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AERODYNAMIC INTERFERENCE OF POWER-PLANT SYSTEM ON A BLENDED WING BODY

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Abstract. *The aim of this research is to study the aerodynamic characteristics of a blended wing body configuration (BWB) and the effects of the powerplant arrangement. Different studies have shown that the engines and inlets could be placed on pylons over the upper surface near the trailing edge of the central wing section. This arrangement is accepted to reduce the internal noise and to increase airccraft safety on the takeoff and landing stages. The present work presents an experimental analysis of the engine-airframe integration on a BWB configuration. In order to study the interference between the nacelle and the BWB, the pylon was not included.*

Keywords: *Blended wing body, BWB*

1. INTRODUCTION

Due to the environmental restrictions at the airports and the market economy, the aviation industry seeks alternatives to develop an aircraft that generate lower operating costs, lower ecological climatic and acoustic impacts. In the decade of 1990 appears the proposed called Blended wing body (BWB) as a long-range subsonic aircraft configuration. The "Blended wing body" could be understood as a smooth combination of the wing with the fuselage. Over the last decades the international aviation community has shown a growing interest in developing this type of aircraft.

The BWB is not a completely new configuration. There were tailless aircraft that were not successful because of the control limitations and stability. However, technological advances and new materials have allowed the operation of military aircrafts with a format of flying wing similar to the BWB. These advances make feasible the possibility of implementating and operating such aircraft for civil transport in the near future. The different areas of aeronautical engineering are committed to the development and optimization of the BWB.

One way to improve the profitability of future aircraft would increase the capacity of passenger transport. This would reduce the direct operating costs (DOC) per passenger and decongest the major airports due to reduced frequency of flights. However, the format, manufacturing processes and size limitations imposed by existing infrastructure at the airports may have limited the maximum capacity of passengers to the conventional aircraft configuration (Bolsunovsky *et al.*, 2001).

Regarding the noise impact, the jet has reduced more than 20dB noise emission, compared to the first aircraft reaction (Green, 2002). This decrease is largely because of the implementation of the turbofan engine high by pass. But in the last two decades, although increasing the ratio of by pass, it has not achieved greater reduction in noise emissions (Hall and Crichton, 2007).

In the last 50 years, the aviation industry has based aircraft design, both medium and long range in what is known as conventional configuration. It is a thin, tubular fuselage joined to a couple of swept, tapered, high aspect ratio wings, with stabilizer surfaces on the tail and stationary engines placed in the lower surface of the wings (H.Ghigliazza *et al.*, 2007). The two new long-range aircraft on the market, Boeing 787 and Airbus 380 maintained the basic configuration of the B-47.

The conventional configuration is approaching to an asymptote in terms of productivity and performance characteristics. Therefore different studies are in development to find alternatives that allow aircraft more efficient, lucrative and better to the ecological requirements (Martínez-Val *et al.*, 2007).

2. The BWB configuration

Over the past yeras the BWB configuration has attracted great interest of the aviation industry, government and researcherts(Liebeck, 2004; Smith, 2000; Law and Dowling, 2005). The BWB promises to reduce aircraft fuel consumption and low pollution, the elimination of high-lift system and the power plant airframe over the upper surface of lifting body classifies this setup as a silent and large transport aircraft(Martínez-Val *et al.*, 2007).

The Tailless aircraft has advantages compared to the conventional configuration. The cargo and passengers can be transported inside a spacious structure with a winged shape. The elimination of the stabilizers reduces the weight of the aircraft, causing less drag and greater maneuverability. In the first BWB these advantages, practically were annulled by the longitudinal and lateral instability of the aircraft. The combination of swept wings and location on the tips of both elevators, sush as the aileron, corrected the problems mentioned above(Bowers, 1984). In 1989 the first generation of BWB was submitted to questions concerning the future of aircraft transport(Liebeck *et al.*, 1994). Later, in 2006, the silent aircraft project, SAX("Silence Aircraft eXperimental") was started (Nickol, 2008). The Silent Aircraft initiative is a multidisciplinary project that aims to reduce the issue of noise to be imperceptible in the urban surroundings of the airports (Hall and Crichton, 2007).

