PIV INVESTIGATION OF AN AIRFOIL WITH A GURNEY FLAP

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Abstract

This paper reviews the research on NACA 23012 and FX66-17AII-182 airfoil performances for different angles of attack at Re » 3.10^5, based on chord, both with clean configuration and the flaps. The performances were measured using 2D-PIV (Two-dimensional Particle Image Velocimetry) system and pressure measurement.

This report also describes new methods in Gurney flap research, using 2D-PIV system and Kutta-Joukowski Lift Theorem or static pressure assumption to evaluate airfoil lift.

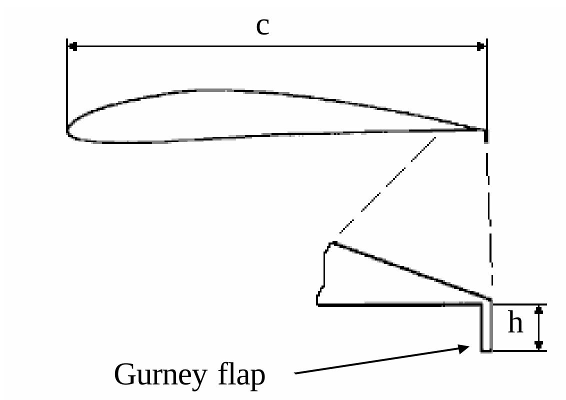

Fig. 1: NACA 23012 profile fitted with a Gurney flap (c – chord length, h – Gurney flap height).

1 Introduction

The Gurney flap is a vertical short strip added to the trailing edge on the pressure side of a wing. It can have relatively powerful effect on the aerodynamics of a wing, increasing lift with only small change of drag penalties.

The most common application of this device is in racing-car spoilers, where it is used to increase the down-force. The Gurney flap was applied to some helicopters, where the flaps are fitted on the horizontal inverted wing to improve performance during the high-powered climb or on vertical tails, to increase the force produced by a horizontal stabilizer. The Gurney flaps were also tested on delta wings and wind turbines.

2 Evaluation methods

The flow around the airfoil NACA 23012 with a Gurney flap and without a Gurney flap was thoroughly measured with 2D-PIV, which made possible to obtain very detail look on a velocity vector field and circulation of the flow, both instantaneous and time-averaged values.

The detailed values of the circulation around the airfoil enable to use Kutta-Joukowski Lift Theorem to calculate the lift of the airfoil, to see the influence of the flaps on the flow and finally, altogether with the force measurements, to calculate aerodynamic performance of the airfoil.

Circulation method

The airflow is considered to be a potential two-dimensional flow sufficiently far from the airfoil (outside the boundary layer). There rules Kutta-Joukowski Lift Theorem in such an idealized flow:

$$F_y = r \cdot u \cdot \Gamma , \qquad (1)$$

where:

F_y ....lift [N]

r ....free stream density [kg/m³]

u .... free stream velocity [m/s]

Γ ....circulation around the profile [m²/s]

$$\Gamma = \oint_c v \cdot \cos a \cdot ds\,, \qquad (2)$$

where:

c...........closed path

v...........velocity vector [m/s]

a ....angle between v and ds

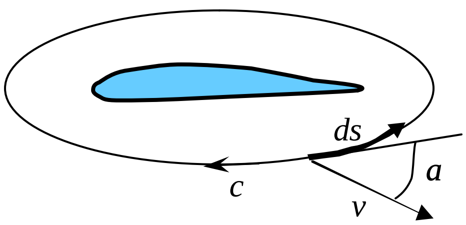

Fig. 10: Total circulation.

Thorough knowledge of the velocity field around the profile is the base for evaluating of the total circulation integral (eq. 2) and subsequently for calculating the profile lift (eq. 1).

Pressure coefficient method

The other way of the lift evaluation from the velocity flow field is using the pressure coefficient. If the static pressure in the whole flow field and inside the boundary layer is assumed to be constant, then the pressure coefficient can be declared as a ratio:

$$C_{P_i} = 1 - \left(\frac{u_i}{u_\infty}\right)^2, \text{ where:} \qquad (3)$$

u_∞ .... free stream velocity [m/s]

u_i .... local stream velocity [m/s]

Subsequently the lift coefficient is calculated:

$$C_L = \Sigma_{i=1}^{n} C_{Pi(low)} - \Sigma_{i=1}^{n} C_{Pi(high)} \qquad (4)$$

Pressure distribution and the lift coefficient measured on the airfoil FX66-17AII-182 were compared with numerical simulation (Fluent).

