AERODYNAMIC STUDY OF A BLENDED WING BODY; COMPARISON WITH A CONVENTIONAL TRANSPORT AIRPLANE

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Abstract

Blended-wing-body (BWB) aircraft are being studied with interest and effort to improve economic efficiency and to overcome operational and infrastructure related problems associated to the increasing size of conventional transport airplanes.

The objective of the research reported here is to assess the aerodynamic feasibility and operational efficiency of a great size, blended wing body layout, a configuration which has many advantages.

To this end, the conceptual aerodynamic design process of an 800 seat BWB has been done completed with a comparison of performance and operational issues with last generation of conventional very large aircraft. The results are greatly encouraging and predict about 20 percent increase in transport productivity efficiency, without the burden of new or aggravated safety or operational problems.

1 Introduction

From the middle last century to nowadays subsonic jet transport configuration has substantially not changed: circular cross-sectional slender body with swept wing and empennage, and podded engines hung on pylons beneath and forward of the wing. In the last years a new concept of airplane design has been started to be considered, the blended-wing-body (BWB) concept. Studies [1, 2 , 3] concluded that the BWB was significantly lighter, had a higher lift to drag ratio, and had a substantially lower fuel burn per passenger than a conventional subsonic transport.

The present study shows how airplane design has evolved from a basic body to a geometry that will produce aerodynamic results competitive with a conventional airplane. The study is fundamentally from aerodynamics point of view.

2 Design evolution

The goal of this study is the design of a subsonic jet transport with the following requirements:

- Max passengers number: 800
- Design range: 12,000 km
- Design Mach number: 0.82
- Max takeoff weight: 380,000 kg
- Operative empty weight: 185,000 kg

The estimation of the operative empty weight [4] has been performed on the base of a composite structure and agrees with previous results.

The wing span can not exceed 70 meters to avoid problems in the airports because fits easily within the 80-m box for Class VI airports. That is to say, the occupied space in the airport is similar to a 400-500 passengers conventional airplane, however it permits a 50% more capacity, about 600-800 passengers. Also, the goal is to reduce the fuel burned to less than 15 kg per passenger and 1,000 km that is the typical consumption of modern jet airplanes.

The maximum weight has been obtained from the operative empty weight, the design max pay-load of 95,000 kg and the necessary fuel to fulfill the design mission range of 12,000 km. The airplane's size and the configuration are not relevant for this study, because the objective is only aerodynamics.

The influence of basic geometrics parameters in the improvement aerodynamic efficiency of a BWB plane has been analyzed. From a near configuration of a lifting body the model has been evolved by geometrics changes that affected firstly to the plantform, subsequently to the wing section used in the airplane central section and finally to the twist and wingspan to satisfy the design requirements.

Navier-stokes computational fluid dynamics (CFD) methodology was employed. Also tests in the low speed wind tunnel n°2 of Escuela Universitaria de Ingeniería Técnica Aeronáutica (Universidad Politécnica de Madrid) have been performed to confirm the results from CFD. The correlation of the values is very acceptable.

The comparing parameters chosen for all the models are: ***ML/D*** (Mach x Lift-Drag ratio), ***MP/D*** = ***ML/D*** · ***P/W*** that includes the effect of airplane weight itself, ***D*** (drag obtains with the max takeoff weight) and ***C*** (mass of fuel burned per passenger and 1,000 km). ***P*** is the design payload weight. The altitude of flight is 10,000 m and the specific fuel consumption is $15 \cdot 10^{-6}$ kg/Ns.

Five different configurations models have been studied whose results are presented below.

2.1 Model 1 (lifting body)

The first idea was to study the aerodynamic feasibility of an airplane without wings (lifting body) as shown in figure 1.

