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Vadla Raghavender
Institute of Aeronautical Engineering, Dundigal, Hyderabad, v.raghavender@iare.ac.in

Priyanka Vatte
Vardhaman College of Engineering, Hyderabad, priyankareddy@vardhaman.org

V Varun Dr.
Institute of Aeronautical Engineering, Dundigal, Hyderabad, v.varun@iare.ac.in

M. Pala. Prasad Reddy Dr.
Institute of Aeronautical Engineering, Dundigal, Hyderabad, p.prasadreddy@iare.ac.in

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Computational Fluid Dynamic Analysis of Vortex Generators on MAV

1. V.Raghavender, Assistant Professor,Institute of Aeronautical Engineering, Hyderabad
   Email –Id: v.raghavender@iare.ac.in
2. V. Priyanka , Assistant Professor, Vardhaman College of Engineering, Hyderabad
   Email –Id: priyankareddy@vardhaman.org
3. Dr.V Varun, Associate Professor, Institute of Aeronautical Engineering, Hyderabad
   Email –Id: v.varun@iare.ac.in
4. Dr M Pala Prasad Reddy, Associate Professor, Institute of Aeronautical Engineering, Hyderabad
   Email –Id: p.prasadreddy@iare.ac.in

ABSTRACT

Micro Vortex generators are very small components deployed on the wings to control airflow over the upper surface of the wing to affect the boundary layer over it. These are employed onto a Micro aerial vehicle (MAV) of fixed wing type with an S5010 which is a low Reynolds number airfoil. This airfoil provides good aerodynamic results as compared to many low Reynolds number airfoils. Micro vortex generators are used to enhance the performance through controlling airflow at different speeds and angle of attack.

The comparison of a half part of the MAV wing which is designed in CATIA, with and without the vortex generators on its leading edge at 10% of its chord length is done to show how the vortex generators improve the performance and control authority at different speeds and angle of attacks. These are shown with the velocity and pressure distribution around the wing by considering laminar flow in the simulation.

Keywords: Vortex generators, micro aerial vehicle (MAV), design, performance.

1. Introduction

Micro Aerial Vehicle

A micro air vehicle (MAV), or micro aerial vehicle, is a class of Miniature UAVs that has a size restriction and may be autonomous. Modern craft can be as small as 15 centimetres. Development is driven by commercial, research, government, and military purposes; with insect-sized aircraft reportedly expected in the future. The small craft allows remote observation of hazardous environments inaccessible to ground vehicles.

Three types of configuration has been explored in the MAV design namely, fix wing design, flapping wing design, and rotary wing design. For MAVs with linear dimensions in range of 10cm to 15cm, fixed wings are commonly adopted because fixed wings are simple in concept and can easily be implemented. The fixed wings become less efficient as the size and speed of the vehicle decreases. Also at low Re, the viscous boundary layer is thicker and can result in a high drag and also there is deterioration of performance due to laminar boundary separation. MAV will also experience highly unsteady flows in their environment and there is a need to overcome the additional drag and loss of lift without increase in the size.

For small angles of attack, the pressure gradient is modest, and the flow can remain laminar and attached; as the angle of attack increases, the adverse pressure gradients grows, and the flow experience separation on the upper surface. Depending on the specific situation, the separated flow may experience laminar-turbulent transition and reattach to form a laminar separation bubble. The laminar separation and the phenomena followed largely determine the MAV's aerodynamic performance. Hence our main criterion is to apply bumps i.e vortex generators to improve the aerodynamic performance of the MAV.

1.1 Vortex Generators

Vortex generators are small components employed on the MAV wings control airflow to avoid separation, but rather delay the formation and reduce the intensity of separation, we should thus accelerate and "energize" slowing layer. Over the years many solutions have been designed to control the influencing boundary layer. A very effective,yet simple solution is to use turbulators/ Vortex generators. Proper location of vortex generators is very important. They should be positioned precisely in the transition region of the boundary layer.

2. Design Of A Wing

Before designing a wing it is necessary to select an airfoil. The Selection of an airfoil in the aircraft is the major critical aspect, as the co-efficient of lift for an airfoil is an index of total lift generated by the wing. Since all the MAV's operate at low Reynolds number, nearly 40 low Reynolds number airfoils has been analyzed for aerodynamic performance at various angles of attacks and at a velocity of 15 ms-1 and Reynolds number 80000 to 120000. This zone is mostly avoided because of the high fluctuations in lift and drag. In this zone the coefficient of lift reduces and drag increases rapidly as the Reynolds number decreases and respectively vice versa. Generally MAV's don't fly in this region. Since chord length and velocity are restricted to the desired limits, Reynolds number of the design falls into this region. So, there is no other option than to operate the MAV in the Forbidden Region.

