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"AERODYNAMIC PERFORMANCE ANALYSIS OF LOW SPEED WIND TURBINE AEROFOILS WITH INVERTED DIMPLES"

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ABSTRACT
A clean, fuel-free source of the energy wind turbines obviously create energy without generating the damaging pollutants that result from burning coal, gas and other fossil fuels. Even though we have various renewable energy sources, Wind energy has become one of the key solutions to the prevailing energy crisis. To economically produce the maximum power by using wind turbines the aerodynamic parameters of the blade profile must be assessed. The key parameters in the wind turbine blade performance are lift and drag coefficient. NACA-0015 and NACA-0018 airfoils were highly preferred for horizontal wind turbine blade under low Reynolds number configuration. Analysis of the effects of flow over NACA-0015 airfoil with and without inverted dimples and NACA0018 were done by using computational fluid dynamics methods. The widely used CAE software ANSYS CFX was used for analysis and simulation. Three models were analyzed for lift and drag performance i.e. one with the regular surface of NACA0015, other with inverted dimples on the upper surface of NACA0015 aerofoil, and the last with a regular surface of NACA0018 aerofoil. The depth of the dimples was selected as 3mm i.e. 1% of the chord length and was placed at a distance of 210mm i.e. 70% of the chord length from the leading edge. The ratio of the coefficient of lift and coefficient of drag, coefficient of performance was calculated by numerical methods at a various angle of attacks. With the advancement of highly configured computational methods, the flow behaviors of the fluid and its effects were accurately analyzed. The difference between the ratio of the coefficient of lift and coefficient of drag were compared. Due to the addition of inverted dimples over the upper surface of the airfoil, it was found that there was an increase of 5% efficiency in the performance.

KEYWORDS: Angles of Attack, Coefficient of Lift, Coefficient of Drag, Coefficient of performance, Inverted dimples, NACA0015, NACA0018, Reynolds number..

1. INTRODUCTION
Wind turbines blades are components used for converting the wind energy into rotational motion which in turn can be converted to any other mechanical force or electrical energy based upon its application. In such applications aerodynamics with low Reynolds number plays a vital role. Hence some research on this low Reynolds number aerodynamics is significant before designing a wind turbine blade. The most important parameters are the selection of airfoil and its aspect ratio. In a 2D airfoil, it is necessary to study the flow separation behavior over an airfoil and implement some methods to control it and increase the performance. Researchers and scholars made various approaches to control the flow separation over an airfoil at different Reynolds number and angles of attack. Hui Hu et al. [1] experimentally studied the laminar flow over a Low Reynolds number airfoil. P. D. Gall et al. [2] had placed dynamics roughness i.e. actual humps which oscillate with unsteady motion on the leading edge of the airfoil. The experimental & numerical analysis was performed to check aerodynamic efficiency. Deepanshu Srivastav [3] analyzed numerically the effect of outward and inward dimple over upper surface of the airfoil to control the flow separation. A CFD analysis of the flow behavior on wind turbine blades for a various angle of attacks was done by Bushan Patil et al. [4]. Sandesh K. Rasal et al. [5] used circular dimples on the NACA-0012 airfoil to obtain a better performance result. Izzet Şahin and Adem Acir [6] have numerically analyzed and experimented with the NACA-0015 airfoil for wind turbine applications.

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From the above discussions, it was found that NACA-0012 with circular dimples and other shaped dimples were significant for laminar flow with low Reynold number. Also, NACA -0015 can be used for turbine applications. The idea of introducing inverted dimples over the regular upper surface of the NACA-0015 low Reynolds number airfoil can be analyzed and compared with NACA0018 of the regular surface to find the performance of the models.

Airfoil nomenclature
An airfoil is a body that will produce more Lift than Drag when set at a suitable angle in a fluid flow. To fulfill this the leading edge of the airfoil is rounded and the trailing edge is sharp so that the flow happens smoothly. Fig-1 shows the airfoil with its nomenclature.

