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Design and Analysis of Winglet for Low Subsonic Speeds

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Abstract

Winglets are vertical or angled extension devices attached at the wingtips. They improve the aerodynamic efficiency by reducing the induced drag caused by wingtip vortices.This paper describes a wingtip analysis that is performed on a rectangular wing of NACA 2412 cross sectional airfoil. The objective of the proposed paper is to compare maximum aerodynamic efficiency of the wings with winglet and without winglet at low subsonic speeds. A rectangular wing with and without winglet is studied. In this investigation a wing of constant wing span, aspect ratio, chord and wing area is analyzed under idea flow conditions for reduction in induced drag. XFLR5 software is used for the analysis. Vortex lattice method is used in this software to solve the equations in the assumed inviscid flow.

Key Words: *Winglets, Cant angle, Induced drag, Wingtip vortices, Vortex lattice method.*

1.INTRODUCTION

Drag is summation of all forces that resist an aircraft motion. There are various types of drag caused by various factors which together form the total drag. One of these is the Induced drag that results from generation of wingtip vortices downstream of the lifting surfaces. This type of drag is induced by lift force. For a lifting wing, the pressure on the upper surface is lesser than the lower surface. Hence, wingtip vortices are formed at the tips of the wings as shown in figure.1. Wingtip vortices are circular pattern of rotating air left behind a wing as it produces lift. These wingtip vortices reduce the lift and increase the lift induced drag.

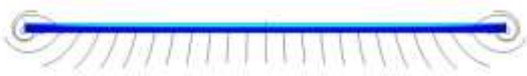

Figure 1: Wingtip vortices

To overcome this problem wingtip devices such as winglets are used. A winglet is used to improve the efficiency of aircraft by reducing the lift induced drag caused by wingtip vortices [1, 4, 6]. Winglets are the extensions mounted at the tip of the aircraft wings. These winglets diffuse the vortices shed at wingtips and thus increase the aerodynamic efficiency of the wing.

In the mid 1970's, research into winglet technology for commercial aviation was pioneered by Richard Whitcomb. Whitcomb focused on applications of winglets for large airplanes at a high subsonic airspeed. This research in a full size aircraft revealed that the winglets can bring improvement of more than 7% in aerodynamic efficiency. For airlines, this reduces millions of dollars on fuel consumption. [2]. Recent advancement in winglet is also made in an Unmanned Aerial Vehicle (UAV) application where methods for designing and optimizing winglet geometry for UAVs were investigated at Reynolds numbers near 10^6 [3]. The methodology is applied in UAVs to improve the performance.

2. TECHNICAL DETAILS

XFLR5 software is used in this numerical analysis to study the increase in maximum aerodynamic efficiency due to winglets. XFLR5 software includes design and analysis using vortex lattice method (VLM), lifting line theory (LLT) and 3D panel model. The analysis is carried out in this paper to calculate coefficient of lift (C_L), coefficient of drag (C_D), aerodynamic efficiency using vortex lattice method on the mean camber line [7, 11].

Assumptions made in vortex lattice method regarding this analysis are:

- The flow is inviscid, incompressible and irrotational.
- Influence of thickness on aerodynamic forces is neglected. The airfoil is assumed to be thin.

Vortex lattice theory is based on Prandtl’s lifting line theory. Prandtl suggested that a fixed vortex filament would be subject to a force from the KuttaJukowski theorem. To determine the lifting force on a wing, Prandtl replaced the wing with a fixed vortex filament, and since a vortex cannot end in a fluid, Prandtl connected a vortex at each end that extend to infinity. The horseshoe vortex replaces the wing. The combination of vortices is known as a horseshoe vortex [8, 10]. The horseshoe vortices are shown in figure.2. The downwash created by the fixed vortex along the span of the wing could be determined, where the vortex along the wing is located from one tip of the wing to the other tip. For a more precise calculation of the lift along the span of the wing, more horseshoe vortices can be added, each with a span less than the previous. Extending the number of horseshoe vortices results in the integral form of the induced velocity along the span of the wing, then the lift can be calculated as the integral over the span of the wing.

