Computational Study on Effect of Passive Vortex Generators on Delaying Stall Angle

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***Abstract*- The problem being considered is the abrupt loss of lift/downforce and the increase in drag caused by 3-dimensional flow separation over wings. The displacement thickness of a flow that separates grows dramatically, changing the external potential flow and pressure field. The alteration of the pressure field causes a rise in pressure drag, and if it is severe enough, it may also cause loss of lift and stall. In this study, flow over a wing with and without vortex generators is analyzed computationally. At different positions and angles of attack, the impacts of vortex generators are investigated. The analytical findings indicate that an increase in pressure on the side of the previous separation causes better lift/downforce and less drag.**

Index Terms- computational fluid dynamics, flow separation, vortex generators, stall angle

I. Introduction

Flow separation or boundary layer separation is the detachment of a boundary layer from a surface into a wake. Separation occurs in flow that is slowing down, with pressure increasing, after passing the thickest part of a streamline body or passing through a widening passage. Separation occurs in flow that is slowing down, with pressure increasing, after passing the thickest part of a streamline body or passing through a widening passage. In aerodynamics, flow separation results in reduced lift/downforce and increased pressure drag, caused by the pressure differential between the front and rear surfaces of the object.

Figure 1a and 1b: Impact of Vortex Generators on flow separation in wings

A vortex generator (VG) is an aerodynamic tool that consists of a tiny vane that is often fastened to a lifting surface (or airfoil, like an aeroplane wing) or a wind turbine rotor blade. The VG produces a vortex that prevents local flow separation and aerodynamic stalling by removing some of the slow-moving boundary layer in contact with the airfoil surface.

II. Literature Review

The literature contains very little information about the stall behavior of finite wings, particularly that which persists for a long time into post-stall. In published work on post-stall wing aerodynamics, force and moment data are frequently lacking after the first stall and instead focus on generic stall behavior that depends on variables like planform. Other research suggests theoretically based empirical techniques to include 3D effects and aspect ratio adjustment into current force and moment coefficient data-sets far into post stall. [1]. Several flow control methods, including slot blowing, tangential blowing, and synthetic jets, have been successfully tested to reenergize boundary layers and hence decrease flow separation. It has been discovered that one especially effective way for enhancing fluid mixing rates involves the deliberate creation of near-surface streamwise vortices. In the low-momentum near-wall region deep within the boundary layer, the vortices act to entrain high-energy flow from the unaltered outside airstream. The most popular and widely used streamwise fluid vortex generators are mechanical passive vane vortex generators, which were first developed by Taylor and Hoadley. They typically consist of thin solid strips mounted to the surface. Yet, it has been demonstrated that vane vortex generators increase drag due to an increase in downstream surface skin friction as well as a local pressure increase resulting from the device's blocking of the flow. An active fluid jet vortex generator, suggested by Wallis, is a substitute for vane vortex generators. [2]. Instead of using solid vane vortex generators, fluid is injected through wall-bounded jets that are angled and skewed (relative to the freestream flow) to create longitudinal vortices for flow control. The majority of air-jet vortex generators (AJVGs) are made up of a series of tiny orifices that are embedded in a surface and fed by pressured air, as shown in Fig. 1. The interaction between the jets coming from each orifice and a freestream fluid flow causes longitudinal vortices to form. The orifices are skewed at an angle with the freestream flow and pitched at an angle with the surface tangent. [2]. Passive AJVGs would be able to recover some of the power lost due to blade stall, allowing for attainment of rated power output at slightly lower average wind speeds, according to a theoretical performance simulation of a 500kW stall-regulated wind turbine based on Blade Element Momentum Theory [4].

III. Methodology

A. Numerical model:

The k-ω SST (shear stress transport) turbulence model is the one employed in the CFD. A very well-liked two-equation eddy-viscosity model is the SST k-ω turbulence model [Menter 1993]. The advantages of both worlds are combined in the shear stress transport (SST) formulation. The SST k-ω model can be utilized as a Low-Re turbulence model without the need for additional damping functions because the model can be employed directly all the way down to the wall through the viscous sublayer by using a k-ω formulation in the inner regions of the boundary layer. In the free-stream, the SST formulation also flips to a k-ω behavior, avoiding the usual k-ω issue where the model is overly sensitive to the inlet free-stream turbulence features.