So hence from the table we see that S5010 is one of the better airfoils which can be considered for a MAV wing design. S5010 is a (s5010-il) S5010 i.e, Selig S5010 low Reynolds number airfoil with max thickness 9.8% at 27.6% chord and max camber 1.8% at 32% chord.

3. Analysis

The FLUENT is opened with MAV wing mesh file consisting of with and without the vortex generators at - 10° AOA. Similarly it is done for 0° and 10° AOA. Boundary conditions are given to each of the wing type with two different speeds so that we can compare well with different AOA. As the material type chosen in FLUENT is air, the laminar model is considered automatically. In case of such laminar model, the FLUENT tries to solve the Navier-Stokes equation.

BOUNDARY CONDITONS	**VALUES**	
	CASE(1)	**CASE(2)**
Upstream :constant velocity inlet[m/s]	85	120
Density [kg/m3]	1.225	1.225
Viscosity [kg/m-s]	1.7894e-05	1.7894e-05
Temperature [K]	288.16	288.16
Ratio of specific heats	1.4	1.4

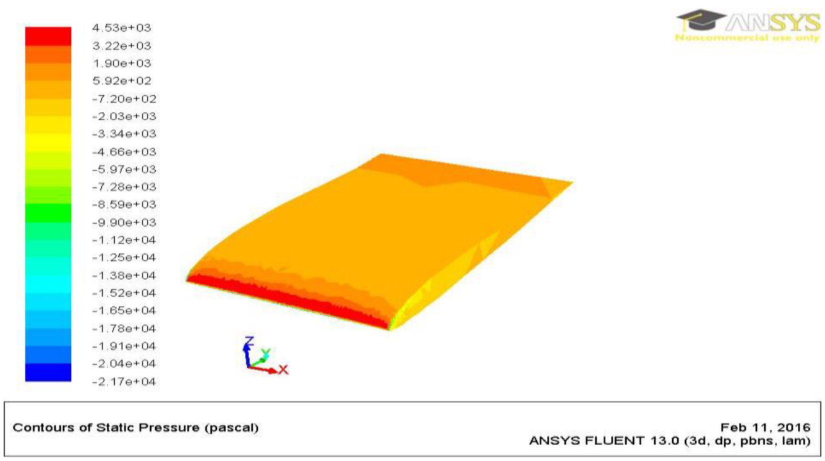
Table 1: Boundary Conditions for case(1) for 85m/s and case(2) for 120m/

3.1 ANALYSIS OF MAV WING WITH AND WITHOUT VORTEX GENERATOR AT 0.25 MACH NUMBER(85m/S)

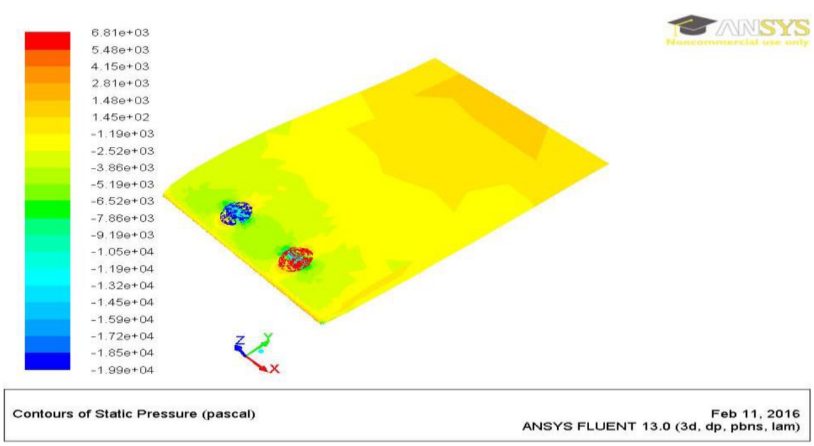
1. After specifying boundary the conditions, solution intialization from inlet is given and run calculation is noted (i.e, iterations) upto 1000. Now wait until the solution is converged. That means the solution no longer changes with any iteration. For (-10°, 0°,10°) AOA, solution is converged at 86,60 and 73 for without vortex generators and with vortex generators , the solution is converged at 88,63 and 84.

Static pressure, dynamic pressure and velocity Contours of each angle is compared without and with the vortex generators at 85m/s .

AT -10° AOA



Fig



Fig

Fig 1 : Static pressure contour for without and with vortex generators at -10° AOA (85m/s)

We see that the high pressure is evenly distributed on the leading of MAV wing followed by decrement and sudden increment in pressure at the trailing edge of the wing proving it to be a flow seperation. In fig the pressure reduces drastically because of the presence of vortex generators. On the bumps, the pressure is max on left bump and the right bump experiences the lowest pressure on it.

