CFD simulation over a Hook Winglet configuration

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Abstract - *The importance of winglet design in aerodynamic engineering, particularly in addressing the challenge of drag reduction and enhancing aircraft performance has been highlighted. Through the utilization of CATIA-V5 for design and ANSYS for simulation, various winglet configurations were analyzed, revealing distinct efficiencies. The findings emphasize the critical role of winglets in improving fuel efficiency, minimizing drag, and prolonging engine life, with the hook-shaped winglet demonstrating the highest effectiveness. This research underscores the significance of selecting optimal winglet designs to maximize aerodynamic performance and operational efficacy in the aviation industry.*

Key Words: **Winglet, Computational Fluid Dynamics, Hook, Wingtip vortex, Aircraft, Induced drag etc.**

1.INTRODUCTION

A winglet is a device used to enhance the performance of aircraft via lowering the lift induced drag as a result of wingtip vortices. It is a vertical or angled extension at the recommendations of each wing. Winglets improve efficiency with the aid of diffusing the shed wingtip vortex, which in flip reduces the drag due to lift and improves the wing's lift over drag ratio. Winglets increase the effective aspect ratio of a wing without adding significantly to the structural stress and subsequently important weight of its structure.

Winglets boom a plane's operating efficiency with the aid of lowering what is called induced drag at the tips of the wings. An airplane's wing is formed to generate negative pressure on the upper surface and positive pressure on the lower surface as the aircraft moves forward. This unequal pressure creates lift across the upper surface and the plane can go away the ground and fly.

Winglets, which are airfoils operating much like a sailboat tacking upwind, produce a forward thrust inside the circulation field of the vortices and decrease their strength. Weaker vortices suggest less drag at the wingtips and lift is restored. Improved wing efficiency translates to greater payloads, reduced fuel consumption, and an extended cruising range which can allow an air carrier to enlarge routes and locations.

Due to the overall acknowledgement of world warming, the aviation enterprise, along with many other transport industries are confronted with increasingly stricter emission regulations from government agencies around the arena to lessen the carbon footprints of future aircraft. Consequently, in today's world of aviation, winglets are typically meant to increase the overall aerodynamic efficiency of aircrafts. They reduce the vortices generated along the surface of the wing via lowering the pressure gradient at the tip of the wing, hence equalizing the pressure difference between the upper and lower surface of the wing and minimizing the magnitude of the vortices generated at some point of flight. This translates to reduced drag and higher average gasoline economic system without requiring any drastic changes of an aircraft's structure elsewhere. However, various designs may also provide different grades of performance depending on the physical dimensions, wing form and flight characteristics of the aircraft.

The idea of attaching wingtip devices to the wing dates to the end of the 20th century. Several experiments and studies were completed with few fixed-wing aircrafts, but it become no longer until the 1970s during the oil crisis that the idea got re-enlightened and commercialized among aircraft manufactures and aviation agencies.

Winglets, along with other wingtip devices can be considered a mainstream element among subsonic and transonic contemporary aircrafts. They are seen in various aircraft sizes, ranging from small sized piston props to large jet propelled transonic and supersonic jets.

2. CONFIGURATION DETAILS

In this paper B737A, B737C and B737D are the airfoils chosen for root section, mid span and tip, as it is ideally suited to any environment where speed is important. They are shown in figure 1, 2 and 3 below.

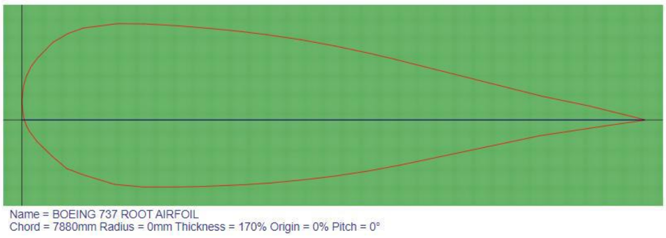

Fig -1: B737A Root Airfoil

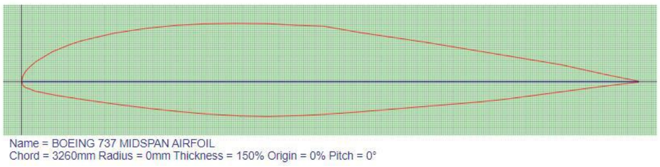

Fig -2: B737C Mid Airfoil

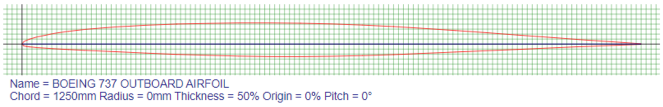

Fig -3: B737D Tip Airfoil

3. COMPUTATIONAL DESIGN

CATIA tool has been used to do the computational design of hook winglet as shown in figure 4 and table 1. The aircraft Wing has been considered as tapered as it gives more lift at high speed.