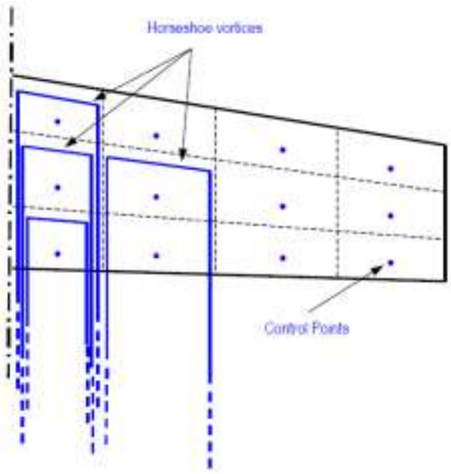

Figure 2: Vortex lattice method [11]

The vortex lattice theory begins with a basic two dimensional definition of the wing geometry then superimposes a grid on top of the wing. For each square in the grid there is a control point and a horseshoe vortex. The velocity at the control point is deduced by applying the BiotSavart law, to each segment of the horseshoe vortex that surrounds the control point. The BiotSavart law describes the strength of each vortex line in the horseshoe. From the strength of each vortex the velocity at the control point can be determined. The boundary condition stipulates that the flow must be parallel to the surface [8]. These equations are placed in a matrix corresponding to their location in the lattice across the surface of the wing. The XFLR5 software used in this analysis solves these matrices efficiently.

3. METHODOLOGY

A cambered airfoil NACA 2412 with chord 180mm is considered [5]. The coordinates of the airfoil are imported into the XFLR5 software and the analysis is run for the same. The figure.3 shows the NACA 2412 airfoil imported into XFLR5. The value of zero lift drag coefficient (C_{D_0}) for viscous flow condition is found to be 0.01. Reynolds number of 119,119 is considered for the analysis of airfoil in viscous flow.

Figure 3: NACA 2412 airfoil

Using the same airfoil a rectangular wing is molded and analyzed for inviscid flow condition. Values of coefficient of lift (C_L) and induced drag coefficient (C_{D_i}) are noted down. Total drag coefficient (C_D) is calculated by adding zero lift drag coefficient and induced drag coefficient. Maximum aerodynamic efficiency is then calculated from the obtained values of C_L andC_D [8, 9, 10]. The above procedure is repeated for wing with extended span and for a wing with winglet of cant angle 45°. The rectangular wing, wing with extended span and wing with winglet, designed and analyzed in XFLR5 are shown in figure.4, figure.5 and figure.6 respectively. The aspect ratio, wing area and wing span are kept constant.

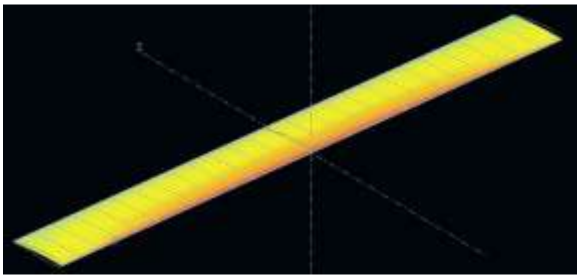

Fig 4. Rectangular wing

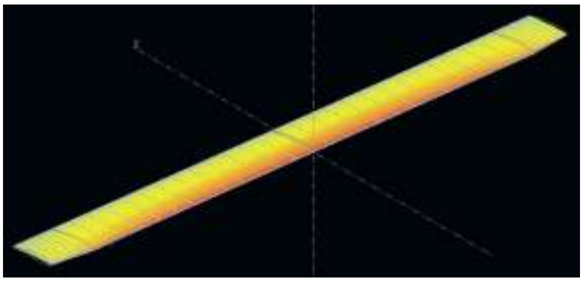

Fig 5. Rectangular wing with extended span

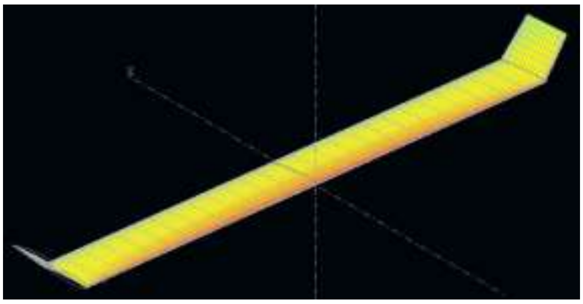

Fig 6. Wing with winglet

Total drag coefficient is given by,

$$C_D = C_{D_O} + C_{D_i} \quad ---------- \quad (1)$$

Induced drag coefficient decreases with increase in aspect ratio.

