[Balakrishnan*, 2.(8): August, 2015]
ISSN 2349-6193
Impact Factor (PIF): 2.243

IJESMR

International Journal OF Engineering Sciences & Management Research

DESIGN MODIFICATION OF WINGLET CONCEPT TO INCREASE AIRCRAFT'S EFFICIENCY

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Keywords: (Trailing vortex; aerodynamic efficiency; wave drag mach number; profile drag; lifting surfaces; coefficient of drag).

ABSTRACT

Winglets are small wing-like lifting surfaces, fitted at the tips of some wings, usually with the objective of decreasing the trailing vortex drag and thereby increasing the aerodynamic efficiency of the basic wing. Fitting winglets can provide improvements in aerodynamic efficiency for a range of lift and Mach number conditions by decreasing the trailing vortex drag by amounts that more than compensate for any increases in the profile and wave drag contributions. The project intends to show the influence of winglets on aircraft wings by comparing both wings with and without winglets and also by analyzing different shapes of winglets on a wing. The wing used for this purpose is the Boeing 737 variant wing. All the design including that of the wing and the winglets were done using CATIA V5 software. The analysis of the wing and winglets are done by using FLUENT software.

The project studies the difference in the coefficient of drag on the wing with the use of winglets and different shapes of winglets are analyzed and their respective drag coefficients are studied. Then a new winglet is constructed with the design software and flow over that winglet is analyzed. The result shows the difference in drag with and without using the winglet and also by using different shapes of winglets.

INTRODUCTION

A winglet is a near-vertical extension of the wing tips. The upward angle (or cant) of the winglet, its inward or outward angle (or toe), as well as its size and shape are critical for correct performance and are unique in each application. The wingtip vortex, which rotates around from below the wing, strikes the cambered surface of the winglet, generating a force that angles inward and slightly forward, analogous to a sailboat sailing close hauled. The winglet converts some of the otherwise-wasted energy in the wingtip vortex to an apparent thrust [5].

This small contribution can be worthwhile over the aircraft's lifetime, provided the benefit offsets the cost of installing and maintaining the winglets. Another potential benefit of winglets is that they reduce the strength of wingtip vortices, which trail behind the plane. When other aircraft pass through these vortices, the turbulent air can cause loss of control, possibly resulting in an accident. This possibility is greatest near airports, where slow approach and departure speeds create the strongest vortices, and the minimum spacing requirements between aircraft operations at airports is largely due to these vortices.

Winglets produce an especially good performance boost for jets by reducing drag, and that reduction could translate into marginally higher cruise speed. But most operators take advantage of the drag reduction by throttling back to normal speed and pocketing the fuel savings. Large winglets such as those seen on Boeing 737 aircraft equipped with blended winglets are most useful during short-distance flights, where increased climb performance offsets increased drag. Raked wingtips are now preferred over small winglets for long-distance flights, where increased fuel economy during the cruise phase is more important.

PURPOSE OF WINGLETS

General

Designed as small aerofoils, winglets reduce the aerodynamic drag associated with vortices that develop at the wingtips as the airplane moves through the air. By reducing wingtip drag, fuel consumption goes down and extended range. Winglets have become one of the industry's most visible fuel-saving technologies and their use continues to expand.
Winglets are aerofoil's operating just like a sailboat tacking upwind produce a forward thrust inside the circulation field of the vortices and reduce their strength. Weaker vortices mean less drag at the wingtips and lift is restored.

Improved wing efficiency translates to more payloads, reduced fuel consumption, and a longer cruising range that can allow an air carrier to expand routes and destinations.

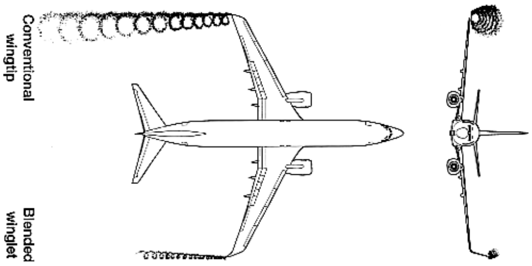

Fig.1.Evident Tip Vortices

Tip Vortices

Wingtip vortices are tubes of circulating air which are left behind a wing as it generates lift.

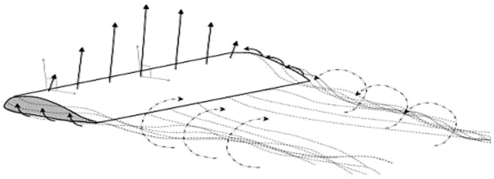

Fig.2.Tip vortices on an aerofoil producing lift

Wingtip vortices are tubes of circulating air which are left behind a wing as it generates lift. One wingtip vortex trails from the tip of each wing. The cores of vortices spin at very high speed and are regions of very low pressure.

