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AERODYNAMIC DESIGN AND COMPUTATIONAL ANALYSIS OF VENTED NACA2412 AIRFOIL- A COMPARATIVE STUDY

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ABSTRACT

In the field of aerodynamics over the past decades, numerous studies have been dedicated to develop airfoils that produce higher amount of lift over a wide range of angle of attack. The flow over the suction surface of the airfoil must remain attached in order to generate lift otherwise the aircraft is bound to stall. This paper aims to introduce a novel technique on passive blowing flow control, namely, 'vented airfoil'. In the vented airfoil, the high momentum fluid from pressure surface is injected into suction surface just upstream of the flow separation point. The first part of the study will be a critical assessment of computational data for the NACA2412 airfoil. The second part will comprise of similar computational analysis of the vented NACA2412 airfoil. The 2D model of the airfoil was developed with CATIA V5 and SSTK-ω turbulence model was used for CFD analysis. The critical comparison between the resulting data of conventional NACA2412 and vented NACA2412airfoils will be useful to determine the reliability of the above mentioned stall delaying technique.

KEYWORDS: Vented airfoil, NACA2412, Passive Flow Separation Control, Blowing Flow Control, CFD, Suction Surface, Pressure Surface & Stall Delay

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Original Article

INTRODUCTION

A major contributing factor in the increase of pressure drag on an airfoil is the adverse pressure gradient. Since the leading edge of an airfoil is a stagnant region, the pressure around the leading edge is highest. As the flow traverses along the suction surface of the airfoil, it expands and pressure drops slightly below the free stream pressure value. Because of this phenomenon, the flow adjacent to surface and far enough from the leading edge detaches from the surface and reverses in flow direction causing a loss of momentum. This momentum loss around the trailing edge in turn results in rise of pressure slightly above the value of free stream pressure. This latter increase in pressure is termed as the adverse pressure gradient. This phenomenon due boundary layer separation results in the formation of vortices or eddies. A variety of techniques have been studied in the past decades to delay flow separation. The methods of manipulation of the flow to manoeuvre the boundary layer in order to delay flow separation, increase lift, decrease drag, delay stall and increase lift-to-drag ratio are generally categorized as flow separation control methods. These methods are further classified into active and passive techniques based on their implementation. In this paper, the topic of interest will be passive blowing flow separation control. Blowing is a process of injecting high momentum fluid into the boundary layer to negate the effect of adverse pressure gradient on the suction surface of the airfoil. Whereas suction is the process of extracting the fluid from the suction surface just upstream of the boundary layer separation point. These effects can be achieved by both active and passive methods of flow control. Passive methods do not need any kind of controller, they can be achieved by design alterations, whereas, active methods need some kind of controller/actuator or sensor to monitor and alter the flow using various instruments.

A lot of research has been done on flow control. The first being in 1904, Prandtl [1] studied passive fluid suction on a cylindrical surface to keep the flow attached to the surface and cease the formation of eddies on the rear. In 1993, Lacaine [2] extensively designed and studied wings with variable camber and slots. This study demonstrated that with the application of multiple slots, the maximum coefficient of lift was increased significantly. Also, slotted wing was seen to have maximum lift when it is fitted with split flap. Shehata et al. [3] studied application of passive flow controlled NACA0015 airfoil in well turbines. A slot with a certain diameter located at 45% of chord length from the leading edge had a torque coefficient increase of 42% than that of the airfoil without suction slot. This results were obtained at stall angle of 13.6°. Yousefi et al. [4] conducted a study on blowing and suction slot geometry optimization on NACA0012 airfoil. The study concluded that the blowing jet widths of 3.5% to 4% of the chord length are most effective for tangential blowing, and smaller jet widths are better effective for perpendicular blowing. The suction jet width of maximum 2.5% improves lift-to-drag ratio.

Proposed Ideology

The passive flow control technique proposed in this paper utilizes injection of fluid from pressure surface into suction surface. Vents are designed inside the airfoil for the purpose of introducing high momentum fluid jet into the boundary layer in order to delay the flow separation. For the application over a wide range of angle of attack, the two blowing vents are positioned such as, one at 30% of the chord length while other close to the trailing edge. The vent width at all openings is kept near 2% of the chord for optimum performance. The first blowing vent simply acts as a slot for the airfoil to add high momentum fluid into the boundary layer which helps the flow adhere longer to the suction surface of the airfoil at higher angle of attack. The second vent is created to overcome the trailing edge vortices which reduces pressure drag for a wide range of angle of attack.

