Geometry Modification Effect on The Aerodynamic Characteristics of NACA 0015 Using CFD.

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Abstract. The airflow around two-dimensional standard NACA 0015 airfoil effect was studied and analysed. The study was performed by simulating three geometrical modification airfoils (bumps NACA 0015, multi-element NACA 0015, and a backward-facing step NACA0015). Using SST (Shear Stress Transport) turbulence model and compared with standard NACA 0015 was the performed methodology. The research focuses on two cases (at different attack angles from 0 to 18 degrees with Re=1.65x10⁶). Case I: the numerical analysis method data for the coefficient of lift of standard NACA 0015 (baseline case study) is compared to the previous experimental data. Case II: the coefficient of pressure, coefficient of lift, the contour of static pressure, and the velocity contour for standard NACA 0015 (chord length c=1m) were calculated and compared with three geometrical modifications NACA 0015 airfoil. The CFD software ANSYS FLUENT version 17.1 was used for the computations in the present study. As a result, the geometrical modification influences on the aerodynamic properties of NACA 0015 was investigated. Compared to standard NACA 0015 airfoil, a significant improvement in the lift coefficient for multi-element NACA 0015 was noticed especially at the angle of attack (6°,14° and 18°) while slight improvement was noticed in the lifting coefficient for the other two models (bumps NACA 0015, and a backward-facing step NACA0015) at AOA 14 degree.

Keywords: Geometry modification, Aerodynamic, NACA 0015, ANSYS Fluent.

