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ANALYSIS OF INFLUENCE OF PLAIN FLAP AND GURNEY FLAP ON AERODYNAMICS COEFFICIENTS OF THE AIRFOIL SELIG 1223 BY FINITE VOLUME METHOD

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Abstract. *Aerodynamics studies the behaviour of the flow of air or others gaseous fluids about bodies of arbitrary shape and compute the resulting forces and moments on these bodies. For an aircraft wing the lift and drag forces and the pitch moment are the more important results. High lift surfaces are devices used to increase the lift force of the wing, increasing in most case, the drag force too. The gurney flap and plain flap are two simple devices that can be used to increase the lift coefficient. The two-dimensional steady flow about the aerofoil can be computed using Computational Fluid Dynamics on the solution of Navier-Stokes equations. The main purpose of the developed study is to analyse the influence of these high lift devices on the behaviour of an aerofoil of an aircraft wing used at an airplane of the Aerodesign Competition. In this paper, a numerical study of the effect of these two high lift devices on SELIG 1223 aerofoil is presented. The typical Reynolds number of the flow is 2.0 to 8.0 x10^5. The flow was computed by the Finite Volume Method, using computational code ANSYS FLUENT. An unstructured grid with a boundary layer mesh close to the aerofoil is used on the discretization of the domain. A comparison for evolution of aerodynamics coefficients versus angle of attack, pressure coefficient distributions on the contour and streamline flow pattern for clean aerofoil and aerofoil with plain and gurney flap devices are presented.*

Keywords: *Gurney Flap, Plain Flap, Lift, CFD, FLUENT.*

1. INTRODUCTION

The main objective of SAE Aerodesign competition is to manufacture a small aeroplane with maximum lift and minimum drag. The efficiency of a wing is a result the three components of the aerodynamic force and of the three components of moments. The most important are the lift and drag forces and the pitch moment (Anderson, 2001). The high lift devices are used to increase the lift of the wing, with a small increase on drag force, and a small change in the stalling incidence, with an increment of the maximum value of the lifting coefficient (Rosa, 2001). The gurney flap and plain flap are two devices that can be used to increase the maximum lifting coefficient.

The gurney flap is a simple device consisting of a flat plate attached to the trailing edge perpendicular to the chord on the pressure side of the wing (Wang *et al*, 2008). Figure 1 shows the aerofoil SELIG 1223 with a gurney flap with a relative height *h*/*c*=2.08 %, where *c* is the aerofoil chord. In the late 1960s, the American race car driver Dan Gurney was the first to use this flap on an inverted wing to increase the downwash force with a minimal effect on aerodynamics of the car (Jain *et al*., 2015). Experimental results for the gurney flap was first presented by Liebeck (1978) that shows that even a small gurney flap, *h*/*c*=1.25 %, (Wang *et al.*, 2008) increases the lift and reduces the drag. Liebeck explain that the increase of the lifting force by an increase of velocity close the trailing edge. Gurney flap device changes velocity field close the trailing edge. Two contra-rotating vortices appear close the flat plat, changing the Kutta condition and increasing velocity circulation around the aerofoil (Jang *et al.*, 1998). Those vortices deflect the airflow downstream. The increase percentage of the lift and drag coefficients are function of the relative height *h*/*c* and of the angle between the flat plate and the aerofoil chord (Wang *et al.*, 2008). For Wang (2008) the lift coefficient increases with the relative height of the gurney flap, but the drag coefficient increases too much for *h*/*c* greater than 2%. Jain *et al*. (2015) presents a comparison between experimental results and numerical results computed by CFD for different geometries of the gurney flap, different relative heights and angles.

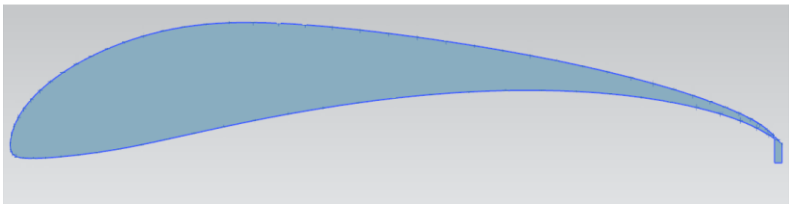

Figure 1. Aerofoil SELIG 1223 with gurney flap h/c = 2.08%

Following Duncan (1959) when a portion of the rear wing is hinged to the wing then that portion is defined as plain flap. The deflection of the plain flap changes the effective incidence and the camber of the aerofoil or of the wing. A positive deflection of the flap, as shown at Fig. 2, changes chordwise loading on the aerofoil, with a maximum close the leading edge and a secondary peak at the flap hinge. At some applications, the plain flap can change the area of the wing. The efficiency of the plain flap depends on the changes of camber and area of the wing (Riebe, 1955). The geometry of the plain flap is defined by the length relative to the chord and the deflection angle (Ockfen and Matveev 2009).

