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S Rajat Singh

Institute of Aeronautical Engineering, Dundigal, Hyderabad, srajatsingh50@gmail.com

Amala Raja Rajeswari Gajula

Institute of Aeronautical Engineering, Dundigal, Hyderabad, gajulaamala06@gmail.com

Praneetha Maccha

Institute of Aeronautical Engineering, Dundigal, Hyderabad, macchapraneetha823@gmail.com

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Aerodynamic Effects Of A Folding Wingtip To Increase Take-Off, Landing And Cruise Performance

S Rajat Singh ^a, G Amala ^a, M Praneetha ^a

^a*Department of Aeronautical Engineering, Institute of Aeronautical Engineering, Hyderabad, 500043, India.*

Abstract

The main purpose of a folding wing tip is to allow aerodynamically efficient high aspect ratio wing. To allow a wing tip to move in flight is to alleviate the loads and achieve lower wing weight or enable wing span to maximize. Thus reduces the induced drag and improve fuel efficiency. The folding wing tip may include spring devices in order to provide an additional gust loads alleviation ability in flight. A wing without a winglet produces wingtip vortices which increases drag as the air from the bottom surface of the wing (high pressure) tries to move to the upper surface (low pressure). To avoid this and have less vortices a winglet is used, around which the flow is same on both surfaces. A folding wingtip can be set at an angle of 0° to have maximum cruise performance and aspect ratio. If the wingtip is set in the range of 15° - 50° it can increase lift during takeoff. This folding wingtip can access any airport in the world because if it is folded at an angle of 90° , it can meet the gate requirements and restrictions of any airport. To study the performance of this mechanism, the wing tip was designed by using CATIA V5 software. The analysis of the wingtip at different angle of attacks was done using ANSYS and XFLR 5 softwares.

Keywords: Folding wingtips; Winglets; Aspect Ratio, Aerodynamic Performance

1. Introduction

Winglets are the type of wingtip devices which are mainly used to reduce the induced drag. Induced drag is a type of drag which is caused by the pressure difference between the lower surface (high pressure) and upper surface (low surface) of the wing. This imbalance in pressure is necessary for the production of positive lift force. The air molecules tend to flows from high pressure region to low pressure region; this produces turbulent wakes in the shape of vortices which are called as wing tip vortices. This means induced drag is generated which decreases the lift of the wing and increases the fuel consumption of the aircraft. The resulting vortices change the speed and direction of the airflow behind the trailing edge, deflecting it downwards and thus inducing downwash behind the wing. As lift increases drag also increases, to reduce the induced drag winglet concept is introduced. After many studies proved that winglets could reduce induced drag by 20% due to decrease in size of wing tip vortices. The wings which are installed with winglets tend to have smaller wingtip vortices this is because of the upward deflection of the winglet and the smaller cross-sectional area which reduce the circulation of air toward the top section. The winglets also maintain the smooth laminar flow at the wingtips which improves lift and reduces the drag due to which the aerodynamic efficiency of the aircraft is increased. Aerodynamic efficiency is defined as the ratio of total lift force to the drag force of the aircraft. The winglets tend to reduce drag and this will improve the aerodynamic efficiency. Increase of

efficiency is proportional to increase in the wing span as the aspect ratio increases. Aspect ratio can be increased with the application of wingtips and aircrafts can carry higher payloads with less fuel consumption. The concept consists of a pair of folding winglets whose angle of attack can be adjusted as per the requirements. The winglets show different effects at different angle of attack. To have better cruise performance, aspect ratio should be more and to increase the aspect ratio, the angle of the winglet should be set at an angle 0° . This will increase the wing span and wing loading of the aircraft, with which it will be able to lift more weight and also reduce fuel intake. In case of takeoff and landing the angle of attack could be set at an angle of 45° so that less vortices are formed, this angle will the induced drag while takeoff and landing, which will reduce takeoff distance. [3], [4], [5]

2. Methods And Materials

2.1 Design

One assembly design was created with an angle constraint to change the angle of the folding wingtip. The main wing is a rectangular wing and the wingtip is in the shape of a tapered wing which is useful to increase the aspect ratio of the wing at various angles. The designs are shown in the figure 1 below.

Figure 1- a) 0° AOA ;b) 15° AOA ;c) 30° AOA ;d) 45° AOA ;e) 60° AOA ;f) XFLR 5 Design

The XFLR design was used to do the preliminary analysis of the wing at different angles and plot various performance graphs like C_l vs α and C_l/C_d vs α .

2.2 Specifications

- The main wing has a NACA 4415 airfoil whereas the winglet has PSU-90-125WL [7]. The airfoil used in the winglet is less cambered when compared to the main wing to reduce the formation of wingtip vortices.
- NACA 4415 was used because it gives a C_l value of 0.5 at 0° angle of attack and is easy to fabricate.
- The span of the wing with and without winglet are 1.560m and 1.068m respectively.
- The Aspect Ratio of the wing with and without a winglet are 16 and 10 respectively.

2.3 Analysis

2.3.1 XFLR 5

The same CATIA design was created in XFLR to study the variation in performance graphs as shown is the figure 2.

The velocity given during analysis was 50m/s.

