ISSN: 2395-7639

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

(A Monthly, Peer Reviewed Online Journal)

Visit: www.ijmrsetm.com

Volume 6, Issue 8, August 2019

Reduction of Induced Drag by Single Slotted Raked Wingtip

Swagat Prasad Das[1]

Department of Mechanical Engineering, Centurion University, Bhubaneswar, India[1]

ABSTRACT: In this research work the main aim is to reduce the induced drag by using single slotted raked wingtip. Here two wingtip geometries such as a sweptback & tapered wingtip and a slotted raked wingtip are taken for the research work. The tip vortex characteristics of the two different wing geometries at various angles of attacks are shown for different Reynolds numbers such as (1.82 x 10^5, 3.12 x 10^5 and 4.16 x 10^5). These Reynolds numbers are found out by changing the value of free stream velocity only keeping other values constant. The prediction for the numerical result of tangential velocity, lift coefficient and drag coefficient of sweptback and tapered NACA 0015 wing are compared with the experimental results. The numerical results that are obtained by using CFD code show a good agreement with the experimental results. It is observed that, the effect of Reynolds numbers on non-dimensional aerodynamic parameters are seen at higher angles of attack, i.e. above 8° for lift coefficient and above 6^o for drag coefficient. It is found that the maximum coefficient of lift ($C_{L\ max}$), stalling angle and non-dimensional aerodynamic parameters are increased whereas the drag coefficient is decreased with increase in Reynolds numbers. It is observed that the induced drag is reduced for a single slotted raked wingtip with increase in aerodynamic efficiency as compared to sweptback & tapered wingtip.

KEYWORDS: Wingtip, Reynolds number, Tip-vortex, Raked, Slotted, Circulation

I. INTRODUCTION

In aerodynamics, induced drag or lift dependent drag is a drag force that occurs whenever a moving object redirects the airflow coming at it. This drag force occurs in airplanes due to wings or a lifting body redirecting air to cause lift. With other parameters remaining the same, induced drag increases as the angle of attack increases. The viscous effects that are governed by the Reynolds numbers have a major influence on the airfoil lift, drag, and other aerodynamic characteristics. So it is essential to analyse the effects of the Reynolds numbers on reduction of wing tip vortex and hence reduction of induced drag. The Reynolds number is a dimensionless number that facilitates a full scale aerodynamic configuration to compare with a test model, giving incite to the forces as well as the aerodynamic characteristics as expected.

Different simulations were made for the three different Reynolds numbers such as 1.82 x 10^5, 3.12 x 10^5 and 4.16 x 10^5. The basic objective of the recent work is to find out the effects of the Reynolds numbers on wing tip vortex and reduction of induced drag using Single Slotted Raked Wingtip.

In a finite wing, there is an opportunity for the pressures acting on the upper and lower surfaces to interact near the wing tip [1]. The shorter the distance between the wing tip, the larger the downwash velocity and the induced drag [2]. The trailing vortex system also generates an up wash in the regions beyond the wing span and a downwash inside the wing span. This downwash produced by the trailing vortex system adds to the downwash produced by the bound vortex system [3].

Aerodynamic efficiency can be improved by increasing the maximum lift-to-drag ratio at the cruise flight condition, because induced drag is typically 30 percent or more of the total drag on a subsonic transport in cruising flight [4]. A 10% drag reduction on a large military transport aircraft is estimated to save up to 13 million gallons of fuel over its lifetime [5]. The worlds total jet fleet is estimated to be approx. 17 thousand aircrafts [6]. Such reduction in drag could result in fuel savings up to $1x10^{10}$ U.S. dollars ($). This drag is even more significant at low speeds, during takeoff conditions, where it accounts for 80-90% of the aircraft drag [7].

ISSN: 2395-7639

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

(A Monthly, Peer Reviewed Online Journal)

Visit: www.ijmrsetm.com

Volume 6, Issue 8, August 2019

Besides the advantages of lowering operating costs, reducing wingtip shed vorticity, and therefore induced drag, may also reduce global warming because of the lower fuel consumption. The world's commercial jet aircrafts generate more than 600 million tons of carbon dioxide per annum [8].

The methods adopted for reducing tip vortices are winglets, wingtip sails, and Raked wing tips. Most of the development work for the winglet was initiated by Whitcomb at NASA [9], [10]. Adding winglets to a wing can reduce and diffuse the vortex structure which originates at the tips [5, 12, and 13]. Also wing tip vortex can be reduced by using active means (i.e. suction at wing tip) rather than using passive means (i.e. shaping the wingtip)[14, 15].

The need of faster and more accurate methods for the calculations of flow fields around the wingtip configurations led to the rapid evolution of CFD. This paper presents the validation of CFD code against experimental data given by McGill University and investigates the 3-D flow structure of two different configurations viz. sweptback & tapered wingtip and wing with slotted raked wingtip, at Re=1.81 x 10^5. Special attention was given to the effects of Reynolds numbers on aerodynamic characteristics of sweptback & tapered wingtip and single slotted raked wingtip.