Local refinements are used to increase the mesh fineness near the model which helps in getting detailed results without increasing the overall mesh size. The velocity inlet is set at 16 m/s. The pressure outlet is at 0 Pa to simulate an open boundary condition. The wing and endplates were assigned a no slip condition while the walls were assigned a slip condition.

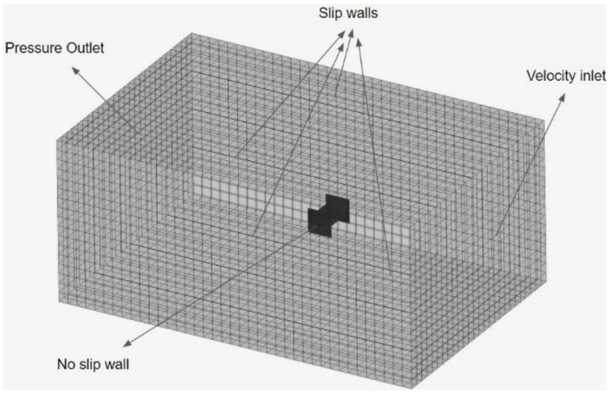

Figure 2: bounding box of mesh

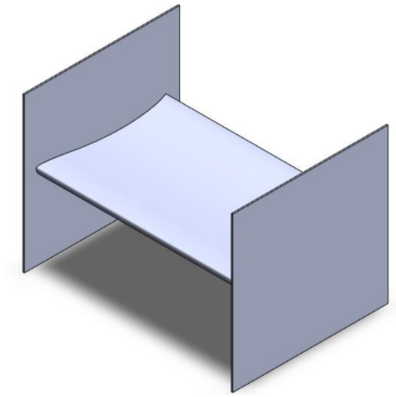

Figure 3: s1223 airfoil with endplates

The airfoil selected was S1223. It is a high lift airfoil used in rear wings of sports and FSAE cars. A chord length of 500mm and span of 830mm was taken. Large endplates were added to reduce the vortices formed. (And reduce pressure leakage from the pressure side to the suction side, thereby avoiding loss in downforce and increasing efficiency of the wing)

Bounding Box Size:

A standard bounding box used for automobile simulations was used. The dimensions are 5 lengths behind, 3 lengths in the front and 2 lengths above and below the geometry. Thus, a bounding box with dimensions 6m x 5m x 9m in the x, y, and z directions respectively was selected.

Mesh Resolution:

The relative sizing of the mesh cells is also very crucial in a mesh independence study. A resolution of 0.15 to 0.25 was iterated and the results were stable at a resolution of 0.23.

Resolution	Cl	Cd
0.15	0.3137	0.0418
0.16	0.3164	0.0427
0.17	0.3143	0.0424
0.18	0.3142	0.0432
0.19	0.3144	0.0438
0.2	0.3178	0.0430
0.21	0.3130	0.0428

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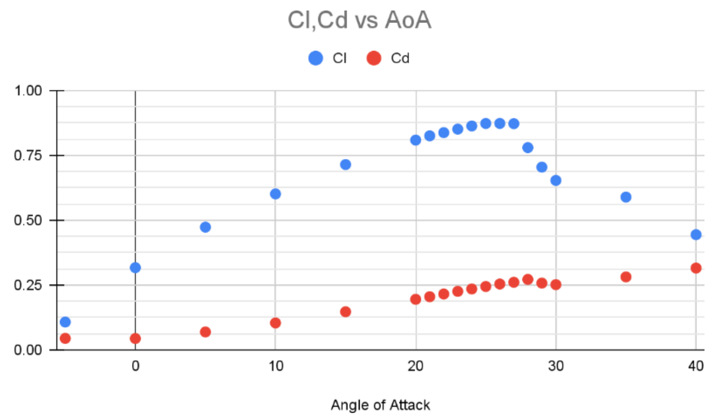
0.22	0.3124	0.0441
0.23	0.3123	0.0439
0.24	0.3066	0.0436
0.25	0.3103	0.0426

Table 1: mesh resolution iterations

Stall Angle Determination:

After the final mesh settings and resolution were obtained, iterations for determining the stall angle of the airfoil and the wing were performed. The wing was set up at multiple Angle of attacks (AOA)'s, starting from -5 degrees, and increased in intervals of 5 up to 20 degrees, after which iterations were performed at every angle, to obtain the precise angle at which the wing stalled. In the graph shown, the Cl increases up to 27 degrees and then goes on decreasing.



