Design of Winglet Device for Aircraft

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***Abstract*—Aircraft winglet is a device placed at set of angle on the end of aircraft wing. This device plays a very important role in improving aircraft performance. The economic raise of the aircraft flight make the aircraft designer and the airline management to find a new technology to reduce the cost. After many search and study in this field the winglet design will be the best way to reduce cost. Winglet design will reduce the fuel consuming by reducing the aircraft drag and make the aircraft more stable during flight, also it will give the aircraft engine longer life by reducing the load on the engine thrust. The aim of this paper is to design and simulate a model of winglet for aircraft. Study about winglet contribution on aircraft performance in term of less fuel consumption and the stability of aircraft flying in continuation cruise flight or during take-off and landing. First author visited to Airbus Manufacturing Company to know the process and to understand how winglet devices are designed and how they contribute on aircraft drag reduction were discussed with the aircraft designing engineer. Study how winglet can reduce aircraft induced drag. Analyses about winglet effect on reducing wingtip vortex. This paper is also aim to design a model of winglet device by using software such as CATIA -V5 and ANSYS. This software play important role in time in use to make the designing, simulation and testing the designed model.**

***Keywords*– Aircraft, Drag, Vortex and Winglet**

I. INTRODUCTION

In aerodynamic engineering, drag reduction is a big challenge. To reduce this drag a device called winglet which is placed vertically at set of angle on the end of aircraft wing. Winglet is played very important role in improving the aircraft performance. Aircraft designers are performing research to improve the aircraft efficiency which will be benefit to both aircraft manufacture and the operators. The rise of operational costs has forced industry to improve the efficiency of commercial air transport and this has led to some advanced developments for reducing drag. Several different types of winglet devices have been developed to improve the efficiency and the selection of the winglet device depends on the specific situation and the airplane type.

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The first theory about the Winglet device was patented by Frederick W. Lanchester, British Aerodynamicist in 1897. But his theory could not reduce the overall drag of the aircraft despite reducing induced drag. He also claimed that the Winglet in his research shows a 20% reduction when compared to type extension of the induced drag and lift- to-drag ratio also improved [1]. In 1994, Aviation Partners Inc. (API) has developed an advance of Winglet design is called blended Winglet and its purpose is to reduce the nosiness of the drag due to sharp edges. Later, "wing grid" concept was developed by La Roche from Switzerland in 1996 and got the clear for his invention. The main purpose was to decrease the strength of the entire above Inventions wake vortex and to reduce induced drag [2].

Aircraft manufacturer has design many different type of winglet device depending on the aircraft type and size. Blended Winglet from Gratzer [3] was developed by Seattle in 1994. The unique design found in this Winglet is no sharp edge at the wing/Winglet connection and followed by smooth curve [4]. Aviation Partners Inc. (API) and the Boeing Company [5] made advance partnership in 1999 for the design of blended winglets. Mike Stowell, APB Executive Vice President mentioned about the interference drag, Aerodynamic phenomenon caused due to an crossing of lifting surfaces, Hence this was the Winglet design formed at the junction developed to overcome the drag of the wing and Winglet interference [6]. The winglets were retrofitted Boeing Business Jets and also in the B7371, now have their services in these flights, American Airlines (Southwest Airlines) and also European airlines [7]. Raked wing tip from the Boeing Company were designed by Herrick and got the patent in 2000 [8]. The tip is attached with the raked wingtip with the main higher than the sweep angle of the main wing. Jets have been designed with long-range Boeing 777 raked wingtip [9]. Wingtip fences are of a special modified both winglets that extend upward and downward from the tip of the wing. Preferred by European Airbus manufacture, it is featured on their full product range [10].

Many research works has been carried out in design and analysis of winglet devices to reduce induced drag by considering a wing of constant aspect ratio, wing area and wing span under ideal flow conditions [11]. A rectangular wing with Blended Wingtip, Raked Wingtip and Winglet are studied [12]. Configurations of different winglets are studied and designed spiroid winglet [13]. The traditional way of reducing induced-drag is to increase the aspect ratio of the wing. However, wing aspect ratio is a compromise of weight, structural load and operational constraints. The alternative solution is the use of aerodynamic structures at the end of the wing, which reduces the strength of the vortices, thus reducing the lift-induced drag. Mayer tested several wingtip shapes by adapting them to a clean wing. The performance of the wing with specific winglet relative to clean wing has been studied quantitatively and qualitatively.

II. DESIGN OF WINGLET

Winglet Airfoil: Generate enough lift while maintaining the lowest possible drag, Should not stall before wing during low speed flight, and the Geometry driven by aerodynamic characteristics of the airfoil.

