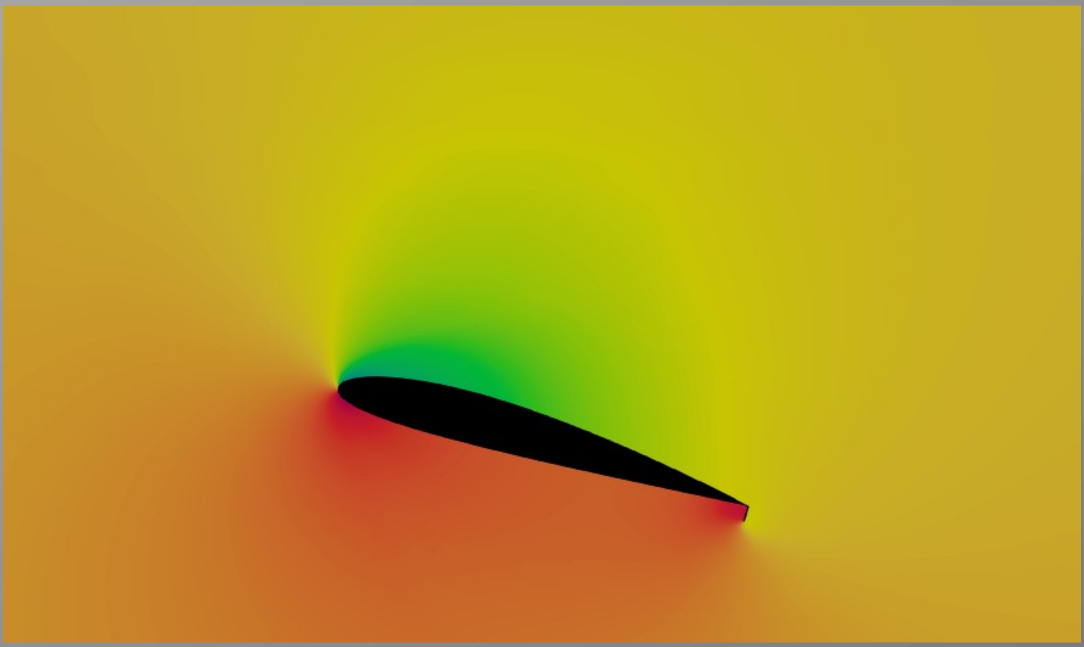
Investigating the Effectiveness of Gurney Flaps for NACA 2412 Airfoil at High Angle of Attack



By-
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Introduction

The NACA 2412 airfoil, widely recognized for its versatility in aerodynamic applications, serves as the foundation for investigating the impact of trailing-edge modifications. The Gurney flap, a small yet effective device, has been employed in various fields to enhance lift and improve flow control. This study focuses on analysing the aerodynamic performance of the NACA 2412 airfoil equipped with Gurney flaps of varying heights at a constant 16° angle of attack in moderate Reynolds number flow.

Objectives

1. To quantify the aerodynamic performance of the NACA 2412 airfoil with and without the Gurney flap.

2. To investigate the influence of flap height on lift and drag characteristics.

3. To identify trends and behaviour of flow separation and pressure distribution, attributed to variations in flap geometry.

CAD Modelling

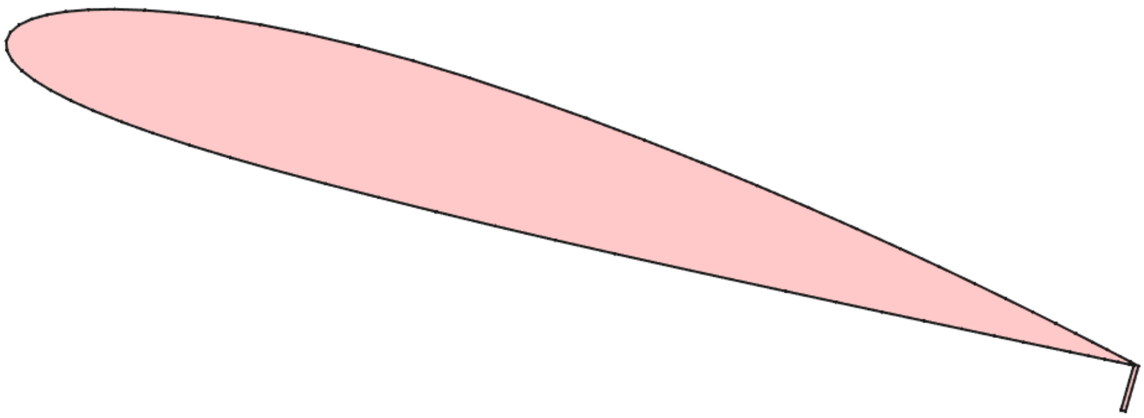

Figure 1 NACA 2412 airfoil with Gurney Flap of 4%c height.

