ANALYSIS OF THE AERODYNAMICS CHARACTERISTICS OF A WING-CANARD CONFIGURATION WITH CANARD DEFLECTION, USING PANEL METHOD

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Abstract: *A study about the aerodynamics effects of a wing-canard configuration, developed to be used in a military advanced trainer, is performed in the present work. A computer code, based on panel method (VSAERO), is the tool used in the present paper. In such code, the wake generated by a lifting surface can be relaxed in the sense the wake is a stream surface and vortices are allowed to roll up. Based on the numerical results a set of studies are performed in order to verify the effects of the canard deflection on the wing and canard flows in low speed maneuver conditions (that is, in the incompressible regime). Such studies are based on the lift distribution along the wingspan for the wing and for the canard and the determination of the lift as a function of the angle of attack and in function of the canard deflection. Complementing the study, the present work shows a brief analysis of how the tip vortex of the canard passing close to the wing surface changes the aerodynamics characteristics of the wing.*

Keywords: aerodynamics; wing-canard configuration; panel method; military advanced trainer; canard deflection.

1. Introduction

Many modern aircraft use canard control surface to increase the maneuver acting, positive control of pitching and reduction of compensation drag. Furthermore, the influence of the canard wake and vortices in the wing, if well dimensioned and designed, could increase the maximum lift of the aircraft. This characteristic is very useful due to the capability of doing curves with small radius, giving the aircraft better chances to complete its mission.

The position of the canard forward to the wing increases the efficiency of the canard, due to the fact of being free of the influence of the induced flow of the wing wake (downwash) either to whatever perturbation induced by the wing wake. In case of positioning the canard closed to the wing, the interference between the two lifter surfaces is much more complex. The upward velocity induced by the lift of the wing (upwash) interferes significantly in the canard flow. And the wake produced by the canard passing near the wing surface changes the flow over the wing. Furthermore, the canard deflection, used as primary control surface, make a considerable change in the lift distribution of the wing, being able to modify completely the pitching moment of the aircraft (Lopes, 2004).

Toward using the wing-canard configuration in an efficiently way, it is necessary to execute a careful study to comprehend the influence of the canard position, dihedral and deflection, in air flow around the wing. The mutual influence can be so powerful that both airfoils should be designed in the same time. This procedure is not habitual to an aircraft with conventional configuration (empennage in the tail of the aircraft).

Over the years, the Computational Fluid Dynamics (CFD) have being changed into a valuable tool for the comprehension of the three dimensional flow characteristics, with many applications for the comprehension of wing-canard configuration. In this work, will be showed studies for a model of a military advanced trainer (Figure 1), using the VSAERO (Maskew, 1986). VSAERO is a commercial computational code amply diffused in aeronautic industry, which is based on Potential Panel Method.

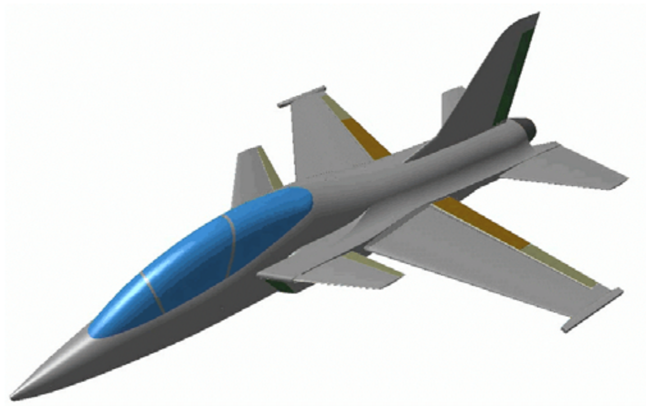

Figure 1 – General characteristics of the advanced trainer used as model.

This study principally aim evaluate the variation of the aerodynamics characteristics of the canard and the wing in order of the canard deflection. Moreover, the present work shows a brief analysis of how the tip vortex of the canard passing close to the wing surface changes the aerodynamics characteristics of the wing.

2. Methodology

To make a quantitative analysis of the interaction effects between the canard and the wing, several authors use experimental methods obtained in complex wind tunnel tests (Gloss, 1974 e 1975), as well, the use of advanced computational codes (Tu, 1992). Wind tunnel tests can be extremely expensive, depending on the model complexity and the quality and quantity of the required measurements. In another way, a computational analysis can require a long time of data processing, even when using high advanced computers. This kind of approach, despite demanding so many resources, is capable of satisfactory results even in situations as high angle of attack and transonic speed. There are another cases where this kind of approach are oversized, like in cases of bland flight condition, in other words, conditions where the flow around the canard and the wing do not produce too complex aerodynamics effects as sonic shock or thick wake, created by the upper surface flow separation. In this cases can be used a simplified approach, like a potential panel method, without compromise the quality of the results (Pfeiffer, 1989).

In the present work, which is studied an advanced military trainer with wing-canard configuration, it was used a commercial computational code called VSAERO (Maskew, 1986). This code runs the simulations in proper way to the low-speed flight that is proposed in this work (Lednicer, 1988). This code based on panel method is capable to perform wakes generated by a lifting surface that can be relaxed in the sense the wake is a stream surface and vortices are allowed to roll up. This characteristic of the computational code is very important to the study, due to the possibility of simulate a lifting surface tip vortex. That kind of aerodynamic effect is indispensable to the study of a wing-canard configuration because the canard tip vortex passes too close to the wing surface to be neglected its effects over the wing flow.

