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# Analysis of Various Shaped Vortex Generators on Aerofoil

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**ABSTRACT:** This project aims at the CFD analysis of triangular shaped vortex generator and rectangular shaped vortex generators to determine the aerodynamic parameters such as co-efficient of lift, co-efficient of drag, lift and drag, and also, thereby we can determine an efficient shape for the vortex generators. In this project, we have introduced an optimal geometry for the rectangular shaped vortex generator and triangular shaped vortex generator. By using an optimal geometry the performance of both vortex generators have increased. By comparing the values of both the vortex generators, triangular vortex generator have better values in all aerodynamic parameters such as co-efficient of lift and lift. The values of co-efficient of lift and lift of both vortex generators are increasing with increasing angle of attacks. But, the triangular vortex generator produces higher values for co-efficient of lift and lift. In the case of co-efficient of drag and drag, the values of both the vortex generators are increased with increasing angle of attack, but triangular vortex generator produces less values for co-efficient of drag and drag comparing to rectangular vortex generator. In short, the triangular vortex generator is better in performance.

**KEYWORDS:** Vortex Generator, NACA 4415, Triangular vortex generator, Rectangular vortex generator, co-efficient of lift, co-efficient of drag, lift, drag.

## I. INTRODUCTION

The efficient performance of aircraft and other aerospace vehicles is critically evident on the aerodynamic properties of their wings. One of the most significant phenomena affecting wing performance is flow separation, a complex process in which the smooth flow of air over the wing's surface becomes turbulent and detaches from the surface. While an aircraft cruising at low altitudes, the air particles near the upper surface of aerofoil retards and stick on the top of the aerofoil's surface due to low momentum caused by viscosity, this layer of air particles leads to form a boundary layer over the wing's surface. And also, all these causes to formation of flow separation over the wings surface leads to a reduction in lift, an increase in drag, and potential instability, all of which can impact the safety and efficiency of the aircraft.

Understanding flow separation over wings is essential for designing high-performance and safe aerospace vehicles. By investigating the causes and effects of flow separation, as well as potential methods for controlling or mitigating it, engineers can improve aircraft performance and fuel efficiency, while also reducing maintenance costs and environmental impact. To mitigate those issues and enhance aerodynamic performance, scientists introduce Vortex generator and employed on the wings of the aircrafts, propeller blades and in some kind of heat exchangers. Vortex generators are small, fin-like structures strategically placed on the wing surface to generate controlled turbulence and improve the airflow's attachment to the wing. These vortex generators create vortices over the wing surface and mixes the high momentum free stream air and low momentum air particles in boundary layer. That's how, vortex generator energizes the air particles in the boundary layer. By energizing the boundary layer, these devices delay flow separation and enhance lift at higher angles of attack. As a result, vortex generators play a crucial role in optimizing aircraft performance, particularly in terms of stall prevention and aerodynamic efficiency.

Vortex generators are available at different shapes, different sizes and in different dimensions according to their applications. In almost all applications, its dimension is considered as small. Mostly these vortex generators are found in the aircrafts cruising at low altitudes because at low altitudes the momentum of air is comparatively low. In this project, we are conducting a CFD analysis of rectangular shaped vortex generator and triangular shaped vortex generator, both are equipped with NACA 4415 aerofoil. Thus, we can determine its efficiency and performance to control the flow separation. Vortex generator actually available in many shapes that is: rectangular shape, triangular

shape, circular shape, gothic shape and so on. The shape of the vortex generator plays an important role in efficiency and functionality of vortex generators. Also, by virtue of shape of vortex generators, same aerofoil which is attached with different shaped vortex generator exhibits difference in the parameters of co-efficient of lift, co-efficient of drag and lift to drag ratio.

