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The Influence of biplane configuration on aerodynamic coefficients

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The paper presents the influence of the biplane configuration on the aerodynamically performances and parameters of the air vehicle. It is studied the influence of gap, stagger and decalage on the lift, drag and moment coefficient and also on the position of the center. In almost all cases it is found that the influence of biplane configuration it is good on one profile and negative on the other.

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1. Introduction

There are many solutions to reduce the induced drag of an air vehicle. One of this solution is the biplane configuration, so, the interest of the biplane is the reduction of induced drag.

A biplane should theoretically produce exactly half of the induced drag of a monoplane for an equal scale if there is no interference between the two wings [1].

The induced drag is proportional to the square of the lift generated. If this lift is also equally split between the two wings, each wing will produce only a quarter of the induced drag of the original wing. So, the induced drag of a biplane must be half of the induced drag of a monoplane. Unfortunately, the interaction effects prevents this. A well designed biplane configuration allows for an approximately 30% for the induced drag comparing with an equivalent monoplane [1].

In order to have the same lift coefficient for the upper and lower wing, the incidence angle of the two wings must be different [1].

This paper presents the influence of the biplane configuration on the aerodynamic performances of the biplane air vehicle.

Studies on the biplane configuration shows that the lift coefficient of the individual wing of a biplane cellule is given by the fallowing relation [2]:

$$C_{LU} = C_L + \Delta C_{LU} \tag{1}$$

$$C_{LL} = C_L - \Delta C_{LL} \tag{2}$$

where C_{LU}, C_{LL} and C_L are the lift coefficients of the upper wing, lower wing and biplane.

$$\Delta C_{LU} = K_1 + K_2 C_L \tag{3}$$

where K_1 and K_2 are functions of gap, stagger and decalage [2].

The change in lift coefficient of the lower wing due to the presence of the upper wing is given by the equation [2]:

$$\Delta C_{DL} = -\frac{\mu}{2\pi}\frac{S_U}{b_U b_L}C_{LU}C_{DL} - \frac{\nu + k}{4\pi}\frac{S_U C_{LU}}{b_U b_L}\left[57.3\frac{dC_{DL}}{d\alpha} - C_{LL}\right] \tag{4}$$

The change in lift coefficient of the upper wing due to the presence of the lower wing is given by the equation [2]:

$$\Delta C_{DU} = -\frac{\mu}{2\pi}\frac{S_L}{b_U b_L}C_{LL}C_{DU} - \frac{\nu + k}{4\pi}\frac{S_L C_{LL}}{b_U b_L}\left[57.3\frac{dC_{DU}}{d\alpha} - C_{LU}\right] \tag{5}$$

where S is the area, b is the span. μ, ν and k are functions of gap, wing span and stagger.

Similar equation for the change in drag are given in [3].

According to Munk, the additional lift coefficient of staggered biplane wing is [4]:

$$\Delta C_L = \pm 2C_L\frac{S}{b^2}\left(\frac{1}{k^2} - 0.5\right)\frac{b}{R}\frac{\delta}{c}\frac{c}{b} \tag{6}$$

where, *R* is a distance used in calculating the induced downwash.

In the case of simple biplane (same profile, same chord and span), results that the lift coefficient of the upper or lower wing differs from that of the biplane by the amount depending directly on the biplane coefficient lift.

2. Experimental measurements

In order to study the effect of interaction between two wings mounted biplane configuration experimental measurements were made 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 about 20 m/s. The two wings are identical: rectangular wings with NACA0012 profile.

2.1 The model

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.

