EXPERIMENTAL ANALYSIS OF AERODYNAMICS CHARACTERISTICS OF ADAPTATIVE MULTI-WINGLETS

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Abstract

The research aim is the study of the potential use of adaptative multi-winglets to get reductions in the induced drag through variations of cant angle winglets. Different studies have been showing that the flow in the wing-tip can be redirect using small aerodynamics superficies, thus reducing the induced drag. The model to be tested is composed of a rectangular wing built from a profile NACA 65_3-018 *constituted of three winglets called tip-sails, which are small wings without sweep at* 25% *chord. The tests were in a regime at a number Reynolds of 350,000. The results are analyzed by the interpretation of lift, drag and mapping of the wake through anemometry techniques of hot wire.*

1 Introduction

The produced vortices in the wing-tip are unavoidable products by the lift presence, so it means, the difficulties due to the force that support the aircrafts in the air. These vortices are responsible for the appearance of the induced drag.

In cruise conditions the induced drag is the responsible for approximately 30% of the entire worthiness of the drag and also 50% in high lift conditions [1].

With the purpose to reduce the induced drag there has been done expansive investigation of methods that can produce favorable effects in the flow existent in the wing-tip and devices that reduce the induced drag.

Modifications in the wing-tip can move away the vortices in relation to the longitudinal aircraft axis or either reduces its intensity [2]. Some of these devices such as winglets [3], tip-sails [4], [5], [6], [7], multi-winglets [8] take an advantage of the air flux making spirals in this region to create an additional traction , and reducing the induced drag. Whitcomb [3] showed that the winglets could crease wing efficiency to 9% and reduce the induced drag to 20%. Other devices break up the vortices into several parts of itself with less intensity facilitating its dispersion [9]. Comparative studies among different types of devices there have been done. In 1996 Kravchenco [2] tested and compared different shapes of wing-tips: winglets and tip-sails. The winglets presented higher aerodynamics benefits up to Mach 1.0, however they presented structural problems to the aircraft. The tip-sails, at low C_L, provided the same benefits, nevertheless, the bending moment in the tip root was less. Also, researches in agricultural aircraft have been realized comparing devices of wing-tips [10]. For this kind of aircraft, besides both aerodynamics and structural properties, the influence of the originated vortices from the realization of aircraft mission is the parameter added in the analysis of devices. Coimbra does comparisons of wing-tips in a type of agricultural aircraft, concluding that a wing-tip such as *delta* presented the major promising according to the better agreement among the requests necessary for the good performance in the agricultural aircraft compared to winglets and arched wings to the low side.

Ilan Kroo et al [11], [12] did a revision in the basis that described the prediction and reduction of the induced drag. In these researches come up a variety of wing-tips and confi gurations too, among them are Winglets, Ring-wings, Box-wings and kinds of nonplanar wings. Besides the potential reductions of the induced drag, it was studied the possible implications concerned to the stability and control, characteristics of vortices in the wake and in the aircraft structure.

By 1980, the winglets have been used to improve the sailplanes performance. Smith at al [8] mentions the works developed by Colling et al (1985) which makes a compilation of winglets for sailplanes tested in models in a scale at the University of Texas A&M. Equally, it was mentioned Marchman (1978) who found out that winglets with symmetric profi le are better to the general aviation, yet, they are less effi cient when applied to tapered wings. Projects of new profi les for winglets used at sailplanes have been developed and tested. Due to the low number of Reynolds, the variation of the profi le along of the winglets span is fundamental importance concerning the good utilization of the winglet. Maughmer M. D et al [13] presented a methodology for the project of winglet profi les. Accomplished experimental studies are compared in computer simulation analysis

Spillman [4], [5], [6], [7] realized a series of studies of small aerodynamic devices named tip-sails. These devices took advantage of the direction of the flow existent in the wing-tips to originate a force in the direction of the aircraft dislocation, and also they present the reduction in the intensity of the vortices. The conclusion is, settling a kind of condition of flight, the geometry in the tip-sail must present twist and taper ratio. The chord in the root must be highly curved and in the tip must be symmetric, this occurs just the behavior of the flow in the wing-tips, because the inclination angle of the air flux in the wing-tip decreases whit radial distance from itself. Spillman investigated the use of tip-sails installed in the tip-tank of Paris MS 760 Trainer Aircraft [4], [5] discovering the better results for a number of 3 tip-sails. The flight tests confi rmed the results achieved in a wind tunnel and showed benefi ts in the wing-tip in relation to the taking off distance and consumption of fuel [5]. Spillman et al did flight tests of Cessna Centurion [6] and Piper Pawnee 235 [7]. All of these tests presented benefi ts to the aircraft performance. Between them the tip-sails are the only device that can reduce fuel consumption and presents structural advantages in the wings.

