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Aerodynamic study of wingtip devices on non-conventional configuration BWB

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Abstract. *In the last decades new aircraft's configurations are being studied to get lower operational costs, ecologic impact and the noise emissions levels. The BWB is a new concept in which the fuselage and a conventional wing are integrated as one single body, like a flying-wing, without tail. The wing tips are devices designed to reduce induced drag on the aircraft, improving the aerodynamic efficiency. These devices can also be used on both stability and control unities. The aim of this paper is continue with the research made in the EESC-USP on non-conventional aircraft configurations, studding numerically the aerodynamic interference of winglets and c-wing devices on a BWB model; in this order to find the best aerodynamic configuration between those three models. First of all, several measurements were taken of the scale model with a measure arm (ROMER) to generate a 3-D model in CAD, then a CFD analyses was carried out. The aerodynamic properties as lift and drag coefficients at several attack angles were obtained. The result shows that the wingtip devices improve the aircrafts performance and its efficiency.*

Keywords. *Blended Wing Body, Wingtips, C-Wing, CFD, no conventional aircraft*

1. INTRODUCTION

In the last decades, the aviation industry faces different challenges, which includes the reduction of noise and gas emissions, in the same way, it has been necessary both for the increase of transport capacity and seeking greater payloads (Liebeck, 2004). Theoretical, experimental and numerical studies have been carried out in order to achieve better aerodynamic efficiency. The wingtip devices and unconventional aircraft are results of these researches (Martínez-val, 2008). The wing tip devices could reduce the characteristics of the wing tip vortices or generate additional forces in directions of the flight or both. In this paper, the winglet and c-wing on a BWB model were studied.

The non-conventional configuration called as Blended Wing Body (BWB) improve the aerodynamic performance due to their high aerodynamic efficiency L/D (lift/drag). Although the BWB has limitations in both the conceptual design and aerodynamic design for larger aircraft, it has been considered as a promissory proposal by the aeronautical sector.

Studies in smaller aircrafts like the UAVs **(Unmanned Air Vehicle)** and private jets (Djojodihardjo and Wei, 2012) are being carried out in order to applying the philosophy BWB.

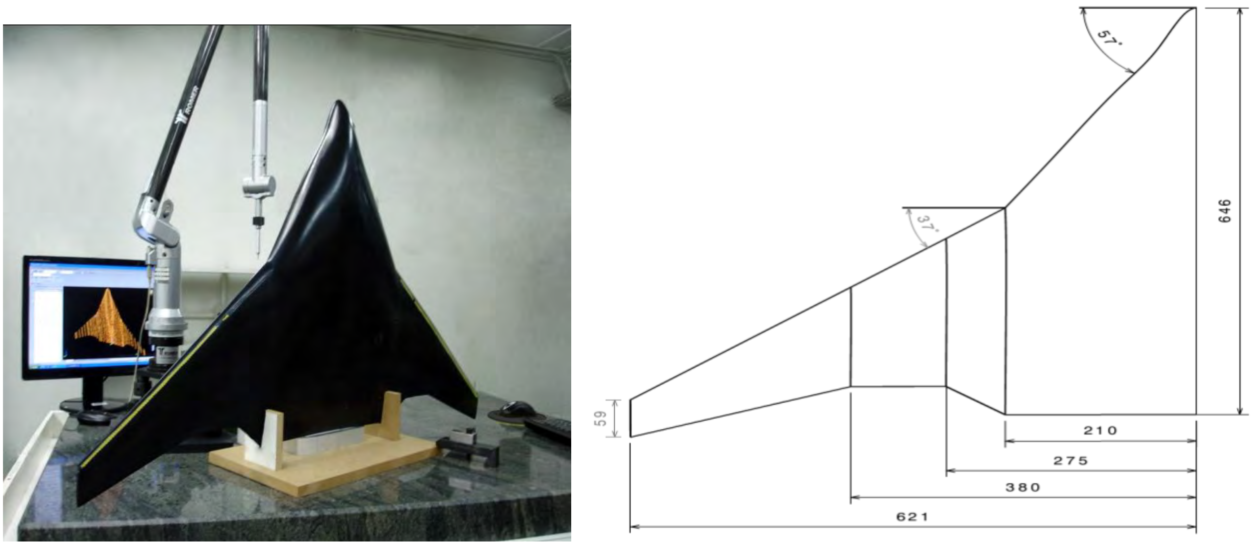
The aim of BWB is to improve the aerodynamic efficiency due to the reducing the wetted area and the interference of surfaces (Doe,2006). The fuselage is designed to have a shape of an airfoil and carefully streamlined with the wing, generating lift together with the wing, increasing the lifting surface area. Thus, most of the elements of a traditional aircraft become part of one wing. The surfaces that do not generate lift are eliminated, with consequent reduction of drag and fuel consumption, therefore, the gas and noise emission are also reduced (Leifsson and Mason, 2004).