II. PROCEDURE

a. Overview

This paper presents a comparison between wingtip vortex flow field done by CFD simulations and experimental measurements done at McGill University by P. Gerontakos and T. Lee, [11] as a validation of the present numerical CFD simulations. Also several parameters were computed for the two different configurations at different Reynolds numbers and presented in graphical format. The Reynolds number is dependent upon the density of the fluid, the average velocity of the airfoil relative to the fluid, the characteristic length of the airfoil, as well as the dynamic viscosity of the fluid. Reynolds numbers were changed by changing the free stream velocity and keeping other parameters constant. We can also be able to predict all aspects of the tip-vortex using modern CFD code with commendable accuracy for an unswept and sweptback wing [16, 17].

The present simulations were run in ANSYS 13.0, which models fluid flow and heat transfer problems in complex geometries. This commercial CFD software solves the general transport equations using the finite volume method. Steady-state, transient, incompressible, compressible, in-viscid, viscid, laminar, and turbulent flows can be solved by using Fluent. The simulations were also run for three different Reynolds numbers (1.82 x 10^5, 3.12 x 10^5 and 4.16 x 10^5) by changing only the free stream velocity. Only the free stream velocities were changed to obtain the different Reynolds numbers. The free stream velocities were set to 35 m/s, 60 m/s. and 80 m/s to achieve the corresponding Reynolds numbers.

b. Complete Geometry Case

The near-field flow structures of two different configurations (such as, sweptback & tapered wingtip and wing with slotted raked wingtip) were investigated using Computational Fluid Dynamics (CFD). The baseline geometry(tapered sweptback wing configuration) was a half-wing model (Fig. 1) used by P. Gerontakos and T. Lee [11] at McGill University in a low speed wind tunnel. The model is an untwisted sweptback, tapered wing with an aspect ratio of 3.654, a taper ratio of 0.375, a semi-span of 51 cm, and a wing area of 713 cm^2. The root chord is 20.3 cm and the tip chord is 7.6 cm. This test model was used for three different free stream velocities for 35 m/s, 60 m/s. and 80 m/s. The locations of the downstream vortex-flow measurement planes (denoted by the dashed lines, x/c_r=2) are shown in Fig.1. The sweep angle at 0.25-chord location was set at 24^0. The square tipped wing had a NACA 0015 section throughout the span at 8° angle of attack.

ISSN: 2395-7639

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

(A Monthly, Peer Reviewed Online Journal)

Visit: www.ijmrsetm.com

Volume 6, Issue 8, August 2019

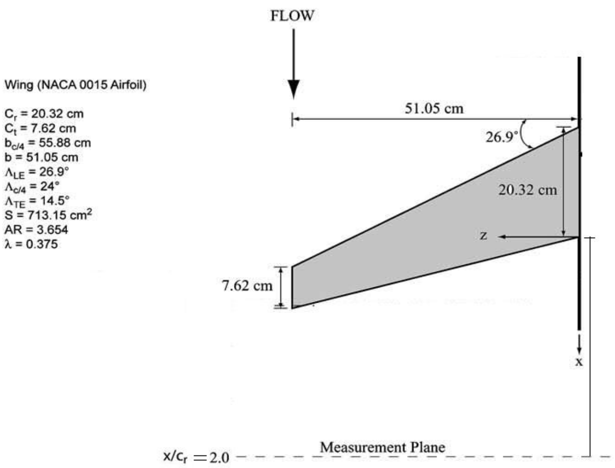


Fig 1- Baseline geometry (tapered sweptback wing configuration)

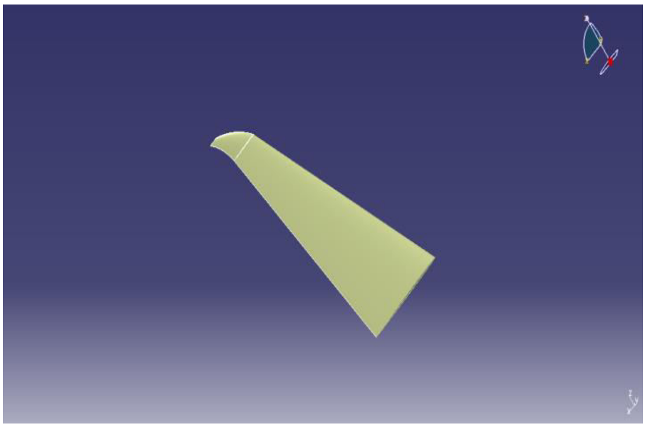


Fig 2-Raked wingtip (modelled as per raked wingtip configuration of Boeing

The second configuration (single slotted raked wingtip) was created from base line configuration. The tapered sweptback wing (baseline geometry) was modified to raked wingtip (Fig. 2) by changing the wing tip geometry only.

