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Optimization of NACA 22112 Airfoil by Implementing Modified Tubercle Leading Edge

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ABSTRACT: *This research exploits the whale-inspired protuberance that can be used as a control technique to improved lift and drag the characteristic in the post-stall regime. Extremely manoeuvrable of the humpback whale, despite its size, is attributed to their pectoral flippers, along which protuberance is present along the leading edge. The idea of changing the leading edge of the airfoil to resemble the leading edge of the whale flipper was inspired by the prior work of the marine biologist who studied the morphology of humpback whale flippers. The protuberance seen along the leading edge of the humpback whale varies in amplitude and wavelength in span. It has been hypothesized that the protuberance act as a form of passive flow control and a form of drag reduction. Leading-edge modification of streamlined bodies can offer performance enhancement like an increase in stall angle, higher maximum lift coefficient, and also delay in flow separation. Here we are conducting a study on performance characteristics of different plan form variations by implementing tubercle on the wing leading edge. The present work demonstrates the development of an airfoil with polygon leading-edge tubercle. It is based on NACA 22112 airfoil with a tubercle on the leading edge. Using CATIA V5 the modified structure of airfoil is designed and is then compared with existing airfoil with their velocity components. The analysis of the structure is carried out in ANSYS FLUENT and finally, we are suggesting a structure with better performance*

KEY WARDS: *Flow separation, Passive flow control, Stall, Tubercle, Vortices*

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I. INTRODUCTION

The wing, which is made of tubercle structures at the leading edge is designed and analyzed in this project. The wing is made of NACA22112 aerofoil, in which the different structure at the leading edge gives a different performance in the stall conditions. That is, the wing can delay the stall at the time of stalling, which helps to improve the performance of the aircraft. Tubercles give rise to streamwise vortices in airflow that flows through the wing, which again energizes the viscous layer.

This enhances overall aerofoil performance. The function of the tubercle is it operates by diverting flow over the aerofoil into more narrow channels. We are concentrating the velocity of 686 m/s for the analysis of the wing with different plan form. Researchers are continuously trying to improve the overall performance of the flight. It seems that the leading-edge tubercles can improve the performance of the flight as well as delay the stall. D. Watts and F. E Fish have done a comprehensive three-dimensional analysis of flow over passive leading-edge tubercles. They studied the characteristics of viscous forces and applied on a finite span wing having leading-edge. In addition to this, their result, says leading-edge shape modifications such as tubercles can increase useful force production while simultaneously reducing parasitic forces [1]. In 2004 Mikiosovic conducted a wind tunnel experiment and through those measurements, he detected the addition of an idealized humpback whale flipper delay the stall angle by approximately 4% [2]. In 2009, two scientists named K. L Hansen and R M Kelson introduced an experimental investigation based on the effect of leading-edge tubercle geometry of two NACA aerofoils with different aerodynamic characteristics. They found that the most beneficial configuration of the tubercle proves to be those with a small amplitude and narrow the wavelength. Also, they concluded tubercle with NACA 5 digit is more beneficial [3]. Another attempt to know about the characterization and design of tubercle leading edge wings is done by three authors named MarkLory, Luigi Marginellid, and David Clifton. By using computational fluid dynamic analysis, they showed that variation in the thickness along the span, create channels of sorts along the chord and if it can be used to break up the separation region and create span wise fences, this increases the coefficient of the lift into the maximum. Also, their observations indicate that a fully 3D shape optimization is necessary to design tubercle within the high performance [5]. Zhaoyu Wei and Yanni Zhang proposed the aerodynamic characteristics and moderate aspect ratio leading-edge tubercle wing. They found wings with a smaller amplitude and wavelength shows the relatively better performance of lift to drag the ratio and by using a fluorescent oil visualization technique they revealed the surface flow structures for the tubercle wing [9]

II. MORPHOLOGY

The humpback whale (Megaptera novaeangliae) is uncommon contrasted with different fin back in its capacity to attempt aerobatic turning moves to get prey. Humpback whales use very portable, high-perspective, proportion flippers for banking. The position, size, and several tubercles on the flipper propose analogs with a specific driving edge control gadget identified with upgrades in hydrodynamic execution on natural and designed lifting surfaces.

