PERFORMANCE ANALYSIS OF WINGLET USING CFD

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Abstract - *Winglets are considered as a powerful means of improving fuel efficiency for modern aircrafts. It is defined as the small fins or vertical extensions at the end of wing. Winglet improves aircraft efficiency by reducing drag which is being induced by the vortices generated at the tip of the wing. This type of device usually increases the effective aspect ratio of the wing without increasing the structural loads. The winglet design is done using Catia and analysis is done using ansys fluent.*

A comparison of aerodynamic characteristics of lift coefficient C_L, drag coefficient C_D and lift to drag ratio C_L/C_D is to be made for different cant angles at various angle of attack.

Key Words: *Wing, Winglet, Vortices, Cant angle, Angle of attack, Lift, Drag*

1. INTRODUCTION

The 1950's saw the beginning of the jet age in our world. In that period, reducing fuel consumption and thereby reducing carbon emissions significantly was one of the foremost responsibilities of aircraft manufacturers. They managed to achieve this difficult task, by changing the wing and fuselage designs, further reducing the airplane mass which resulted in less fuel being carried and burnt.

The device attached at the wingtip is called winglet. It is used to lower the induced drag created by wingtip vortices which improves aircraft efficiency. Winglets can be seen as a vertical or angled extension at the wingtip. Winglets increases the effective aspect ratio of wing by defusing the wingtip vortex shed that reduces drag ratio. This cause less fuel consumption

In 1970's Richard Whitcomb an engineer at NASA's Langley Research centre started research into winglet technology for commercial uses. In 1979 and 1980 small vertical fins installed on KC-135A were tested. As results Richard Whitcomb illumined that attaching winglets on full size aircraft can provide efficiency of more than 7%. That saves millions of pounds in fuel cost. Now days winglets are using by most commercial and military transport jets such as Gulfstream III, IV and V (Renamed to G550) business jets, the Boeing 747-400 and McDonnell Douglas MD-11 airliners, the McDonnell Douglas C-17 military transport, airbus A300, A320, A380, A350XWB jetliner etc. according to airbus "These devices improve aerodynamics, reducing fuel burn by up to 4 per cent – which amounts to annual savings of more than 900 tonnes of CO_2 per aircraft".
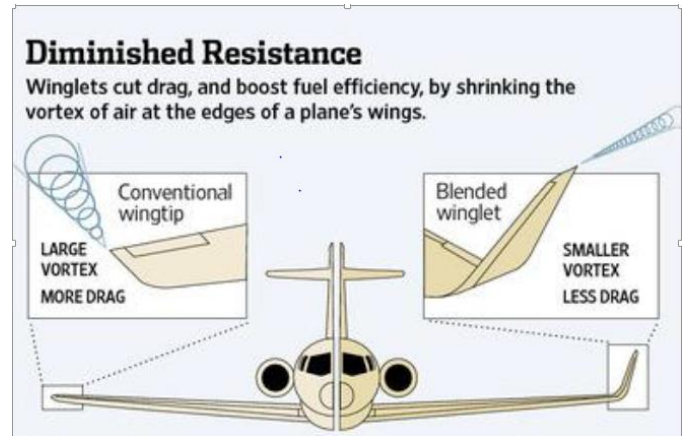

Fig -1: Illustration of vortex development

1.1 History of flight

The flying birds in the sky make human to dream flight. After centuries of research's and developments that dream of flight came true. Still human are learning from birds about flight. Today the history of aviation is spacious extended from a simple kite to supersonic aircrafts. The sector of aviation is so vast, which is always cultivating and reaching many milestones for better performance.

The invention of aircraft begin in 16th, 17th and 18th centuries. Lots of researches been conducted, theories developed, real life testes and ended up with some successful gliders. The start of 19th century change the aviation history. In aircraft many advancement made in aerodynamics, instruments, flight controls, etc. that leads today advanced efficient aircrafts.

From early days wing is the most fundamental part of aircraft structure. This the part which generate the lift force and this force carry the load of aircraft. Designing of the aircrafts always involves advance optimization of wing, which gives efficient aircraft structure

2. LITERATURE REVIEW

- Mervin R Barber and David Selagan have evaluated the benefits that could be achieved from the application of winglet to KC-135 aircraft and compared the results obtained from analytical analysis, wind tunnel test and flight test. They found that introducing winglet can reduce drag, increase lift and improved fuel efficiency significantly. These results gave a hope to conduct further studies on the topic.

