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3 Dimensional Aerodynamic Analysis of Additional Slat and Slot on Airfoil Naca 23018 Using Computational Fluid Dynamic Method

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Abstract

Slat and Slot is one of the components of high lift devices in addition to the flaps used on the wings of the aircraft. It has a function to provide a lifting force when the attack angle of the aircraft wing is high. The topic studied in this study was the flow that crossed the NACA 23018 airfoil with the addition of slats and slots. The research method used is a 3-dimensional analysis method using ansys fluent software. The test object to be used is the NACA 23018 airfoil. This research was conducted numerically using the CFD (computational fluid dynamic) method. The purpose of this study was to compare the characteristics of fluid flow with or without the addition of slats and slots. The speed used is 40m/s with a spacing of 5%, 8%, and 10% chords and the angle of attack used as variation parameters are (α) = 0°, 2°, 4°, 6°, 8°, 10°, 12°, 15°, 16°, 17°, 18°, 19° and 20°. The results showed that with the addition of slats and slots on the NACA 23018 Airfoil, it can increase the lifting force at the high angle of attack, as well as delay the stall due to delays in airflow separation. In the airfoil variation with a slat clearence of S = 10% ($\alpha = 20^o$) has a lift coefficient with the most maximum value and a more even distribution. So in this study, it came to the conclusion that the most effective variation used in the NACA 23018 Airfoil was with a 10% slat clearence at subsonic speed.

Keyword: NACA 43018 airfoil, Slat and Slot, pressure coefficient, lift force, drag force.

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1. Introduction

Aerodynamic performance plays a crucial role in the design and functionality of aircraft, particularly in optimizing the efficiency of the wings during various flight phases, such as takeoff, landing, and maneuvering. A key aspect of enhancing aerodynamic performance involves modifying the wing structure to achieve higher lift, better control, and reduced drag under different flight

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conditions [1]. One such modification includes the addition of slats and slots to the airfoil, components that are primarily used to improve the airflow characteristics at high angles of attack, a critical factor for both high-lift performance and stability during low-speed flight. Slats and slots are devices that are typically placed on the leading edge of the wing, allowing the wing to achieve higher lift coefficients without causing flow separation, a phenomenon that typically leads to aerodynamic stall [2] [3].

Slats are movable surfaces mounted on the leading edge of the wing, designed to extend forward and downward when deployed. By altering the airflow over the wing, slats increase the effective camber of the airfoil, enabling the wing to operate at higher angles of attack without stalling. This increase in the angle of attack corresponds to an improvement in the lift-to-drag ratio, which is essential during takeoff and landing operations. Similarly, slots are small openings placed in the leading edge or the upper surface of the wing, designed to direct air to the upper surface of the airfoil [4] [5]. When deployed, slots allow a controlled flow of air to pass through the opening, maintaining the boundary layer attachment to the surface, thereby delaying flow separation and extending the critical angle of attack. The combination of slats and slots enhances the aerodynamic properties of the wing, particularly under conditions where high lift and control are needed at low speeds [6] [7].

The use of slats and slots, however, is not without its challenges. While these devices improve lift performance, they also introduce additional drag, which can reduce the overall aerodynamic efficiency of the aircraft if not optimized. Therefore, understanding the interplay between slats, slots, and the overall aerodynamic performance of the airfoil is vital for efficient aircraft design. Computational Fluid Dynamics (CFD) offers an invaluable tool for analyzing and predicting the aerodynamic characteristics of airfoils equipped with slats and slots [8] [9]. CFD simulations provide detailed insights into the flow field around the airfoil, allowing researchers to evaluate the effects of these modifications on the lift, drag, and flow separation characteristics of the wing [10].