Chord Distribution: The Chord Distribution is too small then the airfoil will require a large lift coefficient and when it is too big then the high winglet loading causes prematurely.

Winglet Height: The Height of the Winglet is determined by the optimal induced drag relationship.

Twist/Sweep: The Twist/Sweep angles have similar effects on the winglet and they fit the load distribution.

Toe Angle: It controls overall loading on winglet, Effects the load distribution on main wing and it is only optimum for one flight condition.

CATIA (Computer Aided Three - Dimensional Interactive Application) started as an in-house development in 1977 by French aircraft manufacturer Avionics Marcel Dassault. Its computer software used to make 3D design with high performance and excellent view for all design details. This software is used to develop the template of winglets devices. Dimensions are selected for the sketch of the model shown in Fig. 1 and Fig. 2 as taken as example of aircraft size such as Airbus A320 will be set as follows:
Sweep rad=223.072mm, tip base=31.375 mm, seep rad=233.072mm, length vertical=1111.466mm, length leading edge=1144.74 mm.

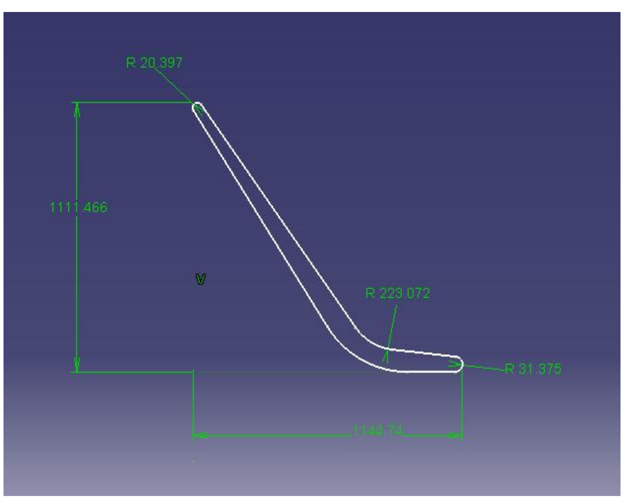

Fig. 1. Geometry of winglet model

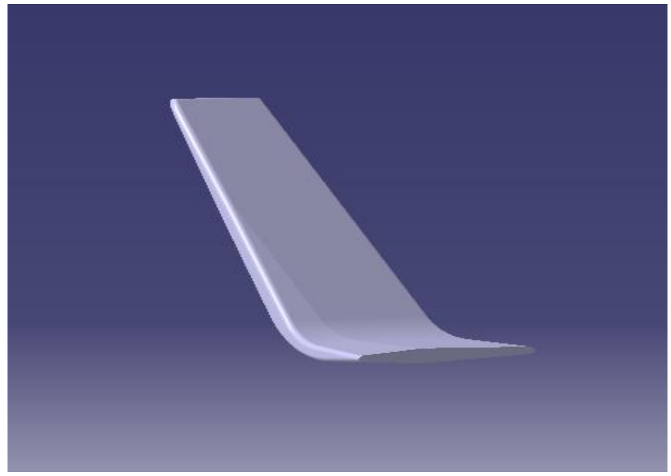

Fig. 2. Solid Winglet model

The generative shape design module of CATIA V5 is used to construct the winglet models. Computational domain is also created using CATIA V5. The dimensions of the computational dimensions are as follows:

- Far field Top = 2.5L (L = Fuselage length)
- Far field Bottom = 2.5L
- Far field side = 2.5L
- Upstream = 2.5L
- Downstream = 5L

ANSYS: ANSYS work pinch-14.0 is used to test and simulate the winglet model in two different speeds at 300Km/hour as take-off speed and 1500 Km/hour as cruse speed. Some pre design setting require on the software as shown in Fig. 3 and Fig. 4:

- Using fluid flow
- Save as IGS
- Geometry-mm dimension
- File-import from CATIA as geometry file
- Using mish tool –fluent launcher