• Gautham Narayan and Bibin John have analysed the performance of different types of winglets, namely, baseline, blended and BMAX winglet. They found that winglets are more effective at lower aspect ratio and provide highest improvement in aerodynamic efficiency at moderate aspect ratio of 10.

• John E. Yates and Coleman have derived the equations to find the drag and lift from the fundamental conservation laws. They found that all drag forces can be ultimately realizes as an entropy rise or total head loss in the far wake. It is proportional to the volume integral of the squared vorticity. Drag can be reduced by reducing the wake.

• S.G.Kontogiannis and D.E.Mazarakos in their study, found that the wing design procedure begins with the aerofoil selection. The aerofoil is the "heart" of the aircraft, producing the appropriate amount of lift. The aerofoil has to be highly efficient in the Low Reynolds regime. In this sense, the primary selection criterion was the ability of the aerofoil to generate as high lift as possible while keeping drag to minimum levels.

• A. abbas et al, researched on aerodynamic technologies to improve aircraft performance. They commented on the use of different winglets under drag reduction technology. Winglets account for the considerable decrease of induced drag during lift and thereby increase longitudinal stability.

• Chakravarthy et al conducted numerical investigation of winglet angles influence on vortex shedding. The winglets with different angles is studied against angle of attack and drag coefficient during take-off. The best winglet model reduces drag coefficient and wingtip vortices.

• Ismat Ara et al, in this paper they studied the performance of winglets on tapered wing. They analysed the blended and double blended type winglets using wind tunnel. Blended wing was found to have high lift to drag ratio than other types. This result justifies the selection of blended winglet for our analysis.

• Hesham S M et al said that the first step in performing a CFD simulation should be to investigate the effect of the mesh size on the solution results. Generally, a numerical solution becomes more accurate as more cells are used, but using additional cells also increases the required computer memory and computational time. The grid with the smallest number of cells displaying an independent solution should be used for the calculations.

• Adam Kosík published a journal on the CFD simulation of flow around an aircraft describing the complete process of modelling and simulation of computational fluid dynamics (CFD) problems that occur in engineering practice. The physical problem of fluid flow is described by the Navier-Stokes equation. He compared the results from measurements on a scaled model in a wind tunnel test, flight tests with results obtained using ANSYS Fluent.

3. PROCESS METHODOLOGY

3.1 Modelling

Design process of the aircraft wing with and without winglets have been carried out using CATIA V5 with the following specifications as mentioned below in the table 1 & 2

Table -1: Specification of the Wing

No	Description	Dimension
1	Airfoil Type	NACA 4412
2	Wing Type	Swept Back
3	Sweep Angle	19.03°
4	Wing Span	22 cm
5	Taper Ratio	0.27
6	Aspect Ratio	3.7
7	Wing Area	130.8 cm2
8	Maximum Chord	9.4 cm
9	Minimum Chord	2.5cm
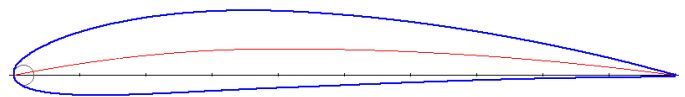
Fig -2: NACA 4412 airfoil

Table -2: Specification of the Winglet

No	Description	Dimension
1	Winglet Type	Blended Winglet
2	Winglet Span	2 cm
3	Winglet Area	5 cm^2
4	Winglet Sweep Angle from the wing tip	47.73°
5	Winglet Taper Ratio	0.12
6	Maximum Chord	2.5 cm
7	Minimum Chord	0.3 cm

The modelling procedure begins with selection of airfoil. The airfoil is the "heart" of the aircraft, producing the appropriate amount of lift. Here we use NACA 4412 airfoil, and data file was created with the airfoil points. The airfoil data was taken from the website airfoiltools.com. When the model of the wing was finished, it was saved as ". step" format file.

