BEST: International Journal of Management, Information Technology and Engineering (BEST: IJMITE)
ISSN 2348-0513
Vol. 2, Issue 3, Mar 2014, 1-10

DRAG COMPARISON ON CUT OFF AND ROUNDED WING TIPS

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ABSTRACT

The Induced drag is a form of a pressure drag which is caused because of the increment of lift which increases when angle of attack increases. Induced drag is also called Drag due to Lift or Lift induced drag or Vortex drag. Induced drag can be minimized by attaching a wing tip cap at tips. There are many wing tip caps. Cut off, rounded, hoerner, end plate, drooped, upswept are few of them. The major aim of this project is to show that the induced drag produced by the cut-off wing tip is lesser when compared to that by the rounded tip. Flow analysis results for cut off and rounded tips are discussed. A comparison between these two is made and finally concluded by suggesting which one is better.

KEYWORDS: Induced Drag, Wing Tip Cap, Cut Off Tip, Rounded Tip, Flow Analysis

INTRODUCTION

All Finite wings, unlike infinite wings have wing tips and their span is finite. There is a three dimensional flow over a finite wing. Infinite wings have no wing tips and flow over them is two dimensional. Induced drag is caused due to formation of wing tip vortices. These vortices are formed due to the leakage of air from bottom to top surface. This leak is due to pressure difference between upper and lower surfaces of wing. Pressure on upper and lower surface is related to lift. More lift on wings implies high pressure difference which in turn would increase the intensity of wing tip vortices. This increases induced drag. Due to this dependency on lift, induced drag is also called Drag due to lift or Vortex Drag. Induced drag is unavoidable byproduct of lift. Induced drag can be reduced by attaching a suitable wing tip cap to the tips. These caps deflect the flow and try to prevent it from reaching top surface. A well designed tip cap can prevent about 20% of spillage at tips and therefore 20% of induced drag is reduced. Software used in calculating results is CATIA V5R18 and ANSYS FLUENT 12.1. In FLUENT the domain specifications are: inlet – 10 times chord at root, outlet – 20 times chord at root, free slip wall – 10 times chord at root.

Figure 1: Wing Tip Vortices

INDUCED DRAG

Source

Consider a finite wing which is producing lift. Lift is produced only when the average pressure below the wing is higher than that above. This pressure difference causes lift. Air has a tendency to flow from high pressure region to low pressure region. Consider flow at mid span. The fluid below wing which is at high pressure can’t escape to the top of the wing but the flow at the tips has a provision to escape to the top of the wing. As a result of this there occurs a kind of leak of pressure from lower surface to top surface. This leak of pressure or flow creates a circular flow at tips called vortices (figure 1). The wing tip vortices drag the surrounding air along with them and result in downward component of air called Downwash. Downwash deflects the local flow direction through an angle 'ϵ' called induced angle of attack.

Calculation of Induced Drag

To calculate induced drag let us assume the following. Consider an infinite wing producing lift for a particular velocity of air. There is no wing tip vortices formed in this case. Let R_1be the resultant force. Let L_1be lift perpendicular to free stream velocity and D_1 be its drag parallel to free stream velocity. Now consider a finite wing. Here wing tip vortices are taken into account. Let R_2 be the resultant force produced in this case. R_2slightly tilted aft ward due to downwash. Let L_2be lift perpendicular to free stream velocity and D_2 be its drag parallel to free stream Velocity. When we compare both these cases we observe that D_2 is more than D_1due to the formation of wingtip vortices (shown is figure 2). The difference between these two gives induced drag D_i.

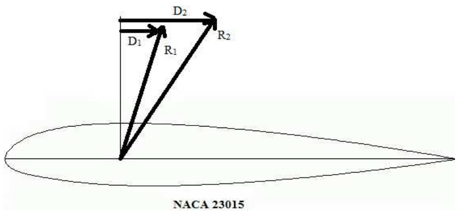

Figure 2: Induced Drag Calculation

i.e. D_2 -D_1 =D_i

D_i = induced drag

Magnitude of induced drag can take the following perspective. Consider a section of the wing. Let free stream velocity approach at a geometric angle of attack 'α'. Due to the formation of downwash, the local free stream direction is tilted by an angle 'ϵ' called induced angle of attack. So the section of the wing sees a reduced angle of attack 'α_{eff}' called Effective angle of attack.

