AEROSPACE TECHNOLOGY CONGRESS 2016

Swedish aerospace technology in a globalised world

October 11-12, 2016 - Solna - Stockholm

Wind Tunnel Experiments of Winglet, C-wing and Fences coupled to a "Blended Wing Body" Model

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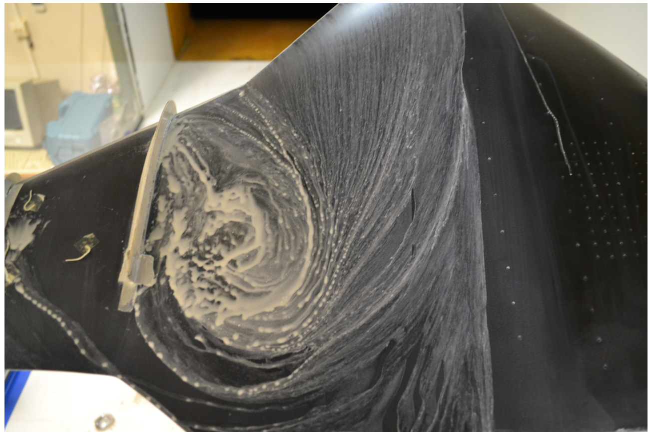
ABSTRACT

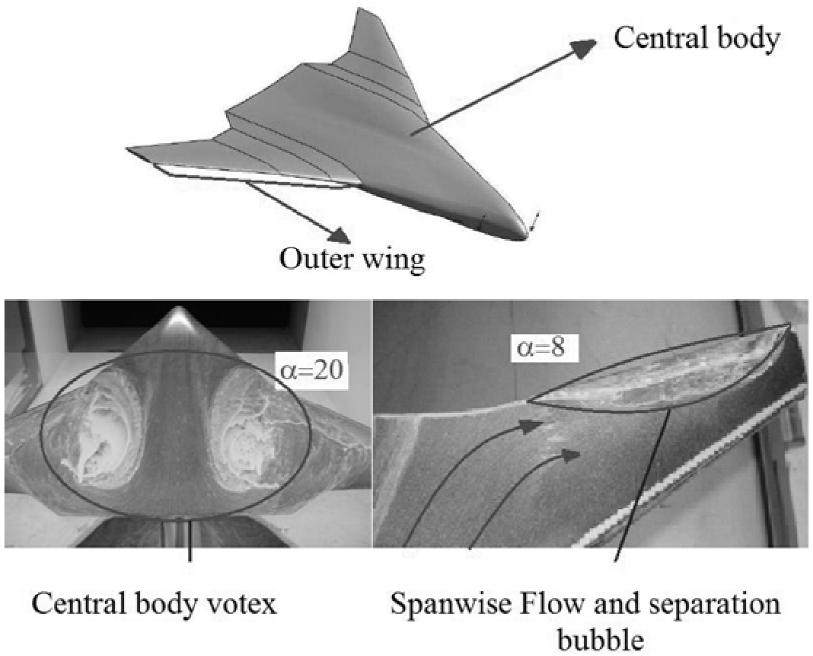
A Blended Wing Body configuration BWB is composed by a conventional outer wing and a central body.

There are several potential benefits of this configuration, however, a pair of large vortex is generated at junction of the two main parts at high angles of attack. In addition, there is a cross flow on the outer wing reducing the slope of C_L-α curve. As results, the aerodynamic efficiency is reduced abruptly although the BWB continues increasing the lift coefficient.

This work performs wind-tunnel tests to analyze the effects of some arranges of fences on the aerodynamic behavior of a BWB at high angles of attack. On the other hand, a droop was implemented at leading edge of the outer wing. The results shows that the fences are efficient at higher angles of attack nevertheless there were some penalties regarding to the drag at low angles of attack.



INTRODUCTION



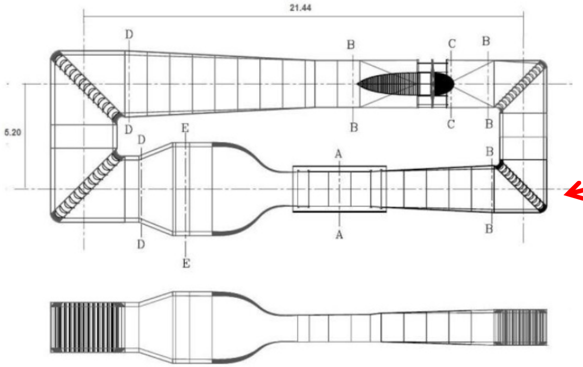
-The Blended Wing Body concept (BWB) has been presented about three decades ago as an environmental friendly alternative able to carry the largest payload through the greatest distance with the lowest fuel consumption.

- Liebeck et al.(1194) compared a conventional wing-fuselage configuration with the BWB. An aerodynamic efficiency of L/D = 27 was achieved, this is 32% higher than the conventional configuration. The TOGW and OEW ware 14% and 10% lower respectively.

