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EXPERIMENTAL STUDY OF SINGLE AND MULTI-WINGLETS

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Abstract

Wingtip devices are used to improve the efficiency of the fixed wing aircraft by reducing the total drag which may lead to reduction in coefficient of lift. The winglet partially acts like an end plate to the aircraft wing. This device reduces the pressure nullification at the wingtips to a large extent and diminishes the adverse effect of the wingtip vortices. Thereby, it results in the reduction of induced drag. Aerodynamic efficiency is an important factor in commercial aircrafts wherein induced drag plays a major role. The strength of wingtip vortices is inversely proportional to wingspan and speed of the plane. So aircraft with large wingspan and high speed will have high wingtip vortices. Thus, the vortices will be maximum during takeoff, climb and landing. Changing the design of the lift producing devices will make changes in the strength of the aircraft. Winglets are extensions at the tip of the wing which reduces the vortex formation. Many types of winglets are available to serve different purposes. The primary focus of this paper is to investigate the effect on coefficient of lift using

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fixed to flexible winglets. A model was fabricated and tested in low speed wind tunnel for different inlet conditions and angle of attack, the coefficient of lift for each winglet is compared.

Introduction

Wing is a lift producing part of an aircraft. Lift is a force acting upwards due to change in the pressure above and below the wing. Pressure below the wing will be higher than pressure above the wing. So at the tip of the wing, air will tend to move towards the top. The resultant of these air movements forms the vortex behind the wingtip. Thus, an induced vortex (drag) is formed. The downwash of trailing vortex system adds to the downwash produced by the bound vortex system, thereby increasing the strength of the wingtip vortices formed. The effect of this vortex formation plays a major role in total drag of the aircraft. Reducing the vortex formation will decrease the operating cost of an aircraft.

These are used as additional lift producing devices in olden aircrafts. Later, its effect on decreasing the induced drag opened a broadway for the winglet design. Vortex diffuser vanes, wingtip sails are also used to reduce the vortex formation. But winglet provides a maximum efficiency.

The downwash of the wing can be reduced by reducing the strength of the wingtip vortices, at a given angle of attack, it is been estimated that for a low speed commercial aircraft over its life time, 13 million gallons of fuel can be reduced by reducing its drag by 10%. For natural causes by reducing the drag produced during flight global warming can also be reduced due to low fuel consumption apart from increasing the efficiency of the aircraft. According to studies (Barnett [2]), more than 600 million tons of carbon dioxide are let out from world’s commercial aircrafts every year. The weight of the aircraft is directly proportional to the strength of the wingtip vortices created. Hence, huge wingtip vortices are generated from aircrafts of large wing during takeoff, landing and climb phases. Along the wind, these vortices prevail for several minutes. Any plane having size smaller than these aircrafts cannot proceed until these vortices clear up. It has the risk of sudden variations in altitudes and uncontrollable situations. These conditions may even lead to failure resulting in flipping of plane upside down.

Theory

Wingtip vortices are the circular patterns of air formed as the aircraft generates lift. Mostly, this type of drag is also called as lift induced vortices as lift is the main cause for this circular formation. The theory behind formation of wingtip vortices is that the pressure difference between the upper part and lower part of the wing, which makes the flow to move from bottom to the top of the wing as air flows from high pressure region to low pressure region in order to nullify the pressure difference created. The oncoming flow stream as the aircraft proceeds forward creates a bound vortex that flows towards the trailing edge of the wing. The bound vortex combines with the tip vortex generated and strengths the vortex formed thus forming a wingtip vortex circulating at the tip. This flow is strong at the tip and decreases to zero as it goes to the mid span.

The tip vortices formed are directly proportional to the weight of the aircraft which means for heavier aircrafts, the tip vortices formed are very large and decrease gradually as the weight decreases.

Since 1976, research has been done on winglets. Winglets are placed at the end of the wing, which acts as a physical barrier so as to weaken the tip vortices formed.

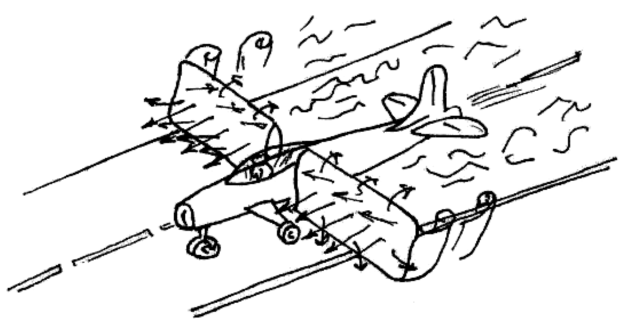

Figure 1. Formation of tip vortices during flow.