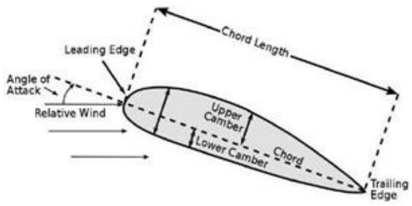

Fig-1: Airfoil Nomenclature [14]

Leading-Edge: the foremost edge of the airfoil that comes to contact with air.
Trailing-Edge: the rear edge of the airfoil. It is thin for the flow to leave smoothly.
Chord: the shortest distance between the leading edge and trailing edge i.e. the straight line from leading edge to trailing edge also known as chord line.
Angle of Attack: angle made by the chord line and relative wind
Camber line: the locus of the mean distance between the upper surface and lower surface.
Camber: the distance between the chord line and the camber line. The camber above the chord line is known as the upper camber. The camber below the chord line is known as the lower camber. When the cambers cross to another side of the chord line they are noted as negative camber.

NACA 4 series
The National Advisory Committee for Aeronautics organizes the airfoils as 4 series, 5 series, and 6 series based on their shape. The 4 series is structured by 4 digits NACA MPXX [7].

- M is the maximum camber divided by 100.
- P is the position of the maximum camber divided by 10.
- XX is the thickness divided by 100.

2. MATERIALS AND METHODS

Numerical analysis
Symmetrical type of airfoil NACA-0015 and NACA0018 were used for analysis for a wind turbine blade. The coordinates of the airfoil were taken from airfoil tools.com and the model was constructed in SOLIDWORKS.

The chord length of the aerofoil for the study was considered as 300mm and the maximum thickness as 45mm for NACA0015 and 54mm for NACA0018. we considered three types of models for analysis

1. NACA0015 with the regular surface. (Fig-2)
2. NACA0015 with inverted dimples on the upper surface. (Fig-3)
3. NACA0018 with the regular surface. (Fig-4)

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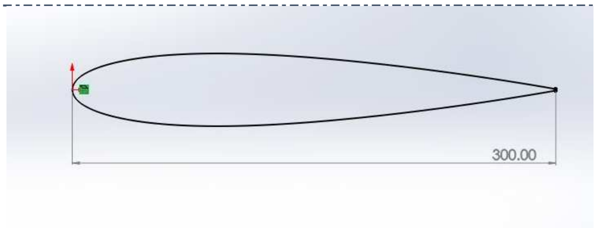

Fig-2: Geometry of NACA0015 with the regular surface.

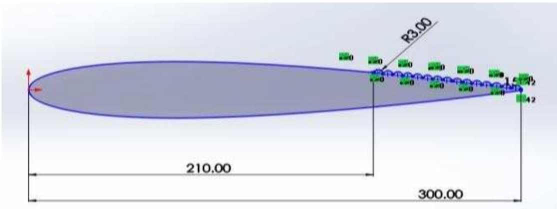

Fig-3: Geometry of NACA0015 with inverted dimples on the upper surface.

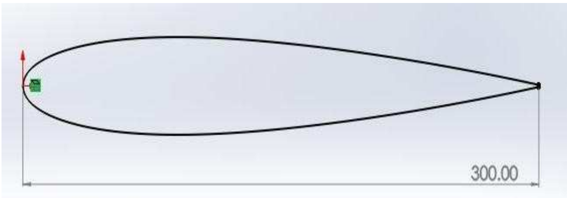

Fig-4: Geometry of NACA0018 with the regular surface.

The dimensions shown in the above figures are in mm. The inverted dimples are created at the end of the aerofoil near the trailing edge i.e.210mm from the leading edge, where the flow starts to separate from that point.

Ansys Fluent has been used for the numerical analysis of aerofoil. The viscous laminar model has been used to determine the coefficient of lift, coefficient of drag, and coefficient of performance. The numerical analysis has been carried out over the NACA 0015 to predict the coefficient of lift, coefficient of drag, and coefficient of performance of aerofoil. The following boundary condition is used with the smallest element size of 0.001m.

Fig-5 shows the structure of meshing for NACA0015 with dimples size is chosen as 1% of the chord length as 3mm.

