Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 1 (2024)

Analyzing the Impact of Winglets on Twin-Engine Turboprop Transport Aircraft Wing using XFLR5

[1]Deepankar Chandra, [2]Anadi Misra
[1] *Research Scholar Dept. of Mechanical Engineering GBPUAT Pantnagar India*
[2] *Professor Dept. of Mechanical Engineering GBPUAT Pantnagar India*

Abstract: - Ongoing advancements in aircraft wing design aims to enhance wing efficiency, particularly by optimizing wing shape and minimizing induced drag through the incorporation of Winglets. This study investigates the impact of adding winglets to the wings of a Twin-engine Turboprop transport aircraft (ATR 72). The primary function of winglets is to improve wing's aerodynamic efficiency, resulting in reduced induced drag and an enhanced ratio between lift and drag coefficients. Using XFLR5 software, the ATR 72 aircraft wing was modeled with varying cant angles for the winglets (0°, 30°, 60°, and 90°). Test results reveal that the wing modification with winglets is most effective at a cant angle of 90°, achieving the lowest induced drag at wingtips. The optimal D_i value is observed at an angle of attack of 90º, reaching 24.728.

Keywords*: Winglets, Induced-Drag, Cant angles, XFLR5*

1. Introduction

The escalating costs of aviation fuel and the pressing environmental concerns, such as global warming, have compelled aircraft manufacturers and airlines to explore solutions for improving the environmental impact of aviation. Enhancing aircraft fuel efficiency, particularly in terms of fuel consumption per seat-mile, is a crucial objective. One prominent technology addressing this challenge is the application of winglets—small fins or vertical extensions at wingtips. These winglets mitigate induced drag caused by wingtip vortices, thereby enhancing the lift-to-drag ratio (L/D) and overall aircraft efficiency.[1,2]

Originating in the late 1800s with Frederick W. Lanchester's "endplates" concept, winglets evolved significantly. Dr. Richard Whitcomb's experiments in 1974 on a Boeing KC-135A aircraft demonstrated the potential benefits of vertical fins at wingtips. However, conventional winglets primarily optimize drag reduction and L/D under cruise conditions, neglecting non-cruise phases like take-off and landing. Recent research focuses on innovative winglet designs, including spiroid winglets, sharklets, and controllable, articulating, or blended concepts. Boeing's patented controllable winglets using Shape Memory Alloys and the idea of multiple winglets recycling trailing vortices' energy exemplify these efforts. Spiroid winglets, pioneered by Aviation Partners, exhibit promising drag reduction compared to blended winglets. In summary, ongoing research aims to maximize aircraft efficiency and optimize performance across various flight conditions, encompassing both cruise and non-cruise phases.[3,4]

XFLR5 stands as a comprehensive analysis tool employed in aeronautical engineering for the calculation of aerodynamic properties related to wings. This tool utilizes various analytical methods, including Lifting Line Theory, Vortex Lattice Method, and 3D Panel Method, to provide a thorough examination of the aerodynamic behavior of wings. Complementing XFLR5 is XFoil, an additional analysis tool specifically designed for the evaluation of airfoil aerodynamics. The synergy between XFoil and XFLR5 is integral, as these tools collaboratively offer a comprehensive analysis package. Their combined capabilities enable the detailed assessment of external flows around basic airfoils, wings, and entire airplanes. By seamlessly working together, XFoil and XFLR5 provide engineers and researchers with a powerful set of tools for understanding and optimizing the aerodynamic performance of aeronautical components and configurations.[5-7]

2. Objectives

The objectives of this research involves a multifaceted investigation into the induced drag characteristics of the NACA 23015 wing, both without winglets and with the integration of various winglet designs. The initial phase focuses on assessing the baseline induced drag using XFLR5 and employing Lifting Line Theory, Vortex Lattice Method, and 3D Panel Method for a comprehensive aerodynamic analysis. Subsequently, winglets are introduced to the NACA 23015 wing using XFLR5, aiming to evaluate their impact on induced drag reduction. Different winglet designs and configurations are explored to identify optimal solutions for enhancing overall aerodynamic efficiency. Utilizing XFLR5, a detailed analysis of the aerodynamic properties of the wing with winglets is conducted, including changes in lift-to-drag ratio and lift distribution. The study also investigates into the optimization of winglet configuration called cant angle, to identify the most efficient position of winglet for induced drag reduction. Ultimately, a comparative analysis is performed, contrasting the induced drag reduction achieved with winglets against the baseline configuration i.e, without winglets, providing a comprehensive understanding of the benefits and trade-offs associated with the implementation of winglets on the NACA 23015 wing.