α_{eff}= α – ϵ

The local lift vector will be perpendicular to local free stream velocity vector which is at an angle of attack of 'α_{eff}'. This is shown in figure 3.

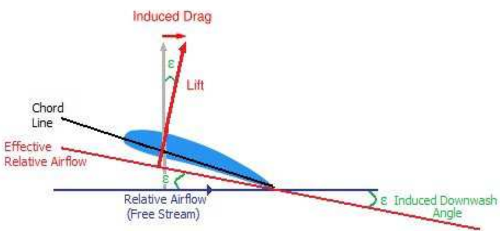

Figure 3: Sketch Showing α_{eff} and ϵ

From figure we can write

D_i = L $sin(\epsilon)$ 1

If ϵ is very small $sin(\epsilon)$ = ϵ which implies

D_i = L ϵ 2

ϵ can be calculated as

$$\epsilon = {C_L}/{\pi\ AR} \qquad 3$$

AR = Aspect ratio

Induced Drag Coefficient can be calculated by the formula

$$C_{Di} = {C_L^2}/{\pi.e.AR} \qquad 4$$

Where e is span efficiency factor

e = 1 for elliptic wing

e < 1 for other plan forms

We can say induced drag is less for elliptical wing. ‘e’ ranges from 0.85 to 0.95 for other plan forms in subsonic regime. From equation 4, C_{Di} is directly proportional to square of C_L. At high $C_{L\ max}$, C_{Di} occupies substantial portion of total drag. C_{Di} is inversely proportional to AR. As AR increases, C_{Di} decreases and vice versa. C_{Di} mainly depends on lift. As lift increases, C_{Di} increases. Due to this we call induced drag as drag due to lift.

Effect of Wing Tip Vortices

There are two aspects which are affected by wing tip vortices. They are as follows.

- Addition of Induced Drag to Total Drag

Consider an imaginary case where in there are no wing tip vortices. In this case the total drag will be the sum of skin friction drag and drag due to flow separation. Both of them combined together are called profile drag. Total drag in this case is equal to profile drag (c_d). In coefficient form it can be written as

$$C_D = c_d \qquad 5$$

Now consider real case where wing tip vortices are formed. From above discussion we conclude that induced drag is formed along with profile drag. So induced drag adds to total drag and it can be written as

$$C_D = c_d + C_{Di}$$

$$C_D = c_d + {C_L^2}/{\pi.e.AR} \qquad 6$$

- Lift Slope Decreases

In imaginary case i.e. no wing tip vortices, C_L vs. α Curve is shown in figure 4. The slope in this case is a_0.

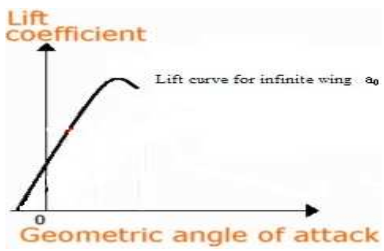

Figure 4: C_L vs α for Infinite Wing

Now in real case, due to the formation of induced drag and downwash the lift decreases. This is shown in figure 5. Let the lift slope of finite wing be ‘a’.

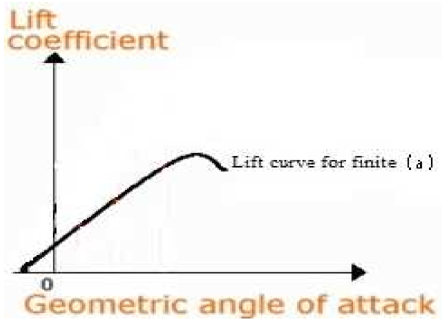

Figure 5: **$C_L$vs α for Finite Wing**

Comparing figures 4 and 5 we see that a < a_0 so the lift slope of wing decreases due to wing tip vortices (a <a_0).

Relative Percentages of Various Components of Drag

It would be useful for us to compare the drag due to various components of aircraft both at takeoff and at cruise. We consider subsonic case and supersonic case. The relative percentages are shown in figure 6. In subsonic case the element labeled wing body, empennage, engine installation, undercarriage, and flaps are contributors of zero lift parasite drag i.e. drag because of flow separation and skin friction. Induced drag is contributor of lift dependent drag and this adds to parasite parasite drag.