Dimensions of the VG also took a vital importance in controlling the flow separation as well as determining the lift, drag and other parameters. Omar Madani Fouatih gave the idea of optimal geometries for the both the vortex generators and also, he compares the micro vortex generators and the macro vortex generators. Also, he found out that the maximum lift co-efficient for an aerofoil with coupled vortex generators increases by 21% and a flow separation is delayed by 17°. The optimal geometry is very important to construct a very efficient and better vortex generator for aircrafts respective to its applications. The length, height, position, yaw angle, distance between VG's, all these includes in optimal geometry. All these parameters are in efficient ratios in optimal geometry. So that, in this project, for both vortex generators the optimal geometry of vortex generators is considered. In this project 3D models are used for the analysis purposes. The optimal geometries are used to construct these 3D models for both the vortex generators. Zhen states that higher maximum lift co-efficient is achieved when the VGs are placed nearer to the separation point. In addition to this, shorter spanwise distance between the VGs also increases the maximum lift co-efficient, rectangular and curve-edge VG performs better than triangular VG.

In this project, the NACA 4415 aerofoil is considered due to its wide application in aviation industry. It is mostly used in smaller Aircrafts, which is cruising at lower altitudes. The NACA 4415 aerofoil is a member of the National Advisory Committee for Aeronautics (NACA) 4-digit series, designed to provide specific aerodynamic characteristics for various aviation applications. This aerofoil is characterized by a camber of 4%, positioned 40% along the chord from the leading edge, and a maximum thickness of 15% of the chord, located 40% back from the leading edge. These dimensions provide a balance between lift and drag, making the NACA 4415 suitable for general aviation and light aircraft, where stable and efficient performance is essential.

In almost all applications, the triangular rectangular shaped vortex generators are preferred rather than other shapes. By analysing rectangular shaped vortex generator and triangular shaped vortex generators, we can determine its efficiency and characteristics to control the flow separation over the wings. This project utilizes the optimal geometry to model the 3D models of both vortex generators for the analysis purposes. And also, both shapes are not complex to manufacture in industrial scale. All these analysis is conducting at low Reynolds number. This project includes three analysis cases. That is, the analysis of NACA 4415 aerofoil alone, the analysis of rectangular vortex generator equipped NACA 4415 aerofoil and triangular shaped vortex generator equipped NACA 4415 aerofoil.

## II. RELATED WORK

[1] Ali Niknahad and Abdolamir Bak Khoshnevis compared that Pressure drag, friction drag, total drag, and drag co-efficient. And also, they found out that by attaching the vortex generators to the bare aerofoil, the drag co-efficient is reduced by 0.161% and 0.806% for triangular and circular vortex generators, respectively.

[2] Zhen found out that higher maximum lift co-efficient is achieved when the VGs are placed nearer to the separation point. In addition to this, shorter spanwise distance between the VGs also increases the maximum lift co-efficient, rectangular and curve-edge VG performs better than triangular VG.

[3] Xinkai Li came in to the inference of the maximum lift co-efficient of the aerofoil with VGs increases by 48.7% compared with the aerofoil without VGs, and the drag co-efficient of the aerofoil with VGs is 84.9% lower than that of the aerofoil without VGs at an angle of attack of 18. However, a VG does increase the angle of attack of the best lift-drag ratio.

[4] Omar Madani Fouatih put forward efficient geometry for the rectangular and triangular vortex generators.

[5] G Vasantha Kumar compared the drag co-efficient values of the Various Shapes of vortex generator.



### III. METHODOLOGY

#### 3.1 GEOMETRY

##### 3.1.1 3D MODEL OF NACA 4415 AEROFOIL, RECTANGULAR VORXTEX GENERATOR AND TRIANGULAR VORTEX GENERATOR EQUIPPED WITH NACA 4415

It is most necessary to model this NACA 4415 for the analysis purposes. Here we considered a test section NACA 4415 aerofoil. Here, NACA 4415 aerofoil have span length of 0.454 m and chord length of 0.150 m. it also has a wing area of 0.069008 m<sup>2</sup> with 2.98 m<sup>2</sup> of Aspect ratio. Both vortex generators have a height of 3mm and length 9mm. it also has a 11° yaw angle for the rectangular vortex generator and 12° for the triangular vortex generator and the distance between each VG's is 3 mm. Thickness of both shapes of VG's are 0.25mm and also, the distance between adjacent VG pairs is 35 mm.