A wing generates aerodynamic lift by creating a region of lower air pressure above it. Fluids are forced to flow from high to low pressure and the air below the wing tends to migrate toward the top of the wing via the wingtips. The air does not escape around the leading or trailing edge of the wing due to airspeed, but it can flow around the tip. Consequently, air flows from below the wing and out around the tip to the top of the wing in a circular fashion. This leakage will raise the pressure on top of the wing and reduce the lift that the wing can generate. It also produces an emergent flow pattern with low pressure in the center surrounded by fast-moving air with curved streamlines. Air at each wingtip to flow outward along the lower surface, around the tip, and inboard along the upper surface producing a whirlwind of air called a wingtip vortex. The effect of these vortices is increased drag and reduced lift that results in less flight efficiency and higher fuel costs.

Effect of Vortices-induced drag on Total drag

- The generation of lift by the wing causes wing tip vortices.
- The tip vortices increase the induced drag on the wing KC_L^2increases.
- Total drag C_D directly related to Induced drag C_{Di} therefore Total drag C_D increases.
- With increase in Total drag the fuel consumption increases & the range decreases.

Types:

Main types of winglets [4] used on aircrafts are as follows:

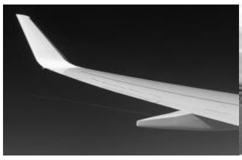

Fig.3.Blended Winglets

Fig.4. Raked Wingtips

Fig.5.Wingtip Fence

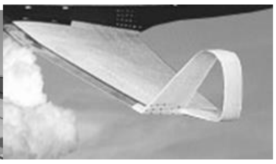

Fig.6.Spiroid Winglets

A net aerodynamic performance improvement made possible by wingtip modifications is satisfying to an engineer, but for an airplane manufacturer or operator the objective is to realize the kind of bottom-line benefits that translate into real savings as measured by cost, noise, engine exhaust emissions, operational flexibility, etc. The potential bottom-line benefits of wingtip devices are reduced fuel burn, increased capability, and improved performance, described below in order of importance[11].

Reduced fuel consumption

By reducing drag, wingtip devices help the aircraft operate more efficiently and, in turn, reduce fuel burn. The fuel savings benefits of wingtip modifications depend on the mission flight profile, particularly the range and time spent at cruise speed. Commercial experience with winglet retrofits on the Boeing 737-300/700/800 indicate a 1.5 percent block fuel savings for trips of 250 nautical miles (nmi), increasing to 4 percent for trips of 2,000 nmi.15 For the Boeing 757-200 and 767-300, block fuel savings were 2 percent for 500 nmi trips and 6 percent for 6,000 nmi. On an annual basis, winglets were projected to result in savings to commercial operators of up to 130,000 gallons of fuel per aircraft on the 737-800 and up to 300,000 gallons per aircraft on the 757-200.16 reduced fuel consumption translates directly into a reduction in cost of operation and increases the income of the particular airliner.

Increased payload-range capability

If less fuel is required to accomplish a particular mission at a specific takeoff weight, then that credit can be realized in more than one way. For example, the aircraft can carry more weight (more payload) the same distance or it can carry the same payload farther (greater range). Figure shows the increase in payload-range capability made possible by winglets on one commercial aircraft, the Boeing 737-800.

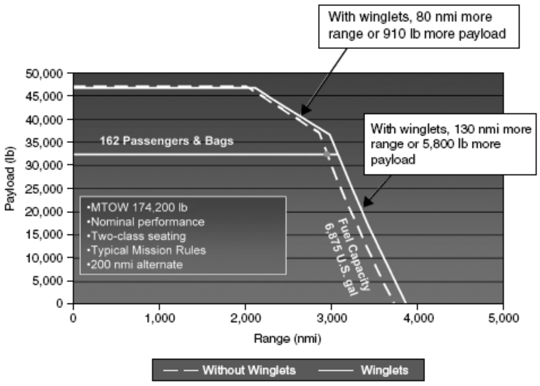

Fig.7.Payload – Range Capability Comparison

The benefits begin to become apparent for ranges beyond 2,000nmi. Between the 2,000 and 3,000nmi range, winglets enable 80 nmi more range or 910 lbs. more payload. Beyond the 3,000 nmi range, winglets allow for 130 nmi more range or 5,800 lbs. more payload.17 In the commercial world, this capability translates into operational flexibility—for example, it offers a greater choice of aircraft along certain routes or the opening up of new routes and destinations that were not previously within range. The increased payload-range capability is valued in military aircraft applications just as it is in commercial aircraft applications. Carrying more payloads to the same distance could mean fewer sorties to accomplish a specific goal, or it could allow servicing more customers with the same number of operational aircraft.

Improved take-off performance

The reduced drag associated with wingtip modifications reduces the thrust levels required for takeoff (reducing community noise at the same time) and enables faster second-segment climb. This increased climb rate allows the use of airports having shorter runways and allows for operations from airports located at higher altitudes and in hotter climates. Alternatively, these advantages may be traded for carrying higher payloads or a combination of both.

Reduction in emissions

Operators of blended winglets are able to gain the additional environmentally friendly benefit of reducing engine emissions and community noise. CO2 emissions are reduced in direct proportion to fuel burn, so a 5 percent reduction in fuel burn will result in a 5 percent reduction in CO2. Nitrogen oxide (NOx) emissions are reduced in percentages that are a function of the airplane, engine, and combustor configuration.