It has been estimated that these edges of tubercles can alter the hydrodynamic qualities of the flipper. These tubercles can delay the stall by providing a higher lift at a higher angle of attack. The capacity to strengthen execution at high approaches would be profitable for the humpback while taking care of and moving where an extended working envelope is required. For instance, the unevenness in lift between the flippers gives a high positive lift on one side, high negative lift on the different makes, and improved capacity to roll and to do as such at higher rates. The most extreme lift direction brought about by setting the two flippers in similar direction makes outsized pitching second about the creature's focal point of mass, empowering the creature to plunge or climb rapidly. The humpback whale tubercle also functions as yaw control so it can turn tightly, which helps them to create a trap to catch their prey. We ought to likewise take note of that the creature may utilize "controlled" slow down to upgrade moving. From the hydrodynamic exhibition abilities of the Flippers with the expansion of the edge tubercles, we will attract analogies to vortex generators that stimulate the stream over an airplane wing. These vortex generators are considered as small tabs and placed on the chord of the wing, which leads to creating momentum exchange and boundary layer.

2.1 Tubercle Effect

To improve aerodynamic efficiency, a scientist named Fish discovered a phenomenon called the tubercle effect. The tubercles on the leading edge of an aerofoil play a significant role. The working of tubercles is inspired by a humpback whale, as it has rounded protuberance on the leading edge of its flippers. By doing various experiments, he found that this tubercle will allow the flow narrower towards the trailing edge of the wing. Another aspect result is that these channels can reduce the flow over wingtips, which in turn reduces the parasitic drag. Later he decided to study the morphological characteristics of a humpback whale. He noticed that even though this whale has a large size, it can still roll and loop in underwater.

The mechanism behind the theory is as the whale moves through the water, sheets of water are flowing over flippers and breaks into turbulent vortexes. Water which passing between the tubercles maintains a uniform flow, allows humpbacks' whale to keep their body grips on the water. Morphology and the location of leading-edge points out that this can be enhanced as a lifting device to control the flow over the flippers. After analysing the whale, he concluded that this tubercle effect could be used on aerofoil as it increases the aerodynamic efficiency. Also, flippers had a cross-sectional design similar to aerodynamic foil for lift generation. He found that these tubercles hold up the angle of attack till stalling. By delaying the time of the stall, we can increase the lift and reduce the drag. The two parameters used are amplitude and wavelength since they affect flow control. Usually, these tubercles are considered as small delta wings because they create a vortex on the upper edge of the tubercle. On the crest region of the tubercle, airflow imposes a downward direction that is why delay occurs at the time of stalling on the aerofoil. An upward deflection of airflow occurs in the trough region. The term angle of attack is more associated with localized up wash. Therefore, the increase in lift found in the trough region while the delay in flow separation is due to vortexes generated on the crest region. Further, separation of flow moves towards the backside of the wig. Later these tubercles are considered a bio-inspired design and used to the manufacture of many aerodynamic vehicles.

III.DESIGN CONCEPT

Generally, tubercles are aerodynamic devices that are inspired by the morphology of the humpback whale flipper, which enhances the aerodynamic performance characteristic of an aerofoil. This allow flow to remain attached for a large angle of attack angles and delays the stall on the leading-edge tubercles is a combination of swept forward and swept backward wing. To decrease the spanwise flow tubercles act as fences. These are responsible for the generation of necessary aerodynamic forces. Tubercles used to channel a flow over the aerofoil narrower and creating high velocities. It found that the presence of tubercles delays in the stall there-by increases lifts and decreases drag. Thus, stall delay and stall mitigation achievable by placing tubercles on the leading edge of the wing. Tubercles built by chord variation and constant thickness act as vortex generators and are passive flow control devices in the aerofoil. Several researchers have demonstrated improved aerofoil performance through the incorporation of leading-edge tubercles. It suggested that tubercles are known as lift enhancement devices and allow the airflow to remain attached to the aerofoil for a larger angle of attack. There are several explanations for the performance enhancements observed for aerofoils with leading-edge tubercles. These include the increase in boundary layer momentum exchange, non-uniform separation characteristics, alteration of the pressure distribution over the aerofoil surface, and vortex lift. Out of which boundary layer momentum exchange is the most accepted one. Tubercles lead to the formation of streamwise vortices. These vortices lead to additional momentum exchange in the boundary layer, which prolongs flow attachment, increasing the maximum attainable lift. Tubercles split the incoming air into narrow passages. Over the crest region, the downwash of the airflow occurs while localized upwash occurs on the trough. As a result, streamwise vortices formed along the spanwise direction of the wing. The peak vortices form close to the wing leading edge, where the magnitude decreases in the streamwise flow while the size of the vortex core increases. So, the vortices increase, this energizes the boundary layer, momentum exchange occurs in the boundary layer the flow becomes more attached. Tubercles act as passive flow control devices so that this tubercle can make flow into narrow channels that entrained between the tubercle and continue to the trailing edge. So due to this increased vorticity, it will increase momentum exchange in the boundary layer and also energizes it so that it can overcome the effect of the adverse pressure gradient. By overcoming the adverse pressure gradient, we can make the flow attached by creating a turbulent boundary layer. Since the separation point of the turbulent boundary layer is more than laminar. But this mainly occurs in the post-stall regime. There will be an earlier separation at a lower angle of attack for an aerofoil with tubercle. At the post angle of attack flow over the tubercle, the peak is still attached compared to the un-modified wing where the flow becomes detached.