3 Experimental equipment

PIV measurements were done in the closed-circuit wind tunnel with an open test section with dimensions 900 x 600 mm (Tu = 3,5 %) on the NACA 23012 airfoil (c = 400 mm with end plates) equipped with removable Gurney flap (GF).

Pressure measurements were done in the open wind tunnel with closed test section and with dimensions 1200 x 400mm (Tu = 1,1 %) on the FX66-17AII-182 airfoil (c = 400 mm) with a removable Gurney Flap and pressure orifices.

4 Results

Lift coefficients for both airfoils and both configurations (clean and with Gurney flap) are calculated from the results of the PIV (NACA 23012) or pressure distribution measurements (FX66-17AII-182).

There are measured 8 areas around the profile during the PIV measurement. Each resultant value is averaged from 60 instantaneous values. Image of the size 1024x1280 pixels contains 123x155 subregions with size 32x32 pixels and overlap 75 %.

Measured and calculated values during PIV measurement – NACA 23012:

$r = 1{,}178 \quad kg/m^3$

$u = 1{,}569 \cdot 10^{-5} \quad m^2/s$ ...*kinematic viscosity*

$u = 15{,}5 \quad m/s$

$g = 7{,}5°$ ...*angle of attack*

$$\mathrm{Re}_{model} = \frac{u \cdot c}{u} = \frac{15{,}5 \cdot 0{,}4}{1{,}569 \cdot 10^{-5}} = 4 \cdot 10^5$$

Measured and calculated values during pressure distribution measurements - FX66-17AII-182:

$u = 13.05 \quad m/s$

$$\mathrm{Re} = \frac{13{,}05 \cdot 0{,}4}{1{,}569 \cdot 10^{-5}} = 3{,}33 \cdot 10^{5}$$

4.1 Kutta-Joukowski Lift Theorem NACA 23012

- Configuration without GF

$\Gamma = 1{,}1299 \quad m^2/s$

$$F_{yP} = r \cdot u \cdot \Gamma = c_L \cdot c \cdot r \cdot \frac{u^2}{2} = 22{,}23 \quad N/m$$

$\underline{\underline{c_L = 0{,}365}}$ … lift coefficient

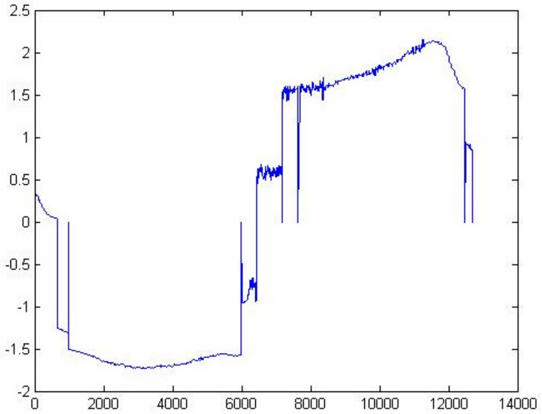

Fig. 11: Circulation values along the closed path – no GF.

- Configuration with 4 % GF

$\Gamma_{GK} = 2{,}5049 \quad m^2/s$

$F_{yPGK} = r \cdot u \cdot \Gamma = 49{,}28 \quad N/m$

$\underline{\underline{c_L = 0{,}81}}$

There are shown measured flow velocities around the NACA 23012 airfoil (with and without Gurney flap) - figures 20-23, and the circulation values along the closed path around the profile - figures 11-13.

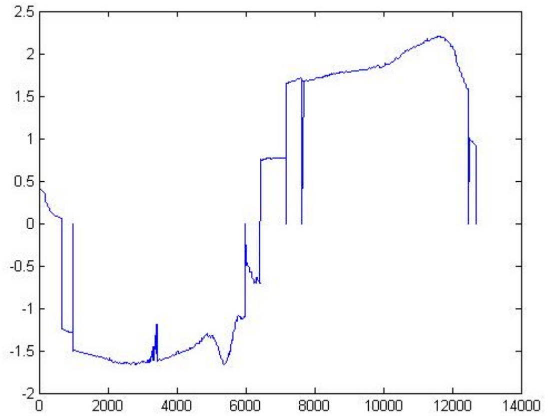

Fig. 12: Circulation values along the closed path – 4 % GF.