The airfoil section was generated in *OpenVSP* and then imported in *FreeCAD* to make the simulation domain. The chord length is 1 m. Three additional models were made with Gurney flaps of height 1%, 2% and 4% of the chord length. The flaps were modelled perpendicular to the chord line and all of them have the same width.

In this work, c = chord-length

Flap height = GFx% = x%c = x% of chord-length

CFD Modelling and Simulation Setup

The CFD modelling and simulations were carried out on the *CfdOF* workbench of *FreeCAD*. Figure 2 shows the computational domain of the simulations. Different boundary conditions are labelled. The inlet is located at 3c from the leading edge while the outlet at 8c. The total height of the domain is 5c. The table below enlists all the parameters used for simulation setup. Inflation layers were added on the airfoil surface to keep $y^+<1$.

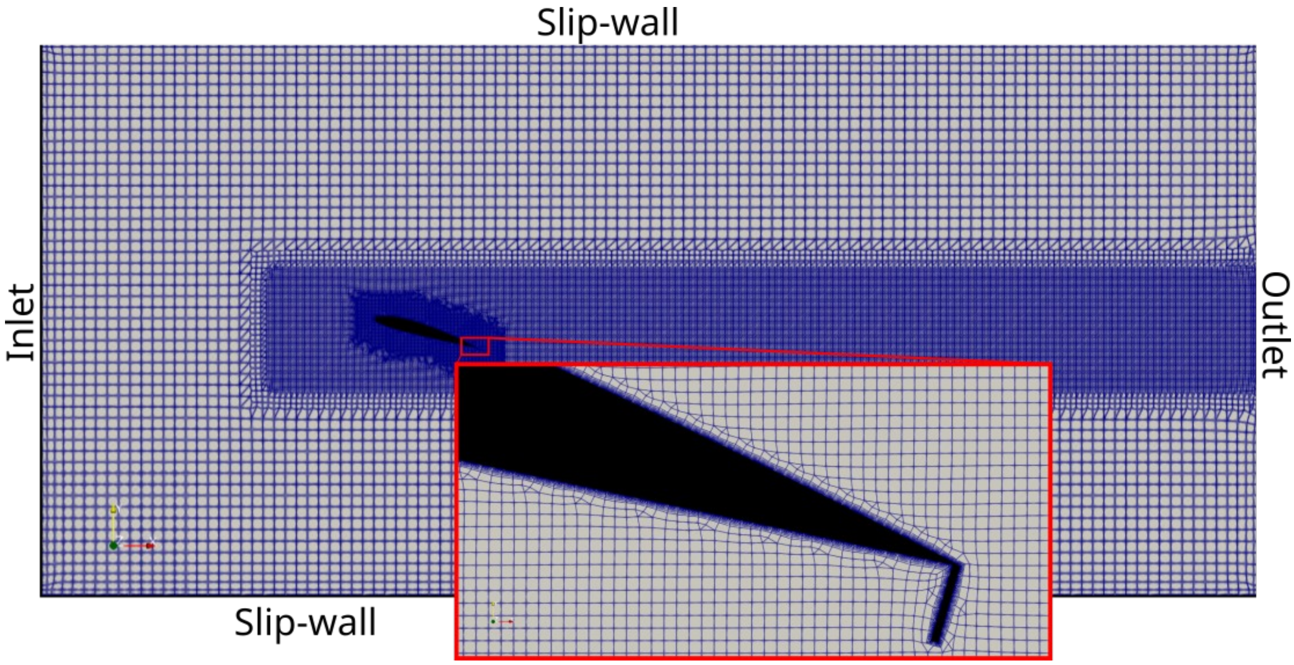

Figure 2 Meshed computational domain

Angle of attack (AoA)	16°
Inlet velocity [m/s]	6
Reynolds Number	400,000
Air kinematic viscosity [m^2/s]	0.000015
Air density [kg/m^3]	1.2
Time dependency	Steady-state
Turbulence model	kOmegaSSTLM
No. of volume cells (different cases)	45.3k - 54k

Results and Discussion

Flow Streamlines and Velocity Vector Visualization:

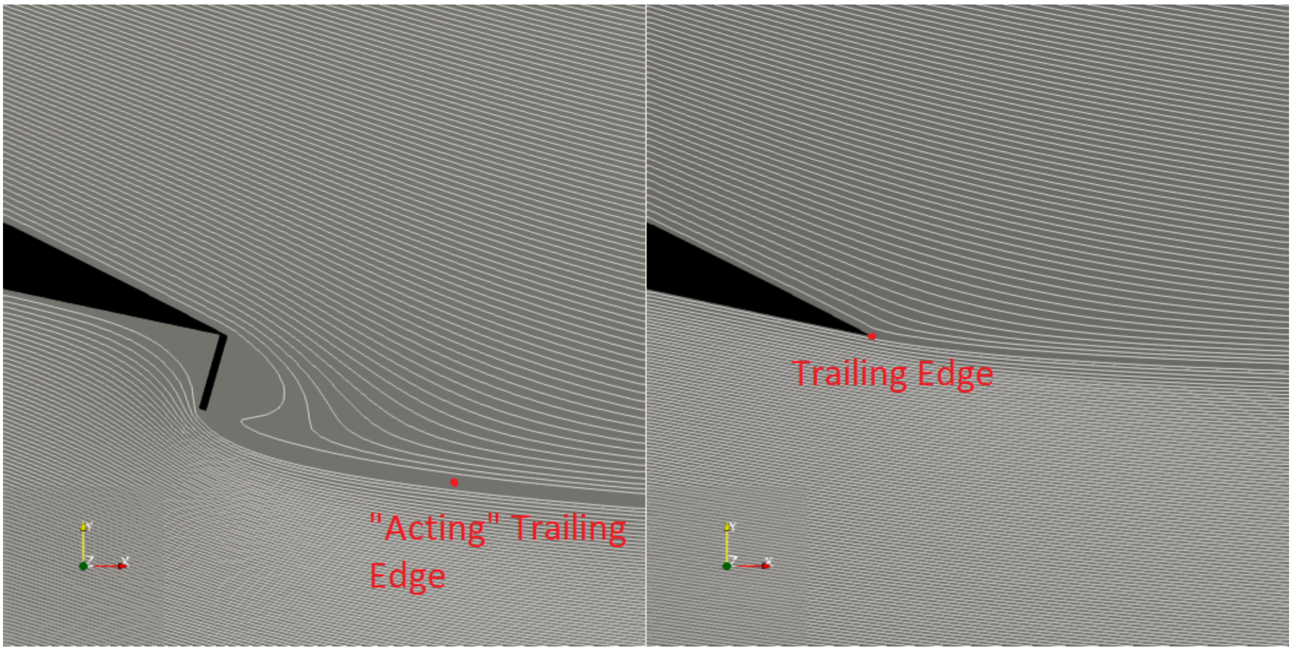

Figure 3 Flow streamlines with Gurney Flap (left) and without flap (right).

Figure 3 depicts the flow streamlines over the airfoil aft and wake region. Since the AoA is quite high i.e 16° and the Re is moderately low, the flow seems to be slightly separated near the trailing edge. But overall the Kutta condition still applies at the trailing edge of the normal airfoil. The Gurney flap reshapes the sharp trailing edge into a bluff-body like structure leading to the formation of a pair of counter-rotating vortices in the wake of the airfoil, as can be seen in figure 4.