Wing-Grid [8] is the set of small wings added to the main wing. The Wing-Grid creates small vortices that dissipate the energy of the main vortices and modifi es the lift distribution restricting the induced drag. The lack of adaptability in the wings for the changing flight conditions let the Wing-Grid a limited use.

The objective this work is to analyze the potential use of adaptative multi-winglets in the induced drag decrease. For that, it was analyzed the influence of winglets cant angle and the use of methodology proposed by Spillman for the winglets project.

2 Experimental configuration

The experimental model used was a rectangular semi-span wing of 0.49 m with a chord of 0.25 m. The wing profi le used was a NACA 65_3-018. Three winglets were added to three cylindrical modules at the tip-tank . These devices allows the variation of the winglets cant angle individually as it can be seen in Figure 1.

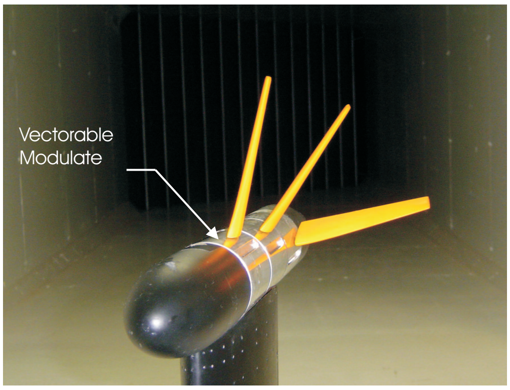

Fig. 1 Cylindrical modules at the tip-tank

The winglets have different profi les along its semi-span . At the root the profi le is based in the

Eppler 387 with 0.05 m chord with a camber of approximated 20^o. At the wing-tip it was used again the Eppler 387 profile modified for a symmetric geometry with a chord of 0.023 m.

The tests were conducted at the Aircraft Laboratory of the Sao Carlos Engineering School, University of Sao Paulo, Brazil. The wind tunnel used was a closed circuit with a test section of 1.2 m x 1.7 m with a turbulence level of 0.25% and the maximum speed of $50m/s$. Further details of the wind tunnel can be found in Catalano [14].

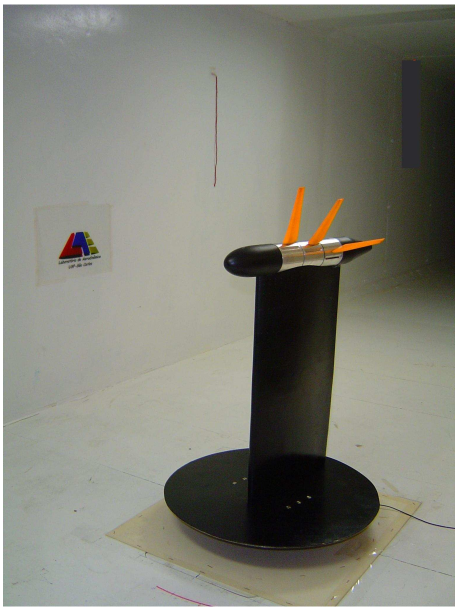

Fig. 2 Model inside the wind tunnel

Figure 2 shows the wing model in the working section as well as the circular end-plate in the wing root to avoid wall boundary layer interference. All the results were corrected for wall interference.

2.1 Winglets geometry

Due to the dimensions of the cylindrical modules at the tip tank, the wing let root chord was fixed to 0.05m. Also, a taper ratio of 0.46 was adopted which fixed the wing let tip chord as a function of its span. In order to determine the winglet span, measurements were performed on the radial variation of the flow angle at the tip. For that it was used a wing model 0.32 scale of the experimental model. These measurements were performed in a 0.26m X 0.39m open circuit wind tunnel .