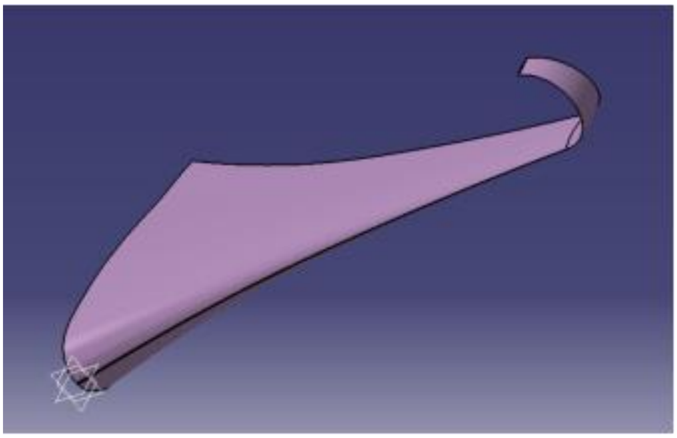

Fig -4: Three dimensional view of hook winglet

Table -1: Geometric characteristics of hook winglet

Root Chord Length	1250 mm
Tip Chord Length	600 mm
Winglet tip Airfoil distance from wing root	16000 mm
Height of hook winglet	2400 mm
Radius of hook winglet	1199 mm

4. MESH GENERATION

Unstructured meshes are meshes with general connectivity whose structure is arbitrary and consequently the connectivity of elements must be defined and stored. The element types are non-orthogonal, including triangles (2D) and tetrahedra (3D). The boundary conditions used are shown in below table 2. In this paper, Ansys-Fluent tool has been used to create mesh and to solve the governing equations.

Table -2: Boundary conditions

Inlet	Velocity Inlet
Outlet	Pressure Outlet
Wing	Wall
Wall	Wall

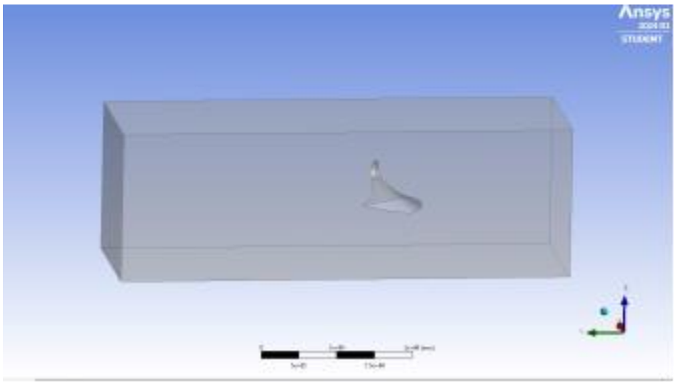

Fig -5: Domain of hook winglet

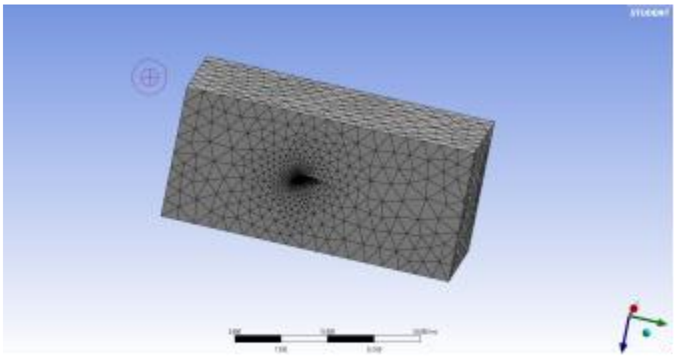

Fig -6: Mesh generation over hook winglet

5. RESULT AND DISCUSSION

CFD simulation has been carried out over the hook wiglet model using Ansys-Fluent tool. In CFD, the k–omega turbulence model is a common two-equation turbulence model which is used as an approximation for the Reynolds-averaged Navier–Stokes equations (RANS equations). The model attempts to predict turbulence by two partial differential equations for two variables, k and ω, with the first variable being the turbulence kinetic energy (k) while the second variable omega (ω) is the specific rate of dissipation. The CFD simulation was carried out using k-omega turbulence model and for the given temperature of 300 k and Mach number of 0.52.