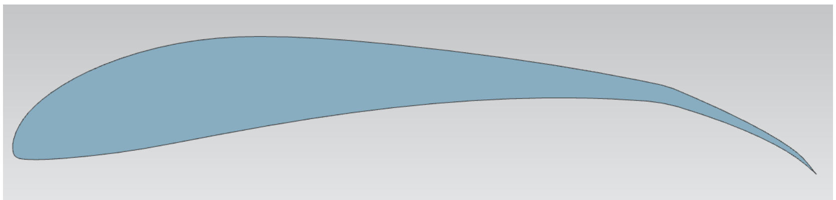

Figure 2. Aerofoil SELIG 1223 with plain flap at x/c= 80% with a deflection angle of 10°

The use of Computational Fluid Dynamics (CFD) to solve Navier-Stokes equations on the computation of flow field at Aeronautics is becoming more and more common. Tulapurkara (1997) shows a comparison of different turbulence models on the solution of two-dimensional flow about aerofoils. Results obtained by several authors as Rumsey and Anderson (1988), Kogan and Migemi (1990) and Lien e Leschziner (1995) are presented.

Theodorsen (1932) and Theodorsen and Garrick (1940) were pioneers on the calculation of the pressure distribution on the contour of an aerofoil. A conformal mapping technique was used. In the 60's panel methods were developed and applied to compute inviscid flow about an aerofoil. Singularity distributions of sources, vortices and doublets on the inside or at the contour of the profile were used (Hess, 1966; Giesing 1968 and Epton 1981). One of the most used software package of panel method was developed by Eppler e Somers (1980) and applied on the computation of flow about aerofoils for a range of Reynolds Number between 2×10^4 e 1×10^8. Drela and Giles (1987) develop a panel method methodology, using the viscous and inviscid interaction, to compute the flow for aerofoils at low Reynolds Number, lower than 1×10^6. That methodology was used by Drela (1989) who developed a new panel method code XFOIL that was used in this paper to compute the evaluations of aerodynamics coefficients versus angle of attack α.

Johnson *et al* (2005) presents the development and application of CFD at Boeing Company and its importance for the company. They refer to the role of the panel methods at the period between 1973 and 1983, of the algorithms that solve Euler's equations between 1983 and 1993 and at last, of those algorithms who solve Navier-Stokes equations with Reynolds turbulence models since 1993 to 2003.

In this article the incompressible two-dimensional flow around a SELIG profile 1223, used in the wing of a model of an aircraft in the SAE Brazil Aerodesign competition, without high lift device and with the gurney flap and plain flap is calculated. The CFD program used was the FLUENT code (Ansys, 2013) with the turbulence Realizable k-ε with Enhanced Wall Treatment (Vu and Shyy, 1990). The numerical results obtained with FLUENT are compared with experimental results from Williamson (2012) and those obtained from panel method through the XFOIL code. Graphs of the lift coefficient c_l and drag coefficient c_d versus the angle of attack α are shown as well as the pressure coefficient distributions on the contour of the profile

2. COMPUTATIONAL PROCEDURE

At this section, the methodology used to compute the incompressible flow around the aerofoil SELIG 1223 is presented. The CFD code from ANSYS, FLUENT, is used to compute the flow field. FLUENT was chosen instead of CFX because it can solve directly two-dimensional flows.

Two steps may be considered for the development of this methodology. The first step is concerned with the mesh generation and the second with computation of the flow field for different angles of attack and for the aerofoil without and with high lift devices, plain flap and gurney flap. The mesh refinement close to the aerofoil contour, at the boundary layer zone, is analysed and results presented at this paper.

The computer machine used has the characteristic shown in table 1.

Table 1-Computer characteristics

Operational system	Windows 10 Pro 64 bits
Processor	Intel® CoreTM i5-4670 @ 3.40 Ghz
RAM	4.0 GB
Video card	Intel® HD Graphics 4600
Hard disk	500 GB

Figure 3 shows the tested aerofoil SELIG 1223. The maximum relative thickness is t/c=12.1% at x/c=19.8% and the maximum relative camber is f/c=8.1% at x/c=49.0%. The aircraft model that used this profile has a trapezoidal wing with c=0.425m at the root and c=0.175m at the tip. The span of the wing is 2,52m. The PegAzuls Aerodesign team of UFERSA Mossoró used this wing at SAE Brasil Aerodesign competition of 2015. The coordinates of the profile SELIG 1223 were obtained from Airfoil Tools (2017).

