Review on Vortex Generators Mounted on Airfoil to Improve the Aerodynamic Performance

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Abstract

In aircrafts lift is the most important factor which depends on wing performance. But during the cruising flight when the angle of attack increases there is change in the aerodynamic factors such as lift and drag forces due to the boundary layer (BL) separation. To delay or avoid this boundary layer separation and improve the aerodynamic performance of the wing vortex generators were introduced. Vortex generators helps to keep the boundary layer attached to the wings upper surface. In previous decades much study is done to control this BL on the different types of airfoils i.e. symmetrical or unsymmetrical. This review is based on study related to improve these parameters so that there will be increment in lift coefficient and reduction in drag coefficient. To overcome these parameters appropriate size, shape, length, position and incidence angle, etc should be investigated to find out the suitable one. These investigations can be performed as numerical based using software simulation and also by experimental approach in a wind tunnel. The main practical advantage of these vortex generators is to reduce parasite drag on airfoil and increase the lift force, they are also demonstrated to be critically important in other applications also.

Summary

In this paper ('Effects of Surface Roughness and Vortex Generators on the NACA 4415 Airfoil' [1]), a comparative study has been done between clean airfoil, airfoil having roughness at the leading edge, and airfoil with VGs on NACA 4415 airfoil having Reynolds number changes from 1 to 2 million. This study observed that the maximum lift coefficient for clean airfoil is 27%, for an airfoil with roughness is about 18% and for an airfoil with vortex generators on the upper surface at 30% of a chord is about 29%. From which it is seen that VGs energized the boundary layer, increased the lift curve slope, and also delay the stall at a higher angle of attack.

In this paper ('The Potential of Hybrid Micro-Vortex Generators to Control Flow Separation of NACA 4415 Airfoil in Subsonic flow' [2]) the study has been done on passive, active, and hybrid micro-VGs which are mounted on NACA 4415 airfoil. In which the models are designed using 3D printing and tested in a wind tunnel at 26.19 m/s at Re= 2.5 x 10^5 and it shows that the hybrid micro-VGs increases lift by 21.2%, increases drag by 11.3%, and lift to drag ratio by at least 8.6% until up to 33.7%. Therefore, from this study, it is concluded that the hybrid-micro VGs are having better performance than active and passive VGs.

In this paper ('Design optimization of the aerodynamic passive flow control on NACA 4415 airfoil using vortex generators' [3]) the focus is on controlling flow separation on NACA 4415 airfoil equipped with VGs and it is based on five geometric parameters of vortex generators. It is performed in wind tunnel at different angle of attacks and Re no. up to 2 x 10^5. From results it is observed that triangular shape is suitable to control the boundary layer separation and the optimum angle of VGs is obtained as 12° with the distance of 3 mm between vortex generators which are located at 50% of the chord. They are also very effective to control the parasite drag. The coupled vortex generators increases maximum lift coefficient as 21% and a flow separation is delayed by 17°.

In this paper ('Shark skin-inspired designs that improve aerodynamic performance' [4]) the concentration is on the shark skin-inspired designs to increase the aerodynamic performance. In previous studies, the focus was on reducing drag, while in this article they have tried to also generate lift and improving the lift-to-drag ratio. First, it trips the boundary layer and generates a short suction along the chord which enhances the lift. Second, the drag reduction can be achieved by generating streamwise vortices with help of spanwise vortices.

In this article ('Aerodynamic Characteristics of Shark Scale-Based Vortex Generators upon Symmetrical Airfoil' [5]) various test has been carried out to determine the effect of shark scale-based VGs on NACA 0015 at Re = 2 × 10^5 and angle of attack which is ranging from 0◦ to 24◦ in increments of 3◦. The results proved that the shark scale-based VGs reduces drag and also helps to increase the maximum coefficient of lift which enhances the overall aerodynamic performance. It also provides aerodynamic effects by causing significant spanwise variation as well as by effectively altering the flow, etc.

