Analytical Testing of Vortex Generators with an Airfoil Profile

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Abstract - **When a wing is exposed to an airstream, the air tends to flow along the surface of the wing while sticking to it. This region, closest to the surface of the airfoil, is said to be boundary layer. However, an adverse pressure gradient formed aft of the maximum thickness of the wing leads to a boundary layer separation. If severe enough, this can lead to loss in lift and might even cause the wing to stall. Vortex generators were therefore invented to ensure that the air sticks to the surface of the wing. They are placed at the leading edge of the wing to create minor vortices that push the air down to ensure that it sticks to the surface.**

Vortex generators are nothing but flat plates placed at an angle to the relative airflow. While this serves the purpose, a vortex generator with an airfoil profile will be more effective and provide better control over the wing. In order to compare the two, analytical tests were carried out. The analytical testing mainly consisted of a CFD analysis between the flat plate and airfoil profiles.

Keywords – vortex generator, airfoil profile, minor vortices, CFD analysis.

I. INTRODCTION

A vortex generator, as its name suggests, creates whirlpool of the air over the confined sections of the wings of an aircraft. This is an aerodynamic device; it consists of vanes usually attached to a lifting surface of an aircraft wing. When the airfoil or the body is in motion correlative to the air, a vortex generator produces a swirl, thus eliminating bit of the decelerated boundary layer which is in touch with the airfoil surfaces, thereafter enhancing the usefulness of wings and control planes such as waggle, conveyors, appendages, and tiller. From past many years, these were basically had a great application in airline transportation and military based aircrafts. They have made inroads to general aviation. They are frequently placed on horizontal stabilizers and on the principal edges of wings.

The main application of the vortex generators is to delay the flow detachment.Inorder to achieve this, vortex generators are generally oriented on the outer planes of the aircrafts and wind energy facility blades. In wind turbine blades and aircraft, vortex generators normally positioned much closer to the prime edge of airfoil inorder to take care of constant airflow above the control planes [1]. They are basically rectangular or triangular in shape, because the local boundary layer, and run in span-wise lines are generally present near the stocky part of the wing.

Vortex generators obliquely placed since they need an angle of attack with reference to the local airflow. An unstable boundary layer is in smaller amount which is likely to be separated from a laminar one, and is desirable to achieve good effectiveness of trailing-edge on the control surfaces [2]. Hence the vortex generators are used to activate this conversion. These generators play a major role in multiengine aircrafts by enhancing the controllability at lower airspeeds condition hence permitting the slower proceedings. It also achieves the slower stall speed which can yield a better takeoff weight, thus refining the useful load [3, 4, 9]. Also, vortex generators used in single-engine aircrafts will reduce the stall speed and hence improve the slow speed handling.

II. BOUNDARY LAYER &FLOW SEPARATION

When there is relative motion between the object and the fluid, the fluid at the vicinity of the object gets disturbed and it starts moving around the object. This effect is found because of the aerodynamic force that is being created between fluid and the object. Magnitude of this force usually depends on many factors namely speed at which the object is moving, object shape, density of the fluid, viscosity of fluid, its compressibility and so on. Inorder to model these consequence, one uses the parameters which is the ratios of these effects to other relative forces present within the issue. If any of the two experiments generates an equivalent value for the similar parameters, then the perspective of the forces are modeled.