3. Methods

3.1. Modeling and Analysis in XFLR5:

In XFLR5, introducing an airfoil involves navigating to Direct Foil Design. Depending on the type or choice of aircraft, one can generate an airfoil by adjusting the existing spline, import an airfoil from a properly formatted ".dat" file, or choose an airfoil by entering its four or five-digit NACA identification number.

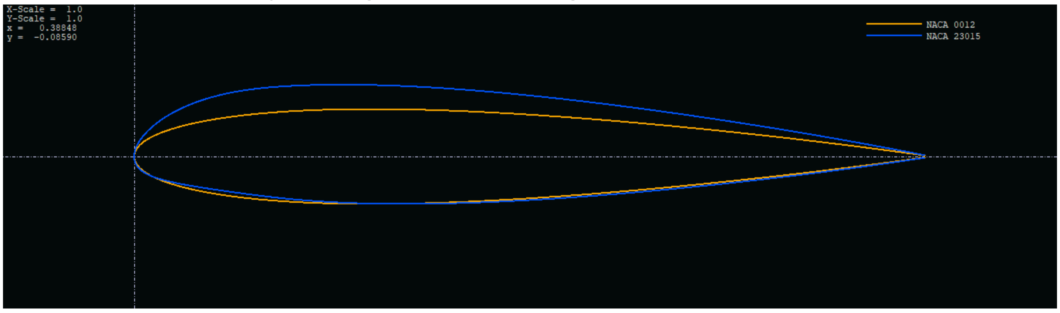

Figure 1. Xfoil direct foil design NACA 23015 and NACA 0012

After choosing an airfoil, (Figure 2.) its aerodynamics can be examined using Xfoil Direct Analysis. Running XFOIL Direct Analysis involved a systematic procedure to assess airfoil aerodynamics comprehensively. Choose the "XFoil Direct Analysis" option. Input the desired NACA 23015 and NACA 0012 airfoil coordinates. Specifying the analysis parameters like the Reynolds number (5x10^6) and Mach number (M = 0.63), to accurately represent the flow conditions. Then the XFOIL Direct Analysis was performed to compute the aerodynamic coefficients, such as lift and drag, across a range of Alpha (angles of attack) from -5 to 20 degrees. The tool provided a detailed analysis of the airfoil's performance, including polar plots and aerodynamic derivatives as shown in the Figure 2. and Figure 3.

