Analysis of low Reynolds number flow past Gurney flap

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Abstract: *The trailing edge region of a single element wing fitted with Gurney flap at low Reynolds numbers has been studied.*

The complex flow separation phenomena on airfoils with Gurney flap at low Reynolds numbers have some specific features as the separation on set and reattachment locations and the streamline pattern.

A detailed study shows the influence of the size of flap on the stall behaviour and on the aerodynamic characteristics.

Key Words: Low Reynolds number,Gurney Flap, flow control, Coanda jet technique.

1. INTRODUCTION

The Gurney flap , first introduced by Liebeck [1], is a mechanically simple device consisting of a small tab attached perpendicular to the lower surface of the airfoil in the vecinity of the trailing edge, with a height that can vary from 1% to 5% of the airfoil chord.

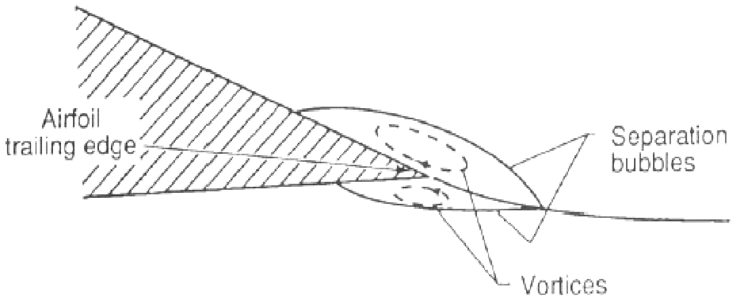
The original Gourney flap was installed on the trailing edge of a rectangular race car wing.

Liebeck's results showed a significant increment in lift compared to the baseline airfoil. In general , the drag of the airfoil increases with the addition of the Gurney flap , but often the percentage increase in lift is greater, resulting in an increased lift-to-drag ratio and therefor a better efficiency and performance.

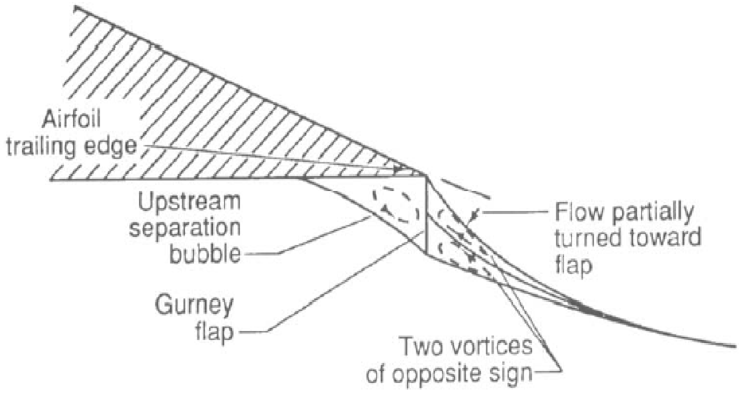
Liebeck sugested that the optimal Gourney flap height should be on the order of 1-2 percent of the airfoil chord.

The increase in lift comes primarily from the efective increased camber on the lower surface without adversaly disturbing the upper surface flow.

Liebeck hypothesized that a flow structure downstream of a Gurney flap has dual recirculation regions as shown in Fig. 1.



a) Conventional airfoil at moderate C_L



b) Hypothesized flow near Gurney flap

Figure 1. Trailing edge flow fields

An interesting feature of the hypothesized flow is the significant turning of the upper-surface trailing edge flow, in terms of producing both increased lift due to turning and reduced form drag due to the longer region of attached flow near the trailing edge. Experiments [2], and numerical studies [3], have supported his hypothesis.

Due to its simple geometry, construction of the Gourney flap is easely accomplished and, weight is low.

In the present work, the Gourney flap is used to enhance lift generation. A special interest has recently been devoted to the aerodynamics of the lift systems at low and very low Reynolds numbers.

This interest is driven by various applications ranging from domestic windmills to special millitary aircraft and unmanned aerial vehiciles (UAV), which are made possible by the recent progress in micro-mechatronics (micro-electro-mechanical systems). Very small aircrafts called micro-air-vehicules (MAV) can operate in various indoors or outdoors environments including tunnels, desert, and jungle [4,5].

Successful design studies for MAV have been presented by different authors such as Grasmeyer and Kennon [6], Morris and Holden [7], and two recent computational studies has been presented by Shyyetal [8] and Mateescu and Abdo [9].

