International Review of Aerospace Engineering (I.RE.AS.E), Vol. 3, N. 2
April 2010

The wake asymmetry of an airfoil with a Gurney flap and their connection with the observed lift increase

Boldes U.[1], Delnero J. S.[2], Marañon Di Leo J.[3], Colman J.[4] and Camocardi M.E.[5]

Abstract – *The present research analyzes the asymmetry in the rolling up shear layers downstream the blunt trailing edge of airfoils with Gurney flaps as a lift enhancing mechanism. Experimental investigations relating the asymmetry of the vortex flow in the near wake region, able to distort the flow increasing the downwash of an airfoil, have been performed. We examine the lift behaviour and near wake region characteristics of the low Reynolds number airfoil HQ17 without and with Gurney mini-flaps of different lengths. The flow immediately downstream the trailing edge down to 2 mini-flap lengths is explored in order to identify signs of asymmetry of the initial counter rotating vortex structures. Experimental evidence is presented showing that for typical lifting conditions the shear layer rollup process within the near wake is different for the upper and lower vortices: the shear layer separating from the pressure side of the airfoil begins its rollup immediately behind the trailing edge creating a stronger vortex while the shear layer from the suction side begins its rollup more downstream creating a weaker vortex. Aspects of a mechanism connecting the different evolution and pattern of these initial vortex structures with the lift increase due to these flaps are presented.*

Keywords: *Flow control; Low Reynolds Aerodynamics; High lift device; Shear layers*

I. Introduction

The wake immediately downstream a common lifting airfoil is asymmetric due to the different external and boundary layer flows on the pressure and suction surfaces of the airfoil. The wake structure in this near wake region is influenced by aero dynamical loading and airfoil characteristics.

Downstream of the trailing edge of a normal lifting airfoil the downwash diminishes rapidly. Hah and Lakshminarayana, in their experimental and numerical study about the near wake of a lifting airfoil [1], confirmed that the asymmetric wake becomes nearly symmetric after only one chord length downstream of the trailing edge.

These authors reported also that the far wake shows a roughly symmetric wake structure in which the airfoil features and aero-dynamical loading which do not influence the wake development anymore. The main downwash occurs within the asymmetric region.

The unsteady nature of the counter rotating vortices behind a Gurney flap complicates, despite a long-standing experience in the classic lift evaluation due to a vortex system bound to a wing, a physical realistic theoretical understanding of the lift increase generated by these miniflaps.

It is known that the highly unsteady nature of flows associated with vortex shedding make difficult its theoretical and experimental understanding. It should be mentioned that up to date there are no theories for predicting the drag coefficient as a function of Reynolds number in vortex shedding conditions of extremely basic bodies as a circular cylinders.

The Gurney flap was studied by many authors [2]- [5], reporting an increase of the lift and lift-to-drag ratio and a reduced form drag obtained at high lift coefficients compared with the same airfoil without the flap.

Giguére et al [6], described experimentally the aerodynamic behavior of these flaps scaling their height with the boundary layer thickness. These authors conjectured that the trailing edge counter-rotating vortices induce streamlines resembling a smooth aerodynamic prolongation of the airfoil, allowing a better trailing edge pressure recovery, adding a virtual camber by shifting downward the Kutta condition.

A more detailed description of the flow structures in the Gurney flap pattern obtained by experiments with laser Doppler anemometry (LDA) was reported [7], [8].

Aspects of the behaviour of airfoils equipped with miniflaps with different lengths were described in [9], reported about the influence of free stream turbulence structure on these devices.

The common fluid dynamic models of airfoils with Gurney flaps describe a change in the flow pattern resembling a camber increment and a downward shift of the external rear stagnation point. But they assume the existence, from a downstream distance of one more less one chord, of a Karman type vortex wake taking no notice of the differences between the near wake flow (horizontal downstream distances below half chord). In some studies about aerodynamic efficiency of Gurney

flaps it is common to find the assumption that the

Manuscript received and revised March x, accepted April x

effect of the vortex wake on lift to drag ratio is detrimental. In order to attain a drag reduction by "*stabilizing the wake"* some authors suggest the use of span-wise holes, slits, serrated flaps and wake-bodies [10], [11], while other recommend to eliminate straightforward the double row of counter-rotating vortices of the wake behind a Gurney type miniflap [12].