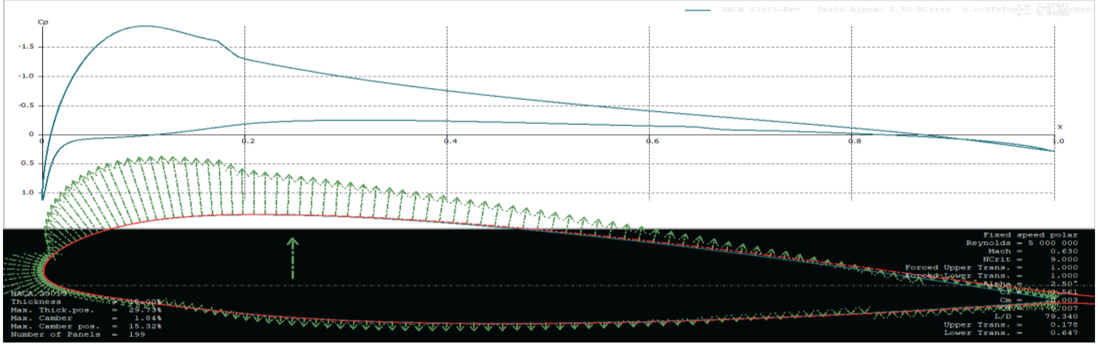

Figure 2. NACA 23015 Foil Analysis at Re = $5x10^6$

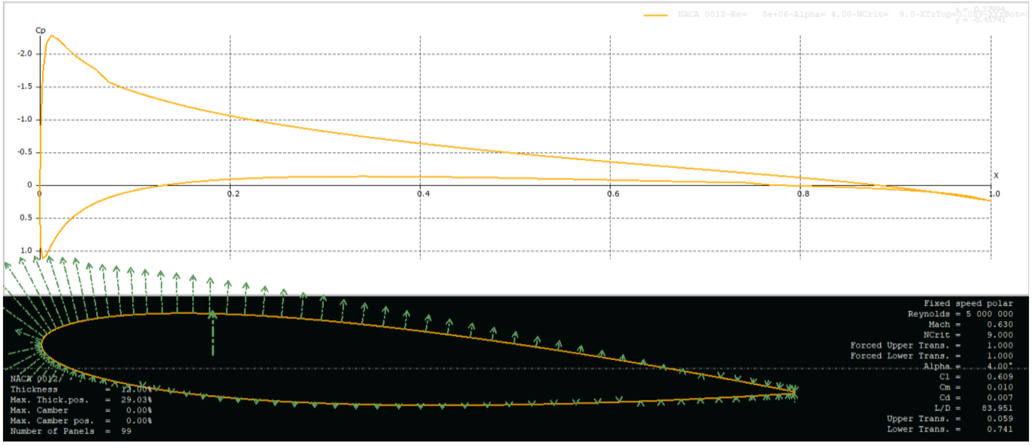

Figure 3. NACA 0012 Foil Analysis at Re = $5x10^6$

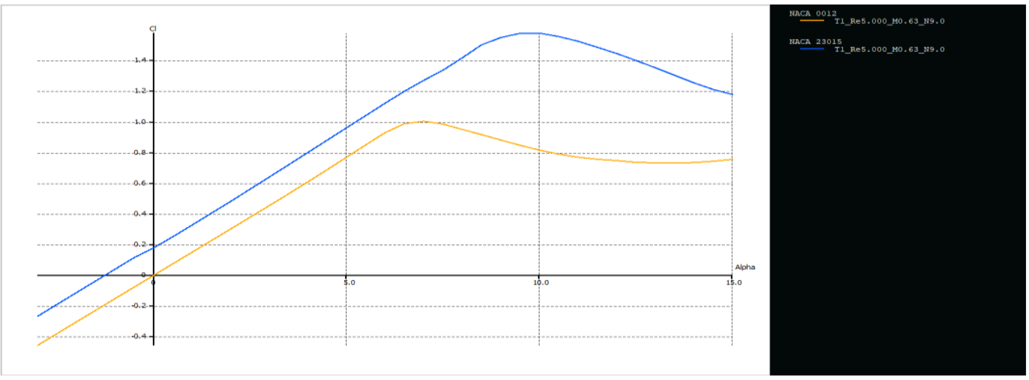

Figure 3. Cl Vs Alpha NACA 23015 and NACA 0012

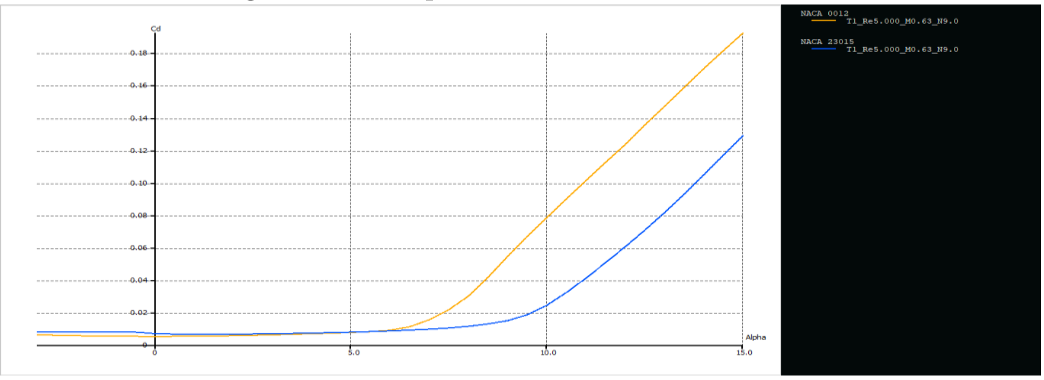

Figure 4. Cd Vs Alpha NACA 23015 and NACA 0012

After reviewing and interpreting the results, the insights were gained to inform further design considerations or optimization processes for enhanced airfoil performance in specific operating conditions. The Reynold's number range and angle of attack (alpha) range can be adjusted to align with the expected flight conditions of the selected wing of ATR 72 aircraft.
Following the completion of airfoil analysis, the wing can be generated within Wing and Plane Design by going to Plane, Define a New Plane. Although this menu allows for the creation of an entire airplane, the focus of this project is solely on the main wing design. So the boxes for elevator and fin can be left unchecked. Subsequently, the baseline wing model can be defined and generated based on the required parameters given in Table 1. of a twin turboprop transport aircraft (ATR 72), whish was extracted from [10]

Table 1. Baseline Wing Data

Airfoil at Root and Tip	NACA 23015
Wing Span	27.14 m
