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Design and Analysis of Aircraft Winglets Using CFD

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ABSTRACT

A preliminary CFD study is conducted to compare the wingtip vortices and induced drag generated by two wing-configurations at cruise conditions. The geometry for a clean wing, a wing with winglets, are modeled in CATIA and numerically analyzed is done using FLUENT ANSYS 15.0 software. The results produced detailed contour and vector plots of the wingtip velocity, pressure and turbulence magnitudes created by each wingtip configuration.

Results revealed two techniques used by wingtip devices to reduce the TUBULENCE and thus the ratio of lift and drag increases slightly. Winglets exhibited the potential for creating a force component in the direction of an aircraft thrust, counteracting the drag on the wing. Alternatively, wing with wing tip reduced the turbulence which causes the vibrations in the wing. Although both concepts are aerodynamically beneficial, the wing with winglet is a promising innovation for future use on passenger aircraft.

Keywords: ***CFD, CATIA, ANSYS FLUENT, lift, drag, turbulence, clean Wing, Wing with winglet.***

INTRODUCTION TO AERODYNAMICS

The flow of air over the surface of an airplane is the basic source of the lifting or sustaining force that allows a heavier-than-air machine to fly. The shape of an airplane is designed to encourage the airflow over the surface to produce a lifting force. The study of flow of gases is also important in many applications such as the design of rocket, jet engines and propellers, vehicles entering planetary atmospheres from space, wind tunnels, and projectile configurations. The applications are almost limitless.

Four fundamental quantities of aerodynamics are pressure, density, temperature, and velocity.

- Pressure: is the normal force per unit area exerted on a surface due to the time rate of change of momentum of the gas molecules impacting on that surface.
- Density: is a substance (including a gas) is the mass of that substance per unit volume.
- Temperature: is a measure of the average kinetic energy of the particles in the gas.
- Velocity: is at any fixed point in a flowing gas is the velocity of an infinitesimally small fluid element as it sweeps through that point.

Airfoil Theory

The cross-sectional shape of the wing is called an airfoil". The wings provide lift by creating a situation that the pressure above the wing is lower than the pressure below the wing.

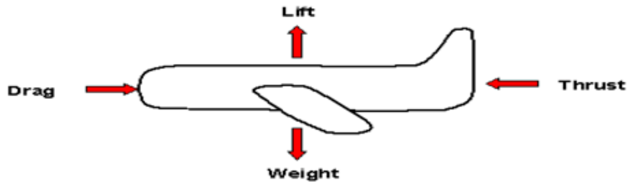

Fig.1.1 Airfoil wing

In many aerodynamic problems, the fundamental forces are Lift, Drag, Thrust and Weight. The properties of continuum flow fields such as flow velocity, pressure, density and temperature are the functions of spatial position and time. Density and flow velocity are the additional property and viscosity used to classify flow fields.

Airfoil Terminology

Lift and Drag is the force perpendicular to the direction of motion is called Lift, and the force parallel to the direction of motion is called Drag.

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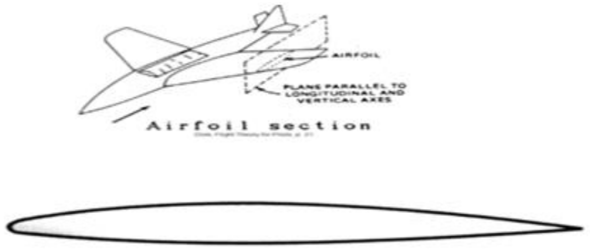

Fig.1.2 Lift and Drag Force

Wing is the curved surface produces more lift than a flat surface. The wing needs to have a camber. i.e., the top needs to be slightly curved, like a hump. The bottom is left flat or straight. An object with this shape is called wing or airfoil. Wing shapes are designed to generate more lift less drag.

Mean camber line (MCL) is the line midway between upper and lower surfaces. The MCL for a cambered airfoil necessarily rises above the chord line. The MCL for a symmetric airfoil is coincidental (same as) the chord line itself.

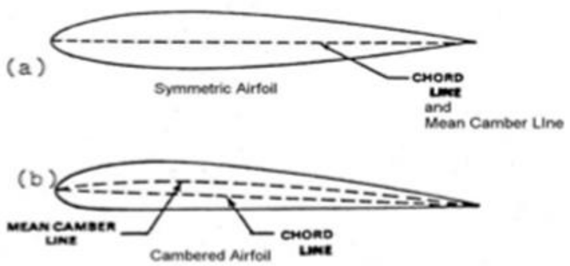

Fig.1.3 Mean Camber Line

Boundary layers: Viscosity is responsible for the formation of the region of flow called the boundary layer. There are two types of boundary layers:
1.Laminar boundary layer
2.Turbulent boundary layer

Laminar boundary layer: The fluids molecules closest to the surface will slow down a great deal, and appear to have zero velocity because of the fluid viscosity. In turn, these surface molecules create a drag on the particles flowing above them and slow these particles down. The effect of the surface on the movement of the fluid molecules eventually dissipates with distance from the surface. The area where these viscous effects are significant is called the boundary layer.

Turbulent boundary layer: Eddies, who are larger than the molecules, form. The slower eddies close to the surface mix with the faster moving masses of air above. As a result, the air molecules next to the wing surface in a turbulent boundary layer move faster than in a laminar boundary layer for the same flow characteristics.

