefficient (CM) for the NACA 2412 and Daviss Smooth airfoils at a Reynolds number of 100000, spanning angles of attack from 0 to 10.5 degrees. The NACA 2412 shows a relatively stable moment coefficient around -0.05, indicating consistent aerodynamic stability. In contrast, the Daviss Smooth airfoil exhibits greater fluctuations, particularly at higher angles of attack, suggesting increased sensitivity to changes in angle and less aerodynamic stability. Overall, the NACA 2412 demonstrates superior aerodynamic stability compared to the Daviss Smooth airfoil at this Reynolds number.

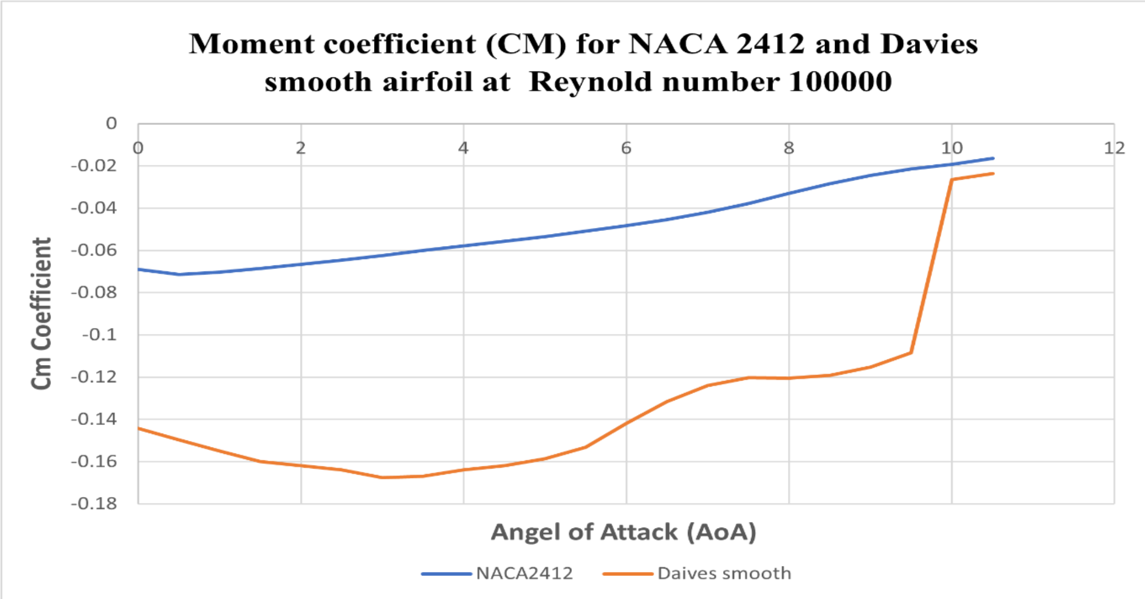

Figure 18. Comparison Results in NACA 2412 and Daviss Smooth Airfoil (CM) vs AoA at Reynolds number 100000

Conclusion

This study looked at how to evaluate the XFLR5 simulation to enhance its use in simulation and the effect of the change in characteristics on airfoil performance, such as shape and Reynolds number. The results show that the validation results were acceptable, and the comparison results analyze the performance of both airfoils (NACA 2412 and Daviss smooth). The results show that the NACA 2412 was better than Daviss smooth based on drag reduction. Whereas the Daviss smooth airfoil gives higher lift compared to the NACA 2412. As the comparison results for the CL/CD coefficient illustrated, the Daviss smooth airfoil was better than the NACA 2412 airfoil, but aerodynamically, increasing the drag force yields more thrust force, and that requires an increase in fuel consumption. In addition, the drag coefficient of NACA 2412 was low and constant for all different Reynolds numbers from 0 to 8 degrees. For these reasons, the NACA 2412 was better than Daviss smooth. The best performance of NACA 2412 was at Re = 100000, and as the Reynolds number increases, the drag coefficient decreases. So, based on that, the favorable use for both airfoils is at higher values of Reynolds number. The moment coefficient Cm results indicate that the NACA 2412 airfoil has stability at different conditions. The Cm decreases as the angle of attack increases for both airfoils. Increasing values of Cm mean that the airfoil is more stable, and the negative sign indicates the nose-down direction.