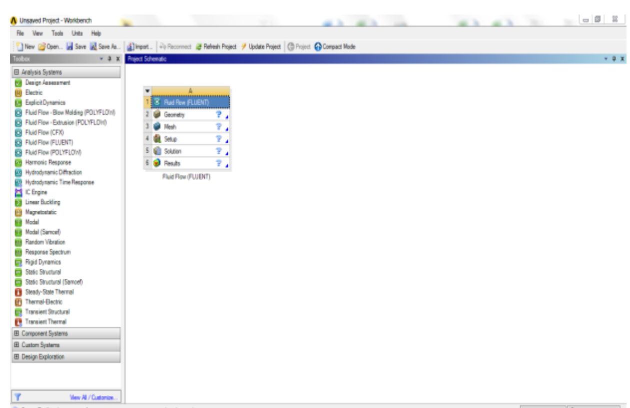

Fig. 3. ANSYS Fluent flow

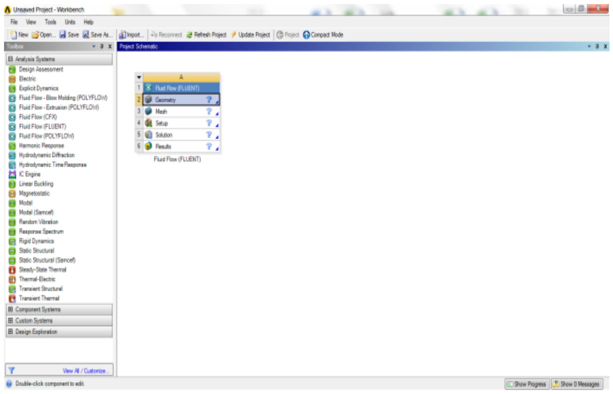

Fig. 4. ANSYS Fluent flow-Geometry

Testing procedure

On ANSYS

1. System select fluid flow (FULENT)
2. Select fluent flow-Geometry as show on Figure.5.

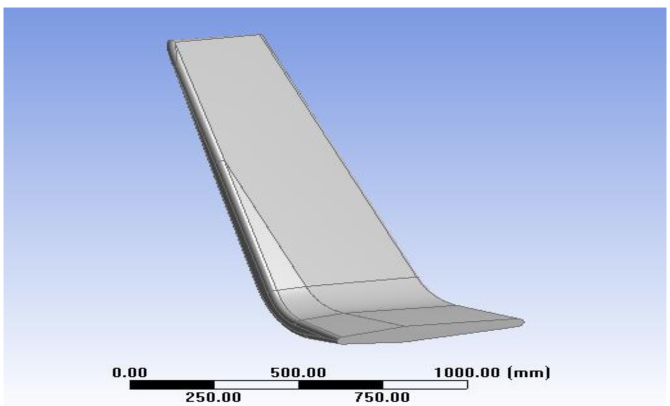

Fig. 5. Solid Geometry of winglet

Mesh Procedure:

The meshing are carried out in for winglet unstructured tetra elements as shown in Fig. 6 and Fig. 7 are selected for these computations. As per the boundary layer calculation, boundary layer thickness is calculated as 10.4 mm and Reynolds number as 7, 23,670 (for the Aircraft speed 20m/s). 12 layers are used inside the boundary layer for both the cases.

The mesh details of the as follows:

- Element type : Unstructured Tetra elements
- Total elements : 2757733
- Total nodes : 491323
- Geometry
- physics preference: CFD
- Solver Preference: Fluent
- Select all the surface required to carry the mesh

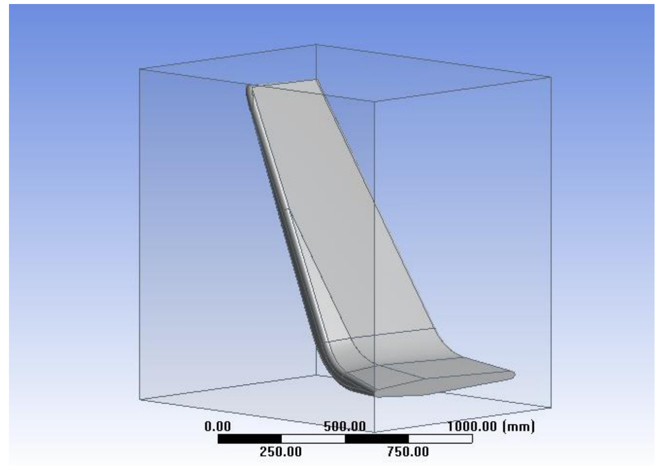

Fig. 6. Mess Box

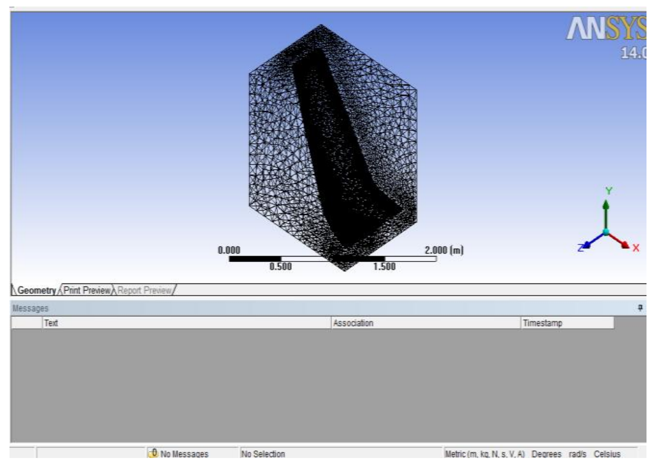

Fig. 7. Mess

Apply front geometry for two sides as air inlet and air outlet as show in Fig. 8 and Fig. 9. After meshing the selection of boundary conditions is made. The selected boundary conditions are represented in the Table 1.