Reduction in noise levels

At airports that charge landing fees based on an airplane's noise profile, blended winglets can save airlines money every time they land. The noise affected area on takeoff can be reduced by up to 6.5 percent. With requirements pending in many European airports for airplanes to meet Stage 4/Chapter 4 noise limits, the addition of blended winglets may result in lower landing fees if the winglet noise reduction drops the airplane into a lower-charging noise category. The noise reduction offered by blended winglets can also help prevent airport fines for violating monitored noise limits.

Cost

The costs of a wingtip modification retrofit include the nonrecurring costs for engineering, for modification of the wing itself, and for tip device design, manufacturing, and installation. To determine if a wingtip modification is cost-effective, the extent and cost of the nonrecurring engineering and of modifying the existing wing must be calculated. The wing modification costs depend on specific wing characteristics, including structural margins and loadings, as well the strength remaining in light of structural fatigue and corrosion. The wing modifications required to accommodate a tip device could be extensive.

Currently, a winglet retrofits kit for a suitable narrow-body commercial jetliner like the Boeing 737 costs from $500,000 to $1 million per aircraft. For a wide-body like the Boeing 767, the costs are between $1 million and $1.5 million. For a jumbo-sized aircraft like the Boeing 747, the costs would probably be higher. Winglets may have a smaller nonrecurring statement of work than other means of achieving similar improvements like a re-engine program.

Added Weight

There are two components of added weight: (1) any modifications to the wing that might add weight (e.g., stiffening of the wing to satisfy static and dynamic requirements) and (2) the weight of the winglets themselves. As examples, commercial designs have yielded total modification weights (winglet plus wing modification) of 340 lb for the 737-700 and 1,358 lb for the 757-200ER.21

Added Span & Height

The height of a winglet varies but can be as great as 10-20 ft. A winglet can also increase the wingspan by several feet. These dimensions impact airfield operations such as parking, taxiing, and maneuvering the aircraft on the ground. If space is critical, a few additional feet of span per aircraft could limit the number that can be on an airfield at any given time, also known as “maximum on ground.” This could constrain throughput for cargo and tanker aircraft, in particular. Winglet height could be an issue if there are obstacles that the winglet would hit when parking or taxiing, damaging both the winglet and obstacle. However, winglets may be more compatible with existing infrastructure than, say, wingtip extensions.

Interference with other Wing Equipment

Wingtip modifications might also impact other wing requirements. For example, a winglet might interfere with antennas or sensor equipment on military airplanes. Wingtip modifications might also impact airplane lighting solutions, anti-icing system requirements, and lightning strike dissipation solutions. Winglets can be efficient ice collectors and raise ice protection issues. Such problems should be thoroughly assessed before committing to any wingtip modification solution. Also, wingtip modifications may alter the effectiveness of high lift or control devices by changing their aerodynamic loading either favorably or adversely. Wings with outboard lateral control devices (ailerons, spoilers, and the like) may be particularly susceptible to changes resulting from the addition of a wingtip device such as a winglet or a wingtip extension.

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Flutter

The flutter [1] characteristics of an airplane are evident at high speed when the combined structural and aerodynamic interaction can produce a destabilizing or divergent condition. Under such circumstances, an airplane with winglets is sensitive to the weight and center of gravity (CG) of the winglets and associated structural wing changes. Additional weight near the wingtip, either higher than or aft of the wing structural neutral axis, will adversely affect flutter.

Fig.8.Winglet Modification Statistics

Southwest Airliners 737 Winglet Modification Summary

Aircraft Type	Retrofit Weight Increase (lb)a	Production Weight Increase (lb)b	Increase in Wing Dimensions Attributable to Winglets	Block Fuel Savings (%)
737-700 (Non provisioned Wing)	340	N/A	8 ft 2 in. (Height) 6 ft 4 in. (Span)	2.4 to 4.0
737-700 (Provisioned Wing)	241	220	8 ft 2 in. (Height) 6 ft 4 in. (Span)	2.4 to 4.0
737-300	783 to 801	N/A	7 ft 6 in. (Height) 8 ft 10 in. (Span)	2.6 to 4.4

American Airliners 737-800 and 757-200 ER Winglet Modification Summary

Aircraft Type	Retrofit Weight Increase (lb)a	Production Weight Increase (lb)b	Increase in Wing Dimensions Attributable to Winglets	Block Fuel Savings (%)
737-700 (Non provisioned Wing)	520	N/A	8 ft 2 in. (Height) 4 ft 7 in. (Span)	3.2
737-700 (Provisioned Wing)	380	380	8 ft 2 in. (Height) 4 ft 7 in. (Span)	3.2
737-300	1,358	N/A	8 ft 2 in. (Height) 9 ft 9 in. (Span)	3.3

Define The commercial experience is that wingtip modifications make sense if one can achieve a 3-5 percent fuel burn improvement, if careful engineering analysis shows that the aircraft have sufficient structural integrity to easily accept wingtip extensions or winglets, and if the modifications are relatively easy to install. The airlines have been able to overcome with little difficulty the initial concerns relating to the added wing height and wingspan in hangars, at gates, and on taxiways. Only one military-unique aircraft, the C-17, features winglets. Designers had a choice of either increasing the wingspan or using winglets to achieve the desired performance, and winglets were chosen because they minimize problems relating to taxi clearance, turning radius, maneuverability, and parking. However, the C-17 design was done before modern analysis and optimization tools were fully developed, and application of these tools could further improve the C-17's aerodynamic performance. As discussed earlier, the retrofit potential of some other military aircraft, such as the KC-10 (based on the DC-10 airframe) and the KC-135 (which is closely related to the Boeing 707 airframe), has been studied and found promising. Other military-unique aircraft, such as the C-5, would require extensive engineering analysis before a judgment could be made.