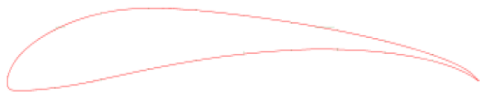

Figure 3. Aerofoil SELIG 1223

Figure 4 shows the control volume used on CFD computations without and with high lift devices. The boundary conditions used on the contour of the aerofoil is a no-slip condition (wall condition). At inlet section (number 1 at Fig. 4) a velocity inlet condition is prescribed, with a velocity of 13 m/s parallel to the axe x. At outlet section (number 3 at Fig. 4) a pressure outlet condition is used with a relative pressure p=0 Pa. At the remaining boundary (number 2 at Fig. 4) a pressure far-field condition was prescribed (For the geometry with plain flap a velocity inlet condition equal of that of section 1 is prescribed.).

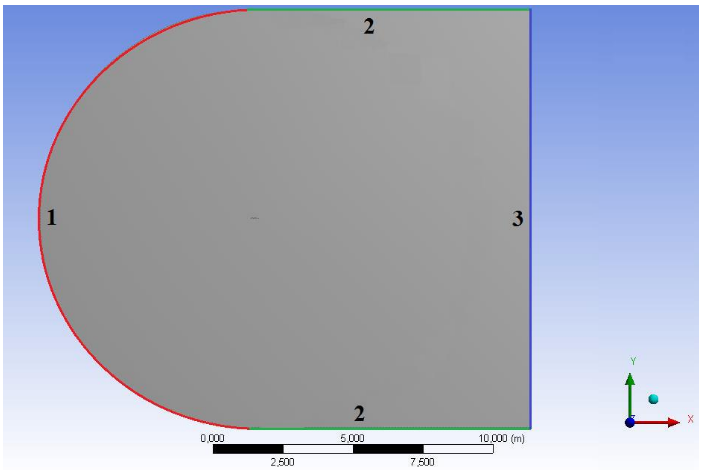

Figure 4. Control volume and boundary sections

Figure 5 shows the mesh built for an aerofoil with gurney flap for an angle of attack α=2º. As the inlet velocity is always parallel to x-axe a new mesh must be create for each angle of attack. The mesh is composed only exclusively with quadrilateral elements. The contour of profile is discretized with 1028 elements, for the calculation flow about the aerofoil without high lift devices and with gurney flap.

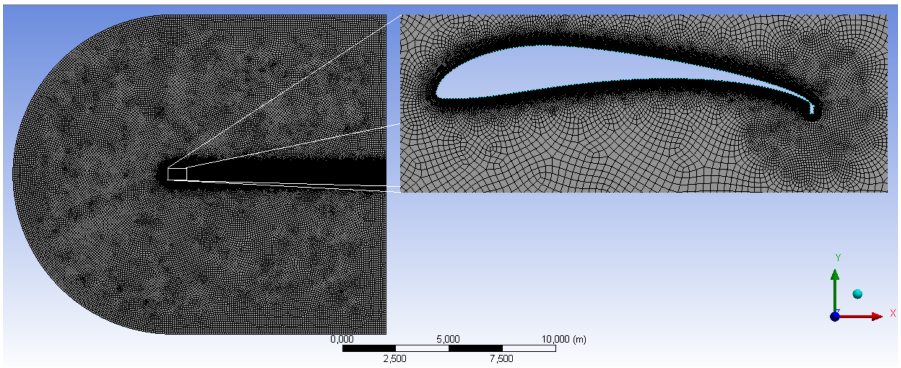

Figure 5. Mesh of SELIG 1223 aerofoil with a gurney flap *h*/*c*=2,08% and an angle of attack α= 2°

On the mesh generation a structured zone (*boundary layer mesh*) has been built close to the aerofoil. The thickness of the first layer is 2.4×10^{-5} m. This value of thickness is chosen so that *y*+ has a value close to one. Twenty layers are prescribed with a size growth rate of 1.1. The mesh close to the aerofoil and at the wake of the flow is also more refined. The minimum size of the elements is equal to 6 mm with a size growth rate of 1.2. Close to the trailing edge the mesh is refined too. The elements have minimum size of 2 mm and a size growth rate of 1.2. The final mesh has 444844 nodes. For the calculation of the aerofoil flow with plain flap, the contour is discretized with 1002 elements and the mesh has 431618 nodes.

The solver settings were specified with the default configuration, implicit formulation and *Flux type ROE-FDS.* The turbulence model used was the *Realizable k*-ε with *Enhanced Wall Treatment* (Vu and Shyy, 1990). For the spatial discretization *Last squares cell based Gradient*, *Second Order Upwind Flow* and *Turbulent Kinetic Energy* and *Dissipation Rate* with *Second Order Upwind* were chosen. Maximum values specified for residuals of the continuity and velocities equations were 1×10^{-6}.