The main aim of placing winglet is to increase lift and efficiency of the aircraft so as to reduce the wingtip vortices formed at the tip of the wing. The pressure difference in the upper and lower surfaces results in upwash and downwash effects causing the air to flow from down to upper surface of the wing, since these winglets act as a physical barrier, the air flowing at the tip tries to go up by moving along the surface of the winglet as the air travels, the strength of the airflow diminishes gradually which results in considerable reduction in the wingtip vortices.

In 1976, Whitcomb started the research initially and introduced the winglet as a physical barrier at the end of the wing. According to Whitcomb, at Mach 0.78, the use of winglet resulted in nine percent increase in lift to drag performance of the aircraft and twenty percent decrease in the total drag production. Before this research in order to reduce the tip vortices, wingspan had to be increased which added weight to the aircraft but the usage of these winglets imposed less weight and efficient too.

Experimental Fabrication

So as to test the vortex formation with and without winglets, the aerofoil of Boeing 737 was taken as the reference aerofoil. CATIA software was used to design the reference wing NACA 66_2-215 by plotting the aerofoil points. Initially, the ribs and spars of the model were designed and then covered using a sheet in the software.

The ribs of the structure were cut from teak wood. While cutting for aerofoil teak wood gives better results in terms of rigidity. The surface finish of the aerofoil is better when compared to other wood types as it gives smooth surfaces. Iron rods were used to connect the ribs, these rods act as spars which were connected by drilling holes into the wood. For the outer shell of the wing surface, aluminum alloy sheets are used. The sheets possess better malleability and give less dent formation during bending.

The wing without winglet is fabricated initially, the dimensions of the fabricated wing are listed - the wing was fabricated for NACA-66_2-215, with a span length of 330 mm, the root chord and tip chord ranging from 165 mm to 40 mm.

For the selected dimensions, the wing is fabricated. Totally, four winglets are selected - three single winglets and a multi-degree winglet.

Figure 2. Fabricated wing structures without winglet (flat).

The angle made by normal component of free stream velocity and tip of the winglet is termed as phase angle. Having $\Phi = 0, 50, 25,$ three winglets were designed and the forth one having all the three angles $\Phi = 0, 50, 25,$ respectively, in the same winglet.

Figure 3. Experimental arrangements for testing with winglet of phase angle 25 degree.

Multi-winglets

The concept behind multi-winglet is that it holds altogether three winglets together holding the advantage of three winglets. The winglet holding $\Phi = 25$ forms the first winglet and the winglet having $\Phi = 50$ forms the next winglet and third one having $\Phi = 0$ as the tip vortices are formed majorly after 30 percent of the wingtip.

The structures of the winglets were made using aluminum alloy sheet metal. Totally, 20 pressure ports are drilled over the surface of the wing. 10 ports at the eighty percent of the wing from the root and 12 ports at fifty percent of wing from the root.

Figure 4. Multi-degree winglet attached wing structure.

Pressure tubes

PU tubes (polyurethane tubes) were used to connect the drilled ports from the manometer valves so as to measure pressure readings. PU tubes give better flexibility inside the structure thereby reducing the error occurred due to airflow at the bend. The pressure valves are connected to the multi-tube manometer.

Mount

So as to mount the wing to the wind tunnel, a steel tube of radius eight millimeter is attached by drilling a hole into the aerofoil section. A rectangular wooden board is used to mount the model into the wind tunnel. The wooden board holds a circular disk made out of plastic where the steel rod from the wing is fixed into it. This plastic disk holds readings and a knob so that the fixed wing can be set at different angles of attack.

Testing

Wind tunnel calibration

Calibrating the wind tunnel is the initial process of testing the fabricated wing. This process is undertaken so as to find the required rpms for testing. Velocities 10, 15, 20, 25 m/s are selected for testing. The tunnel is calibrated and the rpms for the selected velocities are noted, noted rpms = 300, 440, 575, 720.

Model testing

The fabricated model was mounted to the wooden board and fixed to the wind tunnel for testing. At the selected velocities initially, the wing without winglet is tested and the pressure readings are noted.