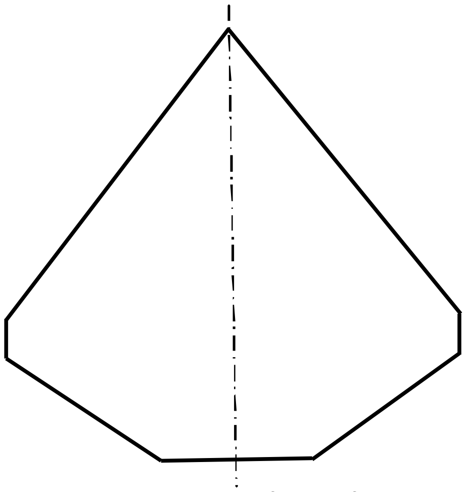

Fig. 1. Initial design plantform: lifting body.

The features of this model are:

- length: 53 m
- wing span: 60 m
- wing area: 1,930 m^2
- design Mach number: 0.8

Figure 2 shows the model analyzed in the wind tunnel and the results obtained of the lifting coefficient (C_L) variation versus angle of attack (a) are given in figure 3.

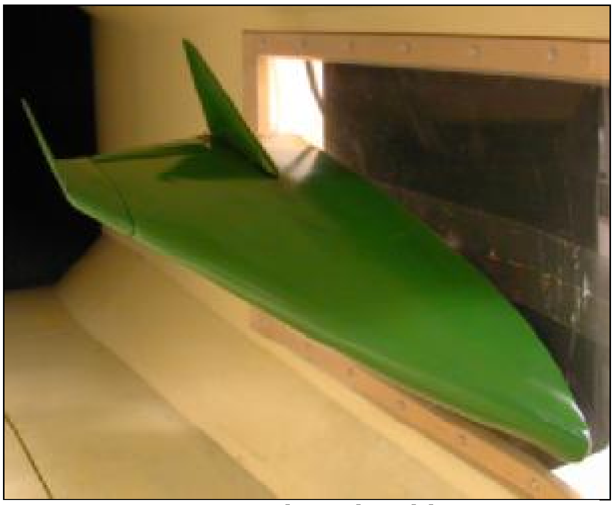

Fig. 2. Wind tunnel model.

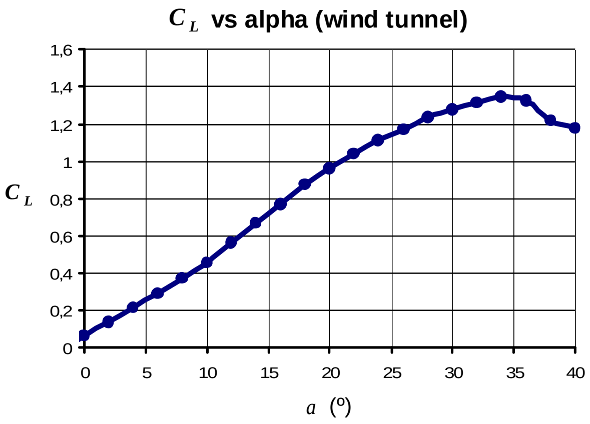

Fig. 3. Wind tunnel test lift coefficient.

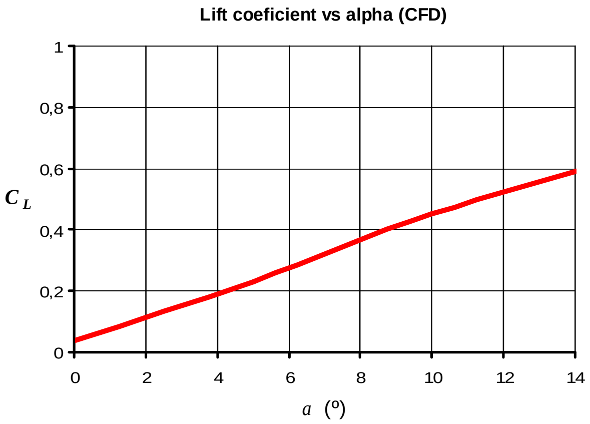

Fig. 4. CFD lift coefficient.