3.1 Modelling

To design a new type of leading-edge aerofoil NACA22112 is selected. The NACA22112 aerofoil coordinates download from the aerofoil tool. The coordinates, upload to the CATIA file, and the creation of the aerofoil done on the workbench. Four different plan forms selected for modelling. The first design is a conventional model. The remaining three studied for better flow control and post-stall properties compared to the standard model. All design studied in this research are listed below:

case1: unmodified wing.

case2: sinusoidal wing.

case3: polygonal wing.

Dimensions of the model are given in Table1. The dimension of the wavelength and the amplitude of the wings are calculated by using compare to the journals.

The model figured out above is the design that is using to analysing the flow over it and the wings that we consider to delay the stall at high Mach number. The polygonal model is the one that we newly introduce

Table 1: Dimensions of the model

Design	Amplitude (mm)	Wavelength (mm)	Chord length (mm)
Unmodified NACA22	-	-	100
Sinusoidal	5	16	100 (longest) 94.96 (short
Polygonal	9.01	32	102.82(longest) 100 (short

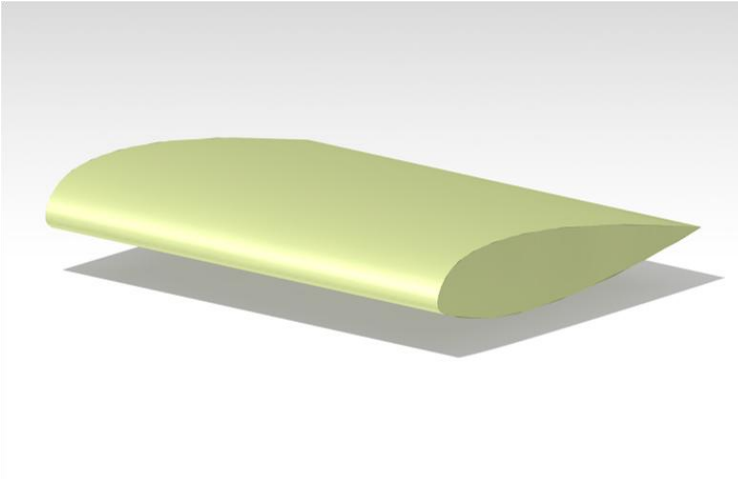

Figure 1: 3D Model of unmodified wing

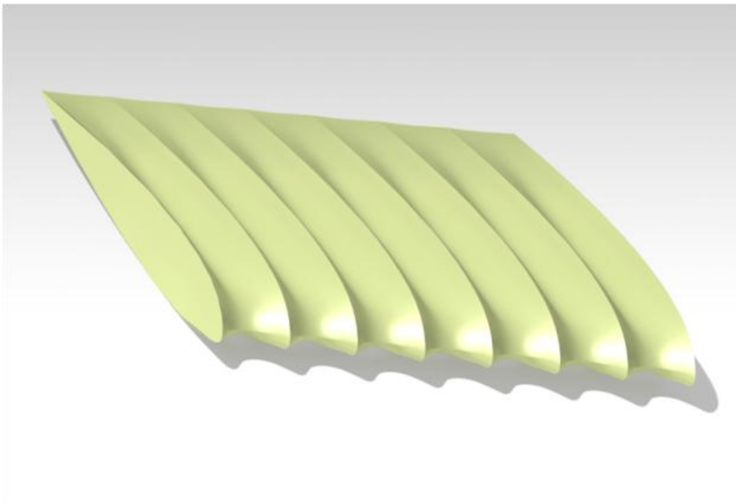

Figure 2: 3D Model of sinusoidal wing

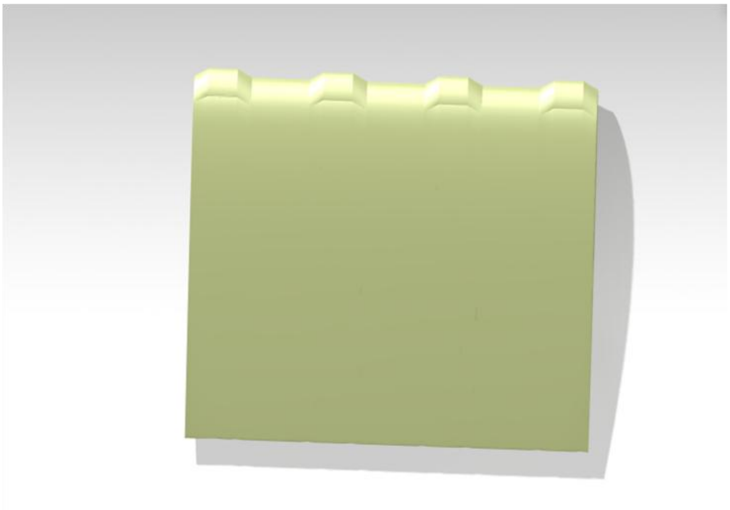

Figure 3: 3D Model of polygon wing

IV. ANALYSIS

ANSYS is a high-performance software. It can be applied to solve a wide range of fluid flow problems. The meshing process is easy compared to other analysis software like CAD. Integration into the ANSYS workbench plan form provides superior bi-directional connections to all CAD systems. Partial differential equations are needed to draw the fluid flow equation. Therefore, to analyse fluid flows, domains are split into smaller sub-domains are often called elements or cells, and the collection of all cells known as mesh. The governing equations discredited and solved. Each model of the wing will mesh in a particular manner for a better result. The meshing of the design is one of the most important steps in the analysis. As the mesh is improved, the results will be better. As the mesh is not improved, then the results will not be accurate. The meshed figure of each wing is shown in figure 4,5,6