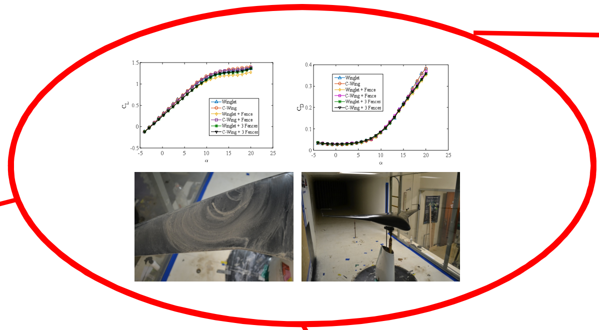
- The Aircraft Laboratory of São Paulo University at São Carlos Enginee ring School developed wind-tunnel testing in a BWB prototype. The main phenomena observed were: stall at high angle of attack, with gradual stall process typical delta wings.

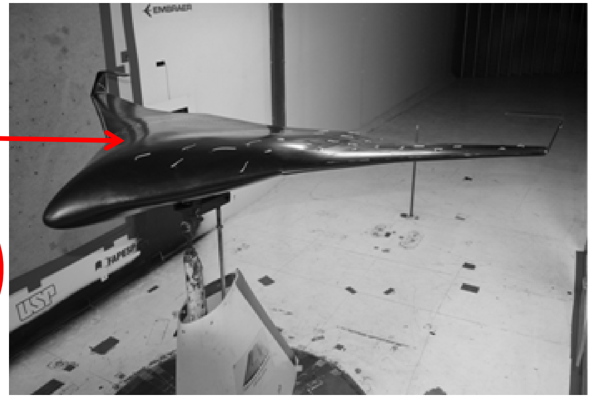
- Oil flow visualization showed the presence of spanwise cross-flow over the outer wing starting from the root going towards to the tip. Finally, two large vortices are observed in the end of the models central body.

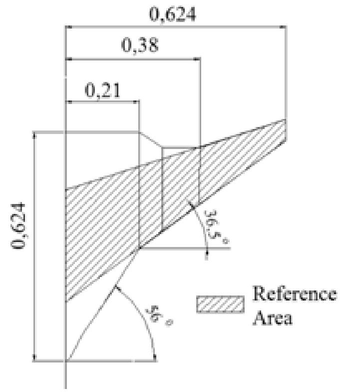
Experimental setup

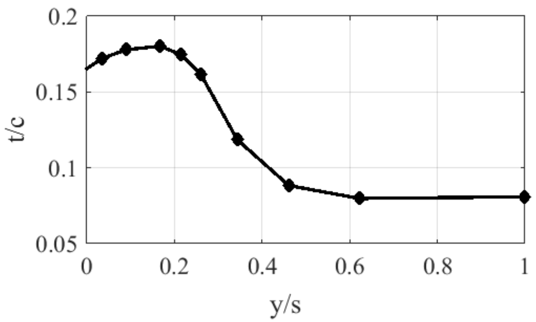


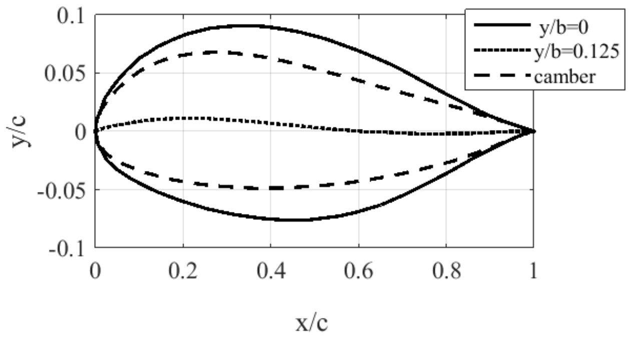
Low-speed closed-circuit wind tunnel at Laboratory of the São Carlos Engineering School,



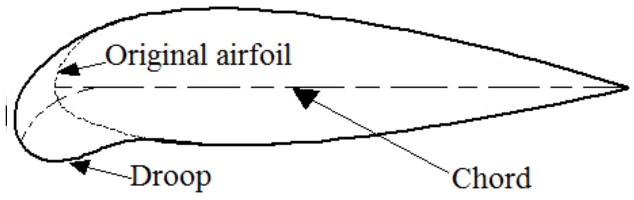






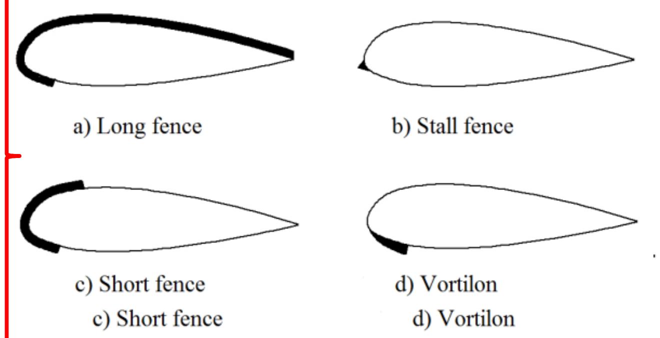


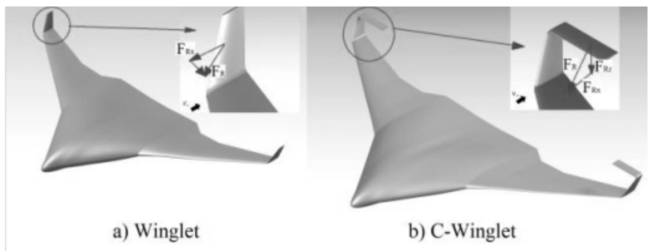
Experimental setup



Droop: his device increases the camber in the leading edge region, consequently the stall will be softer and the boundary layer separation will be delayed by some degrees.

