BIPLANE CONFIGURATION ANALYSIS

Iulian NICOLA[1], Daniel ȚURCANU[2], Tudor PRISECARU[3], Cristian PREDOI[4]

The paper presents a study of the flow around a biplane configuration with the purpose to determine interaction between the two aerodynamic profiles. In order to study the effect of interaction between the profiles in a biplane configuration, experimental measurements were made in a wind tunnel. This paper focus on the flow around the biplane configurations. Also, the experimental results were compared with numerical analysis.

Keywords: biplane configuration, flow, laser Doppler system, gap, stagger, decalage.

1. Introduction

The purpose of the paper is to study the flow around a biplane configuration in order to identify a solution for the design of a drone used for capturing multispectral images. According to its usage, the drone must be able to carry the payload and to fly at low speed, but in the same time to be able to develop speed of 10 m/s.

The study of the flow around the biplane configuration was done both numerical and experimental using laser Doppler method.

With respect to other similar papers, the novelty of this paper consists in studying the biplane configuration using laser Doppler method in combination with numerical analysis and results from efforts measurements.

The experimental determination of the flow around the aerodynamic profile has been done using the laser Doppler method. This method is well suited for velocity measurement having a very high precision, approximately of the wavelength of the laser beam, and it does not influence the measurement process, being a non-intrusive method.

[1] Postdoctoral researcher, University POLITEHNICA of Bucharest, Romania, e-mail: iuliannicola@yahoo.com;
[2] Postdoctoral researcher, University POLITEHNICA of Bucharest, Romania, e-mail: turcanued@yahoo.com;
[3] Prof., The Faculty of Mechanical Engineering and Mechatronics, University POLITEHNICA of Bucharest, Romania, e-mail: tudor.prisecaru@upb.ro;
[4] PhD student, University POLITEHNICA of Bucharest, Romania, e-mail: cpredoi@acttm.ro.

According to Doppler theory, the frequency of the light scattered by a particle and received by a detector is given by the following equation [1]:

$$f_s = f_i \frac{1 - e_i \frac{V}{C}}{1 - e_s \frac{V}{C}} \tag{1}$$

where: c is the velocity of light, f_s is the frequency of light reaching the detector, f_s is the frequency of the incoming light, V is the velocity of the particle, and e_i and e_s are the unit vectors describing the direction of the light.

The Doppler shift is given by the relation [1]:

$$f_d = f_i \left[\frac{V}{c} (e_1 - e_2) \right] \tag{2}$$

The Doppler shift is directly proportional to the corresponding component of the velocity of the particle [1]:

$$v_x = \frac{\lambda}{2 \sin \frac{\theta}{2}} f_d \tag{3}$$

where λ is the wavelength of the laser beam and θ is the angle between the two laser beams.

Although laser Doppler method has a lot of advantages, it also has some disadvantages like: the structure of transparent window may produce light refraction and dislocation within the measured volume caused by homogeneity. Another disadvantage is concerning seeding in order to assure a good signal to noise ratio.

In order to overcome this disadvantages, the glass of the window corresponding to the wind tunnel wall was carefully chosen and the seeding calculated and verified.

2. Experimental Measurements

In order to study the effect of interaction between two wings mounted biplane configuration experimental measurements were made for the flow around the biplane configuration and for the aerodynamically efforts. Experimental measurements were performed for different biplane configurations and also for monoplane in order to compare the results.

All measurements were performed for a 2D case in a subsonic wind tunnel (Prandtl) at a speed of 20 m/s. The two wings are identical: rectangular wings with NACA0012 profile.

2.1 The model and notations

The model consists by two identical rectangular wings with NACA0012 profile. The wing dimensions are: length l = 320 mm and chord c = 107 mm.

The mounting is a wall mounting.

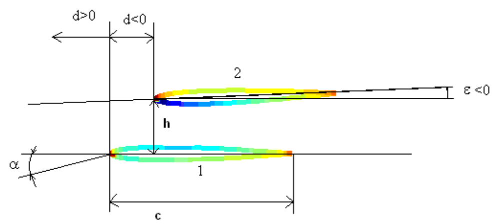


Fig. 1. The biplane configuration parameters

The following geometrical characteristics are define for the biplane configuration having the same aerodynamic profile [2]:

Gap (h) - the vertical distance between the leading edges of the two aerodynamic profiles perpendicular to the free stream.