For a small size micro-air-vehiciles flying at very low speed, the Reynolds number are as low as 1000 or even lower.

The airfoil aerodynamics at very low Reynolds numbers between 400 and 6000 is dominated by viscous effects and flow separation phenomena, which is different from those of conventional aircraft.

This paper presents a study of the effects of varying Gourney flap size on the pressure distribution, lift and drag coefficients, and lift-to-drag ratio of airfoil.

In order to better understand the complex flow separation phnomena in the viscous flows past airfoils fitted with Gourney flap, at low Reynolds numbers, the onset of separation and reattachement locations, separation bubble breakdown stall, and the streamline pattern of the flow have also been calculated and discussed.

2. ON THE N-S SOLVER

The Navier-Stokes and continuity equations for the incompressible flow past the airfoil fitted with Gourney flap can be expressed in non-dimensional conservation form as:

$$\frac{\partial \vec{V}}{\partial t} + Q(\vec{V}, p) = 0 \ , \ \nabla \bullet \vec{V} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{1}$$

where $\vec{V} = \{u, v\}^T$ represents the vector of the dimensionless velocity components and $Q(\vec{V}, p)$, which includes the convective derivative, pressure and viscous terms,can be expressed in 2-D Cartesian coordinates in the form:

$$Q(\vec{V}, p) = \{Q_u(u,v,p), Q_v(u,v,p)\}^T \tag{2}$$

$$Q_u(u,v,p) = \frac{\partial(uu)}{\partial x} + \frac{\partial(vu)}{\partial y} + \frac{\partial p}{\partial x} - \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \tag{3a}$$

$$Q_v(u,v,p) = \frac{\partial(uv)}{\partial x} + \frac{\partial(uv)}{\partial y} + \frac{\partial p}{\partial y} - \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \tag{3b}$$

where p is the dimensionless pressure, nondimensionalized with respect to ρU_∞^2, and $\mathrm{Re} = cU_\infty / \nu$ is the Reynolds number bessed on the chord lenght (ρ and ν are the fluid density and kinematic viscosity).

For steady flows, $\frac{\partial \vec{V}}{\partial t} = 0$ in (1)

The equations are solved by the commercial code Fluent [10]. The nonlinear system of equation implies the segregated solver, thus is solved sequentially PRESTO and QUICK discretization schems are used for the continuity and the momentum equations respectively.

The PRESTO scheme uses the discret continuity balance for a staggered control volume about the face to compute the staggered pressure.QUICK type schemes are based on the weighted average of second-order-upwind and central interpolations of the variable.

As the code solves the incompressible flow equations, no equation of state exist for the pressure, and a SIMPLE algorithm is used to enforce pressure-velocity coupling.

3. RESULTS

Surface Pressures. The pressure coefficient distributions on NACA 4404 airfoil for Reynolds number Re=1000 and for Gourney flaps fitted to the trailing edge of airfoil are presented in Fig.2.

At unstalled incidences the loadings show that the Gourney flaps increase the overall loadings, as well as maximum suction.

There are increases in the trailing edge suction and the trailing edge pressure resulting in a finit pressure difference at the trailing edge of the airfoil.

This is caused by the upperstream face where Gurney flap is decelerating the flow.