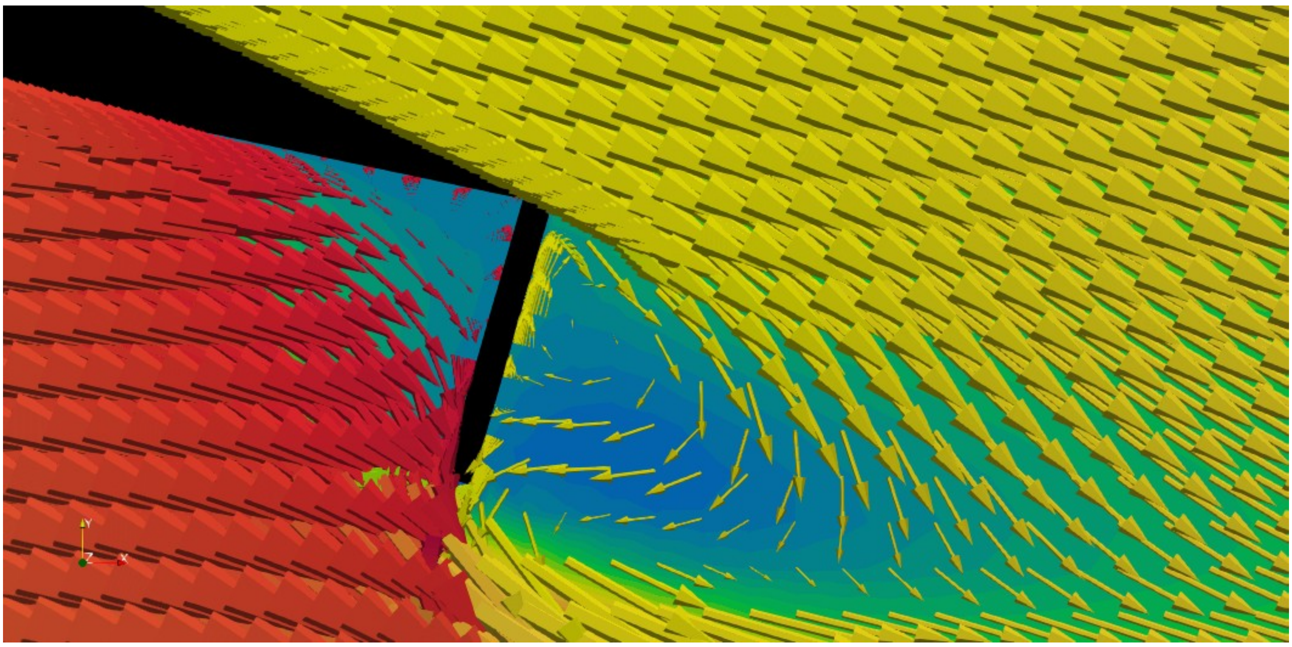

Figure 4 Velocity vector field for the airfoil with the flap.

The presence of these wake vortices shifts the Kutta condition enforcement point downstream, as seen in figure 3. This new point effectively acts as the new trailing edge for the airfoil and causes a virtual increase in the AoA, airfoil camber and even chord-length. Not only the modified location of Kutta condition, but also the presence of vortices in the wake causes an increase in the circulation. All these effects combined together, enhances the lift generated by the airfoil at the same AoA, as is evaluated in the later section.

Velocity and Pressure Contour Plots:

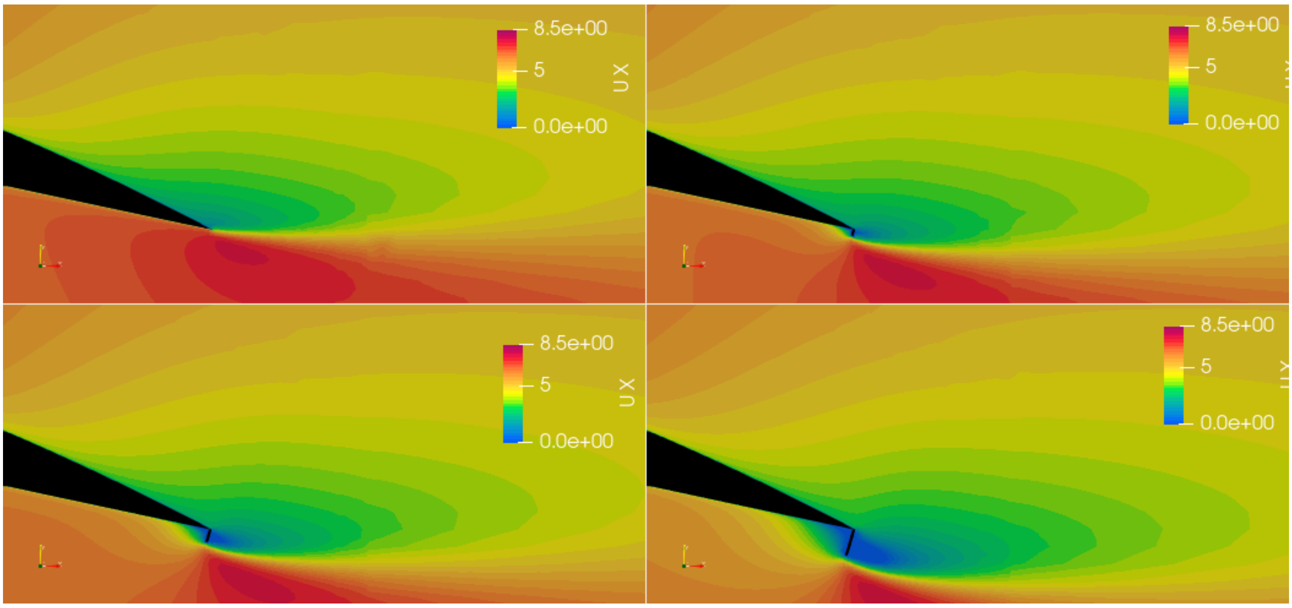

Figure 5 Velocity contours for all cases.