Liebeck *et al.* (1994) compared a conventional wing-fuselage configuration with the BWB. It had an aerodynamic efficiency $L/D = 27.2$, 32% higher than the conventional configuration. The TOGW and OEW ware 14% and 10% lower respectively. Liebeck (Liebeck, 2004) makes a brief historical review of the aircraft evolution until the BWB and the BWB-450, with the capacity of 468 passangers and a range of 7750 miles and compares it with similar convencional aircraft requeriments, as the B747, the A340 and the A380.

Moreover, Kehayas (1998) concluded that the conventional configuration would be better than the BWB, but he warns that the possible technological advances were not evaluated. Denisov *et al.* (1998) suggested a Integrated-Wing-Body configuration (IWB) which is an intermediate configuration between a flying wing and conventional aircraft configuration. The IWB maintains the aerodinamyc advantages of a flying wing, specially (L/D) and would present less technical risk; the format would not change so radically in comparasion to the current aircraft.

The integration of the propulsion system will perform a important role in the development of a new aircraft configurations. In order to reduce the aerodinamyc penalities produced for the powerplant instalation, some aspects are extensivevly reviewed between them: the proximity of the nacelles to the wings, the location of the engines along the span, the geometry of the pylon and the engines placed over surface wing or lower surface wing. The aeronautical industry has a vast knowledge on the structures, both wing-pylon-nacelle and fuselage-pylon-nacelle in convencional aircraft(Hopko *et al.*, 1953; Ingraldi *et al.*, 1993; Dietz *et al.*, 2008; Brodersen and Sturmer, 2001; Fujino and Y.Kawamura, 2003; Riedel *et al.*, 1998). In order to reduce the risk in the implementation of the power plant system, this arrangement was de first option for the BWB(Liebeck, 2004). Therefore, other alternatives have emerged in recent years for the BWB (Hill *et al.*, 2004). Among them is the proposal to embed the turbofans engines over the surface of the central wing near the trailing edge. This configuration allows the removal of the pylon and it reduces the wetted area. This configuration is known as Boundary Layer Ingestion (BLI)(Carter *et al.*, 2006).

Rodriguez (2000a,b) presented some computer simulations of an optimization process of the inlet of the nacelles and compared the BLI to a conventional configuration nacelle-pylon. Both number and size of the engines are issues of the BWB study. A distributed propulsion system has been proposed in order to improve the performance of the BWB(Ko *et al.*, 2003; Leifur *et al.*, 2005). According Re (2005) the implementation of this system could achieve a reduction of 5.4% in TOGW and 7.8% in weight of fuel.

There is a discussion about the limitations and restrictions which would involve the implementation of this aircraft. **?** classifies three areas of the aircraft design as high risk factors: Structure of the BWB (structure, weight, materials, cost, human factors), Propulsion (BLI / inlet, design of nacelles) and operability of the aircraft. Bolsunovsky et al. Bolsunovsky *et al.* (2001) analyzed different configurations for the distribution of passengers in the IWB. This configuration enables the implementation of emergency exits and installation of windows in the fuselage. Regarding the process of pressurization of not cylindrical fuselage of the BWB have proposed the use of composite materials that enable the production of multiple sections semi-oval, arranged inside the main body of the aircraft Mukhopadhyay *et al.* (2004).

Another difficulty that is being addressed is the lack of information in order to predict possivle values of the structural weight of aircraft. This information is important to the development process and design of any aircraft. Methodologies that predict these values are being developed as well as techniques that allow the integration of conventional materials such as aerospace composites Howe; Hansen *et al.* (2008). Eventually the result of the B787 and the use of computer programs (finite element) could be the starting point for estimating structural weight of a BWB aircraft.