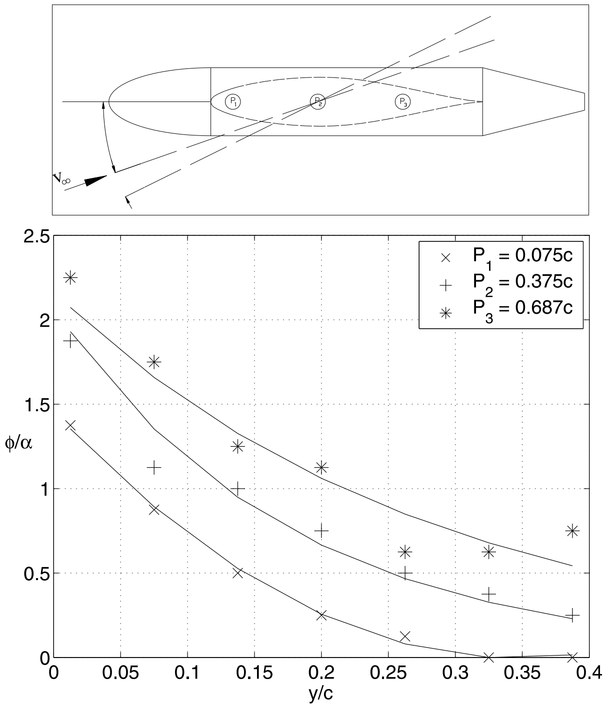

Fig. 3 Local flow direction

A two-tube yaw meter was used to measure the local flow direction at the vertical plane. The speed was $15.25m/s$ which correspond to the number Reynolds of $7.3x10^4$.

Through Figure 3, it can be observed that the relation ϕ/α declines drastically in relation to radial distance from the wing-tip . The decreasing is greater as it is further from the position P3 that is near to the wing leading edge. In the Figure 4 is noted that the flow angle decrease is practically independent of the incidence angle. Spillman [4] got the best results for the tip-sails with 20^o of camber at root. The camber decreases rapidly with the distance from the root to the winglet tip lessening approximately to half part each distance of 6% of the wing tip chord. In this way, it was established that the winglets would have a span of 0.105 m. It also was established that the winglets would not have sweep at 25% chord. The final winglet geometrical configuration can be seen in Figure 5.