VSAERO is a computational code used to aerodynamic calculus of arbitrary configuration in subsonic and sub-critic regime. The nonlinear effects of the wake shape are calculated in an iterative process of the wake relaxation, while the viscosity effects are calculated in an iterative method that joins potential flow and boundary-layer calculus. It is important to make clear that in this work the viscosity and compressibility effects are neglected, due to the low speed flight presented in this study, moreover the focus of this work is the variation of the lifting coefficient (CL) of the canard and the wing provided by defection of the canard, as well, the local lifting coefficient (Cl) along the span of both lifting surfaces.

The program works using a superficial mesh composed by quadrilateral panels, where each singularity of dipole and source are distributed (Morino, 1986). The obtained values on each panel are directed determined by Newmann´s boundary conditions (normal speed equal to zero), in that way controlling the normal component of local flux. The body tangential speed is obtained by determining gradient of the field of the potential speed. The pressure field of the aerodynamic body is obtained by Bernoulli equation. Basing on this pressure field can be obtained the resultant force and momentums that acts in the studied aircraft.

2.1. Model Characteristcs

The used model has the following wing characteristics: surface (including $4.8m^2$ internal to fuselage) equal to $16m^2$, aspect ratio equal to 4.5, sweepback at ¼ of the cord equal to 25º, wing geometric twist equal to 2º, wing incidence at root equal to 3º, root wing section $NACA65_A210$ and tip wing section $NACA65_A009$ (Abbott, 1959).

The canard has the following characteristics: surface (including $3.2m^2$ internal to fuselage) equal to $5.5m^2$, aspect ratio equal to 3.9, sweepback at leading edge equal to 35º, geometric twist equal to 0º and canard section $NACA65_A009$.

2.1.1. Location of the Canard with Respect to the Wing

Was selected a canard position to run the simulations, of the model deflecting the canard, based on the Gloss's works. Gloss (1975) uses three canard positions with the same distance in longitudinal axe of the model, one under the longitudinal line of the wing, other in the same line of the wing and another above the longitudinal line of the wing. In his work are presented the effects of each configuration on the aerodynamics characteristics of couple surfaces. In the previous work (analysis of a wing-canard configuration using panel method, Lopes, ENCIT2004) was shown a analysis of the variation of the aerodynamics characteristics of the model by change the canard position studying haw the position of the canard changes the flow around the two lifting surfaces. In the present work will be shown for one of the positions studied previously, haw the canard deflection changes the aerodynamics characteristics of the closed-couple wing-canard configuration.

For study how the canard deflection interferes in the aerodynamics characteristics of the aircraft, were chosen three deflection angles: 0 degree, 5 degrees and 10 degrees. The same angles studied by Eugene Tu (1992). Despite the model proposed by this author holds some differences of the model in the present work (as canard and wing swept angle much higher), as well, different simulations conditions (transonic regime), some qualitative comparison can be made to guide this study.

In the process of simulation, for each one of the three angles of deflection of the canard were simulated three attach angle of the aircraft (0 degree, 5 degrees and 10 degrees), resulting in a total of nine simulations. This way, can be obtained, a reasonable amount of data, containing the aerodynamic effect provided by the canard deflection.

In the Figure 2 are presented the canard position and deflection. The rotate axis of the canard is in the middle of the canard root chord (meaning root as the section where the canard interferes with the fuselage).

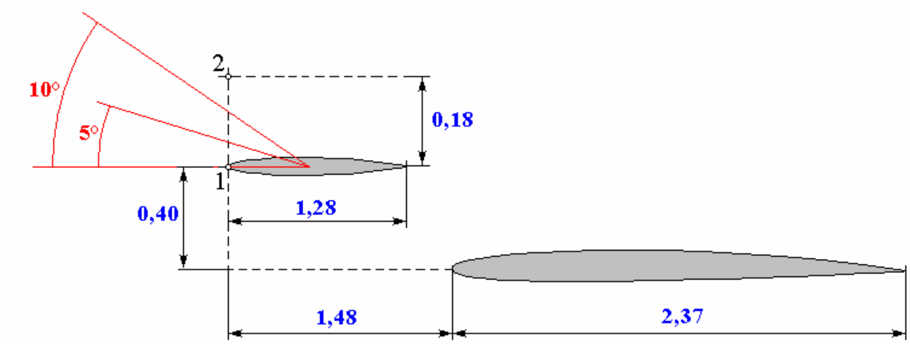

Figure 2 – Scheme of the canard position and the deflection angles.

Intending to study more deeply the aerodynamics effects caused by the canard tip vortex passing near the upper wing surface, was created a different configuration where the canard tip vortex contribution would be more significant than the canard downwash. For the vortex could pass closer to the wing and at the same time minimize the canard downwash effect in the wing, the canard dihedral was changed from 15 degrees positive to 15 degrees negative. And to the canard wake do not cross the wing, it was needed to displace the canard 0.18 m upward, in the positive Z axis direction (see Figure 2).