In figure 5 above, velocity contours are shown. For the given high AoA and moderate Re, the flow is at the onset of separation as is shown by the small blue area near the trailing edge for the original airfoil. Given the averaging nature of the RANS approach, the flow separation is likely underestimated for the given flow conditions.

The Gurney flap pulls the wake bubble downstream and makes it slightly bigger. As the height of the flap is increased, the bubble size increases and shifts progressively towards the immediate downstream of the flap, forming the vortices. This lowers the base-pressure (static pressure in the wake region immediately downstream of the trailing edge or the flap) causing higher suction on the upper surface and encouraging reattachment of the flow at high AoA (as is seen in figure 5), thus preserving lift.

The pressure contours shown in figure 6, demonstrates that the Gurney flap modifies the chord-wise pressure distribution on both the suction-side and pressure-side of the airfoil. The suction peak and extent is increased on the upper surface while the presence of a circulating stagnation region in front of the flap causes the pressure increase in that area of the lower surface.

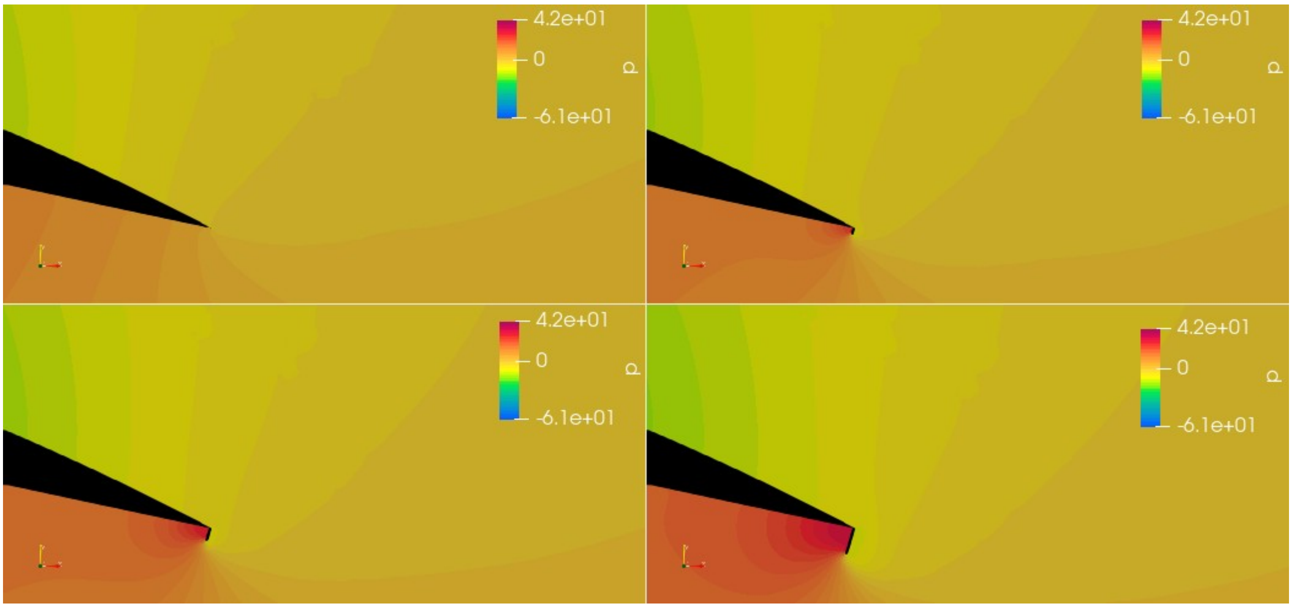

Figure 6 Pressure contours for all cases.

The chord-wise pressure distribution plots shown in figure 7, clearly shows the effect of the Gurney flaps. The effects become stronger as the height of the flap increases. As the flap height increases, the high pressure region area also grows bigger. These increased pressure differences between the upper and the lower side, ultimately causes an increase in the airfoil lift.