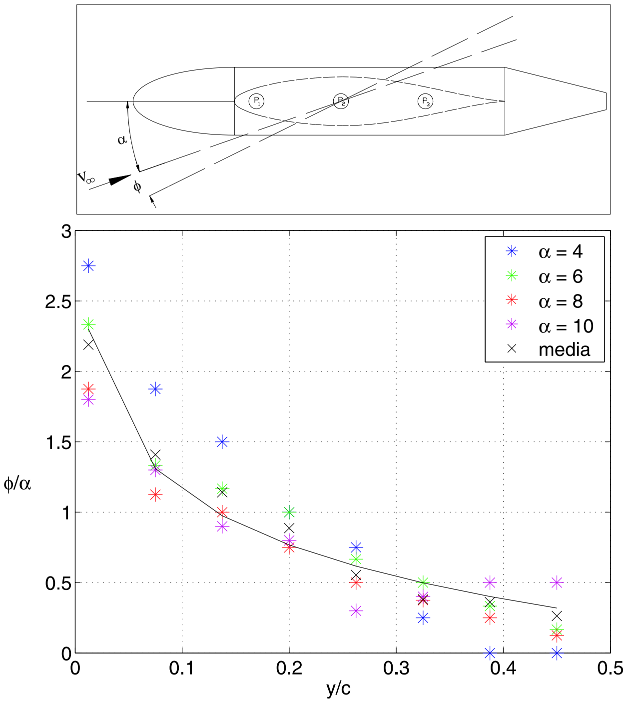

Fig. 4 Local flow direction 0.375c

Confi guration	Arrange	Confi guration	Arrange
Conf 1	n45-n40-n35	Conf 28	90-85-80
Conf 2	n30-n25-n20	Conf 29	75-70-65
Conf 3	n15-n10-n5	Conf 30	60-55-50
Conf 4	0-5-10	Conf 31	45-40-35
Conf 5	15-20-25	Conf 32	30-25-20
Conf 6	30-35-40	Conf 33	10-15-20
Conf 7	45-50-55	Conf 34	0-n5-n10
Conf 8	60-65-70	Conf 35	n15-n20-n25
Conf 9	75-80-85	Conf 36	n30-n35-n40
Conf 10	n45-n30-n15	Conf 37	90-75-60
Conf 11	n30-n15-0	Conf 38	75-60-45
Conf 12	n15-0-15	Conf 39	60-45-30
Conf 13	0-15-30	Conf 40	45-30-15
Conf 14	15-30-45	Conf 41	30-15-0
Conf 15	30-45-60	Conf 42	15-0-n15
Conf 16	45-60-75	Conf 43	0-n15-n30
Conf 17	60-75-90	Conf 44	n15-n30-n45
Conf 18	n45-n15-15	Conf 45	90-60-30
Conf 19	n30-0-30	Conf 46	75-45-15
Conf 20	n15-15-45	Conf 47	60-30-0
Conf 21	0-30-60	Conf 48	45-15-n15
Conf 22	15-45-75	Conf 49	30-0-n30
Conf 23	30-60-90	Conf 50	0-n15-n45
Conf 24	n45-0-45	Conf 51	90-45-0
Conf 25	n30-15-60	Conf 52	75-30-n15
Conf 26	n15-30-75	Conf 53	60-15-n30
Conf 27	0-45-90	Conf 54	45-0-n45

Table 1 Preliminaries confi gurations

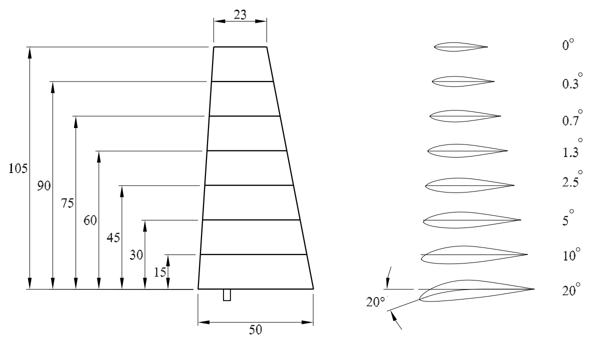

Fig. 5 Sail geometry model

2.2 Tested configurations

A total of 55 confi gurations were chosen with different cant angles that obeyed the system of reference pointed out in Figure 6 and distributed in three groups as following: 28 with cant positive, 8 with cant negative and 18 with mixed cants (positive and negative) . The 3 winglets were always with different cant angle. For all confi gurations, the wing was tested with incidence angle of 8^o and a speed of $23m/s$. The coeffi cients of lift, drag and aerodynamic effi ciency were compared and better confi gurations were chosen as it can be observed in Figure 7. Lift and drag forces were measured by a two component balance.

Finally, the better confi gurations were chosen among the best ones and were analyzed through hot wire anemometry in a grid plane of 900 points at 2.5 wing chord downstream. It was used a modular traverse and constant temperature hot wire anemometry system (DANTEC Streamline 90N10 frame and probe 9055P01).

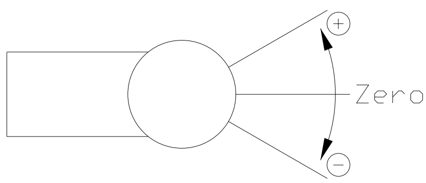

Fig. 6 Agreement of confi gurations

Confi guration	Arrange	Confi guration	Arrange
Conf 48	45-15-n15	Conf 47	60-30-0
Conf 44	n15-n30-n45	Conf 40	45-30-15
Conf 19	n30-0-30	Conf 11	n30-n15-0