In this study, the impact of adding slats and slots to the NACA 23018 airfoil is analyzed using the CFD method. The NACA 23018 airfoil is a widely used airfoil shape, known for its relatively simple geometry and predictable aerodynamic performance. This airfoil is often used as a baseline in many aerodynamic studies due to its ability to represent typical characteristics of subsonic airfoils. The goal of this research is to investigate how the addition of slats and slots influences the aerodynamic properties of the NACA 23018 airfoil, specifically focusing on the lift coefficient (Cl) and drag coefficient (Cd) at varying angles of attack. These coefficients are essential for understanding the lift-to-drag ratio, a critical parameter for evaluating the efficiency of aircraft wings during different flight phases [11] [12] [13]. Computational Fluid Dynamics simulations allow for a comprehensive examination of the flow patterns around the airfoil under different conditions. By varying the geometry of the slats and slots, the study aims to identify the optimal configuration that maximizes lift while minimizing drag. The effects of slats and slots on flow separation, pressure distribution, and vortex formation are analyzed in detail. Additionally, the study seeks to explore the potential benefits of using slats and slots as high-lift devices in improving the takeoff and landing performance of aircraft. The results of this study are expected to provide valuable insights into the design of aircraft wings, particularly for applications where high-lift performance is critical [11] [14] [15].

The addition of slats and slots to an airfoil has been a subject of extensive research in the field of aerodynamics. Previous studies have shown that slats and slots can significantly enhance the aerodynamic performance of airfoils by delaying flow separation and improving the overall lift-to-drag ratio. For example, slats have been shown to increase the maximum lift coefficient by extending the effective operating range of the wing at high angles of attack, which is particularly important during low-speed flight regimes. Similarly, the use of slots has been found to improve the boundary layer characteristics, reducing drag and increasing the stability of the airfoil under various flow conditions [16] [17] [18]. The current study builds upon this body of research by focusing on the specific geometry of the NACA 23018 airfoil and analyzing the effects of slats and slots on its aerodynamic performance using state-of-the-art CFD techniques.The application of CFD in this study is particularly advantageous because it allows for a detailed analysis of the airflow around the airfoil without the need for physical experimentation. CFD simulations provide high-resolution data on velocity fields, pressure distributions, and turbulence characteristics, enabling researchers to gain a deeper understanding of the complex interactions between the airfoil and the surrounding fluid. This approach also allows for the examination of a wide range of operating conditions, such as different angles of attack, Reynolds numbers, and Mach numbers, which would be difficult to replicate experimentally. Furthermore, CFD simulations can be used to optimize the design of slats and slots by adjusting their geometry and placement to achieve the desired aerodynamic performance [17] [19] [20].

In addition to its role in improving aircraft performance, the study of slats and slots on airfoils also contributes to the broader field of aerodynamics by providing insights into the fundamental principles of flow separation, lift generation, and drag reduction. Understanding the mechanisms that govern these phenomena is essential for advancing the design of more efficient and sustainable aircraft. As the aerospace industry continues to push the boundaries of performance, the optimization of wing aerodynamics remains a key area of research, particularly as new materials, manufacturing techniques, and design philosophies are developed. By improving our understanding of the aerodynamic effects of slats and slots, this study contributes to the ongoing effort to create more efficient, high-performance aircraft. In conclusion, the present study aims to investigate the impact of slats and slots on the aerodynamic performance of the NACA 23018 airfoil using Computational Fluid Dynamics simulations. By examining the effects of these modifications on lift, drag, and flow characteristics, the study seeks to provide valuable insights into the design of high-performance aircraft wings. The results of this research will contribute to the development of more efficient wing designs, with applications in both commercial and military aviation. Through the use of CFD, this study offers a comprehensive analysis of the aerodynamic properties of slats and slots, providing a deeper understanding of their role in enhancing the overall performance of aircraft wings.

2. Materials and Method

2.1 Boundary Condition

Boundary condition is a limitation that occurs in the flow after passing through an object by determining the inlet, outlet and wall (side) condition. In figure 1, the process of creating a Boundary Layer is a process that has an important influence on the simulation carried out. The boundary layer must be adjusted to the actual state of the test object model [21] [22].