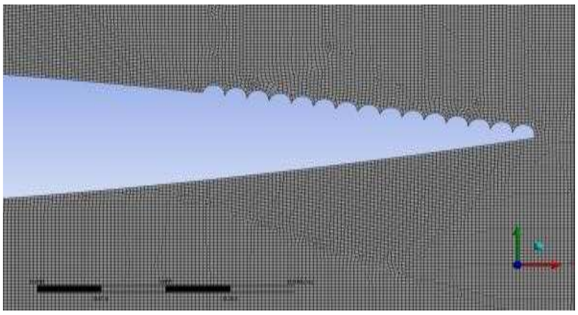

Fig-5: Grid of NACA0015 with inverted dimples on the upper surface.

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Input boundary condition

Table 1: Input BC data

Sl.no	Input	Value
1	Chord length	300mm
2	Maximum Thickness	45mm (0015) 54mm (0018)
3	Velocity of fluid	6 m/s
4	Density of fluid	1.225kg/m^3
5	Angles of attack (in degrees)	0, 10, 12, 15, 17, 21
6	Model	Viscous-SST k-omega
7	Inlet boundary	Velocity-Inlet
8	Outlet Boundary	Pressure-Outlet

3. RESULTS AND DISCUSSION

The Coefficient of Lift and Coefficient of Drag was determined using ANSYS Fluent for both the regular surface and surface with inverted dimples and their performance is represented in the below charts.

Chart-1 shows the coefficient of lift and coefficient of drag performance of NACA 0015 with the regular surface for different angles of attack such as 0, 10, 12, 15, 17,19, 21, 23 degrees. From the below chart we can say that for NACA 0015 aerofoil with the regular surface, as angles of attack increases, the coefficient of drag increases. The value of the coefficient of lift increases initially with the increase in angles of attack, but after reaching 15 degrees the value of the coefficient of lift is suddenly decreasing and goes on decreasing as the angle of attack increases. The point at which the value of the coefficient of lift starts falling is known as the stalling point.

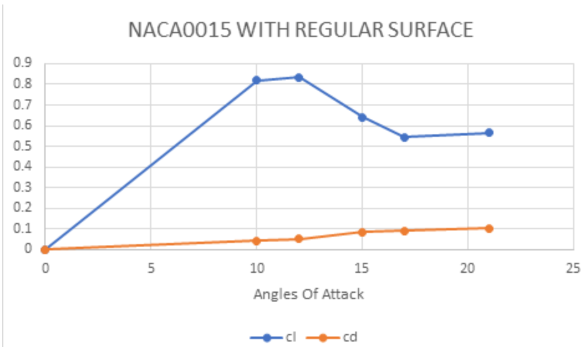

CHART 1: C_L, C_D vs Various angles of attacks of REGULAR SURFACE

Chart-2 shows the coefficient of lift and coefficient of drag performance of NACA 0015 with the inverted dimples on the upper surface for different angles of attack such as0, 10, 12, 15, 17, 19, 21, 23 degrees.

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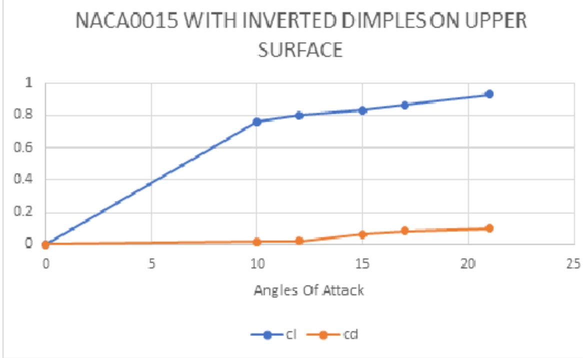

CHART 2: C_L, C_D vs Various angles of attacks of INVERTED DIMPLE SURFACE on the upper surface

Chart-2: Indicates that the for NACA0015 aerofoil with dimples in the upper surface. The coefficient of drag increases. The value of the coefficient of lift increases the above graph shows the same. Here for the same aerofoil the value of coefficient of drag is higher on compared to chart-1 which helps in reducing the aerodynamic efficiency. Although there is an increase in the coefficient of lift with the increase in the angle of attack. Hence, we have to also consider the lift to drag ratio to find the performance of the aerofoil this parameter is known as the coefficient of performance.