Table 2 Selected confi gurations

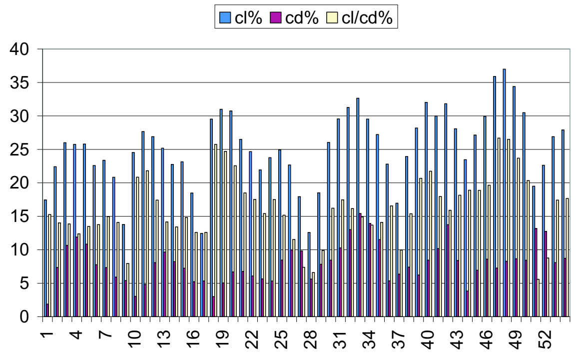

Fig. 7 Results of the tested configurations at $alpha = 8^o$

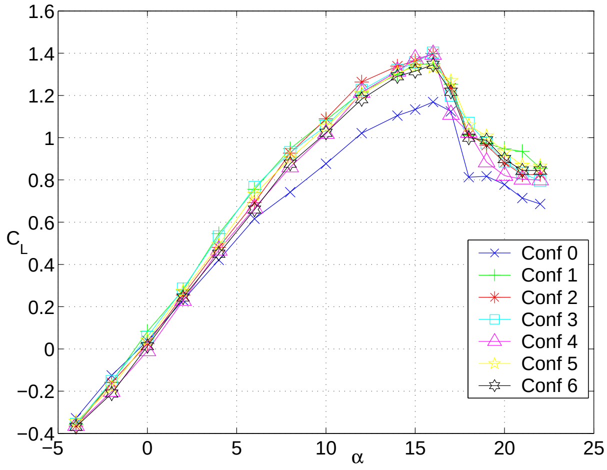

Fig. 8 Coeficiente lift curves

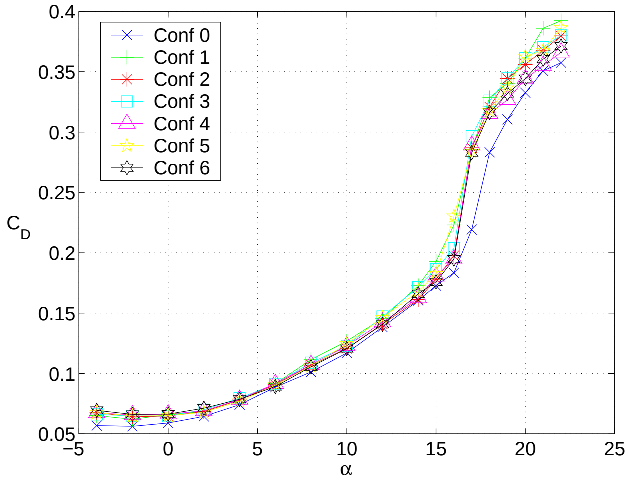

Fig. 9 Coeficient drag curves

3 Results and Discussion

Only the specified results showed below, presented the better reduction of the induced drag. However, some discussion will be presented on the negative effects of each configuration. The results presented are always referred to the winglets off case (configuration 0). The configurations selected are:

- Configuration 1: $+30^oA,\ 0^oB, +30^oC$
- Configuration 2: $+45^oA, +15^oB, -15^oC$
- Configuration 3: $+60^oA, +30^oB,\ 0^oC$
- Configuration 4: $+45^oA, +30^oB, +15^oC$
- Configuration 5: $-30^oA, -15^oB,\ 0^oC$
- Configuration 6: $-15^oA, -30^oB, -45^oC$

3.1 Characteristic curves

An increase in lift was achieved for all the selected configurations. This increase is larger for high incidence angles as is shown in Figure 8.This effect is almost independent of the configurations. Also lift curve inclination has increased for all configurations up to 12 degrees when mutual effect between the tip-tank flow and the winglets shift the inclination back.

The selected configurations presented curves such as C_D similar to those ones existent in the wing without winglet. Nevertheless, for bigger angles of 16^o the configurations showed larger drag coefficient as it is shown in Figure 9.

The increase in effective aspect ratio with the gain in lift led to the dramatic increase on the aerodynamic wing model efficiency as shown in Figure 10. In the Figure 11, the Drag polar also shows a large improvement for all configurations especially at high incidences.

In the Figure 12 the major parameter is the gradient $\partial C_D/\partial C_L^2$ gotten at the linear part of curve and that relates directly to the Drag due to the lift C_{Di}. The configurations presented graphs very close and larger C_D for the minor angles at 4^o. From this angle the configurations presented small gradient $\partial C_D/\partial C_L^2$, so the distribution $+45^oA, +15^oB, -15^oC$ that has smaller gra-