Table 1: Boundary conditions

Component	Boundary type
Inflow	Velocity Boundary (20m/s)
Outflow	Pressure Outlet
Aircraft	Wall
Far field	Slip
Symmetry	Symmetry option

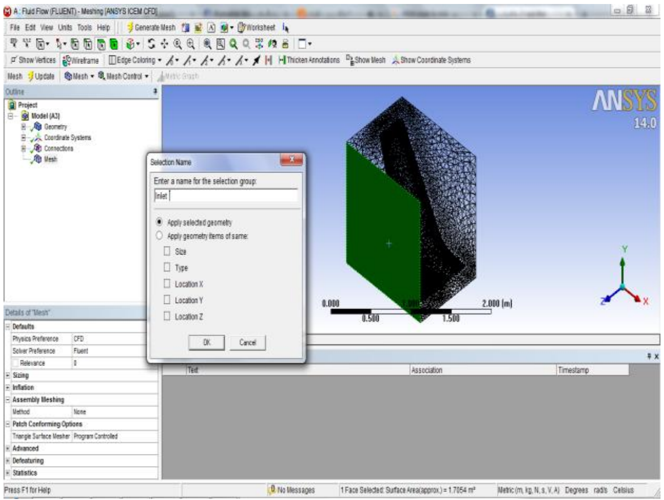

Fig. 8. Geometry as air inlet

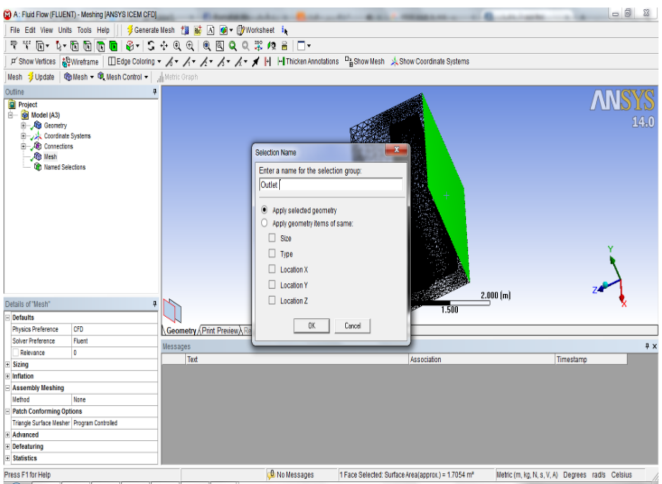

Fig. 9. Geometry as air outlet

- Select material use air as fluid and aluminum as material as show in Fig. 10.
- Set up the air density(kg/m3) =1.225 (constant)
- Viscosity(kg/m-s)=1.7894e05 (constant)

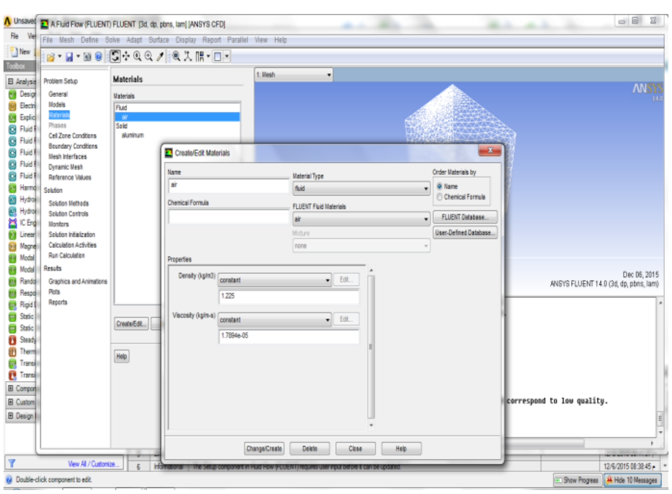

Fig. 10. Material settings

Mesh scale is show in Fig. 11.