In this work, test were carried out in wind tunnel in order to analyze the influence of the propulsion system on a BWB model. Two nacelles were constructed to analyze the aerodynamic effects in the model. The nacelles, without pylon, were placed on a three axis positioner, it is not fixed directy to the model. The nacelles position were modified both vertical and longitudinal axes of the model. This was performed a collection of data on the aerodynamic of lift and drag coefficients as well as the pressure region under the influence of the powerplant. In addition, visualization techniques, oil flow and tufts were also performed.

3. Experimental Configuration

The tests were conducted at the Aerodynamic Laboratory of São Carlos Engineering School, University of São Paulo, Brazil. The wind tunnel used was a closed circuit with a test section of 1.2m x 1.7m with turbulence level of 0.25% and the maximum speed of $50m/s$. Further details of the wind tunnel can be found in Catalano (Catalano, 2001).

3.1 The geometry of the BWB model

The access to detailed information of the specific aerodynamic characteristics is limited, but it was possible to determine a geometry based on the work of Liebeck (2004), Qin *et al.* (2004) and Ikeda (2006). The Figure 1 shows an isometric view.

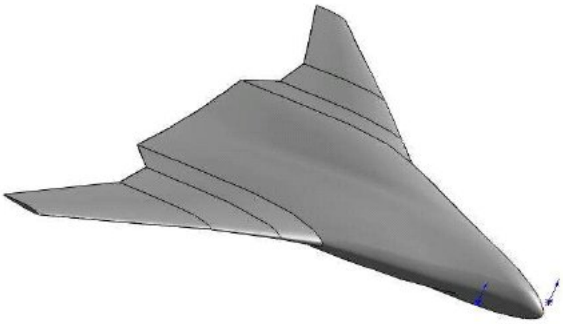

Figure 1. Isometric view of the BWB model

The BWB model is composed of a central lifting section and two tapered and swept wings that provide a smooth combination of the elements that compose it. Adopting the proportions suggested by Qin *et al.* (2004), the model consists of the following sections:

- A thick streamlined centre body: 0 to 0.21m (paylaod).
- A pair of inner wings: 0.21m to 0.38 m (fuel).
- An outer wing: 0.38m to 0.64m.

A drawing of the planform of the model can be seen in the Fig. 2.

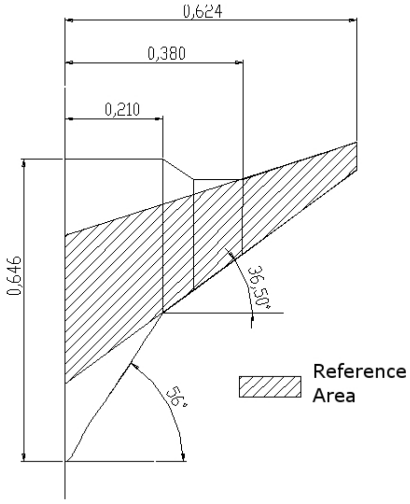

Figure 2. Planform of the BWB model

The leading edge sweep angles are swep back 56^o to the central body and 38^o to the outer wing, respectively. The aspect ratio of the model is $AR = 6.68$ and the wetted area ratio is $S_w/A_{ref} = 3.06$. The aspect ratio (see Fig. 2) and the mean chord taken as reference for the aerodynamic coefficients are $A_{ref} = 0.23m^2$ and $C_{ref} = 0.20m$ respectively. The central body of the aircraft consists of five airfoils from the plane of symmetry of the aircraft, moving spanwise, located at: $y/b = 0$; 0.32; 0.64 ;0.125 e 0.17 respectively. The model was constructed of fiberglass reinforced with carbon fiber using hand lay-up technique for the lamination process.

Two factors were relevant to the choice of airfoils, thickness and the aerodynamic performance at low Reynolds numbers. In the Fig.3 can be seen the wing thickness distribution adopted (Qin *et al.*, 2004). Because of that, Eppler airfoils were chosen whit the same thickness distributions.