2.2. Simplification on the Wing Canard Configuration Model

In aircraft which have wing-canard configuration the deflection of this surface related to the wing is an important design point. The deflection of the canard can change significantly the aerodynamics characteristics of the wing, such as pressure coefficient distribution (Cp) and the local lift coefficient distribution (Cl) along the wing span.

To execute this analysis, were adopted some deflection angles. If were generated a grid for full aircraft would be necessary a brand new grid for each canard deflection.

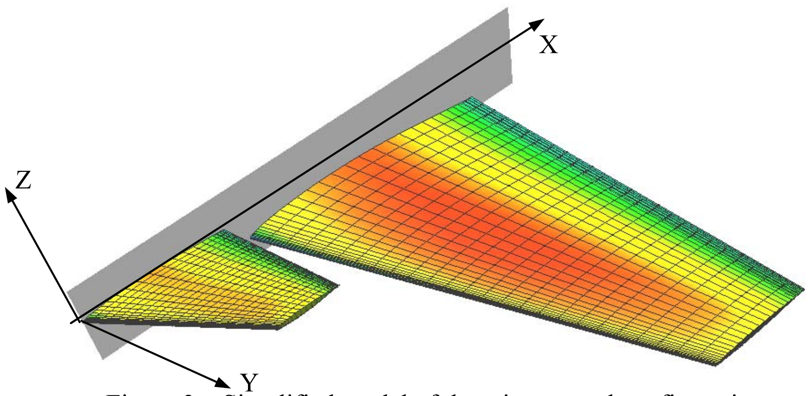

Figure 3 – Simplified model of the wing canard configuration.

Intending to simplify the model, was adopted the arrangement showed in the Figure 3. Right in Y axe position where occur the wing and fuselage intersection is positioned a plane surface parallel to XZ plane. Then is impose a condition that the flow can not goes throw this plane, that means, for the flow passing around the wing surface and the canard surface, the fuselage simply do not exist. Emphasizing that in this work are not simulations with sideslip angle, this new model is a consistent approximation, because the flow deviation caused by the fuselage can be neglected.

3. Result Analysis

An uncommon characteristic of the canard configuration is the attitude change in maneuver. This is not only related to the change of the wing angle of attack, because when the canard is deflected there is a big change of the effective angle of attack for each section of the wing span. This behavior demands a more careful design of the wing, taking in count how the change in flow caused by the canard deflection interferes in the aerodynamics characteristics of the wing.

3.1. Canard Deflection

In the Figure 4 is shown the results of the simulation of the wing canard configuration with a canard deflection of 0, 5 and 10 Degrees, for a wing angle of attack of 0 degree. Can be observed that with the increase of the deflection angle of the canard, there is a great reduction of the local lift in the portion of the wing that is right on the canard wake direction. This outcome happens because the canard downwash increase with the canard deflection. This interaction between the canard and the wing is so powerful that in high canard deflection angles like 10 degrees there is a negative lift in the portion of the wing more affected by the canard downwash.

Comparing these several canard deflection angle, can be observed that the characteristics of the lift (Cl) distribution in the canard span do not change very much presenting the same comportment expected, with Cl maximum displacing to the canard tip due to the high swept angle of the canard.

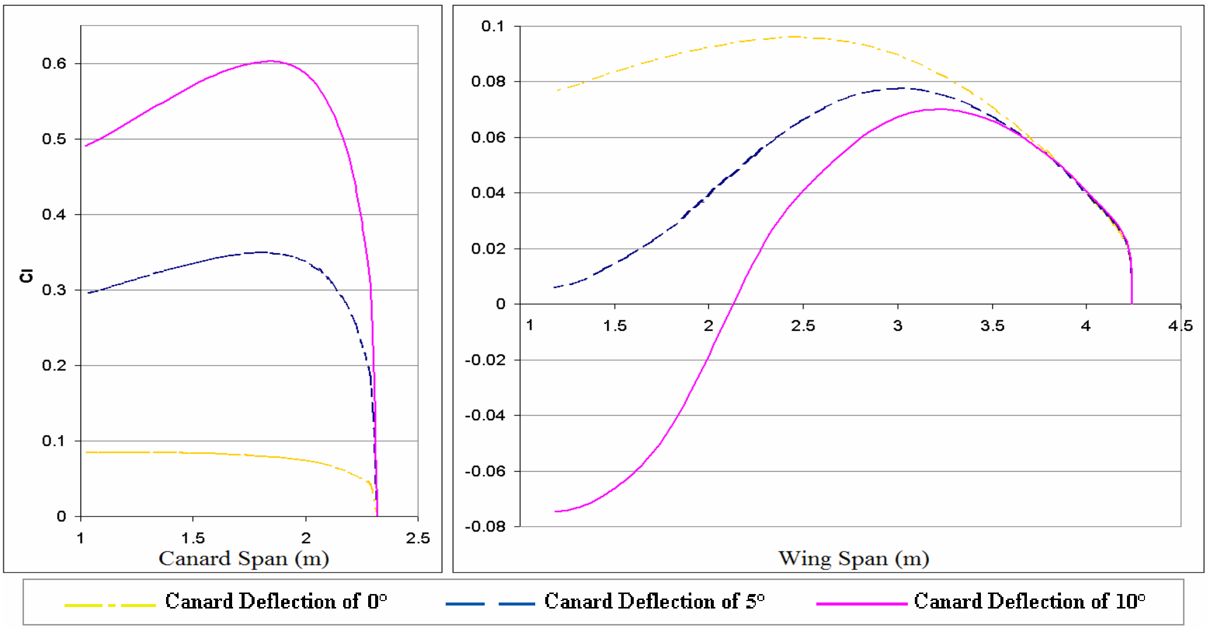

Figure 4 – Comparison of Cl distribution in function of span for α=0°.