#### 3.2 GOVERNING EQUATIONS

The results obtained in the present paper are obtained by solving the continuity and Navier Stokes equations for incompressible flow. Here we considered 3D Models for the analysis purposes.

##### 1. Continuity Equation

Where:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

$\vec{u} = (u, v, w)$  is the velocity vector, with  $u, v, w$  as the components in  $x, y$  and  $z$  directions respectively.  
 $\nabla \cdot$  is the divergence operator.

##### 2. Momentum Equations:

Where:

- $\rho$  is the fluid density,
- $\mathbf{v}$  is the fluid velocity vector,
- $t$  is time,
- $p$  is the pressure,

$$\rho \left( \frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p + \mu \nabla^2 \mathbf{v} + \mathbf{f}$$

- $\mu$  is the dynamic viscosity of the fluid,
- $\mathbf{f}$  represents any external forces acting on the fluid,
- $\nabla$  is the del operator, and
- $\nabla^2$  is the Laplacian operator.

Table 1: Table of Boundary Inputs

Zone	type	velocity
Inlet	Velocity inlet	21m/s
Outlet	Pressure inlet	-
Aerofoil	wall	-

All analysis were carried out in ANSYS FLUENT 2024 version. The solver is steady and pressure- based. The inlet is chosen as velocity inlet and outlet is pressure outlet. The Reynolds number is set to be  $2 \times 10^5$ . the inlet velocity is set to be 21 m/s. Density and viscosity of air are considered as 1.225 kg/m<sup>3</sup> and 1.7894e-05 kg/m-s, both are at standard values of air.

IV. RESULTS AND DISCUSSION

4.1 BASELINE CASE

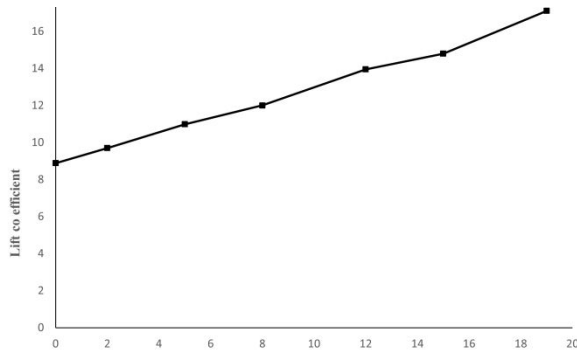


Fig 1:  $C_L$  vs AOA

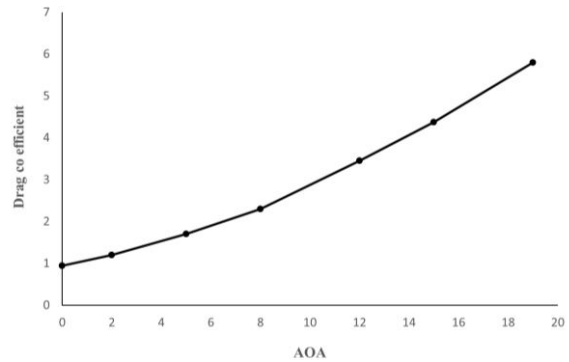


Fig 2:  $C_D$  vs AOA

Figure 1 depicts the values of co-efficient of lift at different angle of attacks of baseline case. It shows an uptrend line. At 19° of angle of attack,  $C_L$  shows its maximum value.

Figure 2 depicts the  $C_D$  values of NACA 4415 aerofoil at different angles of attacks. Maximum of value of  $C_D$  can be found at 19° angle of attack. The value of  $C_L$  is increasing with increasing the angle of attacks. It also has an uptrend line.