The airfoils were modified, so every section has a maximum camber of $(z/c)_{max} = 0,01$ at a $x/c = 0,21$ whit an inflection at $x/c = 0,58$ and negative camber of $(z/c)_{min} = -0,0028$. The profile sections of the central body are shown in Fig.4.

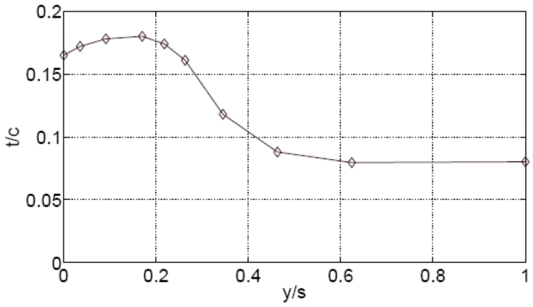

Figure 3. Spanwise thickness distribution

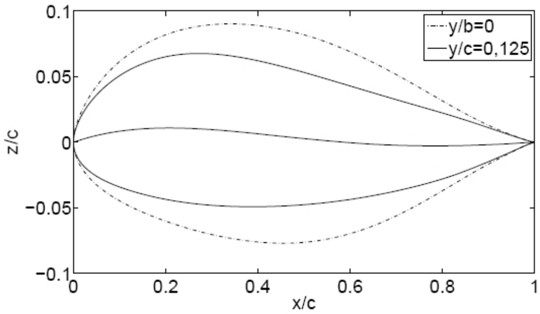

Figure 4. The center body sections at $y/s = 0$ and $y/s = 0,125$

3.2 Tested configuration

A roughness of a zig-zag type was set to 5% over the surface of the external wings with a strip of $0.6mm$. The BWB has 245 pressure taps distributed on the wing center. Two nacelles were constructed of aluminium alloy. More information can be found in Cerón-Muñoz (2009).

In the Fig. 5 can be seen the reference system for the identification of the configurations analyzed. For all configurations, the BWB was tested with a speed of $32m/s$ and a Reynolds number of $3.9x10^5$. The lift and drag forces were measured by a two component balance. Two Scanivalves $ZOC33/64Px$ were used to obtain the pressure values.

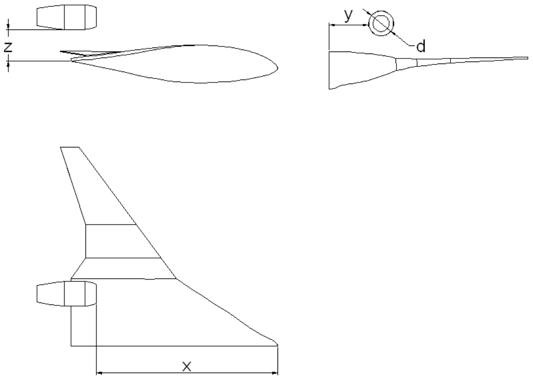

Figure 5. Analysis parameters

Finally,Fig.6 shows the BWB model in the test section. All the results were corrected by the wall interference.

4. Results and discussion

Some results are shown in characteristic curves that analyzed the BWB model. In the configuration without nacelles (clean) the results correspond to a variation of the geometric angle of attack in the range $\alpha = -2^0$ to $\alpha = 20^0$ The results presented for the BWB with nacelles correspond to $\alpha = 4^o$.

Figure 6. BWB model inside the working section

4.1 Lift and drag coefficients

Figure 7 corresponds to the variation of lift coefficient and can be seen that there is a diminution in the slope for angles of attack greater than the 8^o. According to the experiments of visualization, from $\alpha = 8^o$ (see Fig. 9) the external wing of the model stalls modifying the initial inclination. Likewise, the model BWB reaches the $C_{L_{Max}}$ when the angle of attack is approximately equal to $\alpha = 19^o$ and has a value of 1.26. In drag polar curve Fig. 8, can be observed that the highest increases of C_D present for lift coefficients greater than $C_L = 0.85$. The BWB model achieves greater aerodynamic efficiency at $\alpha = 4.5^o$ with a value of 20.71.

