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Investigation the effect of various vortex generator types at different velocities and angles of attack in NACA 2412 Airfoil on lift and drag coefficients

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Abstract: Flow separation near the rear end of the aerodynamic body is the main cause of an increase in aerodynamic drag and a decrease in aerodynamic lift, for that they put a device known as vortex generator (VG) to controlling the flow separation. The vortex generator (VG) is an aerodynamic device, it activating the slow boundary layer motion and modifies the flow about the surfaces which results control of flow separation. Therefor the present work focused on the benefit of the various form of vortex generator (VG) such as rectangle, triangle, and gothic by using different angle of attack (0°,5^0 ,10^0 ,12^0 ,13^0 ,14^0 ,15^0 ,16^0 and 17°) at three different velocities (30, 35 and 40 m/s) for numerical test and (30 and 35 m/s) for experimental test to each one from these vortex generators, the main aim that implemented is comparative analysis for these types to find the best form in specific situation which in turn leads us to compared the values of the lift and drag coefficient for these different shapes of vortex generator (VG) and the most efficient form is given for each velocity and each angles of attack. This in detail study was performed on the NACA 2412 cambered airfoil. To find the better result of different types vortex generator (VG) to determine the value of lift and drag force and the value drag and lift coefficient from the above shapes which designed with the wing by Computer Aided Design (CAD).
Keywords: Aerodynamics, Boundary Layer, flow separation, Vortex Generators, Drag Coefficient, Lift Coefficient.

Introduction

"One of the most prominent causes of drag on bodies in motion through a viscous fluid is flow separation near the rear of the body and at abrupt changes in its geometry"[1], when the flow in the boundary layer is retarded to a point where it can no longer counteract the pressure gradient and separates from the surface that was flow separation. Fluid flow control is a rapidly developing major of fluid dynamics which include involves simple or complex modification of the composition which in turn leads to great engineering benefit like reduce drag, increase lift, improve mixing or reduce noise, this modification may be done by passive or active devices. Passive devices are steady and require no energy. Active control requires actuators which may be driven in a time-dependent manner and require energy [2]. Passive techniques include geometric shaping, using the traditional vortex generators and the placement of longitudinal grooves or rib lets on airfoil surfaces, while the active techniques include steady suction or blowing, unsteady suction or blowing and the use of synthetic jets.This study focused on demonstrating the effect of different types of vortex generators on the characteristics of aerodynamic flow at different speeds and angles of attack, with both numerical and experimental parts, therefore, three forms of traditional vortex generators (rectangle, triangle, and gothic) were selected with angles of attack (0^0,5^0,10^0,12^0,13^0,14^0,15^0,16^0 and 17^0) at three velocities for numerical test (30, 35 and 40 m/s) and two velocities for experimental test (30 and 35 m/s) to explain their effects on a rectangular wing with profile NASA 2412.

The solution approach used by ANSYS Fluent called the iterative solutions using for the numerical test, The value of drag and lift force can be taken by using result of CFD, also been added output of CFD simulation of contours of velocity and pressure, surface pressure and streamlines flow for NACA 2412 wing. The boundary conditions for ANSYS analysis at the input and output are given as the default domain. Three-dimensional steady turbulent flow of standard SST k-ω turbulence model had been solved with poly-hexcore mesh to compute the flow around the wing. Experimental tests for the wing and various types of vortex generators tested in low-speed wind tunnel of (0.7m × 0.7m × 1.5m) rectangular test section. The wing had been manufactured using plastic material using three-dimensional printing technologies. The experimental lift and drag forces were measured by three component balance devices.From the numerical results for lift and drag coefficient notes the Gothic VG has better effect at angle of attack less 140 in all velocities but at angle of attack more than 140 the Triangular VG the best but from the experimental results we note that the Gothic shapes have a better effect than the rest of the shapes in a broader perspective and they have efficiency in improving the properties when compared to the others. The numerical and experimental comparing results show that lift to drag ratio increases with using VGs than without VGs, the numerical CL/CD for the rectangular wing with and without VGs is almost convergent to the wind tunnel experimental results for higher angles of attack but in small angles of attack the results are somewhat deviated out which may be attributed to the measuring system (three-component force balance) and its sensitivity to the alternative forces which is generated by the model.

