

Design & Analysis of Natural Laminar Flow Supercritical Aerofoil for Increasing L/D Ratio Using Gurney Flap

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ABSTRACT: Analysis on supercritical aerofoils are concentrated more on the laminar flow agglutination over the suction surface of aerofoil. For this, gurney flap is embedded over the trailing edge of aerofoil. Due to this, wake stabilization occurs which fixes the laminar flow over the suction side and thus shifts the shock. This project work deals with NLF 0416 supercritical aerofoil for subsonic conditions. i.e., at Reynolds number $1E+06$. Analysis is based on computational fluid dynamics (CFD) using ANSYS FLUENT, where $k-\omega$ (SST) equation is used to solve the model and validated with the experimental results. The aerofoil is optimized by adding gurney flap of 2% chord and thickness 0.75mm, normal to the cusp trailing edge. The performance of the aerofoil is evaluated for 1° to 12° angle of attack under subsonic Mach number. Due to gurney flap, there is a high pressure on the lower side of the aerofoil which increases the lift to drag ratio. This paper concludes that lift to drag ratio of the gurney flap aerofoil is better than the NLF supercritical aerofoil.

KEYWORDS: NLF Aerofoil, Gurney flap, Supercritical aerofoil, Laminar flow

I. INTRODUCTION

Supercritical aerofoils are the aerofoils having flattened surface area at the upper side of the aerofoil and curved shape called cusp edge at the trailing edge surface of the aerofoil. Nowadays the researches are focused on the supercritical aerofoils because of their ability of getting laminar flow naturally. To reduce boundary layer separation and to increase laminar flow region, the method of Gurney flap is carried out. Gurney flap is the flap of small L-section with less thickness attached over the trailing part at 90 degrees, first this flap is used by Gurney for racing cars. He used it for negative lift formation on cars to get more road contact for the racing cars especially it was helped in turning the roads. Later, it was adapted for aerofoils. The length and height of the Gurney flaps were based on the chord percentage of aerofoils. Y.C.Li et al. were investigated gurney flaps of different heights on supercritical aerofoil, in that 2%c Gurney flap is suitable for supercritical aerofoils. Hence for the project NLF 0416 aerofoil is taken because of its laminar flow property and 2%c of Gurney is selected for analysis and the project is followed.

II. RELATED WORK

Y.C. Li et al. (2007), In this paper gurney flap is experimentally analysed with the aerofoil, Four Gurney flaps of different flap heights $h = 0.5\%$, 1.0% , 1.5% and 2.0% chord length, were tested. The results showed that, in comparison with the normal aerofoil, the Gurney flapped aerofoil had better performance than normal aerofoil. When the Gurney flaps were used, the lift coefficient, maximum lift coefficient and the maximum lift-to-drag ratio of supercritical aerofoil were highly improved. The lift-increasing effects of Gurney flaps is mostly used for its ability of shifting the shock on the suction surface.

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

Yufei Zhang et al. (2015), In this paper supercritical natural laminar flow aerofoil optimization takes place which is based on Genetic Algorithm and Computational Fluid Dynamics is analysed. Constraints on pressure distribution are applied to gain appropriate flow field in addition to the L/D performance. Specified favourable pressure gradient constraints are used to improve the expected laminar flow area. Objective of optimization is set to weaken the shock wave and minimize the pressure drag. Using natural transition process NLF aerofoil optimization carried out.

D. W. Bechert et al. (2000), In this paper, Miniflaps called as Gurney flaps are small extensions attached at the trailing edge of an aerofoil which held at normal angle of 90°degrees. The trailing edge shape is the important factor for lift. The pressure at the lower side of the aerofoil is higher than the pressure at the upstream section of the aerofoil because of the Gurney flap attachment.

David Jeffrey et al. (2000), In this paper Gurney flap of single part attached with the end of trailing edge, The vortex wakes provides an increase of flow in the suction area, which is nearer to the downstream side of the Gurney flap and is the cause of the recirculation region layer formation. The Gurney flap, therefore, creates a pressure variation at the trailing edge, and its boundaries hence the circular wakes will create the circulation for flow stability over the aerofoil.