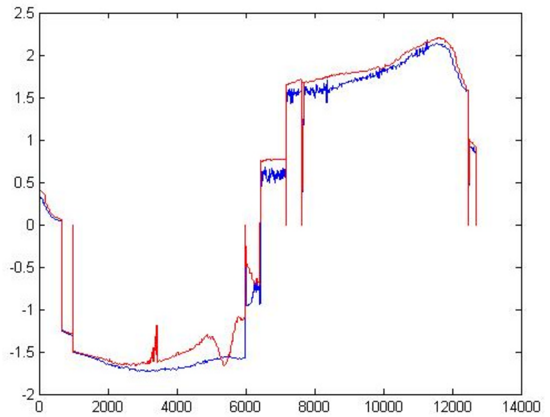

Fig. 13: Circulation values along the closed path (blue - no GF, red – 4 % GF).

4.2 Pressure coefficient *NACA 23012*, PIV measurement

Pressure distributions are shown in the fig. 14.

- Configuration without GF

$c_L = 0{,}405$

- Configuration with 4% GF

$c_L = 0{,}894$

4.3 Pressure coefficient NACA 23012, numerical solution

Pressure distributions are showed in the figure 14 and velocity flow field in the figure 17-19.

- Configuration with 4% GF

$c_L = 1{,}115$

NACA 23012 (γ=7,5°, 4% GF)			
GF (%)	K-J theorem	Cp - PIV	Num. solution
c_L	0,365	0,405	-
c_L with	0,81	0,894	1,115
Increase (%)	122	120	-

Table 1: Comparison of the lift coefficients - NACA 23012.

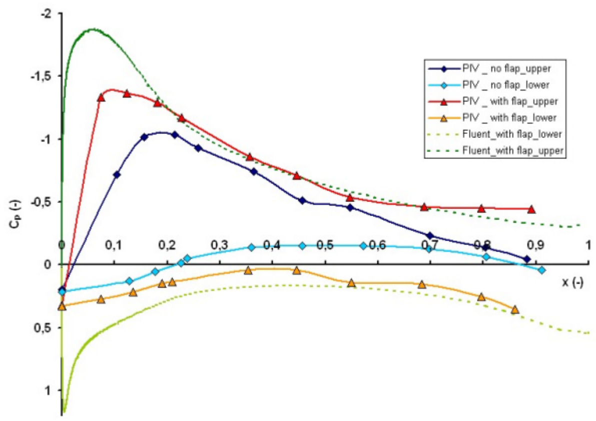

Fig. 14: Pressure distribution obtained from the PIV measurement and numerical solution (blue - no GF, red – 4 % GF, green – 4 % GF).

4.4 Pressure coefficient FX66-17AII-182, pressure measurement

The aerodynamic lift coefficients (lift slopes) of FX66-17AII-182 airfoil are shown in the figure 15 and Table 2.

FX66-17AII-182 (α=7,5°)		
GF (%)	C_L (-)	Increase (%)
0	0,938	-
0,5	1,049	11,8
1	1,148	22,4
1,5	1,214	29,4
2	1,28	36,4

Table 2: Comparison of the lift coefficients - FX66-17AII-182.

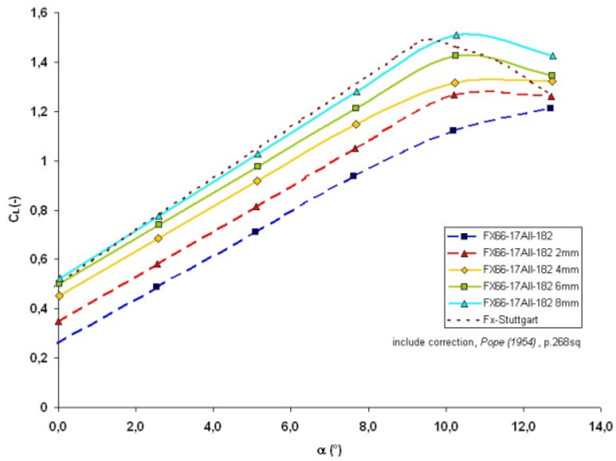

Fig. 15: Pressure distribution obtained from PIV measurement and numerical solution (blue - no GF, red – 4 % GF, green – 4 % GF).