Stagger (d) - distance between the two wing leading edges parallel to the free stream. The stagger is assumed positive when the upper wing is fore of the lower wing.

Decalage (ε) - it is assumed positive when the upper wing is at greater incidence than the lower.

Both gap and stagger are referenced to the chord length of the model.

2.2 Velocity measurements

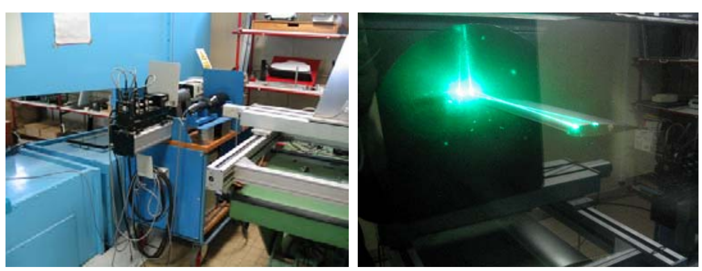


Fig. 2. Laser Doppler velocity measurement system

The velocity measurements were made using the Laser Doppler velocity measurement technique.

Measurements are made for a single component of the velocity, parallel with the direction of the flow. In order to make measurements for two components of the velocity, two pairs of converging laser beams are needed, and both pairs of laser beams most converge in the same point, the measurement point. Measurements for two component of the velocity couldn't be made in the vicinity of the profiles because of the convergence angle. So, in order to better describe the flow near the profiles, only one component of the velocity was measured, the component which has the same direction with the flow. But also, near the profiles, the measurements errors are larger because of the profiles vibratory motion.

For the biplane configuration, the flow velocities around the profiles was measured for the following configurations:

Table 1

Studied biplane configuration for gap and stagger

Biplane configuration	Gap (G)	Stagger (S)	Decalage (ε)	Incidence angle	Obs.
1	$1.5 \cdot c$	0	0	0^o and 5^o	No interaction between the two wings (like 2 monoplanes)
2	$0.5 \cdot c$	0	0	0^o and 5^o	To view the influence of gap
3	$0.5 \cdot c$	$-0.5 \cdot c$	-3^o	0^o and 5^o	To view the influence of stagger and decalage

The measurements were made in a plane perpendicular on the two wings and located at the middle of the wings in order to have a bi-dimensional flow. For the definition of measurements points, a measurement mesh points was defined. The measurement mesh is smoother near the profiles for a better observation of the flow. The most difficult measurements were near the leading edge because of the convergence of the laser beams.

3. Numerical Analysis

Besides the experimental results [3], a numerical analysis has been undertaken using Flow Simulation module from SolidWoks.

There was made an external analysis of the profile excluding internal cavities.

The analysis was made under gravity conditions.

The numerical analysis was made under the following conditions: the fluid used was the air at 101325 Pa pressure and 293.2 K temperature; the walls were considered adiabatic and with no roughness; the flow was considered to be laminar.

The velocity of the flow was set at 20 m/s on X axis in order to have a good comparison with the experimental data and in order to simulate the angle of incidence of 5^o the aerodynamic angles were used (0.0872 rad angle of attack).

The result resolution was set at maximum and the simulation was a 2D simulation on XY plane.