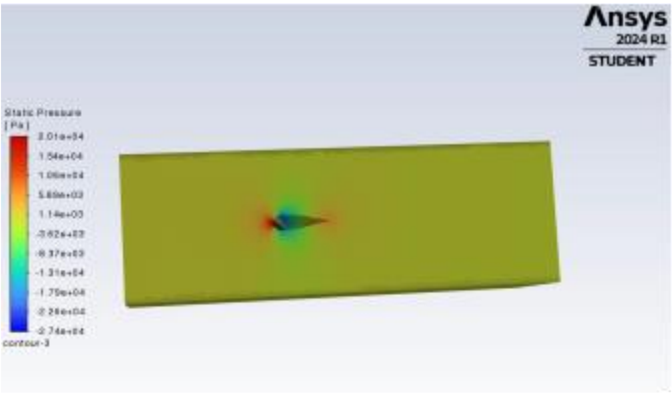

Fig -7: Pressure contour of hook winglet

From the pressure contour plot of hook winglet, as shown in figure 7, there is more static pressure at the leading edge of the wing due to the stagnation point. The flow over the wing at the tip section created more vertices. The pressure acts less at the middle of the wing, while the pressure at the trailing edge of the wing creates more due to flow separation.

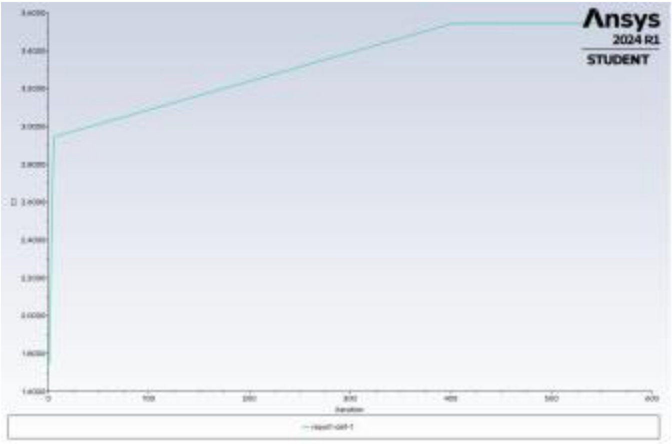

Fig -8: Lift coefficient plot of hook winglet at zero AOA

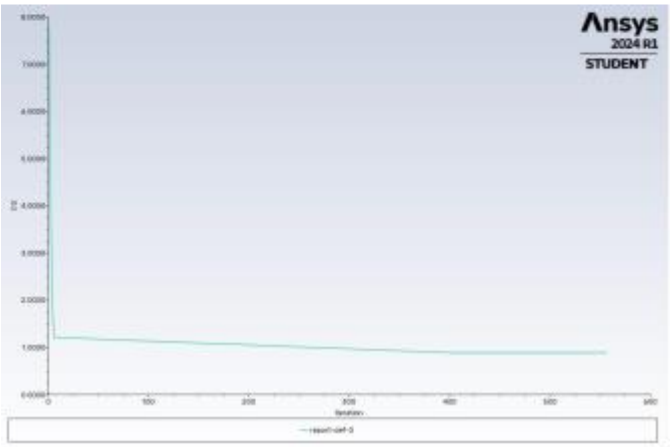

Fig -9: Drag coefficient plot of hook winglet at zero AOA

As shown in figure 8 and 9 above, the coefficient of lift and coefficient of drag are unsymmetrical at zero angle of attack. At zero angle of attack, the coefficient of lift values is quite higher.

6. CONCLUSION

The results revealed that the hook winglet design significantly outperformed by effectively minimizing drag, reducing wing-tip vortices, and improving overall aerodynamic efficiency. These findings highlight the substantial impact of winglet selection on aircraft performance and operational efficacy. Thus, the optimal integration of winglets, particularly hook winglet designs, holds great promise for realizing significant fuel savings, enhancing flight stability, and prolonging engine life, thereby advancing the efficiency and sustainability of aviation operations. Overall, the results highlight the critical role of winglet design in optimizing aircraft performance and efficiency, with the hook winglet configurations emerging as the most effective solutions for drag reduction and fuel savings.

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