METHODOLOGY

Model creation: The geometry of NACA2412 airfoil is created with CATIA V5R20 with the help of its coordinates which are imported from the internet. The design and dimensions of vents in NACA2412 airfoil:

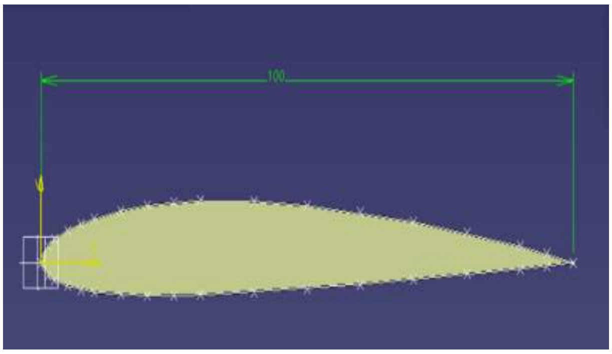

Figure 1: NACA2412 Design.

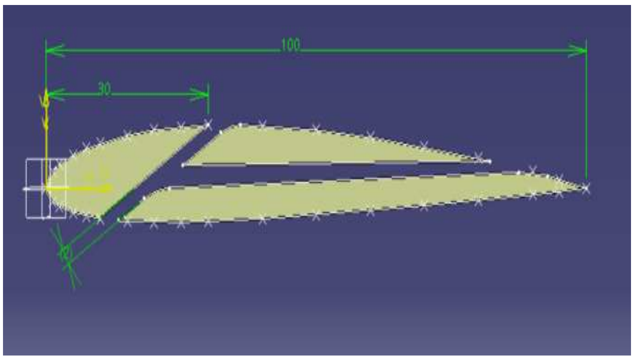

Figure 2: NACA2412 with Vents.

Mesh Generation

For discretization of the computational domain, the c-shape fluid domain is used for mesh generation. The unstructured mesh is created with all triangles method. The meshed model contains inlet, walls, airfoil and outlet. On the airfoil, the edge sizing of 300 number of division is given and mesh refinement is 2. The grids around the areas of airfoil are made fine whereas coarse far away from it. It has 44136 nodes and 86337 elements. Mesh for vented NACA2412 airfoil: 91588 nodes and 178641 elements

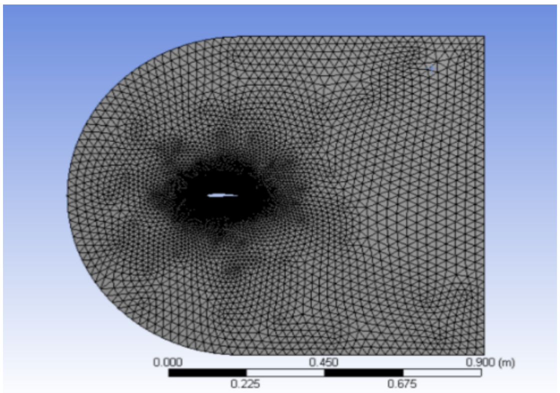

Figure 3: Mesh for NACA2412 Airfoil.

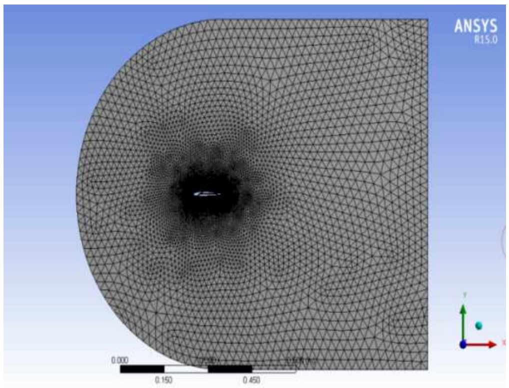

Figure 4: Mesh for NACA2412 with Vents.

Input and Boundary Condition

Table 1: Input and Boundary Conditions

Sl. No.	Parameter	Value
1	Flow medium	Air
2	Flow velocity	5, 10, 15, 20 m/s
3	Density	1.225 kg/m^3
4	Chord Length	0.1 m
5	Angle of attack	0 - 24°
6	Turbulent model	K-ω SST
7	Kinematic viscosity	1.7894e-05 kg s/m^2

COMPUTATIONAL DATA ANALYSIS

Conventional NACA2412 with a Constant Velocity, V = 20m/s

Table 2: Lift, Drag Coefficients and Efficiency for NACA2412 at V = 20m/s

Sl. No.	Angle of attack (AoA)	Coefficient of lift - conventional airfoil (Cl)	Coefficient of drag – conventional airfoil (Cd)	Efficiency (Cl /Cd)
1	0	0.018555	0.001457	12.7313
2	3	0.047117	0.001846	25.52327
3	6	0.074365	0.002206	33.70805
4	9	0.0915	0.003425	26.71329
5	12	0.11769	0.005783	20.35008
6	15	0.130759	0.009711	13.46534
7	16	0.138809	0.013227	10.49412
8	18	0.168249	0.0022442	7.497037
9	20	0.100007	0.008288	12.06591
10	22	0.191112	0.05871	3.255192

Table 2 shows the variation of aerodynamic performance of conventional NACA2412 at velocity 20m/s over a range of 0–22° angle of attack. We can see that the coefficient of lift rises up to a stall angle of attack 18°. The maximum aerodynamic efficiency is achieved at an angle of 6°.