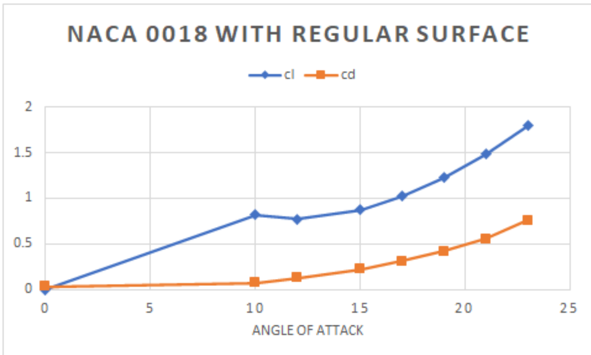

CHART 3: C_L, C_D vs Various angles of attacks of REGULAR SURFACE

Chart-3 shows the coefficient of lift and coefficient of drag performance of NACA 0018 with the regular surface for different angles of attack such as 0, 10, 12, 15, 17,19, 21, 23 degrees. From the above chart, we can say that for NACA 0018 aerofoil with a regular surface, as angles of attack increases, the coefficient of drag increases. The value of the coefficient of lift increases initially with the increase in angles of attack, but it also increases the coefficient of drag with it.

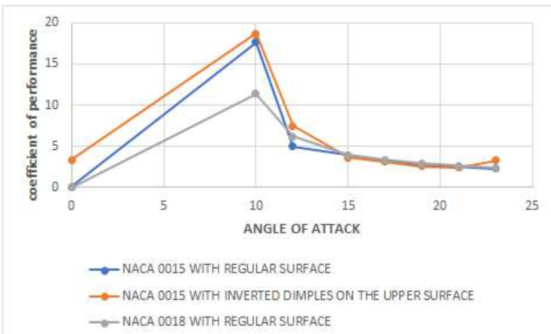

CHART 4: C_P of the regular surface of NACA0015 & 0018, C_P of inverted dimple surface of NACA0015 Vs angle of attack.

Chart-4 shows the coefficient of the performance of NACA 0015 for both the regular surface and with the inverted dimples on the upper surface And NACA0018 with the regular surface. for different angles of attack such as 0, 10, 12, 15, 17, 19, 21, 23 degrees. The coefficient of performance graph indicates that the NACA0015 with the inverted dimples on the upper surface have a higher value as compared to the regular surface of both NACA0015 and NACA0018 at a 10-degree angle of attack.