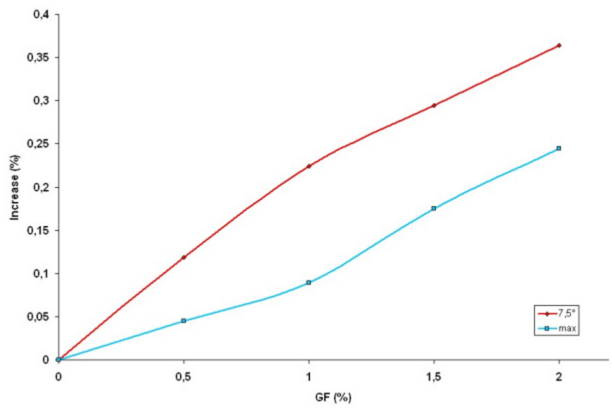

Fig. 16: Increase of the aerodynamic lift coefficient to the size of GF.

5 Conclusion

The images of the flow velocities around the airfoils obtained from the measurement and calculation illustrate in the details the effect of the Gurney flap on the flow.

The comparison of the lift coefficients shows improvement in an aerodynamic performance for Gurney flap configuration.

Hence it was possible to calculate the total circulation and evaluate the lift of the profile with and without the Gurney flap by using the Kutta-Joukowski Lift Theorem or Static pressure assumption.

There is increase of the lift coefficient of the 2D profile NACA 23012 equipped with GF 120% in both methods (K-J lift theorem, Cp calculation). This increase is in good agreement with other available results (Tab.3). Absolute values of the lift coefficient are lower than the results of measurement. This could be caused firstly by an inaccurate indication of a free stream velocity in the wind tunnel and secondly by piling images, selecting of closed path, selecting of an integration step, or an invalidation of potentiality condition in the wake region. Mentioned issues are subject of our next investigation.

Assessed results proved applicability of both methods to evaluate lift of an airfoil.

Lift slopes of 2D profile FX66-17AII-182 with GF were obtained. With respect to Table 2 can be observed rapid increase for airfoils equipped with 0,5 % and 1 % GF.

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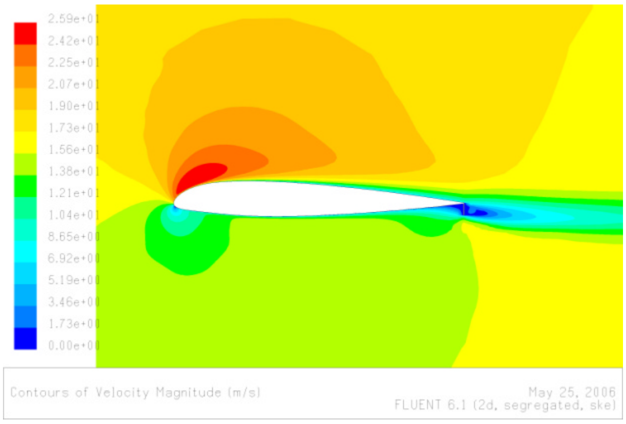

Fig. 17: NACA 23012 with 4 % GF, CFD, velocity flow field.

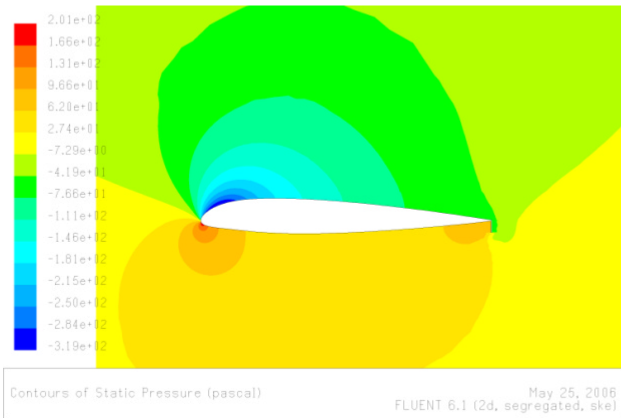

Fig. 18: NACA 23012 with 4 % GF, CFD, static pressure.