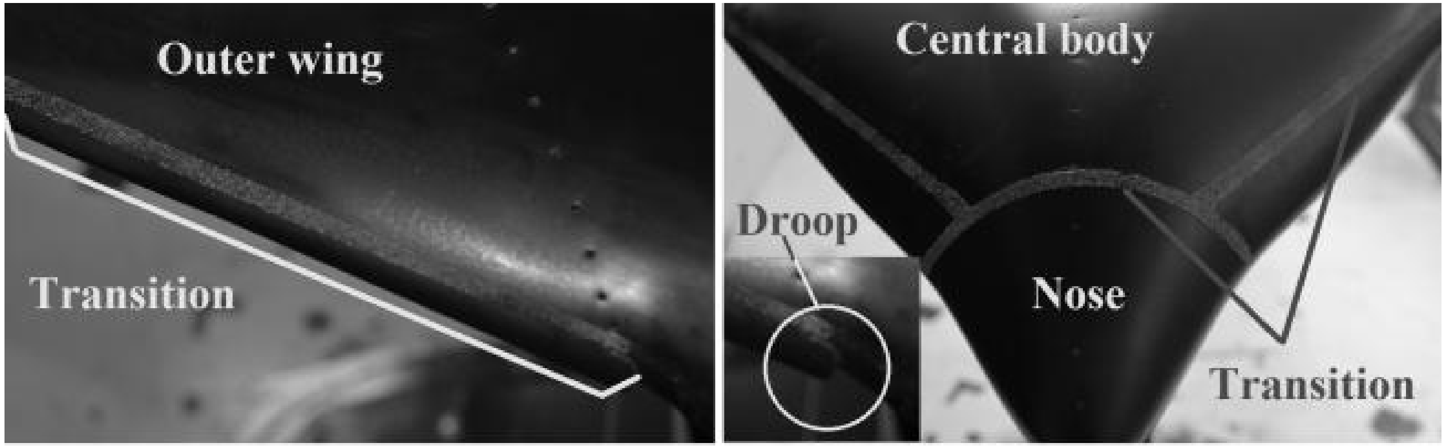
Fences are thin at plates attached perpendicularly on the wing surface distributed along the wing span.
their goal is delaying the separation on swept wings at high angles of attack. T heir height can be around 6% of the chord, following the order of magnitud e of the thickness of the wing





The Winglets are small wings located on the wingtips, generating an aerodynamic force in the direction of flight reducing the drag. For the C-Wing, an horizontal airfoil NACA 0012 was added.