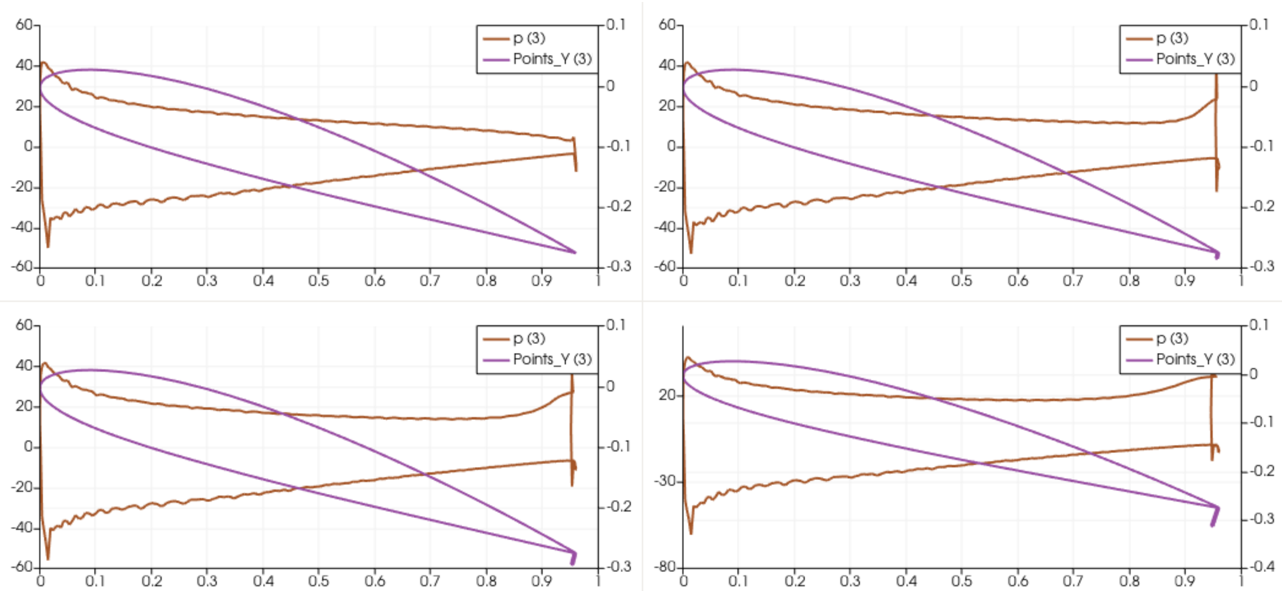

Figure 7 Chord-wise pressure distribution for all cases. Pressure values on left axis.

Lift, Drag and Efficiency:

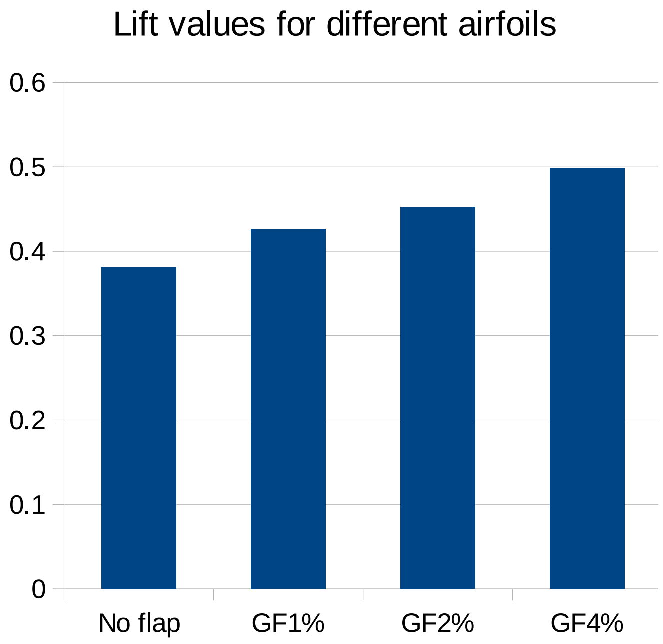

Figure 8 Lift values for all cases.

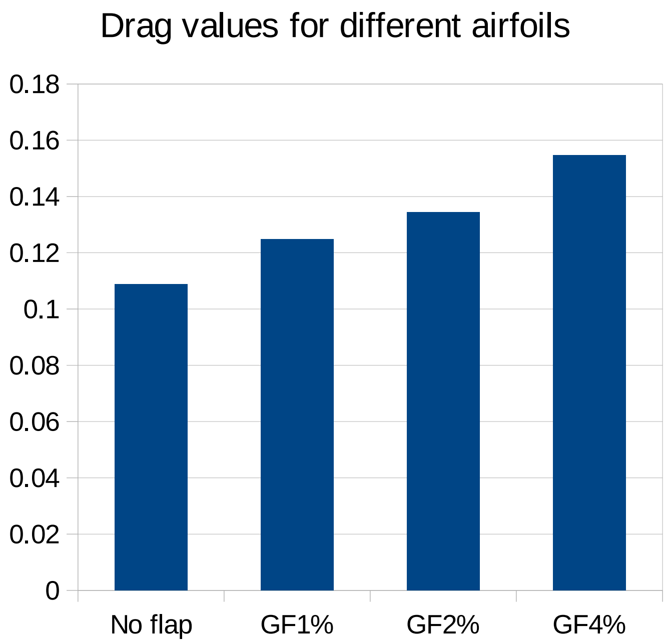

Figure 9 Drag values for all cases.