In contrast we hypothesize that different perturbations at the separating regions of the shear layers from the pressure and suction sides of an airfoil introduce asymmetry in the vortex structures of the near wake region able to produce lift enhancing effects.

The physical phenomena by which the vortex structures of the near wake immediately behind the blunt trailing edge of an airfoil with Gurney flap interact with the fluid pattern around the airfoil, and its connection with the observed lift increase mechanism are still poorly understood.

The turbulent flow behind the blunt trailing edge of an airfoil with a Gurney flap involve separating turbulent boundary layers developing into shear layers which rollup into discrete vortices

The negative and positive vorticity from the separating boundary layers is packed into the rolling up shear layers developing into vortices that convect downstream at the vortex shedding frequency. The Kutta condition is obviously not fulfilled at the blunt trailing edge. In contrast a moving stagnation point appears located rearward and downward from the trailing edge of the airfoil.

Each time a vortex is shed into the wake circulation is produced. According Kelvin's theorem, the periodic vortex shedding from the trailing edge into the wake is connected to time variations of the strength of the bound vortex, which in turn deviates the velocity field inducing periodic variations of the angle of attack of the incident velocity.

Let us concentrate on the near wake flow behind blunt bodies. A periodic shedding of equal counter rotating vortices creates a periodic up and downward lift and periodic drag variations. A body with a Karman type vortex wake, experiences a periodic fluctuating upward and downward lift coupled to the regular counter rotating vortex shedding which induces upward and downward deflections of the flow. A time averaged Karman type vortex street pattern alone could not contribute to a steady lift. The lift required in common aeronautic applications involves a preferential deviation of the oncoming flow visualized by the known up and downwash before and behind a wing. If we focus on the downwash of the flow behind the trailing edge of a conventional lifting airfoil, we appreciate that more lift is connected with more downwash. Therefore it is unrealistic to conceive that a symmetric von Karman vortex street generated behind a Gurney type flap may be connected to a lift increase, as assumed by the common fluid dynamic models of these miniflaps.

In the near wake region of lifting airfoils with a blunt trailing edge the initial eddies of the vortex street rotating in one direction, should be dissimilar to the initial eddies rotating in the opposite direction thus a preferential deflection of the wake connected to a time averaged steady lift will occur.

We explore the near wake, looking for particular asymmetries in the near trailing edge vortex pattern able to promote lasting deviations of the wake flow, associated with lift producing up or downwash.

II. Experimental Procedures

The experiments were carried out at the Boundary Layer and Environmental Fluid Dynamics Laboratory (LaCLyFA) wind tunnel, at the Faculty of Engineering at the Universidad Nacional de La Plata, Argentina, at Reynolds number below 5×10^5.

In what follows, the airfoil is considered with the suction and pressure surfaces located above and below respectively.

The basic tested model was an untwisted wing with a rectangular platform with a chord length of 45cm and a span of 80cm. Each model with the different Gurney flaps was horizontally placed in the test section (1.4 x 1 m^2). The wing was examined within the range of -12 degrees and +24 degrees of angle of attack. Airfoils with miniflaps with similar dimensions have been studied by numerical simulations [12].

The lift and drag of a low Reynolds number airfoil HQ17 without and with Gurney flaps of four different lengths: 1%, 1.5%, 2% and 2.5% of the wing chord have been measured. Simultaneously the near wake vortex region was explored in order to recognize the initial location of the region in which the detached shear layers start to rollup, and the strength and features of the generated vortices.

Lift and drag data were acquired by an aerodynamic two components balance, built by the authors according to [13], based on strain-gages type cells, arranged as a double Wheatstone bridge. Horizontal and vertical loads were measured simultaneously [14].

Velocities were acquired by means of a six channel Dantec Streamline constant temperature anemometer, using an X-wire Dantec sensor probe 55R51 at an acquisition frequency of 2000 Hz per channel. The data was processed by a Vishay series 2310 signal conditioners and amplifiers. Due to the minimal frontal area of the wing sections (0.8 x 0.10 m^2), no blockage correction was applied to the results. Temperature was continuously measured in order to adjust the air density. Turbulent velocities were acquired, at the free stream (upstream of the model), in order to characterize the upcoming flow. Also, measurements were made downstream of the trailing edge along a grid with two horizontal points placed at distances of 2% and 4% of the airfoils chord and 13 vertical intervals of 2mm (see, for details, Figure 2).