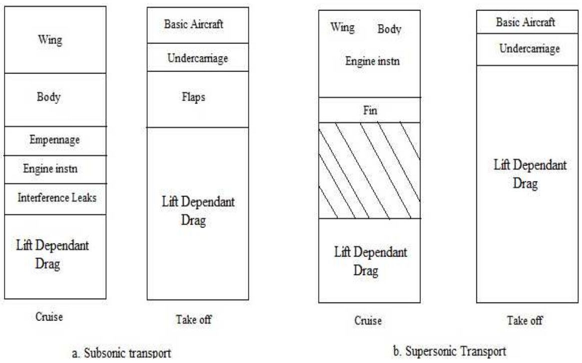

Figure 6: Drag Due to Various Components

In supersonic case more than two thirds in cruise is wave drag i.e. combination of zero lift wave drag and lift dependent drag. At take off most of the drag is lift dependent drag. This is due to low aspect ratio and high angle of attack required for supersonic aircrafts at take-off.

Reducing the Effects of Wing Tip Vortices

There are many ways of reducing effect of wing tip vortices. Few of them are providing a suitable tip shape which prevents air from leaking from bottom surface to top surface. Wing tip shapes include drooped tip, end plate, wing let etc. Other methods of reducing effect of tip vortices are joining both tips of wing from above. This forms box wing

WING TIP CAPS

Wing tip caps are shapes provided for tips for preventing the air from leaking from bottom surface to top surface. Its main purpose is to prevent air from going to top and increasing pressure on top surface. If pressure on top surface at tips equals that at bottom, there would be no lift produced at tips i.e. lift would drop at wing tips. To prevent that we use wing tip caps. There are many wing tip caps having different shapes. Few of them are:

- Cut off
- Rounded
- Hoerner
- Drooped
- Upswept
- End plate

Cut off and rounded will be discussed in detail.

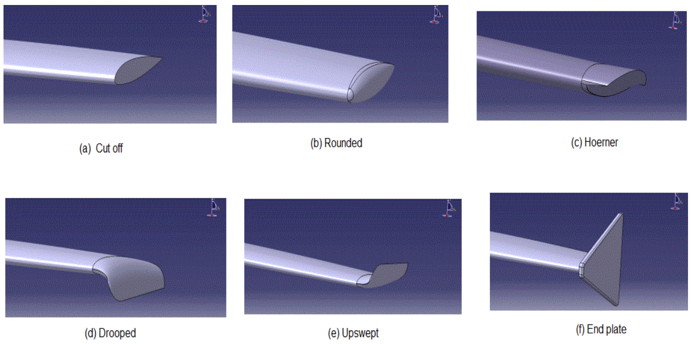

Figure 7: Wing Tip Shapes

COMPARING CUT OFF AND ROUNDED WING TIP

Induced drag coefficient is inversely proportional to AR (from equation 4). So higher the AR, lesser will be the induced drag. In the case of rounded wing tip, the center of the wing tip vortex formed at tip moves a larger distance towards the wing as it moves forward. This is because of the shape of rounded wing tip. As a result effective aspect ratio (which considers span as the distance between the center of two tip vortices) of wing with rounded tip is less than geometric aspect ratio. Due to this induced drag increases.

In the case of cut off tip the center of wing tip vortex moves only a little distance towards wing as it moves forward. The movement of center of vortex in this case is less when compared with that in rounded tip case. As a result effective AR of wing with cut off tip is more than that of wing with rounded tip. This implies that induced drag formed is less for wing with cut off tip. So induced drag in cut off case is less than that formed in rounded tip case. This is shown in following figure.

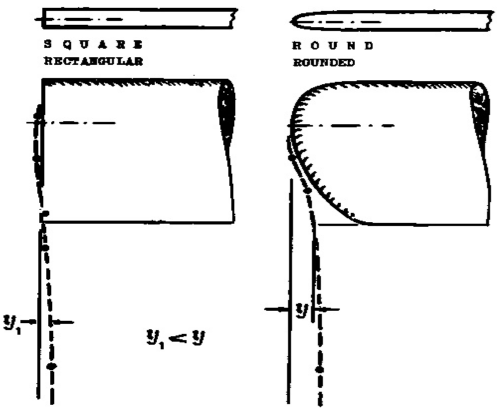

Figure 8: Induced Drag in Wing with Cut off and Rounded Tip

Assumptions for the Problem

The following assumptions have been made.