Velocity contour plots

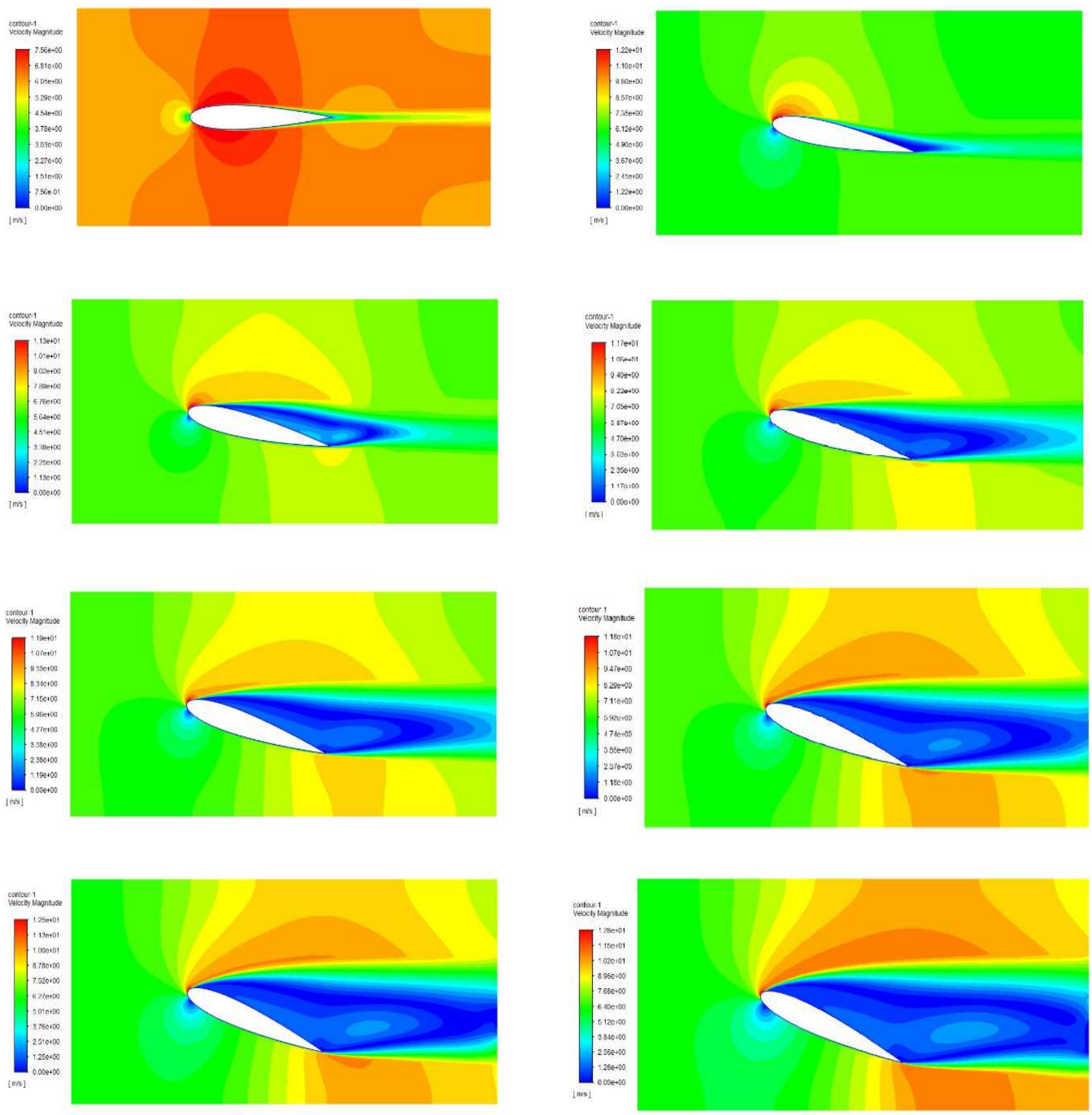

Fig-5: velocity contours of NACA0015 with regular surface at angles of attack of 0,10,12,15,17,19,21, and 23 deg