Wing Surface Area	55.64 m^2
Root Chord	2.6 m
Tip Chord	1.5 m
Aspect Ratio (AR)	13.24
Taper Ratio	1.73

The analysis of the wing, both with and without winglets, was conducted using XFLR5 involved configuring the airfoil and geometric parameters within XFLR5 to accurately represent the specified wing geometry of the selected aircraft wing. The simulation setup included the definition of boundary conditions, such as air density, temperature, and pressure, ensuring a realistic aerodynamic environment in aero data section of the software. The mesh generation process was employed to create a structured mesh around the wing, refining near the surface to capture boundary layer effects effectively.[11]

Table 1. Wing with Winglet Data

Airfoil at Root & Tip/ Winglet Section	NACA 23015/ NACA0012
Wing Span	30.52 m
Wing Surface Area	59.52 m^2
Root Chord	2.6 m
Tip Chord	1.5 m
Winglet Tip Chord	0.8 m
Aspect Ratio (AR)	15.65
Taper Ratio	3.25

For the analysis without winglets, the baseline wing geometry was used, and the simulation was run to determine aerodynamic coefficients, including lift, drag, span-wise load distribution, and bending moment along the wing. The chosen chord distribution, with a constant chord from the root to the middle section and linearly distributed to the tip, was applied as per the specifications shown in Figure 5. [9,12]