- Boundary Condition-zone
- select contact region on Blue
- Select outlet region in Red
- Select testing body in yellow
- Select air inlet and apply air velocity magnitude(m/s) =416.66
- Select solver type= pressure-Based
- Select velocity formulation =absolute
- Select time =steady

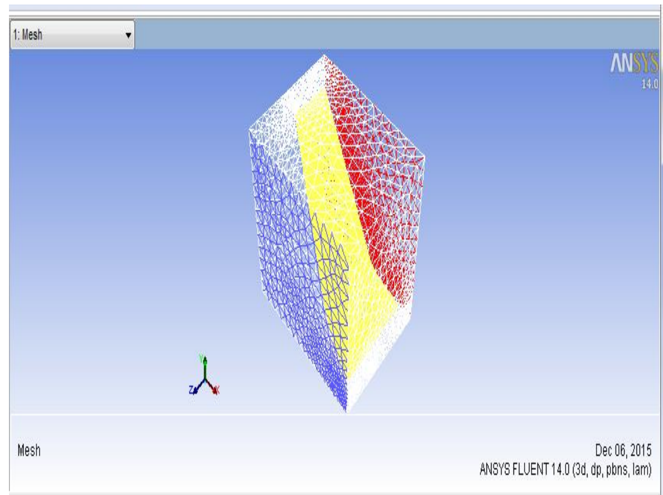

Fig. 11. Material scale

At air speed 350 KM

- For run calculation set the follow parameters
- Number of iteration=5
- Profile file update interval=1
- Reporting interval=1
- Apply pressure =0.0ems to 4.540e
- Set up velocity as 350 KM on the front inlet
- Run the solution

The results obtained are represented in Fig. 12 and Fig. 13.

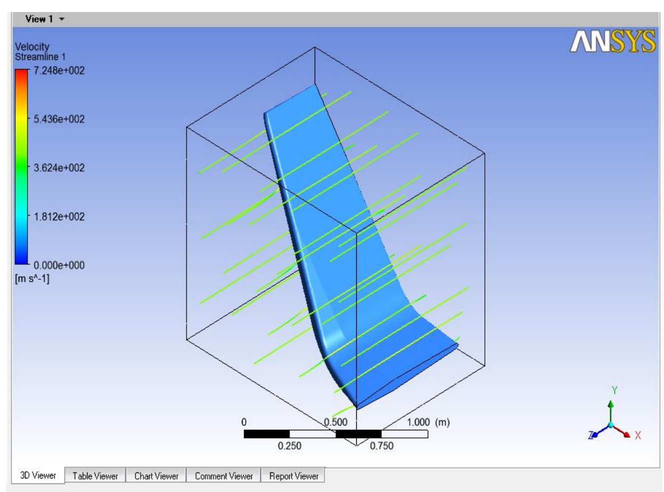

Fig. 12. ANSYS simulation at air speed 350KM

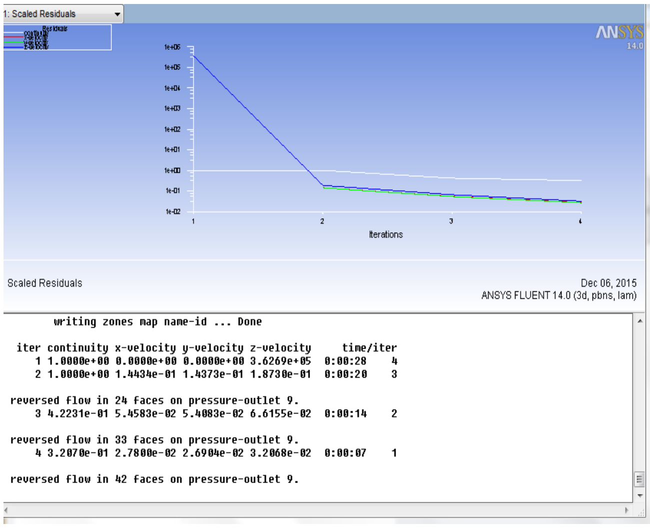

Fig. 13. ANSYS result scale at air speed 350KM

At air speed 800 KM

- For run calculation set the follow parameters
- Number of literation=10
- Profile file update interval=1
- Reporting interval=1
- Apply pressure =0.0ems to 7.250e
- Set up velocity as 800 KM on the front air inlet
- Run the solution

The results obtained are represented in Fig. 14 and Fig. 15.