3. RESULTS AND DISCUSSION

The main objective of this paper is to compare the aerodynamics coefficients, lift and drag, of the aerofoil SELIG 1223 without and with gurney flap and plain flap using a finite volume method code, the FLUENT. Experimental results obtained by Williamson (2012) in wind tunnel for the SELIG 1223 aerofoil with a gurney flap *h*/*c*=2.08% and a Reynolds Number 2.5×10^5 are used for comparison and validation of numerical results. Results of the flow with plain flap are still compared with those obtained with XFOIL code.

Figure 6 shows a comparison between experimental values from Williamson and numerical values obtained with FLUENT of the evaluation of the lift coefficient versus angle of attack with a gurney flap *h*/*c*=2.08%. FLUENT results present very good agreement with experimental data, with a maximum error of 8.22%. Numerical values are in general greater than experimental data. Close the stall angle the difference between numerical and experimental values increase, showing that the flow is not well reproduced, at this Reynolds number, when the separated zone increases.

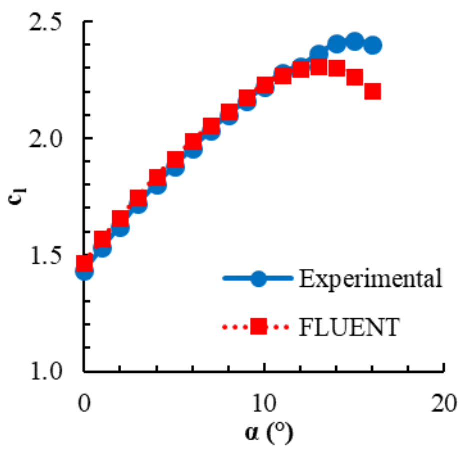

Figure 6. Comparison between experimental data and numerical results of the evaluation of lift coefficient c_l versus angle of attack α for aerofoil S1223 with gurney flap *h*/*c*=2.08% for Re=$2.5\text{x}10^5$

Figure 7[1] show lift and drag polar diagrams, lift-to-drag ratio graph and lift coefficient versus drag coefficient graph, for the aerofoil without gurney flap and with a gurney flap *h*/*c*=1.56% and *h*/*c*=2.08%, computed with FLUENT code for a Reynolds Number 2.5×10^5. The results show that the gurney flap increases significantly the lift coefficient. Comparing the values of lift coefficients at linear zone of aerofoil SELIG 1223 without gurney flap and with gurney flap a percentage increase of 12% and 19% is verified for *h*/*c*=1.56% and *h*/*c*=2.08%, respectively. For the maximum lift coefficients the percentage increasement is 8% for *h*/*c*=1.56% and 11% for *h*/*c*=2.08%. Figure 7 also shows that the stall angle decreases when the relative height of the gurney flap increases. The stall angle decreases from 14º at original aerofoil to approximately 13º and 12º, for *h*/*c*=1.56% and *h*/*c*=2.08%, respectively.

