Design Optimization for Adaptive Slotted Winglets

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Abstract - *The Adaptive Slotted Winglet design using Shape Memory Alloys (SMA) based actuators is optimized for better aerodynamic performance at various stages of flight. Winglets are an upward swept extensions of wingtips that reduce the aerodynamic drag associated with vortices that develop at the wingtips as the airplane moves through the air. The conventional static winglet is designed for a particular mission point due to which it compromises between performance at low and high speeds. The base design is optimized to generate improved winglet design compared to the conventional winglet. The slotted winglets are advantageous in itself by producing lift, reduction of acoustic sound, reduction of winglet twisting and better performance. The autonomous adaptive slotted winglet design provides real-time adaptive behavior compared to the present technologies. The Shape Memory Alloy based actuator reduces the system weight by up to 80 percent compared to the traditional systems. The adaptive changing of the Cant angle and twist angle can be achieved between 0 and 70 degrees up and down during flight. The slotted adaptive winglets by design significantly reduce aerodynamic loads at critical flight points having a variable cant angle and trailing edge control. The winglets are designed and optimized using analysis tools for the best performance.*

Key Words: Slotted wing tip, Shape Memory Alloy, optimization, Induced drag.

1.INTRODUCTION

The efficiency-based drawbacks faced by conventional winglets can be solved by biomimetic the wingtips of the birds. The feathers at the wing tips of birds separate both horizontally and vertically forming slots during gliding. The tip feathers help in producing lift, reduction of sound, prevention of feather wear, reduction of wing twisting, control and stabilization of roll, prevention of stall, attainment of high lift coefficients and reduction of drag. The individual feathers in slotted tips reduce drag by acting as individual winglets. The slotted tip maintains the span factor of the wing and the geometry can be adjusted to the changing flow conditions, has the potential to improve the aerodynamic performance and also significantly reduce aerodynamic loads at critical flight points. The design is based on bird wingtip integrated with adaptiveness to provide better performance according to the mission profile using Shape Memory Alloy (SMA) based actuators. The winglet is divided into individual tips having an aerofoil shape with variable trailing edge control and Cant angle control. The winglet is equipped with along with on-board microcontrollers that analyse the type of the flow and make the wingtip deflect with varying its Cant angle and the Twist angle.

The change or morphing is done by adaptively changing the cant and twist angle, where the shape memory alloys-based actuation system actuates the tip of the slotted winglet along with actuation system based inside the tip which actuates the trailing edge of the tip which further changes the angle of twist. The trailing edge control surface of the tip is similar to the rudder of the vertical stabilizer which yaws according to the requirement inducing the flow on the backward tip. The total yawing moment of all the tips of the slotted winglet provides better control during the manoeuvre. Also, the cant is actuated with respect to the horizontal for various stages of the mission profile. The adaptive winglet can vary its cant and twist according to the incoming flow based on the data from sensors for better control and aerodynamic performance.

2. DESIGN OF ADAPTIVE SLOTTED WINGLET

The design is modelled and optimized in OpenVSP which is an open source parametric aircraft geometry tool developed by J.R.Gloudemans and others working for NASA since 1990's.The Shape memory alloy based actuator and the trialing edge control of each winglet tip is designed in CATIA V5.The base wing has symmetrical NACA 0008 airfoil with max thickness at 8% at 30% chord. The base wing has 1.7m span and 10-degree sweep with 0.5m and 0.2m chord at root and tip respectively. The individual winglet tips of slotted winglet have NACA 0012 airfoil with different sweep and span similar to bird's wingtips.

The slotted winglet has a trialing edge control and Cant angle control. The shape memory alloy torque tube actuator is able to move the individual winglet tip section to change the Cant angle and twist angle with very precise control. The outboard portions of the winglet tips move to the optimal position during operation potentially result in an increase in efficiency by reducing drag and increasing lift and performance required for a particular stage of the mission profile. The ability to achieve an optimal winglet tip position for different aspects of flight may also produce enough yaw control to allow for rudder control reduction, which may provide additional benefits to aircraft efficiencies, such as reduced drag and weight.

2.1 Shape Memory Alloy

Shape memory alloys (SMA) include NiTi, NiTiCu, CuAlNi, and many another metallic alloy which undergo solid-to-solid phase transformations. The alloy is built into to an actuator, where it has the ability to change the Cant and winglet tip trailing edge in flight without the strain of a heavy hydraulic system. This system may weigh up to 80 percent less than traditional systems, changing the Cant angle and twist angle between 0 and 70 degrees up and down in-flight using shape memory alloy technology, which is compact, lightweight, and can be positioned in convenient places on the aircraft.

