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Aerodynamic Performance Analysis of swept Back Wing with Winglets using CFD

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Abstract

The study begins by establishing the fundamental principles of aerodynamics and the importance of winglet design in modern aircraft. Using advanced CFD software, the analysis involves modeling a representative wing both with and without winglets, and simulating different flight conditions and angles of attack. The CFD simulations provide valuable insights into the flow patterns, pressure distributions, and lift-to-drag ratios, allowing for a comprehensive evaluation of the winglets' effectiveness. The results of this CFD analysis offer critical data for optimizing winglet design and configuration. The project aims to provide recommendations for the integration of winglets into existing aircraft designs, highlighting their potential to enhance performance, reduce fuel consumption, and contribute to a more sustainable aviation industry. This research contributes to the ongoing efforts to improve the environmental impact and efficiency of air travel, making it a relevant and significant subject of study in the field of aeronautics.

Keywords
CFD, Swept Back Wing, Aerodynamics, Winglets

I. INTRODUCTION

Computational fluid dynamics (CFD) is a crucial tool in contemporary aerospace engineering, enabling precise determination of various parameters without the need for material expenses. This technology is used to assess the performance of different aerospace components under various conditions [1]. Models like the shear stress transport k-omega (SST k-omega) and k-epsilon are used to examine various aspects of a wing under different flow conditions. Post-processing techniques help identify the locations and magnitudes of stresses, pressures, temperatures, and other relevant metrics. In this study, we focus exclusively on the CFD analysis of a swept-back wing with an SC(2)0612 airfoil [2]. When an aircraft produces thrust, altering the inertia of its wings, the air splits at the leading edge of the wing. It flows over and under the wing at different speeds, reconverging at the trailing edge. So the curved upper surface of the wing accelerates the airflow, creating a low region. Also quite the reverse, the air flowing beneath the wing travels in a straight line over the flatter surface, maintaining the same speed and pressure. The air above the wing does not always exceed the speed of sound. Initially, it attains supersonic speeds before decelerating. As air flows over the wing, it generates pressure waves moving at the speed of sound, creating a buildup of pressure known as a shock wave, which generates drag [3]. This pressure boundary saps energy from the airflow, contributing to drag. Additionally, energy loss can cause the airflow to separate from the wing, further increasing drag. Sweeping the wing backward delays the onset of supersonic flow by reducing air acceleration over the wing. Winglets, which are vertical or angled extensions at the wing, help reduce lift-induced drag caused by wingtip vortices from the third-direction flow due to flow separation over the wing surface. Winglets increase the wing’s aspect ratio without significantly increasing structural weight [4-6].

While increasing the wingspan can also reduce lift-induced drag, it leads to higher pressure and profile drag, as well as increased wing weight. Lift-induced drag can constitute up to 40% of total drag, significantly impacting fuel consumption. Therefore, adding winglets is a more efficient solution to increase the aspect ratio and reduce lift-induced drag. This study focuses on reducing lift-induced drag by attaching various winglet shapes raked, blended, split, and fence - to the main wing tips, which help mitigate vortex generation. In this work, the SC(2)0612 airfoil is used as the base wing. The analysis is conducted at Mach numbers of 0.5, 0.7, and 0.9, corresponding to velocities of 171.60 m/s, 240.24 m/s, and 308.88 m/s, respectively. Computational results are compared with the performance of the base wing without winglets to evaluate the effectiveness of different winglet designs in reducing lift-induced drag [7].