1. Introduction
The wing of the aircraft is one of its main components that is responsible of the aerodynamic characteristics. It improves the performance and efficiency of the aircraft. The take-off, flight control and flight range were examples to its effect. Therefore, since the beginning of the aircraft industry many researchers tried to increase the lift and reduce drag in several ways, including manipulating the geometry of the cross section of the wing (airfoil) [1]. Sogukpinar [2] introduced numerical simulations to 4-digit inclined NACA 00xx airfoils through employing the SST turbulence model. In this study, a comparison of (pressure terms and lift coefficient for NACA 0012 airfoil) experimental results to theoretical ones was carried out. The experimental and theoretical data were found compatible. The coefficient of Lift of NACA 0008-0012 airfoils showed similar performances when using the same simulations methods at 0°-14° AOA. For NACA 0015-0024 airfoils at 10° AOA, increasing the airfoil thickness caused decrease in the lift coefficient and pressure coefficient. Hansen et al. [3] experimentally studied the influence of the change of the leading-edge shape of two NACA airfoils with various aerodynamic properties. The force calculations performed on the modified and unmodified 2D airfoils showed that the tubercles are
further useful for NACA 65-021 aerofoil than for NACA 0021 aerofoil. Abu Tabikh and Ahmed [4] explored at low Reynolds number, the flow behaviour and the aerodynamic characteristics for airfoil consisting bumps. There were two types of study carried out: firstly, a theoretical research on the surface of NACA 4418 aerofoil which consists bumps through the use of Fluent software. Secondly an experimental study on the surface of NACA 0015 airfoil of the step backward with and without bumps inside the step in an open circuit low-velocity wind tunnel. Theoretical and experimental outcomes showed the benefit of using bumps on the surfaces of airfoil within the steps. Zahle et al. [5] examined two dimensions of CFD solver to improve the profile of a leading-edge slat. The results of the numerical and experimental analysis of airfoil configuration were compared; and as was predicted, the multi-element aerodynamic airfoil would reach a CL max of 3.1 depending on the airfoil length chord, which was confirmed in the wind tunnel test. Chowdhury et al. [6] investigated the effect of the backward-facing step configuration on aerodynamic characteristics of a NACA 0015 airfoil. The results showed an improvement in the aerodynamic performance. Mohamed et al. [7] introduced numerical analysis to enhance the performance of vertical axis wind turbines (Darrieus turbine). A numerical sequence model is performed for the different blade airfoils Darrieus rotor by doing a comparison between ANSYS Workbench and Gambit meshing tools. Higher efficiency and new shapes for this turbine were introduced comparing with regular airfoils. In Kannan et al. [8] research, the flow on multiple-element airfoils was studied numerically. ANSYS Fluent was compared to the aerodynamic parameters with the standard airfoils NACA 4412 and 0012. The numerical analysis showed that the aerodynamic characteristics of multi-element airfoils with tail effects were optimal compared to those of the NACA standard. The numerical results, made in a diverse flap and slat angles of diverse conditions, showed that the aerodynamic parameters multi-element airfoils with tail effects were optimal compared to those of the NACA standard. Mishriky and Walsh [9] paper presented a numerical investigation of the influence of the use of the backward-facing step and its position, onto suction side of NACA 2412 airfoil with a Reynolds number of $5.9 \times 10^6$, on the lift coefficient and drag. The results showed that changing the position of the step towards the trailing edge, before or after the transition point of the laminar boundary layer to turbulent, has a noticeable effect onto values of the aerodynamics coefficient. Zhang et al. [10] performed a numerical study of the S series modification (S812, S816 and S830) of wind turbine profiles, effects of relative inclination and their modifications, to improve the aerodynamic performance of the asymmetric modification of the blunt rear edge. The results indicated after a series of calculations on the mentioned models and comparing their aerodynamic coefficients. The airfoil with medium camber is more suitable for asymmetric modification of the blunt trailing edge. The simulations, at a variable attack angle of -10 to 20 degrees and a range of Reynolds numbers of $1.6\times10^6$ - $1\times10^6$, were performed using the computer code developed in MATLAB for aerodynamic profiles, 30P30N, GA (W) -1, RAF 16, NLR 7301. The results found that the maximum lift coefficient for a single slotted flap element decreased for a large attack angle beyond the stall area and for a slat element, the increase in lift was little at a high attack angle. Bashir et al. [12] studied morphing technology on the wings using smart materials and actuators to make them adjust to the different operating manoeuvres. Through achieving a variable span geometry, the analysis of the adaptive wing section was performed. Using the ANSYS FLUENT software, the aerodynamic coefficients in the NACA 4412 profile were calculated for various attack angles before and after the morphed. The results showed when changing the aspect ratio of the wing profile at different attack angles an increase in the aerodynamic performance was noticed. Chowdhury et al. [13] numerically and experimentally analyzed the influence of backward-facing step on the aerodynamic parameters of the NACA 0015 airfoil. The separation point, at free stream velocity and increasing the attack angle, was determined by numerical analysis. The step was placed just before the separation point. The results indicated that the lift to drag ratio increased due to the separation delay when introducing the step. In Khuder [14] research the flow field on the backward-facing step airfoil type NACA 0015 has been studied. Experimental and computational work to control the separation of the flow above it by the blowing method. A practical
study was used on the airfoil containing blow holes technique parallel to the airfoil chord. However, a numerical study was carried out using the Fluent software on three models of the airfoil, first without blowing, second with single blow holes and third with multiple blow hole technique. The results show that the separation of the flow at the airfoil can be delayed using blowing techniques and improving aerodynamic properties. Amit et al. [15] numerically analyzed the effect of the aerodynamic shape, small bump, on the aerodynamic forces of the NACA0012 airfoil. Delay in the separation of the flow that improve aerodynamic forces was noticed. Aziz and Islam [16] studied the Effect of stepped airfoils, step under lower surface, on the aerodynamic characteristics of NACA 4415 airfoil. Numerical and experimental results showed an improvement in aerodynamic properties. Ismail and Vijayaraghavan [17] Numerically studied the effect of the Gurney flap and the inward semi-circular dimple, Geometry modifications, on the NACA 0015 airfoil used in vertical axis wind turbines. The modified airfoil showed an improvement in the aerodynamics of the wind turbine blade.