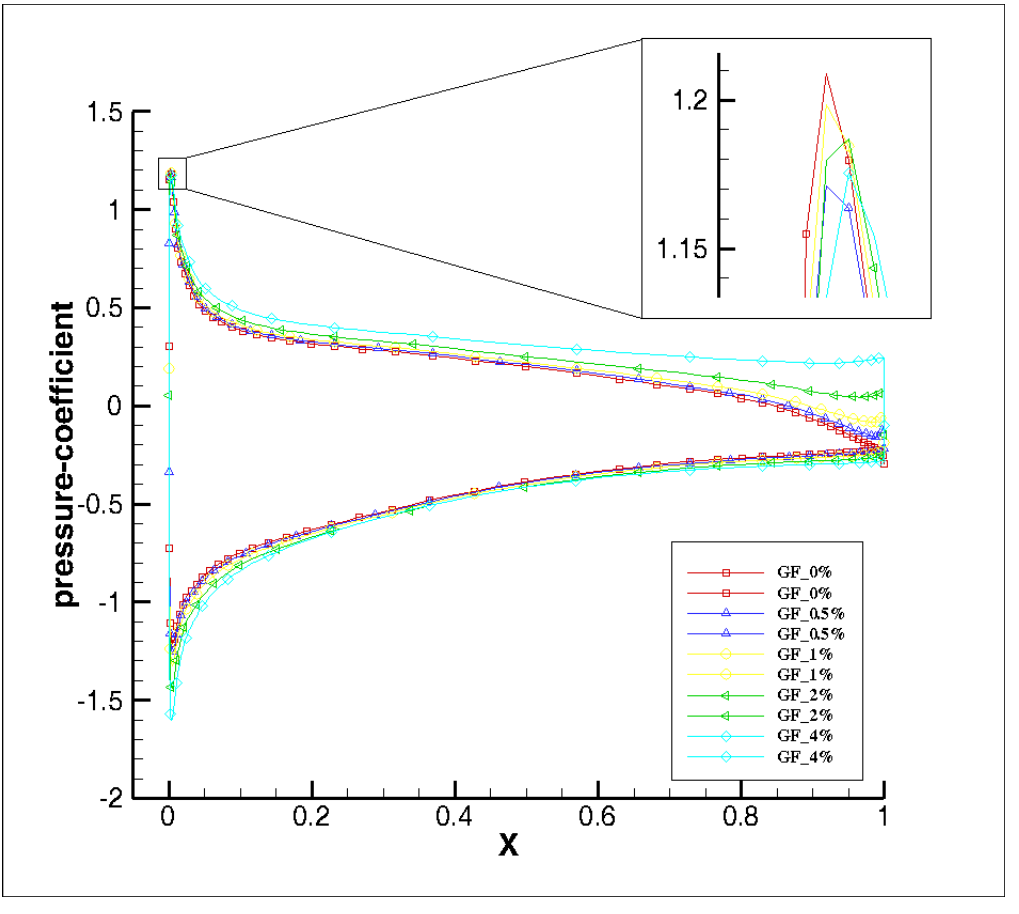
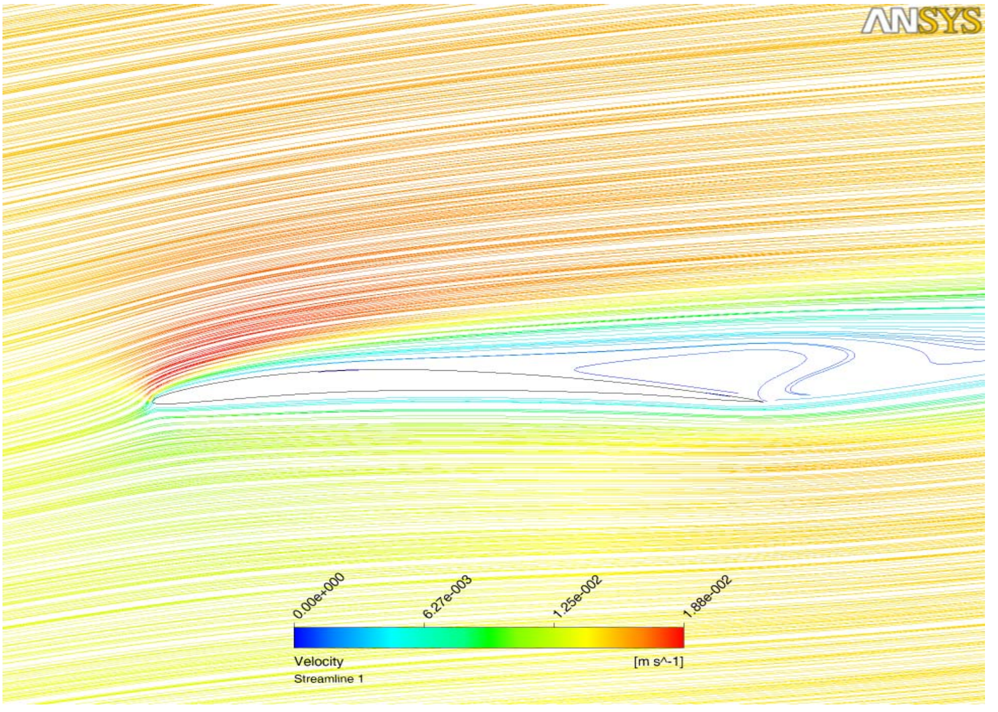