II. LITERATURE STUDY

Literature study gives to assess the performance of various standard and experimental wing tip devices on aircraft wings using modern supercritical airfoil geometry. For comparison, a similar analysis is conducted on a wing with traditional cambered airfoils, the original basis for winglet development [1-5]. The supercritical wing design is modeled after the Airbus A320, while the conventional airfoil is based on the reference platform. Traditional aircraft feature a streamlined body with two wings. Designers focus on enhancing efficiency by reducing fuel consumption and increasing speed [6]. This goal is primarily achieved by minimizing drag forces acting on the aircraft. Induced drag, created at the wingtip due to air separation between the upper and lower surfaces, is a significant concern. This study calculates lift and drag coefficients with and without winglets attached to the wingtip. This academic research project aims to provide a comprehensive overview of supercritical airfoils and their applications, referencing the Airbus-777 series and other commercial aircraft [7]. The scope includes using a variable camber approach to improve the lift coefficient of the SC(2)-0714 airfoil by iterating and modifying the trailing edge angle through simulations. Shape memory alloys (SMAs) offer new possibilities for designing and optimizing winglets with variable sweepback angles due to their shape memory effect. This study examines the aerodynamic performance of various winglets with adjustable sweepback angles during three flight phases of a large civil aircraft: take-off, cruise, and landing, using computational fluid dynamics (CFD). From the optimal sweepback angles found are 35°, 45°, and 50°, respectively [8]. Winglets are added to wingtips to improve efficiency of aircraft by minimizing induced drag from vortices formed on wingtip. These vertical or angled extensions enhance the effective aspect ratio of the wing without greatly increasing the structural stress or weight [9-10].

III. METHODOLOGY

The numerical simulation of fluid flow involves a structured process comprising four main steps. First, the problem is identified by setting the modeling objectives and positioning the model within the domain. Next, in the pre-processing stage, an airfoil model is created and the meshing configuration is established. The solver phase follows, where the physics of the flow (e.g., turbulent or laminar) is represented, appropriate boundary conditions are applied, and various numerical strategies are employed to discretize the governing equations. Convergence is checked through iterative processes until the desired precision is achieved, and the solution is determined using solver settings, including initialization, solution control, and monitoring. Finally, in the post-processing stage, the results are analyzed and presented using graphical diagrams, contours, and detailed reports.

MODELLING

The airfoil we used is supercritical series named SC(2)-0612.According to the specification the data been collected from the A320 manual.The wing is drawn on catia v5 according to the specification.