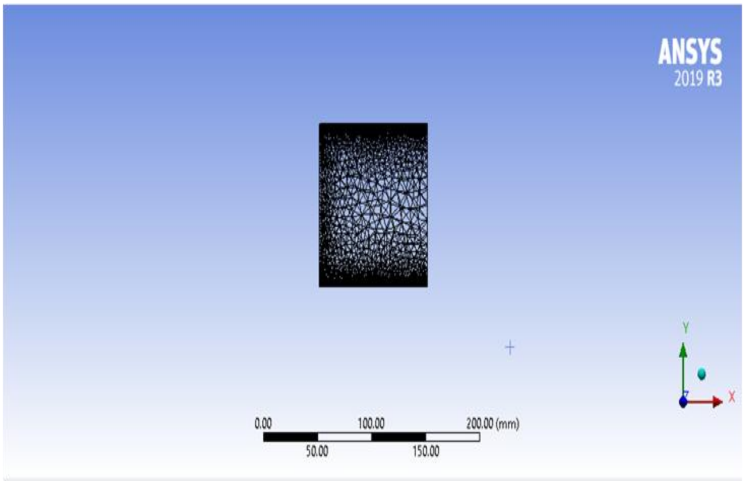

Figure 4: . Meshing of unmodified wing

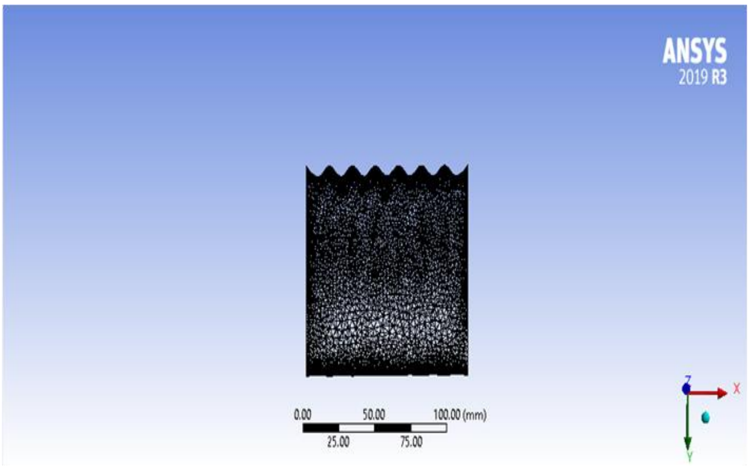

Figure 5: . Meshing of sinusoidal wing

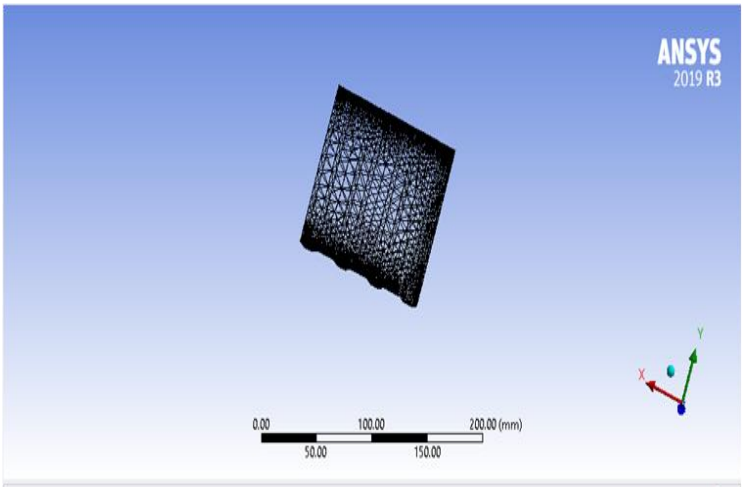

Figure 6:. Meshing of polygon wing

V.RESULTS AND DISCUSSION

Analysis of the wings with different tubercle structure gives a different performance with a different effect. The importance of them is to find out the cause of the stall on the wing. Here the aerofoil wing is considered to be move-in Mach 2. In the case of unmodified wing velocity in the leading edge is more than that in the trailing edge. The high-velocity region is more in the case of the un-modified aerofoil wing. But when it comes to the sinusoidal aerofoil wing, high velocity is located in the trough region of the leading edge. In the case of a polygon plan form, there is comparatively lesser disturbance compared to the unmodified and sinusoidal wing. Here the trailing edge comparatively has high-velocity that is flow leaving the aerofoil is at high velocity with a formation of attached flow. The pressure contour diagram of the polygon model shows an adverse pressure gradient in the boundary layer is decreased by the effect of a vorticity created by the protuberance.

Pressure distribution is better than that of unmodified. Therefore, the polygonal wing gives better performance than the other aerofoil wings. At angles of attack in the pre-stall regime of the un-modified foil, protuberances caused a reduction in lift. However, foils with tubercles generated as much as 50% more lift than the un-modified foil in the post-stall regime of the baseline foil. Over certain angles of attack, these protuberances create a more efficient wing.

Specifically, the post-stall angles of attack of the unmodified aerofoil wing show significant increases in the lift to drag the ratio. The flow is attached to the peaks of the tubercles. For un-modified aerofoil wing, flow separation occurs in the valleys at angles beyond the stall angle. Therefore, in the post-stall regime, the lift-to-drag ratio of the foils with tubercles can be increased substantially.