Constant angle of attack, AOA = 5°

Table 3: Coefficients of Lift and Drag for NACA2412 at AoA=5°

S. No.	Velocity (V)	Coefficient of Lift - Conventional Airfoil (Cl)	Coefficient of Drag – Conventional Airfoil (Cd)
1	0	0.001775	0.000143
2	4	0.00476	0.000155
3	8	0.007268	0.000153
4	12	0.010971	0.000533
5	16	0.014205	0.001469
6	22	0.021736	0.007059

Above table shows the variation of C_l and C_d for NACA2412 airfoil with velocity ranging from 0-22 m/s at an angle of attack 5°.

Vented NACA2412 with Constant velocity, V = 20m/s

Table 4: Lift, Drag Coefficients and Efficiency for Vented NACA2412 at V = 20m/s

S. No.	Angle of Attack (AoA)	Coefficient of Lift - Vented Airfoil (Clv)	Coefficient of Drag – Vented Airfoil (Cdv)	Efficiency (Clv /Cdv)
1	0	0.029038	0.001715	16.93633
2	3	0.049123	0.002727	18.01624
3	6	0.077318	0.003241	23.85713
4	9	0.103996	0.004185	24.84863
5	12	0.126849	0.005885	21.55561
6	15	0.139969	0.008998	15.5557
7	16	0.143301	0.010364	13.82715
8	18	0.163166	0.017146	9.516376
9	20	0.173345	0.02352	7.328883
10	22	0.238613	0.062319	3.828872
11	24	0.055996	0.023249	2.408471

Variation of aerodynamic performance of vented NACA2412 airfoil with respect to increasing angle of attack at a constant velocity of 20 m/s is shown in above table. The maximum coefficient of lift is achieved at an angle of 22°, whereas the aerodynamic efficiency is greatest at 9° angle of attack.

Constant angle of attack, AOA = 5°

Table 5: Coefficients of Lift and Drag for Vented NACA2412 at AoA = 5°

S. No.	Velocity (m/s)	Coefficient of Lift - Vented Airfoil (Clv)	Coefficient of Drag – Vented Airfoil (Cdv)
1	0	0.003142	0.000267
2	4	0.023769	-0.00592
3	8	0.013146	0.000312
4	12	0.015935	0.000571
5	16	0.019692	0.001105
6	22	0.025084	0.00276

Table 5 shows the variation of C_l and C_d for vented NACA2412 with velocity ranging from 0-22 m/s at an angle of attack 5°.

RESULTS AND DISCUSSIONS

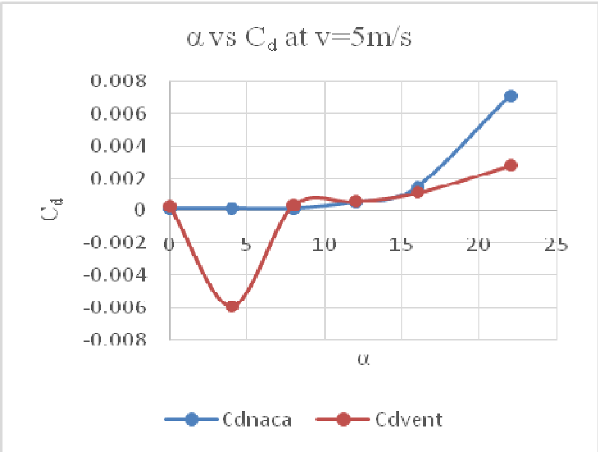

Figure 5

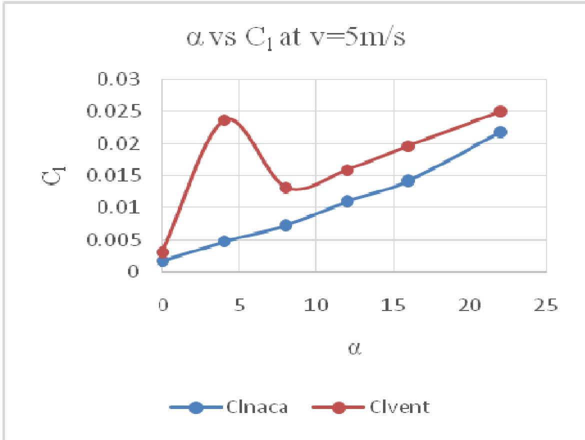

Figure 6

As seen in figure 5, at higher angle of attack, it is found that theC_d of conventional NACA2412 airfoil increases drastically. Whereas the comparison of coefficient of lift for conventional and vented NACA2412 airfoil at lower angle of attack, there is an abrupt rise inC_l of vented airfoil.