Fig -3: Model of wings

3.2 Meshing and Pre-Processing

Meshing process was carried by using ANSYS Meshing and Unstructured tetra elements were selected for these computations. The mesh details of the winglet cases are mentioned in the Table 3

Table -3: Mesh details

No	Mesh Details	Values
1	Number of Elements	282286
2	Number of Nodes	80158
3	Element type	Unstructured tetra element
4	Number of Layers	10

A bullet shaped boundary was created to capture fluid domine in ANSYS design modular and unstructured tetra elements were used to create grids for the surrounding fluid boundary with the 75 cm on each side of the wing and for the ease of 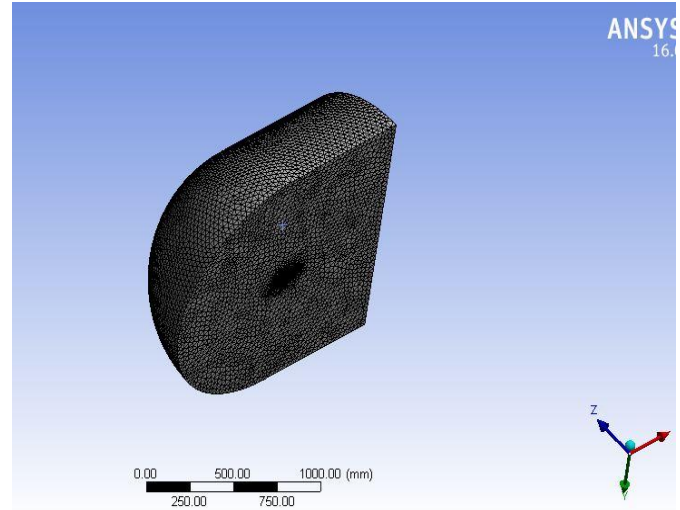solving the symmetry was taken at the root of the wing, surfaces of the wing were given the size of 2.5 mm and the 10 inflation layers were created and figures below demonstrate the same The sizing function scheme will help to reduce the number of element to be exported to FLUENT and also helps to reduce the computational time.
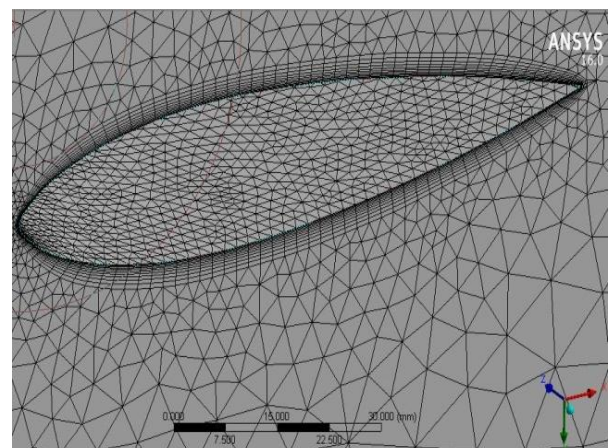

Fig -4: Bullet shaped fluid domain

Fig -5: Inflation near boundary layer

3.3 Boundary Conditions

Computational simulation have been carried out by FLUENT solver using finite volume approach with pressure based solver at steady state. Spalart-Allmaras turbulence model is considered with air- ideal gas as the material. The Spalart–Allmaras model is a one-equation model that solves a modelled transport equation for the kinematic eddy turbulent viscosity. The Spalart–Allmaras model was designed specifically for aerospace applications involving wall-bounded flows and has been shown to give good results for boundary layers subjected to adverse pressure gradients. In ANSYS FLUENT, the Spalart–Allmaras model has been extended with a y+ -insensitive wall treatment (Enhanced Wall Treatment), which allows the application of the model independent of the near wall y+ resolution.

The operating pressure and temperature to be sea level conditions and adiabatic wall conditions are used for all the walls. Initial wall temperature and inlet velocity are specified. At the exit outflow boundary condition is prescribed as an outflow. At the solid walls no slip boundary condition is imposed. Ideal gas was selected as the working fluid. Inlet velocity is taken as 50 m/s. The following boundary conditions mentioned below in the table 4 was used for the Numerical simulation.