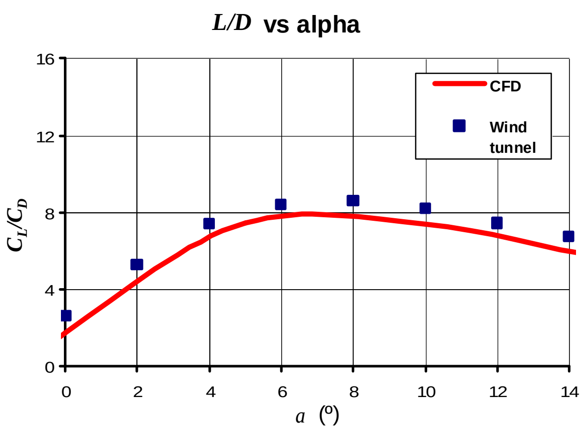

Fig. 5. CFD Lift/Drag ratio validation.

Figure 4 shows the lifting coefficient in function of angle of attack obtained by the CFD method, and in figure 5 the comparison of the lift-drag ratio versus angle of attack obtained by CFD and wind tunnel tests are given. The higher obtained value was 8.

The results of this first model were:

- ***ML/D*** = 6.4
- ***MP/D*** = 1.62
- ***D*** = 459 kN
- ***C*** = 30 kg

2.2 Model 2 (BWB basic line)

Since the results obtained in the first model were not satisfactory it was agreed to develop the design as a BWB concept with small wings (fig. 6).

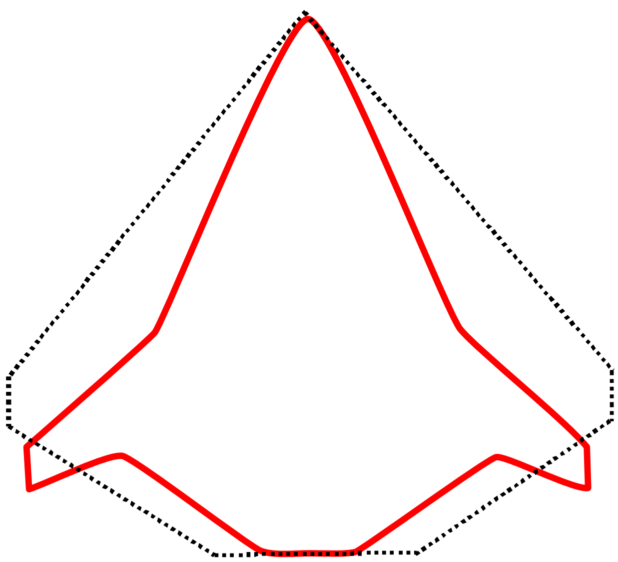

Fig. 6. Plantform comparisons. Model 2 (continuous line) and model 1 (dotted line).

The characteristics of this design are:

- length: 53 m
- wingspan: 55.6 m
- wing area: 1,264 m^2
- design Mach: 0.82

The wing section is a supercritical airfoil with a 12% thickness-to-chord ratio along the span and the wing is not twisted.

A detail of the mesh used for the CFD method can be appreciated in figure 7.

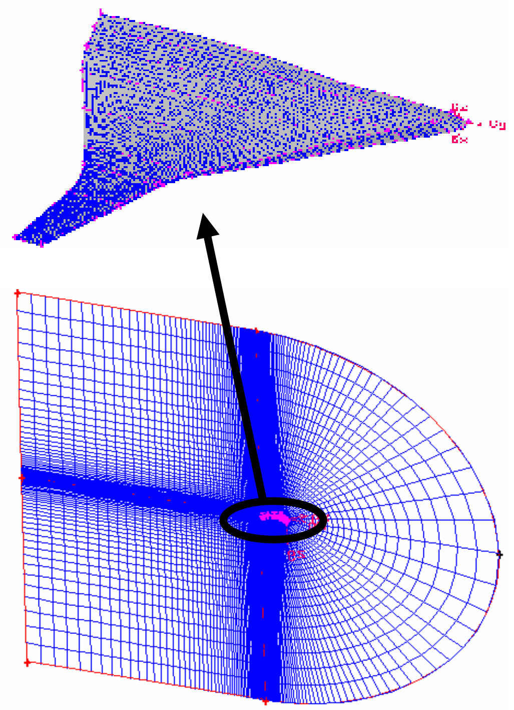

Fig. 7. CFD mesh detail.