This paper focus in the aerodynamic study of a non-conventional model BWB clean, and with two different wing tip devices using a Ansys CFD ® (computational fluid dynamics) software . The goal of the paper is to analyses the behavior of these three arrangement and their interference over the aerodynamic efficiency. More detailed information about the BWB base model utilized can be found in (Ceron-Muñoz,2004).

2. BLENDE WING BODY

The BWB is a concept where the fuselage, wing, tail and engines are integrated as one single body improving the aerodynamic efficiency. In this configuration, the body is designed as an aerodynamic shape and smoothly joined to the wing. This concept diminishes the total drag due to decreasing the wetted area and the interference drag in comparison with a conventional airplane. Besides the fuselage is replaced by an aerodynamic shape which produces lift, where lifting is higher than a conventional configuration. Additionally the hall body's bulk of the BWB allows greater space for passenger, payload or fuel.

An articulate measurement arm was used in order to create a 3D model, as can be seen in Fig 1. Both the configuration and dimensions of the BWB are based in previous works (Ceron-Muñoz, 2004).



(a) (b)

Figure 1: Measurement and geometry of the BWB model

3. WINGLET AND C-WING

The wing tip devices are designed in order to reduce the induced drag. The induced drag is about 30-50 percent of a total drag of an aircraft in cruise, while at low speed and high lift conditions the induced drag gets higher, and it is the main component of the total drag. The winglet and c-winglet on the BWB´s wing tip reduce the influence of the wing tip vortex over the aircraft reducing the induces drag. These devices have been developed and applied to conventional aircrafts and these can be used for decrease the induced drag. For non-conventional configuration this surfaces can be also used both as control and stability surfaces.

Winglets for modern aircraft were first proposed by Dr. Richard Whitcomb at NASA Langley in the mid-1970. At that time, wind tunnel models and subsequent full size flight tests on a Boeing 707 commercial jetliner demonstrated a significant reduction in total drag at high lift coefficients.

During the development of wing tip devices, the winglet has shown achieve greater aerodynamic efficiency. This device controls the flow over the wing tip. Greater winglet produces greater forces in the thrust direction; nevertheless this involves structural problems for the aircrafts.

The C-wing is an adaptation of the winglet, where a small horizontal surface are added on the top of the winglet, developing the same physical effect that the Winglet, creating a lateral force towards the interior of the aircraft and leaning forward, as can be seen in Fig 2b. This force is a result of the deflection in free stream velocity V_∞. This deflection is generated by the pressure difference between the upper surface and the lower surface of the wing near the wingtip, which in turn generates a force component (Twl) which reduces induced drag. The sketch can be seen in Fig 2a, for both configurations.