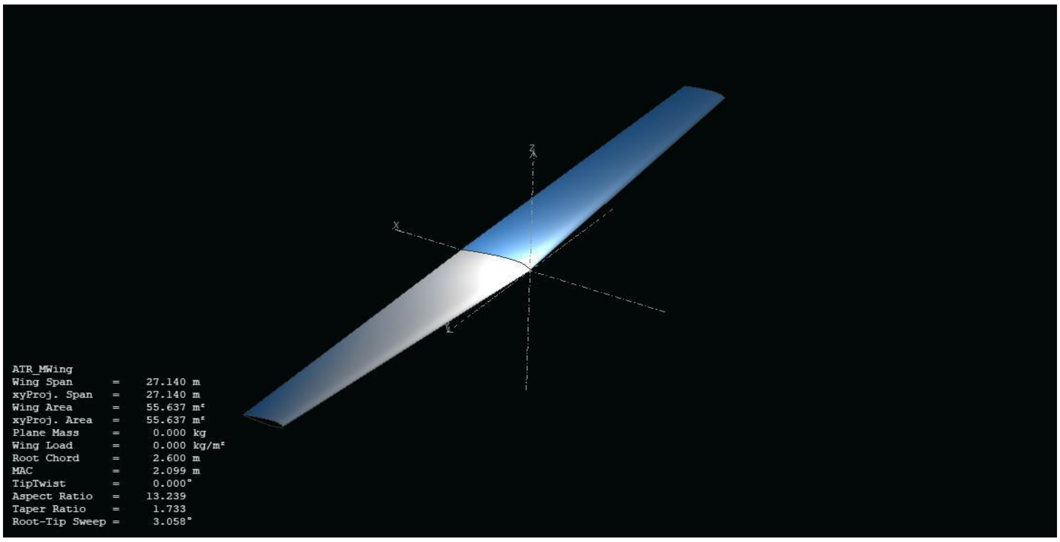

Figure 5. Baseline wing 3D model

To assess the impact of winglets, winglet configurations i.e, upward winglets fins inclined at various cant angles like 0°, 30°, 60°, and 90°, were introduced and systematically varied as shown in Figure 3 The simulations were then executed to investigate the aerodynamic performance of the wing with each winglet type. As shown in figure 6 [9,13]

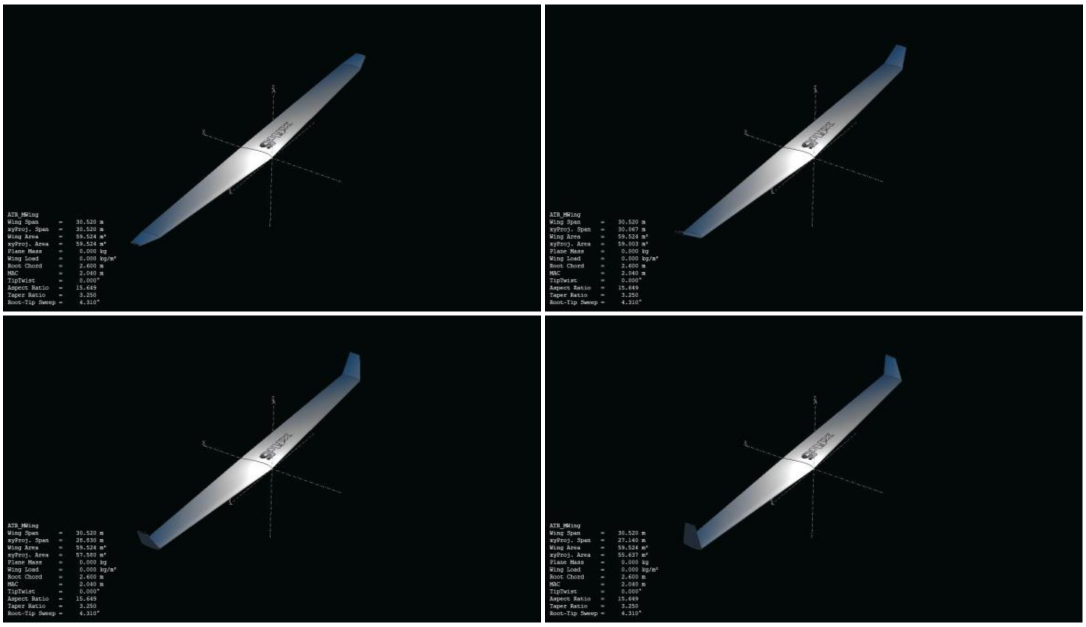

Figure 6. Wing with Winglets at Cant angles 0, 30, 60 and 90 degrees (Arranged Clockwise)

4. Results & Discussion

With the results of the analyzed through cuves shown in Figure 7 and 8, which were investigated at 59m/s takeoff speed and winglet cant angle at 0, 30, 60 and 90 degrees. The specific identification of the winglet at a 90-degree cant angle as the optimum configuration provides valuable guidance for practical implementation in aircraft design, offering a balance between induced drag reduction and overall performance.