The force mainly depend on viscosity of the fluid because the fluid progresses, the molecules at the vicinity of the surface gets attached to the surface. The particles above the surface is bogged down due to the collisions with the surface molecules. Hence they successively hamper the fluid flow on the top. The heavier molecules proceeds apart from the surface, thus lesser is the collisions that is affected by the object surface. Because of this effect the skinny layer of fluid is formed at the vicinity of the surface. It is zero at the surface layer and as it moves away it occurs as the free stream value. Since is occurs on the boundary of the fluid it is termed as the boundary layer. Any flow in the boundary layer will cause the severe problems in aerodynamics which includes minute drag on the object, wing stall, and also the heat transfer which will occur in the high speed flight. Based on the Reynolds number the boundary layer may be laminar or turbulent. For the laminar type there is a layer in the boundary and hence from the surface, thus lesser is the collisions that is affected by the object surface. Because of this effect the skinny layer of fluid is formed at the vicinity of the surface. It is zero at the surface layer and as it moves away it occurs as the free stream value. Since is occurs on the boundary of the fluid it is termed as the boundary layer. Any flow in the boundary layer will cause the severe problems in aerodynamics which includes minute drag on the object, wing stall, and also the heat transfer which will occur in the high speed flight. Based on the Reynolds number the boundary layer may be laminar or turbulent. For the laminar type there is a layer in the boundary and hence stream-wise speed varies in the constant manner and also propagates away from the wall. But in case of layer having greater Reynolds number that is the turbulent layer the velocity is unsteady and swirling effect is found inside the boundary layer. As the aircraft wings experience the air flow, there is decrease in the pressure until it reaches 25% below the wings chord. Frequently the pressure starts increasing again and thus the wind starts flowing form the low pressurized area to high pressurized area. This effect is termed as adverse pressure gradient. Due to the continuous movement of air from low pressure area to high pressure area gradually it loses its energy and hence the flow gets separated from the wing. The air which is above the boundary layer is not affected by skin friction, hence it has more energy than the air which is present within the boundary layer. The vortex generators plays a role as tiny wings and makes small wingtip vortices. These vortices combine the higher energy free-stream air with the lower energy boundary layer, thus permitting the airflow within boundary layer to resist the adverse pressure gradient. The wing can now work at a better angle of attack before the stall is caused because of airflow separation.

III. WORKING OF VORTEX GENERATOR

When the air glides over the wing it gets attached to the surface and hence it causes the lift. If the angle incidence of attack is increased then it will cause the wing to stall. The generators generate their own vortices. The swirls of air energizes the surface above the wings surface that is layered with the air, and causes the air to remain attached to the airfoil for the longer duration of time.

IV. TYPES OF VORTEX GENERATORS

Vortex generators are of many types that gets its application in aircraft field. There are rectangular, triangular, gothic, ogive and the parabolic vortex generators. Among these, the gothic, rectangular and the triangular vortex generators are most widely used. As the name suggests, these are rectangular in shape and are the most commonly used vortex generators in aircrafts. These produce strong and big vortices with very high vorticity but also produce the highest drag, which gives it a slight disadvantage over the other types. The flow separation occurs in the leading edge of the vortex generator. Triangular Vortex generators are triangular in shape and widely used in aircrafts. At small angles of attack (0-10°), these vortex generators give the best drag reduction when compared to rectangular and gothic. The gothic vortex generator takes the shape of an acute arch like that of a lance or spear. These give drag force ranging between that of rectangular and triangular vortex generators for similar angles of attack. The drag coefficient also lies in between that of Rectangular and triangular for the same range of angle of attack. The advantages of using vortex generators are increase in lift coefficient at high angle of attack, stall speed reduction, increased aileron authority, better aerodynamic behavior at low speeds, minimum control speed reduction, takeoff distance reduction, landing distance reduction, steeper climbs and an inexpensive and easy way to improve aircraft performance. The disadvantages include generation of drag, cruise speed reduction, icing and abrupt stall behavior if used incorrectly.

V. VORTEX GENERATOR DESIGN

The vortex generator design involved designing two different vortex generators namely, the standard flat plate vortex generator and a customized vortex generator having an airfoil profile. The necessary parameters required to design the vortex generators are shape, length, location, height and span wise spacing.

A. *Shape:* The three shapes highlighted in the literature survey were considered for the design i.e. the rectangular, triangular and gothic shapes. A qualitative trade study was carried out between the three and the gothic shape was finalized because it best represented the characteristics of the rectangular and triangular shapes.

B. *Length:* The length of the vortex generator was finalized using standard thumb rules. A length lying in the range of 5-8% of the wing chord is considered ideal. Therefore, a final length of 0.02 m was obtained which is 8% of the wing chord.