5.1 Velocity contour diagram

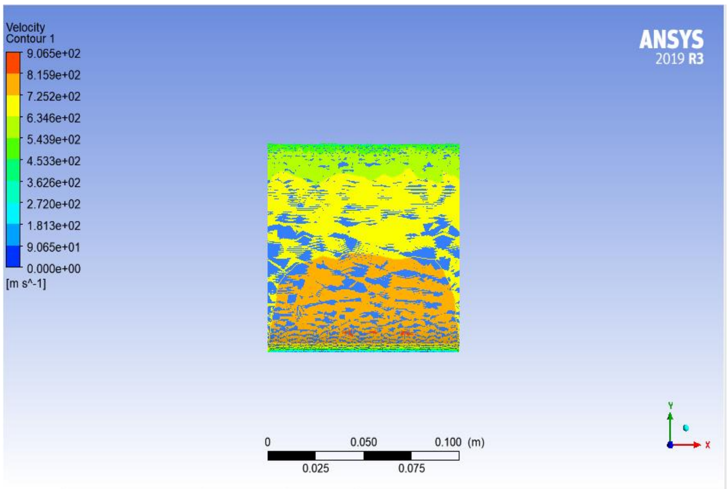

Figure 7: Velocity contour of unmodified wing

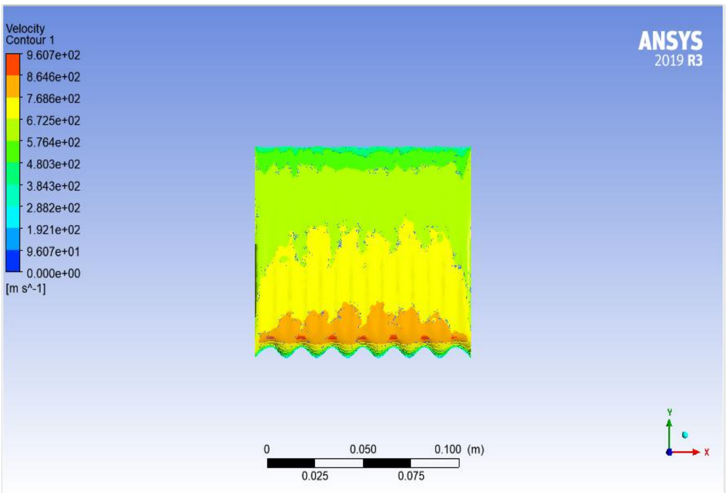

Figure 8: Velocity contour of sinusoidal wing

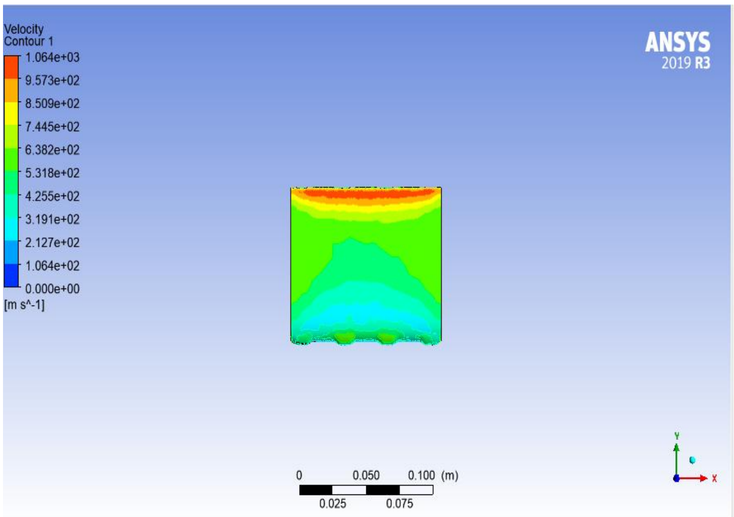

Figure 9: Velocity contour of polygon wing

5.2 Pressure contour diagram:

From the pressure contour of the wings, the polygon wing is the choose us better. In the case of polygon wing, the pressure appeared at the leading edge is 395400 pa. The pressure that appears at the trailing edge is 1277000 pa. The pressure drag is measured by taking the difference in static pressure at the leading edge and trailing edge. So, the pressure drag is -836600 pa.

In polygon wing, the average pressure around the airfoil wall is 886595 pa. Here the pressure drag is less compared to the sinusoidal wing. Since the value of drag is negative, the accelerating force created and there is a considerable increase in lift