DESIGN CONSIDERATION

Apart from the selection of a winglet airfoil, there were five key parameters that had to be chosen to optimize the design:

- Cant angle
- Twist distribution
- Sweepback
- Taper ratio
- Ratio of winglet root chord to sailplane tip chord
- Winglet Airfoil

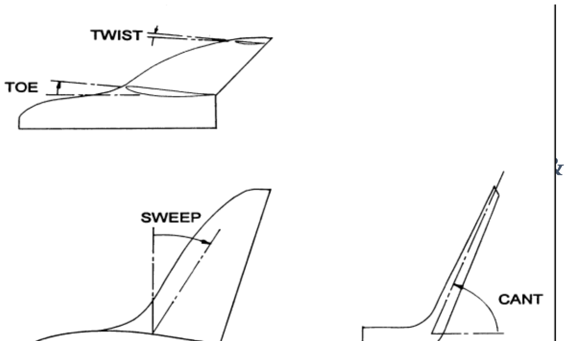


Fig.9.Design Angles

Cant Angle

On winglets that are nominally set to a cant angle of 0 degrees (at right angles to the wing), as the wing deflects, the winglet generates a side load in flight which has a component oriented downward. This is a self-defeating situation, since the winglet generating additional drag by contributing to the weight of the aircraft.

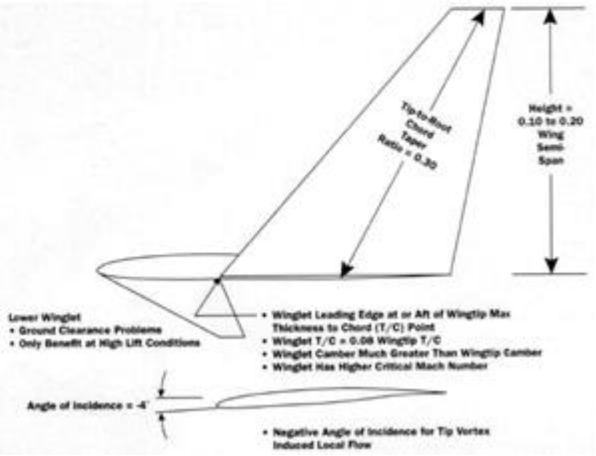


Fig.10.Classic Winglet Design

Thus a more reasonable approach is to set the winglets at least at a cant angle on the ground of 0 degrees plus the in-flight local tip deflection angle.

Sweep back Angle

The selection of the sweepback angle was based on experimental observations. It was first believed that the sweepback angle for the winglet should be equal to that for the main wing (0 degrees), however experience proves otherwise. If a vertical winglet with no sweepback is built, it will be observed that the root of the winglet will stall first and that the tip will remain flying [1].

The optimum situation from an aerodynamic standpoint is to have the aerodynamic loading such that the entire winglet surface stalls uniformly. This can be achieved by sweeping back the winglet, which will increase the loading on the tip. Because of the rapid variation in angle of attack of the winglet as a function of height, a large degree of sweepback is required to bad the tip correctly.

Ratio of Winglet root chord to Wingtip root chord

It would seem that the winglet might ideally be designed as an extension of the wing, and thus the optimum winglet would be a smooth transition of the wing from horizontal to vertical. Experiments suggest otherwise.
If the root chord of the winglet is equal to the tip chord of the wing, then the inflow angle at the tip will be less than when the winglet is a smaller fraction of the tip chord. The result will be that at high speed, the inflow angle may not be sufficient so as to prevent separation of the airflow from the outer (lower) surface of the winglet. Since other considerations require that a toe-out angle be set (about degrees), it is desirable to allow some vortex induced flow to wrap around the wingtip and provide a positive angle of attack for the winglet at all flight speeds.

Twist Distribution

The twist distribution on a winglet is normally selected so as to provide a uniform load distribution across the winglet span. Since the inflow angle is higher at the base, the winglet is twisted to higher angles of attack toward the tip. This is opposite to the general design methodology for wings, which normally have washout so as to decrease the angle of attack towards the tips.

By twisting the winglet to increase the angle of attack at the tip, the entire surface of the winglet could be made to stall simultaneously. Two degrees of twist from root to tip proved to be optimum.

The second benefit of positive twist on the winglet is that the high speed performance is enhanced-there is less likelihood of developing separation on the outer surface of the winglet at low inflow angles.