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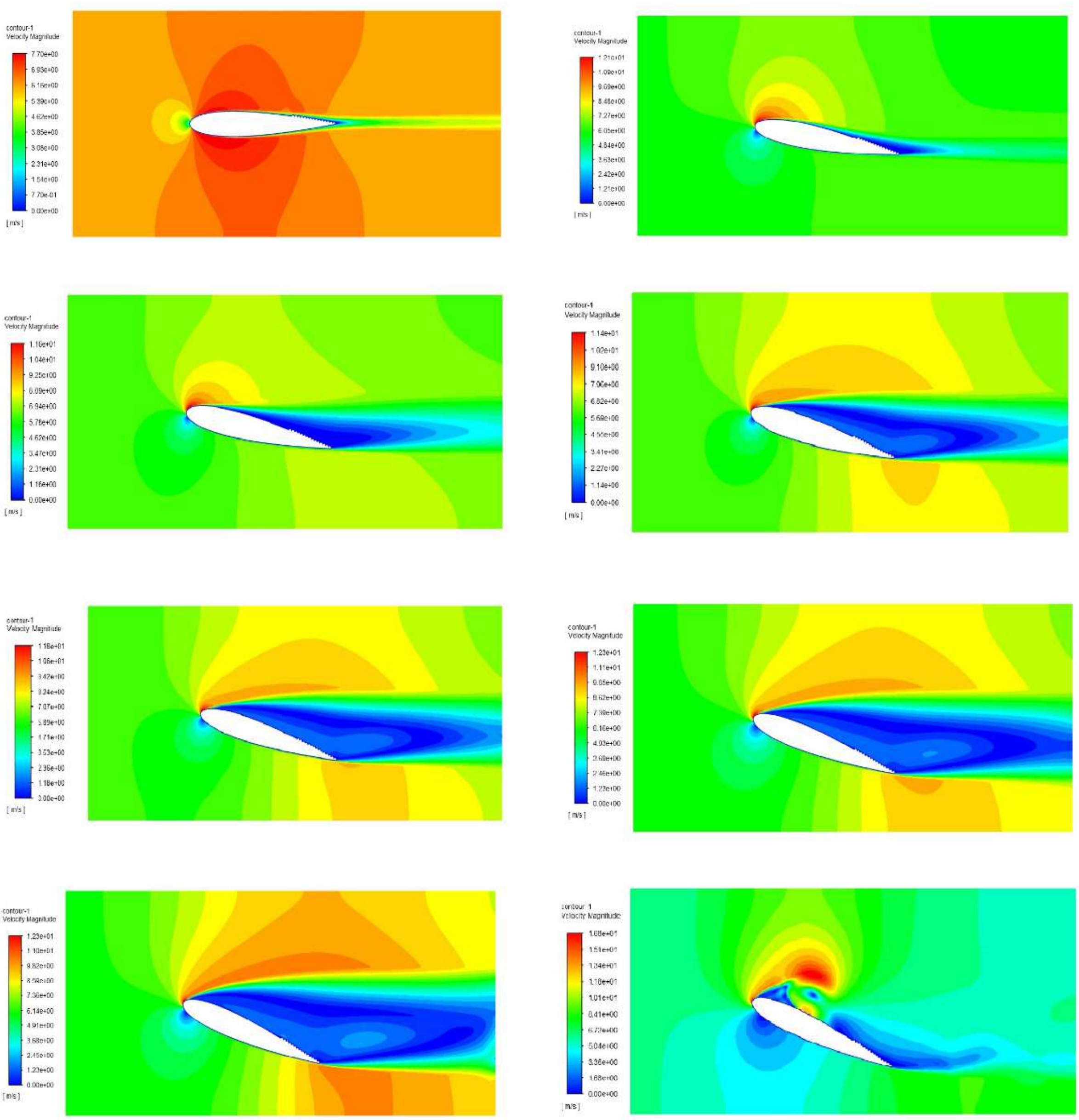

Fig-6: velocity contours of NACA0015 with inverted dimples on upper surface at angles of attack of 0,10,12,15,17,19,21, and 23 deg