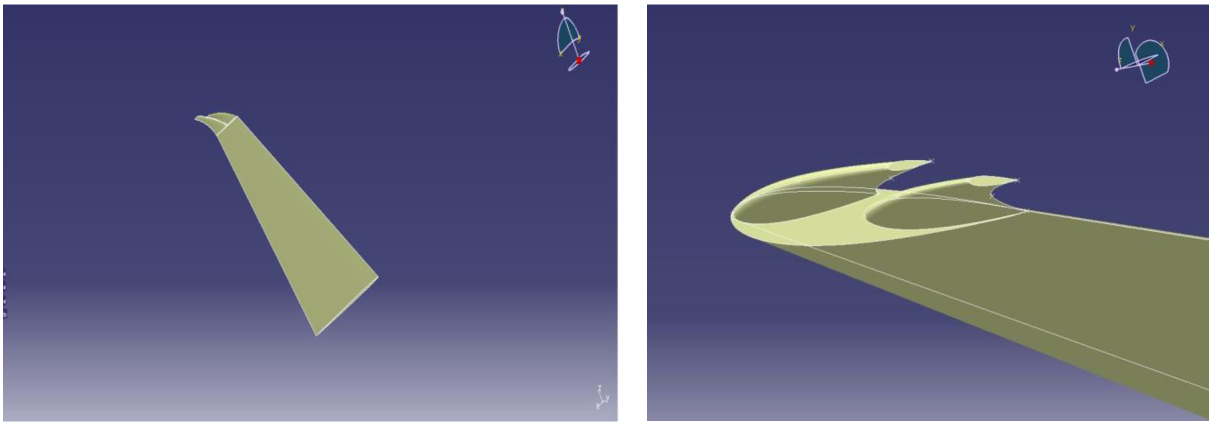


Fig 3- Single Slotted Raked Wingtip (second configuration).

The wing tip was modelled similar to raked wingtip configuration of Boeing 787. Then the raked wingtip geometry was modified keeping a slot like on a bird's feather to get a raked part as shown in Fig. 3 to create the single slotted raked wingtip.

III. RESULTS AND DISCUSSION

The main objective of this work was to investigate the tip vortex characteristics for different Reynolds numbers, for which two different wingtip configurations, such as sweptback &tapered wingtip and single slotted raked wingtip, were taken at various angles of attack. This research work includes **three** sections. The first section tells about the validation of the CFD code with experimental data and the other two sections elucidate the effects of Reynolds number on tip vortex characteristics of sweptback & tapered wingtip and single slotted raked wingtip configuration.

a) ***Validation of the CFD code:***

At free stream velocity of 35 m/s, the non-dimensional tangential velocity distribution ((v_θ/u_∞) was calculated about the vortex centre at 8° angle of attack. This computed value was compared with the experimental result done at McGill University by P. Gerontakos and T. Lee,[11] .

ISSN: 2395-7639

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

(A Monthly, Peer Reviewed Online Journal)

Visit: www.ijmrsetm.com

Volume 6, Issue 8, August 2019

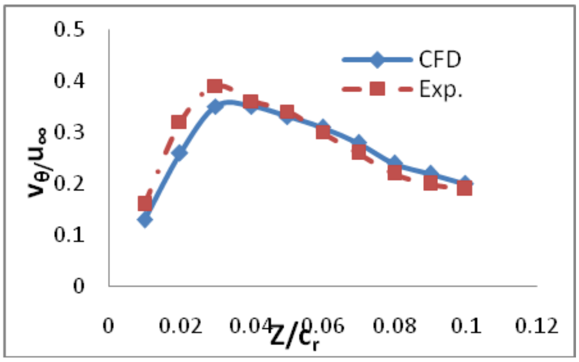


Fig.4. Non-dimensional tangential velocity about the wingtip vortex core.

Fig. 4 shows a comparison between numerical simulations done in Fluent and the experimental result of v_θ/u_∞. The simulation shows a good agreement with the experimental data.

b. Investigation of sweptback tapered wing

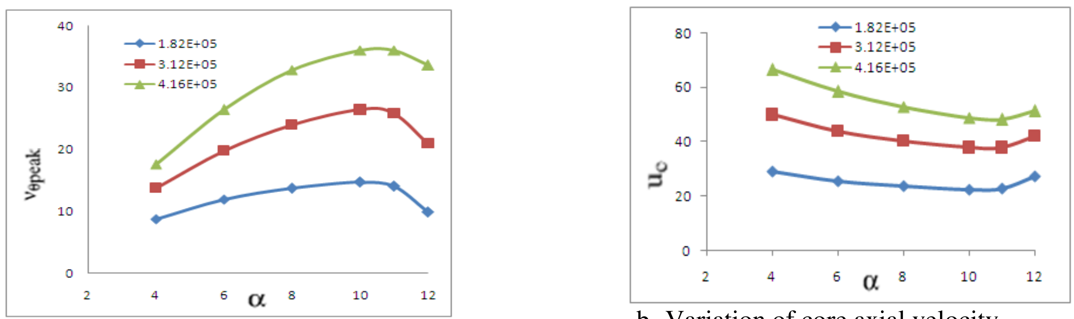
The circulation can be calculated either by taking line integral of velocity around a closed curve or by the surface integral over vorticity [18, 19]. The circulation value can be obtained from the surface integral as follows...