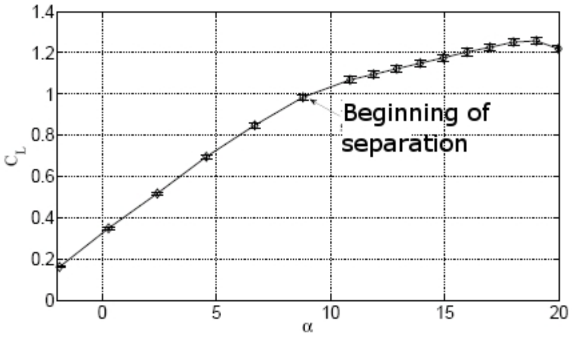

Figure 7. Lift coefficient fot the BWB clean

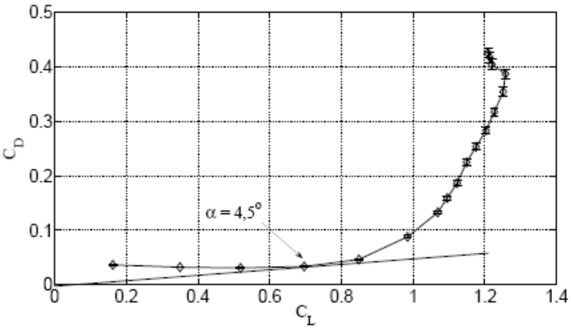

Figure 8. Drag polar curve

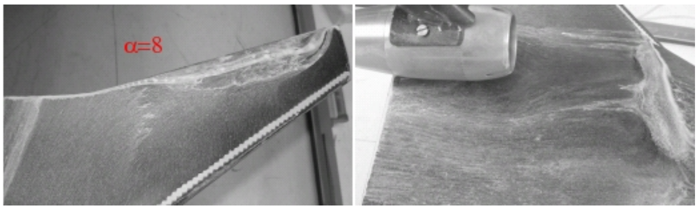

Figure 9. Oilflow visualization

In Fig. 10 and Fig. 11 can be observed that the settings have a tendency to increase the drag coefficient. The arrangement of the nacelles located away downstream of the model are those with smaller variations in drag coefficient, whereas the positions upstream were the major effects caused.