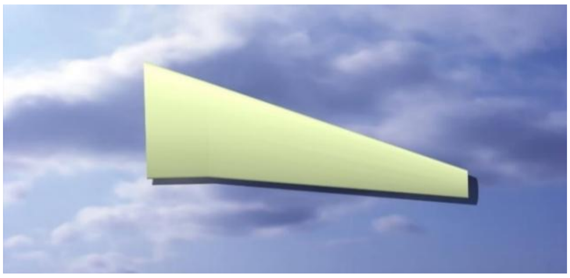

Figure 1 Wing Without Winglet

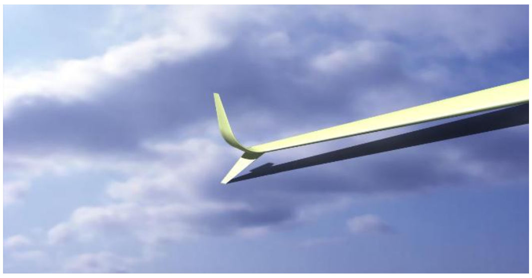

Figure 2 Wingtip Fence

Figure 3 Blended Winglet

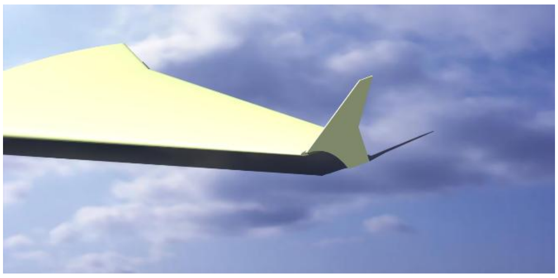

Figure 4 Wingtip Fence

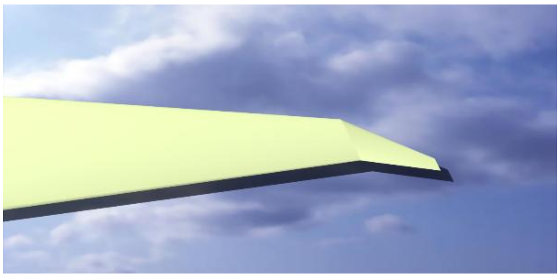

Figure 5 Raked Winglet

IV. RESULTS AND DISCUSSION

This experiment goal is to measure lift and drag coefficient for the wing which don't have winglet and which have different type of winglets like blended, raked, split and wingtip fence for different mach number (0.5,0.7,0.9).

Mach Number to Coefficient of Lift

With the change of different mach number how Coefficient of lift changes is illustrated on fig 6. Lift Coefficient is higher on the wing has blended and raked winglets. And the remaining winglets like wing without winglets and split and wingtip fence are giving less lift compare to other winglet that is illustrated in fig 6.

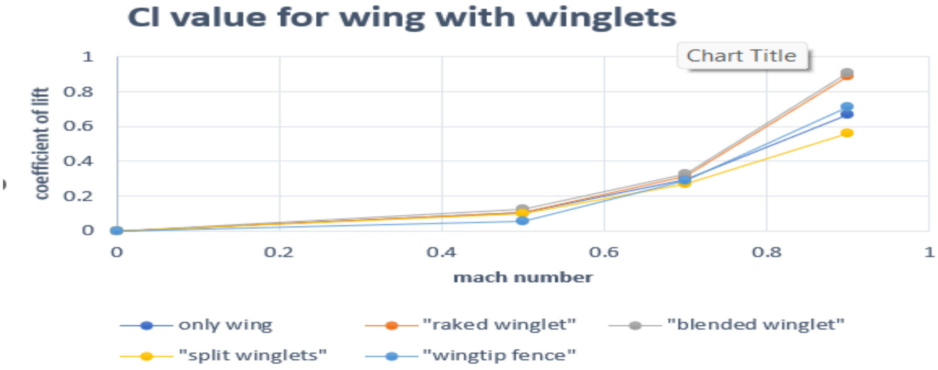

Figure 6 Cl Valves for Wing and with Winglets

Mach Number with Coefficient of Drag

By the change of different mach number how Coefficient of drag changes is illustrated on fig7.Drag Coefficient is higher on the wing has blended winglets.And the remaining winglets like wing without winglets and split and wingtip fence and also raked winglet are giving less lift compare to other winglet that is illustrated in fig 7.

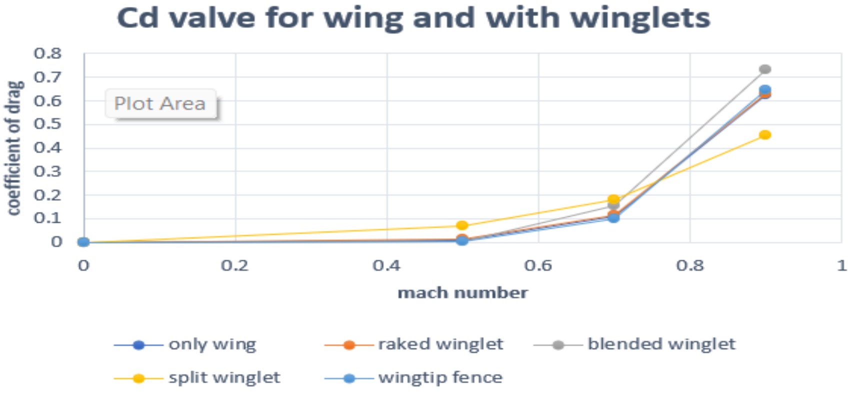

Figure 7 Cd Valve for Wing and with Winglets

Pressure Contour

Pressure contour of the wing and different winglets in below figures. The top surface is having a lower static pressure then bottom surface. The high intensity blue area on the surface having a minimum static pressure and bottom surface red region is maximum static pressure this pressure gradient is responsible for lift generation.