The goal of the present study is to investigate the effect of three geometrical modification airfoils (bumps NACA 0015, multi-element NACA 0015, and a backward-facing step NACA0015) using SST turbulence model, on its aerodynamic characteristics. Different angles of attack from 0 to 18 degree and Reynolds numbers = 1.65x10^6 were considered. Moreover, the numerical analysis results of the NACA 0015 aerofoil (baseline case study) were compared with the experimental results that were performed earlier [18]. CFD software ANSYS FLUENT version 17.1is used for these computations.

2. Computational methodology

One of the branches of mechanical engineering that uses numerical methods to solve problems involving fluid flow is computational fluid dynamics (CFD). It is the science of predicting the flow of fluid by solving the fluid flow differential equations for mass, momentum, and energy. Govern these processes using a numerical algorithm on a computer to simulate the free flow of a liquid and the interaction of a liquid (liquids and gases) with surfaces applied in specific engineering and flow conditions.

ANSYS Fluent CFD software version 17.1 was used as a tool to design sections in the present study. The steady flow field about airfoil has been simulated numerically by resolving the incompressible two-dimensional, Navier-Stokes equations on unstructured grids domain of complex shape. The simulated flow fields (SST turbulence model) were used to discuss the mechanisms of flow separation, and to explain the aerodynamic characteristics between two-dimensional standard and geometry modifications of airfoil NACA 0015. To merge the superior performance of the k-ω model near the wall area for the superior strength of the model, Menter (1994) developed the SST model (Shear Stress Transport) [19]. Using equations (1) and (2), the Shear Stress Transfer model is expressed in terms of k and ω. [2].

\[
\rho \left( \frac{\partial k}{\partial t} + \rho u \cdot \nabla k \right) = \nabla \cdot \left( \mu_\ell \nabla k \right) - \rho \beta_0 \cdot \kappa \omega \\
\rho \left( \frac{\partial \omega}{\partial t} + \rho u \cdot \nabla \omega \right) = \nu_T \left( \nabla^2 \omega \right) + \rho \left( \gamma - 1 \right) \frac{\partial \sigma_{avg}}{\partial \omega} \nabla \cdot \left( \nabla \omega \right) - \frac{\partial \sigma_{avg}}{\partial \omega} \nabla \cdot \left( \nabla \omega \right) + \left( \mu + \sigma_{avg} \mu_T \right) \nabla \cdot \left( \nabla \omega \right)
\]

Where:- k=kinetic energy of turbulence, ρ= density, γ,β,β0 =turbulence-model coefficients, ω =specific dissipation of turbulence kinetic energy, \( \mu_T = \) turbulent viscosity, \( \mu = \) dynamic viscosity, \( \sigma_{avg}, \sigma_1 = \) turbulence-model coefficients, \( \mu_T = \) turbulent viscosity.

Where the static pressure(P) can be represented in the equation (3) below:

\[
P = \min \left( P_R, 10 \rho \beta_0 \cdot \kappa \omega \right)
\]

Here, the production term \( P_R \) is expressed by the following equation:

\[
P_R = \mu_T \left( \nabla u \cdot \left( \nabla u + \left( \Delta u \right)^2 \right) - \frac{2}{3} \left( \nabla \cdot u \right)^2 \right) - \frac{2}{3} \rho \kappa \nabla \cdot u
\]

The viscosity of the turbulence (\( \mu_T \)) is expressed with the equation (5):

\[
\mu_T = \frac{\rho u_k}{\max \left( \alpha_1, \omega S^* \right)}
\]

Where: \( - \alpha_1 = \)Brachard’s structural parameter

Where, the characteristic magnitude of the average velocity gradients is \( S \) and can be expressed by the equation (6): -
The interpolation functions \( f_{v1} \) and \( f_{v2} \) are indicated by the equations (7 and 8): -

\[
f_{v1} = \tanh \left\{ \min \left[ \max \left( \frac{\left( \frac{\mu}{\rho \omega} \right)}{\left( \frac{\beta_0^* \omega l_\omega}{\rho \omega} \right)} \right), \frac{4 \rho \mu K \omega}{\max \left( \frac{\rho \sigma \omega}{\rho \sigma \omega \beta_0^* \omega l_\omega} \right)} \right] \right\}
\]

\[
f_{v2} = \tanh \left\{ \max \left[ \frac{\sqrt{\frac{K}{\left( \beta_0^* \omega l_\omega \right)}}}{\frac{500 \mu}{\rho \omega l_\omega}} \right] \right\}
\]