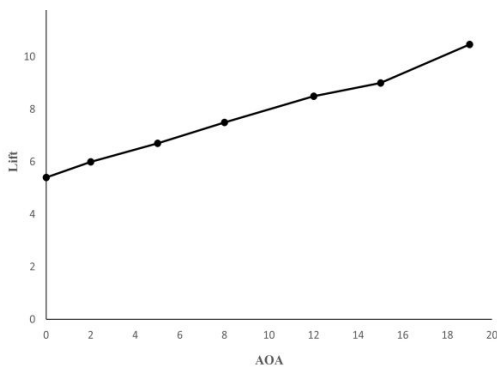


Fig 3: Lift vs AOA

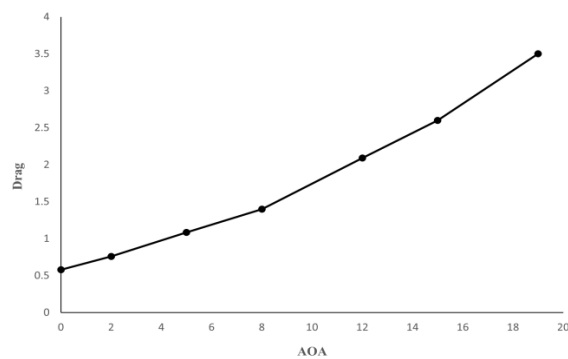


Fig 4: Drag vs AOA

Figure 3 depicts the Lift values of NACA 4415 aerofoil at different angle of attacks. Lift also increases with increasing angle of attacks, gives an uptrend line in the plot. Lift has a maximum value at 19° angle of attack.

Figure 4 showcases the Drag of NACA 4415 aerofoil at different angle of attacks. The drag values are increasing with increasing angle of attacks. Maximum value of drag can be found at 19° angle of attack.

4.2 VALIDATION STUDY

The results from the baseline case are compared with the previous work of [4] Fouatih. We have got better values in the case of baseline, rather than the previous works of [4] fouatih. The baseline analysis was carried out in a fluid domain of dimension of 0.46 m × 0.46 m. The inlet velocity was fixed to 21 m/s (which corresponds to a Reynolds number of  $2 \times 10^5$  same as in [4] fouatih's work. NACA 4415 aerofoil geometry for analysis was constructed with 0.152 m chord and 0.454 m span. The results for lift co-efficient and drag co-efficient are depicted in figure 5 and figure 6. Due to the limitations of wind tunnel, values of co-efficient of lift and co-efficient of drag, in the journal of [4] fouatih are lesser than present work