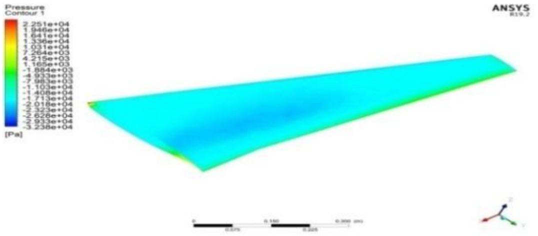

Figure 8 Only Wing (for M=0.5)

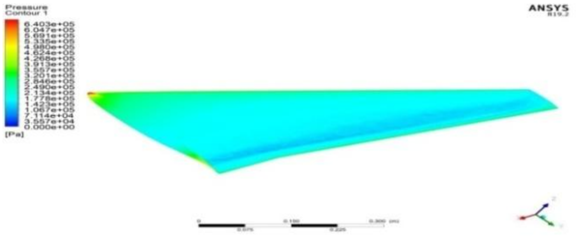

Figure 8.1 Only Wing (for M=0.7)

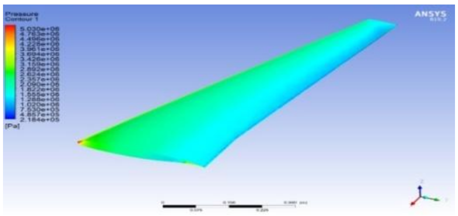

Figure 8.2 Only Wing (for M=0.9)

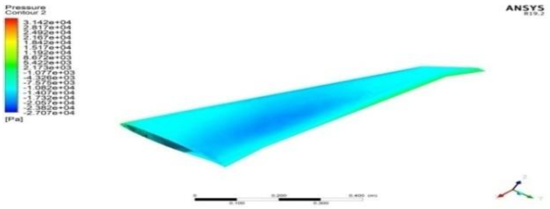

Figure 9 Ranked Winglet (for M=0.5)

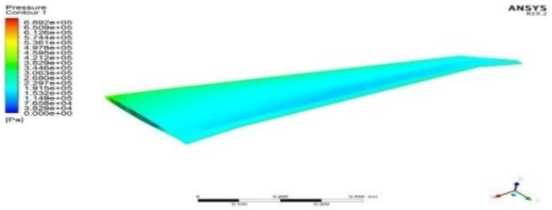

Figure 9.1 Ranked Winglet (for M=0.7)

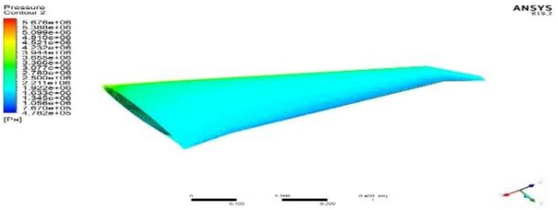

Figure 9.2 Ranked Winglet (for M=0.9)

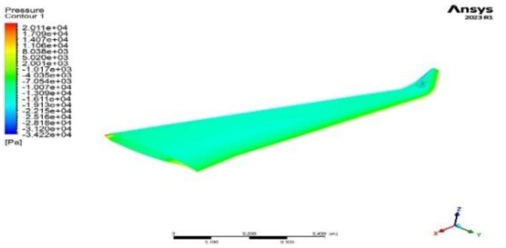

Figure 10 Blended Winglet (for M=0.5)

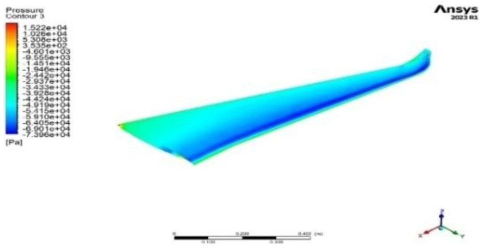

Figure 10.1 Blended Winglet (for M=0.7)