III. AEROFOIL VALIDATION

Modelling

The aerofoil coordinates for the NLF 0416 aerofoil is imported into CATIA. The points are then joined by a spline to create the profile of the aerofoil. Before importing aerofoil coordinates in CATIA, coordinate points are scaled to the required dimensions (1000mm) in excel sheet.

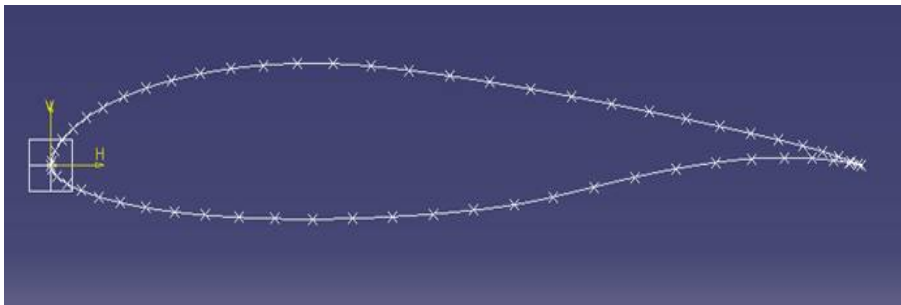


Fig 1. Cad Model of NLF 0416 2D-Aerofoil

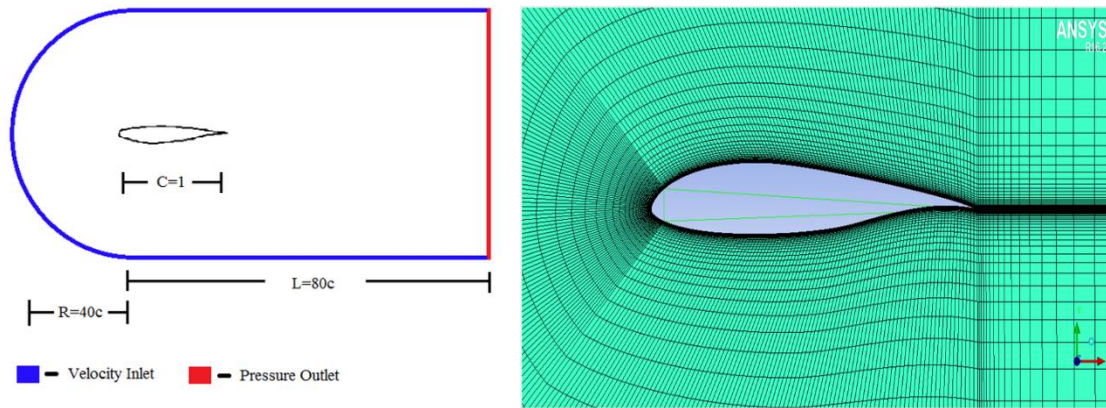
Meshing

The next step involved in this project is CFD meshing. The software used for the aerofoil meshing is ANSYS ICEM CFD now import the cad file to ICEM CFD workbench. Input boundary conditions as velocity-inlet, pressure outlet in the domain and the aerofoil as wall. Hence, grid independency elements & nodes are 123018 & 122339.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016



(a) (b)

Fig 2. (a) Computational domain for NLF 0416 aerofoil (b) NLF 0416 aerofoil mesh (Close-up view)

Here the Hexa meshing is carried out, After meshing done, transfer the meshed file to the FLUENT software for analysis.