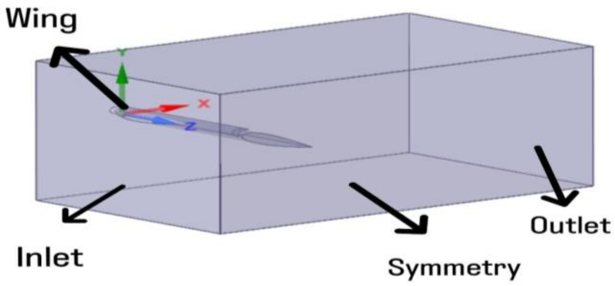

Figure 1. Domain and Boundary Condition

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2.2 Meshing

Unstructured mesh is applied to the meshing process, where the results will later divide into 3 forms of cells, namely tetrahedral, prismatic and pyramid. The boundary layer around the surface of the airfoil is made 5 layers of boundaries. Meshing in figures 2 and 3 is the discretization stage of the continuous fluid domain into a discrete computational domain so that it can be harmonized by the equation (in this case the fluid flow) in it and then produce a solution [17] [19].

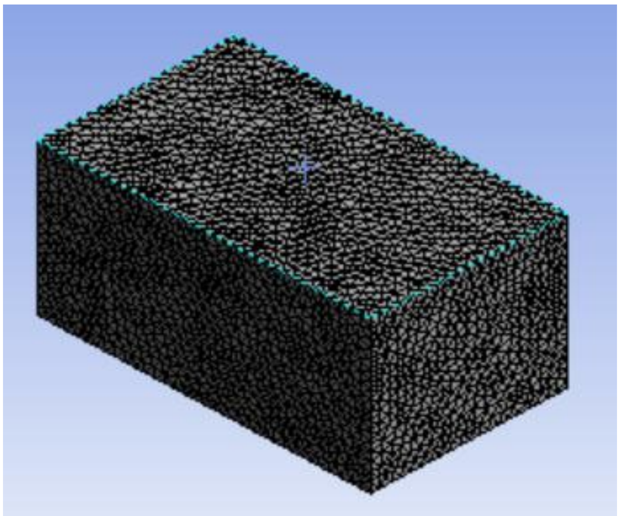

Figure 2. Meshing Globally

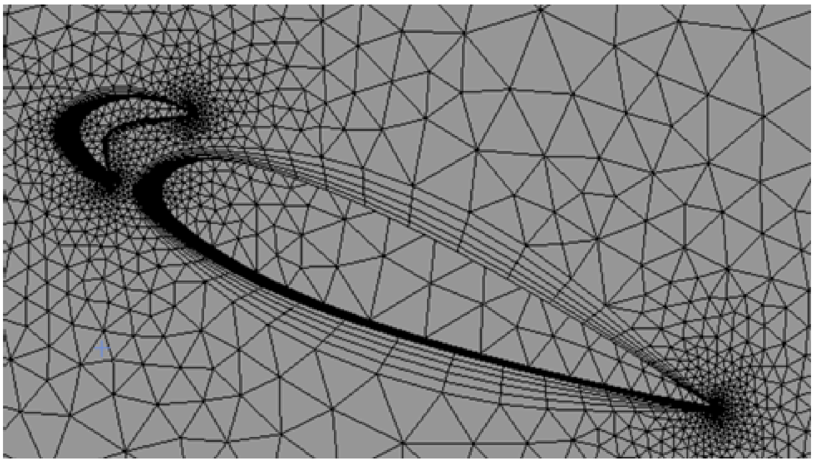

Figure 3. Meshing Around the Wing

3. Results And Discussion

Model geometry making using Solidworks 2019 software and to analyze lift and drag areodynamic forces on NACA 2412 using ANSYS Workbench 16.2 software, simulation on ANSYS using wind speed of 40 m/s and steady flow speed [8] [9] [12]. The result of the simulation in this study is in the form of visualization of the flow that occurs when passing through the airfoil and also the value of the coefficient drag and coefficient lift.