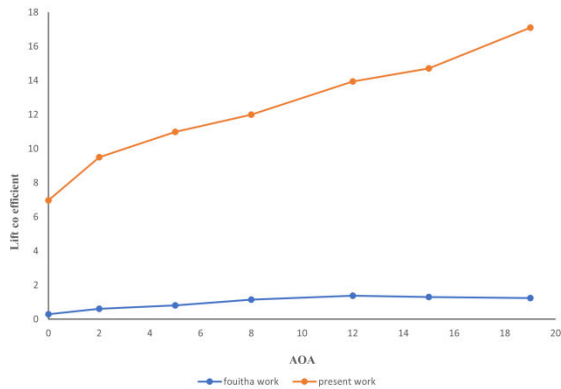


Fig 5: Lift co-efficient vs AOA

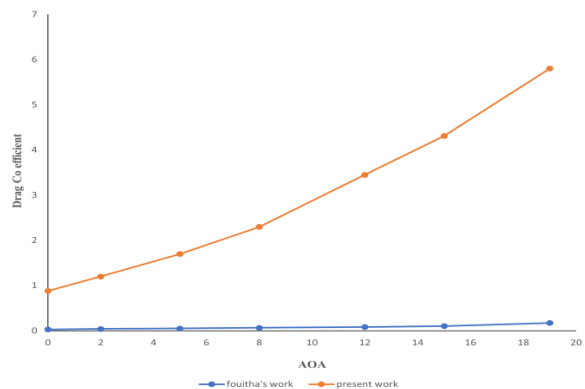


Fig 6: drag co-efficient vs AOA

### V. CONCLUSION

Both triangular vortex generator equipped NACA 4415 aerofoil and rectangular Vortex generator equipped with NACA 4415 aerofoil have analysed at 0°, 2°, 5°, 8°, 12°, 15°, and 19°. Both the vortex generators are arranged at the counter rotating configuration over the top surface of the NACA 4415 aerofoil. For both the vortex generators, the 3D analysis is conducted in this project.

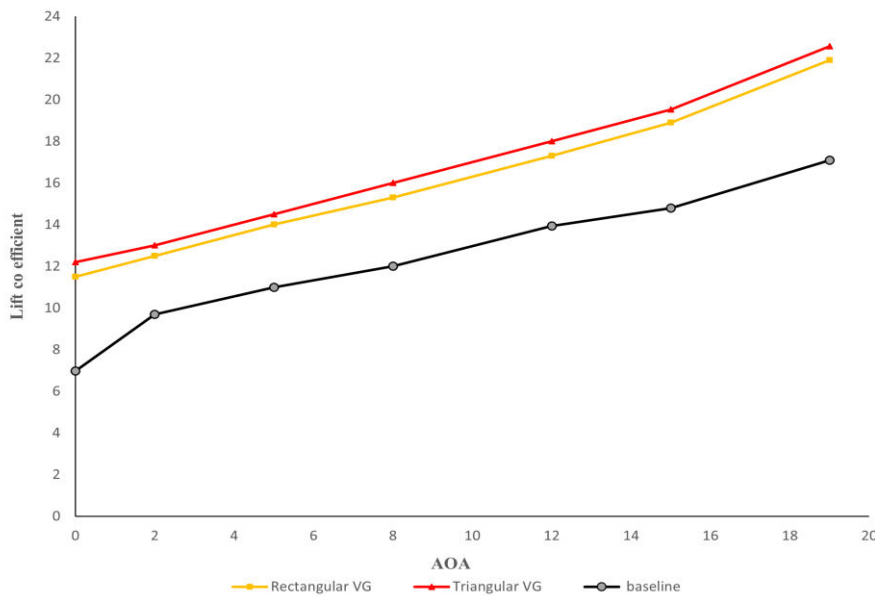


Figure 7:  $C_L$  vs AOA plot of Rectangular VG, Triangular VG and Baseline

Figure 7 depicts  $C_L$  values of baseline case, rectangular vortex generator and triangular vortex generator at various angles of attack. Both the vortex generators have an uptrend line in the above graph triangular vortex generator has an uphold in values of  $C_L$  for every angle of attacks. At 19° angle of angle of attack, both the vortex generator shows its maximum co-efficient of lift value. Triangular vortex generator outperforms than rectangular vortex generator in the case of co-efficient of lift.

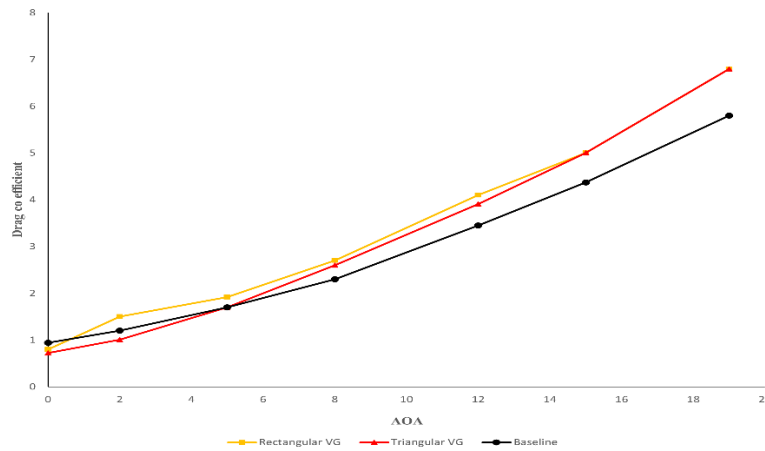


Fig 8:  $C_D$  vs Angle of attack plot of Baseline, Triangular VG and Rectangular VG