Analysis of 2d-nlf 0416 aerofoil

Input the boundary conditions in the inlet, outlet, velocity magnitude and direction in order to analyse. Set the velocity components at the inlet according to angle of attacks, and the gauge pressure at the inlet & outlet as zero. Consider the aerofoil model as a wall so that no flows can pass through the aerofoil. Turbulence intensity is 0.1% and the turbulent viscosity ratio is 0.1 times of dynamic viscosity. Velocity given is 14.61m/s for setting $Re = 1e^6$, since the model having 1m length. For the model part, K- ω (Shear Stress Transport) equation is used to perform the analysis on 2-D NLF 0416 aerofoil and this aerofoil is further remodelled for optimization. Before remodelling normal analysis would be carried out for validation purpose.

Table 1. Boundary Conditions

Inlet Velocity		14.61 m/s
Reynolds number		1.0×10^6
For 12°	x-component	14.2907364467
	y-component	3.037589802847
Gauge pressure at the inlet and outlet		0
Aerofoil type		Model
Domain		C- Mesh

The above table (1) describes the boundary conditions included for the analysis of NLF aerofoil at 12° of Angle of Attack (AOA) with its x & y velocity components.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

Table 2. Values of 0416 aerofoil from experimental analysis⁽²⁾

Angle of Attack (α)	Reynolds Number	Coefficient of Lift (C_l)	Coefficient of Drag (C_d)
12°	1.0x10 ⁶	1.55	0.023354

The above table (2) describes the experimental values of NLF 0416 aerofoil which is referred from paper⁽²⁾ for the validation purpose.

Table 3. Validated CFD values for 0416 aerofoil

Angle of Attack (α)	Reynolds Number	Coefficient of Lift (C_l)	Coefficient of Drag (C_d)
12°	1.0x10 ⁶	1.5461	0.025354

The above table (3) describes the analysed CFD values of NLF 0416 aerofoil and hence the same analysis procedure is followed for the remodelled Gurney NLF 0416 aerofoil.

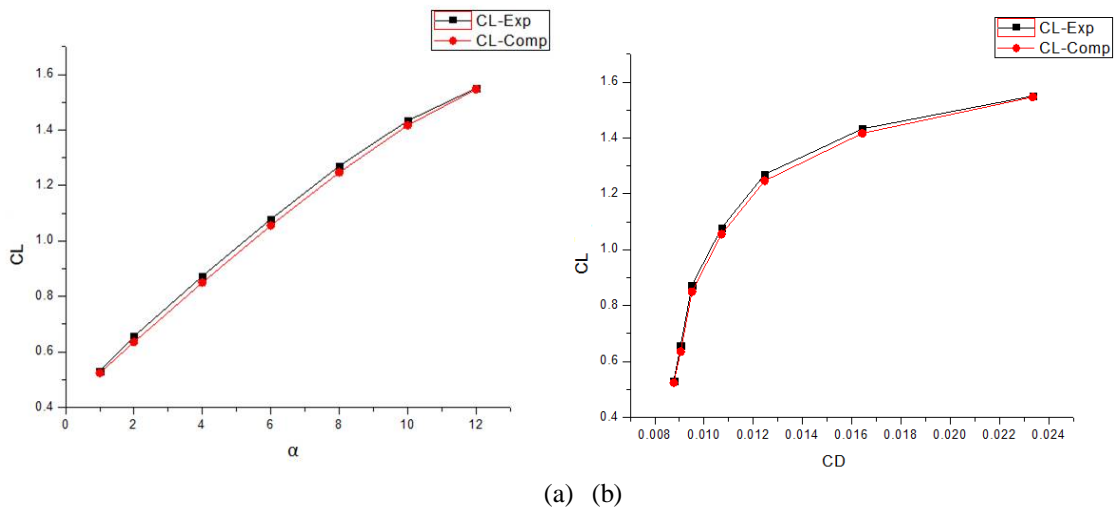


Fig 4. (a) Lift coefficient (b) Lift/drag polar

From the above figure (a) the lift coefficient which describes the graph of α (angle of attack) Vs C_L (coefficient of lift) varies from 1° to 12° of angle of attack for both experimental and computational analysis.