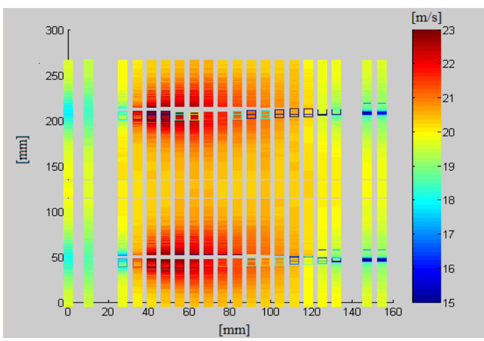
4. Results and Discussions

4.1. Configuration 1

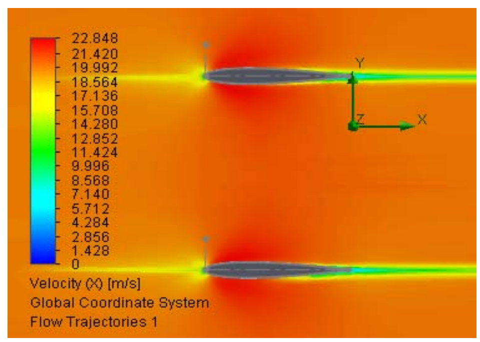
4.1.1. 0^o incidence angle

The results from the flow velocity measurement and numerical analysis are presented in the image below (figure 3). The flow around the two profiles is similar as a flow around a monoplane configuration in both experimental data and numerical analysis. There are no mutual influence between the two profiles. Also the velocity field is symmetrical for the two profile. The velocities are the same for intrados and extrados for the two profiles resulting a zero lift at this angle of incidence. The stagnation phenomena can be seen at the front of the leading edge. Also, at the rear of the wing, the wake is very well defined.

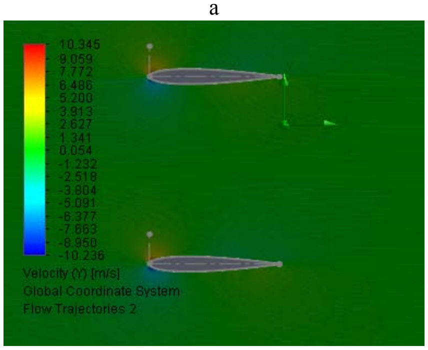
During experimental measurement, because of the wing vibrations, the measurement error is grater near the profiles. When the flow passes between the two profiles, because of the profiles thickness, the velocity of the flow increases and when the thickness of the profiles is getting smaller, the velocity of the flow decreases.



a



b



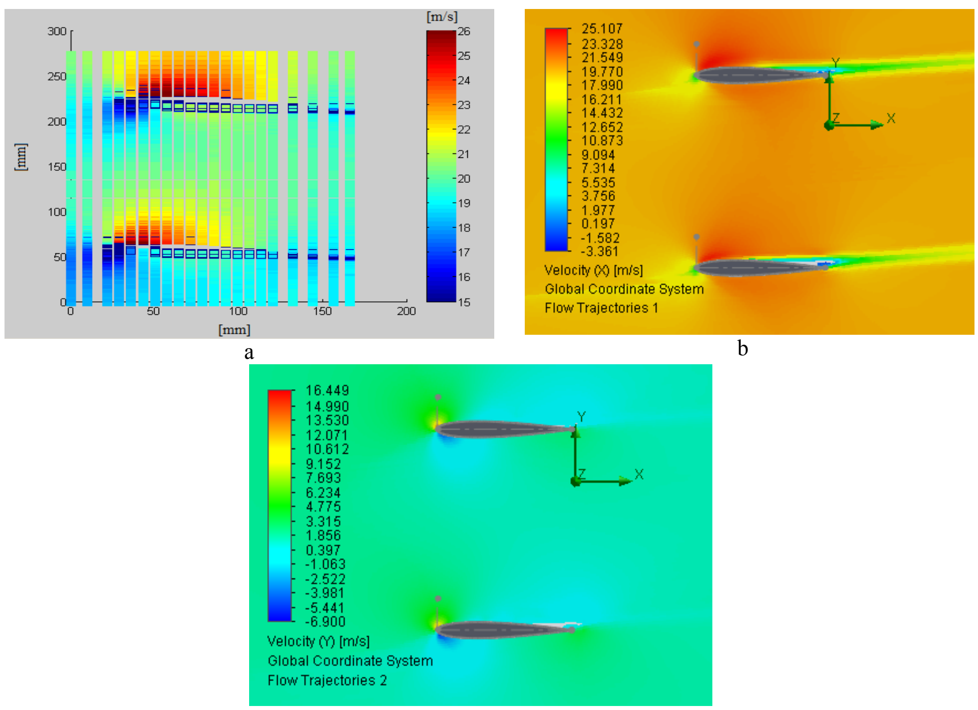
c

Fig. 3. The field of velocities for the configuration 1 at zero incidence (a – velocity on X axis, experimental measurement; b – velocity on X axis, numerical analysis; c – velocity on Y axis, numerical analysis)

4.1.2. 5° incidence angle

For an angle of incidence of 5°, the influence of the biplane is presented in the figure from below. It can be seen that the flow velocities under the upper profile are greater than under the lower wing. Also the stagnation phenomena is more pronounced for the lower profile.