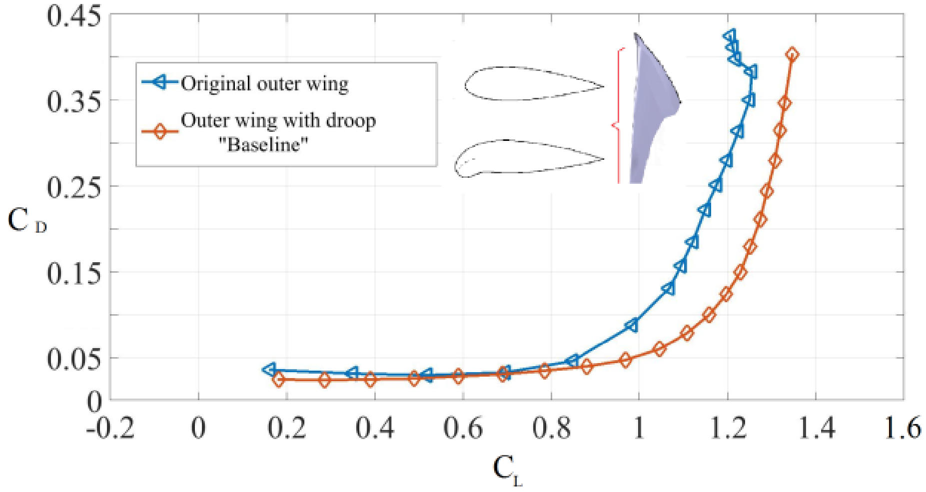
Experimental setup

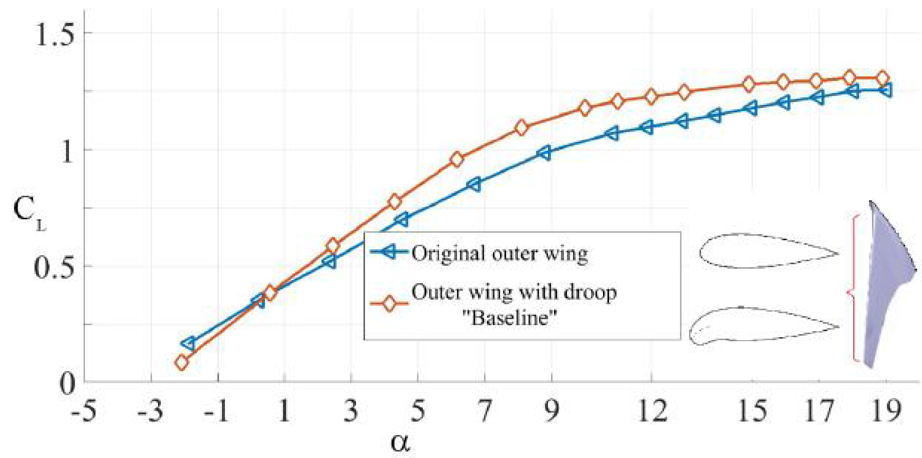


a) Transition at outer wing b) Transition at central body

The boundary layer transition is forced through a roughness strip manufactured with sand adhered to the surface. On the outer wing, the transition region is located at 5% of the local chord on the upper surface. In the central body, the strip roughness followed the previous proportion, however, in the region equivalent to the nose, the transition was fixed transversely

Results and discussion





Droop effects : The figures show the lift and drag coefficient curves The droop effect is analyzed in two phases of the lift coefficient curve: firstly for $\alpha<9^{o,}$ where the curve slope is increased by the droop due to the favorable pressure gradient raise; secondly, when $\alpha>9^{o}$, the slope was decreased. Noteworthy the C_L tends to be the same value at high angles-of-attack.

The results shows that the central body is the main lift generator $\alpha>9^{o}$ and the outer wing separation is predominantly related to the swept angle and not to the airfoil camber. Oppositely, the droop modifies the C_D behavior for $\alpha>9^{o}$, e.g. the drag coefficient is lower for the same lift coefficient.

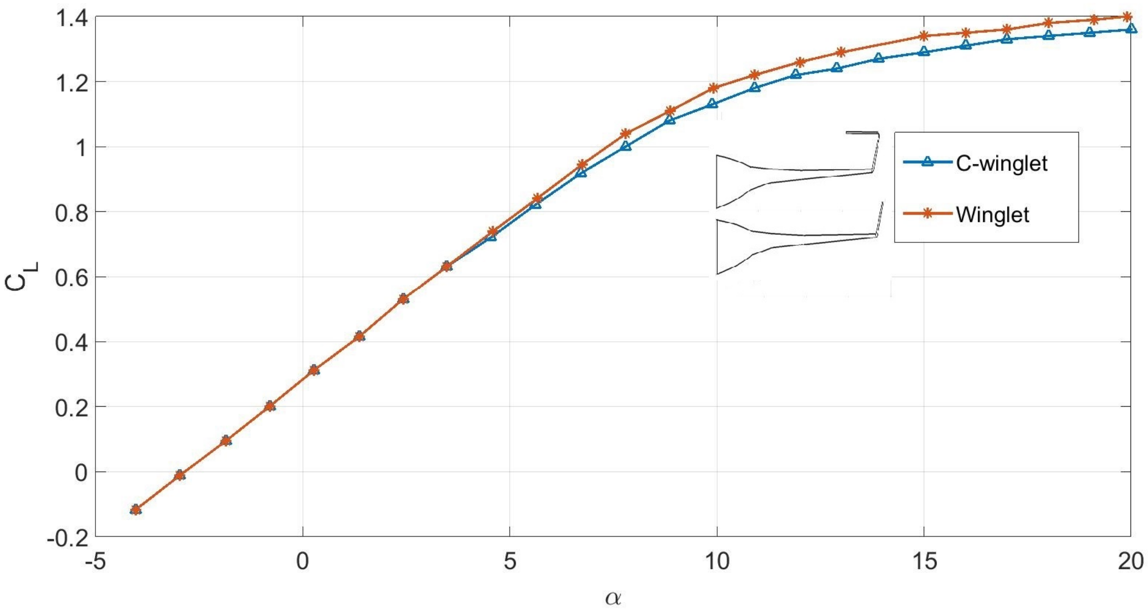
Results and discussion

Configurations tested

The configurations tested were: 1) Winglets, 2) C-wing, 3) Winglet/ 3 fences, 4) Winglet/Internal fence and 5) C-wing/ Internal fence.