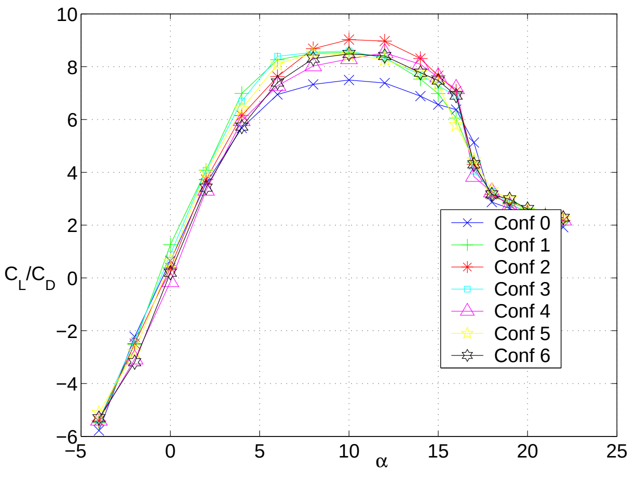

Fig. 10 Efficiency curves

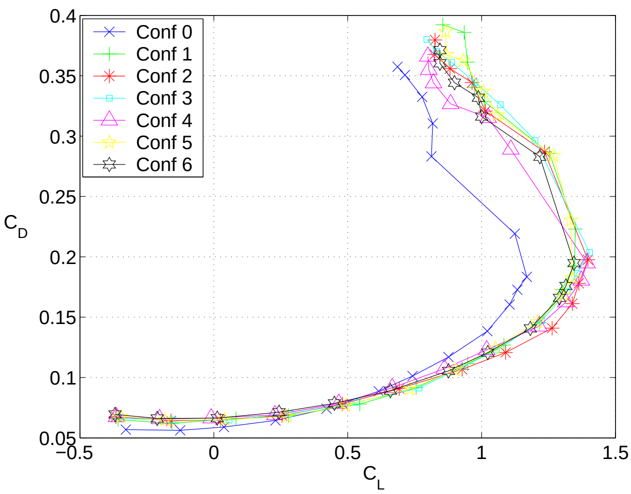

Fig. 11 Polar curves

dient is the one which has more advantages.

The potential flexibility of operation of an adaptative multi-winglets system proposed is shown in Figures 13 and 14. It is possible to change the positions of the configurations in order to maintain best performance with reference to climb rate and maximum range.

3.2 Anemometry

The axial speed mapping was realized in a distance of 2.5 times of the wing model chord downstream the trailing edge. The mapped area was 280x280mm in the plain *yz* (perpendicular to the direction of the flow). In the Figures 15 up to 18, it presents the intensity of turbulence gener-