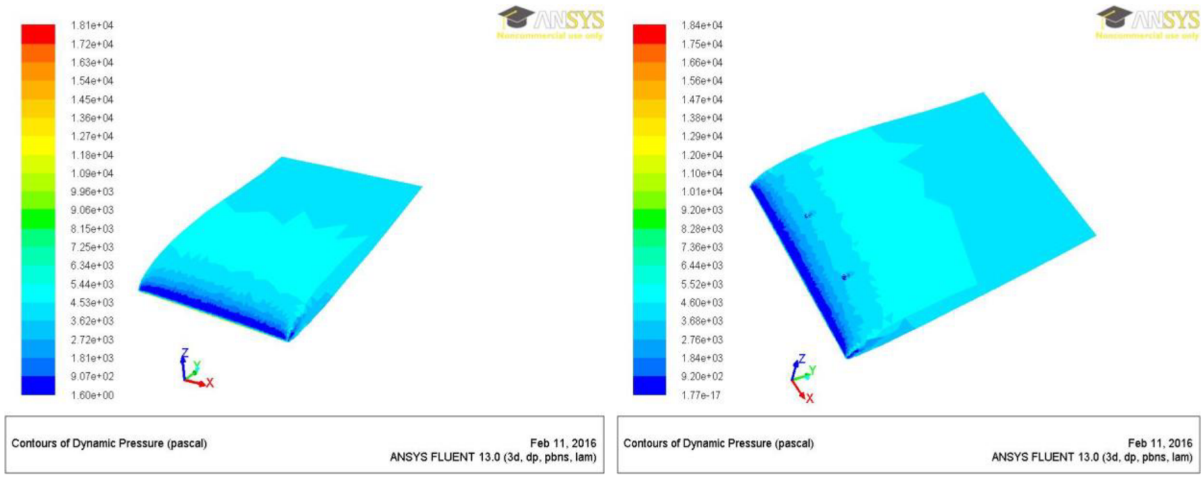


Fig 2: Dynamic pressure contour for without and with vortex generators at -10° AOA (85m/s)

From fig 2, there is no much difference in the pressure distribution in both the cases except for the lowest pressure acting on the vortex generators.

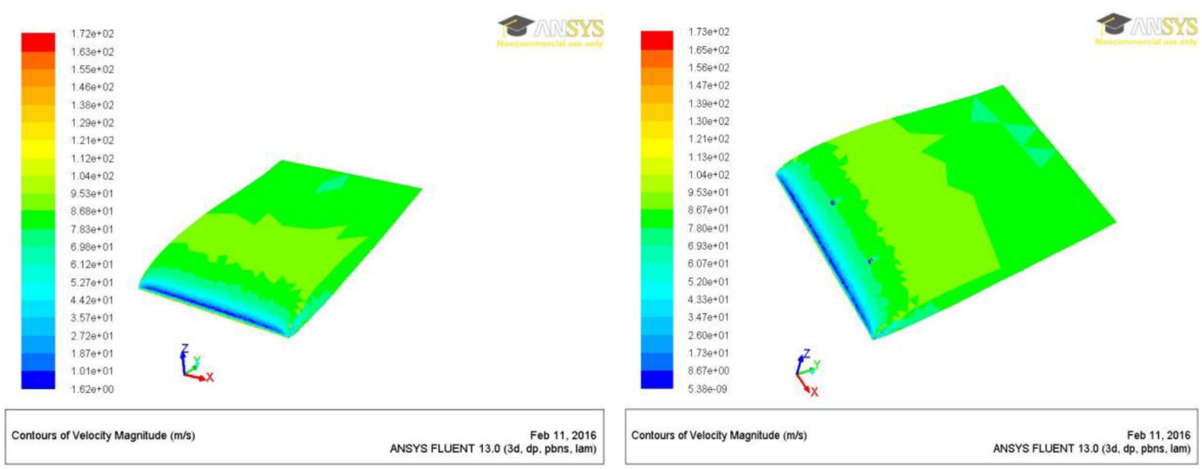
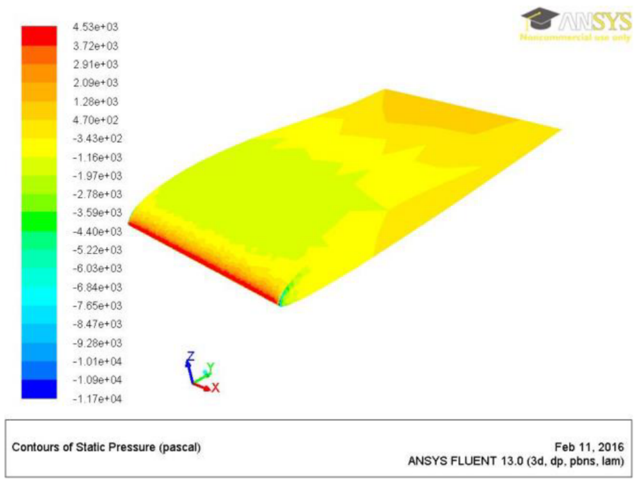