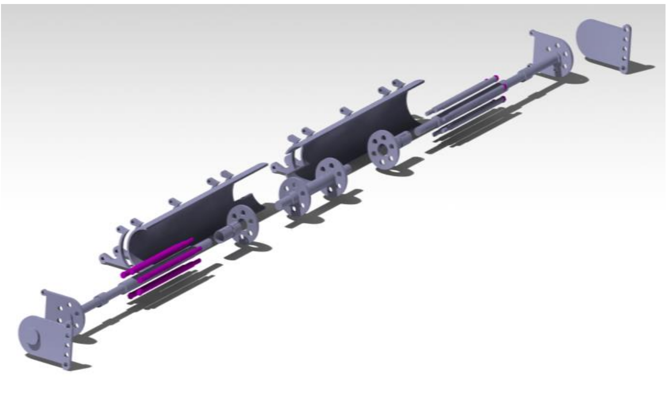

Fig -1: Assembly of shape memory alloy-based actuator

For the design of actuator for Cant angle and twist angle change in wire form can be modelled in properly size actuators for application as the actuation stroke is now known for engineering stresses of 100, 200, 300, 400, and 500 MPa. To handle the aerodynamic loads the design has a Ni19.5Ti50.5Pd25Pt5 wire actuator by selecting a wire diameter that will carry the desired actuation load using equation,

$$F = \pi \sigma d / 2$$

Knowing the operating stress to achieve maximum stroke using this material is between 350 and 400 MPa for lives of 100–1000 cycles. The length of the wire may determine by,

Length = stroke / actuation strain

The shape memory alloy used is a Ni19.5Ti50.5Pd25Pt5 wire which is winded and connected to heat jackets for triggering the shape memory effect which further leads to an extension of the wire and the torque tube actuator thus further actuates accordingly with 70 degrees actuation upward and downward.

The design uses Shape Memory Alloy based actuators which weighs up to 80 percent less than traditional systems which are the Hydraulic or electromechanical which helps in reducing the main wing tip loads.

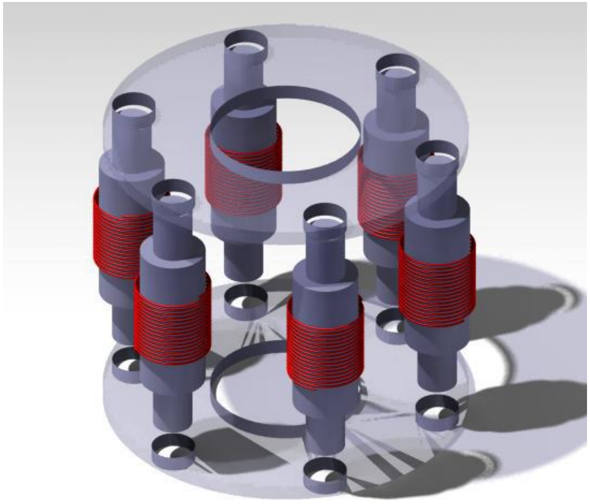

Fig -2: Ni19.5Ti50.5Pd25Pt5 wire winding with base designed in CATIA V5.

2.2 Winglet Design

The design of the individual tips of the winglet is similar to the conventional blended winglet, here the slotted winglet is a structure having an aerodynamic shape similar to the airfoil with its tips blended with the main wing perfectly attached by an actuation system both at the tip of the winglets roots and inside the tip just ahead of the trailing edge.

The tips of the winglet are arranged in linear manner to the tip of the wing where each tip of the slotted winglet is connected to the Shape memory alloy actuator which helps in dynamic motion of the winglet tips respective to the incoming flow and also the adjusting the winglets for better performance in various stages of the flight. For the trailing edge control, the winglet tip is fused with a small and lighter shape memory alloy actuator the trailing edge of the tip is capable of in-flight adjusting and adaptiveness based on the input conditions.