By analogy with the flow behind usual blunt bodies the width of the blunt trailing edge, which coincides with the length of the mini-flap H, was taken as a significant scale of the motion in the near wake region. The leading edge of the miniflap is attached to the trailing edge of the airfoil.

Figure 1 shows the schema of a Gurney mini-flap configuration and the anemometer sensor location. Figure 2 shows the grid measurement schema.

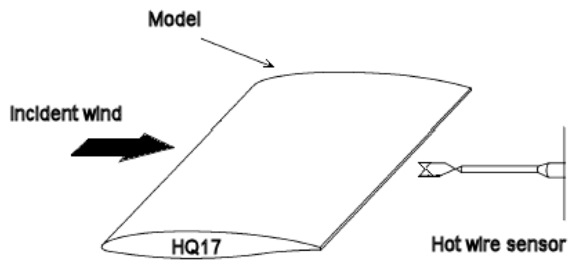

Figure 1. Experimental setup

Figures 3 and 4 shows the C_L and C_D obtained values, plotted as a function of the angle of attack, for the plain wing and for the different miniflaps sizes. We could say that all the miniflaps increase the lift and drag coefficients, in comparison with the clean airfoil. From the drag point of view, for all the Gurney sizes, a little bit less drag is exhibit by the smaller one (1%c).

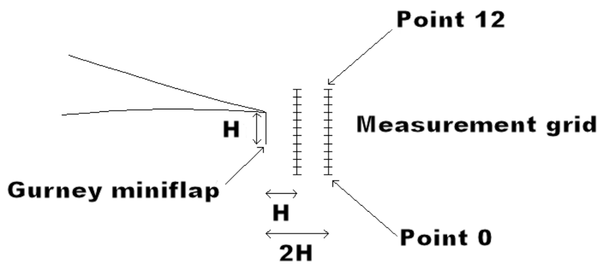

Figure 2. Measurement grid

In order to obtain more accurate information about the scale of the turbulent structures which appear intermittently in the flow downstream the trailing edge, a wavelet analysis was performed. This procedure retains information in time domain as well as in the frequency domain. The wavelet analysis of the velocity data allows the identification of aspects of turbulent structures which can be connected to transport events. The continuous wavelet transform used in this paper, is known to be appropriate for analyzing turbulent flow data [15], [16].

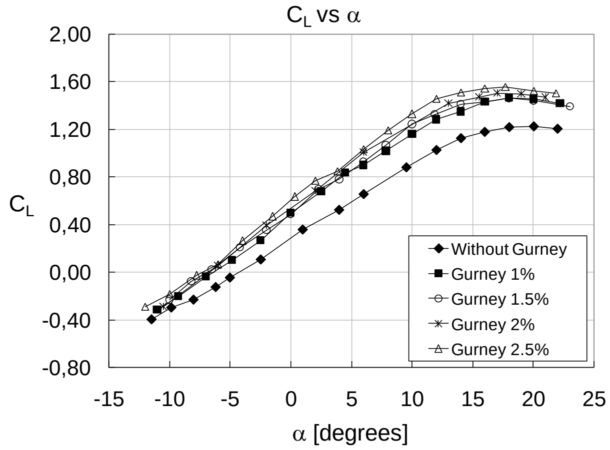

Figure 3. C_L vs angle of attack

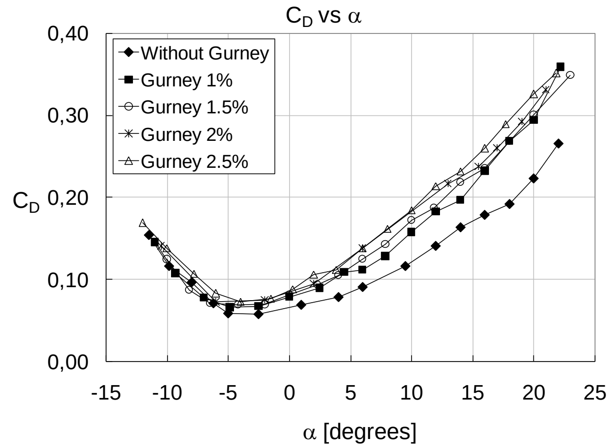

Figure 4. C_D vs angle of attack

Our aim was to compare time scales, intensities and frequencies of the turbulent structures in the wavelet map behind the Gurney flap. Some wavelet interpretation criteria used by Mahrt [17], estimating the time extent and frequency of a particular detected structure directly from its wavelet graph scale. The velocity-time records were explored in order to detect features related to the second derivative of a Gaussian g2 (usually called the 'Mexican hat' wavelet). Assuming frozen flow theory, one can deduce the Turbulent Spatial Scale for the velocity component, looking for the maximum in the wavelet map.