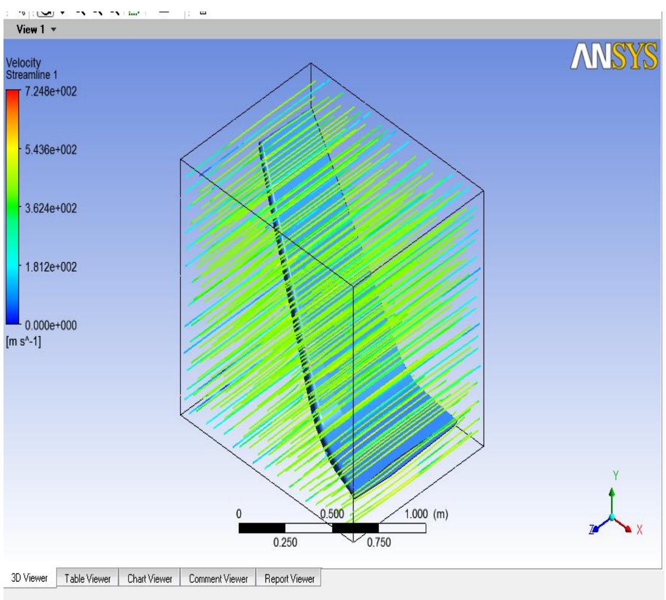

Fig. 14. ANSYS simulation at air speed 800KM

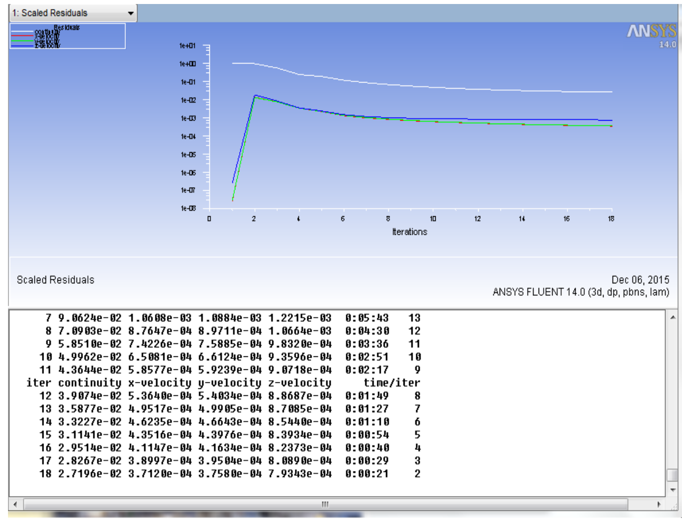

Fig. 15. ANSYS result scale at air speed 800KM

At air speed1300 KM

Cruise velocity -Fluent

- File → Read → Case. select the mesh file Navigate to the working directory and.
- Grid → Check. would be reported at this time any errors in the grid.
- Grid → Info → Size.
- Grid → Scale. We must define grid units
- For run calculation set the follow parameters
- Number of literation=20
- Profile file update interval=1
- Reporting interval=1
- Apply pressure -110753pa to 758511.1pa
- Set up velocity as 1300 KM on the front air inlet
- Run the solution

The results obtained are represented in Fig. 6 and Fig. 17.