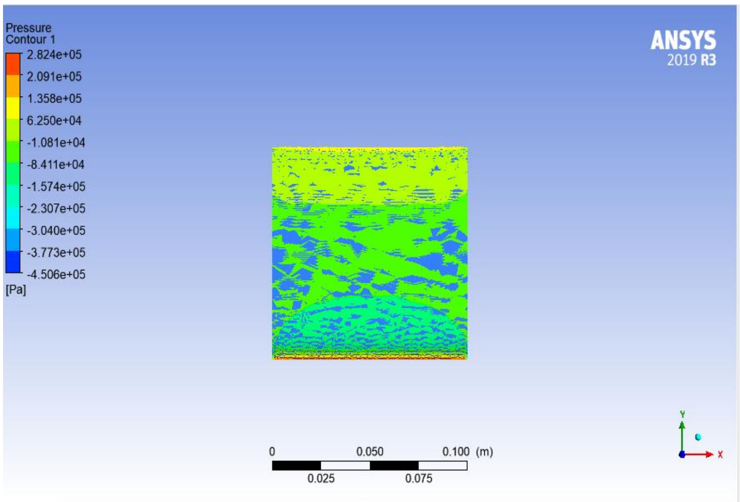

Figure 10: Pressure contour of unmodified wing

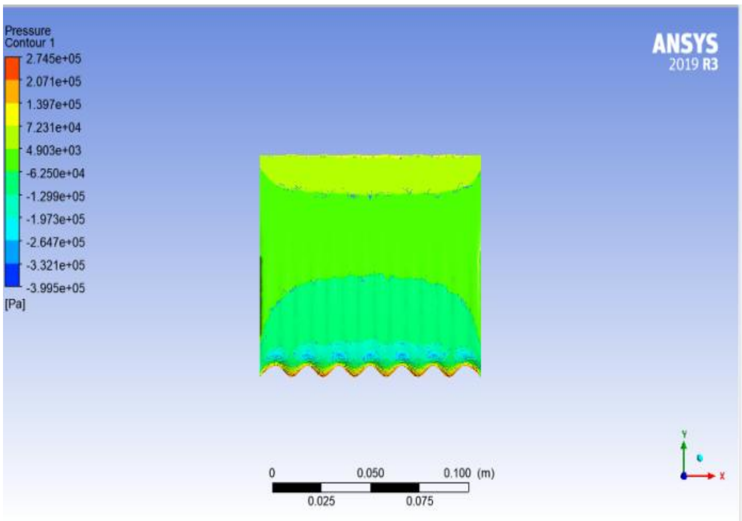

Figure 11: Pressure contour of sinusoidal wing

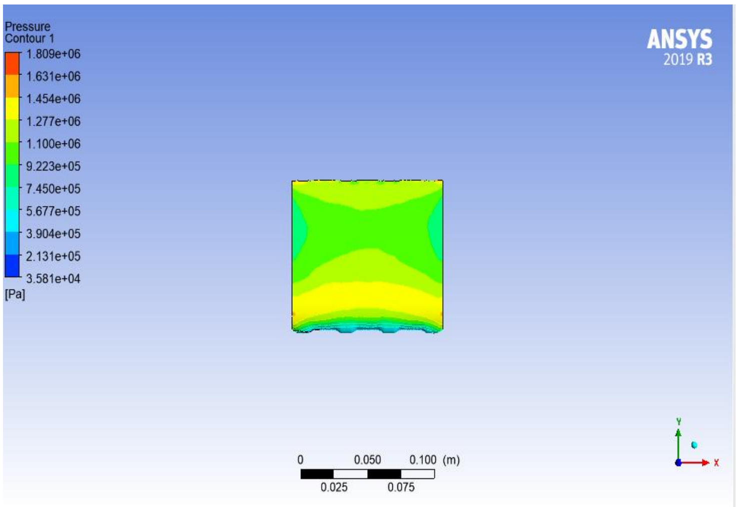

Figure 12: Pressure contour of polygon wing

5.3 Path line:

These are path lines that define the behavior of the flow of fluid. These path lines were analyzed during graphical post-processing of the converged stimulation. Each color represented a particular magnitude of velocity. To generate streamlines, starting at the center of each element on the inlet and export the data out. Therefore, n elements (cells) on the inlet, n number of streamlines need to generate. Then, the next step to trace each streamline separately and export the relevant information (velocity magnitude, pressure, or any other user-defined variable).After creating the streamlines at the center of each cell on the inlet in ANSYS. Finally, exporting the streamlines information out as a CSV file. However, opening the file in excel distinguishes the streamlines from each other. Also, streamlines are the same as path lines.These path lines are focused to give a graphical representation of flow over the wing.