On the other hand, other research such as **S. Kishore Kumar et al. 2016** [3], the main aim that was implemented in this numerical study comparative analysis of different form of vortex generator (VG), so they had taking various shape as rectangle, triangle, and gothic shapes, results based on various attack angle at 0° and 10°. This in detail study was performed on the NACA 0012 symmetric airfoil. Flow separation near the rear end of the aerodynamic body is the major reason of aerodynamic drag, to avoid this separation was use a device known as vortex generator (VG) to controlling the flow separation. To find the better result of different types vortex generator (VG) they determined the value of drag force and the value drag coefficient from the above shapes which designed by Computer Aided Design in CATIA V5 software. The value of drag force can be taken by using result of CFX, also they found the output of CFX simulation of streamline flux at the rear end of NACA 0012.The boundary conditions for ANSYS analysis at the input and output are given as the default domain. At two different angles, the models are analyzed to compare the best form in specific situation has a different angle of attack. In this comparative analysis study have been compared the values of the drag coefficient for different shapes of vortex generator (VG) and the most efficient form is given. According to the analysis, the triangular shape vortex generator gives minimum amount of drag force and also delays flow separation through increasing velocity near the surface.

But **Antonio Carlos Daud Filho et at. 2013**[4], An experimental analysis was carried out in the Aerodynamics Laboratory of the Engineering School of São Carlos, of the University of São Paulo. The study focused on the effect of vortex generators on the aerodynamics of several types of airfoils which are widely applied in the design of wind turbine blades, such as NACA 63-415, NACA 63-215 and NACA 63-430 to conduct these experiments a low-speed wind tunnel was used. Tests were made for these airfoils with and without the three different sizes of vortex generators which were placed at 10% of the chord from the leading edge at Reynolds number 320,000 to measure forces, pressure distribution and moments over each airfoil. The results show up an improvement in the maximum lift coefficient for NACA 63-215 and NACA 63-415, in addition to that the lift-to-drag ratio was also increased for NACA 63-215 at angles of attack close to the stall. Taking into consideration, there wasn't any improvement for the NACA 63-430 performance in which the drag was increased and the slope of the lift curve was reduced.

While **Sutardi et at. 2015** [5], focused on evaluating the impact of the vortex generator attachment on the NASA LS-0417 airfoil profile, this airfoil used as application in wind turbine blade widely. NASA LS-0417 profiles with and without vortex generator the model for this experimental study. The chord length of the profile is 110 mm, while the span is 210 mm. The symmetrical profile NACA 0012 is the vortex generator profile attached on the upper surface of the main profile (NASA LS-0417). The chord length of the vortex generator is 7 mm with two different height values 1 mm and 2 mm. The experiment was done in open wind tunnel with maximum free stream velocity can attainable which approximately 19 m/s and the turbulence intensity approximately at the midline of the tunnel is 0.8%. The dimension of wind tunnel cross section octagonal shape is 30 cm x 30 cm and of 45 cm to 60 cm adjustable length, in two different velocities for free stream of 12 m/s and 17 m/s corresponding with Reynolds numbers (Re) of 0.83 x 100000 and 1.18 x 100000 based on chord length of the airfoil and the velocity of free stream. Angle of attact (α) was various from 0 degree to 24 degree. Measured the drag force and lift force using force balance with inaccurate measurements of approximately 0.77% and 2.47% at measured drag of 0.65N and at measured lift of 0.202N, respectively. Study of flow visualization was done by using the oil flow method to get a qualitative image of the flow structure on the airfoil surface. Results showed the vortex generator attachment on the NASA LS-0417 profile was not able to get better the profile performance compared to unmodified profile, in spite of that the Reynolds number shows an effect on the airfoil performance at flow conditions performed, when the Reynolds number large there was increase in CL/CD of approximately 36% at angle of attack (α) 6 degree. Finally, based on the results of flow visualization, attachment of the 2mm vortex generator on the airfoil NASA LS-0417 surface results in an advancement of boundary layer separation at the two Re's conducted, the 2mm vortex generator accelerates airfoil stall at approximately 16 degree, while the 1mm vortex generator is relatively no effect on the airfoil stall angle.

From the other side, **Mahbubur Rahman et al. 2015** [6], focused on separation of subsonic flow over a NACA0012 airfoil with 00 to 200 angle of attack and using vortex generators for controlling flow separation. The adding of vortex generator (VG) lead to reduced drag-coefficient and increases lift-coefficient when incident angles being large. Also notify in this experimental research on the effect of vortex generator (VG) on the fluid flow and aerodynamic forces which was acting on the airfoil. The ability of dealing with passive flow or activity it has enormous technological importance. The result showed more focus on modern control of passive flow by using the methods of vortex generator, which were mainly used to achievement of drag reduction, Lifting reinforcement, controlling flow separation etc. In a subsonic wind tunnel the test was done with dimension 1m×1m rectangular shape at flow speed 25m/s without vortex generator (VG) airfoil was placement and with a tilt of the vortex generator, an angle of attack from 0 to 20 degrees. By using vortex generator the test result appears a significant reduction in drag coefficient and increased lift coefficient. The comparing of coefficient for pressure, lift and drag between the airfoil without the vortex generator and airfoil with vortex generator help us to understand how does a vortex generator feeding the boundary layer flux to delaying the stall.

