Design and Analysis of Wingtip Devices

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Abstract—Wingtip vortices are circular patterns of rotating air left behind a wing as it generates lift. These wingtip vortices cause wake turbulence, induced drag and imparts down wash. It reduces lift, increases drag and increases fuel consumption. To address this problem, wingtip devices are used. These devices are an extension of the wing at its tip, with change in geometry as compared to the wing. These wingtip devices prevent the formation of wingtip vortices by redirecting the flow of fluid emerging from the lower surface of the wing. The main goal of the proposed paper is the numerical investigation of Wings with and without wingtip devices and thus comparing the parameters for both the designs. In this research work, a wing of constant aspect ratio, wing area and wing span is analyzed under ideal flow conditions for reduction in induced drag. Xflr5 software is used for analysis. Vortex lattice method is used in the software to solve the equations in the in viscid flow conditions assumed. A rectangular wing with Blended Wingtip, Raked Wingtip and Winglet are studied.

Keywords—Wingtip devices, Induced drag, Vortex lattice method.

I. INTRODUCTION

Research into winglet technology for commercial aviation was pioneered by Richard Whitcomb in the mid 1970’s. Research into winglet technology for commercial aviation was pioneered by Richard Whitcomb in the mid 1970’s. Whitcomb revealed that in full size aircraft, winglets can provide improvements in efficiency of more than 7%. For airlines, this translates into millions of dollars in fuel costs [1]. Aircraft designers have always been searching for methods to improve the overall efficiency of the aircraft which would be beneficial for both the aircraft manufacturer and the airlines. In case of aircraft design process, reducing the overall drag at a compromising level would be one of the most challenging processes.

There are many factors which influence the amount of aerodynamic drag than an aircraft generates, which include shape, size, and inclination of the aircraft with the flow, and conditions of the flow passing the aircraft. For a lifting wing, the air pressure on the top of the wing is lower than the pressure below the wing. During the flight, pair of counter-rotating vortices is formed at the wing tips. The wing tip vortices produce a swirling flow of air behind the wing which is very strong near the wing tips and decreases toward the wing root. The effective angle of attack of the wing is decreased by the induced flow of the vortices and varies from wing tip to wing root. The induced flow produces an additional, downstream-facing, component of aerodynamic force of the wing. This additional force is called induced drag. Induced drag differs from the other forms of drag through a phenomenon of converting the dissipated kinetic energy into heat gradually. Vortex wake is a unique feature of induced drag [3]. The tip vortex generated from an Airplane may cause a hazardous effect on the flight safety of other Airplanes which are taking off or landing at the airport [6]. Controlling the vortical flow over the wing have various benefits such as enhancement of lift force, generation of forces and moments for light control, reduction of drag, attenuation of noise due to vortex/blade interaction [4]. Addition of wingtip devices helps reducing this induced drag and increases the overall efficiency of the aircraft. Due to wingtip devices, the aircraft can climb to initial altitude faster and save fuel due to a more efficient climb profile. Otherwise, the aircraft can take off at lower thrust settings, which reduce the aircraft noise footprint and extend engine life [1]. The new Boeing 787 and Airbus 350 will have special wings, which do not have a separate winglet, but have raked, and blended wingtips integrated without a sharp angle between the wing and the winglet [2]

II. TECHNICAL DETAILS

Using mathematical formulas, a numerical analysis is carried out to study the trailing vortices and the induced drag produced due to the wingtip devices. Xflr5 software includes design and analysis capabilities based on lifting line theory (LLT), the vortex lattice method(VLM) and a 3D panel method.

VORTEX LATTICE METHOD (VLM)

This study is carried out using the vortex lattice method (VLM) on the mean camber line. NACA 2412 airfoil is used. The free stream velocity, wing span and angle of attack considered are constant throughout this study. The Xflr5 software calculates the coefficient of lift,
coefficient of drag, aerodynamic efficiency using vortex lattice method.

VLM is a numerical, computational fluid dynamics method used for aircraft design based on potential flow. The VLM models the lifting surfaces such as a wing of an aircraft, as an infinitely thin sheet of discrete vortices to compute lift and induced drag. The influence of the thickness and viscosity is neglected. By simulating the flow field, one can extract the pressure distribution and the force distribution around the body. This knowledge is then used to compute the aerodynamic coefficients that are important for assessing the aircraft’s handling qualities. While the VLM cannot compute the viscous drag, the induced drag stemming from the production of lift can be estimated. The wing is modeled as a set of lifting panels. Each panel will contain a single horse-shoe vortex (as shown in fig 1). A bound vortex is located at the panel one-fourth chord position with two trailing vortex shed from each end. The observed values calculated for each panel and are integrated to get the readings for the complete wing. The corresponding values of a wing without a wingtip device are juxtaposed with those of a wing with wingtip device.

The assumptions made in the vortex lattice method regarding this problem are:

- The flow field is incompressible, in viscid and irrotational
- The lifting surfaces are thin. The influence of thickness on aerodynamic forces is neglected.
- Small angle approximation- Both the angle of attack and the angle of sideslip are small.