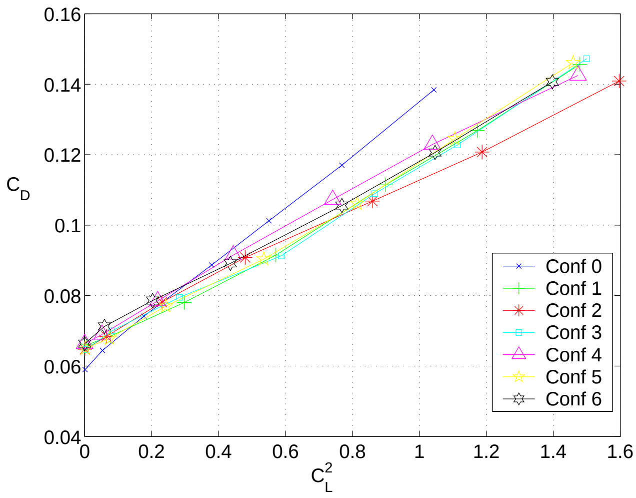

Fig. 12 Drag due to the lift curves

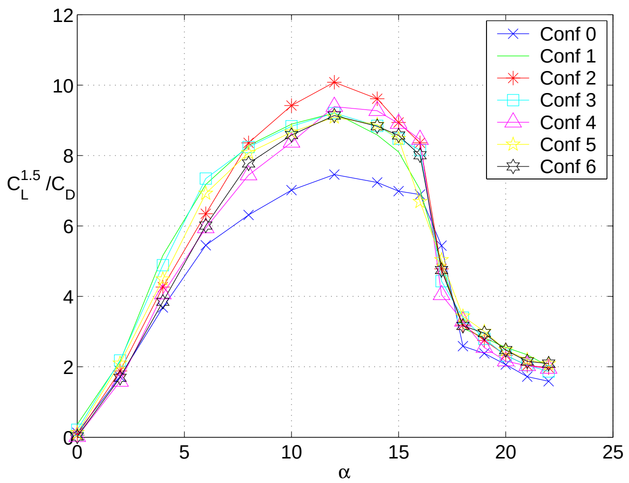

Fig. 13 Climb rate factor

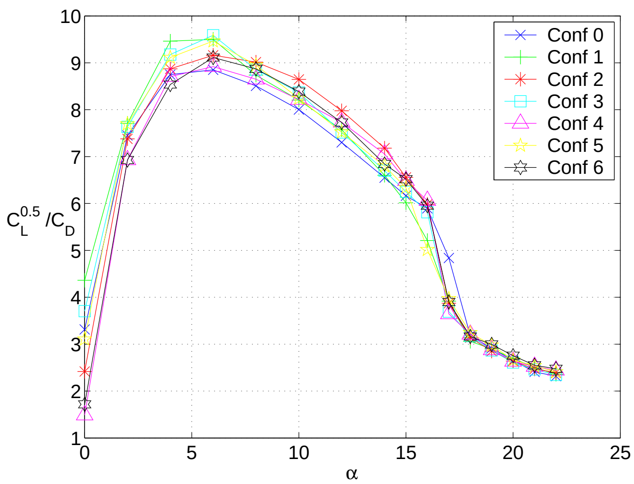

Fig. 14 Maximum range factor

ated by the model without winglets and by the model with the confi gurations $45^oA, 30^oB, 15^oC$; $60^oA, 30^oB, 0^oC$; $45^oA, 15^oB, -15^oC$ respectively. It can be observed that the wing wake do not vary considerably on its size. At the tip the size of the wake is influenced mainly by the tip-tank wake. Nevertheless, a slight diminution in the intensity of the turbulence in the regions near the tip-tank exists.

In the graphs of speed, Figures 19 up to 22 can be seen the dislocation tip tank wake away from the wing tip and the reduction of wake size compared to the wing without winglets. Also, it can be seen an increase in the effective span for the tested confi gurations.

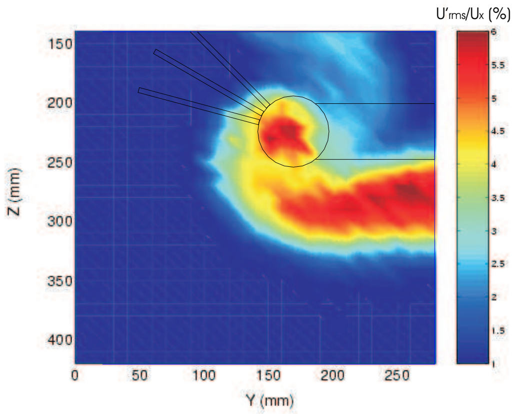

Fig. 16 Intensity of the turbulence $45^oA, 30^oB, 15^oC$ at $3c$ $\alpha = 8^0$

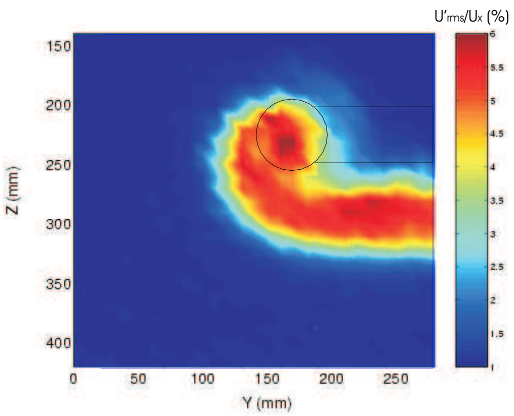

Fig. 15 Intensity of the turbulence Winglets off

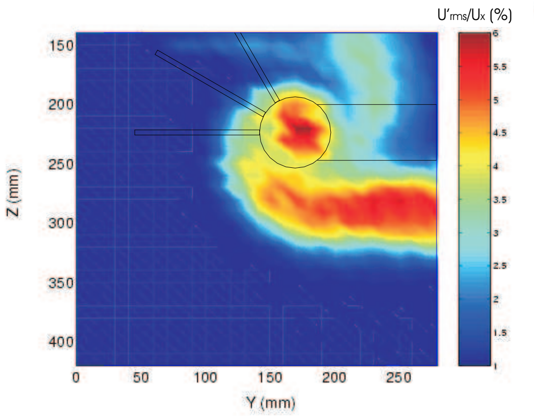

Fig. 17 Intensity of the turbulence $60^oA, 30^oB, 0^oC$ at $3c$ $\alpha = 8^0$

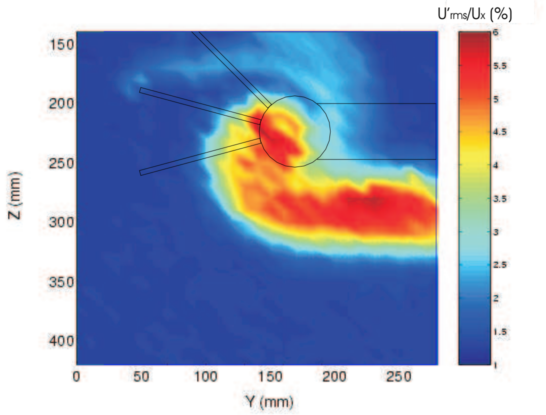

Fig. 18 Intensity of the turbulence $45^o A, 15^o B, -15^o C$ at $3c$ $\alpha = 8^0$