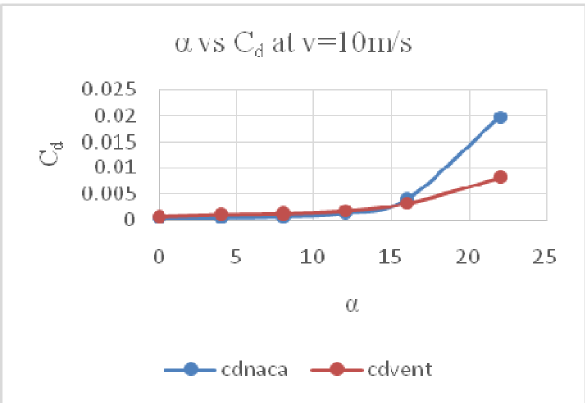

Figure 7

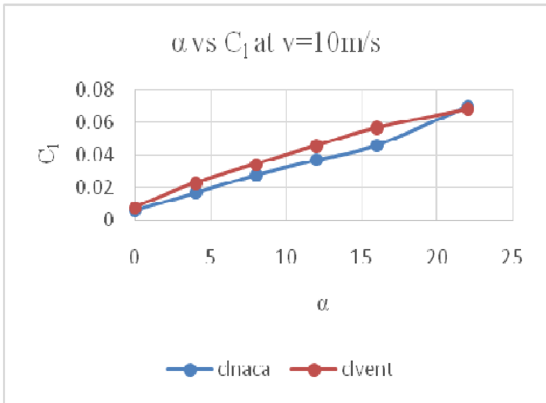

Figure 8

At velocity 10m/s, $C_l$for vented airfoil remains higher than that of conventional NACA2412 airfoil throughout the range of angle of attack as shown in figure 8. Whereas in figure 7, C_d drastically rises for conventional NACA2412 airfoil above 15° angle of attack.

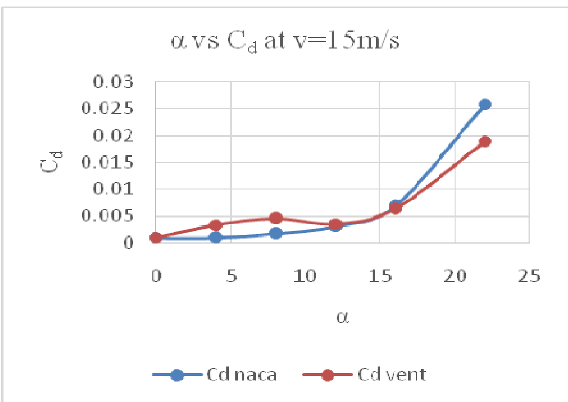

Figure 9

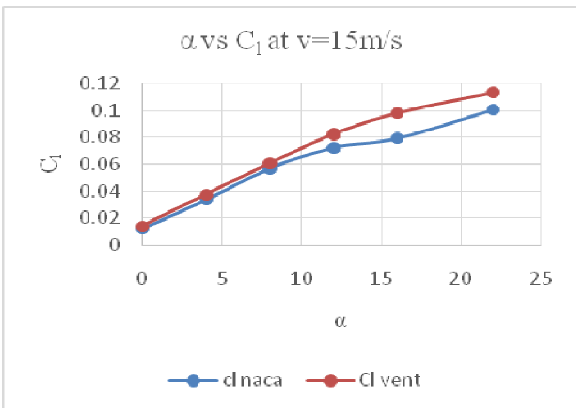

Figure 10

In figures 9 and 10, at velocity 15m/s both C_d and C_l for conventional and vented airfoil trace almost similar curve.

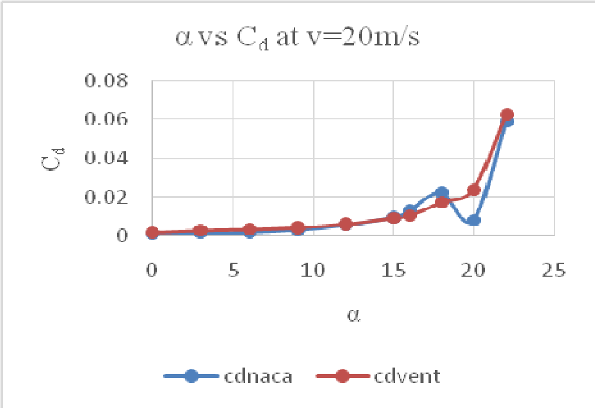

Figure 11

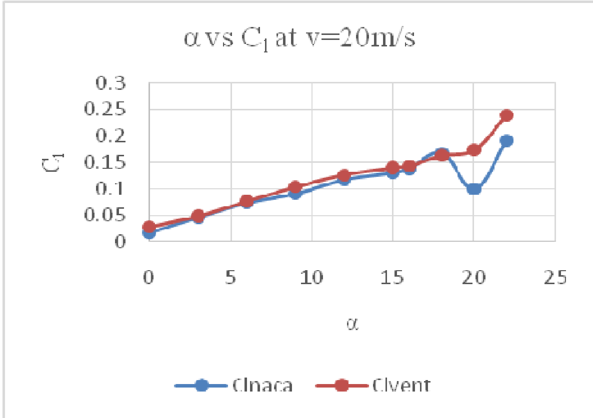

Figure 12

In figure 12, it can be clearly seen that at velocity 20m/s, the conventional NACA2412 airfoil stalls at 18° angle of attack, whereas the C_l for vented airfoil keeps on increasing till 22° angle of attack.