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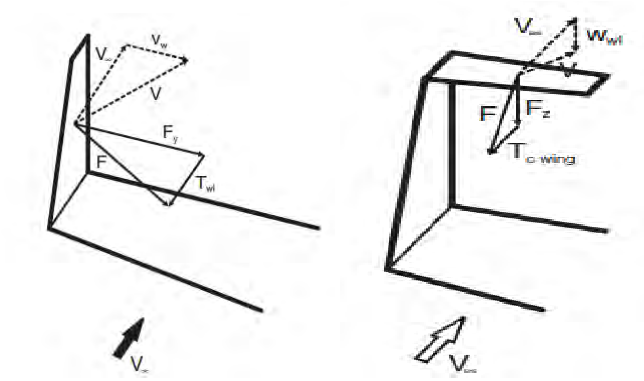
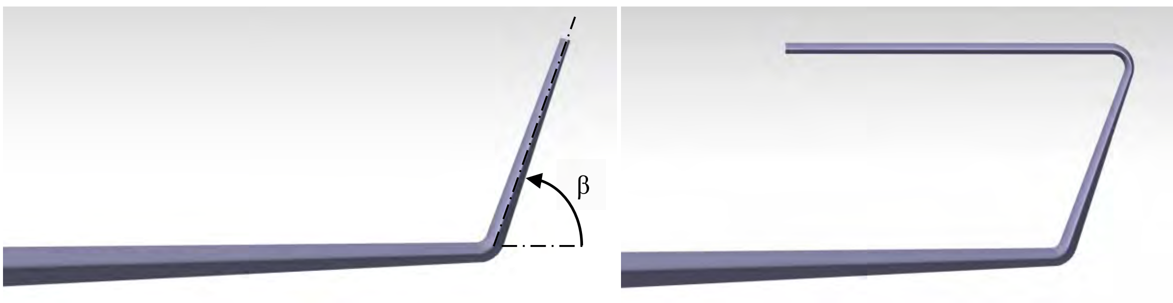


(a) **(b)**

Figure 2: Schematic graph of the forces produced by the Winglets (a) and the C-Wing (b) (Slingerland and Verstraeten,2008).

4. METODOLOGY

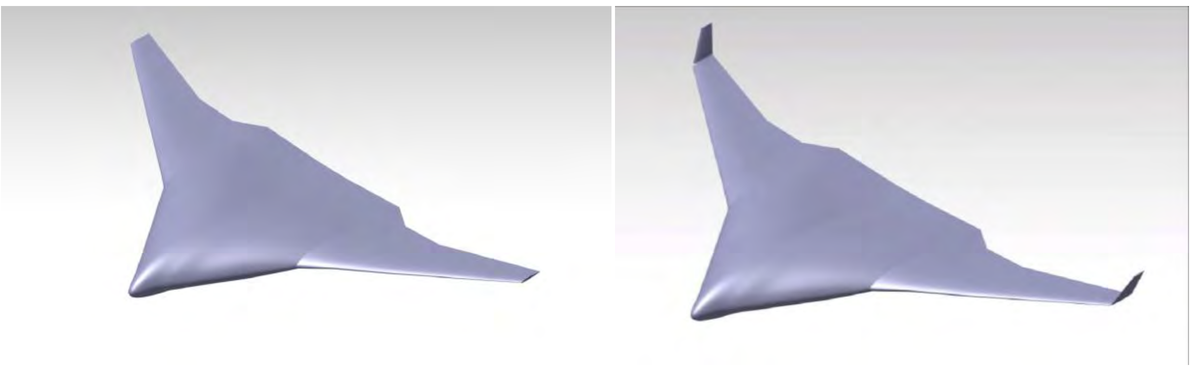
First of all, CFD simulations was taken to the clean model, in order to get the geometrical dimensions for the winglet and c-wing, see fig 3. Based in Whitcomb studies for winglets design the CANT (β) angle was set in 72 [degrees]. Then a line was created at the tip of the clean model with the CANT angle slope to obtain the velocity components and compute the twist for the winglet. With a winglet span of 61.75 [mm], where the velocity components are equal to the free stream velocity. The twist for the bottom 2.24 [degree] (outward), and the twisty of the top of the winglet is 1degree (inward), which give an effective angle for the winglet of 4 [degrees]. The airfoil shape for the winglet is the same as the clean model wing tip. Based in Whitcomb also the sweep angle of the winglet was set in 37 [degrees], for the c-wing model a symmetrical airfoil was chosen, with a torsion (downward) of 2 [degrees] and length of [110 mm].