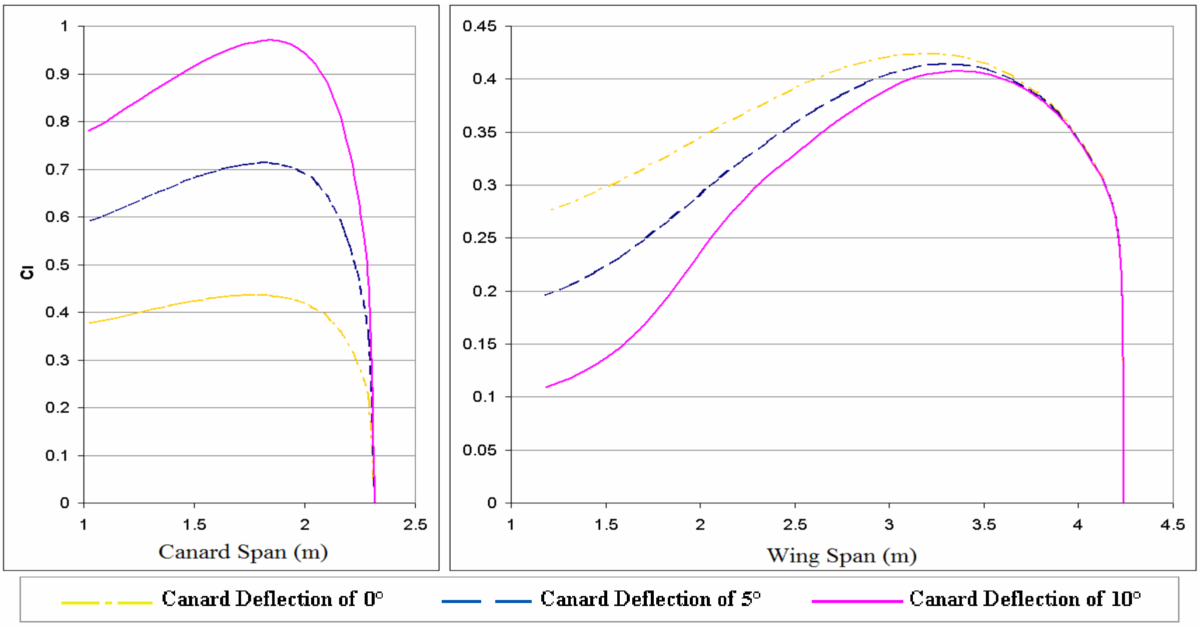

Figure 5 – Comparison of Cl distribution in function of span for α=5°.

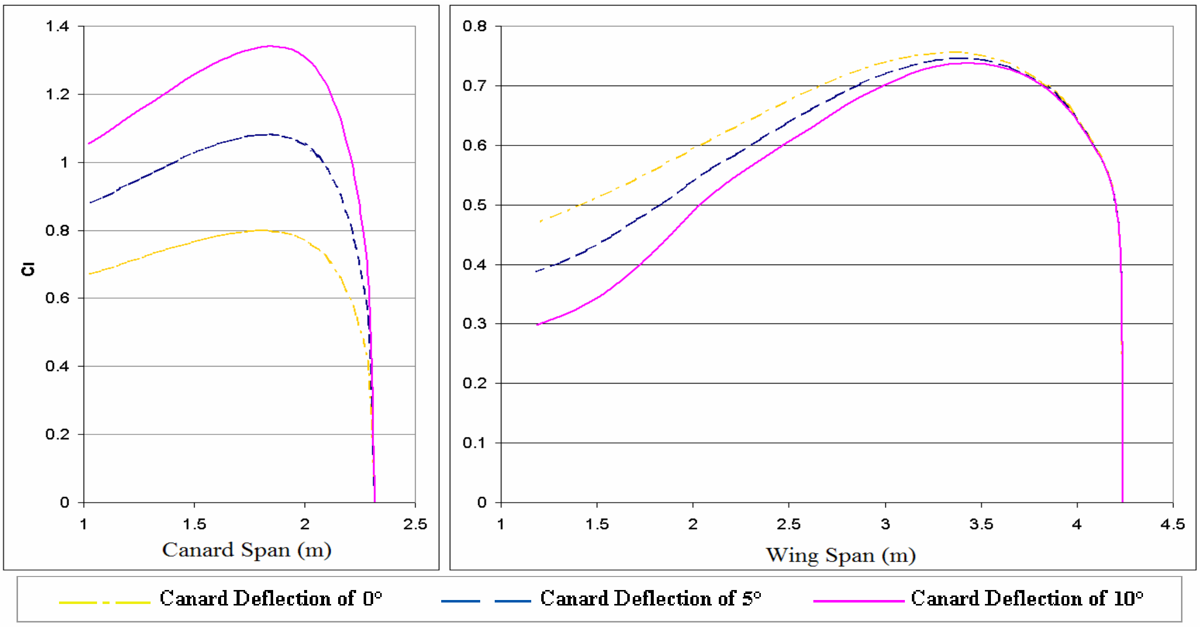

Figure 6 – Comparison of Cl distribution in function of span for α=10°.