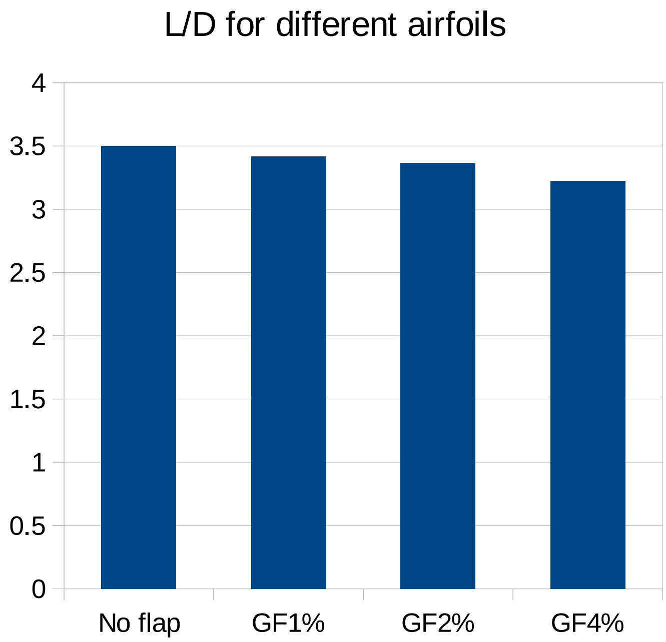

Figure 10 L/D values for all cases.

Figures 8 and 9 shows respectively the lift and drag values for different Gurney flap heights. Both lift and drag values show a direct proportionality relation with the flap height. However, as shown in figure 10, the L/D ratio decreases with the increase in flap height. While the blunt body effect of the flap shows a positive effect on the lift characteristics of the airfoil, the wake created by it increases the pressure drag of the airfoil.

	Lift	**Drag**	**L/D**	**Incremental Lift Change**	**Incremental Drag Change**	**Incremental L/D Change**	**Total Lift Change**	**Total Drag Change**	**Total L/D Change**
No flap	0.38114	0.10888	3.5	-	-	-	-	-	-
GF1%	0.42655	0.12485	3.4164	11.91%	14.67%	-2.39%	11.91%	14.67%	-2.39%
GF2%	0.45257	0.13438	3.3677	6.10%	7.63%	-1.43%	18.74%	23.42%	-3.78%
GF4%	0.4988	0.15467	3.2249	10.21%	15.10%	-4.24%	30.87%	42.06%	-7.86%

The table above presents the average of lift and drag of the last 200 iterations, for each flap height simulation. Both incremental percentage change and accumulated percentage change are calculated, as the flap height is successively increased from 1%c to 2%c to 4%c.

Results show that as the flap of 1%c height is added to the airfoil, the lift improves by ~12% with slightly more drag penalty than the lift, causing an overall decrease in L/D. As the flap height is increased to 2%c, the trend is same but the increment from 1%c values is not very high. When the height is increased to 4%c, the drag values shows a significantly higher jump compared to the lift values. Thus a large reduction can be seen in L/D values.

If the objective is to maximise the lift, then with a small penalty of ~1.4% on L/D, the GF2% could be chosen over the GF1% to get a total lift improve of 18.7%.

Chord-wise Lift and Drag Distribution:

Figure 11 shows the lift distributed along the chord. While there is no perceptible change on the upper surface, the effect of the Gurney flap is clearly visible on the lift values of the lower surface, becoming more stronger as the flap height increases.