Thus, we find the stall angle to be 27 degrees for the selected S1223 airfoil. For a standard 2D S1223 airfoil the stall angle is 13 degrees. As the used geometry has large endplates to reduce vortices the stall angle is delayed as compared to the 2D Airfoil

B. Vortex Generator Iterations:

Different standard and custom designs of vortex generators were iterated. The best design was selected on the basis of strength of vortex formed, inter mixing of adjacent vortices, induced drag due to vortex generator and loss/gain of downforce of the wing. The designs are:

1. V shaped:

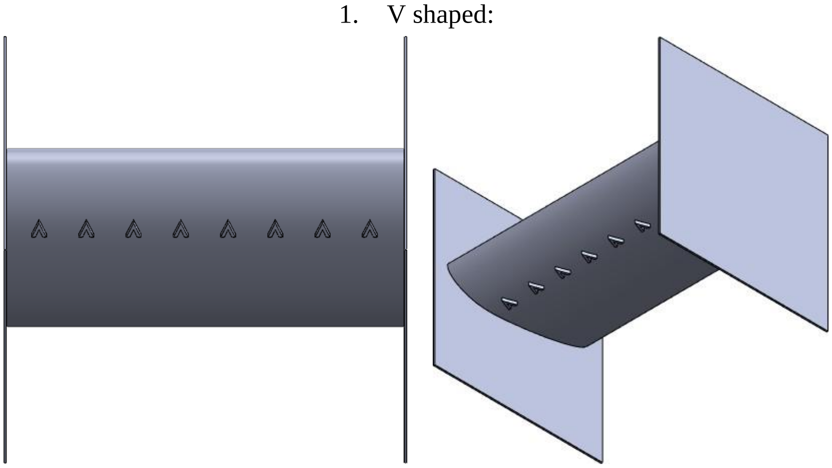


Figure 5a and 5b: design of V shaped VG

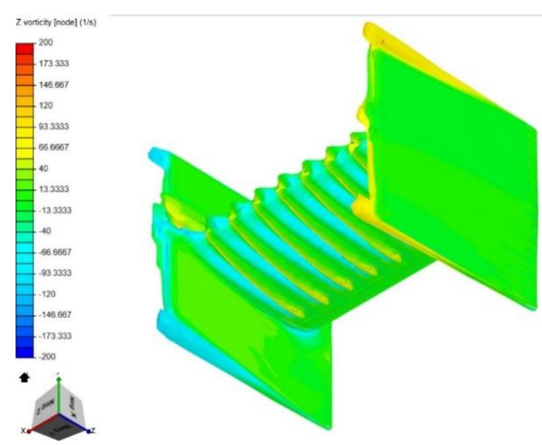


Figure 6: vorticity induced by V shaped VG

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2. U shaped:

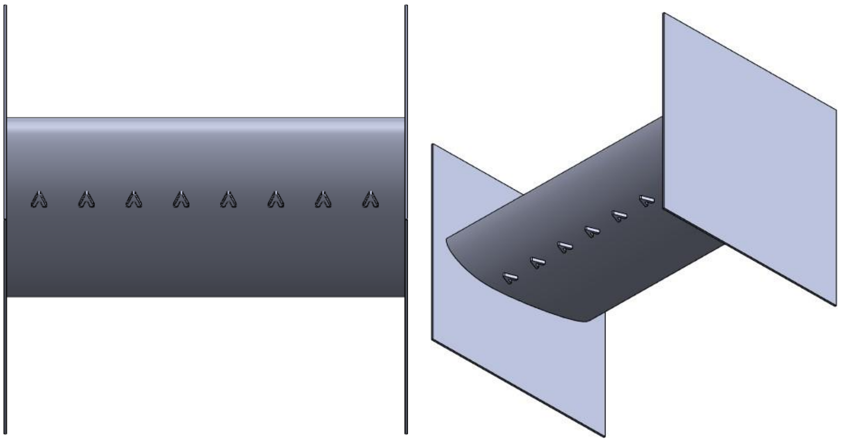

Figure 7a and 7b:design of U shaped VG

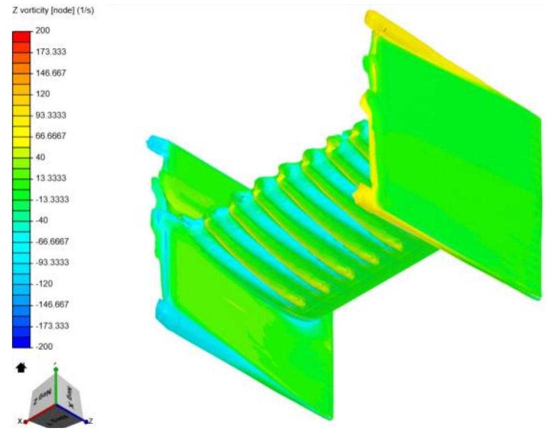

Figure 8: vorticity induced by U shaped VG

3. Triangular

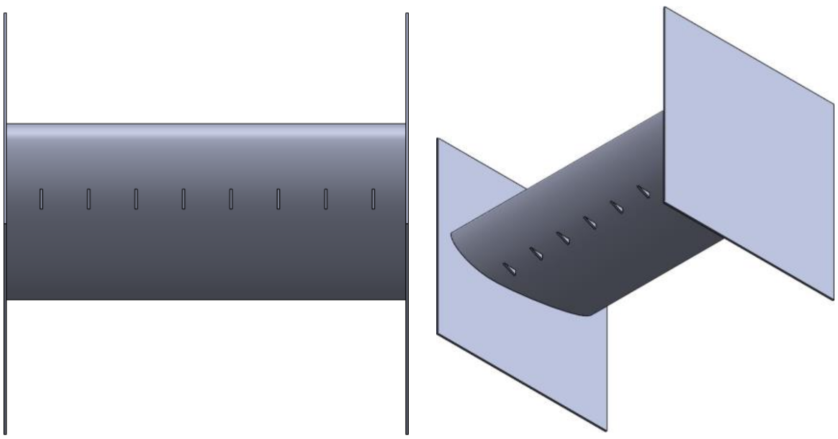

Figure 9a and 9b:design of triangular VG

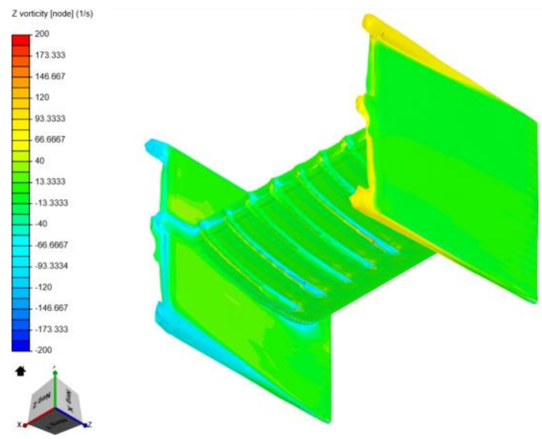

Figure 10: vorticity induced by triangular VG

4. Triangular alternate pattern:

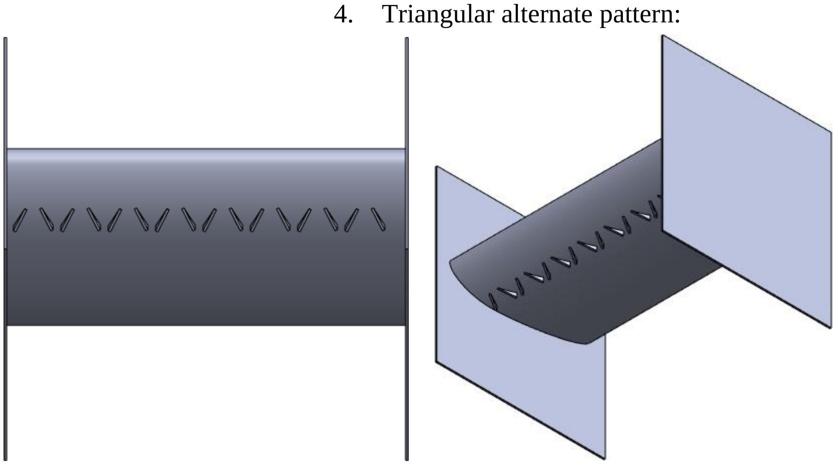

Figure 11a and 11b:design of triangular alternate VG

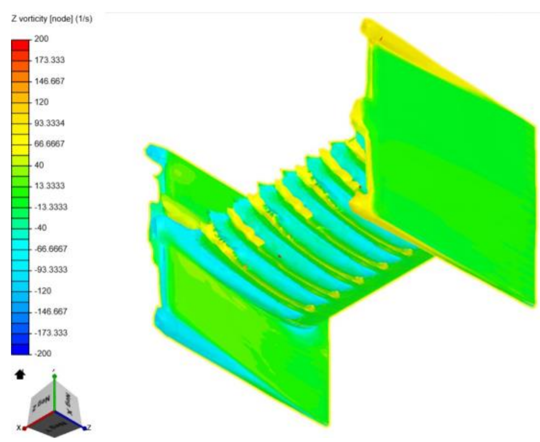

Figure 12: vorticity induced by triangular alternate VG

5. Parabolic:

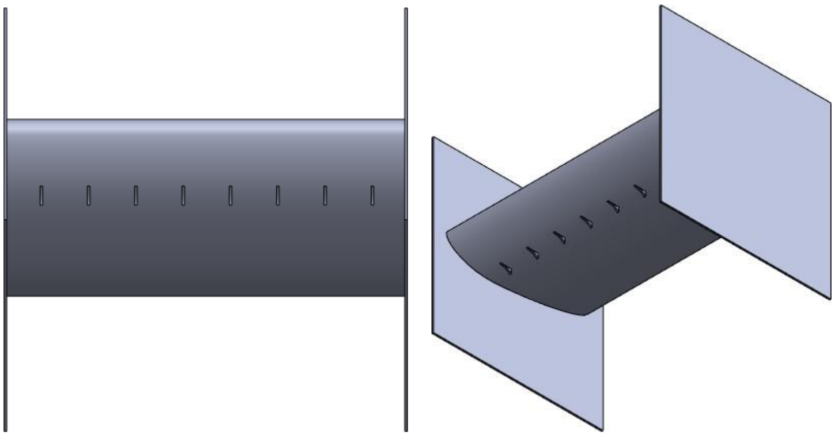