Fig 3 Velocity magnitude contour for without and with vortex generators at -10° AOA (85m/s)

From fig , the velocity at the leading edge of the MAV wing is minimum and it increases as it goes towards the trailing edge. At the mid of the trailing edge there exists a low velocity area. In fig 3, the velocity distribution is same except for the minimum velocity at the vortex generators.

AT 0° AOA



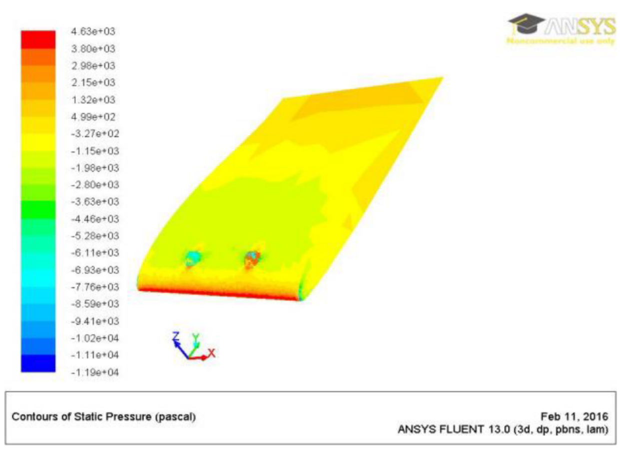


Fig 3: Static pressure contour for without(a) and with(b) vortex generators at 0° AOA(85m/s)

From fig 3 In both cases the pressure is highest at the leading edge of the wing. But when it comes to pressure on vortex generators, it is maximum on the right side and minimum on the left side.

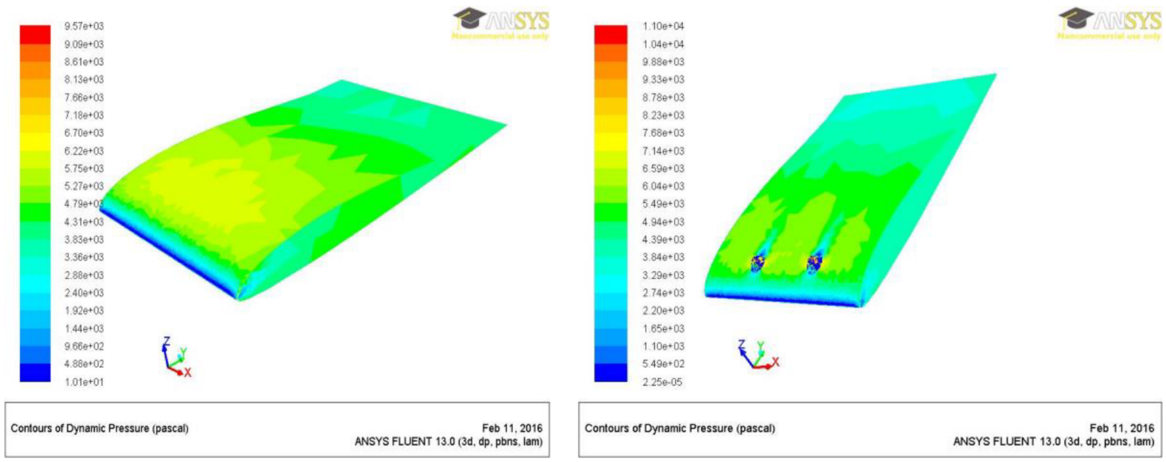


Fig 4: Dynamic pressure contour for without and with vortex generators at 0° AOA (85m/s)

From fig 4, the pressure is minimum at leading edge and it increases suddenly over the wing with the decrement as it goes towards the trailing edge. In fig 4, Vortex generators to create low pressure aft with max pressure traces on them.