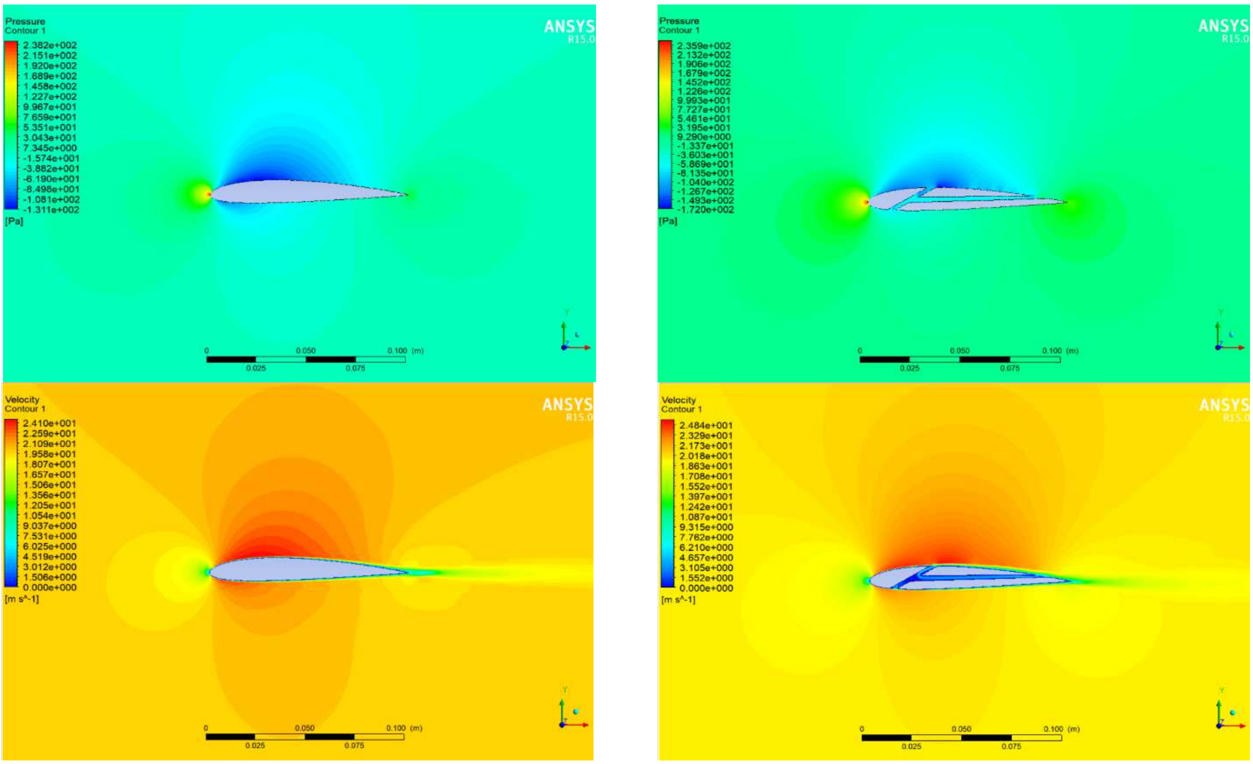

Figure 13: Pressure and Velocity Contours for NACA2412 and Vented NACA2412 Airfoils at 0° Angle of Attack.