Results and discussion

C_L Coefficients

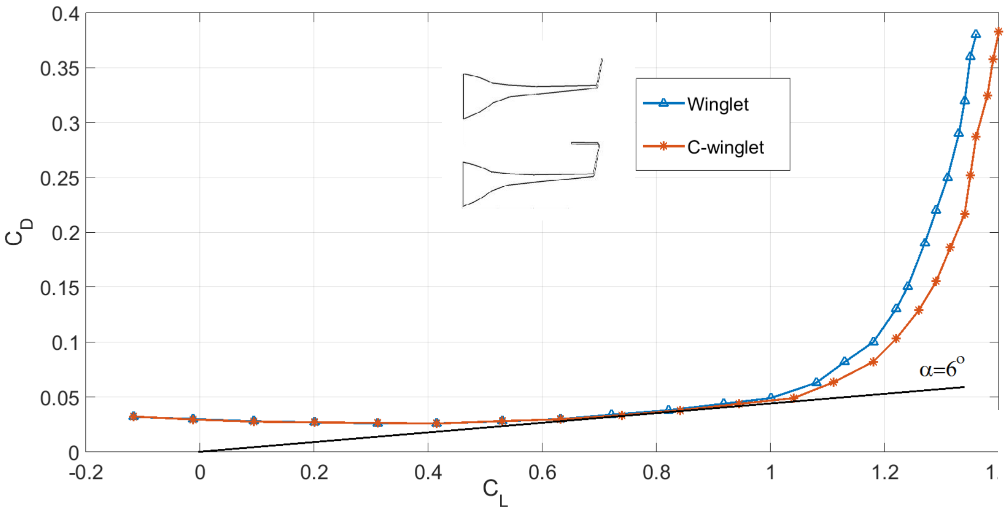


-To $\alpha < 5^o$ both the lift coefficient and the slope curve are similar.

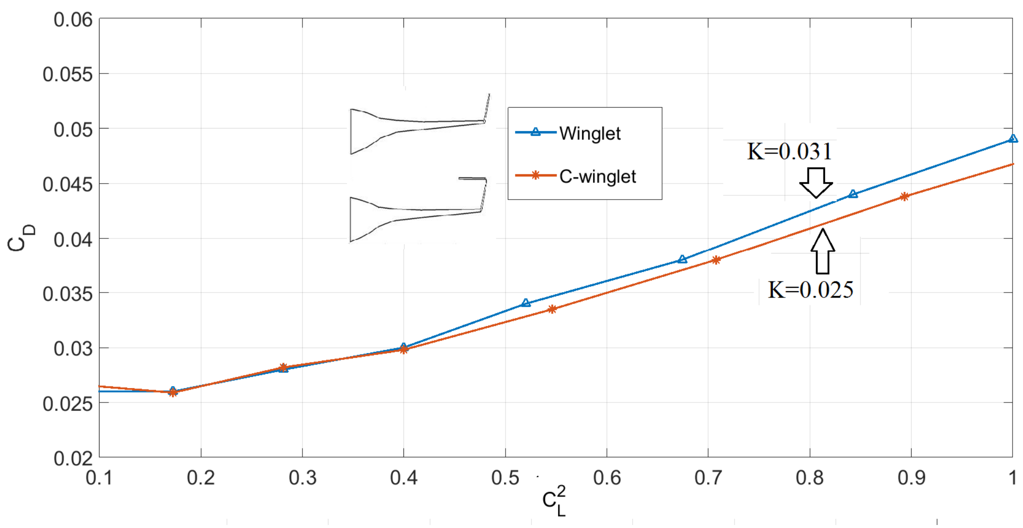
-From alpha higher the, C-wing configuration shows higher C_Ls. Probably, the horizontal C-wing airfoil is responsible of this increase.

- Both cases the pre-stall was smooth and the stall will be achieved at $\alpha > 20^o$.

Results and discussion



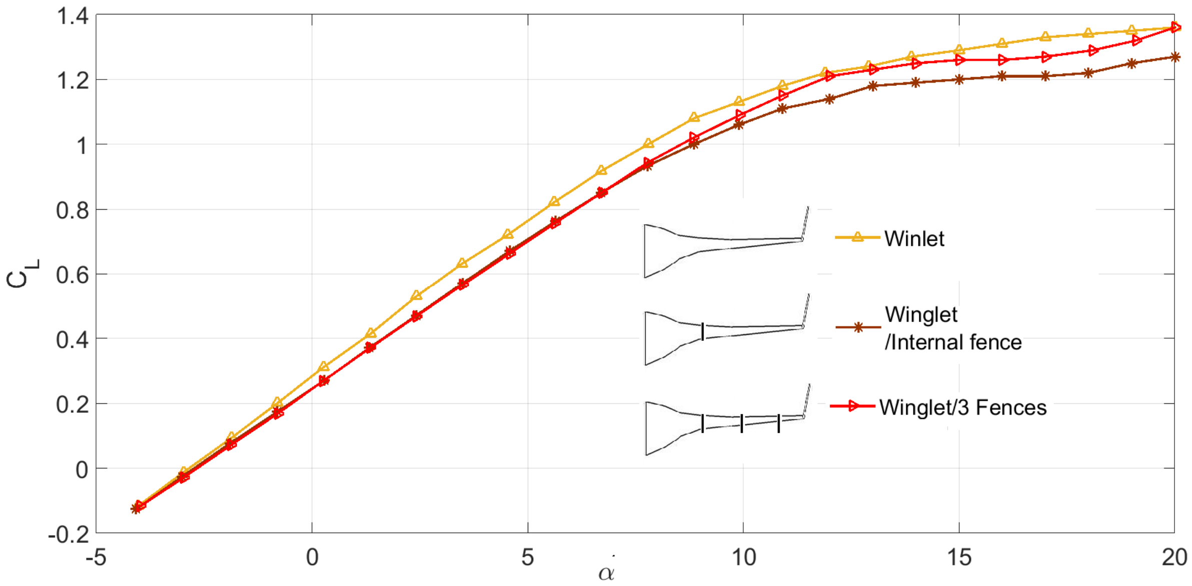
The angles of attack for the maximum C_L/C_D were equal, nevertheless, the C-wing was more efficient at higher angles of attack.