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3.1 Coefficient Drag

The following is a graph of the coefficient of drag Airfoil NACA 23018 with 13 variations of angle of attack 0º, 2º, 4º, 6º, 8º, 10º, 12º, 15º, 16º, 17º, 18º, 19º and 20º here can be seen performance comparison on distance variations slat (slat clearence) 5% chords, 8% chords, and 10% chords compared to Airfoil NACA 23018 without slat slots. NACA 23018 airfoils without slat have the most stable drag coefficient upward movement as the angle of attack increases although it tends to be of lower value than naca 23018 airfoil after adding slat. The most significant increase in the drag coefficient was seen in the airfoil with a slat at a 5% chord clearence slat, that is, from a value of 2.0085666 at an angle of attack of 12º to a value of 4.0426816 at an angle of attack of 15º [12] [14]. The addition of slats to the airfoil affects the increase in the value of the drag coefficient, but the amount of slat clearence does not have much effect on the increase in the value of the drag coefficient. It can be seen in chart 4 that the maximum drag occurs at slat clearence of 8% chords instead of in slat clearence of 10% chords. However, the value of the drag coefficient increases as the angle of attack increases [15].

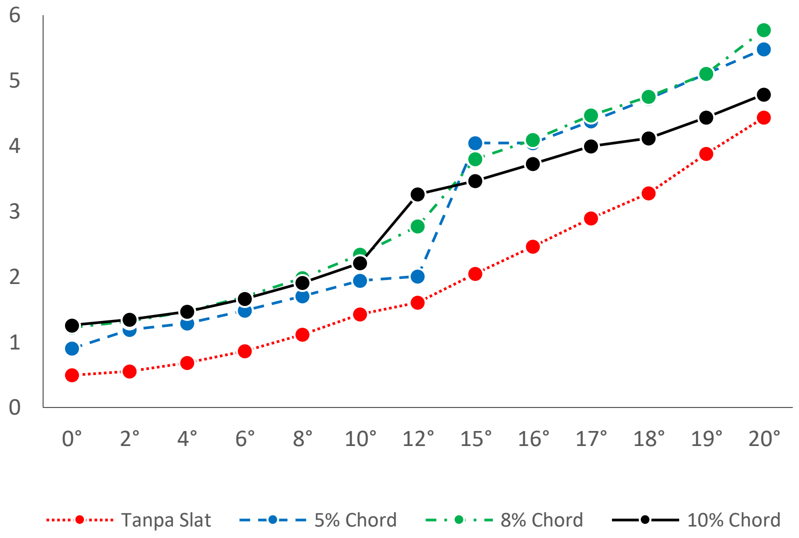

Figure 4. Coefficient Drag Chart Against Angle of Attack

3.2 Coefficient Lift

The following is a graph of the coefficient of Lift Airfoil NACA 23018 with 13 variations of angle of attack 0º, 2º, 4º, 6º, 8º, 10º, 12º, 15º, 16º, 17º, 18º, 19º and 20º here can be seen performance comparison on variations in slat distance (slat clearence) 5% chords, 8% chords, and 10% chords compared to Airfoil NACA 23018 without slot slat slot . From the graph, it can be seen that the variation of the NACA 23018 airfoil with a slat clearence of S = 10% chords is able to produce the highest lift coefficient value (CL) as well as being the highest maximum value compared to other variations of CL 31.939765 [16] [17]. And it is stable to maintain the elevator in the absence of stalls until it reaches the angle of attack α = 20º. When the speed is 40 m/s the lift coefficient tends to be stable when the angle of attack is below 10º on the airfoil with or without slat, but when angle of attack is above 10º there is a stall on the airfoil without slat. After the NACA 23018 Airfoil was added slat, the graph experienced a significant increase in lift, and as the slat clearence increased , the lift coefficient increased [10].