Figure 2- a) C_l vs α ; b) C_m vs α ; c) C_l/C_d vs α ; d) C_l vs C_d

- These graphs show that a winglet increases the C_l produced as angle of attack is increased. The design without the winglet is represented using a red dotted line.
- The C_l/C_d graph has an improvement when a winglet is added.

2.3.2 ANSYS

2.3.2.1 Operating Conditions

Table 1: Operating Conditions

Velocity	50 m/s
Temperature	273 K
Pressure	101325 Pa
Density	1.225kg/m ³

2.3.2.2 Geometry

CATIA file was imported in the Geometry section in the Fluent workbench and edited using Design modeler (DM). In DM an ideal enclosure was created in which there was sufficient space behind the model for drag formation. After creating the enclosure I created a Boolean Operation (subtract). Then the boundaries were named used Named selection-Inlet, Outlet, Walls, Aircraft. The Geometry is shown in Figure 3.

Figure 3- Geometry

2.3.2.3 Meshing

Mesh influences the accuracy, convergence and speed of a simulation. One of the purposes of meshing is to actually make the problem solvable using Finite Element as illustrated in Figure 4. By meshing, you break up the domain into pieces, each piece representing an element.

Figure 4- Mesh

2.3.2.4 Setup

The time used was steady. The viscous model was selected as the Shear Stress Transport (SST) Model. The SST model performance has been studied in a large number of cases. In a NASA Technical Memorandum, SST was rated the most accurate model for aerodynamic applications. The Transition SST model in ANSYS Fluent expands upon the traditional SST $k-\omega$ transport model which is a hybrid turbulence model that uses the $k-\omega$ model near the wall and the $k-\epsilon$ model in the far field. The Transition SST model expands upon the traditional SST transport equations by implementing two additional equations to track the intermittency and transition onset criteria using empirical correlations developed by Menter et al. [11] Reference values were computed from the inlet and the pressure was considered from the specifications table. The solution was then initialized by the Hybrid Initialization method.

3. Results And Calculation

3.1 XFLR 5

From the graphs we can see that the design without the winglet has C_l when compared to designs with winglet at an angle between 0° - 45° . C_l/C_d is also less for a wing without winglets. This shows the importance of a winglet and how it increases performance, while take-off or landing the pilot can set the wingtip at an angle between 15° and 45° for best C_l at low angle of attacks of the aircraft. When at cruise the pilot can set it at an angle of 0° to get maximize the C_l/C_d value and decrease fuel consumption.

3.2 ANSYS

Lift and drag values at 3 different angle of attacks were calculated and compared.

- Lift and drag values at 0° angle of attack were 28N and 6N respectively and shown in figure

Calculation complete.

Drag	(n)
-----	-----
wall-wing-solid	6.5355415
Lift	(n)
-----	-----
wall-wing-solid	28.620435

Figure 5- Lift and drag values at 0° angle of attack

- Lift and drag values at 30° angle of attack were 30N and 3N respectively and shown in figure 6.

Calculation complete.

Drag	(n)
-----	-----
wing	3.3264311
Lift	(n)
-----	-----
wing	30.869243

- Lift and drag values at 45° angle of attack were 61N and 5N respectively and shown in figure 7.

Calculation complete.

Drag	(n)
-----	-----
wing	5.0569845
Lift	(n)
-----	-----
wing	61.90126

Figure 7- Lift and drag values at 45° angle of attack

- Lift plots of all 3 angles are shown in figure 8.

Figure 8- Lift plots for 0° , 30° and 45° respectively

These plots show increase in lift per iteration and how the lift value was found out. We can observe increase in lift as the angle of attack is increased.

3.3 Pressure Contours

The pressure contours are ideal as there is low pressure over the wing and high pressure below as shown in figure 9.

Figure 9- Pressure Contours

3.4 Vortices Formed

The least vortices are formed at an angle of attack of 30° when compared using figure 10.

Figure 10- a) 0° AOA; b) 30° AOA; c) 45° AOA

There are vortices in figure 10 present at all angles but the least at 30° . A good modification which could be considered for reducing vortices is to add another small wingtip.

4. Conclusion

- The C_l value is higher for wingtips at an angle of 0° , 15° and 30° degrees when compared to a wing without winglets.
- C_l vs C_d plot shows why a winglet is important as at higher C_l values there is less C_d .
- The winglet with 0 degree gives the maximum C_l/C_d value, this increases cruise performance and fuel efficiency. So when cruising the winglets should be set at 0 degrees to increase the aspect ratio.
- During descent wingtips will give better lift as angle of attack is negative.
- The Mesh, Pressure Contours are appropriate.
- There is a decrease in drag when the wingtip is folded at an angle of 45° and 30° .
- The wingtips should be folded at an angle during take-off and landing as more lift is generated when compared to a horizontal wing.
- There was a significant increase in the L/D ratio as the angle of attack was increased as the angle was increased. 0° - 4.66; 30° - 10; 45° - 12.2.
- A folding wingtip can increase the performance significantly as the pilot can change the angle as per the mission and the situation.
- A folding wingtip can also increase fuel efficiency as the take-off distance is reduced with high lift generated by angled wingtips and the aircraft can glide while cruising as the aspect ratio increases from 10 to 16. This will reduce fuel consumption.

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