The induced drag coefficient is given by,

$$C_{D_i} = \frac{C_L^2}{\pi A \epsilon} \quad ---------- \quad (2)$$

Where, A is the aspect ratio of the wing, ∈ is wing Oswald efficiency factor.

The relation between Aspect ratio (A), wing span (b) and wing area (S) is given by,

$$A = \frac{b^2}{S} \quad ---------- \quad (3)$$

4. RESULTS

The aerodynamic efficiencies in all the three cases are obtained from XFLR 5 software and compared in Table 1.

Table 1: Results obtained from XFLR5

Wing type	Span (mm)	Wing area (cm^2)	Aspect ratio	$\frac{C_L}{C_D}$
Rectangular wing	1620	2616	9.00	26.44
Wing with increased span	1900	3322	10.87	27.67
Wing with winglet	1900	3322	10.87	28.81

4. CONCLUSION

Analysis is carried on rectangular wing, wing with increased span and wing with winglets using for low subsonic flow in XFLR5 software. The values obtained from this analysis show that the maximum aerodynamic efficiency is increased by 4.65% for wing with increase span and maximum aerodynamic efficiency is increased by 4.12% than maximum aerodynamic efficiency wing with increased for wing with winglet. It is seen that the aerodynamic efficiency is increased significantly for the wing with winglet.

Despite of the benefits of winglets, there are few demerits of winglets. They increase the complexity of the wing and increase the cost. They change the stability and control of the aircraft. Winglet design may sometimes increase the viscous drag and nullify the increase in aerodynamic efficiency. Hence, the winglets have to be designed carefully keeping all the demerits also in consideration.

REFERENCES

[1] M. AAzlin, C.F Mat Taib, S. Kasolang and F.H Muhammad, “CFD Analysis of Winglets at Low Subsonic Flow”, *Proceedings of the World Congress on Engineering 2011*, vol. 1, July 2011.

[2] Mohammad Salahuddin, MohdObaid-ur-Rahman, Shaik Jaleel, "A Report On Numerical Investigation Of Wings: With And Without Winglet", *International Journal Of Research In Aeronautical And Mechanical Engineering*, vol.1 issue.1, 2013.

[3] Jacob Weierman, Jamey D. Jacob, “Winglet Design and Optimization for UAVs” *28th AIAA Applied Aerodynamics Conference*, 2010.

[4] Whitcomb, Richard T., “A Design Approach and Selected Wind-Tunnel Results at High Subsonic Speeds for Wing-Tip Mounted Winglets". NASA Technical Report Server, July 1976.

[5] P.A.AswathaNarayana, SumanaInaganti, PrajnaBhat, RashmiUgargol, Sonal M Suvarna, “Design and Analysis of Wingtip Devices”,*International Journal on Mechanical Engineering and Robotics*, vol. 3, issue. 2,2015.

[6] Yates , J . E . , and Donaldson, C., “A Fundamental Study of Drag and an Assessment of Conventional Drag-Due-To-Lift Reduction Devices”, *NASA Contract Report 4004*, 1986.

[7] Aditya Kotikalpudi, Brian Taylor, Claudia Moreno, Harald P fer, and Gary J. Balas, "Aerodynamic Analysis using XFLR-5"

[8] Anderson, John D., "Fundamentals of Aerodynamics", edition. 4, *McGraw-Hill*, 2007, pp 437-443.

[9] David G. Hull, "Fundamentals of Airplane Flight Mechanics", *Springer*, 2007.

[10] L J Clancy, "Aerodynamics".

[11] "Analysis of Foils and Wings Operating at Low Reynolds Numbers", *Guidelines for XFLR5 v6.03*, 2011.