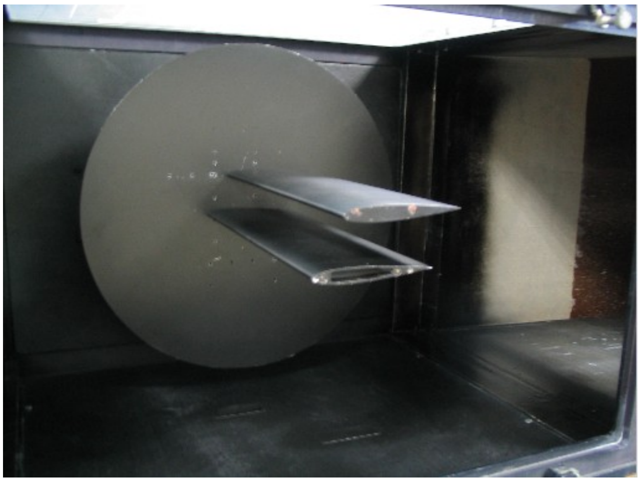

Fig. 1. The biplane model

2.2 Notations

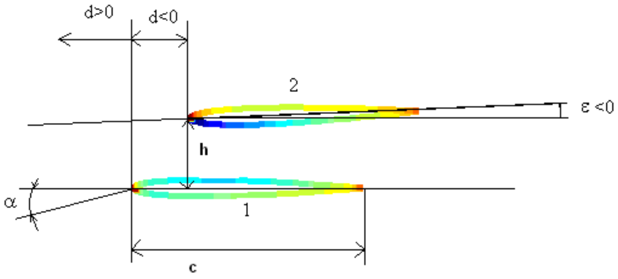

Fig. 2. The biplane configuration parameters

The following geometrical characteristics are define for the biplane configuration having the same wing profile:

Gap (h) - the vertical distance between the leading edges of the two wings 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.

2.3 Measurements of efforts

For the measurements of efforts the wings are mounted on a disc and with the help of a bar on the Monnin balance. The scale has five measuring channel for: flow speed, lift, drag, time and impact.

Initially, the aerodynamic balance was calibrated using calibrated weights. According with the test protocol requirement, the zeroes were acquired with the wind tunnel stopped. Each measurement was corrected for the gravity.

The first measurement was made for a monoplane configuration in order to compare the results obtained for the biplane configuration with the monoplane configuration and to ensure a bi-dimensional flow. The curves of the lift coefficient as a function of incidence angle and moment coefficient as a function of incidence angle were used to determine the slope of the lift coefficient and the position of the center.

In order to study the influence of the biplane configuration, the fallowing biplane configurations were studied:

Table 1 Studied biplane configuration for gap and stagger:

ε=0	d/c=-0,25	d/c=0	d/c=0,25	d/c=0,5	d/c=0,75	d/c=1
h/c=1,5		x				
h/c=1,25		x				
h/c=1	x	x	x	x	x	x
h/c=0,75		x				
h/c=0,5	x	x	x	x		
h/c=0,25		x				

Table 2 Studied biplane configuration for decalage:

ε=-3 and ε=+3	d/c=-0,25	d/c=0	d/c=0,25	d/c=0,5	d/c=0,75	d/c=1
h/c=1,5						
h/c=1,25						
h/c=1	x	x		x		
h/c=0,75		x				
h/c=0,5	x	x		x		
h/c=0,25						

3. Results from experimental measurements

First measurements were made for a monoplane configuration resulting a slope for the variation of the lift coefficient with the incidence angle of 6,535 and a position for the center of $0.26 \cdot c$ from the leading edge. The results are very close with the one founded in the literature in the case of a bi-dimensional flow (6.28 for the slope of the variation of the lift coefficient with the incidence angle and 0.25·c for the position of the center par rapport with the leading edge).

3.1 Gap analysis

In gap it is found that the slope of $C_z(\alpha)$ increases with the vertical distance between the two wings. In the case of a monoplane configuration the slope of the $C_z(\alpha)$ is 0.114 (6.535) and in the case of a biplane configuration with a gap of $1.5 \cdot c$ the slope is 0.227. Comparing the two results we observe that the slope of $C_z(\alpha)$ for the biplane configuration with a gap of $1.5 \cdot c$ between the two wings and is two times the slope of the monoplane configuration. In conclusion, for a gap of $1.5 \cdot c$ between the two wings there is no influence between the two wings.