The aerodynamic efficiency coefficient of the BWB with C-wing was increased. this can be indicated by the lower slope curve (K)

Results and discussion

C_L Coefficients

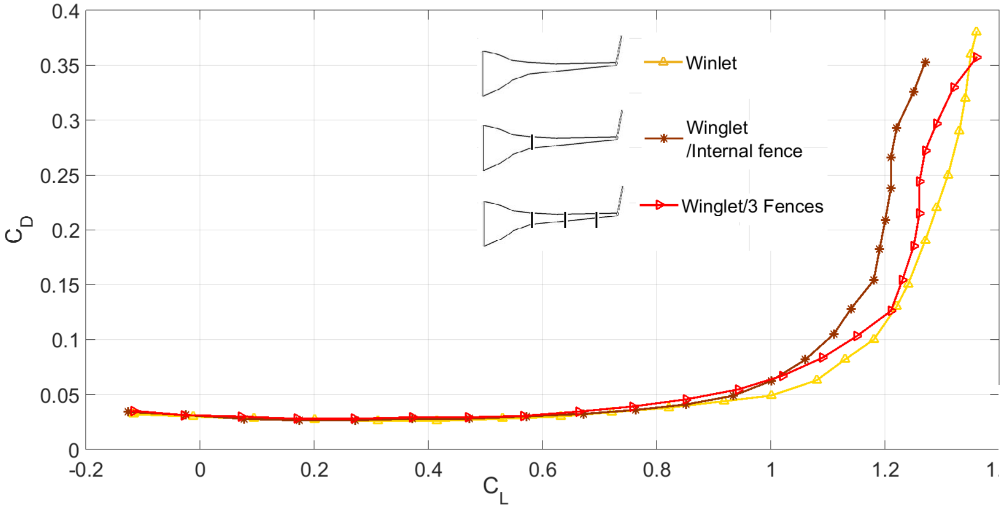


-The CLs were reduced by the presence of the fences .

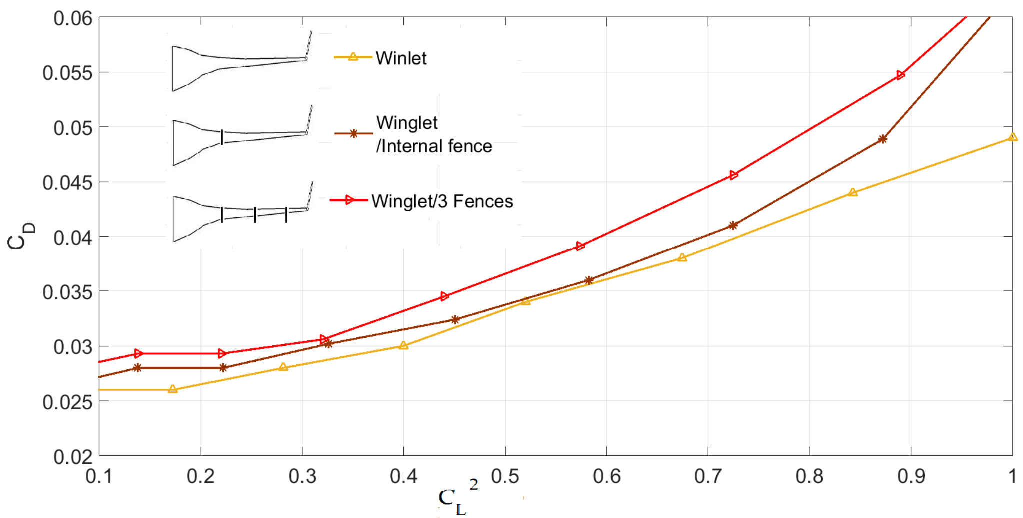
-The arrange with 3 fences was closer to t he winglet configuration in the pre-stall.

-The pre-stall smooth behavior is remained, it will be achieved at $\alpha > 20^o$.