Table -4: Boundary Conditions

No	Boundary Condition	
1	Model	Spalart–Allmaras model
2	Fluid	Ideal gas
3	Flow Condition	Steady state
4	inlet	Velocity Inlet = 50 m/s
5	Outflow	Pressure Outflow
6	Symmetry	Symmetry
7	Fairfield	Wall
8	Top and Bottom Wall	Wall (No-Slip)
9	Solver	Pressure Based

4. RESULT AND DISCUSSION

The analysis is done for four cases, i.e. wing without winglet, wing with winglets at cant angles 30^0, 60^0 and 90^0. the results were tabulated as follows.

Table -5: Results of no Winglet case

Alpha	lift	cl	drag	cd	cl/cd
-2	-27.4787	-0.1301	1.119426	0.0053	-24.5472
0	0.380183	0.0018	-11.5935	-0.05489	-0.03279
2	36.58201	0.1732	-1.77419	-0.0084	-20.619
5	56.85841	0.2692	22.51525	0.1066	2.525328
8	98.9953	0.4687	56.7528	0.2687	1.744325

Table -6: Results of 30^0 Winglet case

Alpha	lift	cl	drag	cd	cl/cd
-2	-20.7833	-0.0984	6.779921	0.0321	-3.06542
0	9.251108	0.0438	20.71995	0.0981	0.446483
2	54.78852	0.2594	24.0571	0.1139	2.277436
5	85.94237	0.4069	20.80443	0.0985	4.130964
8	112.5974	0.5331	46.80469	0.2216	2.405686

Table -7: Results of 60^0 Winglet case

Alpha	lift	cl	drag	cd	cl/cd
-2	-29.7387	-0.1408	3.569491	0.0169	-8.33136
0	15.81982	0.0749	-17.3405	-0.0821	-0.9123
2	59.89987	0.2836	-25.5778	-0.1211	-2.34187
5	87.42085	0.4139	17.34055	0.0821	5.041413
8	117.054	0.5542	46.29778	0.2192	2.528285

Table -8: Results of 90^0 Winglet case

Alpha	lift	cl	drag	cd	cl/cd
-2	-2.06988	-0.0098	13.32751	0.0631	-0.15531
0	0.549153	0.0026	-25.1765	-0.1192	-0.02181
2	51.07118	0.2418	-21.079	-0.0998	-2.42285
5	82.81642	0.3921	20.55098	0.0973	4.029805
8	109.5348	0.5186	48.28318	0.2286	2.268591

4.1 Pathlines
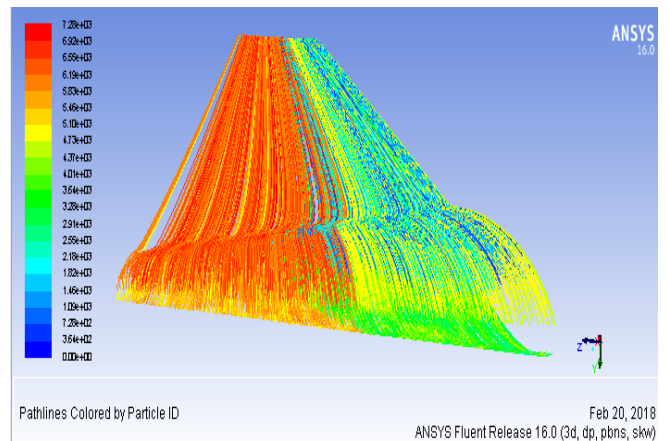
Fig -6: No Winglet case
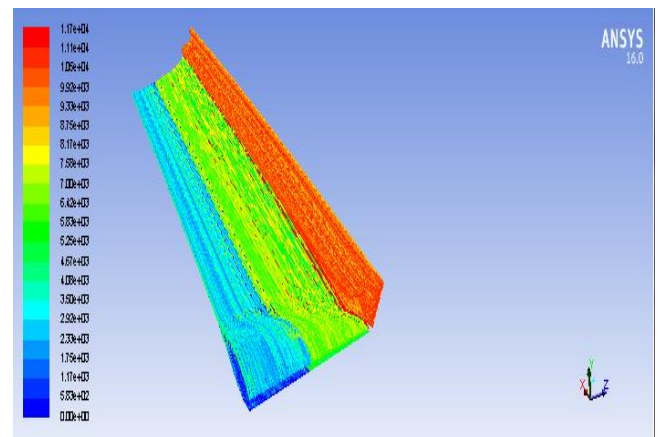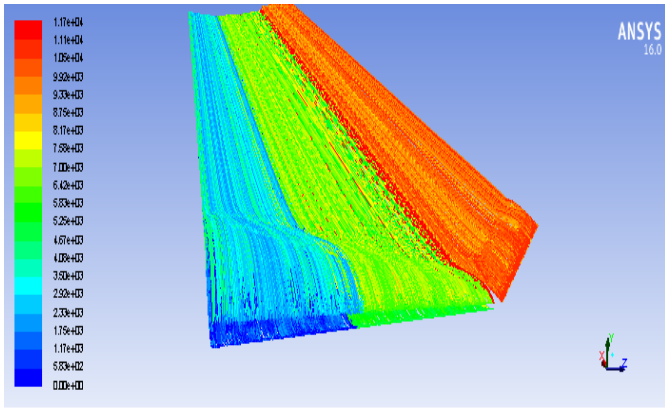