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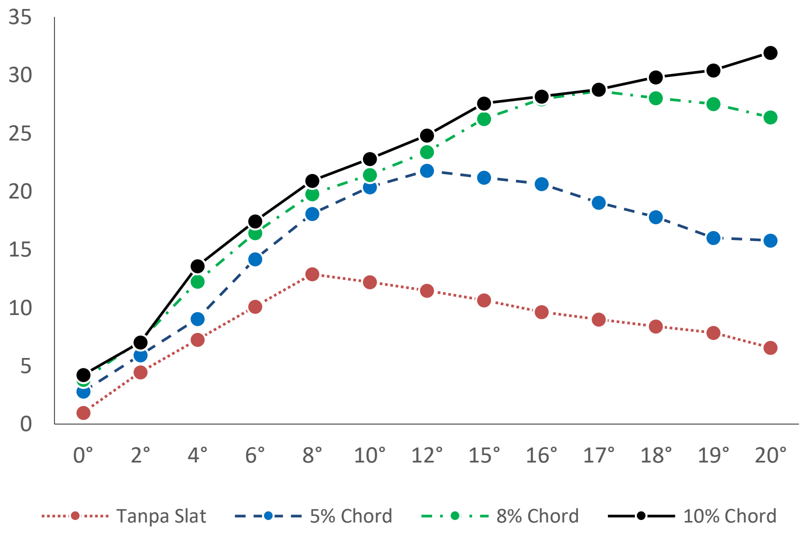

Figure 5. Coefficient Lift Against Angle of Attack Chart

3.3 Lift to Drag Ratio (C_L/C_D)

Figure 4.3 shows a graph between the lift to drag ratio of Airfoil NACA 23018 with 13 variations of angle of attack 0º, 2º, 4º, 6º, 8º, 10º, 12º, 15º, 16º, 17º, 18º, 19º and 20º on variations in slat distance (slat clearence) of 5% chords, 8% chords, and 10% chords compared to naca Airfoil 23018 without slat slots. The lift to drag ratio value rose rapidly on the 23018 naca airfoil with or without slat. However, this increase only persisted at the angle of attack of 8º, after which all airfoil variations experienced a decrease in the value of the lift to drag ratio except for the NACA 23018 airfoil with a slat clearence of 5% chord which actually increased to an angle of attack of 12º before finally dropping drastically. The overall variation of the NACA 23018 airfoil tested, was stable to experience a decrease in lift to frag ratio values at a speed of 40m/s [10] [20] [21].

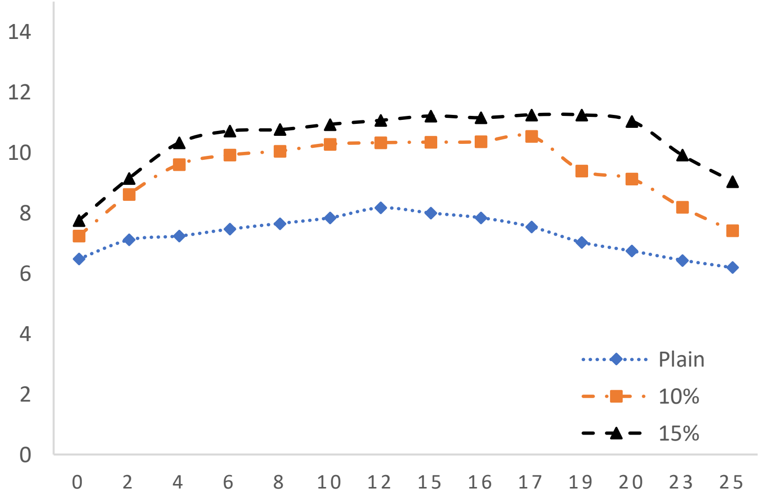

Figure 6. Lift to Drag Graphics Against the Angle of Attack

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From these data, it can also be concluded that the variation that has the highest performance is in the variation of airfoil without slat at the point (α = 0º to α = 8º) after that for an angle of attack above 8º it is proven that the best performance is shown by airfoil with a slat clearence of S = 10%. The drag coefficient also rises rapidly as the slat clearence rises when compared to airfoils without slats. At low angle of attack the addition of a slat with a certain slat clearence has helped to produce an additional lift resulting in an increase in the value of /. However, as the C_L/C_D angle of attack increases, the value / continues to decrease. C_L/C_D [10] [14] [21].