Flow classification

Flow velocity is used to classify four different flows according to speed regime.
They are

- Subsonic Flow
- Transonic Flow
- Supersonic Flow
- Hypersonic Flow

Compressible Aerodynamics: According to the theory of aerodynamics, the flow is considered to be compressible if its change in density with respect to pressure is non-zero along a streamline. Gas flows with a Mach number 0.3 below changes in density with respect to the change in pressure of less than 5%. Furthermore, that maximum 5% density change occurs at the stagnation point of an object immersed in the gas flow and the density changes around the rest of the object will be significantly lower. The flows Transonic, supersonic, and hypersonic are compressible.

Incompressible Aerodynamics: An incompressible flow is a flow in which density is constant in both time and space. A flow problem is often considered incompressible if the effect of the density changes in the problem on the outputs of interest is small. This is more likely to be true when the flow speeds are significantly lower than the speed of sound. Effects of compressibility are more significant at speeds close to or above the speed of sound. The Mach number is used to evaluate whether the flow is incompressible or compressible.

RESULTS AND DISCUSSIONS

The design of different airfoil shapes are developed and analysis is carried out to find different characteristics of aerodynamics such as lift, drag, turbulence contours and vectors, turbulent kinetic

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energy, velocity, pressure contours at different winglets. The results observed in two cases as follows in table 6.1 and 6.2

Wing without winglet

TABLE 6.1

Parameters of Airfoil in Wing without winglet

S.No.	Parameters	Values
1	Lift	2794.1349
2	Drag	225.17796
3	Lift/Drag	12.40856298
4	Turbulence	0.005464

Wing with winglet

TABLE 6.2

Parameters of Airfoil in Wing with winglet

S.No.	Parameters	Values
1	Lift	9094.5001
2	Drag	713.89094
3	Lift/Drag	12.739355
4	Turbulence	0.00038828689

When the lift increases the drag decreases then the turbulence is reduced. From table 6.1 wing without winglet and table 6.2 wing with winglet and compared the two winglets which is gives better results. From table 6.3 shows that the parameters in different winglets.

TABLE 6.3

The parameters difference in two winglets

Parameters	Without winglet	With winglet
Lift	2794.1349	9094.5001
Drag	225.17796	713.89094
Lift/Drag	12.40856298	12.739355
Turbulence	0.0054648	0.00038828689

From table 6.3 gives a better result in wing with winglet compared to wing without winglet. The turbulence is reduced in wing with winglet. And also lift increases the drag is decreases. Compared to all parameters the better result shows wing with winglet.

- A WINGLET is a device used to improve aircraft efficiency by lowering the induced drag caused by wingtip vortices.
- In present rising fuel prices and environmental concerns, efforts to decrease fuel consumption and lower emissions are of profound interest to the aviation industry.
- In recent years there has been intense research and study into aerodynamic devices that provide commercial aircraft with longer range and more efficient rates of fuel consumption.
- Such wingtip devices that could maximize the range and minimize the fuel consumption of commercial aircraft are winglets and wingtips.
- The benefits to an aircraft's performance are due to the ability of winglets and wingtips to reduce the induced drag, or drag due to lift, generated by a three-dimensional (3-D) finite wing.
- On a clean wing, i.e., a wing with no wingtip devices, this difference in pressure between the lower and upper surfaces of the wing causes air to flow from the lower surface to the upper surface of the wing at the wingtips.
- The flow of air from the lower surface of the wing to the upper surface of the wing at the wingtips produces a downwash onto the top of the wing.
- The downwash of air onto the upper surface of the wing at the wingtip has the affect of vectoring the flow of air over the wing downward.

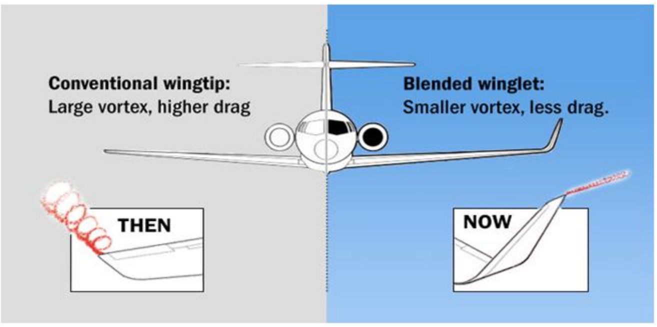

Fig. 6.1 different winglets

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CONCLUSION

- The present study serves as a preliminary investigation into the aerodynamic effects of the addition of winglet on the turbulence and L/D ratio.
- In addition, the advantages and disadvantages of 3-D finite wings with winglets and without winglet configurations were investigated.
- The results presented in this study reveal the reduction turbulence and consequently slightly increased the L/D ratio.
- This study has shown that clean wing configurations, i.e., wings without wingtip devices, produce the highest turbulent viscosity when compared to wing configurations that employ winglets.
- The winglet design employed in this study demonstrate the potential to produce a component of force in the thrust direction of the aircraft by concentrating the otherwise turbulent flow behind the wingtips into a more energy-efficient flow, thereby increasing the L/D ratio.
- The streamline design of the raked wingtip provides less resistance to the flow over the wingtips and, in this way, conserves the energy of the flow.
- The results of this preliminary study suggest that wings designed with winglets can indeed increase the L/D ratio and decrease the turbulence on a wing during cruise conditions.
- This reduction of the turbulence on an aircraft's wing offer advantages in terms of an aircraft's performance including improved fuel efficiency, increased range, and reduced wing loading.

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