$$\Gamma = \oint (udx + vdy) = \iint \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) dxdy$$

Where vorticity (ζ) is given by...

$$\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) = \zeta$$

Both the line and surface integral methods were used to calculate the circulation. As no significant difference was found between these two calculation methods so only line integral method was used to find out the circulation. Different flow parameters were computed for the three different Reynolds numbers at various angles of attack and represented graphically in Figure 5.



a-Variation of peak Tangential velocity

b- Variation of core axial velocity

IJMRSETM

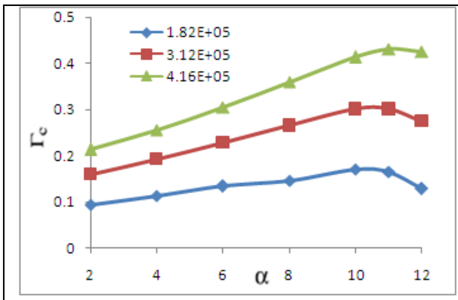
ISSN: 2395-7639

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

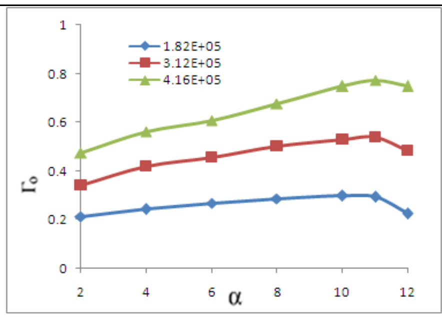
(A Monthly, Peer Reviewed Online Journal)

Visit: www.ijmrsetm.com

Volume 6, Issue 8, August 2019



c- Variation of Core circulation

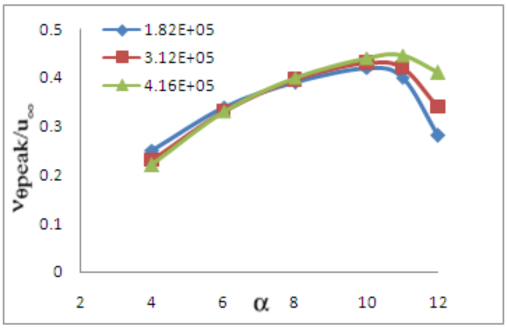


d- Variation of Total Circulation

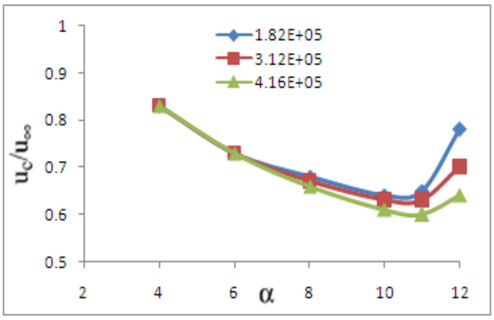
Fig 5- Variation of flow parameters with angle of attack for three different Reynolds numbers

It is noticed that with increase in angles of attack, the values of $v_{\theta peak}$, Γ_c and Γ_0 were increased and u_c was decreased. It is found that, while increasing the angles of attack, the flow parameters ($v_{\theta peak}$, Γ_c and Γ_0) show a continuous increasing trend whereas u_c shows a decreasing trend for different Reynolds numbers.

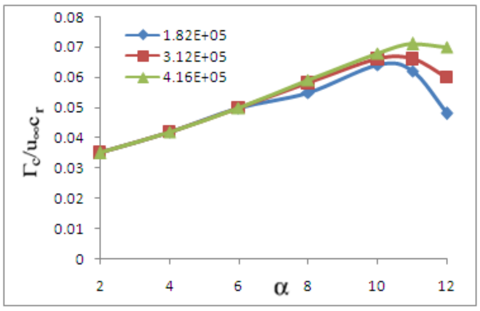
Dimensionless flow parameters were computed for the three different Reynolds numbers at different angles of attack and presented in graphical format in Figure 6.



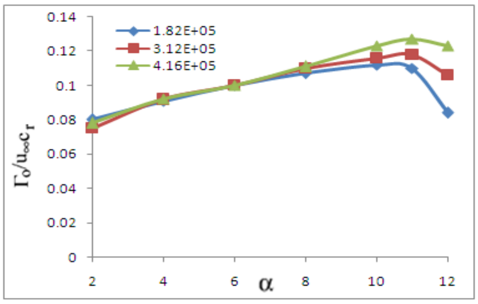
a-Variation of peak Tangential velocity



b- Variation of core axial velocity



c- Variation of Core circulation



d- Variation of Total Circulation

Fig 6- Non-dimensional flow parameters for the three different Reynolds numbers at different angle of attack

No significant difference in $v_{\theta peak}$, Γ_c, Γ_o and u_c was found at lower angles of attack but the effect of Reynolds numbers was noticed at higher angles of attack. The flow parameters increase with increase in Reynolds numbers at higher angles of attack (i.e. above 8^o).