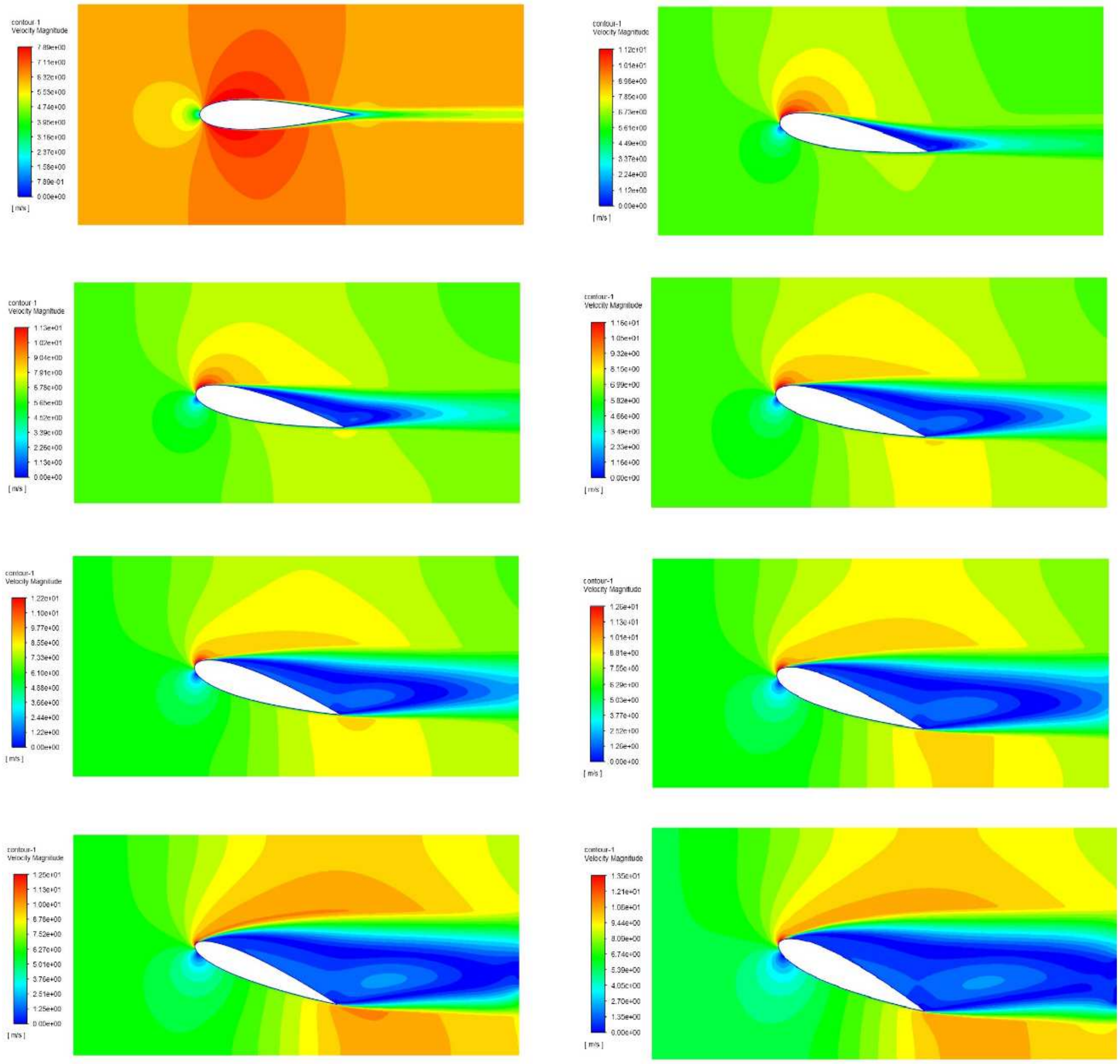

Fig-7: velocity contours of NACA0018 with regular surface at angles of attack of 0,10,12,15,17,19,21, and 23 deg

It clearly shows that for NACA0015 aerofoil with inverted dimples on the upper surface has a higher velocity region over the upper surface of the aerofoil as compared to aerofoil with a regular surface (NACA0015 and NAC0018) on higher angles of attack. Due to the low pressure in the upper surface of the aerofoil with inverted dimples has a high lift coefficient.

4. CONCLUSION

In this paper, NACA0015 models with the regular surface and with dimples on the upper surface and NACA0018 with the regular surface were analyzed for coefficient of lift and coefficient of drag. Performance at a velocity of 6 m/s. The size dimples were considered as 1% of the chord length. The numerical analysis shows that

- Although the presence of dimples increases the value of the coefficient of lift, it also increases the coefficient of drag with the increase in angles of attack.
- NACA0015 aerofoil with inverted dimples on the upper surface has a higher velocity region over the upper surface of the aerofoil as compared to aerofoil with a regular surface (NACA0015 and NACA0018) on higher angles of attack.

- The high-velocity region in the vicinity of the upper surface is created due to the addition of inverted dimples over the upper surface of the aerofoil.
- There is an increase of approximately 5% of coefficient of performance between the NACA0015 with the regular surface to the aerofoil with inverted dimples on the upper surface.

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