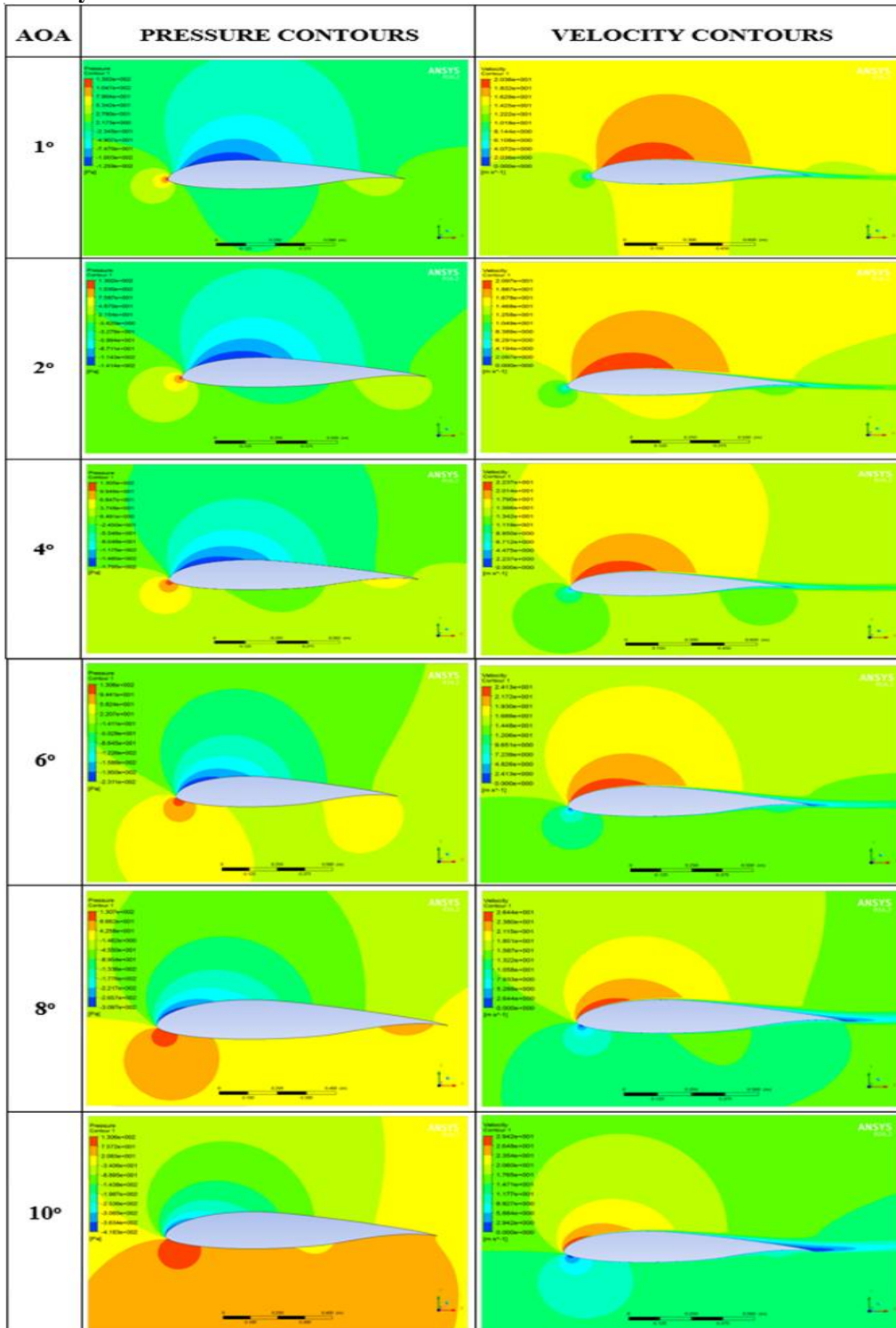
From the above figure (b) the lift/drag polar which describes the C_D (coefficient of drag) Vs C_L (coefficient of lift) varies from 1° to 12° of angle of attack for both experimental and computational analysis.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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Pressure & Velocity Contours at Re No. $1e^6$ for NLF 0416 aerofoil