Another conclusion is that the lift given by the lower profile is greater than the one of the upper profile. In this case, for an incompressible flow, the increase of the flow velocity generate an increase of the dynamic pressure and decrease of the static pressure, resulting the lift. As the difference between the velocities in the upper part of a profile is greater than in the lower part of a profile, the lift increases. In this case, the differences between the velocities in the upper and lower parts of the profiles is grater for the lower profile resulting a greater lift. In conclusion, the influence of the biplane configuration is more benefic for the lower profile than for the upper profile.



a b c

Fig. 4. The field of velocities for the configuration 1 at 5° incidence (a – velocity on X axis, experimental measurement; b – velocity on X axis, numerical analysis; c – velocity on Y axis, numerical analysis)

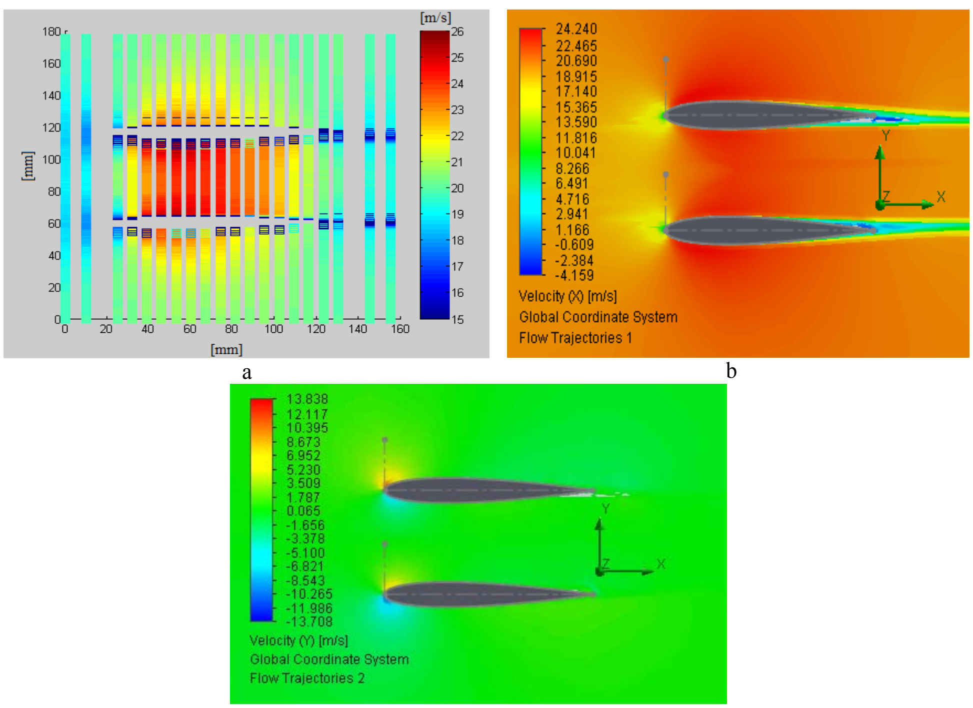
4.2. Configuration 2

4.2.1. 0° incidence angle

Comparison of figure 5 and figure 3 show that in the case of a smaller gap, the flow velocities between the two wing increases. In figure 3a ($1.5 \cdot c$ gap), the maximum velocity is approx. 23 m/s, while in the case of a $0.5 \cdot c$ gap, the maximum velocity is approx. 26 m/s. Also, in this case, the flow around each profile is no more symmetric. Although, at this angle of incidence, the lift of the system is zero, the lift of the lower wing is positive and the lift of the upper wing is negative.

In the experimental measurement, the difference in the velocities of the flow between the lower and upper part of each profile is approx. 3.5-4 m/s. For a gap of $1.5 \cdot c$ there were no differences between the velocities of the flow.