3.4 Velocity Magnitude Contour

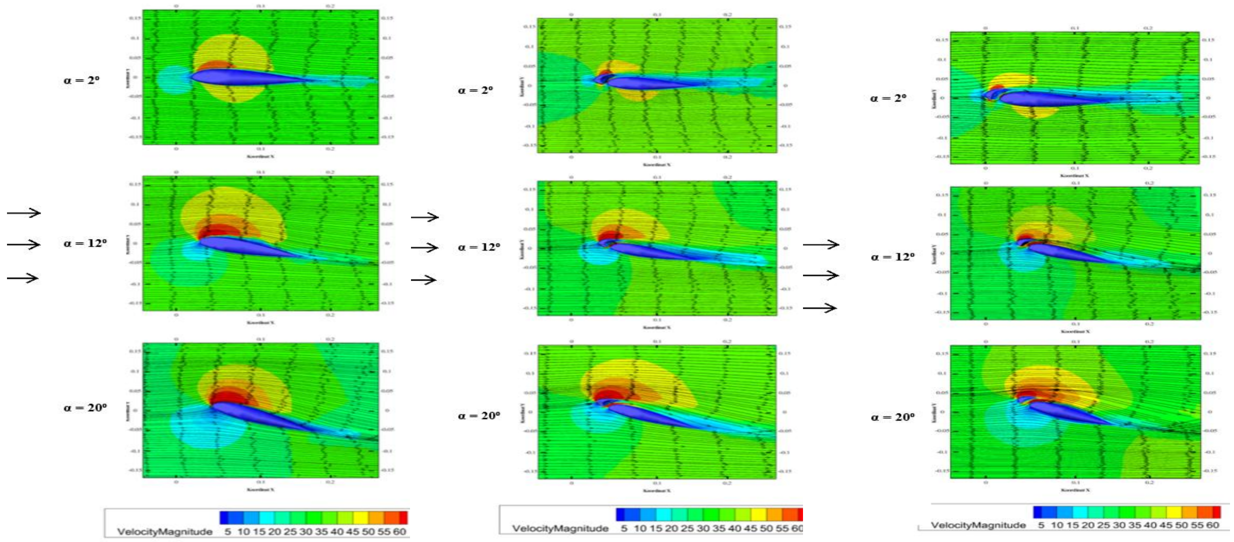

Figure 7. (a) Velocity Contour on NACA 23018 Airfoil Without Slat (b) Velocity Contour On Slat Clearence 5% (c) Velocity Contour On Slat Clearence 10%

In this section will be shown the scheme of taking the contours of the midspan cross section with a detailed review. The flow characteristics of the midspan need to be reviewed from the phenomenon of midspan flow. To see the large distribution of velocity in the area under review by looking at the contours of the velocity coefficient (velocity contour), from this it can also be seen regarding the stagnancy point and the separation point of the air flow passing through the surface of the airfoil. In this velocity contour [7] [10] [12], the freestream speed is 40 m/s with the greatest speed of about 96 m/s. In general, the color contours that appear on the upper surface of the airfoil are reddish, while on the lower surface they are bluish. This means that a higher airflow speed occurs on the upper surface of the airfoil.In the picture, it can be seen that there is a change in the color gradation on the velocity contour that occurs in the NACA 23018 Airfoil without slats and by using slats, along with the change in the angle of attack on each slat clearence. In variations without slat (α = 0º) there is a difference in contour color that is not too sigifikan and even tends to be flat yellowish green even though there is a slight yellow to orange contour. This indicates that there is a not too large pressure difference between the upper surface and the lower surface of the airfoil, so that the efficiency value of the resulting lift is not maximum or low [10] [14] [21].