III. Discussion and Conclusions

The measured lift values are consistent with those described by Schatz [12] in their computational experiments. It is also interesting to point out that these authors subscribe to our perception in considering the influence of features of the wake flow on the wing aerodynamics when they mentioned that particular characteristics of the wake had direct influence upon the increase of the section drag coefficient.

From the top and the trailing edge of a mini-flap two shear layers emerge which roll up into a pattern of alternating counter rotating vortices establishing an *absolute wake instability* [18]. The Karman vortex street in the wake of a cylinder exhibits this type of instability.

When an absolutely unstable scenario exists, arbitrary disturbances injected in the flow stay at or propagates upstream and/or downstream of its point of introduction. Therefore it is to be expected that the vortex structures generated behind the airfoil are able to influence upstream and downstream conditions.

Absolute instabilities can be found in laminar and turbulent flows. They are characterized by a clear peak in the spectrum of the fluctuations in the wake and its surroundings. The near wake regions were the rollup of the shear layers evolve into the initial vortical structures behind the tested airfoils display a significant peak in the spectra of the velocity fluctuations indicating a clearly identifiable absolute instability shown in Figs 5 and 6.

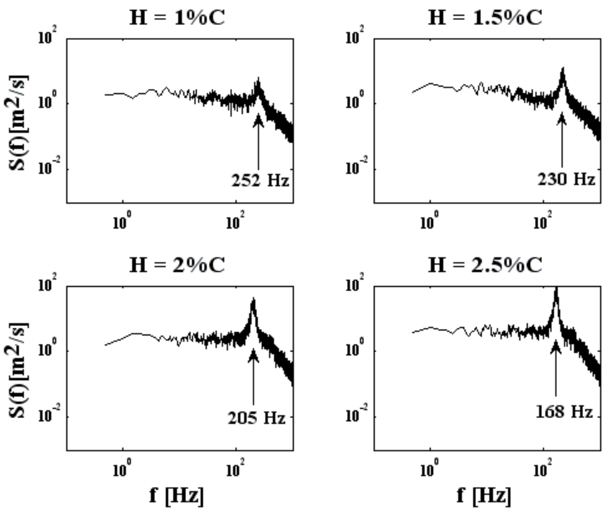

Figure 5. Power Density Spectra Distribution for different Gurney flap sizes related to the airfoil chord (C) at point 2 of the grid and 2H downstream into the wake (v component)

We assume that major spectral peaks take place in near wake regions where the rollup of the shear layers evolve into vortices before flowing downstream. During its generation these vortex structures are subjected to a slow downstream motion remaining in the vicinity of the trailing edge for some time. Therefore an anemometric probe placed in these sectors will be frequently immersed in these vortices in order to extract vortex related flow data.

The height of a spectral peak measured at a fixed point is a result of the strength of the passing vortex but also of the time that the rolling up shear layers remain near the measuring point before being convected downstream.

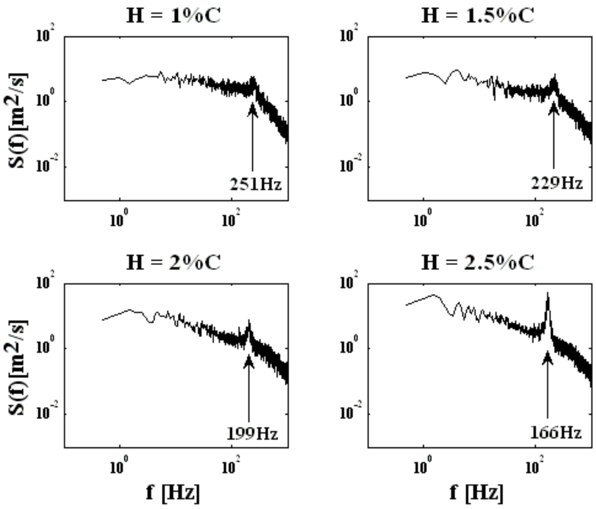

Figure 6. Power Density Spectra Distribution for different Gurney flap sizes of the airfoil chord (C) at points 7, 8, 9, and 10 of the grid, corresponding to the trailing edge of the profile, and at 2H downstream into the wake (v component)

However we were not interested in finding the exact location of the regions where the vortices develop. In our experiments we explored the flow immediately behind the trailing edge in regions exhibiting a dominant spectral peak, with the aim to find evidences of an enduring asymmetry able to deviate the flow in the near wake region, enhancing the downwash.