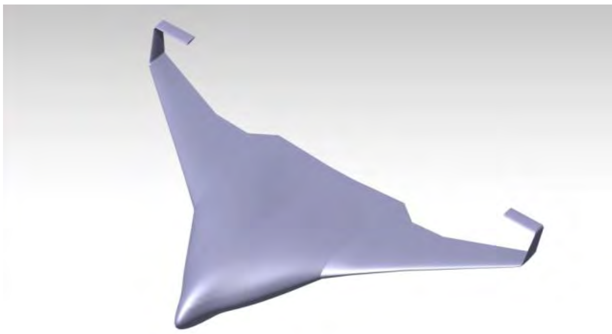
(a) (b)

Figure 3: Wing tip devices, Winglet (a) and C-wing (b)

CATIA CAD tool was used to create the models, as shows in the fig 4, ANSYS-CFX CFD software was used to compute and analyzed all the flow properties and their characteristics on the three models.



(a) (b)



(c)

Figure 4: (a) BWB, (b) BWB with Winglets and (c) BWB with C-Wing

In Fig. 5 can be seen the BWB meshed with an unstructured grid. The number of elements and nodes was 3.520.838-643.728 for the clean model, 3.662.068-668.350 for the winglet model and 4.060.723-740.523 for the c-wing model, besides inflations layers was added in order to capture the boundary layer effects. The turbulence model used for the simulation is Shear Stress Transport model (SST), recommended for high accurate boundary layer in the CFX solver modeling guide. The dimensions of the computational domain are 5 [m] length, 2.5 [m] height and 1.2 [m] width. The physics parameter chosen for simulation are, pressure 1 [atm], density 1.223 [Kg*m^3], and a isothermal heat transfer model with temperature equal to 288 [K], because in this regimen, the flow can be treated as incompressible flow, with free stream velocity of 35 [m*s^-1], all the values are International Standard Atmosphere (ISA) at sea level.

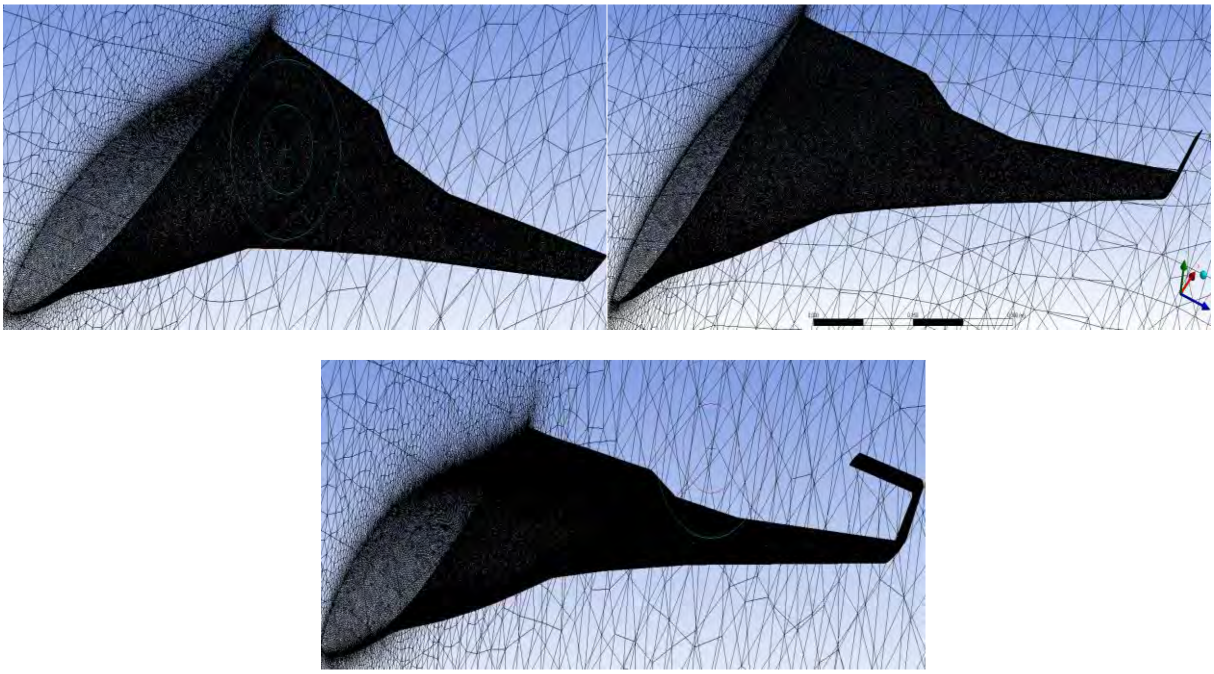


Figure 5: The wall mesh of BWB and wingtip device

5. RESULTS AND DISCUSSION

In this section, the result from CFD software for the three models (BWB clean, BWB with Winglets and BWB with C-wings) is presented. The data COLLECTION obtained is plotted from the lift coefficient versus angle of attack curve, drag coefficient versus angle of attack curve, drag polar and lift-to-drag versus angle of attack curves.