Figure 8 shows streamlines at high angle of attack over the CFD model.

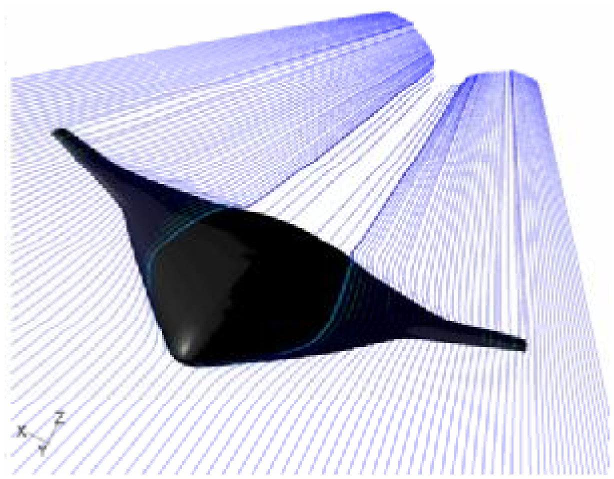

Fig. 8. Streamlines over CFD Model

The pressure coefficient (***Cp***) contours over the model are represented in figure 9 and the graphs on figures 10, 11 y 12 represent the values of drag coefficient (C_D), C_L and ***L/D*** respectively versus the Mach number and angle of attack. It is observed that for the cruise lifting coefficient equal to 0.22 the ***L/D*** obtained is 14.8 at a = 0.5º, angle of attack consistent with cabin deck angle requirements (typically less than 3 degrees).

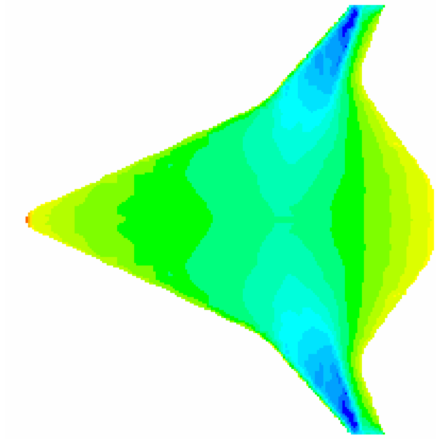

Fig. 9. Upper pressure distribution at M = 0.8 & a = 3º.

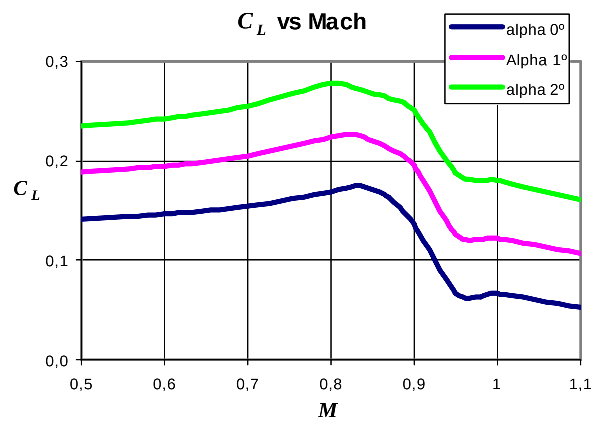

Fig. 10. Lift coefficient vs Mach number.