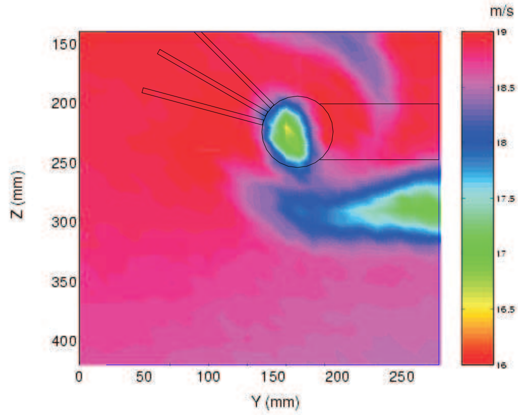

Fig. 20 Distribution of axial velocidade $45^o A, 30^o B, 15^o C$ at $3c$ $\alpha = 8^0$

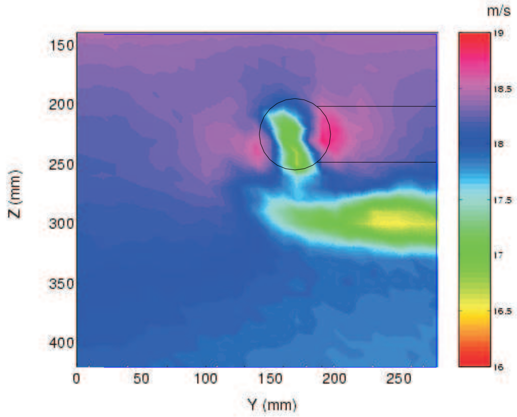

Fig. 19 Distribution of axial velocidade Winglet off at $3c$ $\alpha = 8^o$

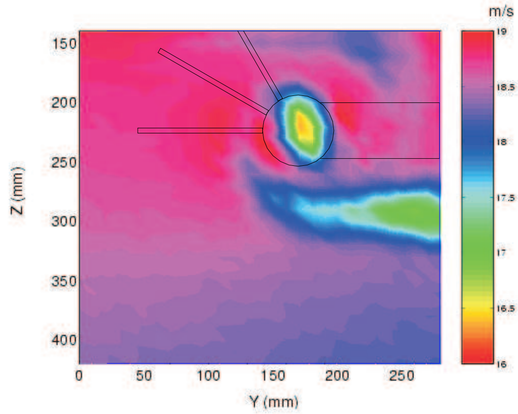

Fig. 21 Distribution of axial velocidade $60^o A, 30^o B, 0^o C$ at $3c$ $\alpha = 8^0$

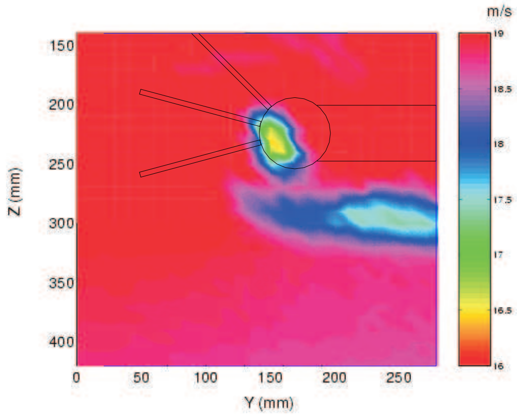

Fig. 22 Distribution of axial velocidade $45^oA, 15^oB, -15^oC$ at $3c$ $\alpha = 8^0$

4 Conclusions

Adaptative multi-winglets system was investigated in wind tunnel experiments in order to show the effect on the aerodynamic characteristics of a low aspect ratio wing. Results showed potential benefits in combining configurations of three winglets on the aerodynamic characteristics of a wing. The optimization of the Adaptative multi- winglets system for each operational maneuver may result in improvement for the whole flight envelope from climb to maximum range. However, some tests are still required at cruise configuration in order to accurately study the potential benefit.

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