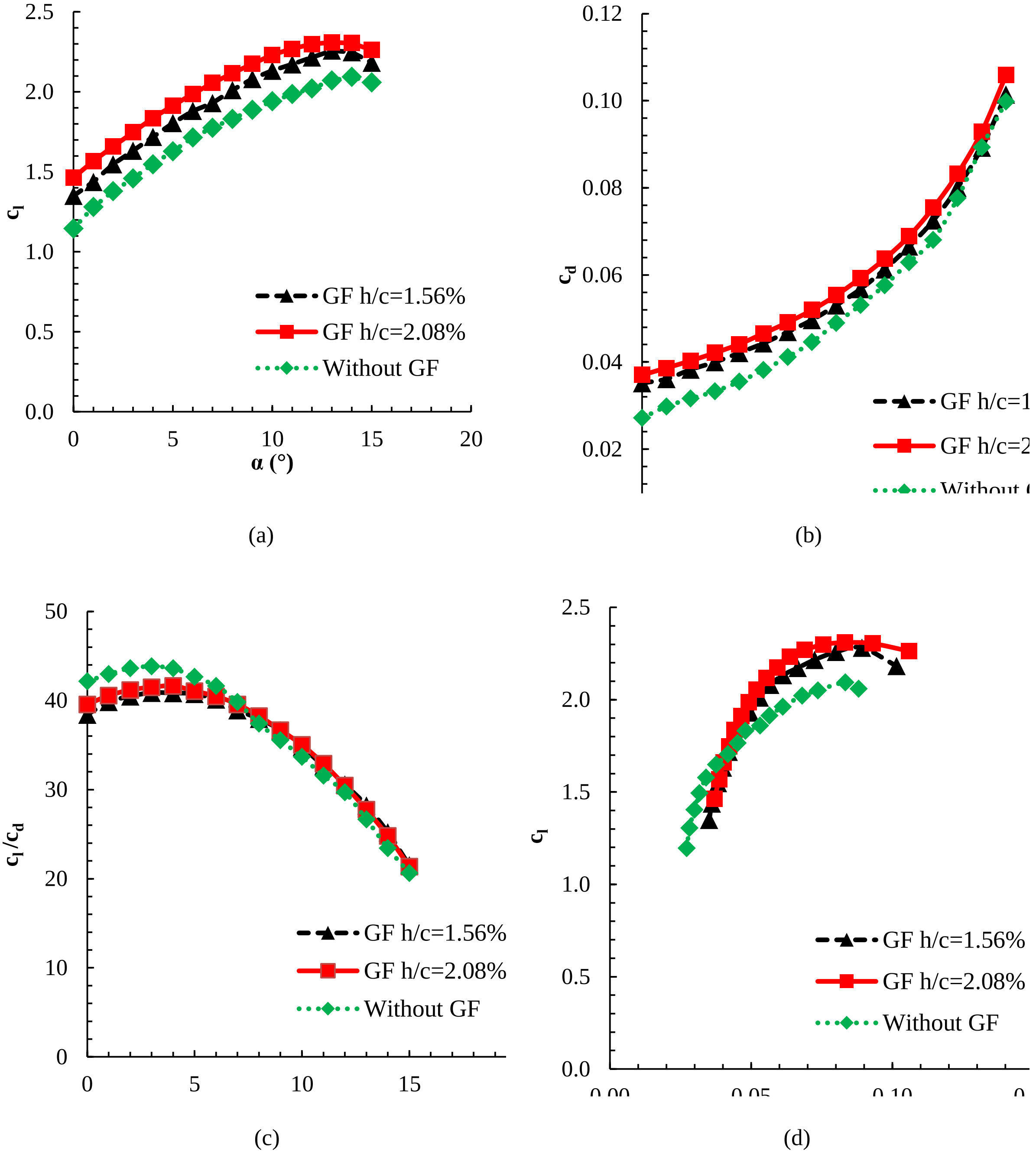

Figure 7. Comparison of aerodynamics coefficients of original aerofoil S1223 and aerofoil SELIG 1223 with gurney flap *h*/*c*=1.56% and *h*/*c*=2.08%: (a) $c_l \times \alpha$; (b) $c_d \times \alpha$; (c) $c_l/c_d \times \alpha$ and (d) $c_l \times c_d$

[1] At Fig. 7 the short name *GF* is used as abbreviation of *Gurney Flap*.

Figure 7(b) shows a comparison of evolution of drag coefficient c_d versus angle of attack α. For angles of attack lowers than 10º there is a considerable increase of drag coefficient at aerofoils with gurney flap relative to the original aerofoil. There is also an increase of drag coefficient with the relative height of the gurney flap h/c. For α greater that 10º the values with and without gurney flap are very close. For the aerofoil with h/c=1.56% and α greater than 10º the drag coefficients are almost equal. Figure 7(c) shows a comparison of the aerodynamic efficiency for the aerofoil with and without gurney flap. The results show that if the angle of attack is lower than seven degrees the aerodynamic efficiency of aerofoils with gurney flap are lower than that of the original aerofoil. For angles of attack greater than seven degrees, the opposite is observed. These results do not depend on the relative height of the gurney flap. Results shown at Fig. 7(d) present the same behaviour.

Figure 8 shows the effect of the plain flap on the lift coefficient for a range of angles of attack between zero and fourteen degrees. The results are present for a plain flap with deflection angle of δ=10º, articulated at a relative distance of the trailing edge of x/c=20%. The computed values of XFOIL and FLUENT are very close and the resulted curves have the same behavior. The maximum difference between the curves, approximately 7%, is observed close to the stall angle. The results of the XFOIL are lower than the results obtained with the FLUENT, almost for all the angles of attack.