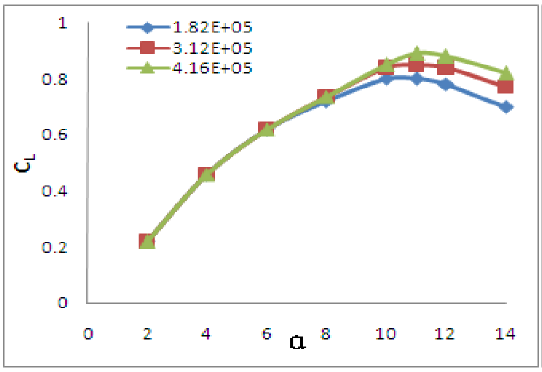
ISSN: 2395-7639

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

(A Monthly, Peer Reviewed Online Journal)

Visit: www.ijmrsetm.com

Volume 6, Issue 8, August 2019



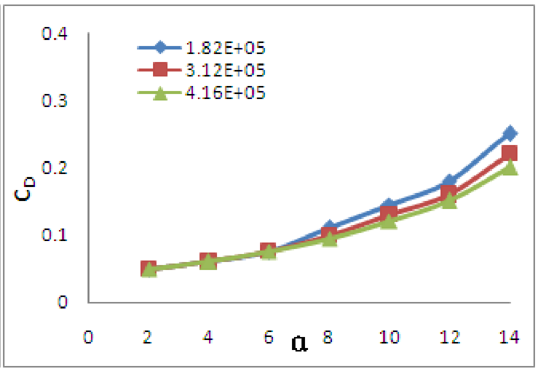


Fig 7- Variation of lift coefficient with angle of attack **Fig 8-** Variation of Drag coefficient with angle of attack

Between angles of attack of 2° to 14°, the values of lift and drag coefficients were calculated. Figure 7 and 8 shows the variation of lift and drag coefficient respectively with different angles of attack for the three different Reynolds numbers. Till 8° angle of attack no significant effect of Reynolds number was noticed on C_L. But after 8° angle of attack, noticeable changes in the (C_L~ α) curve were found for different Reynolds numbers. It was observed that, the maximum C_L and stalling angle increases with increase in Reynolds numbers. But in case of drag coefficient the effect of Reynolds numbers was noticed earlier than lift coefficient (i.e. above 6° angle of attack). The Drag and lift coefficients were decreased and increased respectively with increase in Reynolds numbers at higher angles of attack.

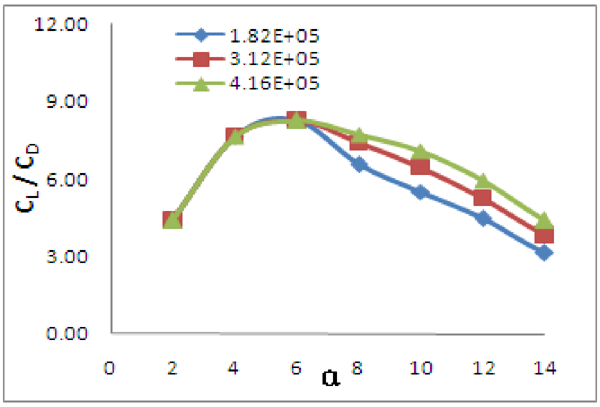


Fig 9- C_L / C_D with angle of attack

Aerodynamic efficiency (C_L / C_D) was also calculated and represented graphically format. Figure 9 shows the variation of aerodynamic efficiency with different angles of attack between 2° to 14° for the three different Reynolds numbers. The aerodynamic efficiency was not affected by any variation of Reynolds numbers at lower angles of attack but it increases with Reynolds numbers at higher angles of attack (i.e. above 6 degree).

c. Investigation of single slotted raked wingtip configuration

The dimensionless flow parameters were computed for the three different Reynolds numbers and presented graphically in Figure 10. The detailed comparison between sweptback & tapered wingtip and wing with slotted raked wingtip for three different Reynolds numbers are given in next section.