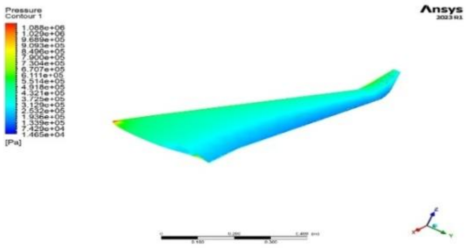

Figure 10.2 Blended Winglet (for M=0.9)

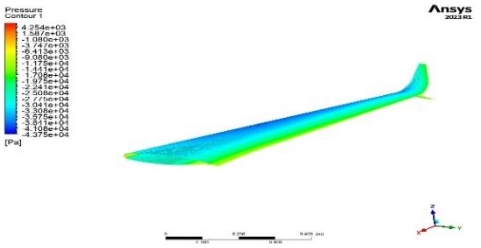

Figure 11 Split Winglet (for M=0.5)

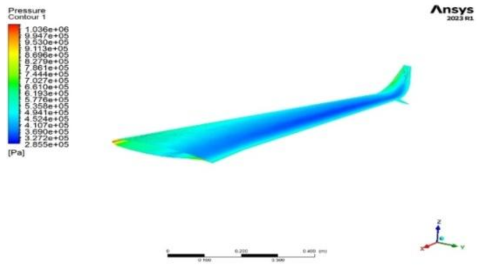

Figure 11.1 Split Winglet (for M=0.7)

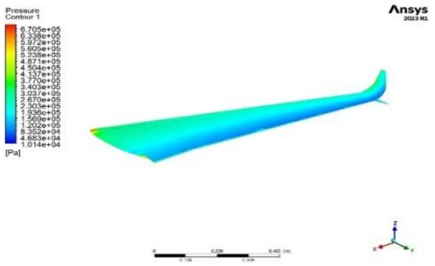

Figure 11.2 Split Winglet (for m=0.9)

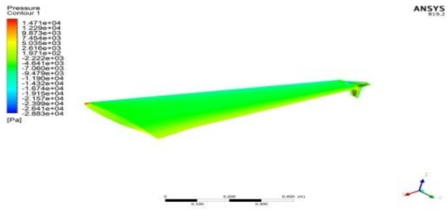

Figure 12 Fence Winglet (for M=0.5)

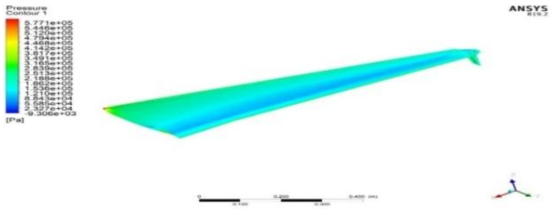

Figure 12.1 Fence Winglet (for M=0.7)

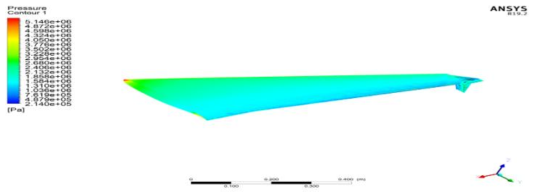

Figure 12.2 Fence Winglet (for M=0.9)

V. CONCLUSION

After completion of the analysis, we can conclude the most aerodynamic efficient design of the winglet by comparing each other. Adding winglet is efficient when Airplane is cruising because the wing with winglet creates less drag and less negative lift. From the simulation's results we can say that the induced drag is reduced with the use of winglet. the wing which doesn't have winglet produce higher drag force than the wing which have winglet. And also, the wing which doesn't consists of winglet produce lesser lift force than the other have the winglet .when the Airplane is cruising higher will be the velocity a wing with winglet produces higher lift comparatively higher lift than the other doesn't have the winglet. It is efficient to use winglet to reduse the drag and it will also increases the efficiency of the airplane.

VI. REFERENCES

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