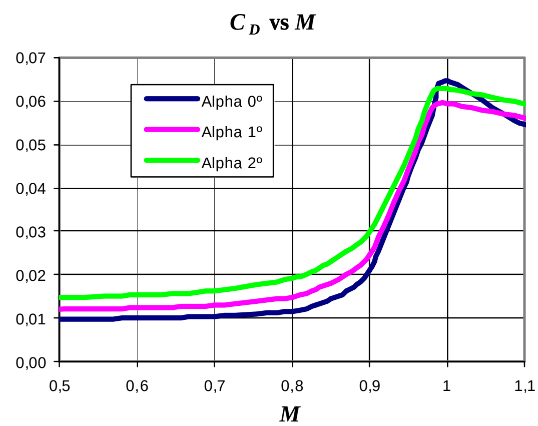

Fig. 11. Drag coefficient vs Mach number.

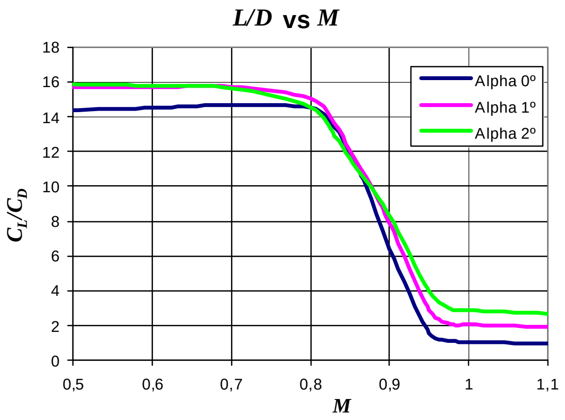

Fig. 12. Lift/Drag ratio vs Mach number.

The results obtained for this model are:

- ***ML/D*** = 12.1
- ***MP/D*** = 3.07
- ***D*** = 248 kN
- ***C*** = 16.3 kg

2.3 Model 3

The new design, evolved from the last one, has these characteristics:

- length: 53 m
- wing span: 65.7 m
- wing area: 1,470 m^2
- design Mach: 0.82

The wing section is the same as in model 2 with a 12% thickness-to-chord ratio along the span. The wing span has been increased and the plantform has been modified, exactly the leading edge swept of body and wing. An adequate distribution of the cross-sectional area is conserved.

Geometric changes mentioned above can be appreciated in figure 13.

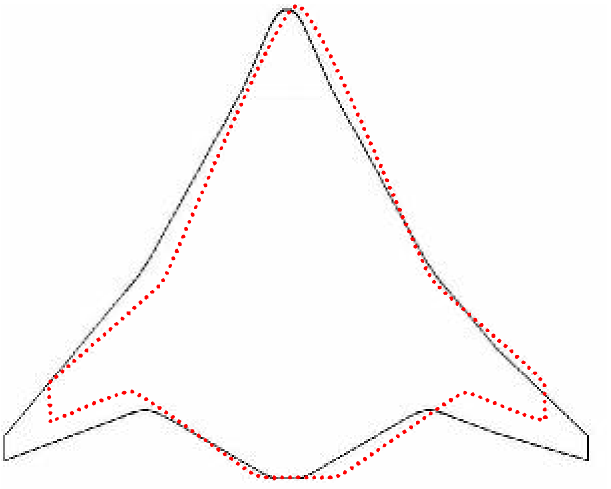

Fig. 13. Plantform comparisons . Model 3 (continuous line) and model 2 (dotted line).

Figure 14 shows the pressure coefficient (***Cp***) contours and in figure 15 the Lift/Drag ratio versus Mach number are shown. For ***a*** = 0º the corresponding ***L/D*** value is 16.5. This means that the increase in ***L/D*** against model 2 is an 11.5%.