The drag coefficient at zero incidence angle $C_{x\ min}$ for the monoplane configuration is 0.011 and for the biplane configuration with a gap of $0{,}25 \cdot c$ is 0.068. For a gap of $1.5 \cdot c$, $C_{x\ min}$ is 0.029. Analyzing the drag coefficient we can conclude that the slope for biplane configuration decreases with the gap between the two wings. In the case of $C_{x\ min}$, the influence of the biplane configuration is negative.

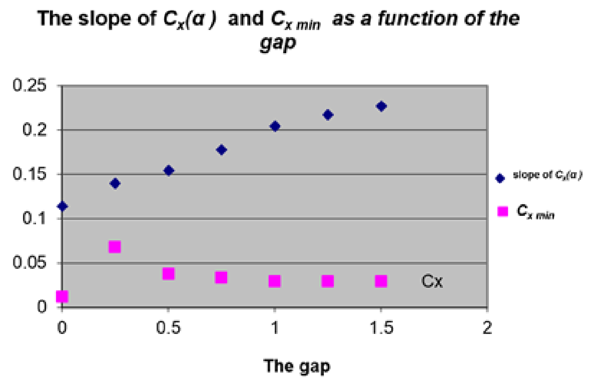

Fig. 3 – The slope of Cx(α) and Cx min as a function of h/c

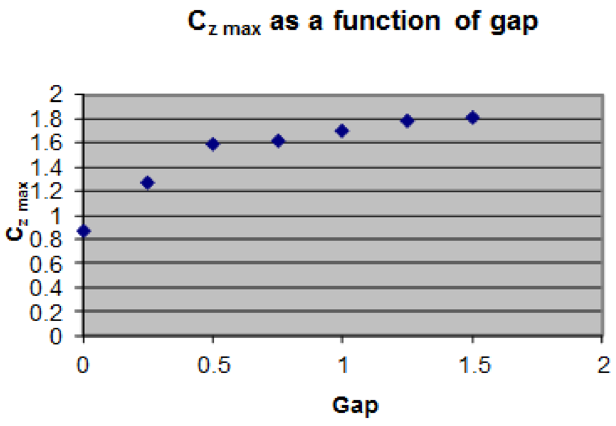

Fig. 4 - Cz max as a function of gap

In gap it is found that the position of the center doesn't change.

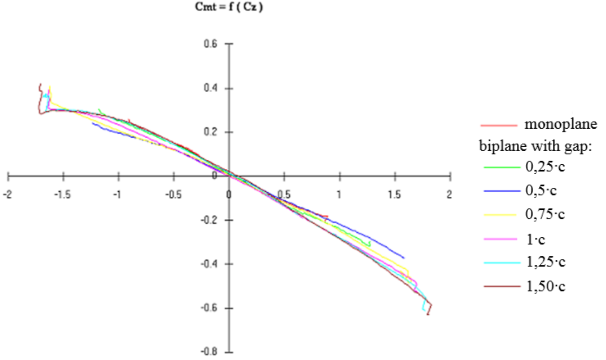

Fig. 5 - The position of the center

$C_{z\ max}$ and the module of the coefficient of moment increases with the gap between the two wings because of the diminution of the influence of wing on each other. In the case of a monoplane, $C_{z\,max} = 0.8658$ and for a biplane configuration with the gap of $1.5 \cdot c$, $C_{z\,max} = 1.8158$, more than two times the value for monoplane.

3.2 Stagger analysis

For a gap of $1 \cdot c$, measurements made for a stagger of $-0.25 \cdot c$, 0, $0.25 \cdot c$, $0.5 \cdot c$, $0.75 \cdot c$ and $1 \cdot c$, doesn't show any influence on the slope of $\frac{\partial C_z}{\partial}$, the variation of the results being smaller than the measurements incertitude. But for a gap of $0.5 \cdot c$, the slope of $\frac{\partial C_z}{\partial}$ show a minimum for a stagger of 0. The slope increases if the module of the stager increases.