Regarding the numerical analysis, the results are the same with the remark that the difference between velocities between the two profiles and the external part of the biplane configuration are smaller. Also the vertical component of the velocity between the two profiles is zero.



a b

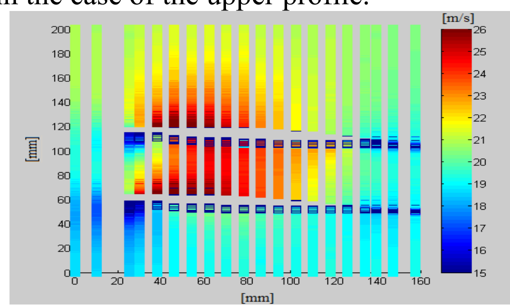
c

Fig. 5. The field of velocities for the configuration 2 at zero incidence (a – velocity on X axis, experimental measurement; b – velocity on X axis, numerical analysis; c – velocity on Y axis, numerical analysis)

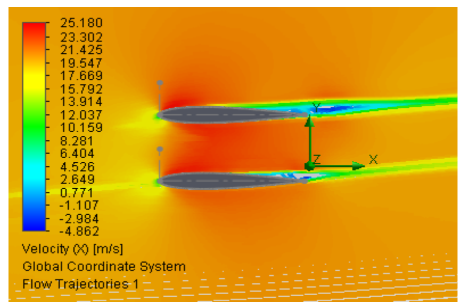
4.2.2. 5^{o} incidence angle

At this angle of incidence, in both experimental measurement and numerical analysis, both profiles presents a positive lift but the lift of the lower profile is greater than the lift of the upper profile. The difference of the velocity of the flow between the upper and lower part of the lower profile is approx. 7 m/s, greater than in the case of the upper profile (in the experimental data). The influence of the biplane configuration is greater than in the case of a $1.5 \cdot c$ gap.

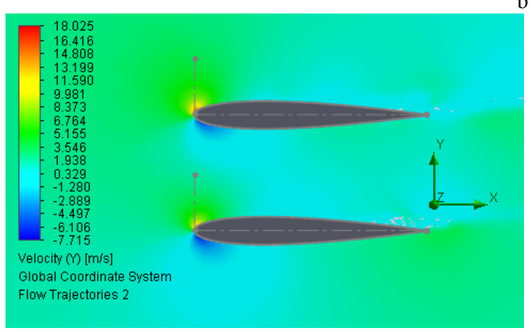
In the numerical analysis the difference of the velocity of the flow between the upper and lower part of the lower profile is approx. 2.7 m/s, also greater than in the case of the upper profile.



a



b



c

Fig. 6. The field of velocities for the configuration 2 at 5o incidence (a – velocity on X axis, experimental measurement; b – velocity on X axis, numerical analysis; c – velocity on Y axis, numerical analysis)

4.3. Configuration 3

4.3.1. 0^{o} incidence angle

In this case the upper profile is in front of the lower profile and it can be seen that the stagnation of the flow is grater for the upper profile because of the decalage of -3^{o}.

The difference of the velocities from the upper and lower part of the profile is greater for the upper profile, but the velocity in the upper part is smaller than the velocity in the lower part of the upper profile, resulting a negative lift. Although the incidence angle is zero, the lower profile has a small lift given by the biplane configuration. The resulting lift of the configuration is negative.