The effective angle of attack over the canard is composed by the aircraft angle of attack (α) add up to the canard deflection and the upwash contribution deriving from the wing. Observing the Figure 4, 5 and 6 can be noted the variation of the wing upwash contribution to the Cl of the canard. To make easier to visualize, in Figure 7 were exposed in the same graphic all the curves of the canard Cl in function of the canard span. The curves are exposed in such way that the sum of the canard deflection to the aircraft angle of attack results in 10 degrees. The difference of canard Cl presented in the graphic is resulted by the contribution of the wing upwash to the effective canard angle of attack. As the Cl of the wing grows is observed an increase in the upwash of the wing interfering in the canard flows. The obtained results are curves nearly identical with an offset in Cl between them. Also, can be observed in Figure 7, that Cl differences between curves do not have a linear comportment. These characteristics make clear that the interaction between the canard downwash and the wing upwash presents variables very difficult to foreseen without rigorous analysis.

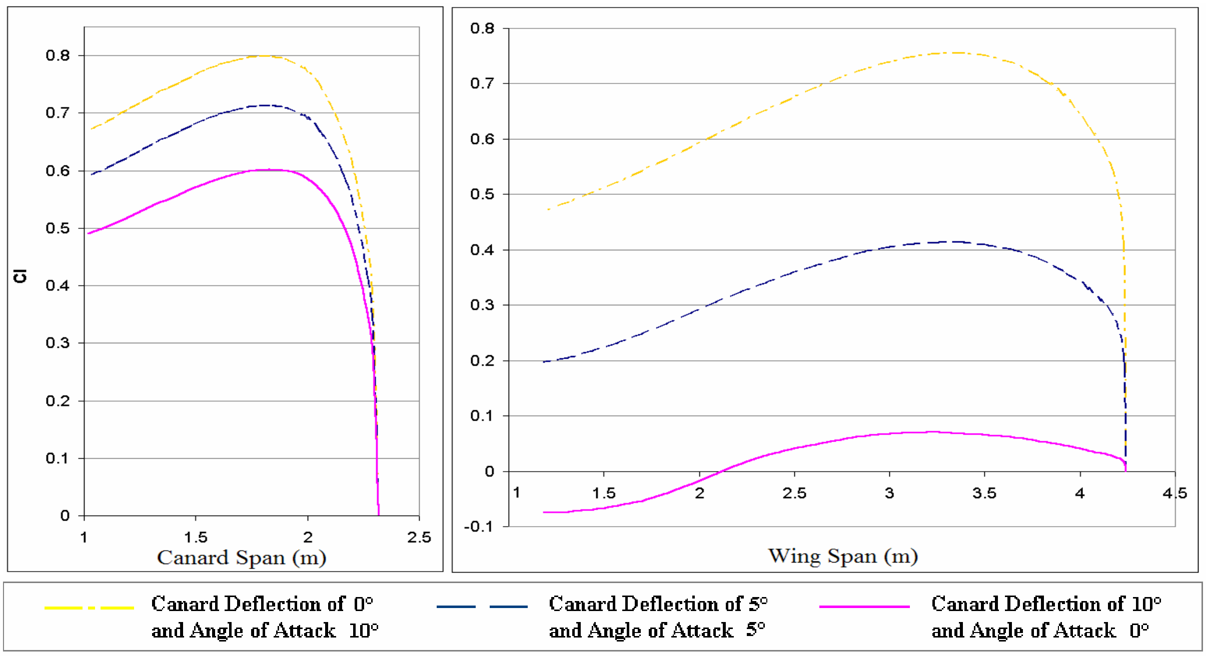

Figure 7 - Comparison of Cl distribution in function of span for canard deflection of 0° and α=10°, canard deflection of 5° and α=5° and canard deflection of 10° and α=0°.

In the Figure 8 is showed the Cp distribution along the chord to some wing stations. Can be notice for deflection angle of 5 degrees, the leading edge at station of 25% of the wing span presents positive Cp at the upper surface and negative Cp at under surface. Nevertheless, in the middle to the trailing edge of the chord, it is observed a normal behavior of the Cp for this angle of attack. Namely, the Cp at the upper surface exhibits values smaller than the Cp at the under surface, and as the distance to the canard increase smaller is its influence to the Cp distribution of the wing. For the canard deflection angle of 5 degrees the integral of the Cp still results in a positive Cl. However, for the canard deflection angle of 10 degrees the difference of Cp between the upper surface and the under surface at the leading edge is even greater resulting in negative Cl in the wing station of 25% of the wing span. This same comportment can be observed in the station of 50% of the wing span, but, for canard deflection of 10 degrees the Cp integral results in Cp very close to zero, that is in accordance with Figure 4 where the Cl curve intersects the axis near to 2 meters of wing span.