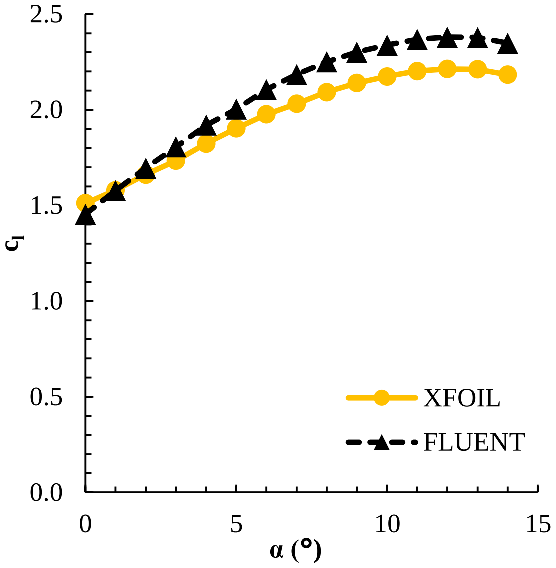

Figure 8. Lift polar diagrams of aerofoil S1223 with plain flap at x/c=80% with a deflection angle of δ=10° computed with FLUENT and XFOIL codes for Re=2.5×10^5

Figure 9[2] presents the influence of plain flap on the aerodynamics characteristics of aerofoil SELIG 1223, computed with FLUENT code. Results for the original aerofoil and for configuration with plain flap at a trailing edge distance x/c=20% and δ=5º and δ=10º were computed. Figure 9 (a) presents a comparison of lift polar diagrams without and with plain flap. In linear zone of the graph an average increase of 23% is observed for a δ=10º and 17% for δ=5º. The maximum value of lift coefficient also increases with the plain flap. There was an increase of 14% for δ=10º and 12% for δ=10º. The stall angle for the aerofoil with plain flap also decreases in comparison with original aerofoil. For δ=5º the stall angle changes from α=14º to α=13º and for δ=10º the reduction is two degrees. Graphs of evolution of drag coefficient versus angle of attack α, presented at Fig. 9(b), show that the drag coefficients of the two aerofoils with plain flap are lower than those of the original aerofoil. The aerofoil with the plain flap δ=10º has the lower value of c_d. Figure 9(c) shows a comparison of aerodynamic efficiency of the three aerofoils. As expected in the view of lift increase and drag reduction due to the plain flap, the plain flap increases the aerodynamics efficiency of the aerofoil. As shown in Fig. 9(c) this increase, relative to original aerofoil, is greater for an angle δ=5º than for an angle δ=10º.

Pressure coefficient, C_p, distributions over the aerofoil contour are plotted at Fig. 10. Fig. 10(a) shows the effect of gurney flap with h/c=2.08%. The value of the minimum pressure coefficient is lower but the curves are similar. Fig. 10(b) presents a comparison between pressure distribution of SELIG 1223 with any high lift devices and the same aerofoil with the referred plain flap of δ=5º. It is clear the increase of the area bounded for the plotted curves when a plain flap is considered. The suction peak of pressure on upper surface is lower than on the geometry with gurney flap and the pressure distribution is smoother. The load pressure distribution is more uniformly distributed, with an increase

[2]At Fig. 9 the short name *PF* is used as abbreviation of *Plain Flap*

of the load pressure for *x*/*c* between 0.2 and 0.9. A second coefficient pressure peak appears at the pivot point of the plain flap.