Fig -7: 30^0 Winglet case
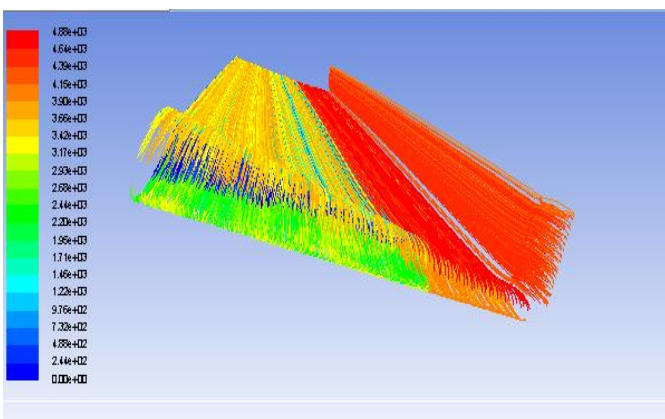
Fig -8: 60^0 Winglet case

Fig -9: 90^0 Winglet case

Comparing the pathlines of wing without winglet and the wing with winglets, the mixing of flow from the top and the bottom at the wingtip for no winglet case is prevented in the winglet case. Thus we can see the prevention of wngtip vortices.

4.2 Plots

From the results obtained from the analysis, different graphs are plotted to compare the results, they are C_L versus Angle of attack, C_D versus Angle of attack and C_L/C_D versus Angle of attack
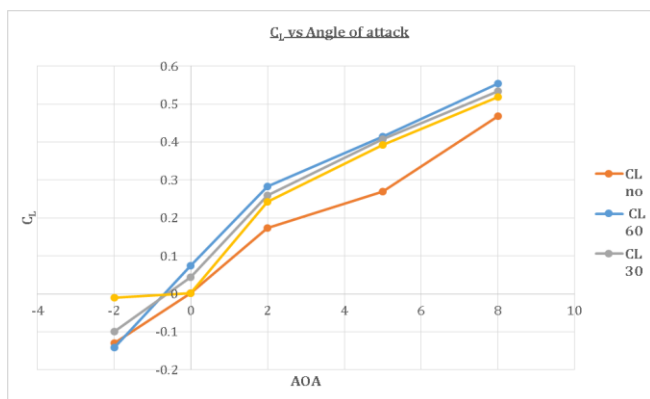
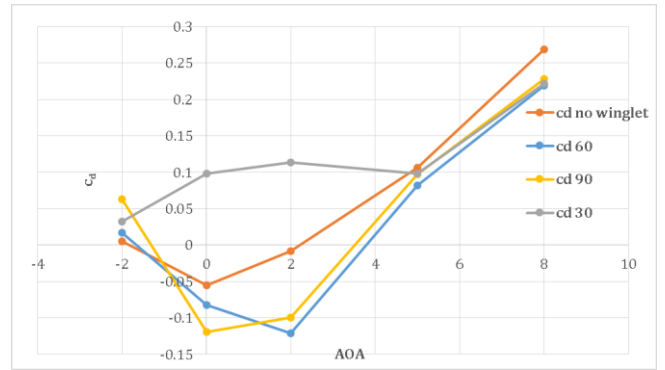