Results and discussion



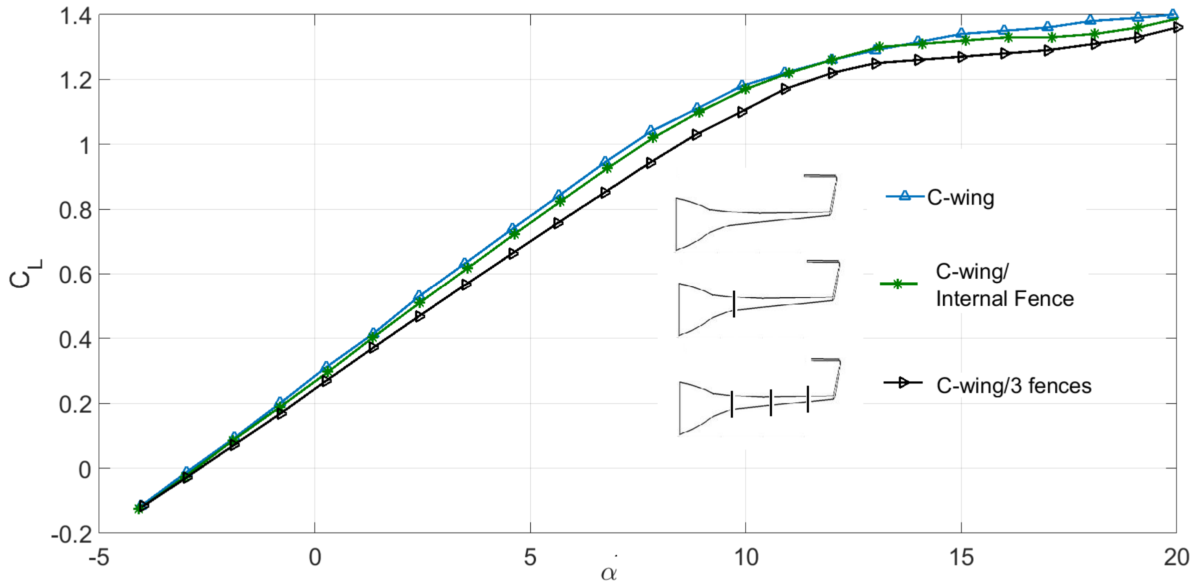
The angle of attack for the maximum C_L/C_D was not modified.
At high angles of attack the internal fence in creased the drag.



The aerodynamic efficiency coefficient of the BWB was markedly affected by the fences, being the worst for the three fences arrangement

Results and discussion

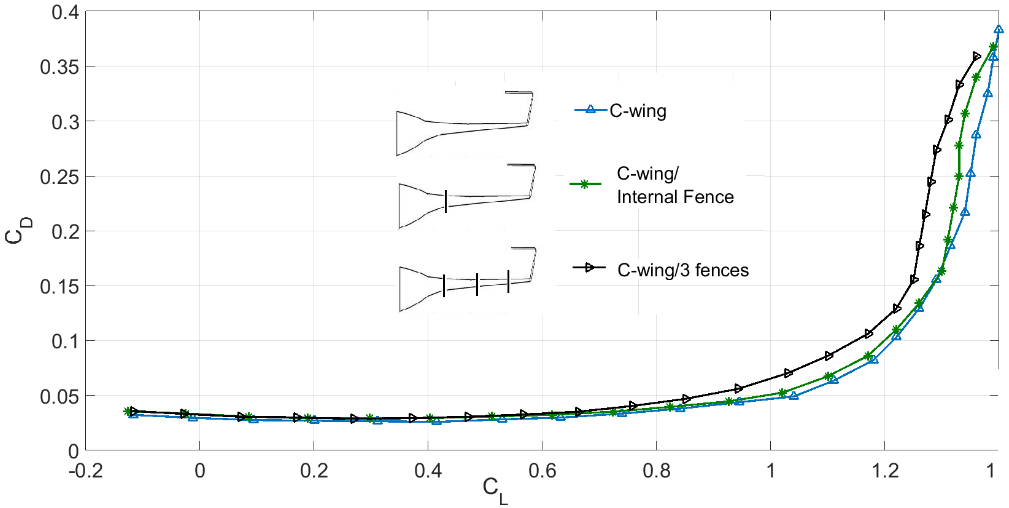
C_L Coefficients



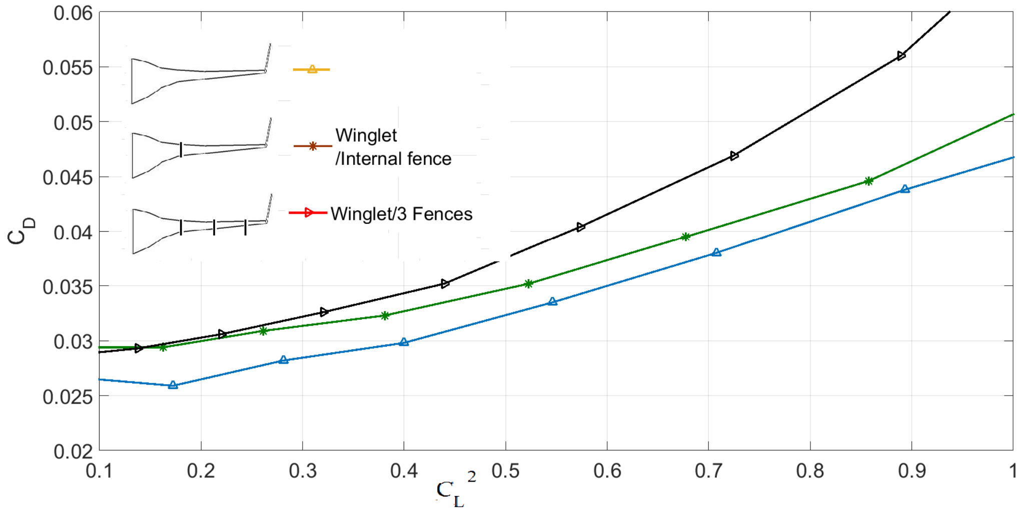
-The lift coefficients of C-wing and internal fence did not get important variations, however for the 3 fences configuration the slope and C_L max. were reduced.