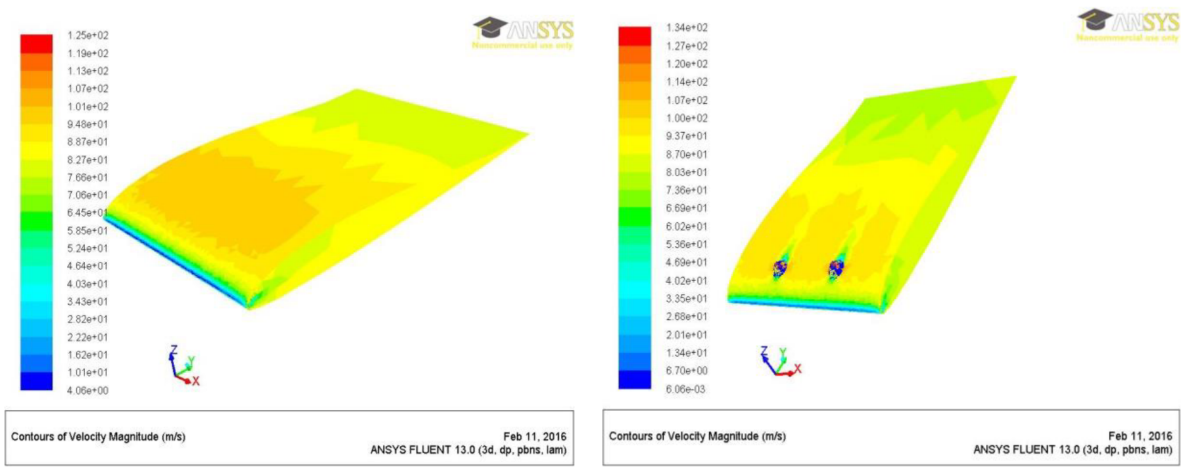


Fig 5 Images of velocity magnitude contour for without (a) and with(b) vortex generators at 0° AOA (85m/s)

From fig 5 Velocity is minimum at the leading edge of the MAV in both the cases and increases as it goes towards the trailing edge. In fig 5, the velocity is maximum on the vortex generators.

AT 10° AOA

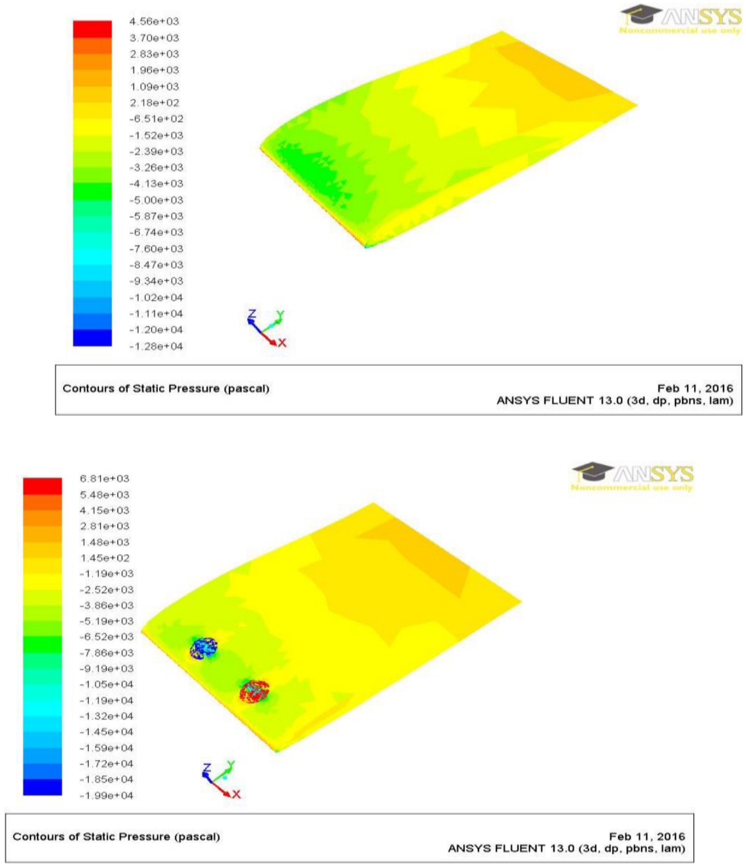


Fig 6 : Static pressure contour for without and with vortex generators at 10° AOA (85m/s)

In fig 6, the static pressure is less on the leading edge and increases till the trailing edge of the wing. In fig 6, the pressure is a bit low near the vortex generators and increases as we go towards the trailing edge with max pressure on the right vortex generator and minimum on left one.