After the pressure, readings are noted, the wing is cut at eighty percent and the fabricated winglets are attached. Tests are carried out at three different angles of attacks angle of attack $= 0, 5, 10$ and four different velocities. When the tests are over, the attached winglet is removed and the next winglet is attached for testing. Including the wing without winglet, 48 tests are carried out and the pressure values are noted.

Inference

From the pressure values noted the coefficient pressure for each winglet at each angle of attack and velocity is calculated. c_p curve is drawn using the calculated values from which the coefficients of lift values are calculated. The wing without winglet is represented as flat. The lift coefficient vs. velocity graphs are given below.

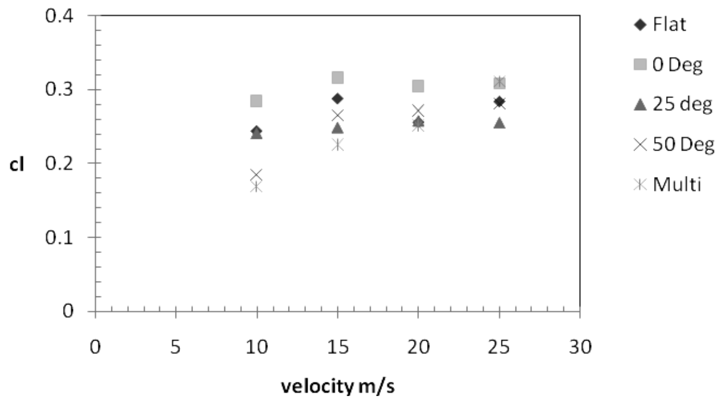

Figure 5. Coefficient of lift vs. velocity for angle of attack 0 degree.

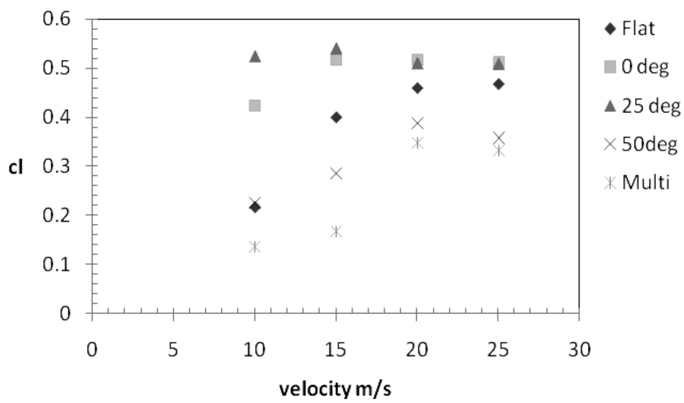

Figure 6. Coefficient of lift vs. velocity for angle of attack 5 degree.

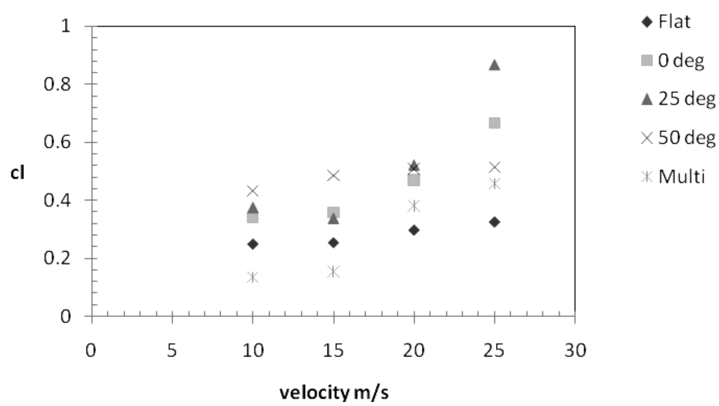

Figure 7. Coefficient of lift vs. velocity for angle of attack 10 degree.

Conclusion

The experimental results obtained from the values of coefficient of lift are compared for all the selected winglets. It is observed that multi-winglet is more efficient for higher velocities in less angle of attack. When angle of attack is getting into stalling angle, multi-winglet is not efficient as much as single winglet. For our unsymmetrical wing NACA 66_2215, the winglet of 25 degree phase angle is more efficient for higher angle of attacks. The 0 degree phase angle winglet is giving better results in lower angle of attack. Both 25 degree and 50 degree are maintaining higher coefficient of lift even in less induced drag condition. It is observed that the 25 degree phase angle winglet is showing sudden stalling at higher velocities.

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