Taper Ratio

As taper ratio increases, the optimum twist distribution for the winglet varies more linearly from root to tip. From a construction standpoint it is also easier and more accurate to build a winglet with a linear change in twist angle along the winglet span. This favors a winglet with a larger tip chord. We also want to try to maximize the tip chord so as to maximize the Reynolds's number

Toe-out

The determination of toe-out was based on the simple consideration that we were trying to maximize the speed at which no further benefit is gained from the winglet, and thus select an angle of attack (alpha) setting for the winglet that will minimize the high speed drag [1].

Winglet Aerofoil

The winglet airfoil was designed with the following considerations:

- To minimize drag at low CL conditions.
- To design the winglet airfoil to be tolerant of low Reynolds number

The airfoil has the traditional under camber removed from the lower surface trailing edge area, which minimizes the tendency to form detrimental laminar separation bubbles at low or negative angles of attack.

The design process of the wing and its winglet are explained in the following sections. The details of the wing construction and wing modifications are specified in the following sections.

SPECIFICATIONS OF WING

The wing chosen for the design and analysis is the single-span wing of Boeing 737-800 aircraft. There were three aerofoil's chosen for the overall design of this wing- root, mid-span and outboard. The details are given below:

Wing span : 34.32
Gross area : 124.58
Aspect ratio : 9.45
Taper ratio : 0.159
Root Chord (%) : 7.88
Tip chord(%) : 1.25
Dihedral : 6 degrees
Sweep angle : 25.02 degrees

A. Aerofoil's

The wing was constructed by combining three different sections of aerofoil's root, mid-span and the outboard aerofoil's. The details of the aerofoil sections are given below,

Root
Thickness : 15.4%
Camber : 1.9%
Trailing edge angle : 14.2°
Lower flatness : 21.9%
Leading edge radius : 4.1%

Max C_L angle : 1.24
Max C_L angle : 15.0
Max L/D : 33.158
Max L/D angle : 5.5
Max L/D C_L : 0.907
Stall angle : 4.0
Zero-lift angle : -1.5

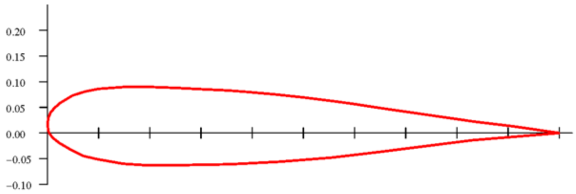


Fig.11.Root Aerofoil

Mid-span

Thickness : 12.5%
Camber : 1.5%
Trailing edge angle : 12.2°
Lower flatness : 43.2%
Leading edge radius : 2.2%
Max C_L angle : 1.183
Max C_L angle : 15.0
Max L/D : 40.179
Max L/D angle : 7.0
Max L/D C_L : 1.055
Stall angle : 7.0
Zero-lift angle : -1.5

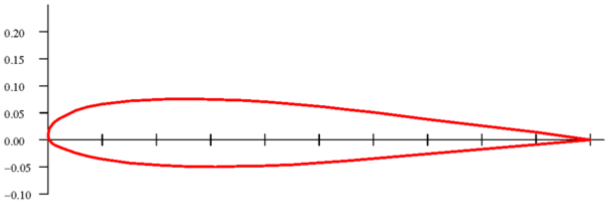


Fig.12.Mid-span Aerofoil

Outboard

Thickness : 12.5%
Camber : 1.5%
Trailing edge angle : 12.2°
Lower flatness : 43.2%
Leading edge radius : 2.2%
Max C_L angle : 1.183
Max C_L angle : 15.0
Max L/D : 40.179
Max L/D angle : 7.0
Max L/D C_L : 1.055
Stall angle : 7.0
Zero-lift angle : -1.5

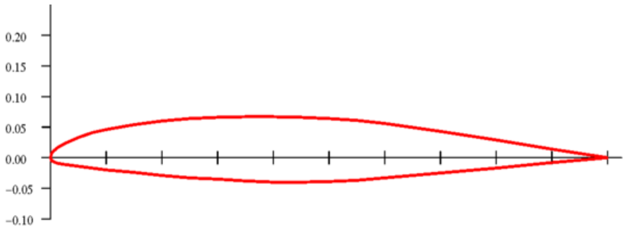


Fig.13.Outboard Aerofoil

Construction of New Winglet

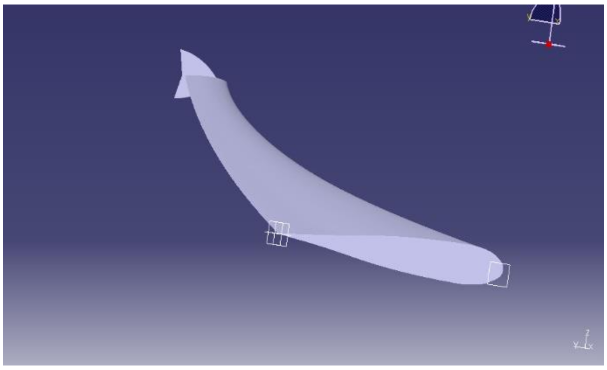


Fig.14.New Winglet - CATIA

The wing taken is same is in the previous cases Boeing 737-800 wing. This wing is fitted with anew winglet having a slightly modified shape of a shark fin. These kinds of winglets having only the upper element are used in Airbus A320. But in this case we’re using winglets having both upper and lower elements.