Figure 8 depicts the  $C_D$  versus angle of attack plot of baseline case, rectangular vortex generator and triangular vortex generator. For triangular vortex generator, it has a lowest  $C_D$  value at  $0^\circ$  angle of attack. Both the vortex generators have an uptrend in  $C_D$  versus angle of attack plot. And also, rectangular vortex generator has an uphold in the  $C_D$  value plot till the  $12^\circ$  angle of attack. But, after  $12^\circ$  angle of attack, both the vortex generators have slightest differences in values. Both the vortex generators have an uphold in values while comparing to the baseline case. In short, in the case of coefficient of drag at various angle of attacks, the triangular vortex generator showcases the better performance in the case of drag.

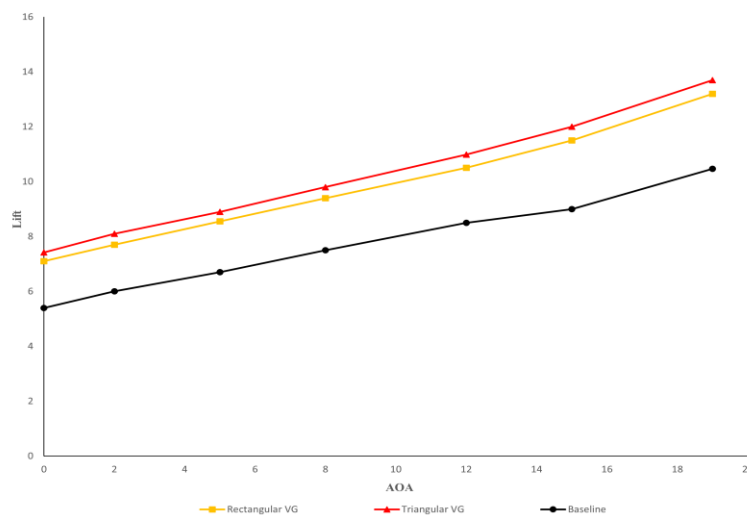


Fig 9: Lift vs Angle of attack plot of Baseline, Triangular VG and Rectangular VG

Figure 9 depicts comparative plot of lift versus angle of attack of rectangular vortex generator equipped with NACA 4415, triangular vortex generator equipped with NACA 4415 and NACA 4415 aerofoil case. Both the vortex generators have an uptrend in the case of lift produced. The triangular shaped vortex generator equipped with NACA 4415 aerofoil outperforms than rectangular vortex generator equipped with NACA 4415. Both the vortex generator produces maximum lift at  $19^\circ$  angle of attack. Both the vortex generators have an uphold in values rather than baseline case. The triangular vortex generator produces more lift. However, triangular vortex generator showcases better performances in terms of lift.