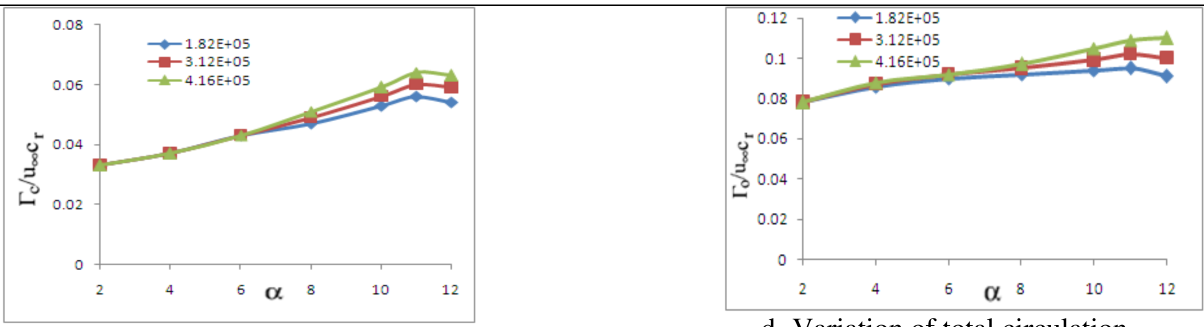
ISSN: 2395-7639

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

(A Monthly, Peer Reviewed Online Journal)

Visit: www.ijmrsetm.com

Volume 6, Issue 8, August 2019



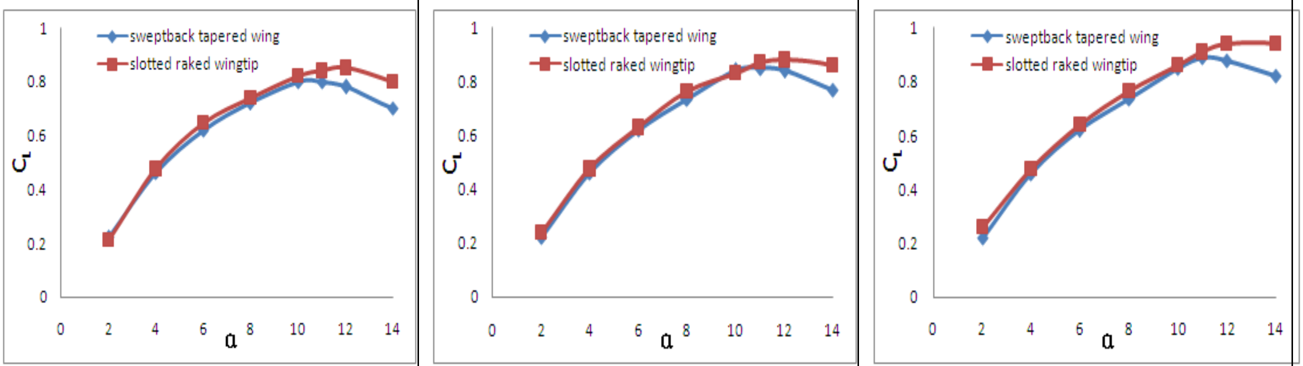
c- Variation of core circulation

d- Variation of total circulation

Fig 10- Non-dimensional flow parameters of single slotted raked wingtip for the three different Reynolds numbers

➢ ***Comparison between two configurations (sweptback & tapered wingtip and wing with slotted raked wingtip)***

The graphs shown in Figures 11, 12, 13 entails about the comparison of lift coefficient, drag coefficient and aerodynamic efficiency respectively, between sweptback & tapered wingtip and single slotted raked wingtip for three different Reynolds numbers.



a- C_L curve for Re No- 1.82E+05

b- C_L curve for Re No- 3.12E+05

b- C_L curve for Re No- 4.16E+05

Fig 11- Variation of lift coefficient

The graphs shown in Figures 10 shows comparison of lift coefficient, between sweptback & tapered wingtip and single slotted raked wingtip for three different Reynolds numbers. . Till 10^o angle of attack no significant difference was found for the C_L- α curve but above that noticeable changes were detected. The values of C_L and α_{Stall} are increased for single slotted raked wingtip as compared to sweptback tapered wingtip (figure 11)

IJMRSETM

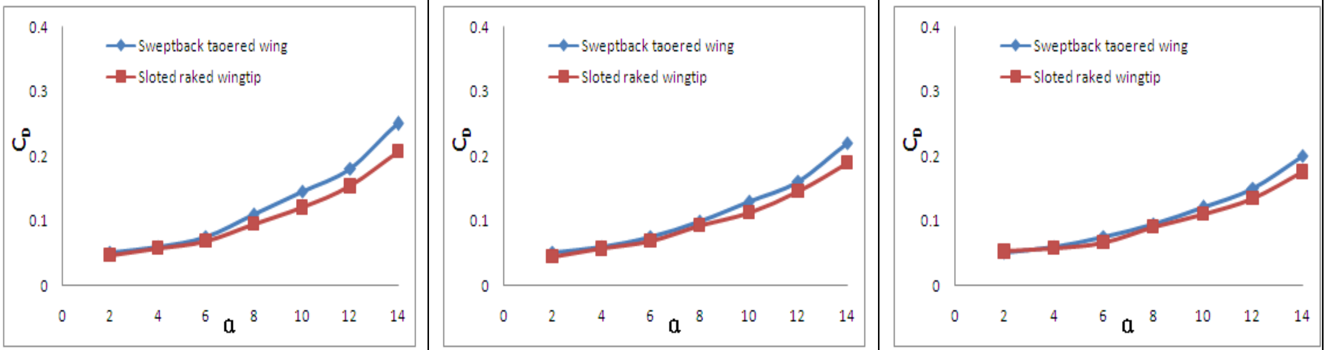
ISSN: 2395-7639

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

(A Monthly, Peer Reviewed Online Journal)