5.1. Lift and Drag Coefficient

The lift coefficient (C_L) versus angle of attack (α) for three models is shown on Fig.6. From the curve, it is observed that the three models show the same trend, as the results was evaluated until an angle of attack of 20 [degrees]. It was not possible to find the máximum lift coefficient, because the fuselage may have a behavior similar which presents a

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delta wing. The delta wing can get an angle of attack for maximum lift coefficient about 40 [degrees] (Wirchman, 2010).

Change of the slope appears at three curves at α around 8 [degrees]. This alteration is due to the flow separation, which occurs on the external wing section. This means the lift generated after 8 [degrees] is generated by the central section of the body, the separation can be see it on fig. 7 (BWB clean, BWB with winglet and BWB with C-wing).

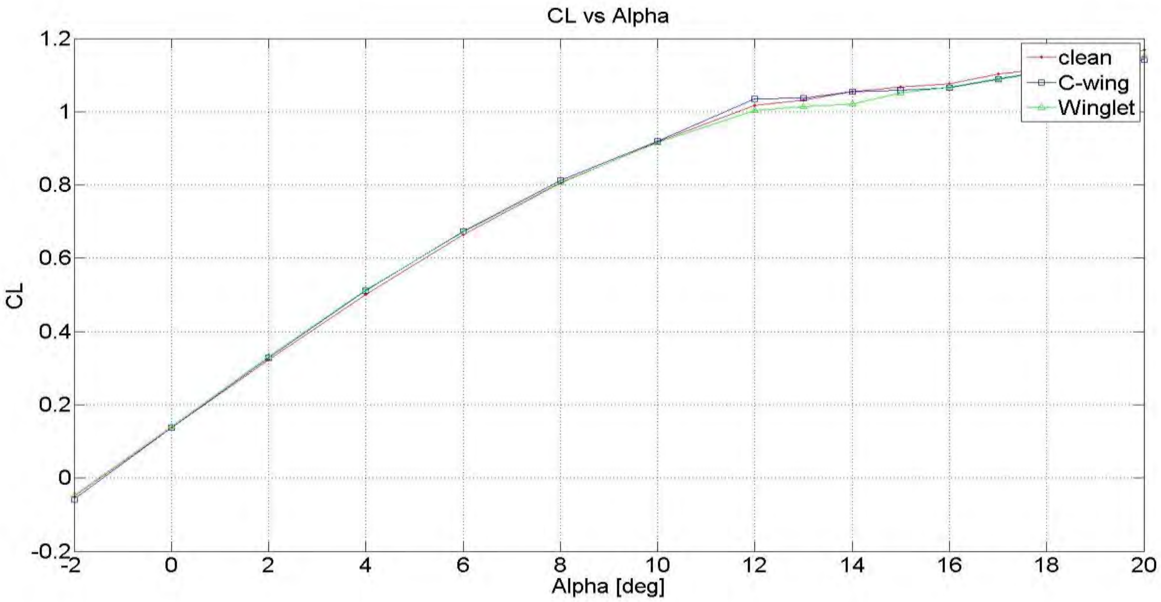
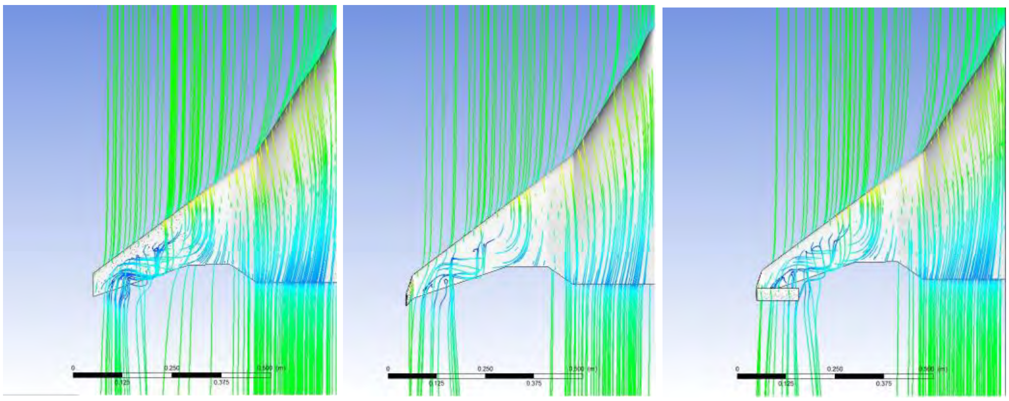