By exploring the near wake region searching for regions with the highest spectral peaks we found the following differences in the behavior of the shear layers separating from the suction and pressure surfaces of the airfoils.

For typical lifting conditions the shear layer rollup process within the near wake was always different for the upper and lower vortices: the shear layer separating from the pressure side of the airfoil began its rollup immediately behind the trailing edge of the mini-flap creating a stronger vortex, while the shear layer from the suction side initiated its rollup more downstream generating a weaker vortex. These results are summarized in Table 1 and 2.

The larger intensity of the vortex generated by the rolling up of the shear layer separating from the pressure side of the airfoil found for all the flap sizes is illustrated by the spectra shown in Figures 5 and 6. Also, closer examination of the wavelet graphs displayed in Figs 7 and 8 shows that the highest strength of the vortex from the suction side is more diffused involving a larger region of the wake than the more energetic vortex generated by the shear layer separating from the pressure side of the airfoil, which exhibits its highest intensity concentrated in a smaller region.

1% - 1H		
Point	**Frequency [Hz]**	**S(f)v [m ^{2} /s]**
2	251	5,7
7	251	4,46
1,50% - 1H		
Point	**Frequency [Hz]**	**S(f)v [m ^{2} /s]**
2	215	7,32
8	229	6,15
2% - 1H		
Point	**Frequency [Hz]**	**S(f)v [m ^{2} /s]**
2	199	28,5
9	203	4,14
2.5% - 1H		
Point	**Frequency [Hz]**	**S(f)v [m ^{2} /s]**
2	167	146
10	169	45,3

Table 1. Power Density Spectra Peaks and peak Frequency for Gurney flaps of different sizes, at the downstream distances H

1% - 2H		
Point	**Frequency [Hz]**	**S(f)v [m ^{2} /s]**
2	252	7,36
7	251	5,96
1,50% - 2H		
Point	**Frequency [Hz]**	**S(f)v [m ^{2} /s]**
2	230	13,6
8	229	6,39
2% - 2H		
Point	**Frequency [Hz]**	**S(f)v [m ^{2} /s]**
2	205	53,4
9	199	8,5
2.5% - 2H		
Point	**Frequency [Hz]**	**S(f)v [m ^{2} /s]**
2	168	117
10	166	55,7

Table 2. Power Density Spectra Peaks and peak Frequency for Gurney flaps of different sizes, at the downstream distances 2H. (Points 7, 8, 9 and 10 are located at the trailing edge level of the airfoil for each Gurney flap size and Point 2 always corresponds to the level indicating the trailing edge of the Gurney flap). It can be seen that the spectral peak S(f) of the flow behind the trailing edge of the mini-flap is always larger than the corresponding peak behind the leading edge of the mini-flap

This behavior was also confirmed by wavelet analysis. Such Figures illustrates the wavelet graphs for H =1.5% C, performed at points 2 and 8 immersed in the route of the vortices from the pressure and suction side of the airfoil respectively.

According Kelvin's theorem, the vortex shedding of a lifting airfoil into the wake is connected to time variations of the strength of the bound vortex. It is quite evident that for an airfoil with Gurney flap the vortex shedding behind the trailing edge must also connected with the overall circulation around the airfoil. The stronger vortex generated by the rolling up of the shear layer from the pressure side of an airfoil, is connected to an augmented circulation of the bound vortex promoting a lift increase, which can not be counteracted by the lift decrease due to the weaker opposite circulation connected to the counter rotating rolling up shear layer from the low pressure surface.