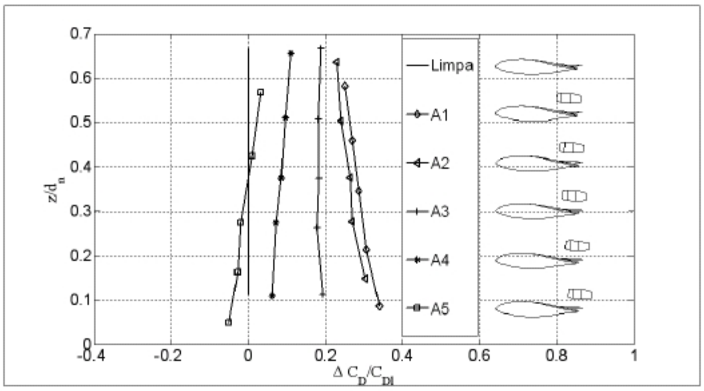

Figure 10. Variation of C_D x vertical axis $\alpha = 4^o$

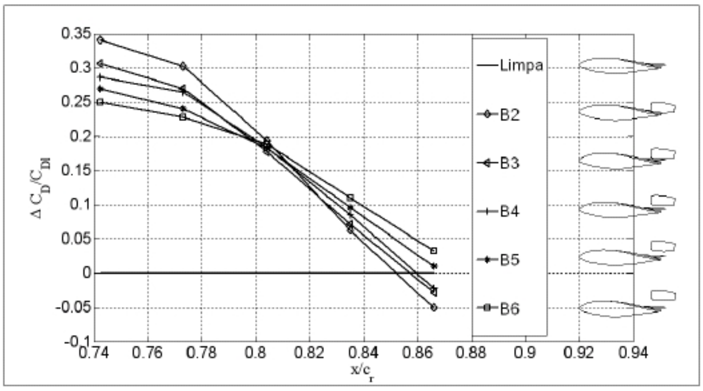

Figure 11. Variation of C_D x longitudinal axis $\alpha = 4^o$

In Fig. 12 and Fig. 13 can be observed that the arrangement have a tendency to decrease the lift coefficient. The settings located downstream of the present largest decreases C_L. The variations were smaller in the angles of attack 6.7^o and 10.8^o.

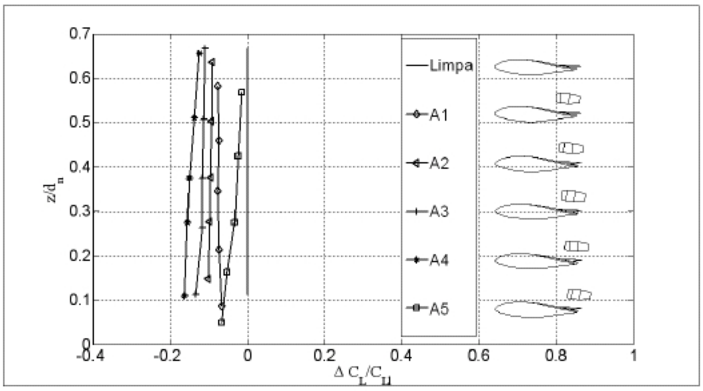

Figure 12. Variation of C_L x vertical axis $\alpha = 4^o$

Finally, this shows a C_P distribution along the wingspan of the model. In Fig. 14 and Fig. 15 can be observed the three-dimensional effects flow in the BWB. The separation bubble is located approximately at $x/c_{raiz} = 0,45$. To increase the angles of attack, the values of C_P minimum are incremented and suction peak moves upstream, so the section $y/b = 0$ to $C_{p_{min}}$ has a value of -0.77 located at $x/c_{local} = 0.45$ at the section $y/b = 0,169$ the suction peak is located at $x/c = 0,02$ for a value of $C_p = -1,5$. Fig. 15 shows that in the section $y/b = 0.169$ there is a high adverse gradient that drives the separation. Note that in Fig. 9, the aircraft is entering into a stall in the direction tip to root. This situation is not desirable and it is evident as a flaw in the aircraft design.