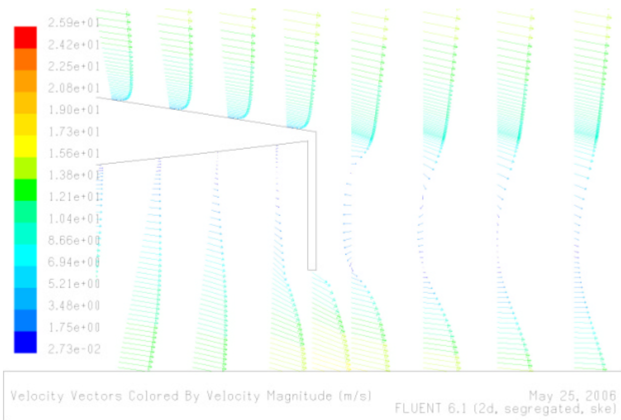

Fig. 19: NACA 23012 with 4 % GF, CFD, flow field near GF.

Velocity Field around the Profile - PIV

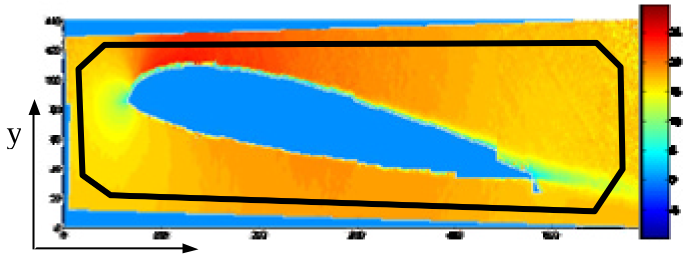

Fig. 20: Piled image of X-component velocity field around the profile with closed path – no GF (results in m/s - PIV).

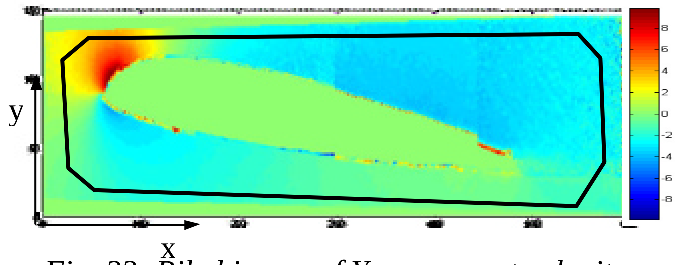

Fig. 22: Piled image of Y-component velocity field around the profile with closed path – no GF (results in m/s - PIV).

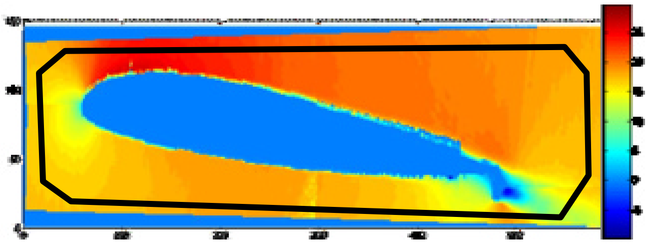

Fig. 21: Piled image of X-component velocity field around the profile with closed path – 4 % GF(results in m/s - PIV).

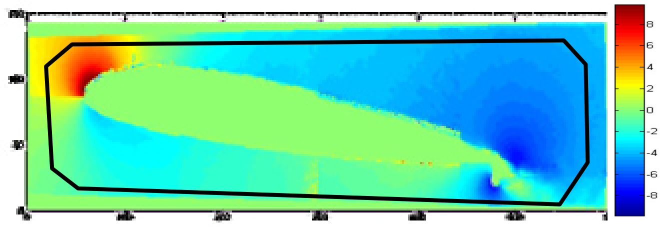

Fig. 23: Piled image of Y-component velocity field around the profile with closed path – 4 % GF (results in m/s - PIV).

	1	2	3	4	5	6	7	8
Airfoil NACA	**0012**				**23012**	**63_2-215**	**23012**	
References	[6]	[9]	[5]	[3]	[10]	[1]	**This report**	**This report**
Angle of attack [°]	7	7	6	6	7	6	7	7
C_L	1,2	0,7	0,5	0,6	0,6	0,7	0,37	0,41
C_L with GF	1,7	1,2	0,9	1,25	1,05	1,05	0,81	0,89
Increase [%]	**41,67**	**71,43**	**80,00**	**108,33**	**75**	**50,00**	**122**	**120**
Re	*8.10^5*	*$2,1.10^6$*	*8.10^5*	*$8,5.10^5$*	*6.10^5*	*$2,4.10^5$*	*4.10^5*	*4.10^5*
Note	*Force m.*	*3 % GF*		*CFD*	*Force m.*		*PIV, K-J*	*PIV, Cp*

Table 3: Comparison of lift coefficient results.