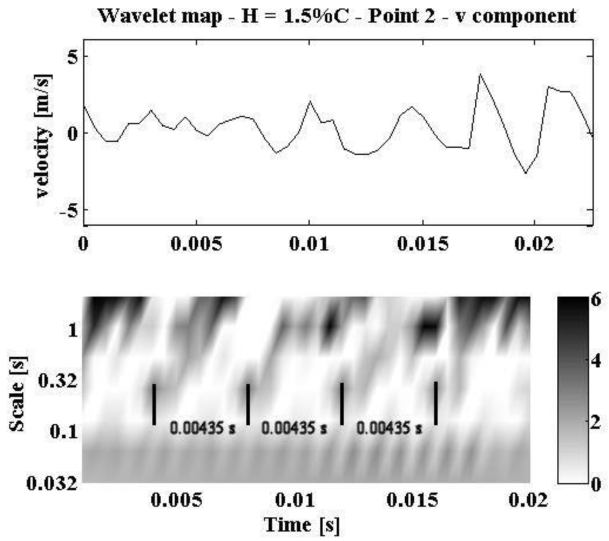

Figure 7. Wavelet map for the Gurney flap of 1.5% of the airfoil chord (H) at point 2 of the grid and 2H downstream into the wake (v component). It shows the scale of the structures, period of 0.00435 s.

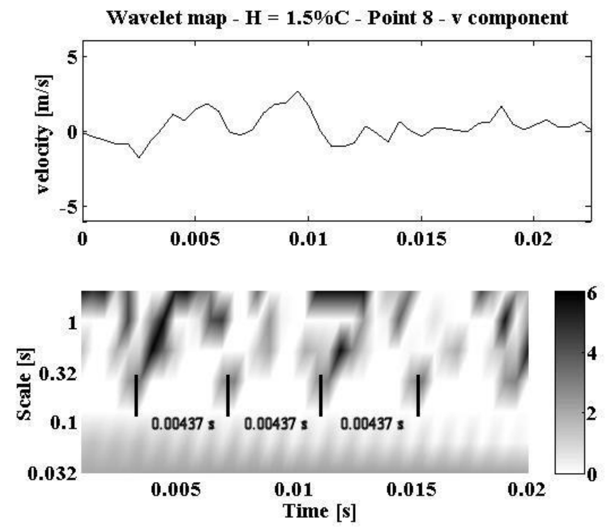

Figure 8. Wavelet map for the Gurney flap of 1.5% of the airfoil chord (H) at point 8 of the grid and 2H downstream into the wake (v component). It shows the scale of the structures, period of 0.00437 s.

It seems reasonable to infer that the increased strength of the lower vortex and its proximity to the downwind surface of the mini-flap deflects the location of the free rear stagnation point.

Due to the asymmetry of the initial vortices the mean location of this stagnation point is slightly shifted downstream and downward in comparison with the mean position of the stagnation point behind a blunt body with a classic Karman vortex street.

How can we explain the asymmetric behavior of the initial vortices? Existing research shows that the shear layer separating from the pressure side of the airfoil is influenced by the intermittent shedding of the vortex structures originated along the upstream surface of the mini-flap. Such structures have been recently visualized [19].

These authors carried out detailed time-resolved PIV visualizations of the flow around an airfoil with Gurney flap. They reported the presence of a new mode, not described in previous experimental or numerical works, in addition to the known Karman type vortex shedding mode. They showed that this mode was originated by the intermittent shedding of fluid from the upstream side of the gurney flap which interacts with the Karman type vortex wake. They suggested that this interaction could be part of a mechanism responsible for a significant portion of the overall lift increment. Such observations are qualitatively consistent with a simple interpretation of a mini-flap acting as a small barrier behaving as a passive perturbation device.

The intermittent shedding of vortex structures from the upwind region of the mini-flap into the wake reported [19], can be interpreted as a perturbation mechanism acting on the shear layer emerging from the pressure side of the airfoil at its separation point from the trailing edge. The shear layer detaching from the suction side is submitted to a very different perturbation. Therefore it is to be expected that the corresponding vortex structures generated by the rollup of the shear layers will also be different introducing asymmetry in the vortex pattern of the near wake region.

It is known that turbulent shear flows are very sensitive to small changes in initial or boundary conditions and to different types of perturbations applied during transition [20]. Such perturbations could generate particular perturbation dependent shear layer organized structures that dominate the downwind evolution of the layer [21].