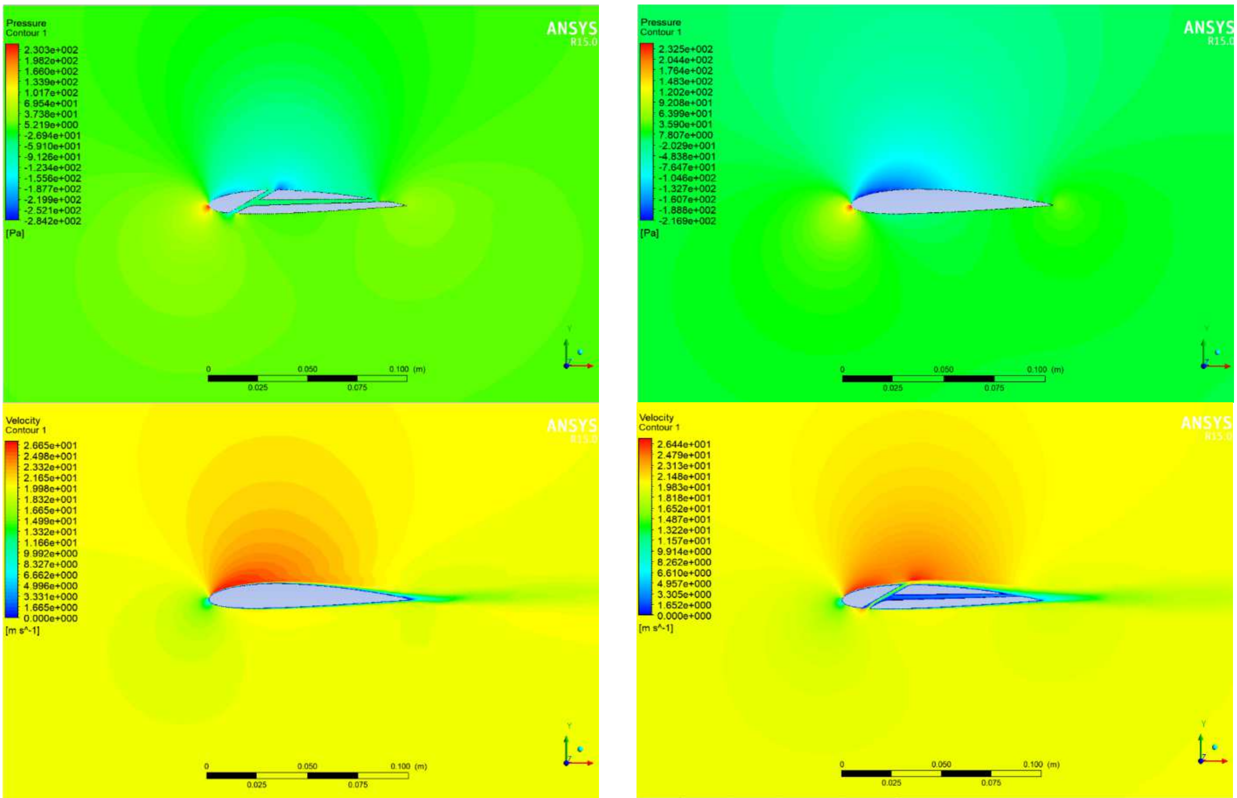

Figure 14: Pressure and Velocity Contours for NACA2412 and Vented NACA2412 Airfoils at 5° Angle of Attack.

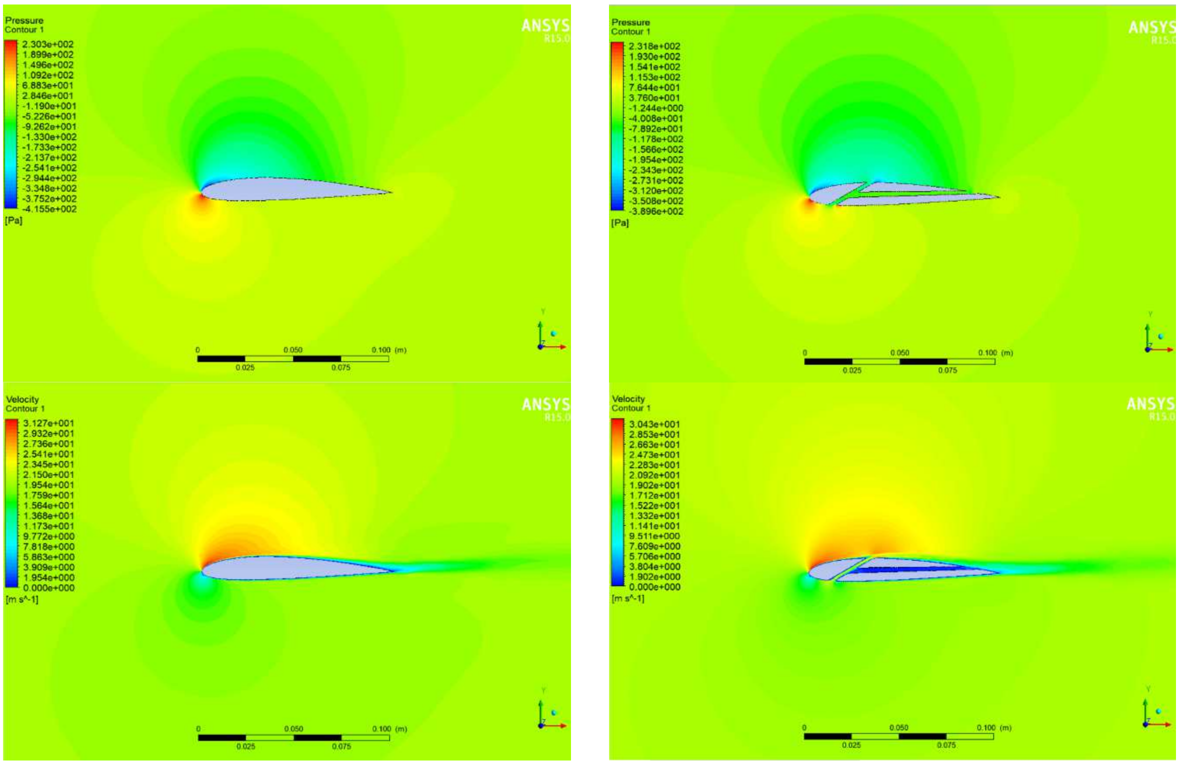

Figure 15: Pressure and Velocity Contours for NACA2412 and Vented NACA2412 Airfoils at 10° Angle of Attack.