Furthermore it does not account for any geometrical deviation such as the sweep, twist or dihedral angle but for the relative simple case of a rectangular wing it yields accurate results. By obtaining the value of the circulation it is possible to calculate the lift. However it is obvious that this model has too many restrictions in order to be used for designing processes. The idea of the Vortex-Lattice Method is now to divide a wing of any arbitrary shape into small sections, the so called panels, to overcome this restriction.[1]

The required strength of the bound vortex on each panel will need to be calculated by applying a surface flow boundary condition called Neumann Boundary Condition. It states the usual condition of zero flow normal to the surface, which implies that only tangential flow exists. For each panel the condition is applied at the ¾ chord position along the center line of the panel. The normal velocity is made up of a free stream component and an induced flow component. This induced component is a function of strengths of all the vortex panels on the wing. Thus for each panel an equation can be set up which is a linear combination of the effects of the strengths of all panels.

For validation of the software, a symmetric airfoil NACA 0012 is considered for further analysis.

**NACA 0012**

A symmetric NACA 0012 airfoil is considered. The coordinates of the airfoil are imported into the software and is run for analysis. The values of Coefficient of lift(Cl), coefficient of drag (Cd) and aerodynamic efficiency (L/D) are noted down. Using the same airfoil, a 3D rectangular wing is designed. The readings are taken down for a constant value of Reynold’s number. Different innovative wingtip geometries are attached to the rectangular wing namely blended wingtip, raked wingtip and blended with raked. These different wingtip devices are analyzed in Xflr5 software at an angle of attack of 5° and a free stream velocity of 10m/s.
The values obtained have satisfied the standard results.

III. CALCULATING THE TOTAL DRAG

Total drag is given by

\[ C_D = C_{D0} + C_{Di} \]

The first part is referred to as zero-lift drag coefficient \( C_{D0} \) and the second part is called lift-related drag coefficient or induced drag coefficient \( C_{Di} \) [5].

\[ C_{Di} = \frac{C_L^2}{\pi A e} \]

where,

The induced drag coefficient is inversely proportional to the wing aspect ratio (AR) and wing Oswald efficiency factor (e)

\[ AR = \frac{b^2}{S} \]

The Aspect ratio, given by

The aspect ratio plays a significant role in induced drag as it is the main factor which is responsible for the span efficiency [3].

Some typical values of the Aspect ratio are given in the table below[2] -

<table>
<thead>
<tr>
<th>Type of Aircraft</th>
<th>Typical aspect ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fighter jets</td>
<td>2-3</td>
</tr>
<tr>
<td>Small Aircraft</td>
<td>6-8</td>
</tr>
<tr>
<td>Business Jets</td>
<td>7-8</td>
</tr>
<tr>
<td>Large Commercial Aircraft</td>
<td>8-10</td>
</tr>
<tr>
<td>Sailplanes</td>
<td>20-50</td>
</tr>
</tbody>
</table>

To calculate the change in Aerodynamic efficiency for a wing with different wingtip configurations a NACA 2412 airfoil is considered for analysis.

NACA 2412

Using a NACA 2412 airfoil, the value of \( C_{D0} \) is calculated for viscous flow conditions. A rectangular wing is molded of the same airfoil and analyzed for inviscid flow conditions. A graph is plotted between the observed values of \( C_L \) and \( C_d \) and the total drag is calculated using the above formula. A tangent is drawn on the \( C_l \) vs \( C_d \) curve and the intersection point obtained is the point of maximum aerodynamic efficiency.

The observed value of \( C_{D0} \) is 0.006 for NACA 2412 in viscous flow for Reynolds number 3,000,000. Total drag is thus obtained by adding this value of \( C_{D0} \) and the induced drag coefficient. The above procedure is repeated for different wing configurations. A chord of 180mm is considered for calculations.

<table>
<thead>
<tr>
<th>Wing type</th>
<th>Rectangular wing</th>
<th>Rect. wing with increased span</th>
<th>Wing with winglet</th>
<th>Blended Wingtip device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span(mm)</td>
<td>1640</td>
<td>1800</td>
<td>1840</td>
<td>1840</td>
</tr>
<tr>
<td>Wing area(sq cm)</td>
<td>2952</td>
<td>3240</td>
<td>3295.637</td>
<td>3231.3</td>
</tr>
<tr>
<td>Aspect ratio</td>
<td>9.11</td>
<td>10</td>
<td>10.27</td>
<td>10.48</td>
</tr>
<tr>
<td>Cl/Cd</td>
<td>33.508</td>
<td>34.95</td>
<td>35.73</td>
<td>35.128</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

The aerodynamic analysis carried out using XFLR5 seems to generate reasonable results. The effect of wingtip device is captured, which shows significant contribution to avoid wingtip vortices. The values acquired from this analysis shows that the Cl/Cd ratio has increased by 4.33% for a wing with increased span, 6.63% for a wing with winglet and 4.83% for a wing with blended wingtip. Hence one can conclude that by increasing the span the aerodynamic efficiency increases and it can be further increased by adding a wingtip devices. Even though the percentage increase in aerodynamic efficiency is higher for a winglet they generate additional interference drag, and this is the reason blended wingtips are preferred for commercial aircraft. From the results obtained, using a wingtip device has proved efficient in reducing the induced drag but it also has its own limitations, being increased structural weight and aeroelasticity, which has not been considered in this project.

V. ACKNOWLEDGEMENT

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REFERENCES


[6] Wing tip vortex structure behind an airfoil with flaps at the tip, by YANG Ke & XU ShengJin, School of Aerospace, Tsinghua University, Beijing 100084, China, 2011


[8] Aircraft design: a conceptual approach by Daniel P. Raymer