Chart -1: C_L versus Angle of attack

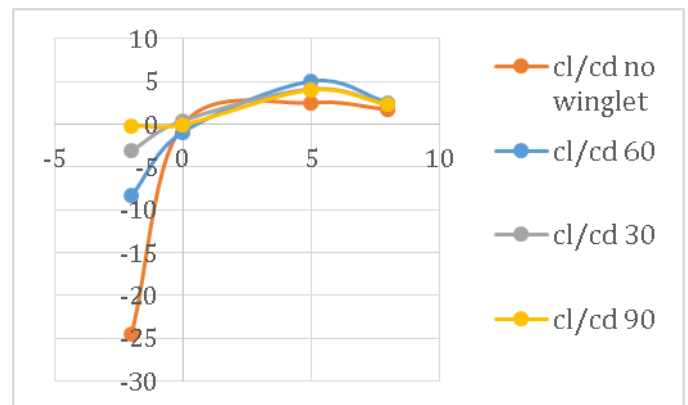**Chart -2**: C_D versus Angle of attack
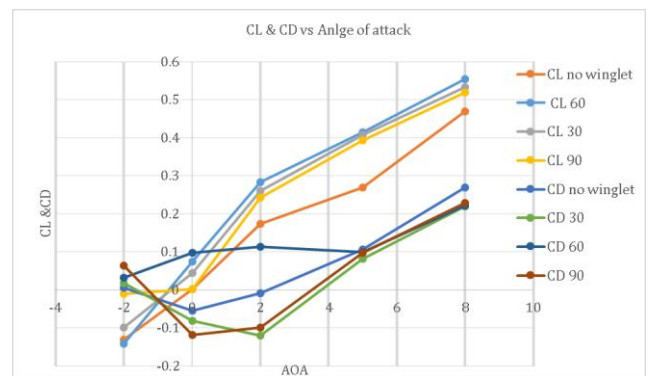

Chart -3: C_L/C_D versus Angle of attack

Chart -4: C_L&C_D versus Angle of attack

- As we can see from the path line diagram, the turbulence is more in no winglet case and is less or negligible in case of wing with winglet. This is due the ability of winglet to delay or to reduce the wingtip vortices. Winglet act as a barrier between low pressure and high pressure sides of wing, that is top and bottom.

- From the pressure contour, we can infer that, pressure distribution is more uniform in case of wing with winglet than in wing without winglet. This is because the flow is less turbulent when we place the winglet.

- From C_L graph, C_L is least for wing without winglet. For higher AOA, winglet at 60° has maximum C_L and for negative AOA winglet at 90° has maximum C_L.

- From C_D graph, C_D is maximum in no winglet case. For cant angle greater than 2°, C_D is minimum for 60° winglet and for cant angle less than 2° C_D is minimum for 90° winglet.

- From C_L/C_D graph, C_L/C_D is least for no winglet case. C_L/C_D is maximum for cant angle 30° at angle of attacks greater than 4°.For angle of attack 0° to 4°, 60° winglet has maximum C_L/C_D. For angle of attacks lesser than 0°, 90° winglet has maximum C_L/C_D.

- Thus we can conclude that winglet improves the C_L and C_D values of the wing.

5. CONCLUSIONS

The aim of this project was computational analysis of the wing without winglet and the increase aerodynamic efficiency after attaching the winglet at wingtip, also to find the aerodynamic performance with different cant angles and angle of attack. The rising cost of fuel, operating cost and increasing CO2 in atmosphere is the reason aircraft industry started researching to get efficient aircraft designs. The aircraft industries found some design modification in wing design by adding winglets to reduce the drag and air vortex but researcher will always continue to find better outcomes. In this research it was ascertained that adding the winglets to the wingtip increase the aerodynamic efficiency in terms of C_L/C_D. Furthermore, the reduction in air vortex behind the wing, was proven in this study by the adding a winglet to the wingtip.

By utilization of CFD to predict the performance of the Numerical Model of wing, large amount of time and money can be saved for testing the wing in the wind tunnel. Calculations show that trends of numerically-simulated curves are in excellent agreement with trends of experimentally-obtained ones

Thus we can conclude that, different angle of attacks has different optimum cant angles. Also optimum cant angle will be different for different airfoil section. So we cannot stick on to a single cant angle. So a varying cant angle winglet will be preferred.

ACKNOWLEDGEMENT

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