- The geometric dimensions of tip shape have been arbitrarily taken keeping in mind artistic view of tips.
- The values obtained are approximate and the mesh was coarse not fine.
- Wing specifications of the model are taken from wing specifications of Raytheon (Beech) BARON E55 aircraft.
- The wing is operated at sea level.

SPECIFICATIONS

Airfoil Specifications

The chosen airfoil is NACA 23015. It is a five digit airfoil.

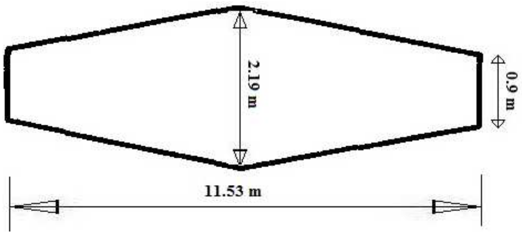

Figure 9

Its design lift coefficient is 0.3

- Maximum camber is located at a distance of 15% of chord from leading edge
- Maximum thickness is 15% of chord

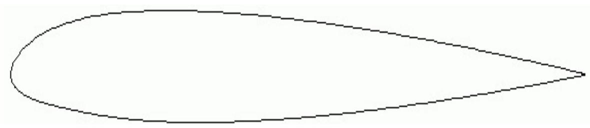

Figure 10: NACA 23015

WING SPECIFICATIONS

Wing of **Northrop Beech Baron E55** was taken as test piece. The specifications of wing are:

- Wing span = 11.53m
- Wing area = 17.47m^2
- Aspect ratio = 0.422
- Wing root chord = 2.19m
- Wing tip chord = 0.9m

FLOW SPECIFICATIONS

Flow is passed over wing at sea level. Ambient conditions are

- Pressure = 101325 Pa
- Temperature = 288.16 K

- Density = 1.225 Kg/m^3
- Velocity of flow = 100 m/s
- Angle of attack = 4^0

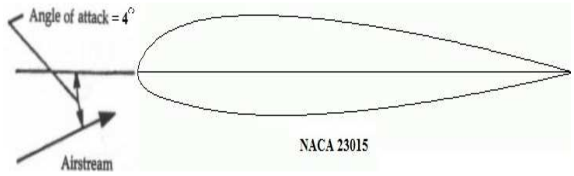

Figure 11: Airfoil

RESULTS AND DISCUSSIONS

Infinite Wing (No Wing Tip Vortices) Results

Let us consider an ideal case where in no wing tip vortices are formed. To model this we have to create a domain whose breadth is equal to span of wing. The distance between wing surface and inlet is 10 times root chord and that from outlet is 14 times root chord. In this model no wing tip vortices are formed because domain ends at tips.

Now on passing the flow of 100 m/s at an angle of attack of 4^0, we obtain the following data.

Coefficient of lift = 0.14488

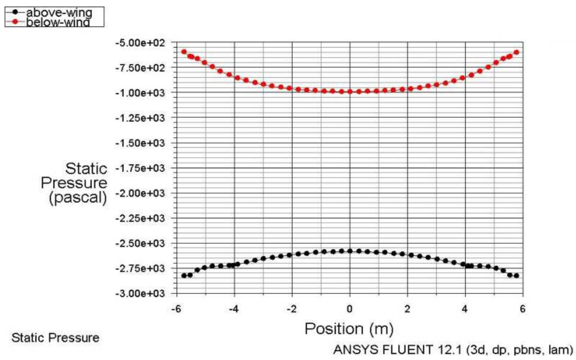

Figure 12: Pressure Distribution over Ideal Wing

Static Pressure just above and just below the wing is shown in figure 12. Black curve in above figure shows static pressure just above wing and red curve shows static pressure just below wing. We see that pressure above is less than that below i.e. lift is being generated. From the graph we observe that static pressure at both the tips above wing is not increasing. This shows that there is no leakage of air from bottom to top surface i.e. no wing tip vortices are formed. Due to this lift at tips is not lost.

Cut off Wing Tip Results

This is one of the wing tip caps whose tip is cut by a plane which is perpendicular to the axis of the wing. Cut off wing tip is easy to manufacture.