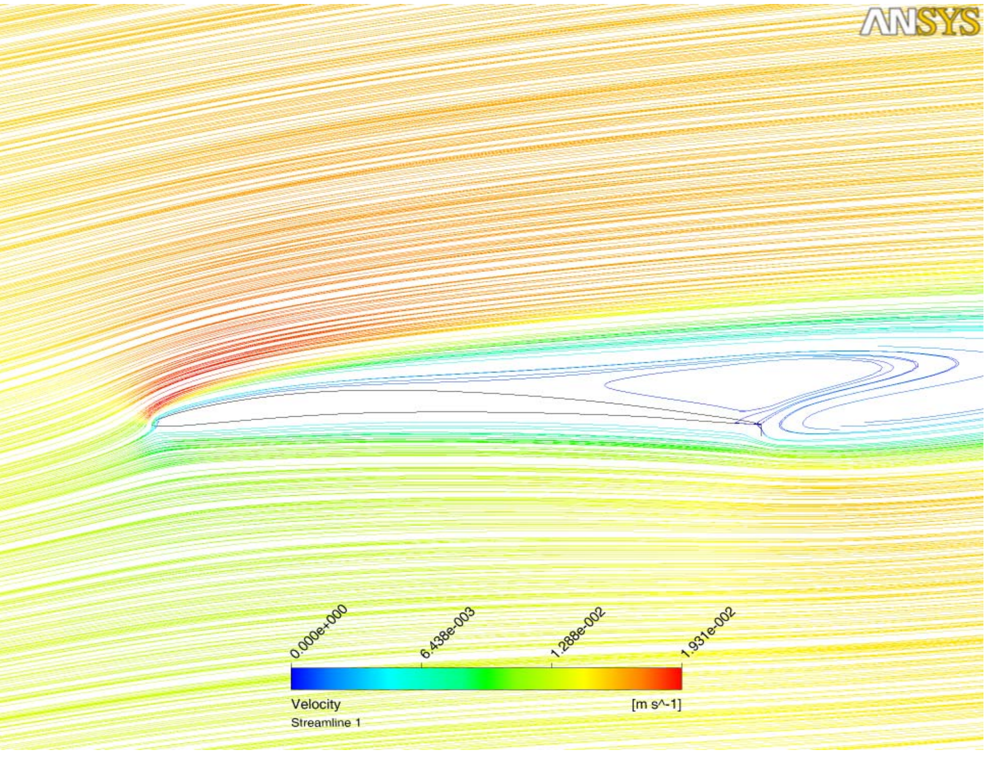
Figure 2. Surface pressure at $\alpha = +8.0\deg$

At near stall incidence,depending on the flap size,($\alpha = +8.0\deg$) the Gourney flaps produce a localized suction peak near the leading edge peak promoting boundary layer separation and reducing the stalling incidence (the bubble breakdown).

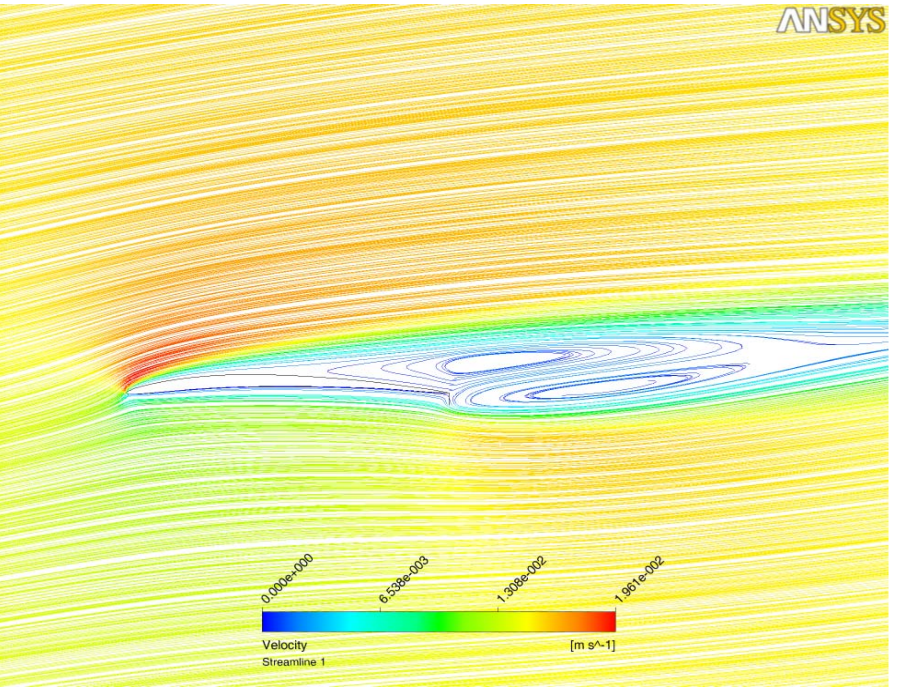
These trends are confirmed from the streamline patterns of the flows shown in Fig.3.



a) Gurney Flap 0%



b) Gurney Flap 2%



c) Gurney Flap 4%

Figure 3. Streamline contours for NACA 4404 airfoil at Re=1000 and α=+8 deg

Streamline contours. The streamlines contours are presented at Re=1000 and **α** =7^o for NACA 4404. They show two distinct counter rotating vortices directly downstream of the Gourney flap and an off surface stagnation point where the streamlines bounding the vortex region meet to form the make.