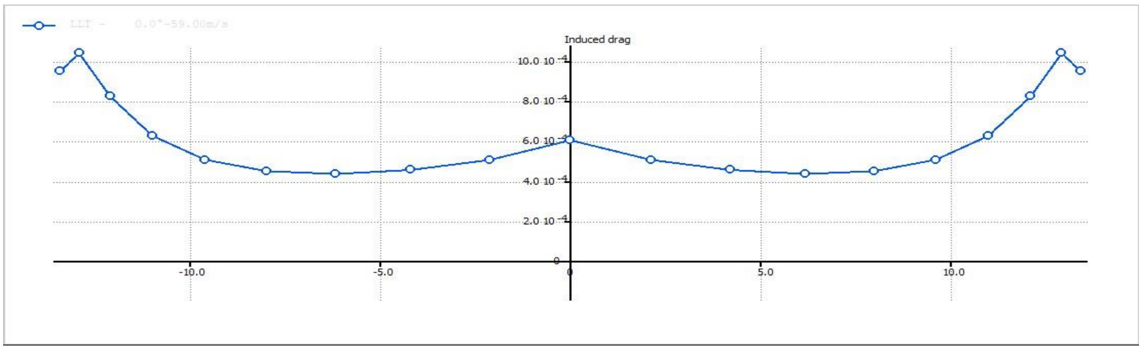

Figure 8. Induced Drag curve along the Wing span of the Baseline wing

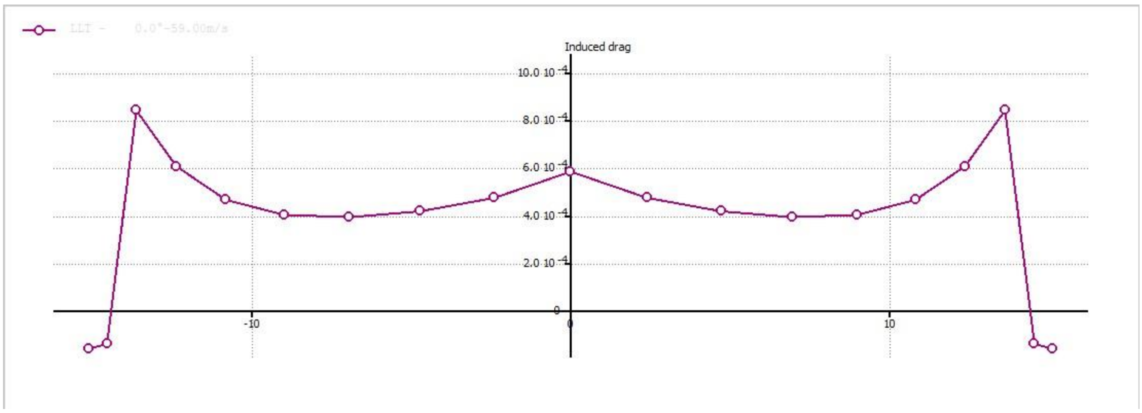

Figure 8. Induced Drag curve along the Wing span of the Wing with Winglet at 90^0

The comparative analysis between the baseline wing with and without winglets gave the insights, with the winglet configuration at a cant angle of 90^0 emerging as the optimum configuration for minimizing induced drag, particularly during takeoff conditions. The optimization process included variations in cant angle highlighted the critical role of parameter tuning in achieving the most efficient setup for induced drag reduction. [14] This specific fin type winglet design exhibited remarkable efficacy in disrupting wingtip vortices, leading to a substantial reduction in induced drag [15] and a notable improvement in aerodynamic efficiency which can be seen in Figure 9, 10 and 11 showing the reducing trend of Induced Drag with increasing cant angle configuration.