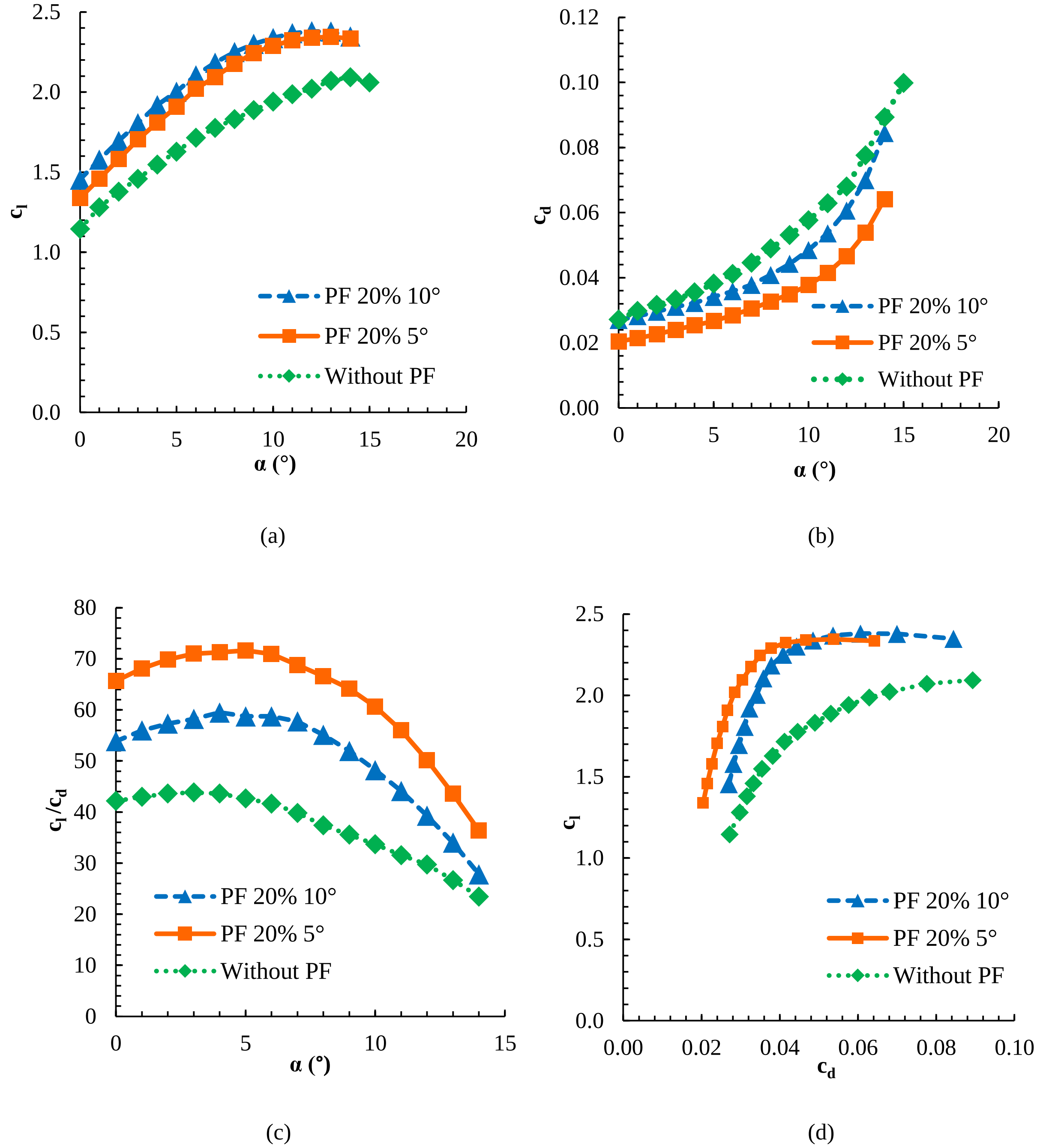

Figure 9. Comparison of aerodynamics coefficients of original aerofoil S1223 and aerofoil SELIG 1223 with plain flap at relative distance of trailing edge x/c=20% and δ=5° and δ=10°: (a) $c_l \times \alpha$; (b) $c_d \times \alpha$; (c) $c_l/c_d \times \alpha$ and (d) $c_l \times c_d$

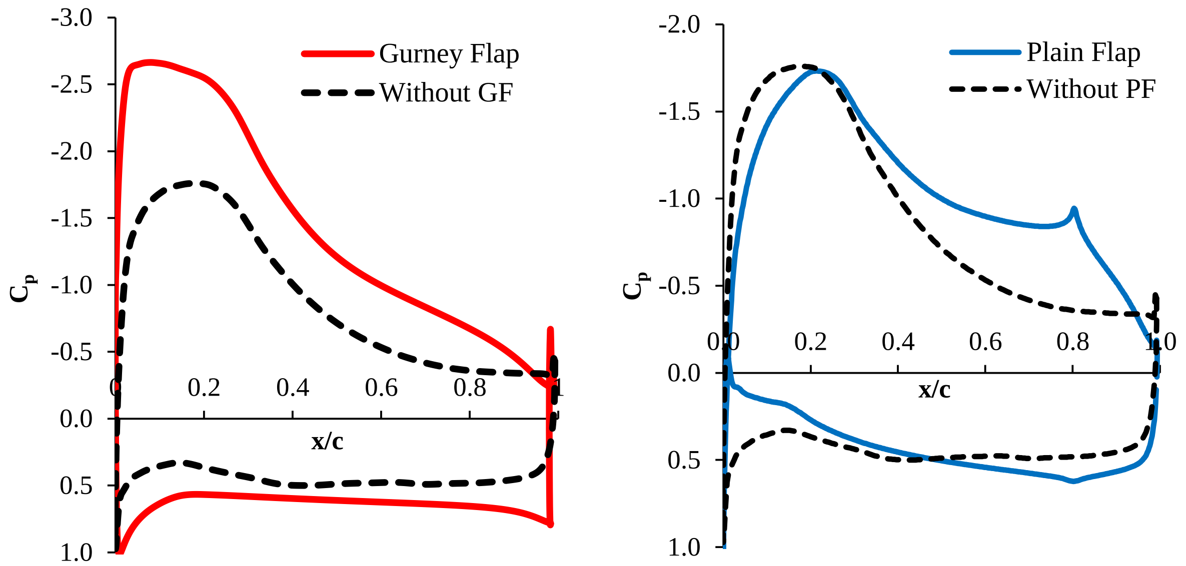

Figure 10. Comparison of pressure coefficient distributions over the aerofoil contour for Re=2.5×10^5: (a) gurney flap *h*/c=2.08% and (b) plain flap at relative distance of trailing edge *x*/*c*=20% and δ=5°

Figure 11 presents a detail of the velocity field close to the trailing edge of the aerofoil with a gurney flap *h/c*=2.08% for an angle of attack α= 2°. The two counter-rotating vortices downstream of the gurney flap that change the Kutta condition downstream of the gurney flap are shown.