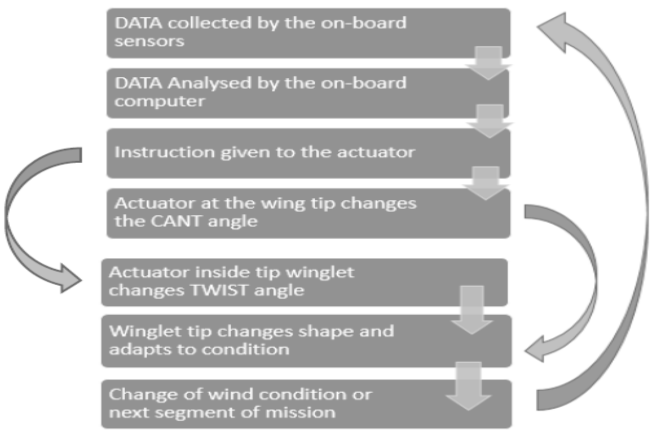

Fig -3: Real-time working process of the design.

2.3 Analysis

The slotted winglets are designed with Cant angle control and trailing edge control attached to the base wing with different combinations of winglet dihedral to determine the best improvement in lift-to-drag ratio.

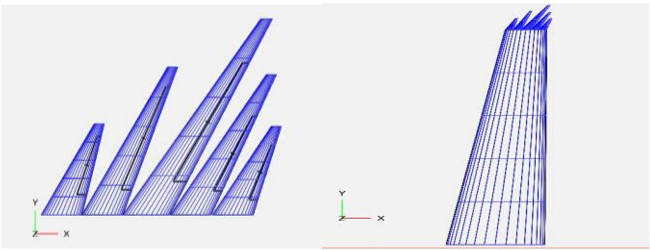

Fig -4: Sketched view of slotted winglets with base wing

Now doing multiple configuration test for the various change of the Cant angle with respect to the base wing.

Table -1: Multi-Winglet Combinations Evaluated.

Multi-Winglet Combinations	
LABEL	ANGLE OF WINGLETS
0	Baseline 1.7m span wing
1	0^0, 0^0, 0^0, 0^0, 0^0
2	-40^0, -30^0, -20^0, -10^0, -0^0
3	0^0, 10^0, 20^0, 30^0, 40^0
4	-20^0, -10^0, 0^0, 10^0, 20^0

Now checking various parameters like Lift Co-efficient, Drag Co-efficient and Lift by Drag versus the Angle of attack which would help in understanding the Aerodynamics of Winglets.