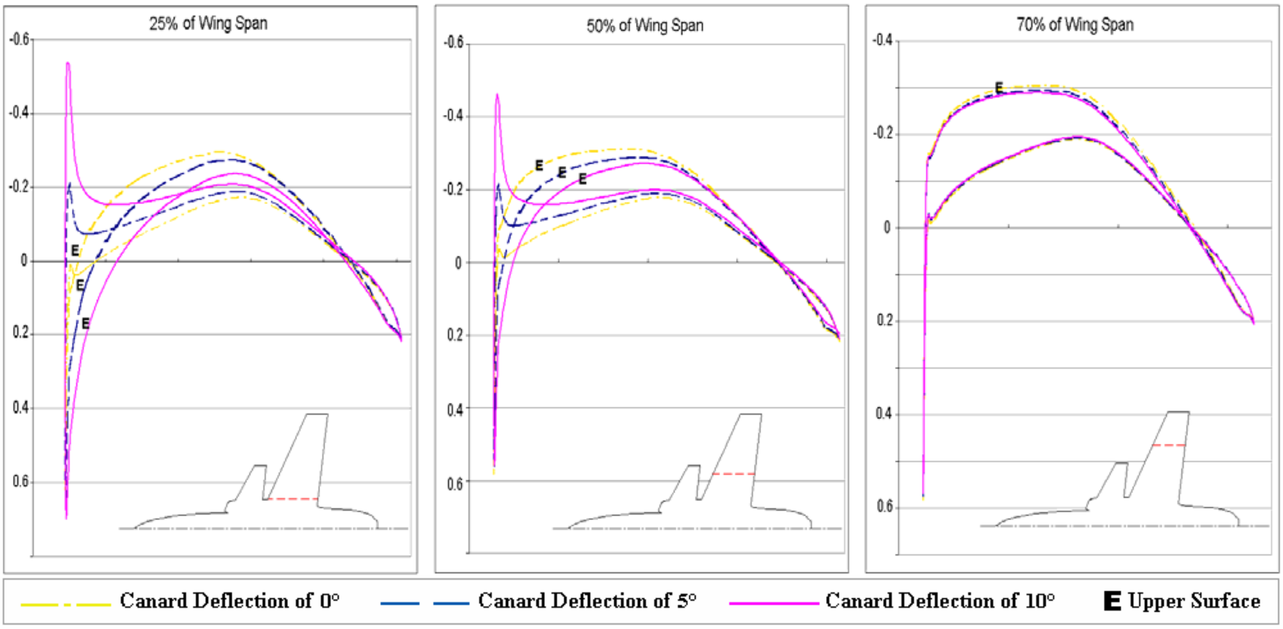

Figure 8 – Comparison of Cp distribution in function of wing chord for α=0°.

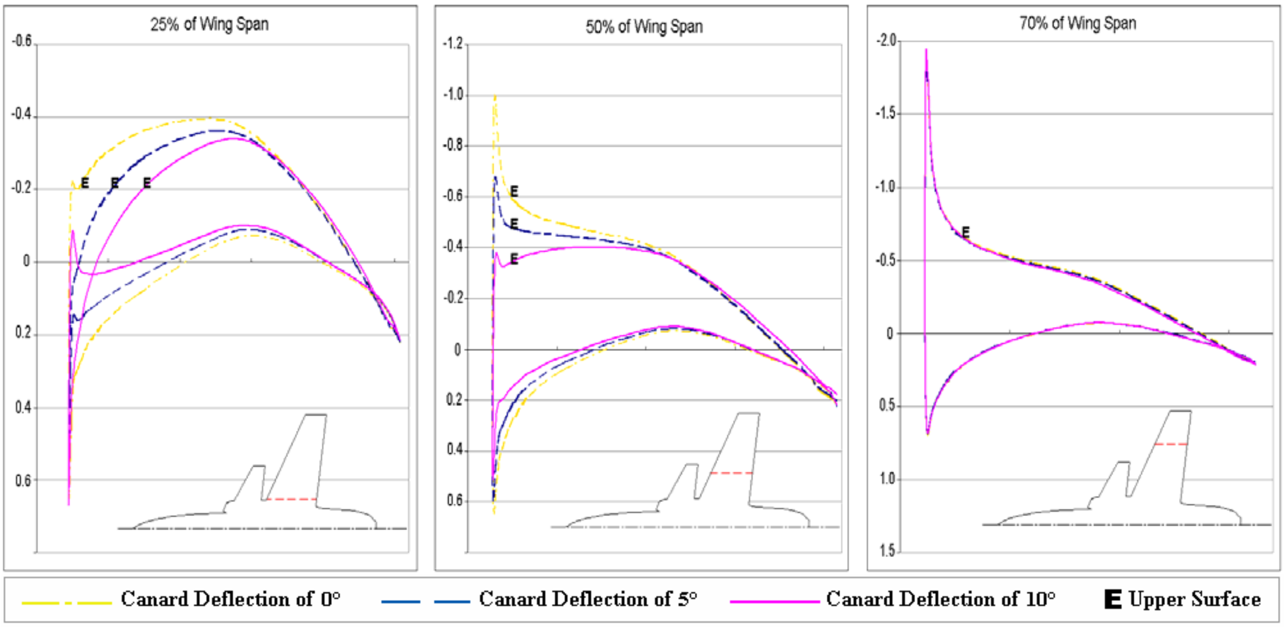

Figure 9 – Comparison of Cp distribution in function of wing chord for α=5°.