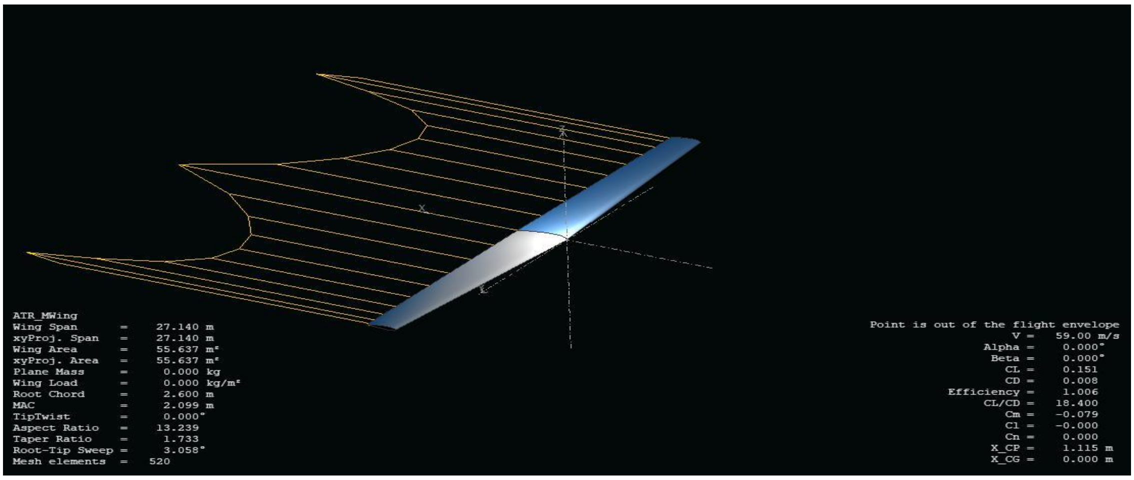

Figure 9. Induced Drag profile on Baseline wing

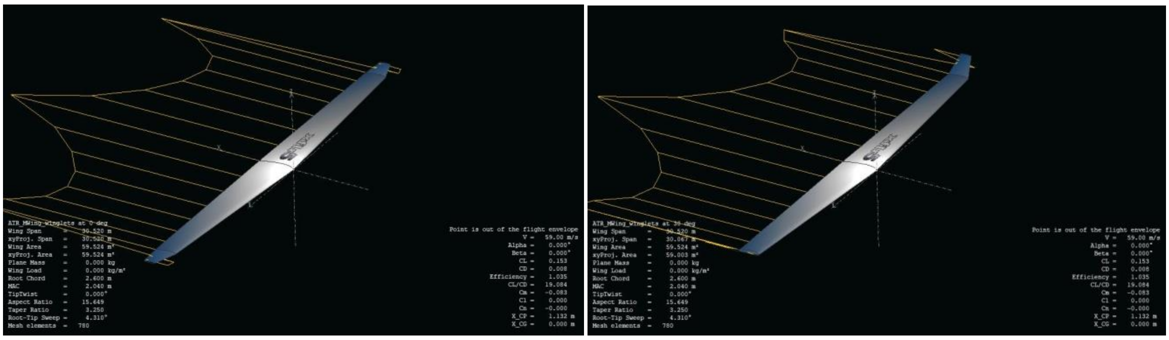

Figure 10. Induced Drag profile on Wing with Winglet at 0 and 30 degrees respectively

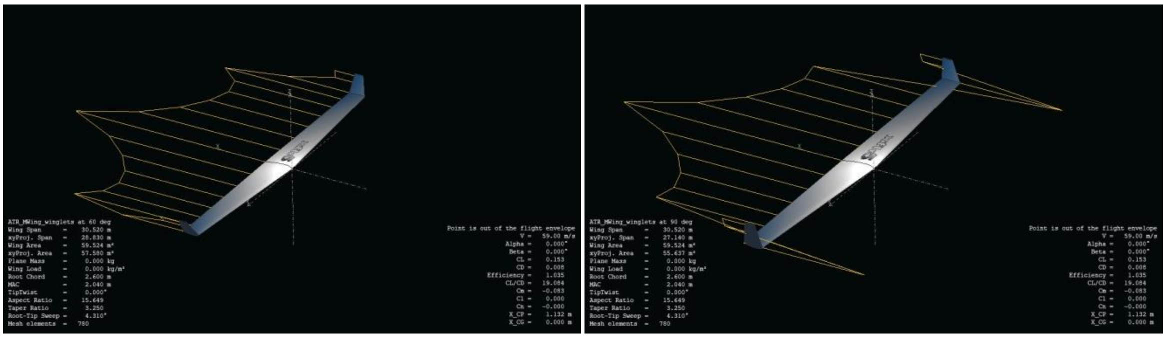

Figure 11. Induced Drag profile on Wing with Winglet at 60 and 90 degrees respectively

The lift-to-drag ratio demonstrated a significant enhancement, indicating the pronounced benefits of the winglet at a 90-degree cant angle in reducing induced drag more over it is acting as forward thrust while maintaining lift, crucial for optimizing takeoff performance.