Figure 13a and 13b:design of parabolic VG

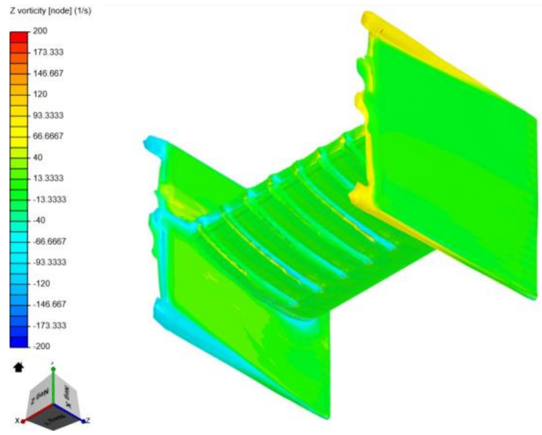

Figure 14: vorticity induced by triangular alternate VG

6. Delta Wing:

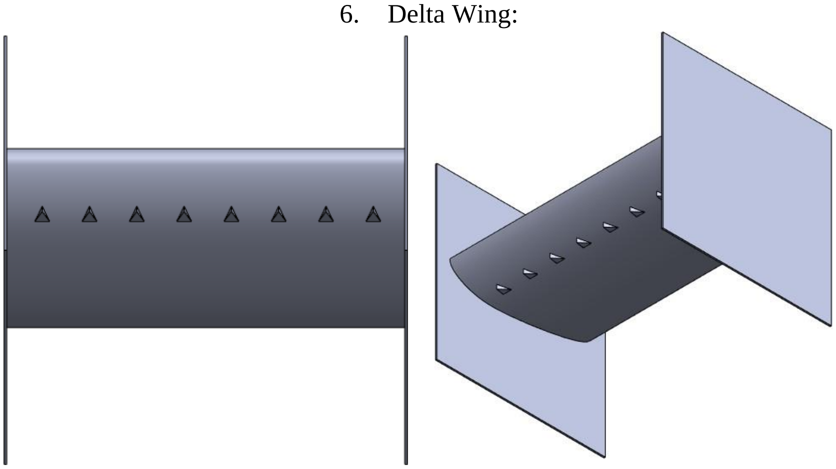

Figure 15a and 15b:design delta wing VG

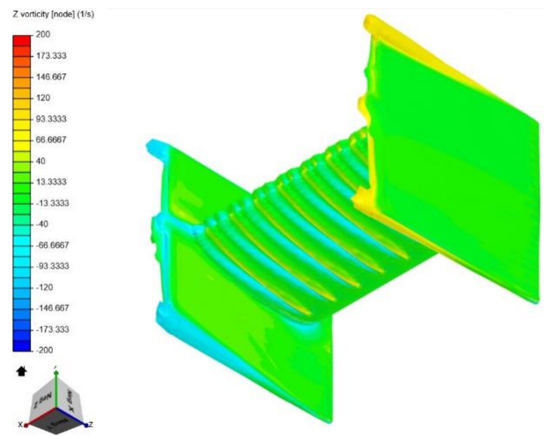

Figure 16: vorticity induced by delta wing VG

The VG finalized was the “delta wing” as a result of its ability to generate a powerful vortex that was able to last up to the trailing edge. It also gave a significant increase in downforce with a minor drag increase. The other alternative was the “alternative triangular pattern”; however, it induced more drag than the delta wing.