Where, \( l_\omega \) is the distance for the nearest wall. For Shear Stress Transfer, default model constants are specified by:

- \( \sigma_k = 0.85 \), \( \sigma_k = 1.0 \), \( \sigma_{\omega 1} = 0.5 \), \( \sigma_{\omega 2} = 0.856 \), \( \beta_1 = 0.075 \), \( \beta_2 = 0.0828 \), \( \gamma_1 = 0.5 \), \( \gamma_2 = 0.44 \), \( \beta_0^* = 0.09 \), \( \sigma_1 = 0.31 \)

3. Approach

The CFD software ANSYS FLUENT was used for this computation to create the work environment in which the geometric model is simulated. The main part is to create a grid that surrounds the object, so it is necessary for the CFD analysis process.

3.1 Preparing geometric model

The procedures work is importing the coordinates vertices (i.e. texts file to create the curve) of the airfoil [20][21] in the ANSYS DesignModeler and create the surface to the curve. Next, create the geometry for the C-mesh domain by using sketcher toolbox and dimension toolbox after creating a coordinate system at the tail of the airfoil. To remove distortions in the boundary zone, a C-shaped type was used. The arc radius length of a C-shaped type was taken 12 times greater than the chord length from the leading edge of the airfoil until the inlet and taken 21 times from trailing edge toward open boundary. The purpose is to minimize the influence of the boundary zone in the calculation. The final step of creating the C-Mesh is creating a surface between the boundary and the airfoil by using Boolean operations. A computational domain is shown in Figure 1.

3.2 Generate meshing

Computational grids were generated using software. The mesh is built to be very thin in regions near to the aerodynamic airfoil, in the section of the boundary layer, and coarser further from the aerodynamic airfoil. The grids utilized in this work are unstructured triangles grid, and to confirm the computed aerodynamic results are not dependent on the size of the grid, the density of the grid increased until an insignificant difference reached the solution towards convergence. Closed-up of airfoils section are shown in Figure 2, to be employed in numerical analysis. No slip condition is applied on the surface of the airfoil.

3.3 Setting boundary conditions

The mesh boundaries were set to the x and y velocity components, and the end boundary the property “pressure-outlet” to simulate the zero-gauge pressure. The airfoil itself is given as wall properties. The boundary conditions are shown in table 1.

3.4 Setting up FLUENT (Initializing and solving)

The geometries and meshes were imported into FLUENT and "double precision" was selected as system parameters, to ensure higher precision. The residuals for the turbulence model were set at \( 10^{-6} \) and the maximum iteration count at 1500.
Figure 1. Computational domain and boundary condition.

| Standard NACA0015 | Bumps NACA0015 | Backward-facing step NACA0015 | Multi-Element NACA 0015 |
|-------------------|-----------------|-------------------------------|-------------------------|
| ![Image a]        | ![Image b]      | ![Image c]                    | ![Image d]              |

Figure 2. Closed-up of airfoils section at 0° AOA.

Table 1. Computational conditions.

| Input                      | Value          | Input                        | Value                        |
|----------------------------|----------------|------------------------------|------------------------------|
| Wind speed                 | 25 m/s         | Density of fluid             | 1.225 kg/m³                  |
| Operating temperature      | 300 k          | Kinematic viscosity          | 1.5111 × 10⁻⁵ m²/s          |
| Operating pressure         | 101325 pa      | Attack angle (Deg)           | 0° to 18°                    |
| Models                     | Shear Stress Transport turbulence | Fluid                  | Air                          |
| Reynolds number            | 1.65E+6        | Turbulent kinetic energy     | 4.1840E-7 m²/s²             |
| Specific dissipation rate  | 2.7778 1/s     | Airfoil chord length         | 1m                           |
4. Result and Discussion

The results are divided into two parts:

In part I the numerical result curves were compared and validated with the experimental results of a previous study [18].