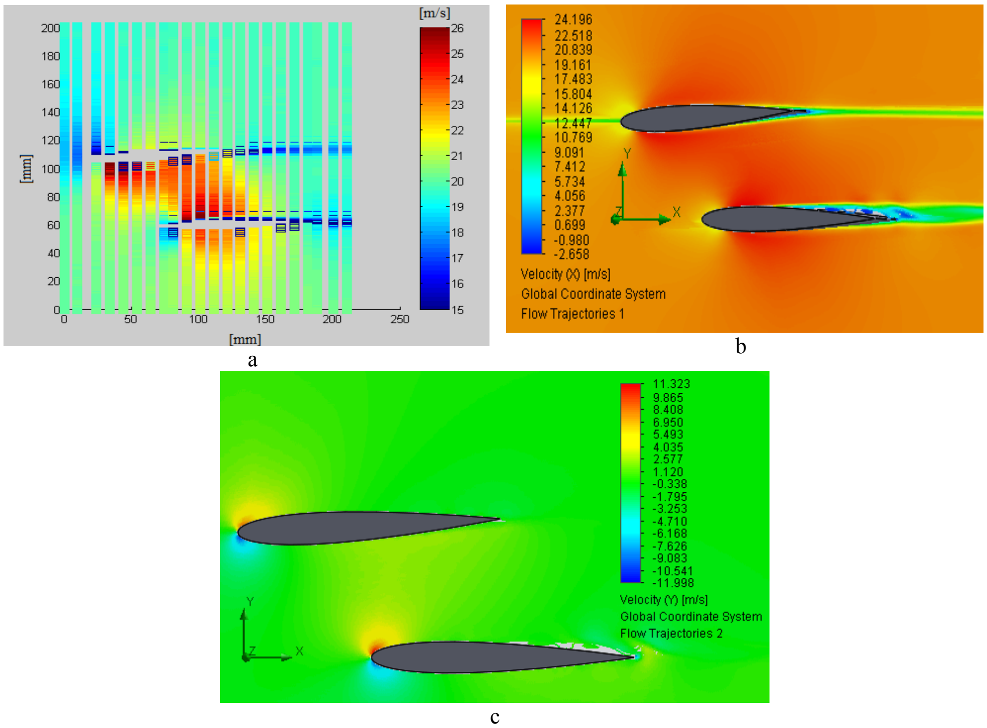


Fig. 7. The field of velocities for the configuration 3 at zero incidence (a – velocity on X axis, experimental measurement; b – velocity on X axis, numerical analysis; c – velocity on Y axis, numerical analysis)

4.3.2. 5^{o} incidence angle

In this configuration, the stagnation phenomena is more pronounced for the lower profile. For both of the profiles the velocity is grater in the upper part of the profile than in the lower part. This difference is grater for the lower profile.

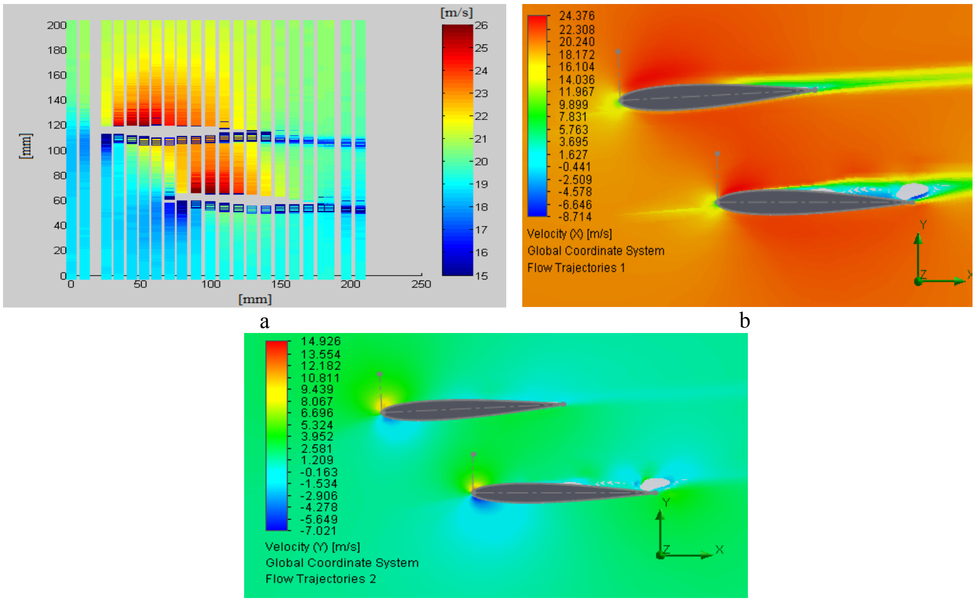


Fig. 8. The field of velocities for the configuration 3 at 5o incidence (a – velocity on X axis, experimental measurement; b – velocity on X axis, numerical analysis; c – velocity on Y axis, numerical analysis)

Both experimental velocity and efforts measurement combined with numerical analysis for all configurations, show a positive influence for one profile and negative for the other.

The conclusions stated above are sustained also by the following tables.