IV. Results

Via CFD simulation, we were able to see that the stall angle of the wing got delayed and was now stopped at 32 degrees with the addition of the delta wing vortex generators on the suction side of the wing.

With the vortex generator, we can also see the flow remaining attached at a 27-degree angle of attack on the wing, as illustrated in the particle trace chart below.

Due to the vortices created up to a 32-degree angle of attack, the flow is kept in place.

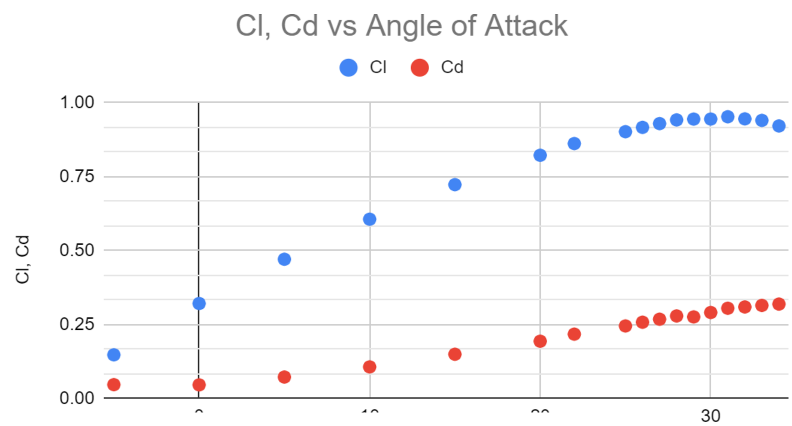

Figure 17: graph showing the airfoil stall angle (32 deg)