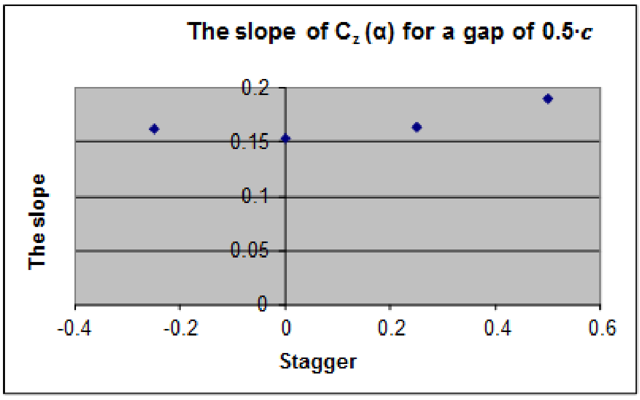

Fig. 6 - The slope of Cz (α) for a gap of 0.5·

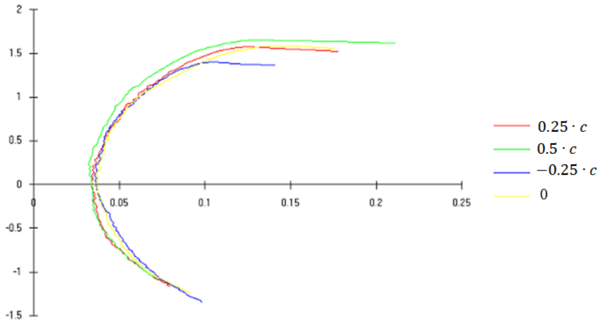

Fig. 7. The polar for the variation of stagger for a gap of $0.5 \cdot c$

After studying the coefficient of moment as a function of stagger we can conclude that if the wing from above is in front of the lower wing the coefficient of moment is positive if the angle of incidence is positive. The coefficient of moment is calculated according with the leading edge of the lower profile.

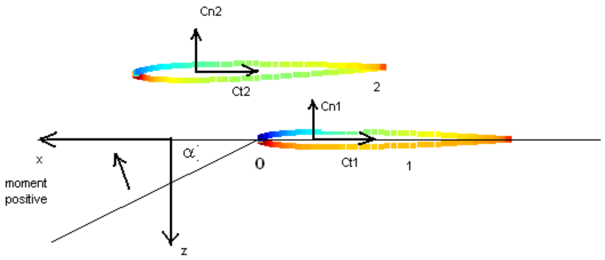

Fig. 8. Diagram for the study of the moments

Analyzing the above diagram results that in the case of the lower profile, the moment with respect to O is due to the effect of the normal force resulting a nose dive. In the case of the upper profile, the effect is a nose-up moment (positive moment).

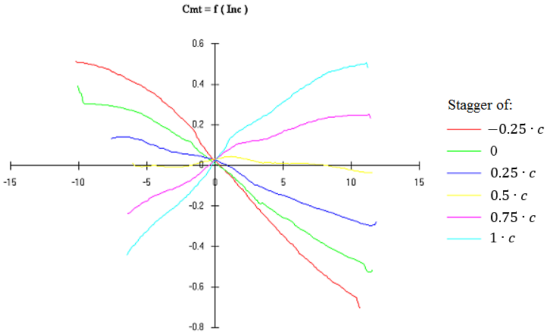

Fig. 9. The coefficient of moment as a function of stagger for a gap of $1 \cdot c$

The position of the center depends inversely with the stagger. For a negative stagger ($-0.25 \cdot c$) the position of the center is at $1.37 \cdot c$ form the leading edge of the lower profile and if the upper profile is moved further in front of the lower profile, the center passes in front of the leading edge of the lower profile. This effect is notable for the two gap tested $0.5 \cdot c$ and $1 \cdot c$.

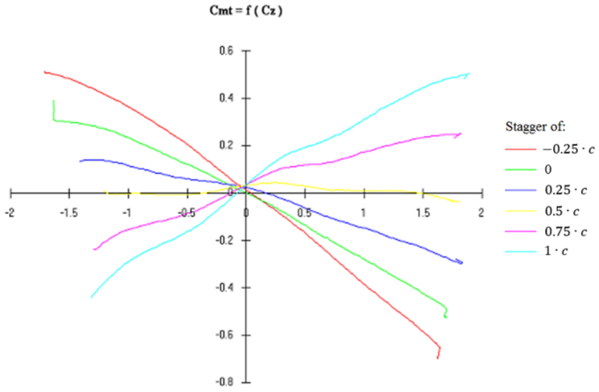

Fig. 10 - The coefficient of moment as a function of lift coefficient for stagger

The slopes of the coefficient of moment as a function of stagger gives the position of the center.