This study ('Passive flow control of shock-induced dynamic stall via surface-based trapped vortex generators' [6]) provides an approach for controlling the flow in a 2D dynamic stall at variable freestream on SC 1095 airfoil having surface-based trapped vortex generators at Re = 6.1 × 10^6 and Mach 0.537 ± 0.205. Results showed the best geometry can reduce the peak negative pitching moment by 9-23% (during transonic phase) and 19-71% (during the dynamic stall phase). And the peak drag is reduced by 8-20% during the transonic phase while the dynamic stall phase reduced drag by 15-44%. And the lift-to-drag ratio was increased by 3-28% per one rotor cycle.

This article ('Analytical Testing of Vortex Generators with an Airfoil Profile' [7]) focuses on the comparison between the flat plate and airfoil profiles by CFD analysis. As per the test, the results revealed that the vortex generators cause an increase in drag but it also helps to increase the lift. At a 5deg angle of attack the lift increases by 11.31% and the drag by 12.11% with the help of custom vortex generators when they were compared with standard flat plate vortex generators. Whereas, at an15deg angle of attack the custom VG increases lift by 3.46% and drag by 10.8% when they were compared with the standard flat plate VG at the same angle of attack. Therefore, it is concluded that the custom generators provide additional lift when compared with the flat plate VGs.

In this article ('Numerical Simulation of the Boundary Layer Control on the NACA 0015 Airfoil Through Vortex Generators' [8]) the influence caused by VG on NACA 0015 at Re = 2.38 × 10^5 and at an angle of attack 3 and 6deg located before and after a recirculation bubble caused by the boundary layer detachment. Results showed that at an angle of attack 3deg there is a strong reduction of the recirculation bubble which leads to a drag reduction of 1.43% with the help of generators. Whereas, at an angle of attack 6deg the effect was lower and there was no formation of longitudinal vortices which results in an increased lift as well as drag by 0.35% and 0.33%, respectively.

This study ('Testing the Efficacy of Micro Vortex Generator Geometries on Boundary Layer Separation Mitigation' [9]) investigates the vortex generators performance by considering airfoil aerodynamics. In this article, numerical study was conducted for a NACA 4414 airfoil which is equipped with vortex generators to increase the lift coefficient and to delay the boundary layer separation. For this study trapezoidal VG and delta wing VG were use from which it is concluded that the trapezoidal VG increases the critical angle of attack and also performed best for all angle of attack. Whereas as compare to the trapezoidal VG the delta wing VG did not show any positive effect when they are placed on the airfoil, but they are capable of producing strong vortices.

In this study ('Study of Vortex Generator Effect on Airfoil Aerodynamics Using the Computational Fluids Dynamics Method' [10]) NACA 4412 airfoil is used to increase the aerodynamic capabilities of the aircraft wing. The airfoil with straight vortex generators and the comparison between plain airfoil and airfoil that is applied to the VG at angle of attacks 0deg, 5deg, 10deg, and 15deg whereas, the VGs are placed at 24% from the leading edge.in this article it is concluded that the lift coefficient value changes with the change in angle of attack. But, with the use of vortex generators the lift can be increased on the wing of the aircraft. From this study it is observed that the most lift increases at 5deg which is about 13%.

This article ('Dimples and Vortex Generator Performance on Airfoil Surface' [11]) is a comparative study between the inward dimple, outward dimple, and triangular vortex generators which are mounted on NACA 4415 airfoil at Reynolds number 50000 and 100000 and placed at 50% of the chord length. Results show that at Re = 50000 the triangular vortex generators provide a higher value of lift coefficient as the AoA increases followed by baseline, inward dimple, and outer dimple. There is almost 22% the difference between the triangular VG and baseline. Also, the drag coefficient value is higher in the case of triangular VG followed by baseline, outward dimple, and inward dimple. In terms of lift-to-drag ratio, the inward dimple produces a higher value. Whereas, at Re = 100000 the triangular VG shows a higher coefficient of lift as compared to the other cases. And they produce the lowest coefficient of drag and the lift-to-drag ratio is higher at high AoA in case of inward dimple and it is higher at low AoA in case of triangular vortex generators.