Visit: www.ijmrsetm.com

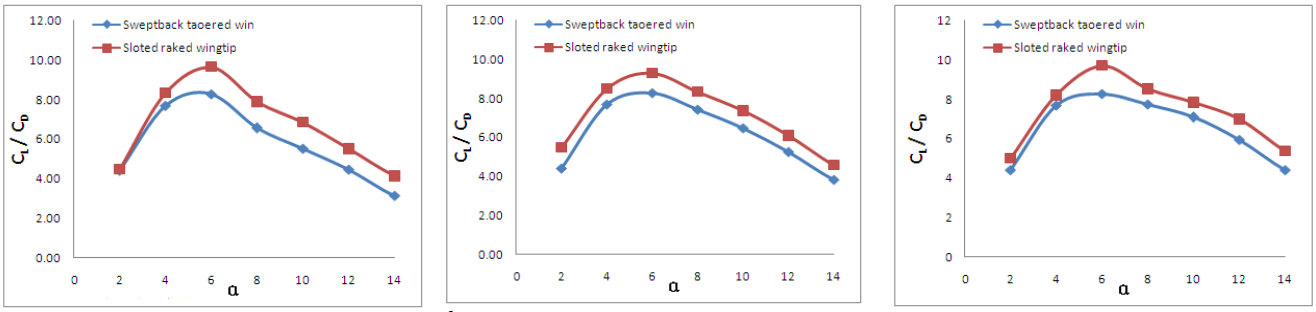
Volume 6, Issue 8, August 2019



a- C_D curve for Re No- 1.82E+05 | b- C_D curve for Re No- 3.12E+05 | c- C_D curve for Re No- 4.16E+05

Fig 12- Variation of drag coefficient

Figure 12 shows different values of drag coefficients at various angles of attack for the three different Reynolds numbers. At lower angle of attack (i.e. less than 5^o) no noticeable difference was found in C_D but the effect was noticed on the slotted raked wingtip configuration above 5^o angle of attack.



a- C_L / C_D curve for Re No- 1.82E+05 | b- C_L / C_D curve for Re No- 3.12E+05 | c- C_L / C_D curve for Re No- 4.16E+05

Fig 13- Variation of aerodynamic efficiency (C_L / C_D)

Figure 13 gives the comparison of different aerodynamic efficiencies (C_L / C_D) and it was found to be more for single slotted raked wingtip than sweptback tapered wingtip.

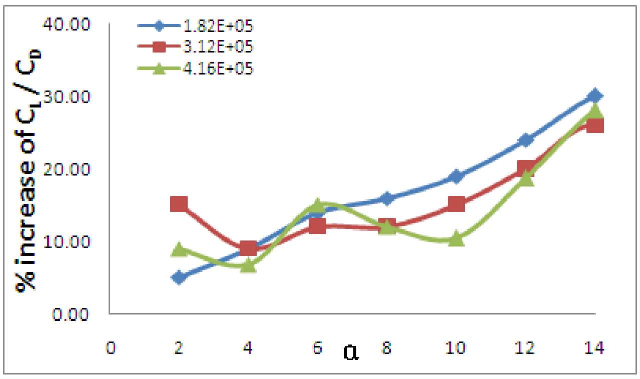


Fig 14- Comparison of aerodynamic efficiency for different wing tips.

Fig 14 shows the increase of aerodynamic efficiencies for single slotted raked wingtip as compared to sweptback tapered wingtip.

IV. CONCLUSION

In this research work the influence of Reynolds numbers for two different wingtip configurations (such as, sweptback tapered wingtip and the single slotted raked wingtip) were investigated at different angles of attack by using the numerical simulations in FLUENT.

The flow structure of a tip vortex behind a sweptback and tapered NACA 0015 wing with an AR of 3.654 was investigated for three different Reynolds numbers (i.e. $1.81x10^5$, $3.12x10^5$ and $4.16x10^5$) at different angles of attack for the two different configurations (sweptback-tapered wingtip and single slotted raked wingtip). Numerical simulations done in the current study has shown very good agreement with the experimental measurements done by P. Gerontakos and T. Lee at McGill University in predicting the formation of wing tip vortices for a sweptback tapered wing.