The total height of the winglet is 2.35ft between the top and bottom edges of the fins. The winglet angle is 60^0 and it starts from 75% of the chord length. It was constructed using CATIA and analyzed in FLUENT.

Meshing of New Winglet

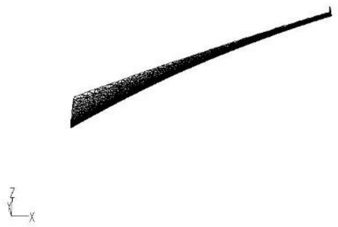


Fig.15.Meshing of New Winglet

The winglet meshing and analysis was done in FLUENT software. The shape of element used is tetra/hybrid. The number of nodes used is 4. When the new winglet is attached to the wing, the meshing elements increase in number. To get accurate results, the proper number of elements should be there.

In this case, the total number of elements used in splitting the test section is about

Continuum Region – New Winglet

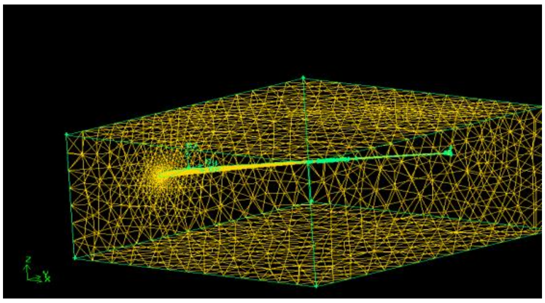


Fig.16.Continuum - New Winglet

This is the region of continuum where the flow is being analyzed .The boundary conditions are applied and the force constraints are applied. It is this region inside the cuboid that the flow is analyzed and the properties are studied.

By defining the region of continuum we may only be concerned about the flow properties inside that region which makes it more accurate. Here the inlet is pressure for field or free stream velocity of 0.7mach and the outlet is default outflow.

New Winglet – Static Pressure

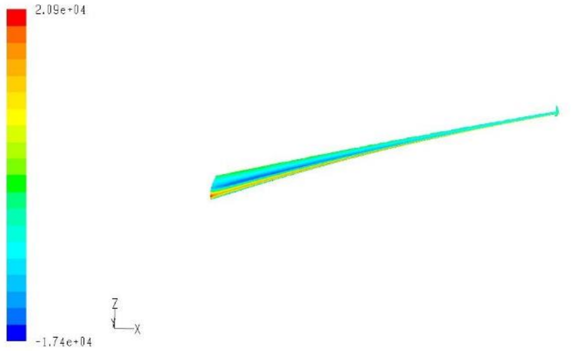


Fig.17.Static Pressure – New Winglet

The static pressure distribution over the span of the wing does not have much difference compared to the original wing or the one fitted with the previous two types of winglets as all the three winglets are studied and analyzed at a speed of 0.7 mach.

The static pressure varies from about 1.03×10^{04} Pa at the leading edge to -1.13×10^{03} Pa at the trailing edge. The static pressure component is has least values at the mid chord, in this case as low as -2.01×10^{04}Pa.

New Winglet - Dynamic Pressure
As it can be seen in all the cases the flow accelerates once it passes the leading edge. This phenomenon increases the dynamic pressure at the mid-chord and the trailing edge region. At winglet region, the dynamic pressure gradient value low compared to the value along the span because of flow disturbances at the wing-winglet junction. The value at the leading edge is about 1.85×10^{04} Pa and varies along the chord to reach a value of 2.68×10^{04} Pa at the mid-chord and then decreases again lower down the trailing edge of the wing to 1.68×10^{04} Pa.

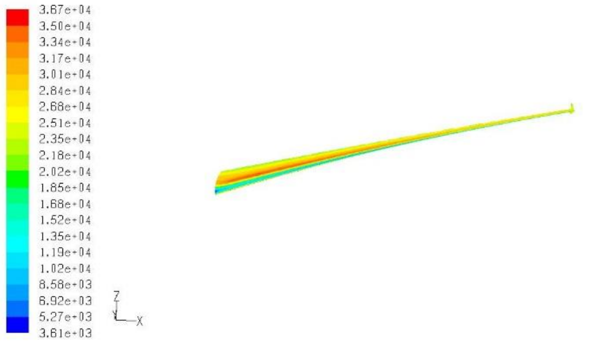


Fig.18.Dynamic Pressure – New Winglet

New Winglet - Vorticity Magnitude

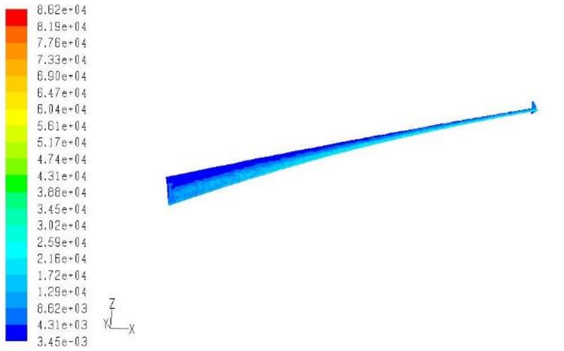


Fig.19.Vorticity Magnitude – New Winglet

The magnitude of Vorticity in case of the new winglet shows similar results to the previous winglets. The magnitude of Vorticity decreases along the chord of the wing. The value is 4.31×10^{03} at the leading edge and decreases to 3.45×10^{-03} at the trailing edge of the wing with a new kind of winglet.