Future work may focus on the 3D airplane design by designing the airplane control parts, such as the wing with flaps, ailerons, and rudder, to study how the airplane stabilizes under different aerodynamic conditions.

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Authors' Contributions

The manuscript was conceived and designed by the author; they performed the research and analysis, interpreted the results, and wrote and revised the manuscript.

Fundings

This research received no specific grant.

Data Availability

Data are available from the corresponding author upon reasonable request

References

[1] Anderson, J. D. (2017). Fundamentals of aerodynamics (6th ed.). McGraw-Hill Education.

[2] Drela, M. (1989). XFOIL: An analysis and design system for low Reynolds number airfoils. Conference on Low Reynolds Number Aerodynamics, 1–12.

[3] Shah, R., Patel, N., & Sharma, A. (2021). Computational and experimental analysis of NACA airfoils for UAV applications. Journal of Aerospace Science and Technology, 5(2), 65–74.

[4] Leishman, J. G. (2022). Introduction to aerospace flight vehicles. Eagle Pubs. Introduction to Aerospace Flight Vehicles. https://eaglepubs.erau.edu/

[5] Daniel, J. (2020). Performance analysis of an asymmetrical airfoil for subsonic flight using XFLR5 software. International Journal of Progressive Research in Science and Engineering, 1(8), 8–12. Retrieved from https://www.researchgate.net/publication/345733165

[6] Periyasamy, M., Prabhu, S., & Karthikeyan, M. (2023). CFD and XFLR5 analysis of an active aeroelastic wing. Research Square. Retrieved from https://assets-eu.researchsquare.com/files/rs-2263166/v1_covered.pdf

[7] Rimi, K. N., Rahman, M. S., & Sadi, T. (2023). Optimizing aerodynamic performance of Selig S3014 airfoil through dimensional parametric analysis. Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES), 9, 1–5. Retrieved from https://catalog.lib.kyushu-u.ac.jp/opac_download_md/7157922/2023_p001.pdf

[8] Le Quang Sang, D., Dinh Van Thin, N., Nguyen Huu Duc, N., Nguyen Duc Minh, D., Doan Hong Quan, L., & Le Thi Thuy Hang, T. (2023). Study of the performance of the airfoil of a small wind turbine under low wind speed by CFD simulation. arXiv Preprint, arXiv:2311.11732. Retrieved from https://arxiv.org/abs/2311.11732

[9] Guzelbey, I. H., Eraslan, S., & Dogru, M. (2018). Comparison of experimental results with XFLR5 analysis results in terms of lift. International Journal of Aerospace Engineering, 35(2), 120–130.

[10] Communier, D., Smith, J., & Lee, R. (2017). Validation of XFLR5 predictions for airfoil performance. Journal of Aircraft and Aerodynamics, 29(4), 85–97.

[11] Deperrois, A. (2011). XFLR5 v6 user guidelines. XFLR5 Project. https://www.xflr5.com

[12] Deperrois, A. (2017). XFLR5: Analysis of foils, wings and planes operating at low Reynolds numbers. XFLR5 Project. https://www.xflr5.com

[13] Gudmundsson, S. (2014). General aviation aircraft design: Applied methods and procedures. Butterworth-Heinemann.

[14] Drela, M., & Youngren, H. H. (2001). XFOIL 6.9 User Primer. Massachusetts Institute of Technology.

[15] National Aeronautics and Space Administration. (n.d.). Wing geometry. NASA Glenn Research Center. https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/wing-geometry/

[16] Anderson, J. D., Jr. (2011). Fundamentals of aerodynamics (5th ed.). McGraw-Hill Education.

[17] http://airfoiltools.com/م 08:55 2026/08/05

[18] Marchman, J. F. (2023). Aerodynamics and aircraft performance (3rd ed.). Virginia Tech. https://pressbooks.lib.vt.edu/aerodynamics/