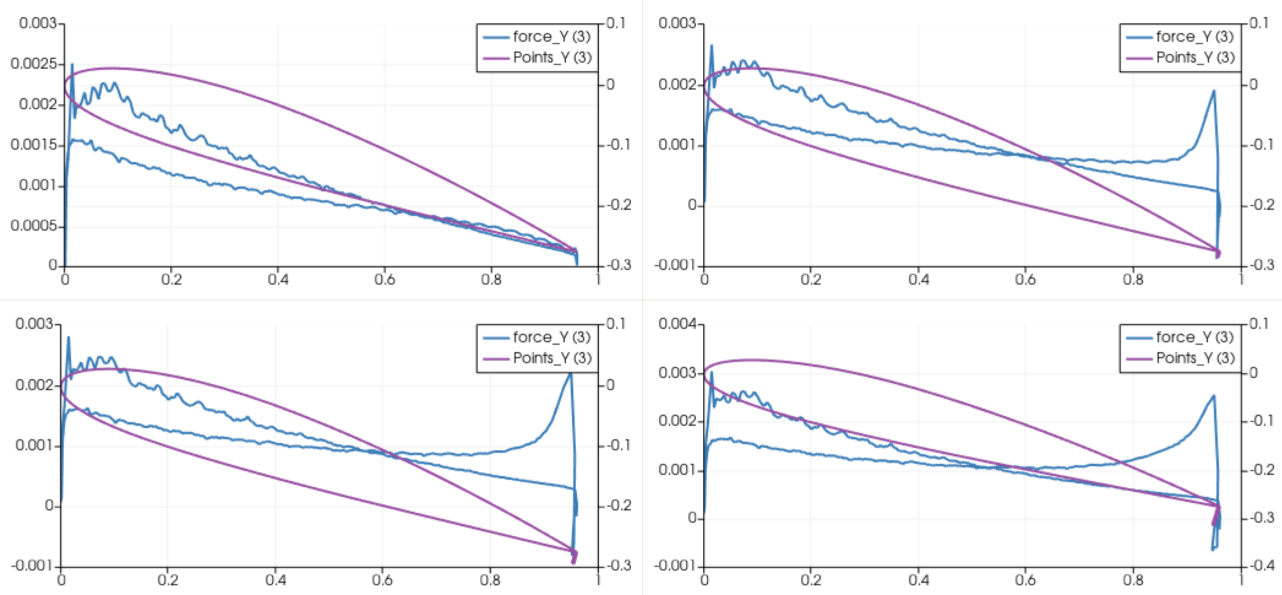

Figure 11 Chord-wise lift distribution for all cases. Lift values on left axis.

Figure 12 shows the drag distribution along chord. The trend seems to be similar for both the surfaces, except for the sharp rise at the trailing edge when the flap is present. The sharp rise can be attributed to the pressure drag increase due to the flap.

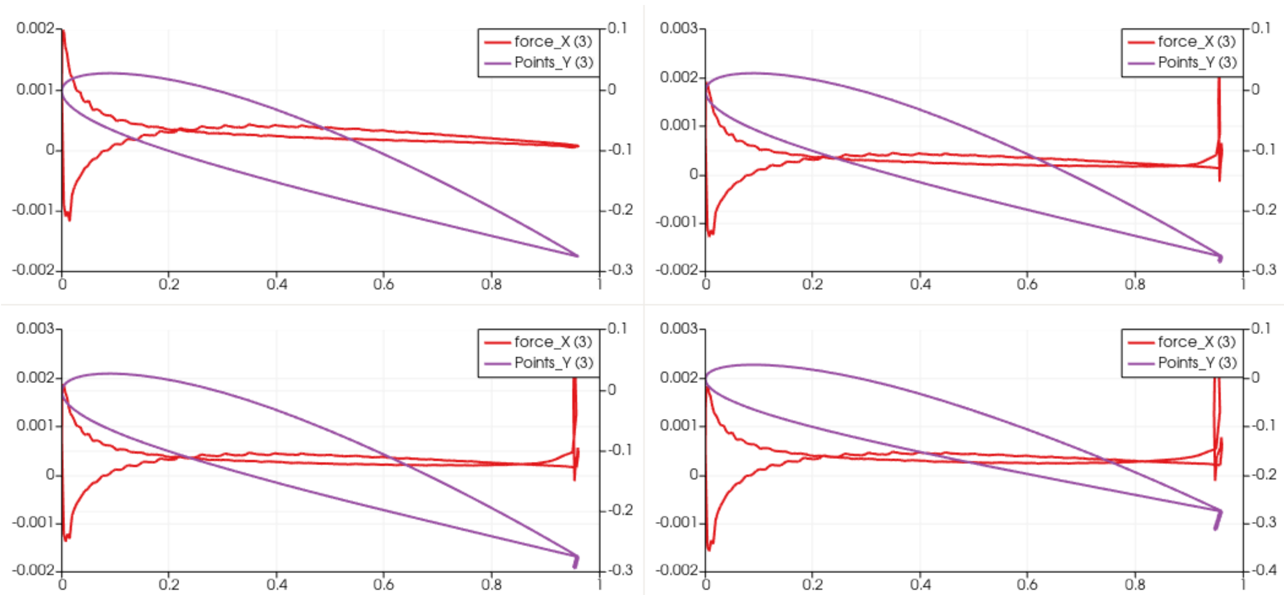

Figure 12 Chord-wise drag distribution for all cases. Drag values on left axis.

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