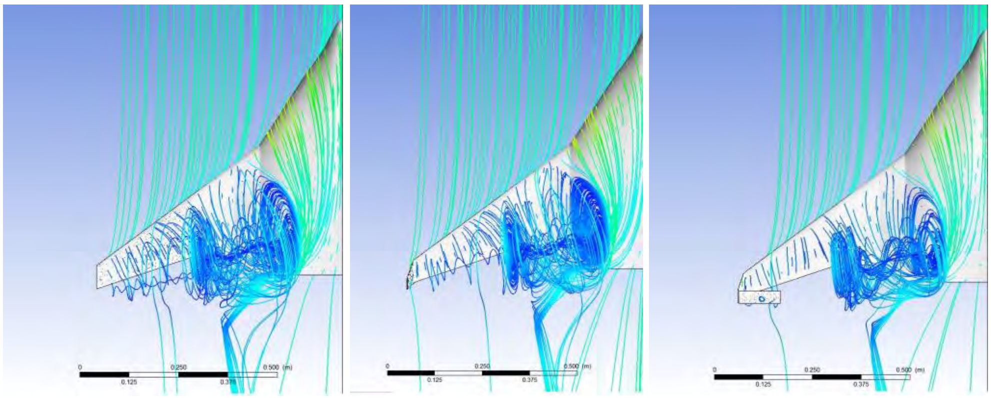
Figure 6: Variation of Lift coefficient (C_l) versus angle of attack (α)



(a) (b) (c)

Figure 7: Visualization of small deviations for α=8°, (a) BWB,
(b) BWB with Winglets and (c) BWB with C-Wing

In fig.8 can be seen the behavior of the flow pattern for the model (a) clean, (b) winglet and (c) c-wing respect at 20 degrees. The stream lines show the flow separation at the wingtips of the models. For the clean model the separation area is higher, so both winglet and c-wing also helps keeping the flow attached to the body (aircraft).



(a) (b) (c)

Figure 8: Visualization of small deviations for α=20°, (a) BWB, (b) BWB with Winglets and (c) BWB with C-Wing

The variation of drag coefficient C_d versus angle the attack (α) (see Fig 9), for BWB clean a constant value of C_d (around 0.02) at low angles of attack (between -2 to 2 degrees). At 4 [degrees], the curve shows a steep rise, with C_d increases as α. For the curves of wingtip devise shows the value of C_d=0.03 at low angle attack (between -2 to 5 degrees). At 6 [degrees] the curve shows rise, and afterwards, C_d increases as α increases with a lower rate compared to BWB clean that is the main objective in this paper.