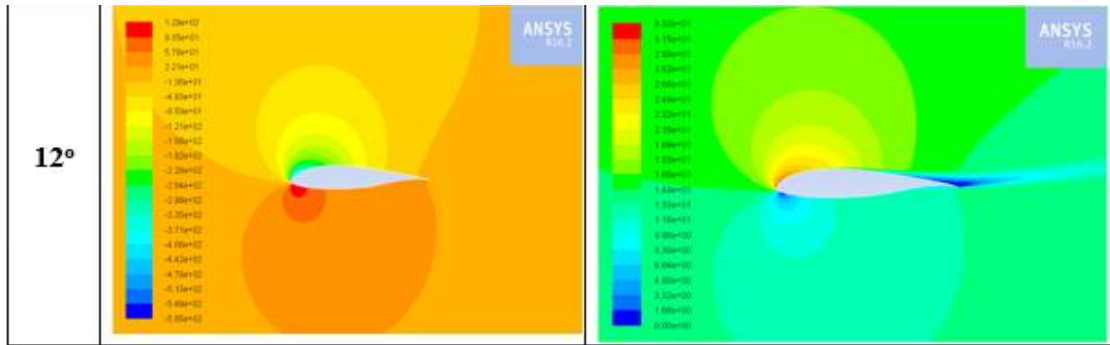


Fig 5. Pressure & Velocity Contours of NLF 0416 aerofoil

From the above Fig 5, we can see the pressure & velocity contours of NLF aerofoil with high pressure to low pressure & high velocity to low velocity is predicted by the scale markings from red to blue. This table ranges from 1° to 12° of angle of attacks. This analysis is done with $1e^6$ Reynolds number and hence the validation is carried out.

IV. AEROFOIL OPTIMIZATION BY GURNEY FLAP

Modelling

Import the aerofoil created earlier i.e., NLF 0416 aerofoil. Remodel the aerofoil by adding gurney flap, which is 2% c of aerofoil with thickness 0.75mm. The Gurney flap is normal to the pressure side of trailing edge cusp. Scale the aerofoil to the required dimensions (1000mm).



Fig 6. Cad Model of NLF 0416 Gurney Aerofoil

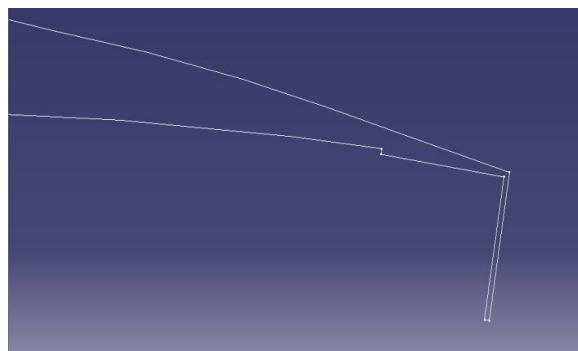


Fig 7. Gurney flap close-up view at the trailing edge of the aerofoil

Meshing

The next step involved in this project is CFD meshing. The software used for the aerofoil meshing is ANSYS ICEM CFD now import the cad file to ICEM CFD workbench. Input boundary conditions as velocity-inlet, pressure outlet in the domain and the aerofoil as wall. Hence, grid independency elements & nodes are 123018 & 122339.