In part II the comparison between the aerodynamic characteristics of the numerical results of NACA 0015 (baseline) with those of modified models was introduced. Figure 3 show the comparison of the aerodynamic characteristics of the numerical results of NACA 0015 (baseline) with the experimental results previously performed in terms of lift coefficient [18]. Figure 3(b), show the lift coefficient created on two-dimensional standard NACA 0015 aerofoil using k-ω SST turbulence model employed in CFD at variable attack angles (AOA). The k-ω SST turbulence model shown results were close to previous experimental results, Figure 3(a).

![Figure 3. Comparison of the lift coefficient over NACA0015 airfoil (k-ω SST turbulence model) with the previous experimental results [18].](image)

The numerical results of Standard NACA 0015 with the other three models in terms of lift coefficient shown in table 2

| α(deg) | Standard NACA 0015 | Bumps NACA0015 | Backward-facing step NACA0015 | Multi-Element NACA 0015 |
|--------|--------------------|----------------|-----------------------------|------------------------|
| 0      | 0.0040778          | 0.00085455     | -0.085793                   | 0.020125               |
| 6      | 0.44378            | 0.35325        | 0.43293                     | 0.68148                |
| 8      | 0.83455            | 0.56012        | 0.53472                     | 0.72541                |
| 10     | 0.94637            | 0.59573        | 0.61982                     | 0.63557                |
| 12     | 0.93177            | 0.65255        | 0.76266                     | 1.0557                 |
| 14     | 0.84602            | 0.93328        | 0.93912                     | 1.4561                 |
| 16     | 1.6412             | 1.0528         | 0.95092                     | 1.5155                 |
| 18     | 1.3412             | 1.1591         | 0.96968                     | 2.2953                 |

The pressure distribution curve of the NACA 0015 airfoil (baseline) at α = 0° angles of attack and three models are shown in Figure 4. The Figure 4(a) showed that no lift was generated at this angle of attack as expected from a symmetric airfoil without a different in the pressure that generated.
At the beginning of the airfoil, Peak pressure \((x= 0.0345585, y = -0.458881)\) showed a normal behaviour of the pressure curve because of the acceleration of the flow. There was fluctuation in the pressure distribution for the second model (Bumps airfoil) at the position range 0.25 - 0.35 \(x/c\) shown in Figure 4(b) with Peak pressure \((x= 0.032766, y = -0.655484)\). A little change in location and value of Peak pressure at the front edge of airfoil gave a slight improvement in aerodynamics coefficients. This is due to the cams located below and above the airfoil surface that change the velocity value for flow. The curve has normal behaviour at the position 0.35 \(x/c\) similar to Figure 4(a). Figure 4(c) shows different behaviour for the pressure distribution\((cp)\) of the mode NACA 0015 with Backward-Facing Step compared to the two previous models at the same angle.

A change in the location of Peak pressure \((x = 0.202112, y = -0.581437)\) which generate unwanted negative lift \(C_L = -0.085793\) was observed, table 2. For the airfoil NACA0015 with Multi-Element, shown in Figure 4(d), there was a difference in the pressure value in the front of the airfoil and generated lift \((CL = 0.020125)\). This is because the flow has additional momentum from the air duct at the front of the wing.

![Figure 4](image_url)

**Figure 4.** Pressure distribution curve for NACA 0015 airfoil (baseline) and three models at 0° AOA.

When the angle of attack is changed to 6° AOA, there is a difference in the distribution of pressure above and below the wing due to different velocity according to Bernoulli’s law as shown in Figure 5. The normal behaviour of the distribution of pressure around standard NACA 0015 airfoil is shown in Figure 5(a). It’s been noticed that the increase in pressure difference between the lower and upper surfaces at the front edge is due to the increased speed at the top surface compared to the lower surface. The difference starts to decrease as flow move towards the trailing edge. The change in the coefficient of pressure for the two models, bumps NACA 0015 shown in Figure 5(b),and Backward-Facing Step NACA 0015 shown in Figure 5(c), and the value of lift coefficient calculated for them \((CL = 0.35325, CL = 0.43293)\) respectively at the angle of attack 6° are close to the standard NACA 0015 airfoil \((CL = 0.44378)\) at the same angle. While, there is a notable increase in the lift coefficient, \(CL = 0.68148\), of the Multi-Element NACA0015 model of Figure 5(c) compared to the previous
models due to increasing of the amount of kinetic energy to flow obtained from the flow channel below the front of the airfoil Figure 2(c).