3.5 Coefficient Pressure Contour

The scheme of data retrieval for the pressure coefficient contours (Cp) on the upper surface of the NACA 23018 airfoil, both without and with slats, is an essential part of understanding the aerodynamic behavior of the airfoil. The pressure contours were obtained for variations of slat clearance at S = 5%, 8%, and 10% of the chord length. The analysis was performed from the perspective of the x and z axes to better understand the flow dynamics around the wing. In these simulations, the maximum pressure value is represented by a red contour, while the minimum pressure value is denoted by a blue contour, as per the findings in previous studies [21][22]. The results from the simulations of the NACA 23018 airfoil, both without slats and with slats, show a clear distinction in the pressure distribution. The pressure distribution on the upper surface of the airfoil indicates the presence of blue areas, which are indicative of low-pressure regions, particularly around the leading edge and fixed slat areas. These low-pressure zones are consistent with the behavior expected when the airfoil experiences high angles of attack or flow separation. As the flow moves toward the trailing edge, the pressure increases, reaching its maximum at the rear of the airfoil. This distribution suggests that the areas around the leading edge and fixed slat are subjected to lower pressures compared to other regions of the airfoil. Furthermore, the analysis reveals an increase in the pressure difference between the leading and trailing edges, as well as between the top and bottom surfaces of the airfoil. This pressure gradient is a key factor in the generation of lift, as it indicates a greater aerodynamic force on the upper surface of the airfoil compared to the lower surface. The simulations also show signs of airflow separation, which is evident from the irregular changes in the pressure contour patterns on the left side of the wing. This is especially noticeable in the airfoil configurations without slats. These findings are supported by the calculation of the lift coefficient (C_L), which shows a decrease in lift as a result of the flow separation event. Overall, the data retrieval and analysis of the pressure coefficient contours provide critical insights into the flow phenomena around the NACA 23018 airfoil. The addition of slats alters the pressure distribution, particularly around the leading edge and slat areas, which helps to delay flow separation and improve the overall aerodynamic performance of the airfoil. The results highlight the importance of slat clearance in optimizing the lift characteristics and controlling flow separation, which in turn influences the overall efficiency of the wing design.