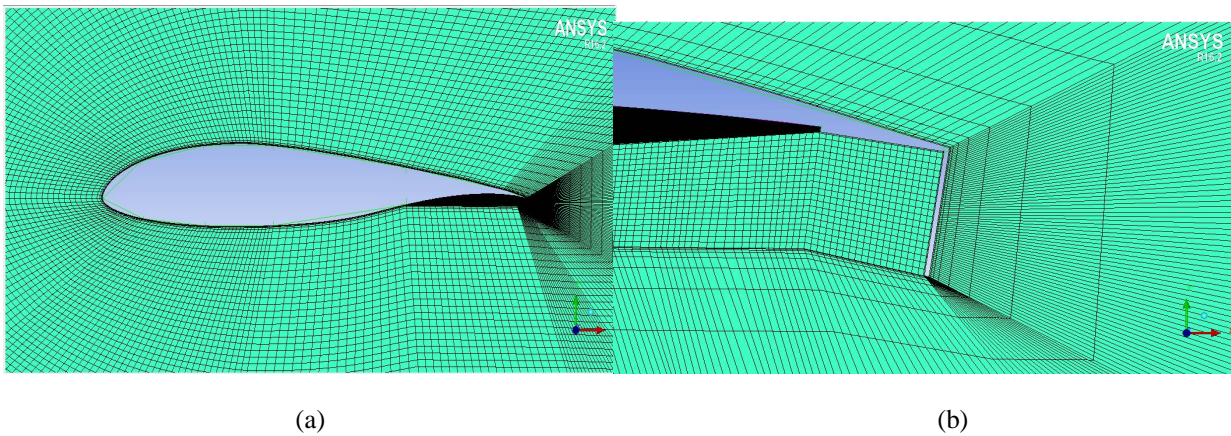


Fig 8. (a) Mesh of NLF 0416 aerofoil with Gurney flap (b) Mesh of NLF 0416 aerofoil with Gurney flap (Close-up view of flap)

Here the Hexa meshing is carried out, After meshing done, transfer the meshed file to the FLUENT software for analysis.

Analysis of 2d-nlf 0416 aerofoil

Input the boundary conditions in the inlet, outlet, velocity magnitude and direction in order to analyse. Set the velocity components at the inlet according to angle of attacks, and the gauge pressure at the inlet & outlet as zero. Consider the aerofoil model as a wall so that no flows can passes through the aerofoil. Turbulence intensity is 0.1% and the turbulent viscosity ratio is 0.1 times of dynamic viscosity. Velocity given is 14.61 m/s for setting $Re = 1e^6$, since the model having 1m length. For the model part, K- ω (Shear Stress Transport) equation is used to perform the analysis on 2-D NLF 0416 aerofoil with gurney flap.

Table 4. Boundary Conditions

Inlet Velocity		14.61 m/s
Reynolds number		1.0×10^6
For 12°	x-component	14.2907364467
	y-component	3.037589802847
Gauge pressure at the inlet and outlet		0
Aerofoil type		Model
Domain		C- Mesh

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

The above table (4) describes the boundary conditions included for the analysis of NLF aerofoil with Gurney flap at 12° of Angle of Attack (AOA) with its x & y velocity components.

Table 5. CFD values of NLF 0416 aerofoil

Angle of Attack (α)	Reynolds Number	Coefficient of Lift (C_L)	Coefficient of Drag (C_D)
12°	1.0x10 ⁶	1.5461	0.025354

The above table (5) describes the analysed CFD values C_L and C_D of NLF 0416 aerofoil.

Table 6. CFD values of NLF 0416 aerofoil with Gurney flap

Angle of Attack (α)	Reynolds Number	Coefficient of Lift (C_L)	Coefficient of Drag (C_D)
12°	1.0x10 ⁶	1.832	0.027653

The above table (6) describes the analysed CFD values of NLF 0416 aerofoil with Gurney flap and hence there is an increase of lift to drag ratio.