![Image](image_url)

(a) Standard NACA 0015  
(b) Bumps NACA0015  
(c) Backward-facing step NACA0015  
(d) Multi-Element NACA 0015

**Figure 5.** Pressure distribution curve for NACA 0015 airfoil (baseline) and three models at 6° AOA.

From Figure 6(a), the pressure difference between the bottom and upper surface of the standard NACA 0015 airfoil increases with the increase of the attack angle 8° and 10° compared with the other models which remain constant as in Figure 6 (b, c, and d). The lift coefficient at 10° AOA for standard NACA0015 is \( \text{CL} = 0.94637 \), table 2, more than the others because the flow is close to the upper surface. While the flow above other models of airfoil at the same angles relatively far from the upper surface due to the appearance of the early boundary layer as a result of the modification and movement of the separation point forward the leading edge of the airfoil. The pressure curve for the Multi-Element NACA 0015 at 10° AOA, in Figure 6(d), shows a different behaviour compared to its behaviour at 8° AOA. A decrease in the lift coefficient because of separation point approaches the leading edge of the airfoil significantly.

By increasing the angle of attack to 12° and 14° for all airfoils, an increase of the area between the upper and lower pressure curves was observed for Multi-Element NACA0015, Figure 7(d), compared to the other models, especially at 14° AOA. This increase in the pressure difference around it gets to a noticeable improvement in the lift coefficient \( \text{CL} = 1.4561 \) compared with the standard NACA 0015 \( \text{CL} = 0.84602 \), table 2. This is due to the flow jet channel below the front of the leading edge, which gives the flow above the suction surface extra energy-momentum that delaying the point of separation. The momentum of the flow jet channels is directly proportional to the angle of attack at this stage. Bumps NACA0015 and Backward-facing step NACA0015 have a high lift coefficient compared to standard NACA 0015 at angle 14° due to Bumps in the front part of NACA 0015. Which generate a turbulent flow that provides kinetic energy to near-surface flow and delays separation.
Figure 8(d) shows the positive change in the pressure distribution around the Multi-Element NACA0015 at 18° AOA compared to another Figure 8(a, b and c). This is due to the increment in the amount of mass flow rate for the flow jet channels. As a result of this, the mass flow rate gave the separation flow enough energy to reattachment and improve the lift. The largest increase in the lift coefficient $CL = 2.2953$ for Multi-Element NACA0015 compared to standard NACA 0015, $CL = 1.3412$, table 2.

Figure 9 display the relation of the lift coefficient of the four models with angle of attack from (0°-18°). Where the classical increase in the lifting coefficient was observed with increased attack angle. At angle 10° a drop in the lift coefficient of Multi-Element NACA0015 was observed due to forward of separation point to the front edge and then increased at angle 12 due to the momentum energy given by the flow jet channels to flow. The Multi-Element NACA0015 lift coefficient curve was increased compared with other models, especially with standard NACA0015 at angle 18° where $CL = 2.2953$, as explained previously. For the Bumps NACA0015 and Backward-facing step NACA0015, the lifting coefficient increased with the increasing attack angle. The values of the lifting coefficient are few compared to the standard NACA 0015 at all angles, with the exception that values at angle 14 being higher than other.
Figure 8. Pressure distribution curve for NACA 0015 airfoil (baseline) and three models at 18° AOA.