C. *Location:* The location of the vortex generator is of paramount importance. Too far behind and flow separation might occur before reaching it. Too far ahead and it may not function efficiently. Thumb rules therefore state that the location of the vortex generator must be at a certain distance from the leading edge of the wing. Thus, a position of 0.042 m from the leading edge was obtained.

D. *Height:* Vortex generator height must be the same as that of the height of the boundary layer. The boundary layer thickness is calculated using the expression:

$$\delta = \frac{5.0x}{\sqrt{Re}}$$

E. Based on the above expression, a boundary layer thickness of 6.67 x 10^{-4}m was obtained. Since, such a value was too small for practical purpose, hence a value of 0.004m was adopted.

F. *Span wise spacing:* The span wise spacing dictates the distance between the vortex generators and also provides the number of vortex generators that have to be used. This distance is calculated using the expression:

$$r = \frac{10SC_L}{\pi^2 b}$$

G. Here, S is the planform area of the vortex

The vortex generator is depicted in the fig.1.

Fig. 1: Model of custom vortex generator on Autodesk Fusion 360

VI. ANALYTICAL TESTING

Once the design of the aircraft was ready, STEP files of three different configurations of the wing i.e. without vortex generators, with standard flat plate vortex generators and with the custom modelled were exported to Autodesk CFD. A basic analysis consisting of 100 iterations was carried out on them at a constant wind velocity of 12 m/s and at two angles of attack That is 5° and 15°. The two specific angles were arrived at since majority of aircrafts are trimmed at around 5° angle of attack during cruise and majority of airfoils stall at around 15° angle of attack.

VII. OBSERVATION

The results obtained from the CFD analysis have been tabulated in Table 1. As seen from the results, the installation of any vortex generator causes an increase in the drag but also results in an increased lift. At 5° angle of attack, the custom vortex generator increases the lift by 11.31% and the drag by 12.11% when compared to the standard flat plate vortex generator at the same angle of attack. At 15° angle of attack, the custom vortex generator increases the lift by 3.46% and the drag by 10.18% when compared to the standard flat plate vortex generator at the same angle of attack.

Condition	*Angle of attack=5°*		*Angle of attack=15°*	
	Lift (N)	*Drag(N)*	*Lift (N)*	*Drag(N)*
Wing without vortex generators	28.05	6.67	52.40	14.72
Wing with standard flat plate vortex generators	38.20	7.10	63.23	16.80
Wing with custom vortex generators	42.52	7.96	65.42	18.51

Table 1: Results obtained from CFD analysis

CONLUSION

The study reflects that the custom vortex generators provides the additional lift over the wing when compared to the flat plate vortex generators. However, the drag force generated by the custom vortex generators was higher than that generated by the flat plate vortex generators which could be overcome with additional thrust.

REFERENCES

[1] Mohammad H. Sadraey- Aircraft Design A Systems Engineering Approach.
[2] Anderson, John. Fundamentals of Aerodynamics. 5th ed. New York: McGraw-Hill,2011.
[3] Alawadhi, A. G. Alex.
[4] John C. Lin; Review of Research on; Low-Profile vortex generators to control boundary-layer separation.
[5] Niels N. Sorensen, F. Zahle, C. Bak, Prediction of the effect of vortex generator on aerofoil performance.
[6] Johari Bin Ismail, Devaranjan A., L. Ramaswamy, Yusof Bin Taib; Design and analysis of vortex generator for an H.E.V. model,2008.
[7] Jeromy L. Reed; Vortex generator articulator,1995.
[8] U Fernandez-Gamiz, G Zamorano and Zulueta; Computational study of vortex path variation with the VGheight.
[9] K.C. Nagaraja, S. Rajanna, G.S. Prakash, P.G. Koppad, and M. Alipour, "Studying the effect of different carbon and glass fabric stacking sequence on mechanical properties of epoxy hybrid composite laminates," Composites Communications, pp. 100425, 2020.