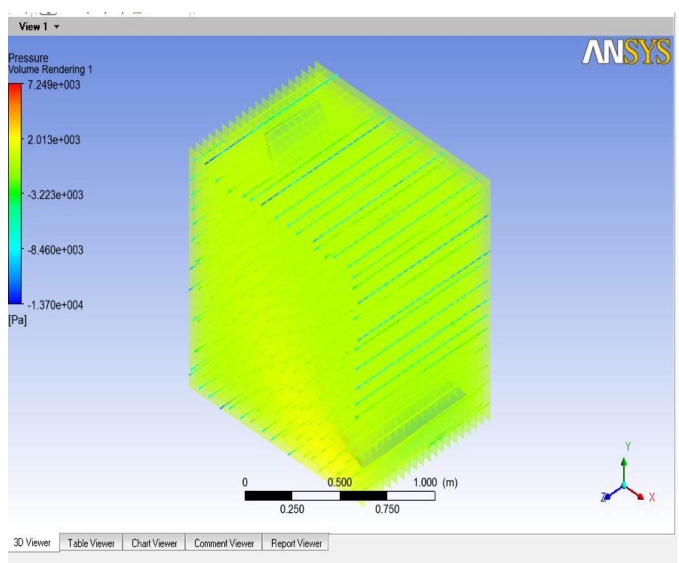

Fig. 16. ANSYS simulation at air speed1300KM

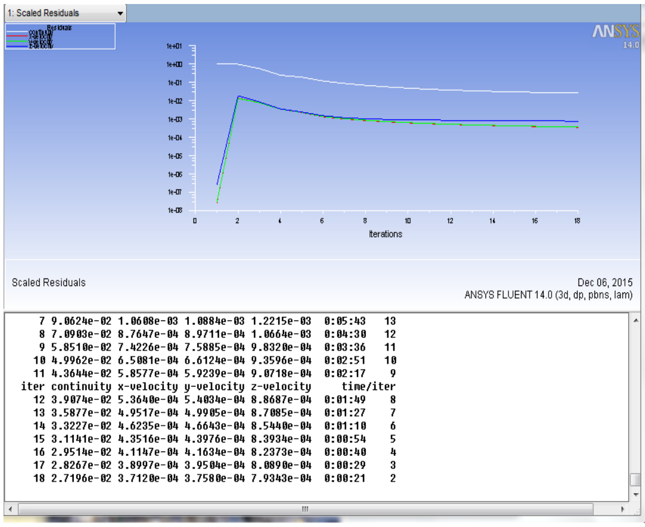

Fig. 17. ANSYS result scale at air speed 1300KM

III. RESULT AND DISCUSSION

Induced Drag: The first object of this project is to find the induced drag contribution in aircraft performance by theoretical approach. From the previous study and research all of them shown are that the winglet device is very good technology to reduce aircraft induced drag. It can reduce up to 7% overall drag [14]. Winglet will increase the angle of attack very quickly during tack-off and the aircraft as show in Table 2 and Fig. 8, will reach its altitude faster than aircraft without winglet, thus will led to used lower engine thrust which will give the engines more time live and low maintenance require.

Table 2: Angle of attack

Angel of Attack							
	speed						
	100	200	300	400	500	600	700
Winglet	0	0.5	35	45	45	48	51
Without Winglet	0	0.5	35	42	43	45	52

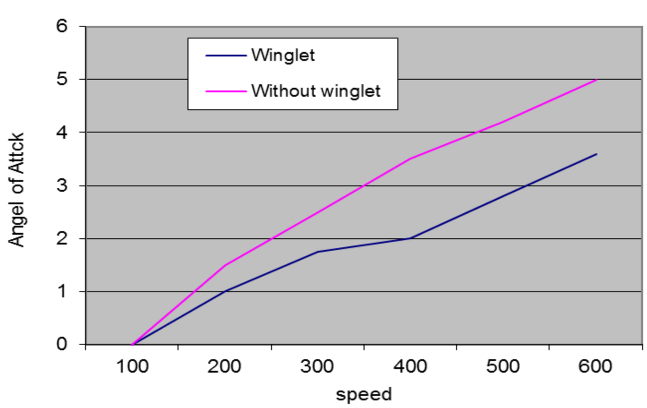

Fig. 18. Angel of attack chart

Aircraft performance: The second objective is to analyze the aircraft performance with and without winglets. The winglet is wake the Vortex and spread them away from the aircraft body witch make the aircraft more stable during cruise flight. Start from this point as dead line will study the effect of winglet in term of fuel consumption due to less drag on aircraft body. This will make the aircraft use less fuel, so it will make it longer flight range without need refueling which will be benefit for the aircraft operator in two ways. First low cost and second will make their flight quicker rather than stop for refuel. Table-3 show the fuel consumption for the same aircraft with same distance of distention and the result are shown in Fig. 19.

Table 3: Cruise Mode 0.8 M

Cruise mode M=0.8			
A/C	Fuel consumption	Rang in KM	% improve
Winglet	37.39	8096.6	0
Without Winglet	38.86	7790.3	3.78

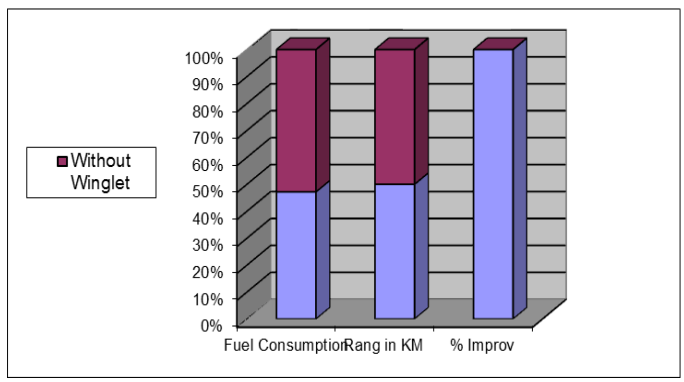

Fig. 19. Cruise mode chart

Take-off distance: The third objective is to study and analyzing the take-off distance for aircraft with and without winglet. Winglet will reduce take-off time by increasing the angle of attack by improving the airflow movement around the aircraft body and reducing the effect of the vortex. Fig. 20 shows the aircraft velocity on take-off and how the aircraft climb rabidly with winglet device. The Aircraft specifications are tabulated in Table 4 for Airbus A320 (source:www.airbus.com).

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Table 4: Aircraft Airbus A320 Specification

Airbus A320 specifications	
MTOW	7800kg
Wing span	34
Wing span (with winglets)	36
Root Chord	7m
Range	6150 km
Payload	16.6 tons
Take off distance	1500 m
Engine Specification	
Type	CFM56
Number of Engines	2
Take-off Thrust	23,500 lbs.