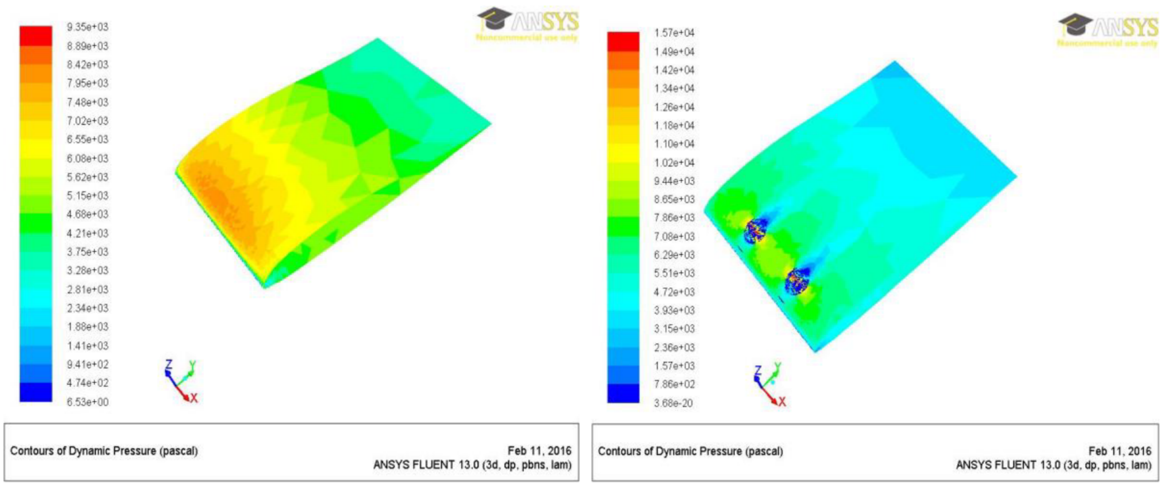


Fig 7: Dynamic pressure contour for without and with vortex generators at 10° AOA (85m/s)

From fig 7, the pressure is moderately high on the half of the MAV wing from the leading edge and decreases as it follows towards the trailing edge. From fig 7, the pressure is more near the vortex generators and a lot of minimum pressure occurs on the vortex generators with a very light maximum pressure on it.

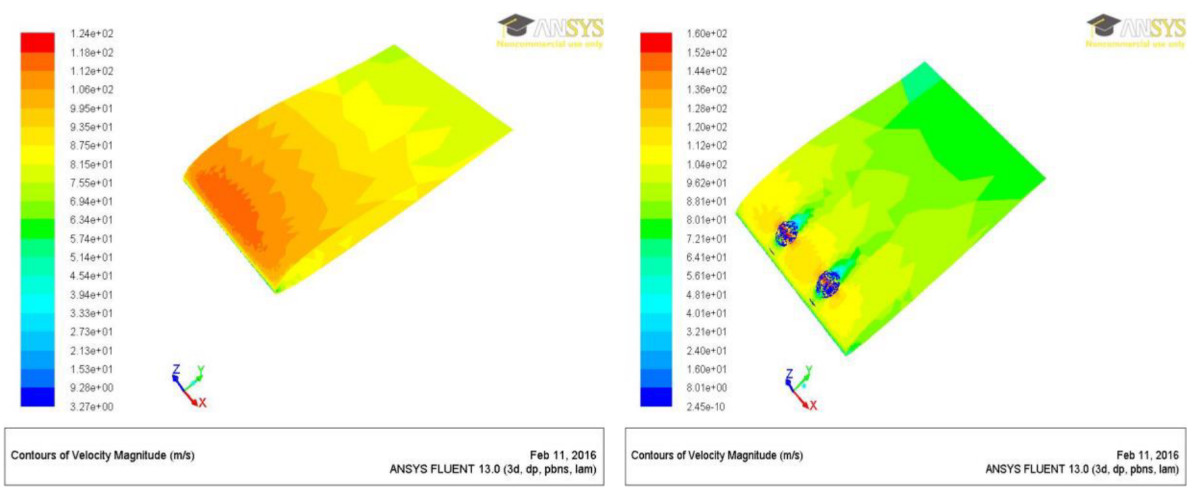


Fig 8: Velocity magnitude contour for without and with vortex generators at 10° AOA (85m/s)

In fig 8, the velocity is maximum at leading edge decreasing from leading edge to trailing edge. In fig 8, the velocity decreases from leading edge to trailing edge with a lot of minimum velocity on bumps and traces of max velocity at the mid of the vortex generators.