In this study ('Aerodynamic performances improvement of NACA 4415 profile by passive flow control using vortex generators' [12]) the NACA 4415 airfoil has been used to improve the aerodynamic performance by using passive devices such as vortex generators. In the end, it is concluded that at a high angle of attacks the lift coefficient improves effectively with the help of vortex generators. Whereas the airfoil without vortex generators provide effective performance at a low angle of attacks.

In this study ('Lift Enhancement of NACA 4415 Airfoil using Biomimetic Shark Skin Vortex Generator' [13]) the aerodynamic performance on NACA 4415 airfoil has been investigated by using shark skin vortex generators which are located at 50% of chord from the leading edge. The conclusion shows that the shark shape vortex generators show more effective aerodynamic performance as compared to other vortex generators. It is observed that it shows the highest lift coefficient but at the same time it also shows the highest drag coefficient.

In the article ('Experimental and Numerical Analysis of the Effect of Vortex Generator Height on Vortex Characteristics and Airfoil Aerodynamic Performance' [14]) wind tunnel test has been carried out to explore the effect of height of VGs. Firstly, the study was focused on VG height and the results showed that the vortex intensity is proportional to the average kinetic energy. Whereas, the effect of VG height is studied in a wind tunnel with H = 0.66δ, 1.0δ, and 1.33δ (δ = boundary layer thickness). When the maximum lift coefficient is compared with the airfoil without VGs there is 48.7% increment was found and the coefficient of drag was found as 84.9% which is lower than that of airfoil without VGs at an angle of attack of 18deg.

In this paper ('Analysis of the Effect of Vortex Generator Spacing on Boundary Layer Flow Separation Control' [15]) to avoid the flow separation and to increase the aerodynamic efficiency on wind turbine blade vortex generators have been used. The effect of VG spacing has been studied by using both the ways numerical as well as wind tunnel experiments. Experimental results showed that the airfoil with VG has increased stall angle of attack by 10deg as compared to an airfoil with no VGs. In the case of an airfoil with VG the maximum lift coefficient increases by 48.77% and the drag coefficient is decreased by 83.28% and also the lift-to-drag ratio increased by 821.86% when the space between VG was $\lambda/H = 5$.

In this paper ('Numerical/experimental investigations on reducing drag penalty of passive vortex generators on a NACA 4415 airfoil' [16]) both the numerical and experimental study is performed to increase the aerodynamic performance on NACA 4415 airfoil by using triangular shape passive vortex generators at Reynolds number 2 × 10^5. From the results it is observed that the optimized configuration is robust for the consider parameters. Also, by increasing the span wise length there is increase in the aerodynamic performance such as lift-to-drag ratio at low angle of attacks.

This article ('Flow separation control of NACA-2412 airfoil with bio-inspired nose' [17]) focuses on achieving the optimum flow separation on NACA 2412 airfoil at low subsonic speed by introducing the bio-inspired nose near leading edge. Results shows that the aerodynamic efficiency increases by decreasing nose length but it decreases at high angle of attacks because of early separation. Therefore, shorter nose give effective aerodynamic performance at all angle of attacks. It is also found that at high angle of attack the aerodynamic efficiency increases with increase in cavity depth. But the aerodynamic efficiency decreases at low AoA due to movement of stagnation pressure. Therefore, for all angle of attacks medium depth cavity is suitable.

In this paper ('Wind tunnel tests of an airfoil with 18% relative thickness equipped with vortex generators' [18]) the focus is on thin airfoils having 18% thick airfoil with vortex generators. NACA 633-418 airfoil has been used in this study and the wind tunnel test is carried out at clean conditions, leading edge roughness and also by different heights and positions of vortex generators. Results shows that leading edge roughness can compensate the loss of maximum lift and also these VGs can decrease the drag at higher angle of attacks. The increment in drag is more for the clean airfoils than that of airfoils having leading edge roughness.