Figure 9. Plots of lift coefficient versus angle of attack for NACA 0015 airfoil (baseline) and three models.
For all models at 0° AOA, as shown in Figure 10, the flow has a stagnation point (Pressure is maximum and velocity is zero at this point) at the nose of an airfoil. At this angle, the contours of static pressure on an aerofoil was symmetrical for both upper and lower surfaces pressure for all models except for Backward-facing step NACA0015 due to unsymmetrical shape. With an increasing attack angle for all models, the stagnation point of the flow moves just under the airfoil leading edge and static pressure increase at lower surface. From 8°-18° AOA, there was a high-pressure region at the airfoil leading edge and low-pressure region on the suction surface of the Standard NACA 0015 Figure 10(a). These pressure regions were concentrated especially at the front edge of the airfoil, which improves lifting, table 2. As for other models compared to Standard NACA 0015 at 14° AOA, an increase in the lift due to the difference between the regions of high-pressure value, especially under the airfoil leading edge, and the region of low-pressure value at suction surface of the airfoil. At 18° angle of attack, Multi-Element NACA 0015 has a high lift from the others because of the noticeable increment in pressure under the airfoil leading edge and its decrease at upper surface Figure 10(d). Drag reduction as well as great improvement of the performance of the airfoil.

Figure 10. Contour results for static pressure over Standard NACA 0015 symmetric airfoil and three geometry modifications using SST turbulence model at velocity of 25m/s.
As shown in contour results for velocity magnitude Figure 11, at 0° AOA, on the nose of the leading edge for all models, the point of flow stagnation where the flow velocity close to zero. This point moves a little to the trailing edge under the lower surface when AOA increase. The velocity for all models at the suction surface was much greater (the fluid accelerates) from the velocity at the pressure surface (an increase of static pressure) when the angle of attack increased.

![Figure 11](image)

**Figure 11.** Contour results for velocity magnitude over Standard NACA 0015 symmetric airfoil and three geometry modifications using SST turbulence model at velocity of 25m/s.
Compared to other models, at the same angle mentioned previously, the contour of velocity magnitude over Backward-facing step NACA 0015 airfoil were unsymmetrical for both upper and lower surfaces because of the asymmetric shape. At 6° AOA Figure 11(b and c), the separation point (momentum loss close to the wall in a boundary layer attempt to move downstream against increasing adverse pressure gradient) around the trailing edge moved toward the leading edge without reattachment flow for both of Bumps NACA 0015 and Backward-facing step NACA 0015 airfoil. For Multi-Element NACA 0015 Figure 11(d), the separation point appears clearly at 8° AOA. At 10° angle of attack, Figure 11(a), the higher velocity is in the suction surface compared to the pressure surface, the higher static force generated at the leading edge of Standard NACA 0015. For Multi-Element NACA 0015 airfoil at(12°-18°) AOA, the separated shear layer reattached to the wing near the jet flow channel edge and the separation bubble (between the separation point and the reattachment point) was formed due to the momentum energy given by the jet channels to flow Figure 11(d).

5. Conclusions
The effect of geometry modification on the aerodynamic properties of NACA 0015 aerofoil using CFD (at different attack angle from 0 to 18 degrees with Re=1.65x106) showed that:

- The modification of the geometry on the NACA 0015 airfoil has an effect on its aerodynamic characteristics in AOA (0°, 6°, 12°, 14°, and 18°) as in the modified Multi-Element NACA 0015 model.
- The lift coefficient for all models increased with an increased attack angle.
- For the model backward-facing step NACA0015 airfoil, the jet flow channel at the front of the step no noticeable effect on aerodynamic characteristics has been noticed except for the value of lift coefficient at AOA 14° compared with Standard NACA 0015 airfoil.
- For the model Bumps NACA0015 airfoil, the Bumps at the front of the airfoil did not have a noticeable effect on aerodynamic characteristics except for the value of lift coefficient at AOA 14° compared with Standard NACA 0015 airfoil.
- Backward-facing step NACA0015 airfoil more efficient when taking off and landing the plane compared to Standard NACA 0015 airfoil.
- The jet flow channels, passive flow control, at the front of the leading edge of the Multi-Element NACA 0015 model have an active role in improving lift coefficient.

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