New Winglet - Coefficient of Lift

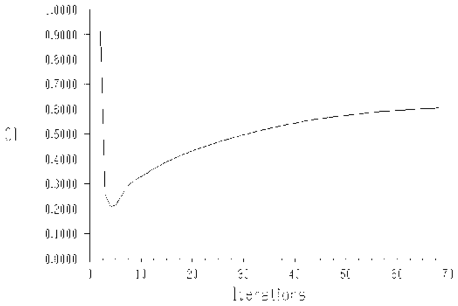


Fig.20.Coefficient of Lift – New Winglet

The above schematic shows the lift generated by the wing with the new kind of winglet at a free stream velocity of 0.7 mach. Analyzed in FLUENT, the graph shows the iterative values of the coefficient of lift generated by the wing when fitted with the new type of winglet.

The coefficient of lift value reaches to about 0.62 before attaining a steady value which is close to the values generated by the previous winglets discussed earlier. As the wing is the same, the addition of the new winglet has brought the change in this value of coefficient of lift.

Coefficient of Drag

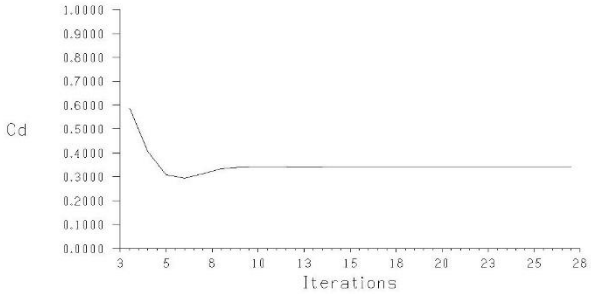


Fig.21.Coefficient of Drag – New Winglet

The coefficient of drag is one of the critical factors which influence the successful use of a particular shape of winglet on any wing because the drag value has to be optimum in order to achieve the best performance results. The most reduced value of drag is favored in almost all the cases.

Here we can see that the drag value has a value of 0.38 which is slightly higher than the previous winglet shapes largely attributed to the increase in area of the new winglet compared to the other winglets.

COMPARISON OF WINGLETS

In this section, a brief summary of the results obtained in the previous sections are given. The results in each of the parameters like static pressure, dynamic pressure, Vorticity magnitude, coefficient of lift and coefficient of drag respectively.

Static Pressure

Static Pressure Distribution (Pa)			
Wing Type	Leading Edge	Chord	Trailing edge
Wing only	9.59×1003	-5.1×1003	-2.63×1003
Blended Winglet	3.28×1002	-4.80×1002	6.49×1002
Wingtip Fence	1.03×1004	-2.08×1004	-1.13×1003
New Winglet	1.03×1004	-2.01×1004	-1.13×1003

Table.1.Static Pressure Distribution Results

Static pressure is the component of pressure which acts normal to the surface of the wing. The static pressure is studied for all cases at a free stream velocity of 0.7 mach. All the three winglets were analyzed applying the same boundary conditions and the results were obtained. Inlet as pressure for field 0.7 Mach and outlet is default outflow. From the results, it is evident that the static pressure is has the largest value at the mid-chord because a large amount of force acts on the perpendicular direction on the wing at the mid-span region.

Dynamic Pressure

Dynamic Pressure Distribution (Pa)			
Wing Type	Leading Edge	Chord	Trailing edge
Wing only	2.50×10^{04}	3.62×10^{04}	3.32×10^{4}
Blended Winglet	1.24×10^{03}	1.54×10^{03}	1.74×10^{04}

Wingtip Fence	2.30×10^{04}	3.63×10^{04}	2.85×10^{04}
New Winglet	1.85×10^{04}	2.68×10^{04}	1.68×10^{04}

Table.2.Dynamic Pressure Distribution Results

Dynamic pressure is the pressure on the wing due to the velocity of free stream air on the wing. The results of the dynamic pressure distribution are summarized and given below. It can be observed that the dynamic pressure is highest at the mid-chord than at the leading edge or the trailing edge. This is because of the acceleration of flow once it passes the leading edge of the wing.

Dynamic pressure increases with increase in free stream velocity. The free stream velocity taken for this particular analysis is 0.7 mach. It was kept the same for all the wing types.