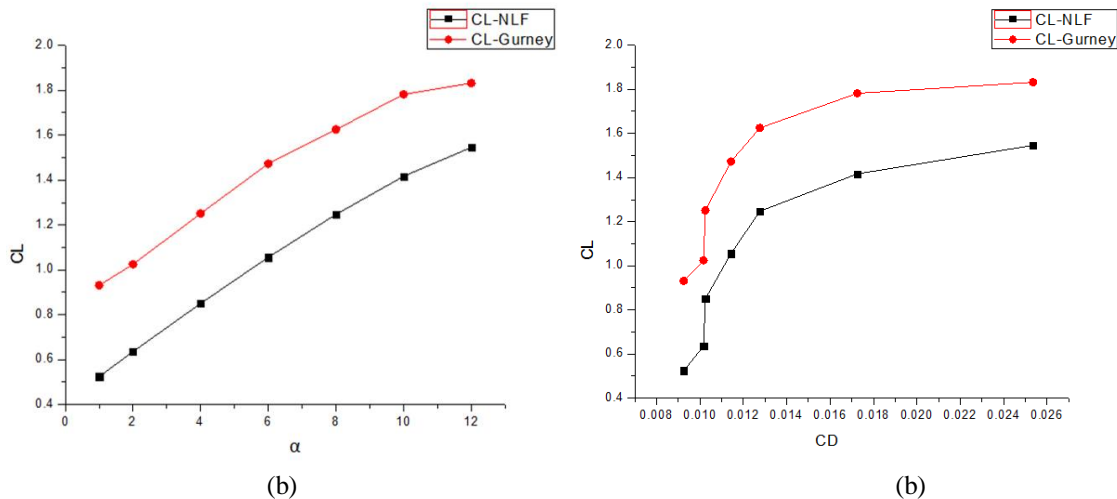


Fig 9. (a) Lift coefficient (b) Lift/drag polar

From the above figure (a) the lift coefficient which describes the graph of α (angle of attack) Vs C_L (coefficient of lift) varies from 1° to 12° of angle of attack for NLF aerofoil and Gurney flap aerofoil.

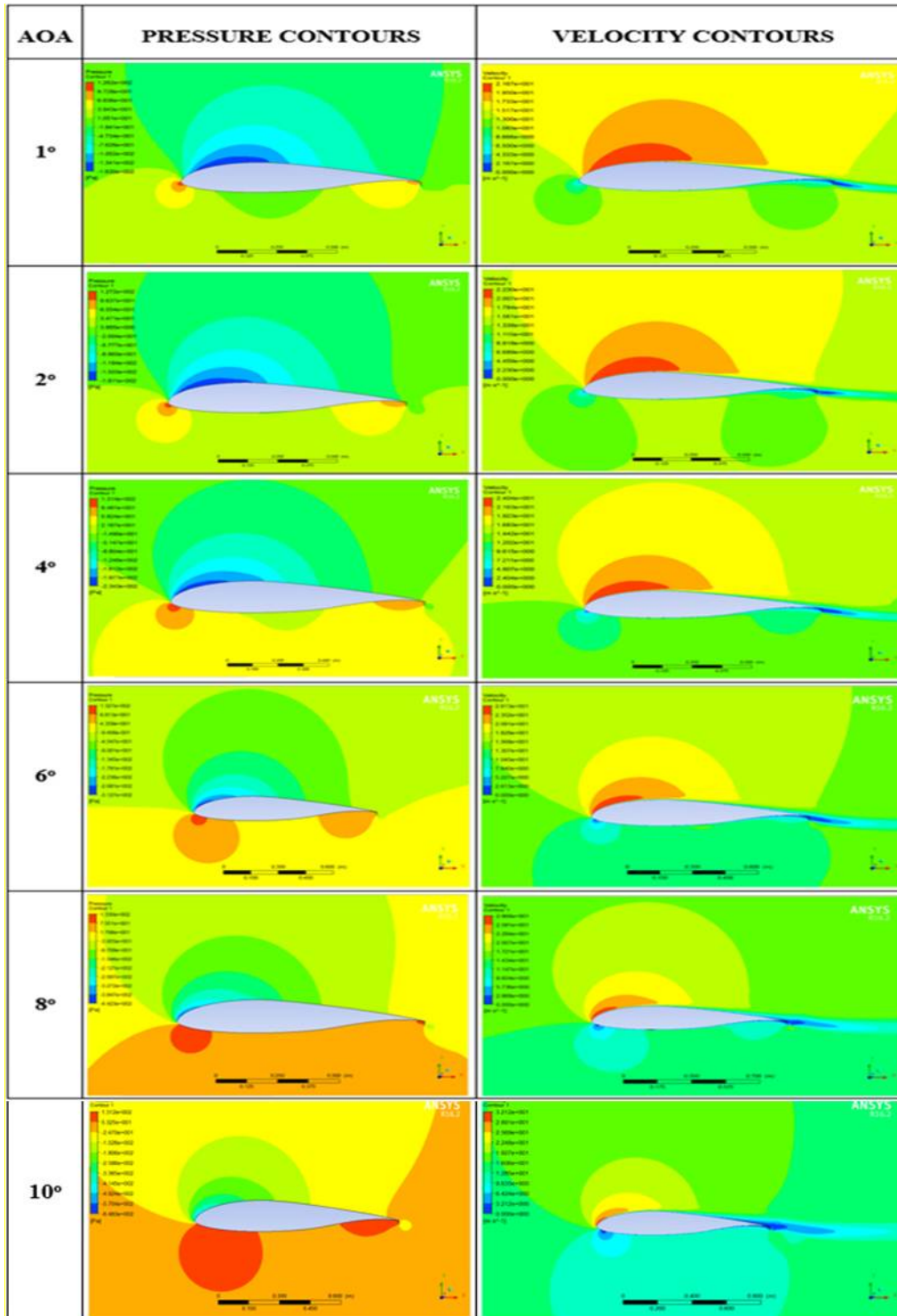
From the above figure (b) the lift/drag polar which describes the C_D (coefficient of drag) Vs C_L (coefficient of lift) varies from 1° to 12° of angle of attack for NLF aerofoil and Gurney flap aerofoil.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