$C_{z\ max}$ increases with the stagger. For a gap of $0.5 \cdot c$, $C_{z\ max}$ has the fallowing values: 1.3962, 1.585, 1.6557, for a stagger variation from $-0.25 \cdot c$ to $0.5 \cdot c$.

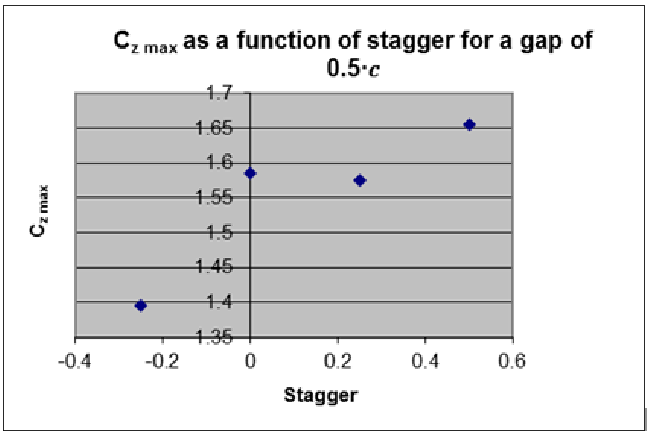

Fig. 11. Cz max as a function of stagger for a gap of 0.5·

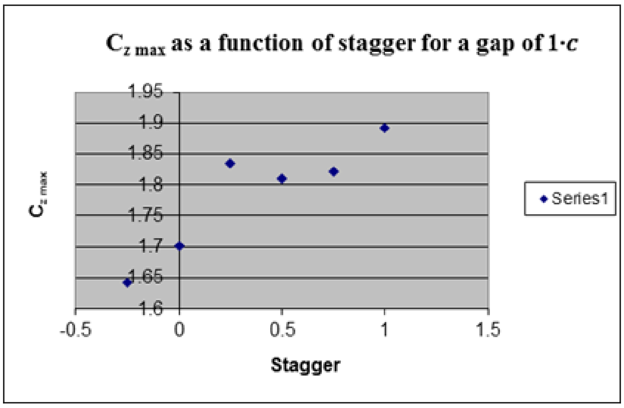

Fig. 12. Cz max as a function of stagger for a gap of 1·

3.3 Decalage analysis

For the same gap and stagger but for angles between the two profiles (decalage) of -3° et +3°, the slope of $C_z(\alpha)$ is the same. The effect of decalage on the $C_z(\alpha)$ is that the curve is shifted to the right or left according to the sign of the decalage. If the decalage is positive, the curve of $C_z(\alpha)$ is shifted to the left with $\varepsilon/2$. This shift also has an effect on the stalling angle. If the decalage is negative, the stalling angle increases up to about 13,5° and if the decalage is positive, the stalling angle decreases at about 10,5°.

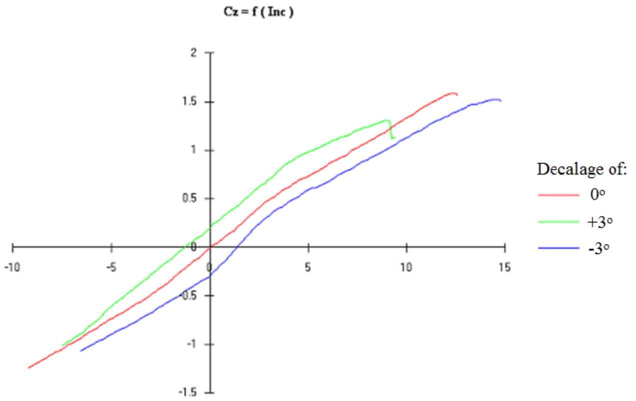

Fig. 13. The curve of lift coefficient as a function of incidence

Regarding the position of the center, the decalage has no effect for the same gap and stagger.