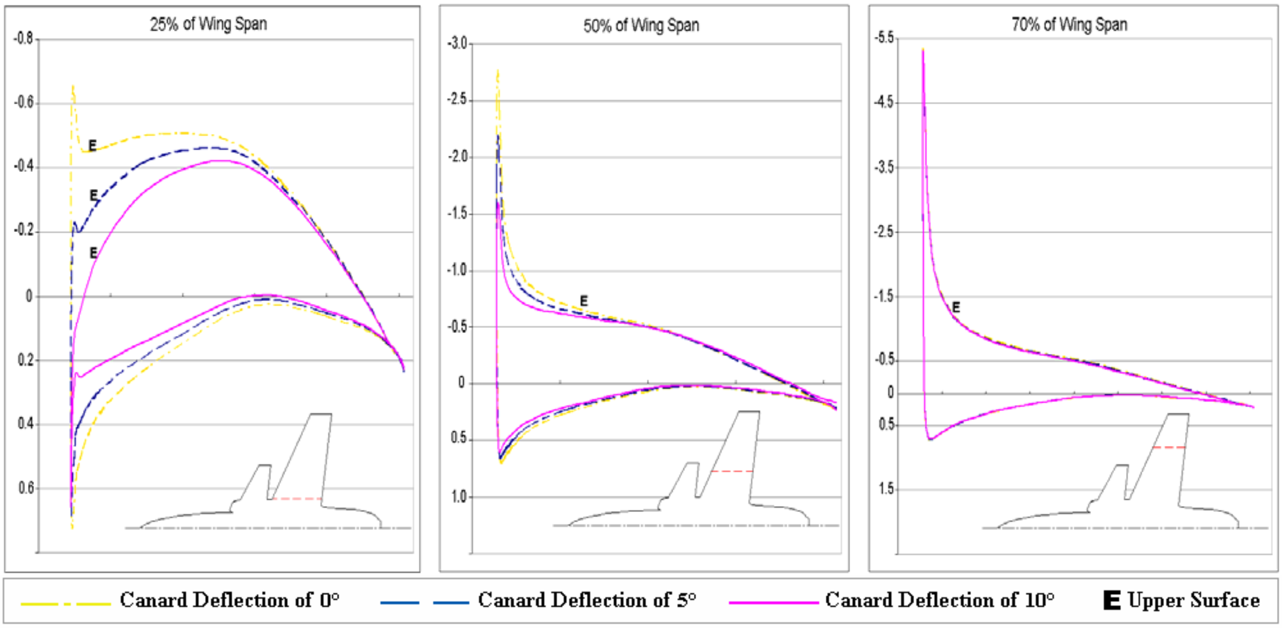

Figure 10 – Comparison of Cp distribution in function of wing chord for α=10º.

3.2. Canard Tip Vortex Effects

An undeniable benefit of the canard configuration is the additional lift caused by the canard tip vortex passing near the upper wing surface. This interaction is not always helpful (Tu, 1992), so that the canard position and the maximum deflection must be very well dimensioned for each design.

In Figure 11 is shown a comparison between the configuration 2 (with negative dihedral), the configuration 1 (configuration used in the aircraft model) and the wing without the canard. The aircraft angle of attack for this simulation is 3 degrees and the canard deflection of 10 degrees. Can be noted for configuration 2 in the wing section where the canard tip vortex passes near the upper surface (2.3m) there is an abrupt increase of Cl.

The main advantage of the vortex passing near the upper wing surface is the energetic enhance of the boundary layer of the affected wing region and subsequent increase of the angle of attack that begins the stall, this way, increasing the wing maximum CL (Tu, 1992). However, the canard tip vortex passing near the upper wing surface present enhance of local lift even for low angle of attack.