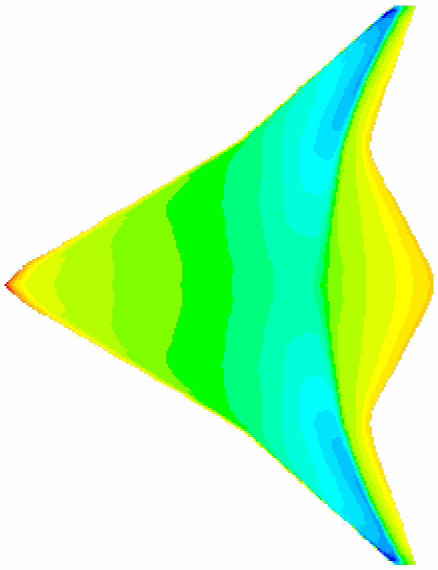

Fig. 14. Upper pressure distribution at ***M***=0.85 & ***a***=1º.

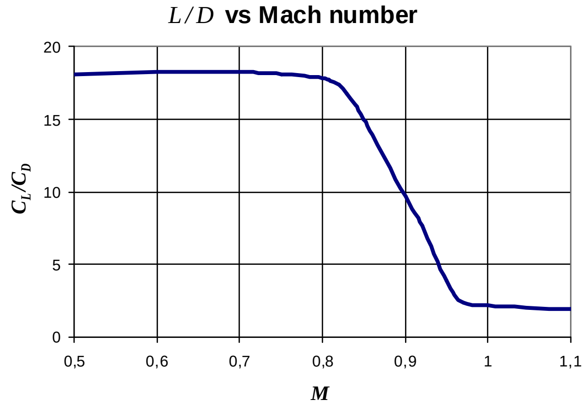

Fig. 15. Lift/Drag ratio vs Mach number at *a* = 0º.

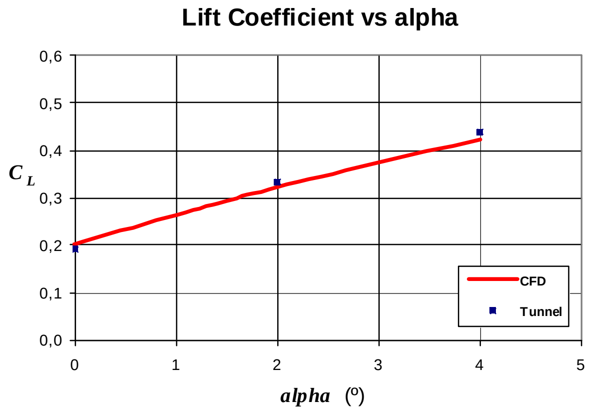

Fig. 18. Comparison of CFD and wind tunnel test.

A three-dimensional view of the model is shown in figure 16 and in figure 17 a picture of the model used for the subsonic wing tunnel tests is shown.

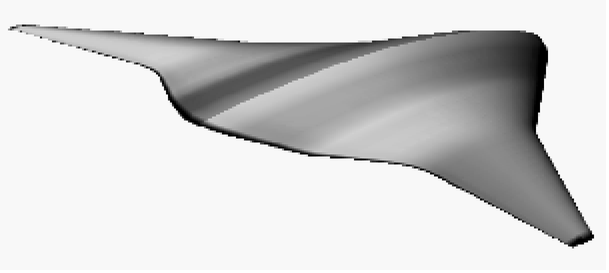

Fig. 16. 3D view of model 3.

Fig. 17. Wind tunnel model.

Figure 18 presents a comparison of the CFD results and the wind tunnel test.

Finally the obtained results for this model are:

- ***ML/D*** = 13.5
- ***MP/D*** = 3.43
- ***D*** = 223 kN
- ***C*** = 14.6 kg

2.4 Model 4

In this new model the previous plantform and wing sections have been kept but the center body section has been reduced to a 10.5% thickness-to-chord ratio. Figure 18 shows the effect of the changes included in this model over the front view of the airplane. It has been verified that the available cargo space is still according to the requirements of this study.