Also the polar are the same for a given gap and stagger. The difference is that the minimum value of C_x will be for a different incidence angle not for zero incidence.

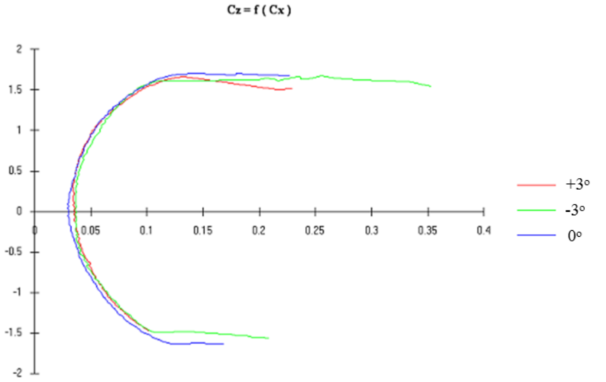

Fig. 14. The polar as a function of decalage

For a gap of $0.5 \cdot c$, $C_{x\,min}$ is smaller for a decalage of -3° (0.031) than in the case of a decalage of +3° (0.051). In the case of no decalage the $C_{x\,min}$ is 0.037.

The dependence of $C_{x\,min}$ with the stagger for decalage of -3° and +3° is presented in the figure below.

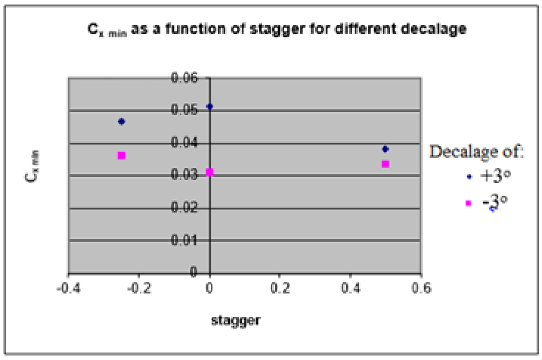

Fig. 15 - Cx min as a function of stagger for different decalage

Analyzing the decalage with the variation of the stagger for a gap of $0.5 \cdot c$ results the same conclusions: the slope of $C_z(\alpha)$ will remain the same; the stall angle will increase for a negative decalage; the value of $C_{x\,min}$ is smaller in the case of a negative decalage than for a positive decalage.

4. Conclusions

By analyzing the biplane configuration results that the mutual interaction of aerodynamic profiles modifies the aerodynamic characteristics of the system: the angle at which the lift is zero; the slope of $dC_z/d\alpha$; and $C_{z\,max}$.

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.

In gap, the slope of $C_z(\alpha)$ increases with the vertical distance between the two profiles, but the slope of monoplane configuration is better than for the biplane configuration. $C_{z\,max}$ and the coefficient of moment increases with the gap while the $C_{x\,min}$ decrease. The position of the center doesn’t change with the gap.

In stagger. Regarding the coefficient of moment, if the upper profile is in front of the lower profile, the coefficient of moment becomes positive for positive incidence angle.

The position of the center is at approximately the inverse of the function of the stagger. The position of the center is very sensible to the stagger. Passing the upper profile in front of the lower profile makes the center passing in front of the leading edge of the lower profile.

$C_{z\,max}$ increases with the stagger.

The slope of $dC_z/d\alpha$ has a minimum value for a zero stagger. The slope of $dC_z/d\alpha$ increases if the stagger becomes negative or positive.

The influence of decalage on $C_z(\alpha)$ consists in shifting the curve in the negative or positive direction depending on the sign of the decalage angle. The value of the shift is $\varepsilon/2$. Also, this has an effect on the stalling angle.

The decalage has no influence on the position of the center and on the polar. The difference is that if the decalage is different than zero, the minimum value of C_x is not at zero incidence.

Acknowledgements

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