Initially, the peak tangential velocity, core circulation and total circulation were found to be increased with increase in angles of attack up to 10^0 and then tend to decrease for all the three Reynolds numbers. The angle of attack was higher for single slotted raked wingtip than that for sweptback tapered wingtip. But the value of u_c was found to be decreased initially up to 10^0 and then increased for all the three Reynolds numbers. No significant difference was noticed in the dimensionless parameters (viz. $v_{\theta peak}$, Γ_c, Γ_o and u_c) at lower angles of attack but at higher angles of attack the effect of Reynolds numbers was observed (figure 5).

For all the three different Reynolds numbers the values of C_L, C_D and C_L/C_D for both the configurations were computed. The effects of Reynolds numbers were not observed for C_L and C_D up to certain angles of attack, but the effects were noticed above 8^o angle of attack for C_L- α curve and above 6^o angle of attack for C_D – α curve. With increase in Reynolds numbers, the value of $C_{L\ max}$ and stalling angle were found to be increased for both the configurations but the drag coefficient was found to be decreased. The effects of Reynolds numbers on aerodynamic efficiency were observed above 6^o angle of attack. With the increase in angle of attack, the percentages of aerodynamic efficiency were increased for all the three Reynolds numbers. It is also found that, aerodynamic efficiency was higher for single slotted raked wingtip than sweptback tapered wingtip for all the three Reynolds numbers.

Based on the present study, it is concluded that, the effects of Reynolds numbers on the aerodynamic characteristics are found at higher angles of attack but not at lower angles of attack. The increase in aerodynamic efficiency is more for single slotted raked wingtip as compared to sweptback tapered wingtip, which ultimately leads to reduction of induced drag. For further investigations, it would be very helpful to investigate its impact on the very low Reynolds numbers and compressible flow.

REFERENCES

[1] Bertin, J. J. and Smith, M. L., Aerodynamics for Engineers 3rd Edition, Prentice Hall, Upper Saddle River, NJ 1998.
[2] Stinton, D., The Design of the Aeroplane 2nd Edition, Blackwell publishing, London, Great Britain 2003.
[3] Hoerner, S.F., Fluid Dynamic Drag Theoretical, Experimental and Statistical Information, Published by the author, Brick Town, N.J. 1965.
[4] Zimmer, H.: Aerodynamic Optimization of Wings at Subsonic Speeds and the Influence of Wingtip Design. NASA TM-88534, 1983.
[5] Thomas, A. S., "Aircraft Drag Reduction Technology – A Summary," Advisory Group for Aerospace Research and Development (AGARD), Report 723, Belgium, 1985.
[6] Air guide, "Jet Aircraft World Fleet Summary," Air Guide Online. 2006. <http://www.airguideonline.com/ aircr_wfleet.htm> (4 May 2006).
[7] Kroo, I. "Nonplanar Wing Concepts for Increased Aircraft Efficiency," VKI Lecture Series on Innovative Configurations and Advanced Concepts for Future Civil Aircraft, Stanford, 2005.
[8] Barnett, A., "Pace hots up in a World forever n the move," Guardian Unlimited. 2006. http://observer.guardian.co.uk/carbontrust/ story/0,16099,1511925,00.html> (4 May 2006).
[9] Whitcomb, R., "A Design Approach and Selected Wind-Tunnel Results at High Subsonic Speeds for Wing Tip mounted Winglets," NASA TN-D-8260, 1976.

[10] Whitcomb, R.T., "Methods for reducing subsonic drag due to lift," Special course on concepts for drag reduction, AGARD, France 1977,pp. 2-1 to 2-11

[11] P. Gerontakos and T. Lee, "Near-field tip vortex behind a swept wing model," Experiments in Fluids (2006) 40: 141–155

[12] Webber, G.W. and Dansby, T., "Wing Tip Devices for Energy Conservation and Other Purposes," Canadian Aeronautics and Space Journal, Vol. 29, No. 2, June 1983, pp. 105-200.

[13] Gerontakos, P., and Lee, T. "Effects of Winglet Dihedral on a Tip Vortex", AIAA Journal of Aircraft, Vol. 43, No. 1, January, 2006.

[14] Sangram Keshari Samal, Dr. P. K. Dash, "Reduction of Wingtip vortex from Suction at Wingtip" , Mechanical Engineering Research; Vol. 3, No. 1; 2013

[15] Sangram Keshari Samal, Dr. P. K. Dash, "Reduction of Wingtip Vortices by Using Active Means", International Journal of Scientific & Engineering Research, Vol. 4, Issue. 4, April, 2013

[16] Sangram Keshari Samal, S. Venkatramanan, Swagat Prasad Das, "Near-field Tip Vortex Behind an Untwisted Rectangular Wing", International Journal Of Research In Aeronautical And Mechanical Engineering, volume. 1, No. 7, November, 2013

[17] Sangram Keshari Samal, Dr. Dilip A Shah, Bharath M, Abhinash Sahoo, "Computational Prediction of Tip-Vortex of a Swept Wing", IJIRSET, Vol. 2, No. 11, November, 2013.

[18] John D Anderson Jr, "Fundamental of Aerodynamics", Fifth Edition. McGraw Hill.