While acknowledging outcomes of reduction in induced drag by varying the cant angle of winglets, it is essential to consider potential trade-offs, such as a marginal increase in parasite drag associated with certain winglet configurations particularly at 90 degree cant angle. The flight condition can be further simulated for cruise condition for the same wing (i.e, at 25000 fts and 130mps speed). These findings contribute not only to the understanding of winglet effectiveness but also emphasize the importance of tailoring winglet designs to specific operational conditions, such as takeoff scenarios. The study's outcomes offer practical insights for engineers and designers seeking to enhance aircraft performance of Twin-engine Turboprop Transport aircraft, especially during critical flight phases like takeoff, and provide a foundation for further investigations into optimizing winglet designs for various operational requirements of aircrafts like ATR72, AN-32, Dash-400 and other type

Refrences

[1] Hallion, R., 2010. *NASA's Contributions to Aeronautics*. National Aeronautics and Space Administration.

[2] Sankrithi, M.K.V. and Frommer, B.J., 2008. Controllable winglets. *United States Patent Document*.

[3] Freitag, W. and Terry, S.E., 2009. Blended winglets improve performance. *Aeromagazine Boeing*, *35*, pp.9-12.

[4] Garvey, W., 2010. Spiroid Winglets–The Way Forward?. *Aviation Week & Space Technology*, p.p60.

[5] Gabor, O.Ş., Koreanschi, A. and Botez, R.M., 2016. A new non-linear vortex lattice method: Applications to wing aerodynamic optimizations. *Chinese Journal of Aeronautics*, *29*(5), pp.1178-1195.

[6] Zheng, X.K., Wang, X.L., Cheng, Z.J. and Han, D., 2017. The efficiency analysis of high-altitude propeller based on vortex lattice lifting line theory. *The Aeronautical Journal*, *121*(1236), pp.141-162.

[7] Septiyana, A., Hidayat, K., Rizaldi, A. and Wijaya, Y.G., 2020. Comparative study of wing lift distribution analysis using numerical method. *Jurnal Teknologi Dirgantara*, *18*(2), pp.129-139.

[8] Deperrois, A. (2009). XFLR5 Analysis of foils and wings operating at low Reynolds numbers. *Guidelines for XFLR5*.

[9] Drela, M. (1989). XFOIL: An analysis and design system for low Reynolds number airfoils. In *Low Reynolds number aerodynamics* (pp. 1-12). Springer, Berlin, Heidelberg.

[10] Jane, F.T., 2023. *Jane's All the World's Aircraft. 1913*. Good Press.

[11] Franco, E., Mattei, M., D'Ambrosio, D. and Iuso, G., 2020. Design and aerodynamic characterization of a small UAV: stability and control derivatives.

[12] Gould, C., 2019. Aerodynamic Shape Optimization of Airplane Winglet & Investigation Into Morphing Winglet Technology.

[13] Brar, R., 2014. *Design of a Blended Wing Body Aircraft* (Doctoral dissertation, San Jose State University).

[14] Manjunath, I.B., Kulkarni, V.M. and Balaraman, P., 2020, February. Geometry optimization studies on nonplanar wingtip devices for typical transport aircraft. In *Journal of Physics: Conference Series* (Vol. 1473, No. 1, p. 012005). IOP Publishing.

[15] Khan, F.N., Batul, B. and Aizaz, A., 2019, October. A CFD analysis of wingtip devices to improve lift and drag characteristics of aircraft wing. In *IOP Conference Series: Materials Science and Engineering* (Vol. 642, No. 1, p. 012006). IOP Publishing.

[16] Raparthi, M., Dodda, S. B., & Maruthi, S. (2023). Predictive Maintenance in IoT Devices using Time Series Analysis and Deep Learning. Dandao Xuebao/Journal of Ballistics, 35(3). https://doi.org/10.52783/dxjb.v35.113