4. Results

4.1 Lift And Drag

AOA	Without vortex generator			With vortex generator		
	Lift coefficient (C_l)	Drag coefficient (C_d)	C_l / C_d	Lift coefficient (C_l)	Drag coefficient (C_d)	C_l / C_d
-10°	-0.03	0.035	-0.857	-0.01	0.029	-0.344
0°	0.0014	0.0069	0.202	0.0022	0.0074	0.29729
10°	0.22	0.032	6.875	0.30	0.036	8.553

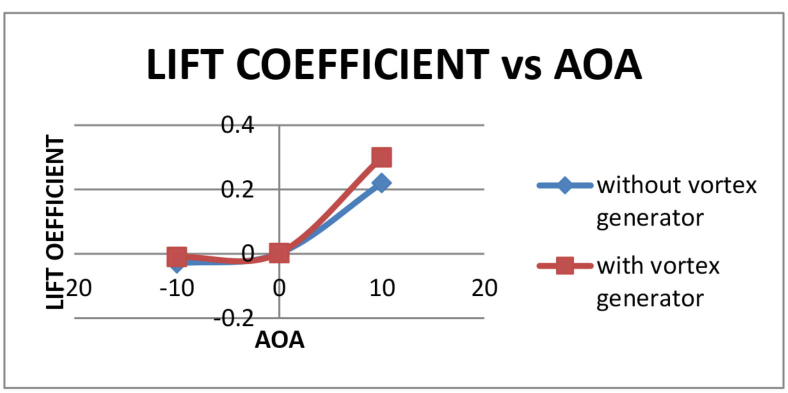
Table 2 : Lift coefficient and Drag coefficient (0.35 mach)

Similarly , calculate the of lift and drag coefficients at 0.25 mach

AOA	Without vortex generator			With vortex generator		
	Lift coefficient (C_l)	Drag coefficient (C_d)	C_l / C_d	Lift coefficient (C_l)	Drag coefficient (C_d)	C_l / C_d
-10°	-0.08	0.027	-2.96	-0.01	0.03	-0.33
0°	0.002	0.008	0.2625	0.021	0.007	0.285
10°	0.01	0.027	0.37	0.02	0.036	0.55

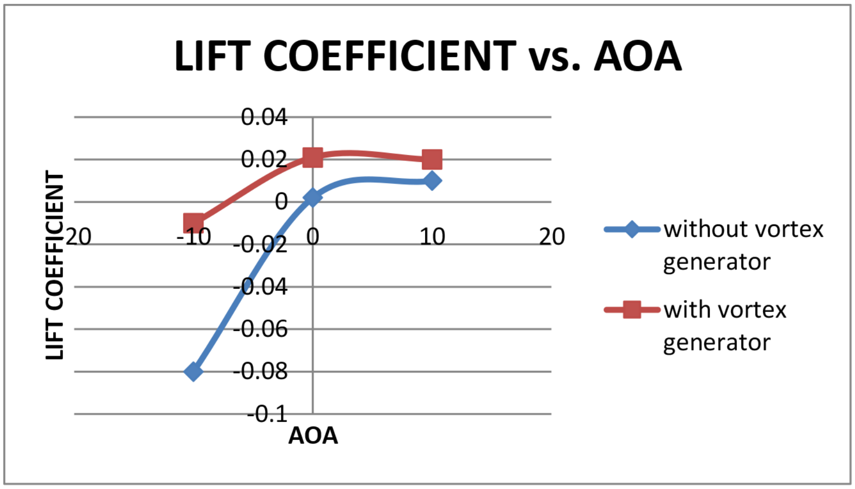
Table 3 : Lift coefficient and Drag coefficient (0.25 mach)

Graphs are plotted for lift coefficient vs. AOA for both with and without vortex generator at 0.35 Mach No. (120m/s) in graph 1 and Mach No.(85m/s) in graph 2.



Graph 1. Lift coefficient vs. AOA (120m/s)

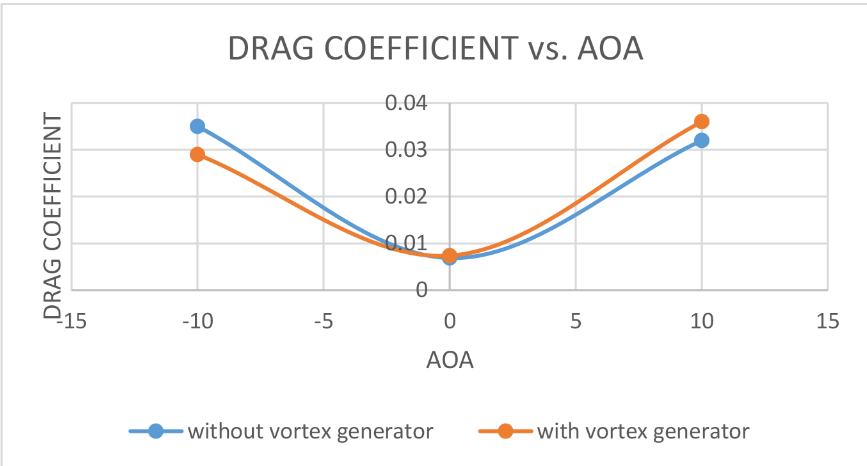
From graph 1, it is seen that for both designs coefficient of lift at 0° AOA is same, but at other AOA there is increase in coefficient of lift for MAV with vortex generator.