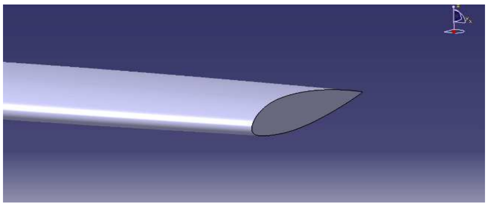

Figure 13: Cut off Wing Tip

On passing a laminar flow of 100 m/s at an angle of attack of 4^o at sea level we obtain the following results.

Coefficient of lift = 0.119

Coefficient of Drag = 0.0139

On plotting pressure on upper surface and lower surface we obtain the following graph. Black curve shows pressure just above wing and red curve shows pressure just below wing. The pressure above is less than pressure below. Lift is generated because of this. We see from the graph that pressure above the wing at both the tips is increasing. This increase is due to leakage of air from bottom to top surface through tips. This causes wing tip vortices. This can be clearly understood when we compare figure 13 with figure 12. In imaginary case there was no loss of lift. Here in this case we have loss of lift. This is due to formation of downwash which is caused because of wing tip vortices.

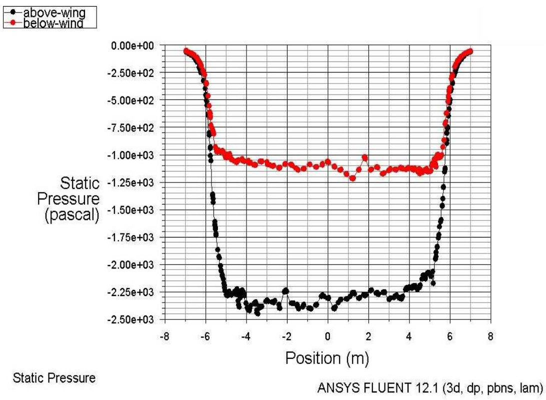

Figure 14: Pressure Distribution on Wing with Cut off Tip

Rounded Wing Tip Results

This wing tip joins the upper surface and lower surface of wing tangentially. This looks like a semicircular cap at tip. This is hard to manufacture when compared with cut-off tip.

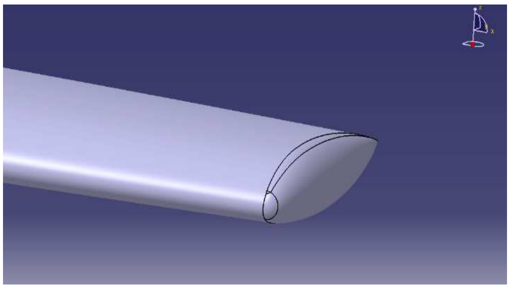

Figure 15: Rounded Wing Tip

On passing a laminar flow of 100 m/s at an angle of attack of 4^o at sea level we obtain the following results.

Coefficient of lift = 0.115

Coefficient of Drag = 0.0147

On plotting pressure on upper surface and lower surface we obtain the graph shown in figure 16. Black curve shows pressure just above wing and red curve shows pressure just below wing. The pressure above is less than pressure below. As expected the pressure above wing at tips is increasing. This increase is due to leakage of air from bottom to top surface through tips which causes wing tip vortices. This leads to downwash and there would be loss of lift at tips. This graph can be clearly understood by comparing it with figure 11.

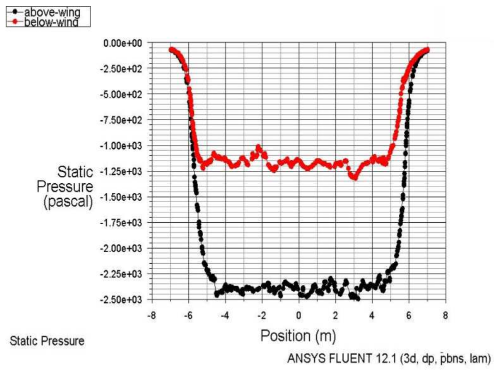

Figure 16: Pressure Distribution on Wing with Rounded Tip

CONCLUSIONS

Comparing the values of C_D for both rounded and cut off, we can say $\mathbf{C_{Di\ cut\ off} < C_{Di\ rounded}}$. Also keeping in mind the discussion under the sub heading ‘Comparing cut off and rounded wing tip’ we conclude that induced drag for wing with cut off tip is less than that obtained for rounded tip.

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