This article ('A Development and Assessment of Variable-Incidence Angle Vortex Generator at Low Reynolds Number of ~ 5×104' [19]) focuses on improvement of parasite drag issues by using variable-incidence-angle vortex generator (VIVG) mounted on NACA 0015 airfoil. From results it is found that at low Reynolds number VIVG can reduce the drag in the pre-stall region and also there is increment in lift-to-drag ratio. It is also observed that at large incidence angle of VIVG there is increment in lift force.

This article ('Computational characterization of the vortex generated by a vortex generator on a flat plate for different vane angles' [20]) focuses on the size of vortex generator on flat plate to improve the aerodynamic performance by using computational fluid dynamics simulations. The results show's that the rectangular vane type vortex generators helps to improve the aerodynamic performance at Reynolds number 27000 and at angle of attacks 10◦, 15◦, 18◦ and 20◦. When the vortex generators height is higher than the local boundary layer than there is change in incident angle of attack.

This paper ('Design and Analysis of Vortex Generator and Dimple over an airfoil Surface to Improve Aircraft Performance' [21]) focuses on design and analysis of VGs and dimple on airfoil to enhance the aerodynamic characteristics. Whereas, at the end it is concluded that the airfoil with dimples can improve the aerodynamic parameters more effectively than that of airfoil having vortex generators.

This study ('Parametric study of low-profile vortex generators' [22]) investigates the trajectory and size of low-profile vortex generators which are having the vane incident angle of 18.5deg and the height to length ratio of ½ at Reynolds number 1350. Also, the vortex generators were placed on the local boundary layer thickness. These low-profile vortex generators can lower the drag and they are cheap and simple. From results it has been proved that the VGs height can directly affect the aerodynamic performance.

In this paper ('Energization of Boundary Layer Over Wing Surface By Vortex Generators' [23]) the study has been carried out on airfoil with and without vortex generators. For this nine sets of rectangular VGs were placed on leading and well as trailing edge of the wing with inclination of 15deg. Also, nine sets of o-give VGs were placed on leading and well as trailing edge of the wing with inclination of 15deg. From result it is concluded that the upper surface increases pressure and reduces drag.

In this paper ('Comparative Analysis of Various Vortex Generators for a NACA 0012 Aerofoil' [24]) the comparative study of vortex generators shapes has been carried out such as rectangle, triangle and gothic shapes on NACA 0012 airfoil at 0° and 10°. in this study it is concluded that the triangular vortex generators provide effective drag reduction.

This study ('Numerical Investigation of Flow Field and Effect of Varying Vortex Generator Location on Wing Performance' [25]) is done over NACA 4412 airfoil with vortex generators at different locations and at Reynolds number 10^5. In this study it is concluded that lift decreases and drag increases at lower AoA. From this study it is concluded that by increase in angle of attack there is significant change in aerodynamic parameters of vortex generators.

This paper ('Experimental investigation of the flow past passive vortex generators on an airfoil experiencing three-dimensional separation' [26]) separates the boundary layer before stall condition and also increases the maximum lift coefficient at Reynolds number 0.87 × 10^6. From results it seems that it increases overall aerodynamic performance and delays the boundary layer separation.

In this article ('The Potential of Hybrid Micro-Vortex Generators to Control Flow Separation of NACA 4415 Airfoil in Subsonic Flow' [27]) NACA 4415 airfoil is used to improve the aerodynamic performance at Reynolds number 2.5 × 10^5. From the wind tunnel experiment is concluded that the lift increased by 21.2% and drag by 11.3% while the improvement is lift-to-drag ratio is about 8.6%. from this study it is observed that the hybrid micro VGs improves aerodynamic performance more effectively than that of active vortex generators which also reduces parasite drag.