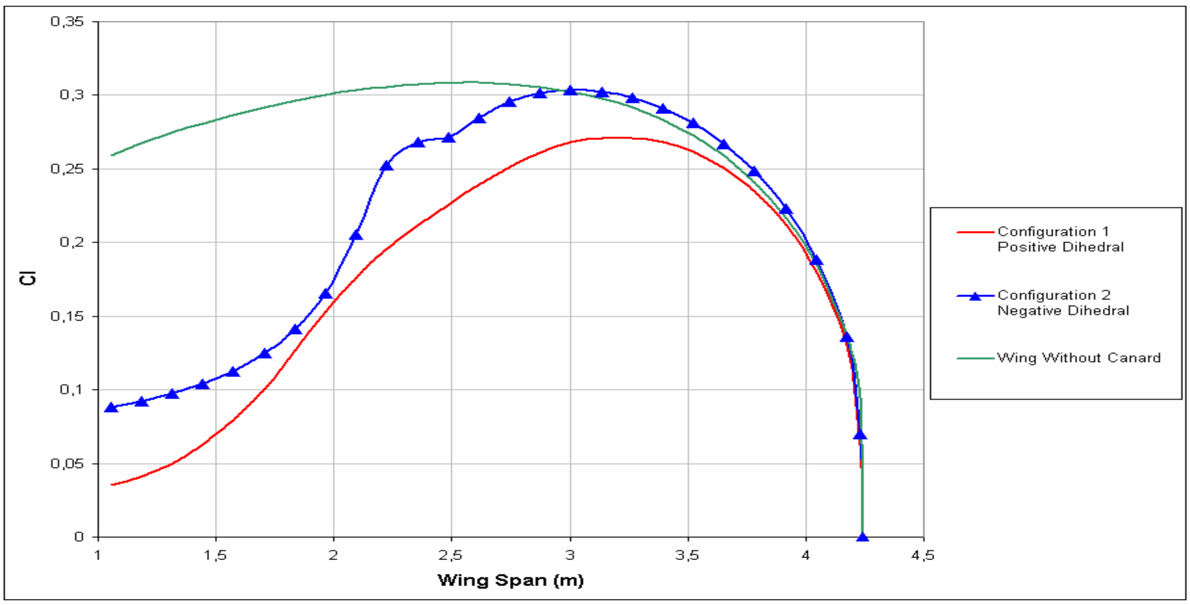

Figure 11 – Comparison of Cl distribution in function of span with canard deflection of 10º and α=3° for configuration 1, configuration 2 and wing without canard.

Another interesting effect of the vortex approximation to the wing is the upwash enhance in the external region of the wing, resulting in increase of the Cl near the wing tip. Can be notice that, due to the utilization of a negative dihedral (-15 degrees) the interference of the canard downwash in the wing root is smaller than the downwash of the positive dihedral configuration. This aspect makes the wing Cl in this region higher in configuration 2. This happens, because the canard root in configuration 2 is more distant to the wing than the other configuration.

4.Conclusions

With the canard deflection and the following raise of lift of the surface, there is a meaningful reduction of the lift in the wing region in the canard wake direction.

In spite of this work do not study the pitching moment of the wing-canard configuration, in function of the canard deflection, the comportment described in the previously paragraph allows to conclude that a positive deflection of the canard results in pitch up moment of the aircraft. In this situation occur an increase of the canard lift and consequent reduction of the wing lift. This close coupling comportment of the lifting surfaces impedes an ease prediction of the pitching moment relative to the empennage volume, which can be easily calculated for a conventional aircraft.

For the canard configuration, the increase of the aircraft angle of attack makes the maximum Cl dislocate to the wing tip direction. Deflecting the canard this comportment increases even more. A wing design for a wing-canard configuration must take this comportment on count. In this way, it is recommended the use of leading edge lift increasing device in the externals sections of the wing, to the take off and lading configuration and for maneuver.

5. Acknowledgments

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6. References

Lopes, Vitor Mainenti Leal, 2004 "Analysis of a Wing-Canard Configuration Using Panel Method" – Proceedings of the 10o Brazilian Congress of Thermal Sciences and Engineering -- ENCIT 2004 Braz. Soc. of Mechanical Sciences and Engineering -- ABCM, Rio de Janeiro, Brazil.

Lopes, Vitor Mainenti Leal, 2004 "Analysis of a Wing-Canard Configuration Using Panel Method." – São José dos Campos, Thesis (Master Degree), Instituto Tecnológico de Aeronáutica (ITA).

Gloss, Blair B., 1975 "Effect of Wing Planform and Canard Location and Geometry on Longitudinal Aerodynamics Characteristics of a Closed- Coupled Canard Wing Model at Subsonic Speeds" – NASA TN D-7910, June1975.

Gloss, Blair B., 1974 "Effect of Canard Location and Size on Canard-Wing Interference and Aerodynamic-Center Shift Related to Maneuvering Aircraft at Transonic Speeds" – NASA TN D-7505, June1974.

Tu, Eugene L., 1992 "Effect of Canard Deflection on Close-Coupled Canard-Wing-Body Aerodynamics" – AIAA-92-2602-CP.

Gloss, Blair B. and Washburn, Karen E., 1978 "Load Distribution on a Closed-Coupled Wing Canard at Transonic Speeds" – Journal of Aircraft, Vol. 15, N°. 4, April 1978, pp. 234-239.

Pfeiffer, Neal J.,1989 "Computational Aerodynamics Applied to General Aviation/Business Aircrafts" – In; Henne, P.A., ed. Applied Computational Aerodynamics. Washington, American Institute of Aeronautics and Astronautics Inc. Cap. 16, pp. 617-635.

Maskew, B., 1986 "VSAERO – Theory Document" – NASA CR-4023, Nov. 1986.

Abbott, I.H. and Von Doenhoff, A.E., 1959 "Theory of wing Sections" – New York, Dover.

Lednicer, David, 1988, "A VSAERO Analysis of Several Canard Configured Aircraft" – Gemini Technologies, Inc. 881485.

Morino,L., 1986 "Computational Methods in Potential Aerodynamics" WIT Press, December 31, 1986.

7. Responsibility notice