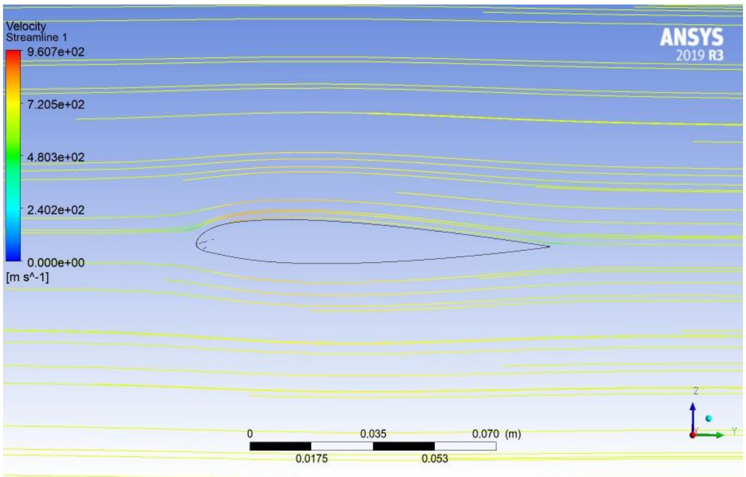

Figure 13: Streamline of unmodified wing

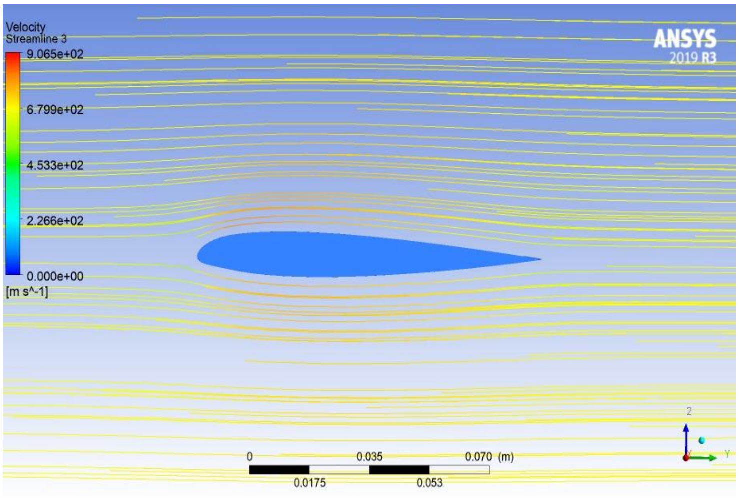

Figure 14: Streamline of sinusoidal wing

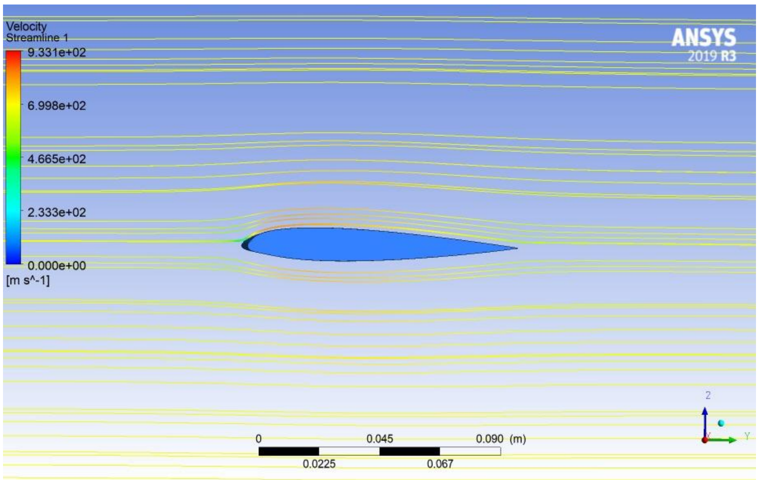

Figure 15: Streamline of polygon wing

VI. CONCLUSION

Based on the results and discussions, we have concluded that the present polygon tubercles are superior compared to the wavy tubercles in many aspects of its lightweight and ability to control. Along the varying leading-edge sweep, an angle is created by the tubercles, which in turn introduce spanwise flow along the leading edge. That flow is in the form of streamwise vortices. As a result of these vortices, low pressures are formed on the foil surface and are responsible for generating added lift past the stall angle of the baseline foil. When compared to the unmodified aerofoil, there is a lack of flow attachment in the pre-stall angles of attack of the modified aerofoil, and due to that at pre stall angles of attack, lower lift coefficients and higher drag coefficients have occurred. The value of the angle of attack where the unmodified aerofoil stalls, flow over the aerofoil is separated and reversed to the leading edge of the foil. Aerofoils with tubercles, on the other hand, maintain a flow attachment on the peaks of the protuberances far beyond the stall angle of the unmodified aerofoil, thereby generating higher lift coefficients in the post-stall regime of the aerofoil with minimizing effects of drag. These vortices have the same characteristics as the delta wing and which has some similarities with our polygon wing. The vortices help to keep an attached flow along the peaks of the tubercles, hence generating more lift and less drag than the unmodified aerofoil. In the pre-stall regime, it is clear that it is more advantageous to retain baseline leading-edge geometry. However, in the post-stall regime, the load characteristics of aerofoils with leading-edge tubercles are significantly