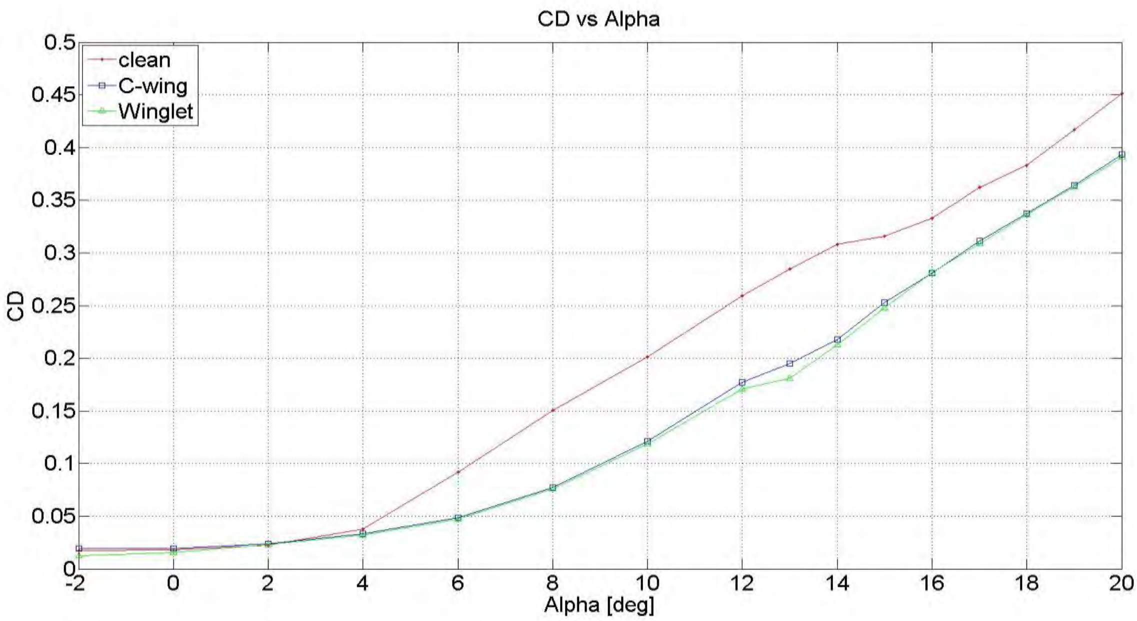


Figure 9: Variation of drag coefficient (C_d) versus angle of attack (α)

5.2 Drag Polar

The drag polar curve can be seen in the Fig. 10 for three models. The curve show for BWB clean the value for C_d at zero lift is approximately 0.02, for BWB with winglet is 0.018 and for model with c-wing is 0.17 approximately. As curves shows that for lift coefficient highest to C_l=0.5 have increased growth in the C_d for BWB clean, but for the other two models this increase begin in C_l=0.7 approximately (Wirchman et al., 2010).

The curves shows that, in the variation angles of attack, the BWB clean generate largest induced drag that BWB with wingtip device (Winglet and C-wing), where this minimization is important for decreased fuel consumption.