Pressure & velocity contours at Re No. 1.0×10^6 for NLF 0416 aerofoil with Gurney flap



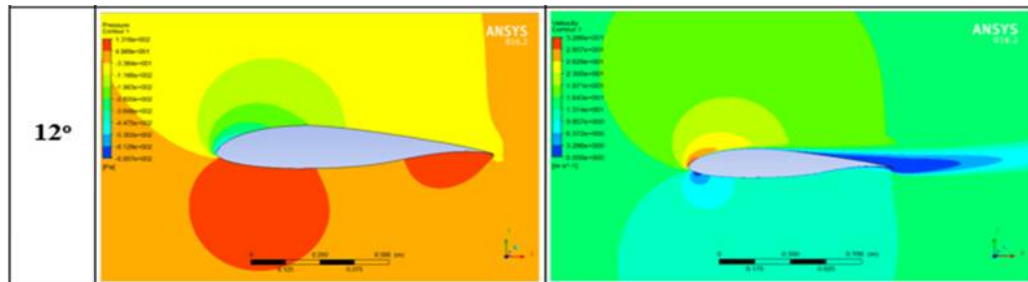


Fig 10. Pressure & Velocity contours of NLF aerofoil with Gurney flap

From the above Fig 10. pressure & velocity contours, we can see the performance of the gurney flap, it creates the wakes at the trailing edge, those circular wakes fixes the laminar flow over the suction side of the aerofoil, due to vortex creation shock wave shifting occurs at the suction side of the gurney aerofoil than the normal supercritical aerofoil and hence it increases the higher pressure at the pressure side of the aerofoil, due to higher pressure at the pressure side of the aerofoil, there is increase in lift to drag ratio on the NLF supercritical aerofoil.

V. CONCLUSION

CFD analysis predicted the performance of gurney flap especially for NLF supercritical aerofoil. Due to Gurney flap, circular wakes occurs at the trailing edge which tethers the laminar flow over the suction side of aerofoil. This shifts the shock formation over the upper layer of aerofoil and also increases the pressure at the downstream of the aerofoil. Hence the lift to drag ratio of aerofoil getting improved. When, we compare the results of NLF aerofoil with Gurney flapped NLF aerofoil, the Gurney aerofoil has 8.4% maximum L/D ratio than NLF aerofoil.

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