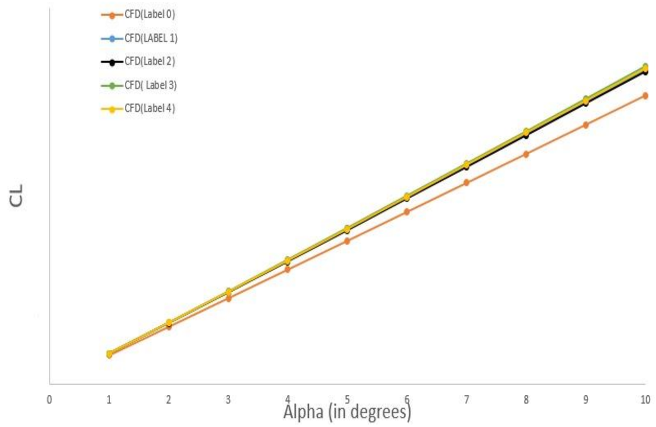

Chart -1: Lift co-efficient v/s Angle of Attack

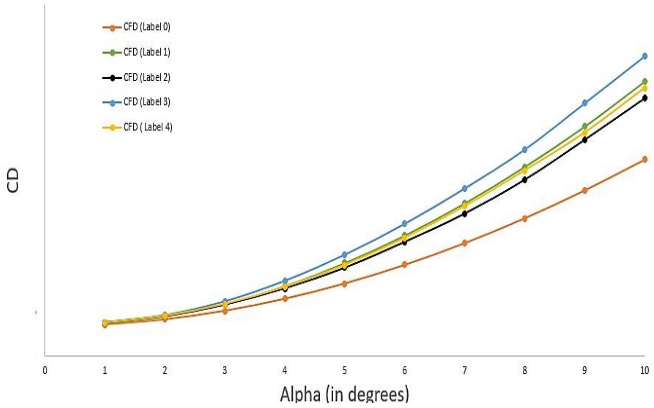

Chart -2: Drag co-efficient v/s Angle of Attack

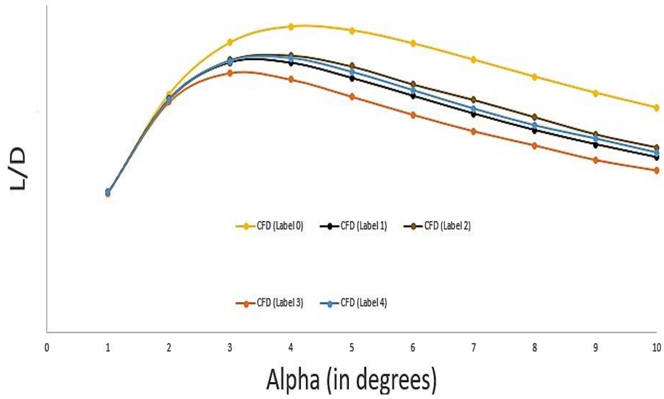

Chart -3: Lift by Drag v/s Angle of Attack

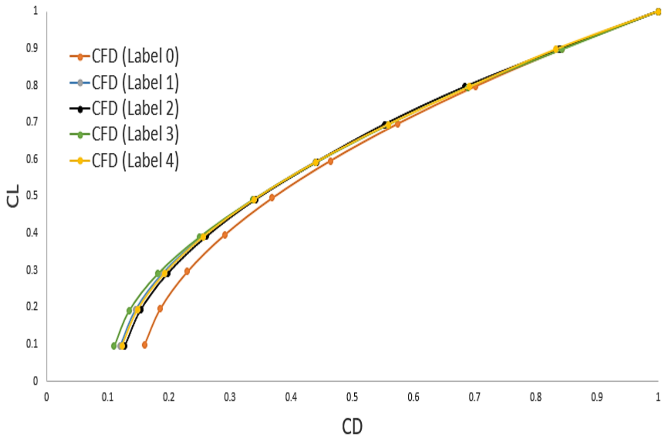

Chart -4: Lift co-efficient v/s Drag co-efficient

Considering the various configuration of winglets for various conditions where the geometry is adjusted to the changing flow conditions, has the potential to improve the aerodynamic performance during all stages of flight from take-off, cruise, landing and loiter.

The slotted winglets are advantageous in itself by producing lift, reduction of sound, reduction of winglet twisting, better performance and also a fully autonomous adaptive system compared to the present technologies. High-speed off-design conditions performance is also improved by the winglet providing lift distribution throughout the Aircraft flight envelope. Additionally, the slotted adaptive winglets by design significantly reduce aerodynamic loads at critical flight points (i.e., active load alleviation) having a variable cant angle and trailing edge control.

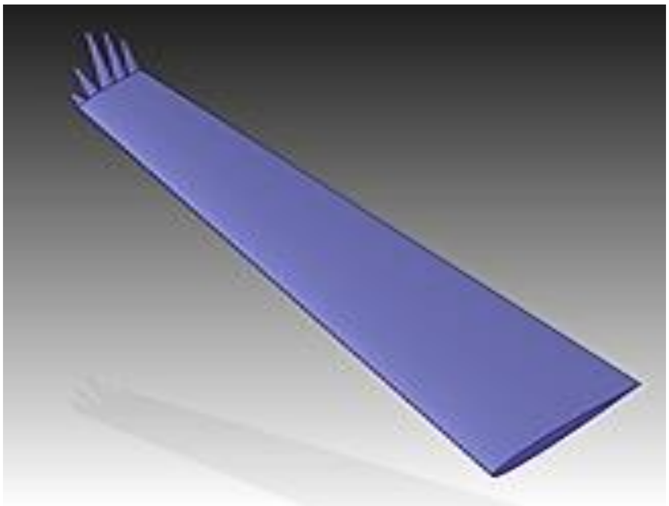

Fig -5: Various configuration angles of the Winglet design

3. CONCLUSIONS

The system proves to have more advantages in producing lift, reduction of sound, prevention of wear, reduction of winglet twisting, control and stabilization of roll, prevention of stall, attainment of high lift coefficients and reduction of drag than the present technologies.

Thus, the slotted winglet design is optimized along with the Shape Memory Alloy based actuator for best efficiency gives a better performance than a traditional winglet.

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BIOGRAPHIES

OMKAR SHRIRAM LAWATE graduated in 2019 with a bachelor degree in Aeronautical Engineering from the VTU, India. Gold medalist for All India Student Design Competition in Aerospace Discipline conducted by National Design and Research Forum (NDRF) under Institution of Engineers (India) for both years 2017 and 2018. 2nd in the National Aircraft Conceptual Design Competition NACDeC, by Aeronautical Society of India for designing LIDAR-equipped Unmanned High-Altitude Platform.