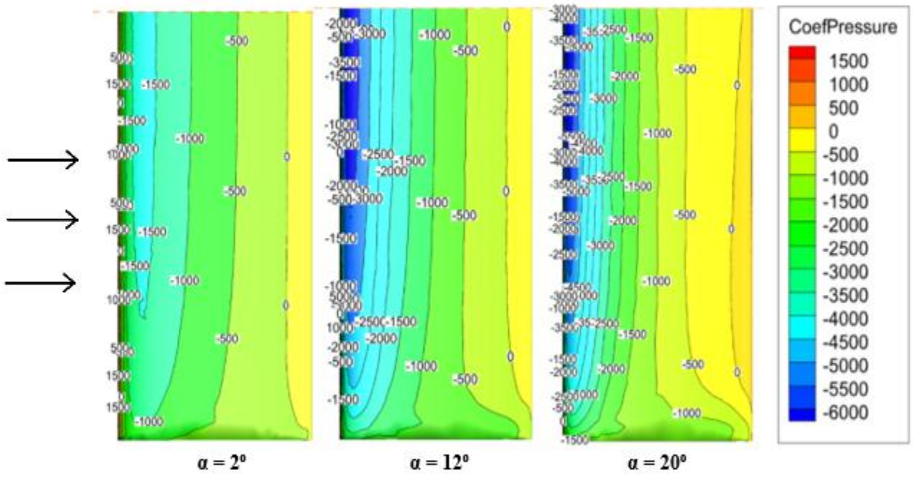

Figure 8. Coefficient Pressure Without Slat

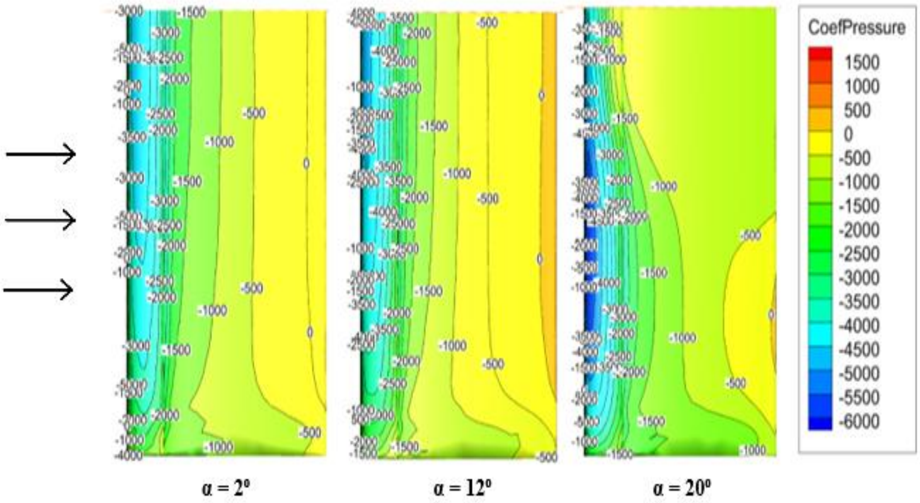

Figure 9. Coefficient Pressure On Slat Clearence 5%

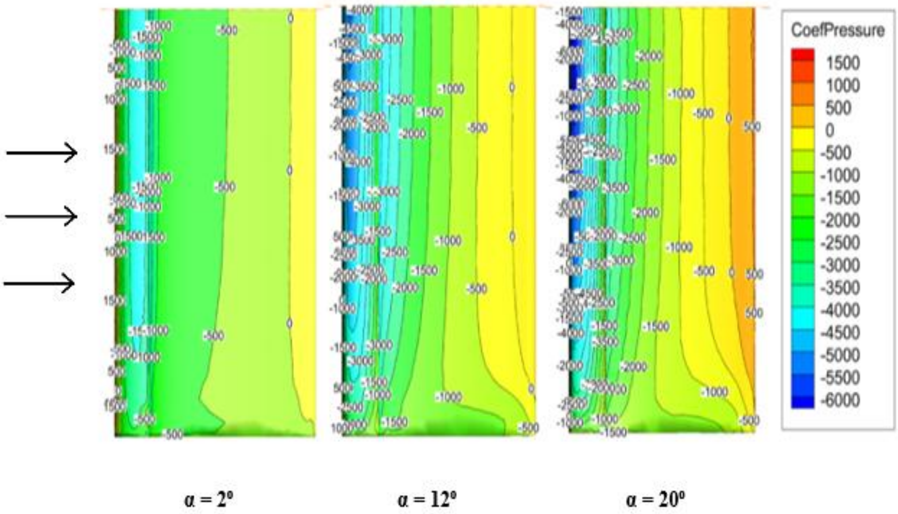

Figure 10. Coefficient Pressure On Slat Clearence 10%

4. Conclusion

In conclusion, the addition of slats and slots to the NACA 23018 airfoil significantly enhances its aerodynamic performance, particularly in terms of lift and flow separation control. The lift coefficient (C_L) increases with slat clearance, with the highest value observed at a clearance of S = 10% at a high angle of attack (α = 20º), while the lowest lift occurs in airfoils without slats at low angles of attack. Although the drag coefficient (C_D) steadily increases with slat clearance, the most stable increase occurs at S = 8%. Furthermore, the addition of slats improves the lift-to-drag ratio (C_L / C_D), especially at low angles of attack, where the slats induce higher lift. Pressure contours show notable changes, particularly around the leading edge and upper surface, with a decrease in flow separation as slat clearance increases. The most effective configuration, demonstrating no flow separation at high angles of attack (α = 20º), occurs at a slat clearance of S = 10%, indicating the optimal performance of the airfoil with this modification.

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