Graph 2. Lift coefficient vs. AOA (85m/s)

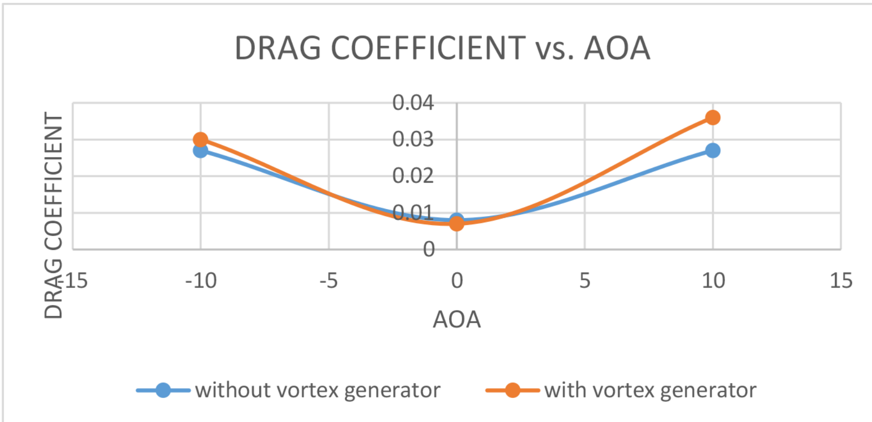
From graph2, it is seen that lift coefficient for MAV wing with vortex generator corresponds to better one than one without vortex generator. From both the graphs1, 2, we can say that in overall view of changing speeds, coefficient of lift is attained well.

Graphs are plotted for drag coefficient vs. AOA for both with and without vortex generator at 0.35 Mach No. (120m/s) in graph 3 and 0.25 Mach No (85m/s).



Graph 3. Drag Co-efficient vs. AOA (120m/s)

Graph 3, shows that drag co-efficient for MAV with vortex generators is less than MAV without vortex generators which is initially at -10° AOA and increases gradually from 0° AOA.



Graph 4. Drag coefficient vs. AOA (85m/s)

Graph 4, shows that drag co-efficient for MAV with vortex generators is less than MAV without vortex generators which is initially at -10° AOA and increases gradually aft 0° AOA.

AOA	WITHOUT VORTEX GENERATOR						WITH VORTEX GENERATOR					
	Static pressure (Pa)		Dynamic pressure (Pa)		Velocity (m/s)		Static pressure (Pa)		Dynamic pressure (Pa)		Velocity (m/s)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
-10°	-43367	9025	3.0018	36246	2.213	243.26	-43583	11183	3.4e-16	36806	2.37e-8	245.13
0°	-23404	9030.58	21.230	19100	5.888	176.59	-23732	9225.9	0.0001	21997	0.0158	189.5

10°	-25593	9096.66	13.040	18678	4.614	174.63	-31241	33979	4.3e-20	31487	2.6e-10	226.73

Table 5: Static, dynamic and velocity values for speed 120m/s.

AOA	**WITHOUT VORTEX GENERATOR**						**WITH VORTEX GENERATOR**					
	Static pressure (Pa)		**Dynamic pressure (Pa)**		**Velocity (m/s)**		**Static pressure (Pa)**		**Dynamic pressure (Pa)**		**Velocity (m/s)**	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
-10°	-21712	4528.55	1.604	18113	1.618	171.96	-21794	5673.9	1.7e-17	18400	5.3e-9	173.32
0°	-11716	4531.66	10.10	9568.4	4.06	124.98	-11889	4628	2.2e-5	10977	0.006	133.87
10°	-12819	4564.3	6.53	9354.5	3.26	123.58	-19862	6814.6	3.6e-20	15729	2.4e-10	160.25

Table 5: Static, dynamic and velocity values for speed 85m/s.

5.Conclusion

Vortex generators are aerodynamic devices used in improving the effectiveness of the MAV wing. In the analysis of a 3D MAV wing with and without vortex generators it is observed that there is good enhancement in the performance parameters of MAV. The lift co-efficient, static pressure, dynamic pressure and the velocity gain or the thrust equipped is better when vortex generators are employed on to MAV at different angle of attacks and speeds. The only difference attained was in drag co-efficient which is slightly unstable when angle of attack is improved more than 0°. In overall view, there is a great attainability in stability of an MAV with vortex generators, which is the most needed criteria.

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