-The pre-stall smooth behavior is remained, it will be achieved at $\alpha > 20^o$.

Results and discussion

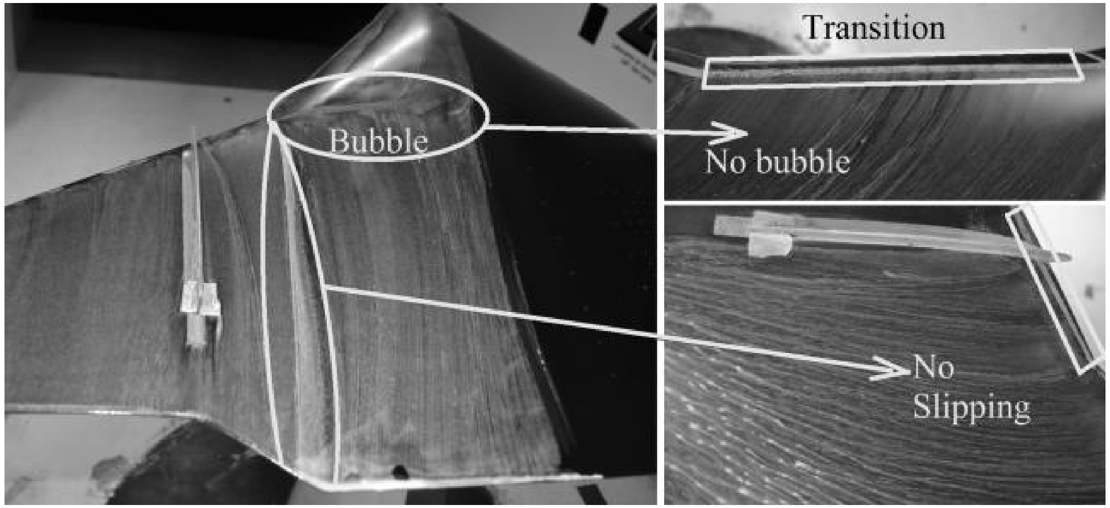


The angle of attack for the maximum C_L/C_D was not modified.
At high angles of attack, the 3 fences increased the drag.



The C_{D0} is increased notoriously by the fences. The slope of the curves suggests that the efficiency coefficient of the BWB was markedly affected by the fences, being the worst for the three fences arrangement even though the internal fenc e can be the most promising.

Results and discussion



A mixture of titanium oxide, vegetable oil and paraf fin was impregnated on the model with objective of visualize the flow path on the aerodynamic surfaces.

Firstly, only the outer wing is tripped therefore it is observed a big bubble in the central body, therefore it is decided to fix the transition in the central body

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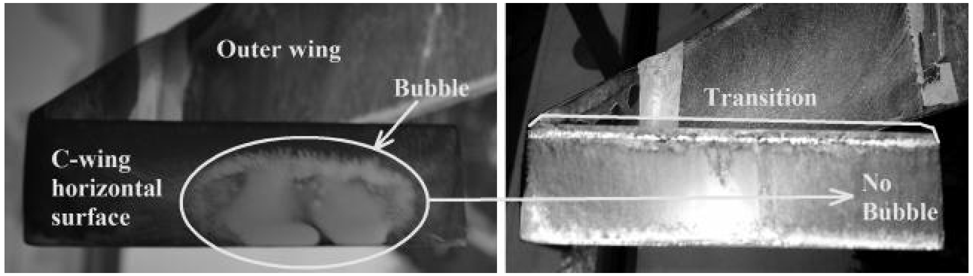
Results and discussion



Due to the low Reynolds number of the C-wing, the horizontal surface was tripped.

Figures shows the presence of a cross flow on the outer wing, despite of the presence of the droop and the fences. Oppositely, at α=20º, the height and length of the internal fence is not satisfactory to avoid the cross flow due to the strength vortex produced in the central body going toward outer wing.

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Conclusions

1.) This paper shows that the BWB aerodynamics is divided in two main surfaces: the outer wing and the central body. The central body behaves similarly to a delta wing, producing lift through two strong vortices. However, the aerodynamic outer wings are affected by these vortex, therefore presenting a satisfactory behavior at low angles of attack.

2.) The droop is added to the outer wing leading edge to delay the flow separation in this surface. Even though the C_L is improved the outer wing stall remains unaltered. The fences showed inefficient to attenuate the cross flow present on this surface at high angles of attack. Additionally the drag is increased and the lift reduced by the presence of the fences.

3.) Besides the fact that the outer wing aerodynamic performance is not totally satisfactory, it is possible to analyze the winglets and C-wing effects. Those devices improved the aerodynamic efficiency as well as reducing the curve slope C_D x C_L^2. Comparing these wing tip devices, the C-wing is the most promising feature.