This study ('Investigation of Flow Field over NACA4412 with a Vortex Generator' [28]) investigate the flow over NACA 4412 with VGs at different angle of attacks and at Reynolds number equal to 10^5. At low angle of attack there is negative effect of lift and drag but there is negligible increase in drag and decrease in lift. Whereas, at higher angle of attacks there is increase in lift. And, there is drag reduction at higher angle of attacks so that the boundary layer is attached to airfoil.

In this study ('Lift Enhancement of an Airfoil Using a Gurney Flap and Vortex Generators' [29]) lift, drag and pitching-moment coefficients were obtained on NACA 4412 airfoil. The gurney flap increases the maximum lift coefficient and decreases the drag. By increasing gurney flap height the nose down pitching moment can be achieved. In this study the use of vortex generator delayed the boundary layer separation and increases the maximum lift coefficient.

In this study ('Effect of Vortex Generator on Lateral and Directional Aerodynamic Characteristics at Medium Angle of Attack' [30]) a numerical computational investigation has been done by applying vortex generators. The results show's that vortex generators have very little influence on the lateral aerodynamic performance and also it helps to put off the critical angle from 22deg to 29deg. All these results were obtained at Reynolds number 0.466 million and mach number of 0.0882.

In this article ('Effects of Vortex Generators on an Airfoil at Low Re' [31]) a wind tunnel test has been carried out to record the effects of vortex generators. From the results it is concluded that the static vortex generators increases lift coefficient whereas, the active vortex generators does not shows any effective aerodynamic performance. These results were recorded at Reynolds number 80000 and 160000.

In this study ('THE EFFECT OF ADDING MULTIPLE TRIANGULAR VORTEX GENERATORS ON THE LEADING EDGE OF A WING' [32]) the triangular vortex generators are used to control the boundary layer separation on NACA 0015 airfoil. In results it is found that the flow remains attached at 16deg and it stalled at 18deg when the spacing between the vortex generators is 1 inch. Using the different spacing there is increase in stall angle. From the both computational and experimental investigation there has been similarities found. Wing having triangular vortex generator produces counter rotating trailing vortices and when they passed through the wing it energizes the boundary layer and delays the stall.

Research Gap

Even though there is much data available regarding the topic of delaying the boundary layer separation with the help of vortex generators to enhance the aerodynamic performance, there are much research gaps are their which holds this VGs in certain negative effects which will again gives some boundaries so that there is some disadvantages of these effects on the aerodynamic performance.

From the literature survey it is observed that in case of higher angle of attacks the effectiveness of these vortex generators to keep the BL at its position is very less. Also, when the experiment or any simulation is conducted it seems the stall angle is much closer to the normal angle i.e. in many cases the stall angle is 17 or 20deg onwards. Also, from the literature survey it is observed that the vortices which are created due to VGs which keeps the boundary layer energized can be more improved so that the stall angle can be moved further to delay the stall.

In terms of passive vortex generator parameters such as shape, size, spacing, chord wise positioning, stall angle, incidence angle and length, etc. these all are having limitations and can be changes as per the selection of airfoil and boundary layer conditions (i.e. inlet conditions) such as applied Reynolds number, inlet velocity, Mach number, angle of attacks, airfoil type, etc. Therefore, after choosing these inlet conditions based on the requirements the vortex generator parameters can be achieved or improved by or from the previous literature survey.

Conclusion

From the previous year's literature it is found that many researchers are working on this topic to improve the aerodynamic performance of airfoil which reduces lift force due to the boundary layer separation. From literature survey it is observed that the appropriate parameters of vortex generators can result in improvement of aerodynamic performance on airfoil. Also, from the literature it seems that the vane-type triangular VGs are mostly used among past researcher's and also it is found that they effectively increases the lift coefficient and also reduces the drag coefficient.

About the position of VGs it should be lower than the boundary layer thickness for effective performance. From most of the papers it is found that the Reynolds numbers at which the experiment has been conducted is between 10^5 to 5 × 10^6. Whereas, the common angle of attacks are between 0deg to 20deg. Generally, after 20deg stall angle is measured in most of the cases. Whereas the length, incident angle, and spacing etc, were observed as secondary parameters.

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