These patterns match that first hypothesized by Liebeck.

Forces. Figure 4 presents calculated forces for the airfoil with a range of Gourney flaps fitted at the trailing edge.

All of the Gourney flaps increased the lift at a given prestall incidence and increase the drag at most values of C_L , but without reduction in the maximum lift-to-drag ration.

Very thin airfoils (about 2-8%) at low Reynolds numbers, exihibat a particular form pf stall. The laminar flow separates from the trailing edge at a small angke of attack and reattches itself almost immediately.

This bubble continues to stretch towards the leading edge as the angle of attack is increased.

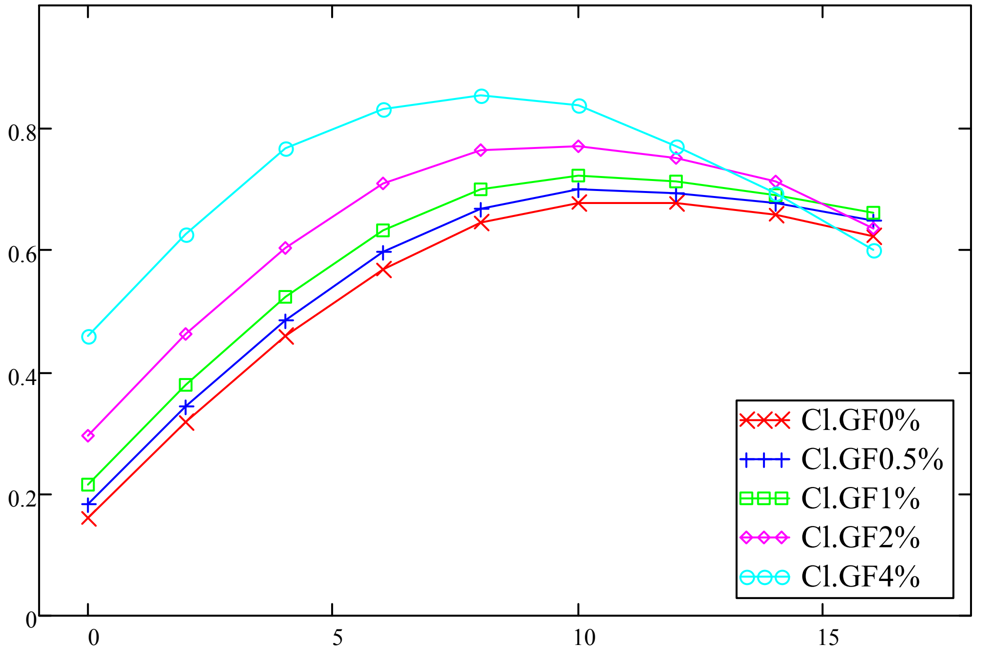
At the angle of attack where the bubble stretches all the way to the leading edge, the airfoil reaches its maximum lift.

Beyong that angle of attack the flow is separated over the whole airfoil,so the stall occurs.The loss of lift is smooth.