more beneficial than without protuberances (unmodified wing). So the polygon plan form is the best for generating a maximum lift by a delay install timing at a higher angle of attack. Here we had taken an approximate value for amplitude and wavelength but series of investigations should carry to find the optimum range of amplitude and wavelength to obtain best-operating conditions for polygon tubercles.

FUTURESCOPE

We took an overview of NACA 22112 aerofoil, which determined the result by performed analysis. The unmodified wing airfoil, which will stall faster than the modified design. The tubercle wing delays stalls to a higher angle of attack. In the post-stall regime the load characteristics of an aerofoil with leading-edge tubercle more beneficial than without tubercle. The presence of tubercle will cause varying leading-edge sweep angle along the span, increases the spanwise flow along the leading edge in the form of streamwise vortices. The presence of streamwise vortices will cause low pressure on the airfoil surface, which in turn generates added lift in the post-stall angle. These results confirm the conclusion that the modified aerofoil has improved all the characteristics of well-known and commonly used aerofoils. The negative effect caused by tubercle in the pre-stall angle can solve by providing an active mechanism that deploys tubercle in the post-stall regime of unmodified aerofoil so that it will give a chance to utilize the full benefit of the tubercle. Therefore, the control surface can get both increased lift and lower drag created by unmodified shape in the pre-stall regime and while retained lift and flow attachment in the post-stall regime. It acts as a reflex aerofoil. So it can be used for the tailless aircraft, further studies are needed on how these wings compensate for the horizontal stabilizer. And this might be helpful for how stall can reduce in the horizontal stabilizers.

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