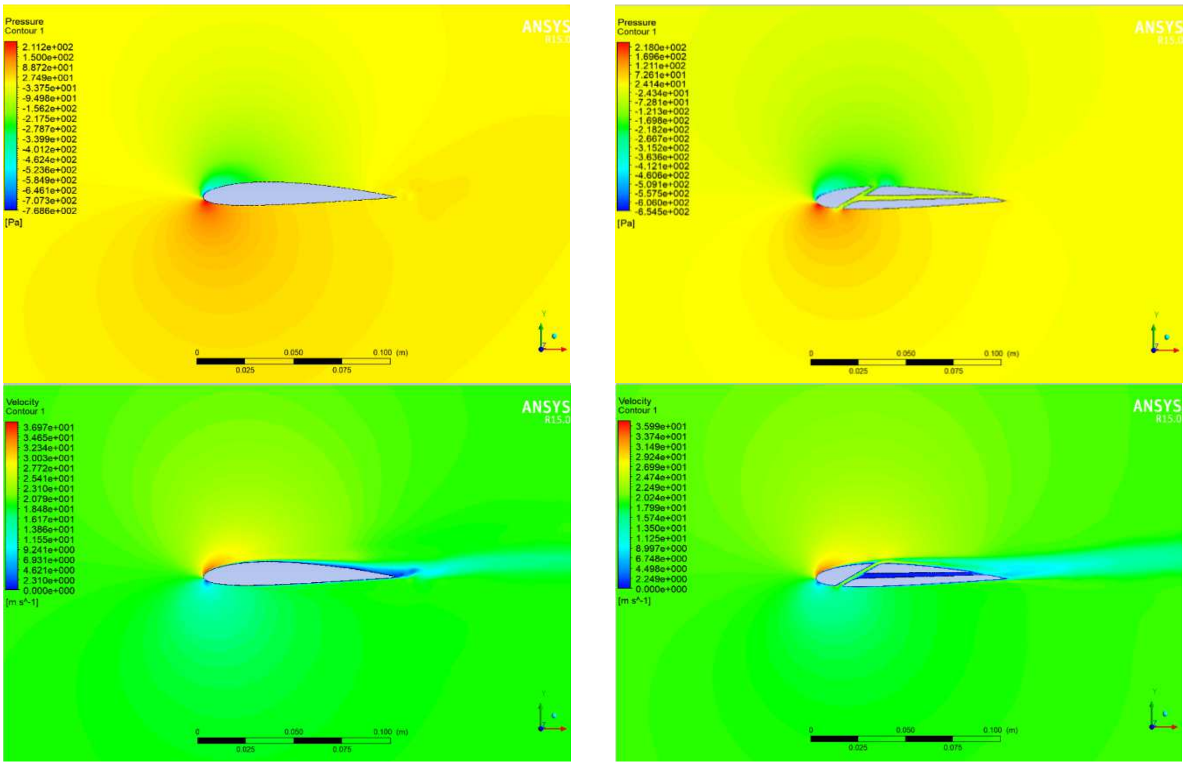

Figure 16: Pressure and Velocity Contours for NACA2412 and Vented NACA2412 Airfoils at 15° Angle of Attack.