Table 2

Results from efforts measurements

Configuration	Slope of the lift coefficient	Position of the center (from the leading edge)	Drag coefficient at zero incidence angle ($C_{x\,min}$)	$C_{z\,max}$
Monoplane Measured	6,535 (0.114)	$0.26 \cdot c$	0.011	0.8658
Monoplane literature	6,28	$0.25 \cdot c$		
Configuration 1 at 0^o incidence	(0.227)		0.029	1.8158
Gap of $0{,}25 \cdot c$			0.068	
Stagger of $-0.25 \cdot c$		$1.37 \cdot c$		
Gap of $0{,}5 \cdot c$			-ε=-3^o: 0.031; - ε=+3^o:0.051; - ε=0: 0.037	1.3962, 1.585, 1.6557, (stagger $-0.25 \cdot c$- $0.5 \cdot c$)

Table 3

Maximum and minimum velocity in the flow resulted from numerical simulation

Configuration	Angle of incidence	$V_{x\,min}$ (m/s)	$V_{x\,max}$ (m/s)	$V_{y\,min}$ (m/s)	$V_{y\,max}$ (m/s)
Monoplane	0^o	-1.153	23.957	-11.734	11.734
	5^o	-4.803	24.583	-5.753	15.183
Config 1	0^o	0	22.834	-9.39	9.488
	5^o	-3.316	25.044	-6.758	16.149
Config 2	0^o	-4.015	24.218	-13.891	14.014
	5^o	-4.885	25.139	-7.761	20.297
Config 3	0^o	-2.372	24.91	-11.977	13.559
	5^o	-8.696	24.372	-7.224	14.884

Table 4

The resulted efforts form numerical simulation

Configuration	Angle of incidence	Force X (N)	Force Y (N)	Friction force X (N)	Torque X (Nm)	Torque Y (Nm)
Monoplane	0^o	0.005	$-6.463e^{-4}$	0.003	$-2.542e^{-5}$	$-2.139e^{-4}$
	5^o	0.003	0.052	0.002	0.002	$-1.262e^{-4}$
Config 1	0^o	0.009	-0.002	0.005	$3.634e^{-6}$	$1.387e^{-5}$
	5^o	0.006	0.136	0.005	$-2.039e^{4}$	$8.724e^{-6}$
Config 2	0^o	0.011	0.017	0.005	$-2.491e^{-5}$	$1.637e^{-5}$
	5^o	0.012	0.07	0.005	$-1.042e^{-4}$	$1.787e^{-5}$
Config 3	0^o	0.01	$-1.7e^{-4}$	0.005	$2.546e^{-7}$	$1.427e^{-5}$
	5^o	0.01	0.069	0.005	$-1.03e^{-4}$	$1.476e^{-5}$

5. Conclusions

A biplane configuration analysis show that the mutual interaction of aerodynamic profiles modifies the aerodynamic characteristics of the system.

The interactions are greater if the profiles are closer to each other. In all cases, the interaction is positive for a profile and negative for the other.

The results obtained during experimental measurement in the wind tunnel and those of the numerical analysis are the same. The only difference between the experimental measurement and the numerical analysis consists in the values of the velocity of the flow. This can be due to the precision making a 20 m/s current flow in the wind tunnel and the approximations made for the numerical analysis.

Also the results from experimental and numerical analysis are the same with the literature [4-7].

Acknowledgement

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132397.

R E F E R E N C E S

[1]. S. Ristić, "Laser Doppler Anemometry and its Application in Wind Tunnel Tests", Scientific Technical Review, Vol. LVII,No.3-4, 2007, p. 64.
[2]. *Aaron Altman*, "Unique stealth unmanned aerial vehicle (UAV) houck aircraft design program", University of Dayton, Final Report, AIR FORCE RESEARCH LABORATORY, November 2008.
[3]. *João Sousa Alves*, "Experimental and CFD Analysis of a Biplane Wells Turbine for Wave Energy Harnessing", Master Thesis, Royal Institute of Technology.
[4]. *C. Thipyopas*, "Optimisation aérodynamique de configurations de microdrones à voilure fixe : effet biplan, voilure souple et interaction aéropropulsive", PhD thesis presented at L'ECOLE NATIONALE SUPERIEURE DE L'AERONAUTIQUE ET DE L'ESPACE, No. **486**, 2007.
[5]. *W. S. Diehl*, "Relative loading on biplane wings", Report National Advisory Committee for Aeronautics. Report no. **458**, 275.
[6]. *R. Fuchs, L. Hopf*, "Aerdynamik". Richard Carl Schmidt & Co., 1922.
[7]. *M. Munk*, "Generale Biplane Theory", NACA TR no. **151**, 1922.