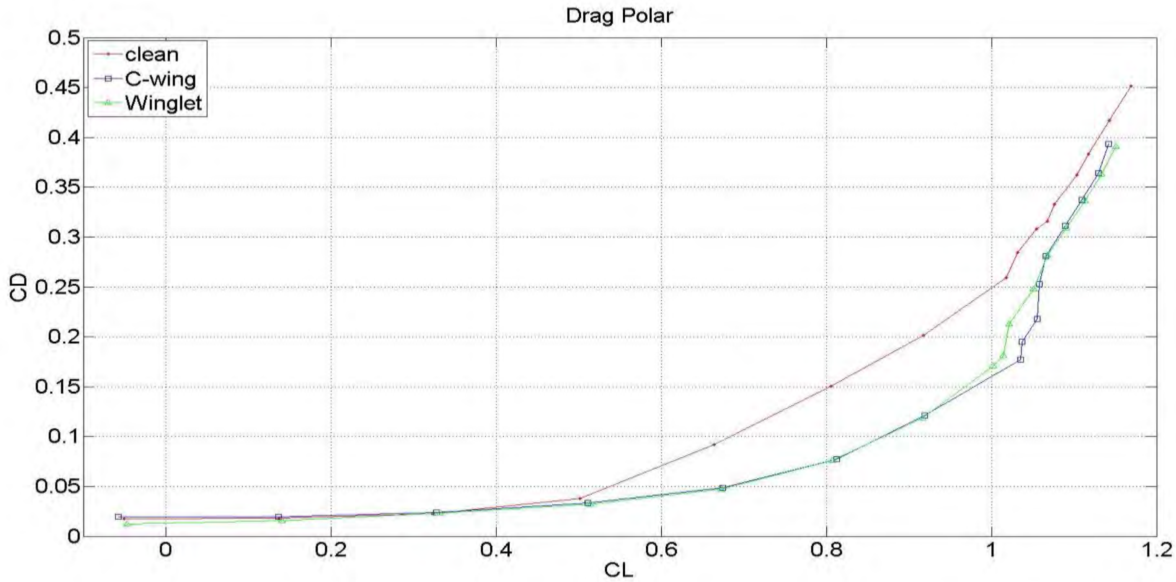


Figure 10: Drag Polar (Lift Coefficient versus Drag Coefficient) curves for three models

5.3 Lift-to-Drag Ratio

The curve Lift-to-Drag ratio (L/D) versus angle of attack is presented on fig. 11. The BWB clean curve shows a maximum value of L/D about 14 at α=2 degrees, while BWB with c-wing curve shows maximum value of about 15.34 at α=4 degrees, and the BWB with winglet curve reaches its maximum value of about 15.88 at α=5 degrees. These angles of attack indicate the optimum flight configuration for three models. This indicates that BWB with winglet has better flight performance compared to BWB clean and with c-wing.

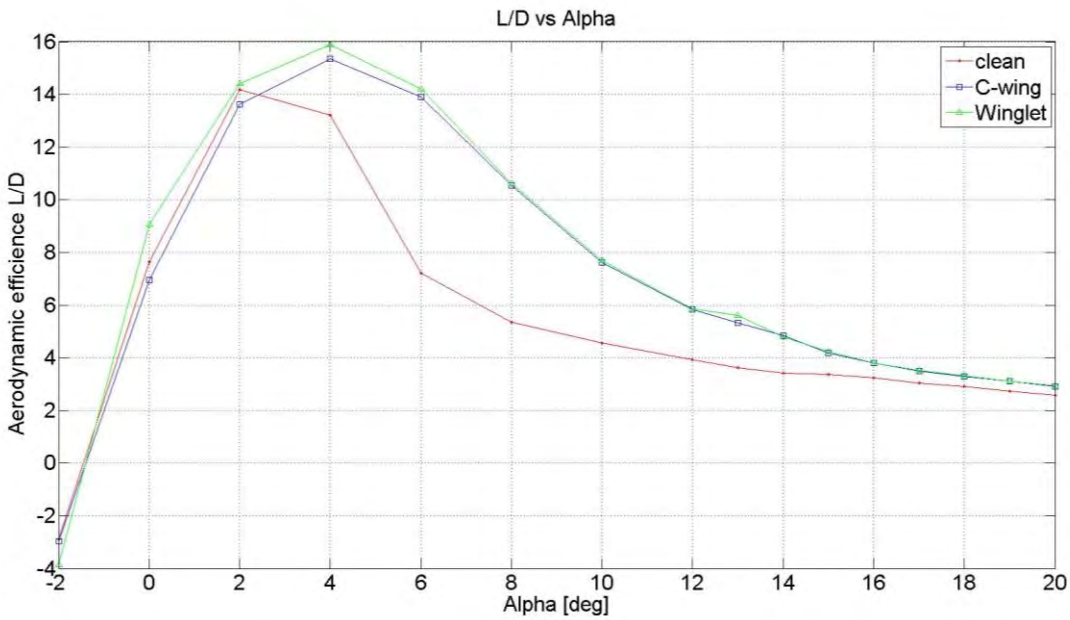


Figure 11: L/D vs Alpha curves for three models

6. CONCLUSION

An analysis of the aerodynamic interference of wingtip device was carried out on a non-conventional BWB model. The device plays an importance in the minimization of induced Drag. The results suggest that both winglets and c-win show improve in the aerodynamic performance of the clean BWB model, where the winglet was the better in this topic.

For the c-wing has a raise of the wetted area, so the induced drag reduction was not as well as by the winglets. Nevertheless, the c-wing model present a similar behavior and the extra surfaces in the c-wing model could be useful in the installation of operation of control devices.

The results given in this work need to be validated with experimental results for the wing tips models, due that the results of the computational tools show trends and can not taken completely as real values.

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