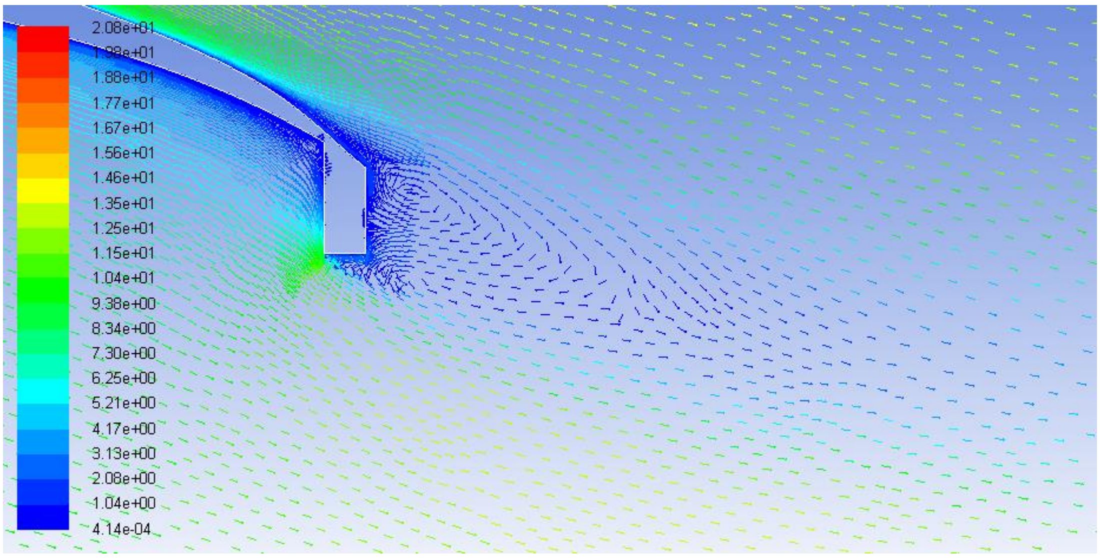

Figure 11. Detail of velocity field close to the trailing edge, with a gurney flap with *h*/*c*=2.08%, showing the two counter-rotating vortices

4. CONCLUSIONS

The main objective of this paper is to analyse the effect of the gurney flap and the plain flap on the two-dimensional viscous incompressible flow about the aerofoil SELIG 1223 used on wing of the aeroplane model for SAE Brasil Aerodesign competition.

The polar curves of the aerofoil and the pressure coefficient distributions on the contour are computed using the XFOIL and FLUENT codes. FLUENT code solves the two-dimensional incompressible flow with the turbulence modulated with Realizable *k*-*ε* with Enhanced Wall Treatment. The domain is discretized using an unstructured grid with a boundary layer mesh close to the aerofoil.

Comparison of numerical results, for the lift coefficient, obtained with FLUENT for SELIG 1223 with a gurney flap h/c=2.08% show very good agreement with experimental results for almost all the computed angles of attack. Close the stall angle the computed values are smaller than the experimental data.

Polar lift and drag diagrams, c_l versus α, c_d versus α, c_l/c_d versus α and c_l versus c_d are computed using FLUENT code. These diagrams compare lift and drag coefficients of the original aerofoil SELIG 1223 and aerofoils with gurney flap h/c=1.56% and h/c=2.08% as well as original aerofoil SELIG 1223 and aerofoils with plain flap at relative distance of trailing edge x/c=20% and deflection angles δ=5° and δ=10°.

Gurney flap and plane flap increase considerably lift coefficient. These high lift devices are special useful at take-off and landing of the aeroplane. They are very easy to manufacture and can be used with a mechanism actuated according to the need of the pilot.

Numerical results also show that plain flap increases efficiency of the aerofoil for almost all the angles of attack computed and the chordwise loading is more uniform. The use of gurney flap of the not increase aerodynamic efficiency in comparison with the aerofoil original, and so it uses is only recommended for short periods as take-off and landing.

5. ACKNOWLEDGEMENTS

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