Vorticity Magnitude

Vorticity Distribution (1/s)			
Wing Type	Leading Edge	Chord	Trailing edge
Wing only	7.04×10^{03}	3.52×10^{03}	1.21×10^{04}
Blended Winglet	1.15×10^{05}	5.21×10^{04}	1.46×10^{05}
Wingtip Fence	2.02×10^{03}	8.10×10^{03}	1.97×10^{04}
New Winglet	4.31×10^{03}	3.45×10^{-03}	8.63×10^{03}

Table.3.Vorticity Distribution Results

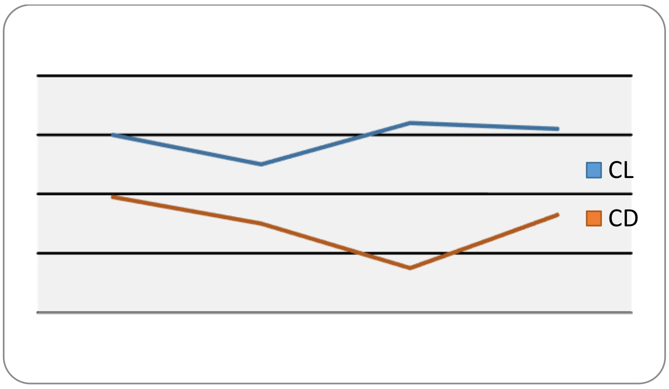
The Vorticity distribution along the wing is a very important factor as far as the performance of any wing is concerned. The position and the magnitude of pressure determine the performance of a wing. Vortices are created when the high pressure on the bottom of the wing meets the low pressure air on the top of the wing. This occurs to a greater extend at the tips of the wings or winglets.

Tip vortices induce a considerable amount of drag on the wing which contributed to the overall drag of the wing. Here, the free stream velocity is 0.7 mach. The magnitude of Vorticity is greater at the tips where the mixing of high pressure and low pressure air take place.

Coefficient of Lift & Coefficient of Drag

Coefficients of Lift & Drag (C_L & C_D)		
Wing Type	C_L	C_D
Wing only	0.6	0.39
Blended Winglet	0.5	0.3
Wingtip Fence	0.64	0.15
New Winglet	0.62	0.33

Table.4.C_L & C_D Results



The coefficient of lift and coefficient of drag values are analyzed at a flow velocity of 0.7 mach. The coefficient of lift is the highest in the case of the winglet fence. The wing has a fair value of C_L when attached with the new winglet. The lift coefficient is determined by various factors mainly the shape of the aerofoil and several other aerodynamic properties.

The drag coefficient value is least in the case of wingtip fence because it reduces the value of induced drag on the wingtips. As a result, the total drag is reduced which increases the value of lift. The new winglet has slightly greater drag values but the lift value is similar to the value of the wing with the wingtip fence.

The flow analyses of wing without winglets and with three different types of winglets were done. In the analysis, it was found that wing without winglet was found to have $C_L = 0.6$ and a $C_D = 0.39$. Wing with winglets showed much better results in terms of higher lift values as well as lower drag values. The least values were observed in case of the wingtip fence where values were $C_L = 0.64$ and $C_D = 0.15$. The reduction in the drag value can be attributed to the reduction in tip vortices by the use of the tip fence. The vortices are cut in such a way that the component of pressure acting on the winglet contributes slightly to the thrust component.
The New winglet designed was found to have $C_L = 0.62$ and $C_D = 0.33$. It was observed that while the lift value was close to the tip-fence value because of the presence of both upper and lower elements, the drag value was higher. This is because of the increase in profile drag since there were slightly curved surfaces instead of pointed edges. Still, the results were found better than that of the blended winglet where the values were $C_L = 0.5$ and $C_D = 0.3$ because of the absence of lower element.

CONCLUSION

Therefore it can be concluded from the analysis that the wingtip fence showed the best performance among the tested wing types and the newly designed winglet showed promising results and can be used after further optimization in design, in-depth analysis and live testing.

In flight at subsonic free stream speed the aerodynamic efficiency of a wing (without winglets) is ultimately constrained by its span. Increasing the span permits decreases in the trailing-vortex drag (at given lift) and may provide an increased aerodynamic efficiency. Winglets, comprising either upper elements, or a combination of upper and lower elements, can similarly lead to decreases in the trailing-vortex drag and increased aerodynamic efficiency. The magnitudes of the increases in aerodynamic efficiency that can be achieved by adding winglets are related principally to the lengths of the winglet elements relative to the basic wing span, to the orientation angles of the elements (cant angles) and to the span wise loading distribution of the basic wing.

In addition to the aerodynamic efficiency in the cruise being important, consideration has to be given too many other aspects, such as non-cruise flight segments, stability and control, wing structure (including its weight and stiffness), flutter and other aero elastic effects, provision of flaps and controls, and ground operations. There are also economic aspects associated with costs of production and maintenance that need to be taken into account. Relatively rarely is a completely new wing design undertaken; more often a design exists which it is desired to modify in order to meet a new requirement. In either situation winglets may be considered as possible features to include in the design process.

In the case where a wing design already exists, and it is desired to increase its aerodynamic efficiency, winglets may well be worthwhile, and preferred over wing tip-extensions, on the grounds that less extensive wing strengthening changes may need to be made for a given level of increase in aerodynamic efficiency. Only a more detailed comparison of the alternative design changes is then likely to provide sufficient information for the right decision to be apparent.

A number of points relating to the detailed design of winglets and the interactions between the wing and winglets are noted.

Some of the more detailed points arising with wing tip-modifications, as well as comments on the relative merits of wing tip-extensions, upper winglets and combined upper and lower winglets, are also. It is suggested that the choice of the particular configuration to refine and bring into service might well be influenced by the existence of a body of experience related to that configuration.

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