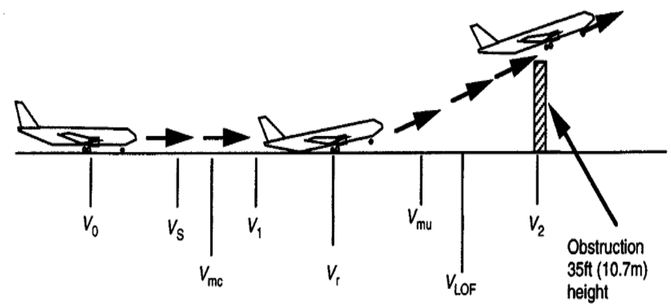

Fig. 20. Take-off Distance phenomena (http://www.diva-portal.org/)

Winglet Design: In this work, winglet design model is chosen by taking Airbuse-A320 as example which has wing span of 35.8m from wing tip to wing tip and it's rectangular in shape. The winglet dimension is 1.45m in height. After the design is made on CATIA-V5, the simulation is performed using ANSYS software to check the strength of the winglet on three different speeds at 350 km per hour as take-off speed and 800 Km per hour & 1200 km per hour as cruise flight speed. From the Fig. 22 it's shown that the flow of the fluid on the module is speared away from its direction of flow, that's mean the winglet is in good design. Also the winglet can handle the pressure applied on it which about 11075Bar, this pressure equal to the pressure on the wingtip during cruise flight at speed of 1300 km per hour. After the setup of the pressure the applied fluid showed the strength of the winglet to accept the high pressure without fail or weakness in its structure. This module was design to be fitted in single aisle aircraft such as Airbus A320. The design takes the specification from Airbus Industry for dimension and material. Aluminum alloy is used in this module as material and solid shape is used for designing. After the module is designed in CATIA v5 software, the ANSYS software is used to do the simulation to check the designed module for strength and its ability to reduce the drag. When the simulation is carried out we found that, the winglet is capable to handle high pressure which reach about 7240 Bar. Also the module is reducing the drag made by the fluid witch is air selected on the system and plot the graph as shown the Fig. 21

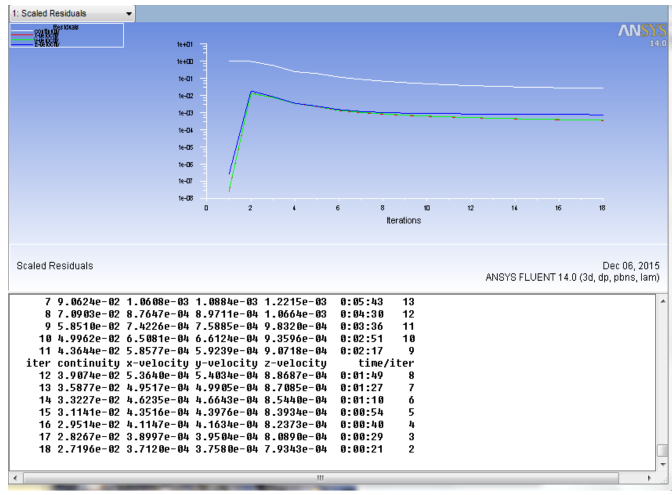

Fig. 21. Drag reduction by winglet

IV. CONCLUSION

From the study of different types of winglet devices and analysis of their contribution in aircraft performance, it is understood that the winglet is the good technology to improve the aircraft performance in term of less fuel consumption. The winglet will reduce the use of aircraft engine at high power so the engine life will be increased. Winglet will increase the angle of attack very quickly during tack-off and the aircraft will reach its altitude faster than aircraft without winglet, thus will led to used lower engine thrust which will give the engines more time live and low maintenance require. The effect of winglet in terms of fuel consumption due to less drags on aircraft body. This will make the aircraft use less fuel, so it will make it can make longer flight range without need refueling which will be benefit for the aircraft operator in two ways. First low cost and second will make their flight quicker rather than stop for refuel. To perform a design of winglet device require a lot of information to gather and make in your consideration before do so. The aircraft size, its weight during tack off, type of wing fitted and so on. In this paper the design has been made by using CATIA-V5 software. ANSYS software is used for fluid simulation. The simulation made on three different speeds, taken speed of 350 km per hour as tack off speed. Then increase the speed to 800 km per hour and make the simulation, this speed can be used during the preparing for landing in negative angle of attack at about -35. The last simulation was made at speed of 1300 km per hour which is the most cruise flight speed. From all the three different speed it can show that the winglet will spread the vortex away from the aircraft body which mean the drag will be reduce on the aircraft tail plane that's make the aircraft more stable at cruise flight. Form all the above result it can concluded that the winglet device is a good technology to enhance the aircraft performance in term of less fuel consumption, more stable cruise flight, less engine load during tack off by reaching the require altitude faster than aircraft without winglet.

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