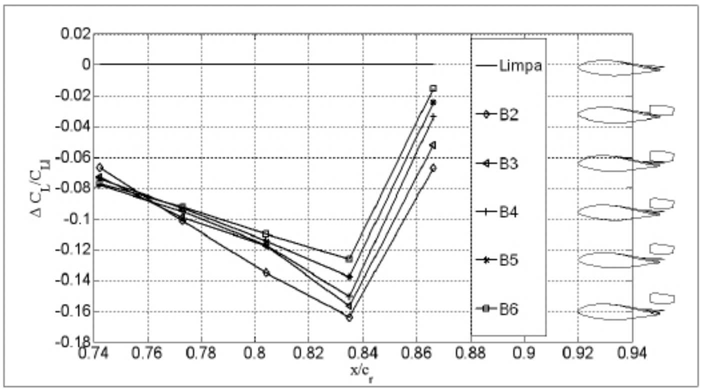

Figure 13. Variation of C_L x longitudinal axis $\alpha = 4^o$

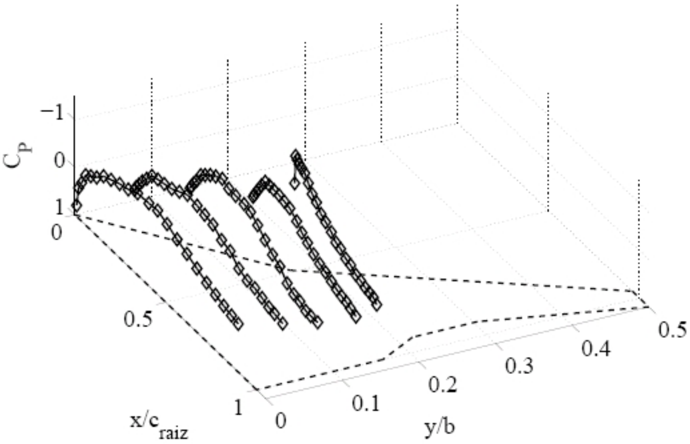

Figure 14. Pressure distribution at $\alpha = 4^o$ for BWB clean

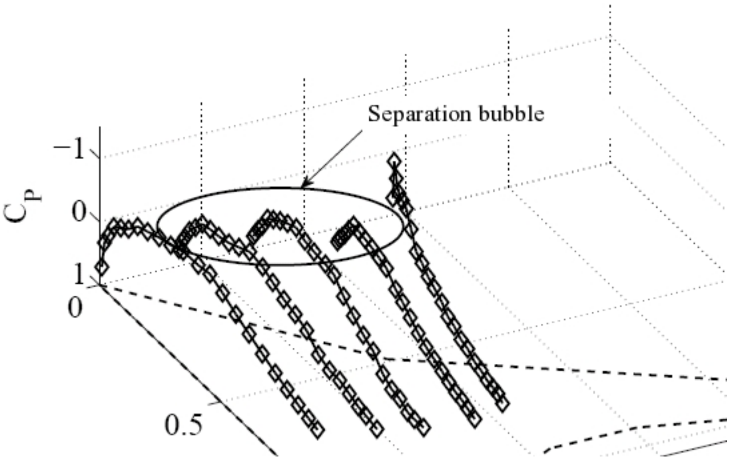

Figure 15. Pressure distribution at $\alpha = 6^o$ for BWB clean

Figure 16 and Fig. 17 illustrate the distribution of pressure coefficients in the central wing with nacelles. In the Fig. 16 can be seen that at $X/C_{root} = 0.8$, $Z/d = 0.11$ show more interference and the configuration $X/C_{root} = 0.83$, $Z/d = 0.26$ (see Fig. 17) it has less interference. It is noticiable that the nacelles does not disturb the flow of the extrados of the model by eliminating of the bottleneck between the surfaces.

Figure 18 demonstrated that the presence of a laminar flow until about $x_{root}/c_{root} = 50\%$.This behavior continues until angles of attack less than 8^o. Moreover, it was observed the presence of strong vortices at the junction central-external wings at $\alpha = 20^o$.

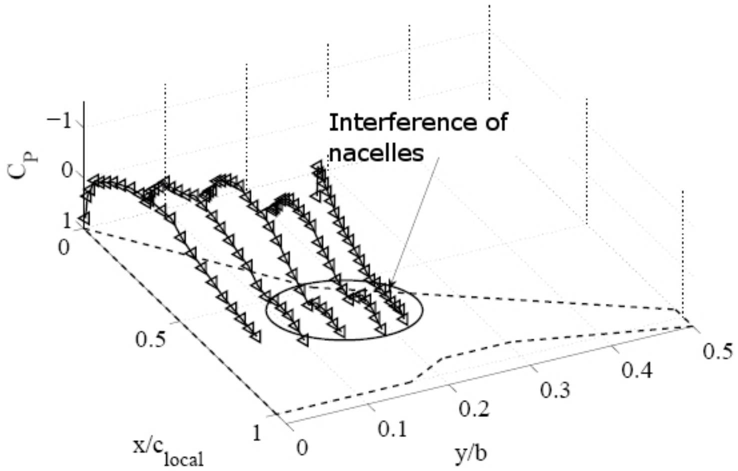

Figure 16. Pressure distribution at $\alpha = 4^o$ for BWB with nacelles $X/C_{root} = 0.8$, $Z/d = 0.11$