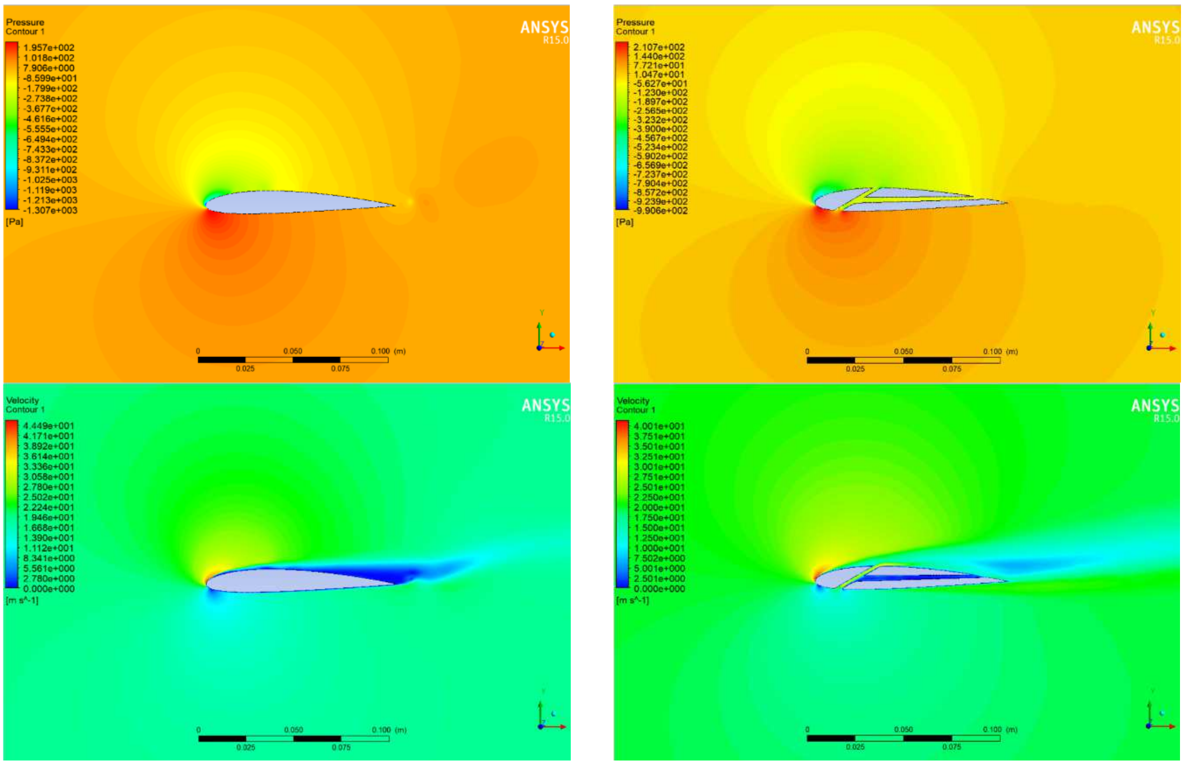

Figure 17: Pressure and Velocity Contours for NACA2412 and Vented NACA2412 Airfoil at 22° Angle of Attack.

CONCLUSIONS

From the resultant data of numerical analysis, it can be concluded that: The vented NACA2412 generates higher lift throughout the wide range of velocity and angle of attack. At a velocity of 20 m/s, the vented airfoil keeps on increasing in coefficient of lift until it achieves a maximum value at 22° angle of attack.

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AUTHOR'S PROFILE

Dr JV Muruga LalJeyan, works with High speed aerodynamics , wind tunnel instrumentation and testing , Was board member of EI Singapore 3 years , 12 plus years of experience in the field of academic, industry and research owner of John plaza shopping mall &vijaya apartments .Around 9 years served as Head of Aviation Studies in various university. Had an excellent number of students working under in various topics in and around india. Received RASHTRIYA GAURAV AWARD for meritorious service, by former governor of Tamil Nadu & Assam at a seminar on economic Growth & National Integration at New Delhi. Life member of 1)Aeronautical society of India 2) IAETSD 3)The institute of engineers IE 4)The Indian Science congress ISC Editorial Board Member for few international journals.

Mr. Tenzin Tadin, is a b-tech student at Lovely Professional University, specializing in Aerospace Engineering with CGPA of 9.38.He consider internships are equally important as compare to scoring a very good CGPA. While pursuing four year under graduate, he had successfully completed two internships to enhance his engineering knowledge and skills. Since aerospace broadly classified into two main body namely, astronautics and aeronautics engineering. His first internship is based on astronautic engineering. Group of engineering students from various branch forms a team called team Digantra, which aims to design and build cube satellite, where he worked as satellite's attitude determination and control sub system engineer. He came up with micro electromechanical sensor which fits perfect for cube satellite in case of size and working capability. While my next internship was on aeronautic engineering which he had designed bi-plane on catia v5r20 and did flow analysis with the help of ansys fluent software. And finally he flew it and received best performer award from Skyy Rider Institution. Apart from internships, he have experienced research work under the guidance of our HOD Dr JV MurugaLalJeyan for three years. His first research work entitled "AERODYNAMIC DESIGN AND COMPUTATIONAL ANALYSIS OF VENTED NACA 2412 AIRFOIL-A COMPARATIVE STUDY". He is a membership of Aeronautical Society Of India and Tibetan Scientific Society. And attended many leader workshops and participated in Indian Science Congress Association [ISCA] 2019 in Lovely Professional University.

Mr. Harmeet Singh, was passionate about airplane from my childhood and that's why I chose science at St. Soldier Divine Public School, as my major in my senior secondary and after appearing for LPUNEST exam, I got an opportunity to pursue B Tech. in Aerospace Engineering from LPU on scholarship of 70,000 per annum. I scored good GPA of 8.72/10. I also worked on one capstone project which was on passive blowing flow control technique namely 'vented airfoil'. I had an expertise in Catia, Creo and Autocad. Along with studies, I was a part of various clubs, out of which mind spark club was the major one which enhanced my communication and presentation skills. I also attended numerous workshops, such as ornithopter workshop which was organized by Aerospace department of Lovely Professional University in 2016.

Mr. Shreyashhoval, is pursuing b tech aerospace engineering from Lovely Professional University LPU. He is an enthusiast towards space science and rocketry. He aims to purse higher studies in the field of propulsion. He had completed his one month internship from TANEJA AEROSPACE from banglore, where he learned about aircraft maintenance and over hauling. He had completed research work under HOD Dr JV MurugaLalJeyan.