The mentioned shedding of the vortex structures generated in the gap upstream of the mini-flap into the wake region were the shear layer is generated, fulfill the conditions of a specific perturbation acting on the region were the shear layer is generated and therefore able to influence the shape and evolution of vortex structures. The studies of Kiya et al [22] - [24] describe interesting aspects of the response of a shear layer perturbed by vortices which also corroborate the asymmetric behavior detected in our experiments.

These authors also found that the entrainment rate of a shear layer can be enhanced by vortex interaction. Moreover, they showed an aspect which is crucial for the present research, pointing out that when adequate vortex structures are injected in a shear layer the rollup process is changed and larger vortices ere generated. This is consistent with the differences in the rollup processes shown in our experiments

The perturbations on the shear layer separating from the suction side of the airfoil are different. The simplified bidimensional picture that emerge from the present considerations correspond to a flow detaching at a blunt trailing edge in which the two separating shear layers are submitted to very different perturbations.

We think that it would be useful and interesting to study experimentally and numerically, the effect of shear layer rolling up behind a Gurney flap due to different periodic forcing, for example by acoustic waves or oscillating plates. The present study aims to give good reason for exploring efficiency improvements by way of a "more favorable vortex wake" behind a Gurney flap by controlling the time dependent evolution of the rolling up shear layers at the near wake, adjusting the rate of shedding, the vortex strength, geometry, size and spacing.

Nomenclature

C	=	airfoil chord
C_L	=	Lift coefficient
C_D	=	Drag coefficient
f	=	frequency [Hertz]
H	=	Gurney mini-flap height
$S(f)$	=	Power Density Spectra Distribution [m^2/s]
v	=	vertical velocity component
α	=	angle of attack [degrees]

Acknowledgements

We thanks Eng. Daniela G. François for their collaboration in the experiments and data processing, and Dra. Ana Scarabino for her collaboration in signal processing.

References

[1] C. Hah et al, Measurement and prediction of mean velocity and turbulence structure in the near wake of an airfoil, *Journal of. Fluid Mechanics. Vol.115, 1982 pp. 251-282.*

[2] R.H. Liebeck, Design of subsonic airfoils for high lift, *Journal of Aircraft Vol. 15, No. 9, 1978, pp 547-561.*

[3] D.H. Neuhart et al, A water tunnel study of Gurney flaps, *NASA TM-4071, 1988.*

[4] A.W. Bloy, Aerodynamic Characteristics of an aerofoil with Small Trailing Edge Flaps, *Wind Engineering, Vol. 19, No.3, 1995, pp 167-172.*

[5] B.L. Storms, Lift Enhancement of an Airfoil Using a Gurney Flap and Vortex Generators, *Journal of Aircraft* Vol. 31, No. 3, 1994, pp 542-547.

[6] P. Giguére, J. Lemay, G. Dumas, Gurney Flap Effects and Scaling for Low-Speed Airfoils, *AIAA Paper 95-1881, 13th AIAA Applied Aerodynamics Conference San Diego,* 1995.

[7] D.R.M. Jeffery, D.W. Hurst, Aerodynamics of the Gurney Flap, *AIAA Applied Aerodynamic Conference, AIAA 96-2418-CP*, 1996.

[8] D. Jeffrey et al, Aerodynamics of Gurney Flaps on a Single-Element High-Lift Wing, *Journal of Aircraft*, Vol. 37, 2000, pp. 295-301.

[9] F. Bacchi, J. Marañón Di Leo, J.S. Delnero, J. Colman, M. Martinez, M. Camocardi, U. Boldes, Determinación experimental del efecto de mini flaps Gurney sobre un perfil HQ–17, *Fluidos-2006 IX Reunión Sobre Recientes Avances En Física de Fluidos y sus Aplicaciones, Mendoza, Argentina,* 2006.

[10] C.P. Van Dam et al, Gurney Flap Experiments on Airfoil and Wings, *Journal of Aircraft (0021-8669),* Vol.36, No.2, 1999, pp. 484-486.

[11] D.W. Bechert, R. Meyer, W. Hage, Drag Reduction of Airfoils with Miniflaps. Can We Learn From Dragonflies?, *AIAA-2000-2315, Denver, CO,* 2000.

[12] M. Schatz, B. Guenther, F. Thiele, Computational Modeling of the Unsteady Wake behind Gurney-Flaps, *2nd AIAA Flow Control Conference, AIAA-2417, Portland, Oregon, USA*, 2004.