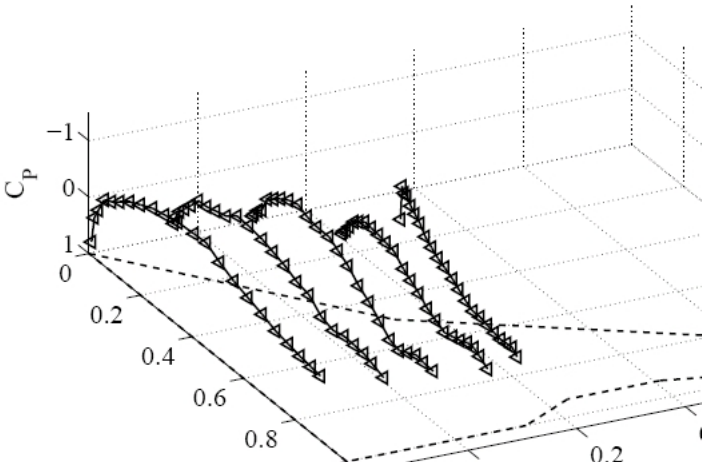

Figure 17. Pressure distribution at $\alpha = 4^o$ for BWB with nacelles $X/C_{root} = 0.83$, $Z/d = 0.26$

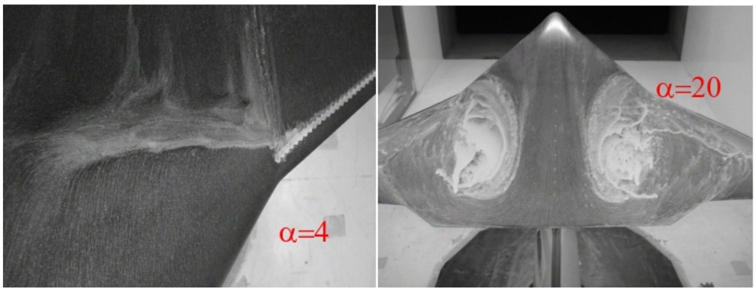

Figure 18. Visualization central-wing

5. Conclusions

This studt was aimed to investigate the aerodynamic characteristics of a BWB model aircraft and the effects of the power plant. One of the advantages that this configuration offered is to produce a efficiency 25% higher than that produced by conventional aircraft, from this perspective, the BWB model met the expectations to a value of $L/D_{max} = 20.7$ for a ratio $b^2/S_{watted} = 2.18$. These values are within the existing envelope in the literature for conventional aircraft (Raymer, 1999),and studies related to this type of aircraft (Ikeda, 2006). However, as it is normal in the process of developing a new product or technology, there are some changes that have to be made in the model for better aerodynamic behavior.

The twist of the outer wings was not satisfactory in their function of delaying the detachment of the boundary layer at the tips of the wings, where it would install the control surfaces of aircraft. Concerning the interference of the powerplant in the aircraft, it was not intended to find the best arrangement of the nacelles. But, rather to identify factors that might lead taking that decision.It was observed that displacement of nacelles toward the longitudinal axis are more influential on the aerodynamic behavior that changes the vertical position. The positions further downstream from the reference model showed the lowest increase drag and reduce lift, the installation of pylons would lead to other results.

The successful design of this type of aircraft can only be achieved by optimizing the integration of disciplines such as aerodynamics, flight control and aircraft structures. In summary, there is an ample scope for future work: installation of windows, emergency exits, aerodynamics, control and structure in the BWB are issues that can be approached from the culmination of this work.

6. ACKNOWLEDGEMENTS

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8. Responsibility notice

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