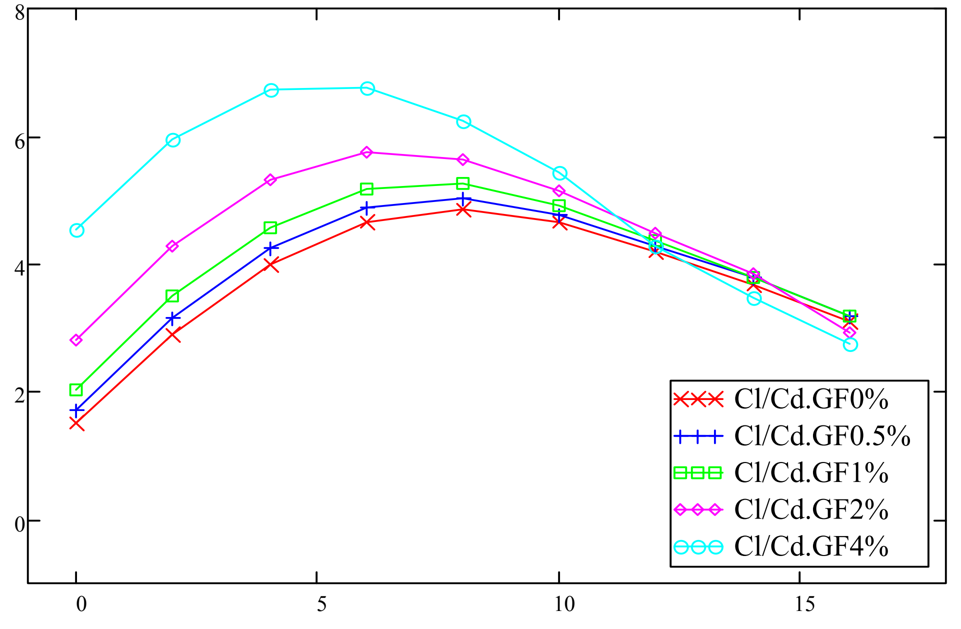
The complete laminar separation results in a rounding of the lift curve (fig.4a).

As the size of flap is increased,the bubble moves forward nearer the leading edge reducing the stalling incidence.

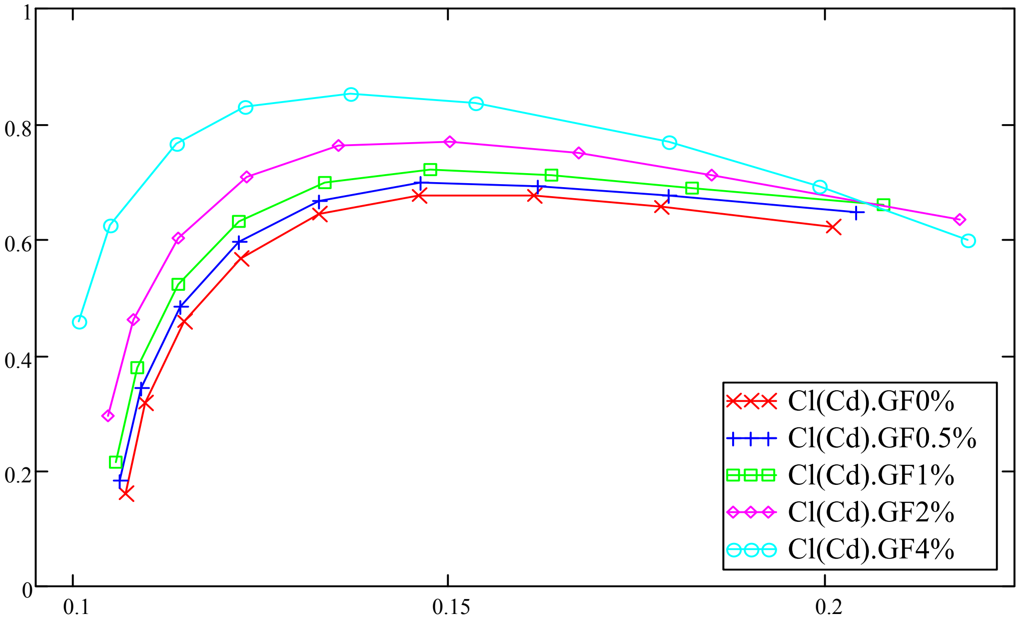
Despite a reduction in stalling incidence the Gurney flaps still increase C_{Lmsx} *and* C_L / C_D .



a) $C_L(\alpha)$



b) $C_L/C_d(\alpha)$



c) $C_L(C_D)$

Figure 4. Forces: a) $C_L(\alpha)$;b) $C_{L/}$ $C_D(\alpha)$;c) $C_L(C_D)$

4. CONCLUSIONS

In response to the growing in the efficient MAVs an interesting concept, namelly the Gurney flap, is chosen for circulation enhancement.

For attached flow conditions the Gurney flap is very effective at increasing circulation around an airfoil leading to a net increse in generated lift compared to the baseline airfoil.

On the wind-ward side of the flap, the local pressures are considerably higher than the leeward side. The lower pressures on the leeward side have a tendency to create a favourable pressure gradient over the upper surface of trailing edge, causing the flow to follow the flap and turn downward as illustred in Fig. 3.

The entire circulation over the airfoil is enhanced, similar in effect to that achieved by the active Coanda jet technique, but more cheeper.

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