As for **B. J. Wendt et at. 1996** [7],studied the experimentally for one type of vortex generator which was symmetric airfoil having a NACA 0012 profile to specify adoption the geometry of vortex generator and flow circumstances effect on shed vortex circulation and cross plane peak vorticity. The geometry and flow standards diverse includes angle of attack a, chord length c, span h, and Mach number M .On the inner surface of a straight pipe placed the vortex generators either isolation or arrangement as a symmetric counter-rotating array. The thickness of the turbulent boundary layer to the ratio of the tube radius S/R w 0.17. It was derived circulation and the peak of vortex data from measurement the plane velocity conducted by about 1 chord downstream of trailing edge the vortex generator. Observed the circulation of Shed vortex and Shed vortex peak vorticity proportional with parameters M, a, and h/6 also the circulation drop in monotonic way with increase airfoil aspect ratio AR and peak vorticity increase with increasing aspect ratio reaching a peak value at AR w 2.0 before fall down.

But if we touch on **Xiaodong Wang et al. 2019**[8], experimental and numerical investigation studied the characteristics of a plate vortex and the aerodynamic characteristics of an airfoil for vortex generators (VG) to search the impact the height of vortex generators (VG) on boundary layer flow control effect through wind tunnel experiments and numerical methods. Have been studying the ratio of VG height (H) to boundary layer thickness (δ) on a flat plate boundary layer first of all, the H values are 0.1δ, 0.2δ, 0.5δ, 1.0δ, 1.5δ, and 2.0δ, the results showed that the density of the vortex and the height of the vortex generator represented a logarithmic relationship and the intensity of the vortex is proportional to the average kinetic energy of the fluid within the height range of the vortex generator (VG). Then have been studying elevation effects on the aerodynamic performance of the airfoils in a wind tunnel using three VGs with H = 0.66δ,1.0δ, and 1.33δ.With and without vortex generator (VG) the stall angle of the airfoil is 18◦ and 8◦ , respectively, so the VG raise the stall angle by 10◦.Comparison to airfoil without vortex generator the maximum lift coefficient of the wing with a vortex generator increases by 48.7%, and The drag coefficient of the wing with the vortex generator is 84.9% less than the drag coefficient of the wing without it with the angle of attack 18◦.The maximum lift–drag ratio of a wing without a vortex generator is higher than that of an airfoil with vortex generator, so the vortex generator has no effect on the maximum lift–drag ratio of the airfoil .However, a VG does increase the angle of attack of the best lift–drag ratio.

Finally **Xin-kai Li et at. 2019** [9], separation of the flow showed the roots of the blade while operating a wind turbine which leading to reduces the wind turbine aerodynamic efficiency .To efficient application of vortex generators (VG) for controlling the blade flow ,the VG spacing impact (λ) was studied on flow control through experiments of wind tunnel and numerical calculations, used the Large Eddy Simulation (LES) method to calculate the flow separation in a flat plate boundary layer under an opposite pressure gradient .Was analyzed the Widely coherent structure of the boundary layer separation and it's the process of evolution in the field of turbulent flow , and comparison of the effect of different VG spacing on the boundary layer separation suppression based on the kinetic energy of the fluid in the boundary layer, the pressure loss coefficient, and the space between the vortex cores . Then, taken the DU93-W-210 airfoil as the search object, and to study the VG spacing effect on the lift–drag characteristics of the airfoil the wind tunnel experiments was done. It found when spacing of the vortex generator (VG) was λ/H = 5 (the distance between vortex cores and the vortex core radius was approximately equal) is more useful for flow control .The kinetic energy of the fluid in the boundary layer was inversely proportional to the VG spacing .Take in consideration if the VG spacing is very small, which mean the vortex is far from the wall this lead to not conducive to controlling flow. The experimental results of the wind tunnel showed that the angle of attack (AOA) of the airfoil with VG increased by 10◦ compared to that without VG. When the distance between vortex cores and the vortex core radius was approximately equal (the VG spacing is λ/H = 5), the maximum lift coefficient of the airfoil with VG increased by 48.77% compared to that of the airfoil without VG, the drag coefficient decreased by 83.28%, and the lift-to-drag ratio increased by 821.86%.

Conclusion

One of the most important factors influencing the formation of separation is:

1. Reynolds Number.
2. The profile of the airfoil shape.

3. Degree of the smooth wing surface.
4. Angle of attack.

In aerodynamics, flow separation can often result in increased drag, especially pressure drag caused by the pressure difference between the front and rear surfaces of an object as it travels through the fluid.For this reason, much effort and research has gone into designing aerodynamic and hydrodynamic surfaces that delay flow separation and keep the local flow bound for as long as possible.The results show that lift and drag coefficients increases with using VGs than without VGs, for all intermediate angles, which meansthe vortex generators performed aerodynamically efficient.

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