[13] S. Tusche, Interner Bericht: *Beschreibung des Konstruktiven Aufbaus und Kalibrierung von 6-Komponenten-DMS Windkanalwaagen*, DLR, Goettingen, 1984.

[14] J.S. Delner et al, Experimental determination of the influence of turbulent scale on the lift and drag coefficients of low reynolds number airfoils, *Latin American Applied Research*. *Vol 35 No.4 – pp. 183 – 188*, 2005.

[15] M. Farge, Wavelet Transforms and their applications to Turbulence, *Annual Rev. Fluid Mechanics,* **24**, 395-457 (1992).

[16] M. Farge, Transformee en ondelettes continue et application a la turbulence, *Journ. Annu.Soc. Math., France,* 17-62 (1990).

[17] L. Mahrt, Eddy asymmetry in the sheared heated boundary layer. *J. Atmos. Sci.*, *48*, 472--492, 1991.

[18] P. Huerre et al, Absolute and convective instabilities in free shear layers, *Journal of Fluid Mechanics*, Vol. 159, 1985, pp. 151-168.

[19] D.R. Troolin et al, Time resolved PIV analysis of flow over a NACA 0015 airfoil with Gurney flap, *Experiments in Fluids* Vol. 41, 2006, pp. 241–254.

[20] D. Oster et al, The forced mixing layer between parallel streams, *Journal of Fluid Mechanics,* Vol. 123, 1982, pp. 91-130.

[21] C. M. Ho et al, Perturbed free shear layers, *Annual Review of Fluid Mechanics*, Vol. 16, 1985, pp. 365-424.

[22] M. Kiya et al, Vortex pairs and rings interacting with shear-layer vortices, *Journal of Fluid Mechanics*, Vol. 172, 1986, pp. 1-15.

[23] M. Kiya et al, Turbulent elliptic wakes, *Journal of Fluids and Structures*, Vol. 13, 1999a, pp. 1041-1067.

[24] M Kiya et al, Separation Control by Vortex projectiles, *AIAA-1999-3400 - AIAA Fluid Dynamics Conference, 30th, Norfolk, VA,* 1999

[1]Dr. Ulfilas Boldes – Consultant - Laboratorio de Capa Límite y Fluidodinámica Ambiental – Facultad de Ingeniería – Área Departamental Aeronáutica – Universidad Nacional de La Plata – calle 116 entre 47 y 48 S/N – La Plata (1900) – Argentina.

[2]Dr. Juan Sebastián Delnero – Researcher - Laboratorio de Capa Límite y Fluidodinámica Ambiental – Facultad de Ingeniería – Área Departamental Aeronáutica – Universidad Nacional de La Plata – calle 116 entre 47 y 48 S/N – La Plata (1900) – Argentina.
Researcher - Consejo Nacional de Investigaciones Científicas y Técnicas, Avda. Rivadavia 1917, CP C1033AAJ,Cdad. de Buenos Aires, Argentina.

[3]Dr. Julio Marañón Di Leo – Researcher/Director - Laboratorio de Capa Límite y Fluidodinámica Ambiental – Facultad de Ingeniería – Área Departamental Aeronáutica – Universidad Nacional de La Plata – calle 116 entre 47 y 48 S/N – La Plata (1900) – Argentina.
Researcher - Consejo Nacional de Investigaciones Científicas y Técnicas, Avda. Rivadavia 1917, CP C1033AAJ,Cdad. de Buenos Aires, Argentina.

[4]Dr. Jorge Leon Colman Lerner - Researcher - Laboratorio de Capa Límite y Fluidodinámica Ambiental – Facultad de Ingeniería – Área Departamental Aeronáutica – Universidad Nacional de La Plata – calle 116 entre 47 y 48 S/N – La Plata (1900) – Argentina.

[5]Ing. Mauricio Ezequiel Camocardi – Research Assistant/PhD Student - Laboratorio de Capa Límite y Fluidodinámica Ambiental – Facultad de Ingeniería – Área Departamental Aeronáutica – Universidad Nacional de La Plata – calle 116 entre 47 y 48 S/N – La Plata (1900) – Argentina.
Fellow scholarship - Consejo Nacional de Investigaciones Científicas y Técnicas, Avda. Rivadavia 1917, CP C1033AAJ,Cdad. de Buenos Aires, Argentina.