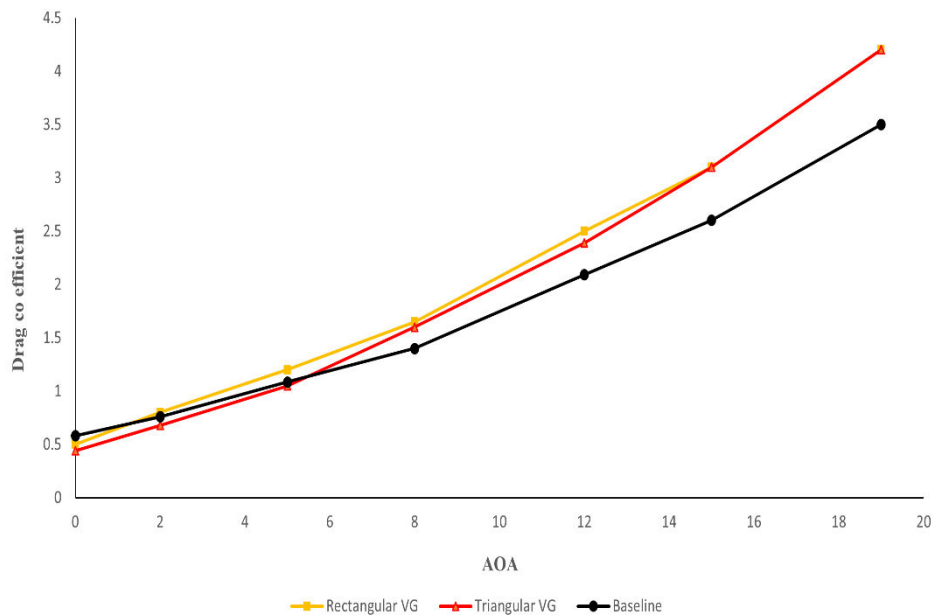


Figure 10: Drag vs Angle of attack plot of Rectangular VG, Triangular VG and Baseline

Figure 10 depicts comparative plot of drag versus angle of attack of rectangular vortex generator equipped with NACA 4415 aerofoil, triangular vortex generator equipped with NACA 4415 aerofoil and NACA 4415 aerofoil. For all 3 cases they have an uptrend in the case of drag. For all the 3 cases, the maximum drag value is found at 19° angle of attack. At 0° and 2° angle of attack, triangular vortex generator has lowest drag values. After 5° angle of attack, the red line of the triangular vortex generator has crossed the baseline case and showcases the higher drag values than baseline case. Triangular vortex generator has lower values than rectangular vortex generator at higher angle of attacks. After 15° angle of attack, the triangular vortex generator and rectangular vortex generator have a slight difference in drag values. So that the rectangular vortex generator has an uphold in the case of drag values while comparing to triangular vortex generator.

The CFD analysis is conducted for both vortex generators equipped with NACA 4415 aerofoil. For all results of  $C_L$ ,  $C_D$ , Lift and Drag, the triangular vortex generator shows excellent performance in terms of those aerodynamic parameters. In the case of both the vortex generators, all aerodynamic parameters such as  $C_L$ ,  $C_D$ , Lift and Drag are increasing with increasing angle of attacks. For lower angle of attacks, the triangular vortex generator exhibits lower values for drag rather than rectangular vortex generator, but when at higher angle of attacks, both the vortex generators exhibit almost similar values for drag. Thus, we can say in terms of drag the triangular vortex generator have an uphold in performance because it produces lesser drag. In the case of lift, obviously both the vortex generators have an uptrend line in the graph. But the triangular vortex generators have higher values than rectangular vortex generator even at 19° angle of attack.

In the case of  $C_D$ , both the vortex generators have slight differences. But, however at lower angle of attacks, triangular vortex generator has lower values than rectangular vortex generator. But after 15° angle of attack, both the vortex generators have only slight difference in values of co-efficient of drag. In short, in the case of  $C_D$ , the triangular vortex generators have an uphold in the case of better performance. From 0° angle of attack, the rectangular vortex generator exhibits higher values for the both the drag and  $C_D$  parameter. For the higher angle of attacks, the triangular vortex generator exhibits lower drag values. In short, we can say triangular vortex generator have better performance in the case of drag.

For every aerodynamic parameter, triangular vortex generator performs better than rectangular vortex generator. The triangular vortex generator has better co-efficient of lift, co-efficient of drag, lift and drag rather than rectangular vortex generator. For higher angle of attacks, the triangular vortex generator exhibits lower drag and  $C_D$  while comparing to rectangular vortex generator. In every aspect of aerodynamic parameters, triangular vortex generator has an uphold in better performance and efficiency.



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