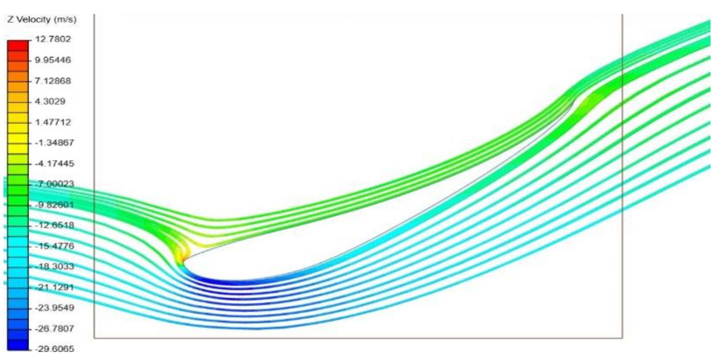

Figure 18: particle trace graph showing flow separation near the trailing edge

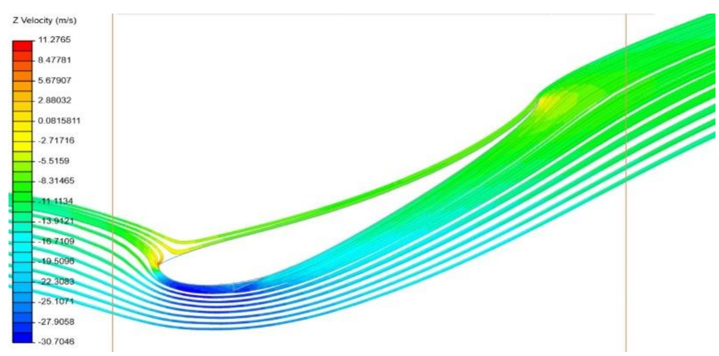

Figure 19: particle trace graph showing flow staying attached till the trailing edge

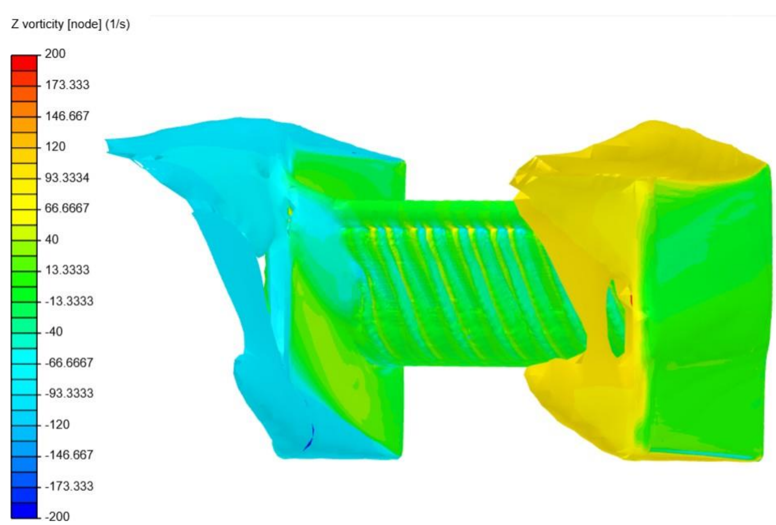

Figure 20: CFD simulation showing vorticity at 32 deg angle of attack of wing

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V. CONCLUSION

Flow separation is a major problem faced by aviation and motorsport industries. Vortex generators prove to be an optimal solution which is easy to incorporate with the wings.

Apart from vortex generators, other methods include tangential blowing, rotating flow accelerators, plasma accelerators. However, these are all active methods which require additional components. Thus, vortex generators are the cheapest and user-friendly solution to this problem.

The separation angle of a standard S1223 airfoil was increased by 5 degrees using Delta wing vortex generators.

This simple yet effective method can also be used in the automobile industry as it strives to increase its fuel efficiency in response to rising fuel prices and emission concerns. Even if the increase in efficiency might be quite small, it comes at a very tiny added cost, making it a worthwhile investment.

Vortex generators are used extensively in motorsports, especially in Formula style cars. They are used to prevent separation of air at the wings which are at considerably higher angles of attack. They are also used to seal off the low pressure generated by the diffusers below the car. This helps in increased downforce without the penalty of drag.

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