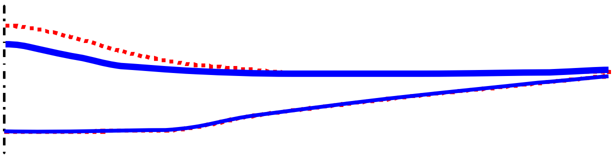

Fig. 18. Airplane front view. Model 4 (continuous line) and model 3 (dotted line).

In figures 19 ***Cp*** contours are shown and figure 20 shows smooth distribution of cross-sectional front area along the aircraft.

A value of ***L/D*** = 18.5 was reached, for a C_L of 0.2 at *a* = 0º. Therefore, the increase in ***L/D*** is of 12% over model 3.

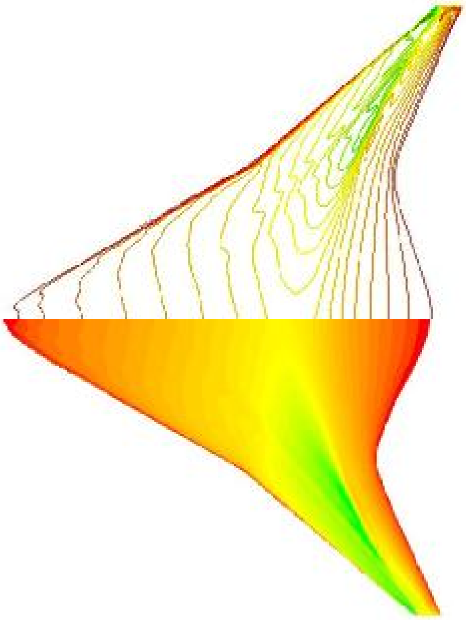

Fig. 19. Model 4 ***Cp*** contours.

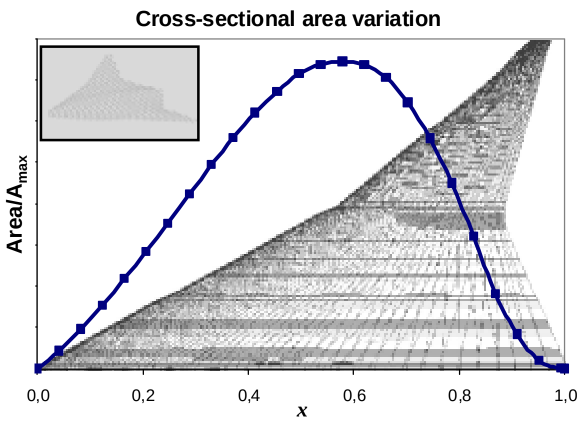

Fig. 20. Cross-sectional areas variation, model 4

The results of model 4 are:

- ***ML/D*** = 15.2
- ***MP/D*** = 3.84
- ***D*** = 199 kN
- ***C*** = 13 kg

2.5 Model 5

In this last model the wingspan has grown to the prefixed maximum of 70 m. Wing has been twisted to achieve an adequate lifting distribution.

The features of this last model are:

- length 53 m
- wingspan 70 m
- wing area 1,490 m^2
- Mach 0.82

Fig. 21 shows a comparison of the new plantform with model 4 and the geometric change mentioned above can be appreciated.

A value of ***L/D*** = 21.3, at ***a*** = 0º was finally obtained. Therefore, the increase in ***L/D*** is of 16% over the previous model.

The results of model 5 are:

- ***ML/D*** = 17.6
- ***MP/D*** = 4.47
- ***D*** = 171 kN
- ***C*** = 11.2 kg

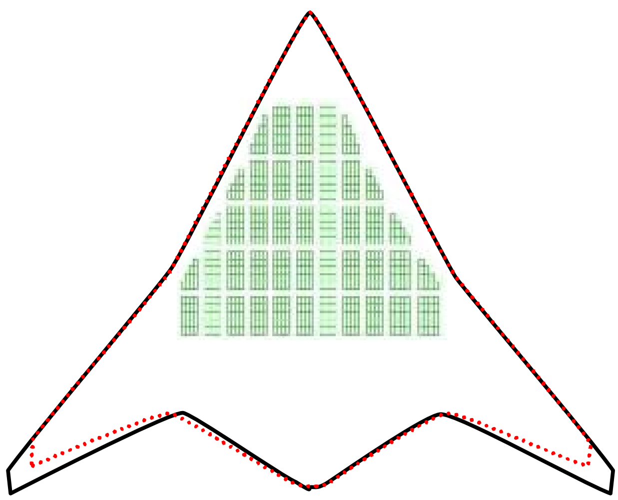

Fig. 21. Plantform. Model 5 (continuous line) and model 4 (dotted line).

3 Conclusions

As a summary of the studies performed a comparative table (Table 1) is given. The parameters analyzed in each model are also compared with a conventional configuration of an airplane manufactured with the same technology.

Model	1	2	3	4	5	Conventional
ML/D	6.4	12.1	13.5	15.2	17.6	15.6
MP/D	1.62	3.07	3.43	3.84	4.47	3.36
D (kN)	459	248	223	199	171	227
C (kg)	30	16.3	14.6	13	11.2	15

Table 1. Models Comparison

It is observed that the consumption saving of the BWB model 5 represents a 25% with respect to the conventional airplane.

Figure 22 represents the design evolution with Lifting-Drag ratio increase and the fuel consumption reduction.

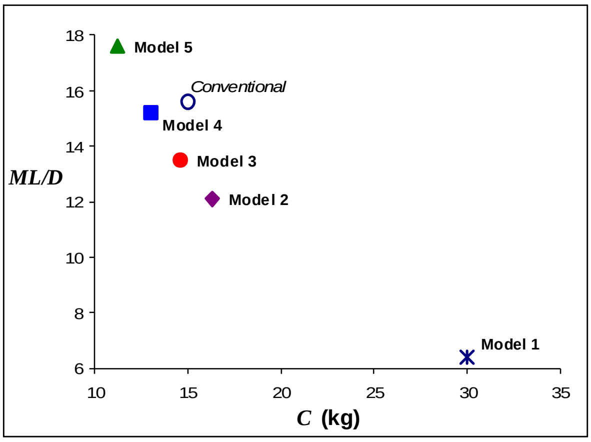

Fig. 22. Models comparison

These values are likely to be improved by means of winglets and others design devices that are being investigated. The study of the airplane stability, which is also in progress, shows that the static margin in function of engine location (data no contemplated in this paper) could be negative, this means that it will be necessary a fly-by-wire control system.

It may also be concluded that as the aerodynamic study of a conventional airplane led to an unchanged lay out in the last 50 years, because it was optimal, the BWB concept seems to have an optimal configuration, that has been shown in this study, and that obviously will be implemented in the coming BWB, with small variations.

The final conclusion is that the future of this kind of airplane does not depend on the technical feasibility, however it will be conditioned by other aspects as the psychological sensation of the users due to cabin size, comfort in the turning for the passengers sitting on farthest ends of the cabin, evacuations strategies [3, 5] and others.

4 Acknowledgements

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References

[1] R.H. Liebeck. Design of the Blended-Wing-Body Subsonic Transport. *Journal of Aircraft*, Vol. 41, No. 1, pp 10-25, 2004.

[2] Denisov, VE, Bolsunovsky, AL, Buzoverya, NP and Gurevich, BI. Recent Investigations of the Very Large Passenger Blended-Wing-Body Aircraft. *Proceedings 21st ICAS Congress*, Melbourne, Australia, CD-ROM, paper 98-4.10.2, September 1998.

[3] Martinez-Val, R and Schoep, E. Flyng winy versus conventional transport airplane: the 300 seat case. *Proceedings 22nd ICAS Congress*, Harrogate, United Kingdom, CD-ROM, paper 113, September 2000.

[4] Roskam, J. *Airplane Design. Part 5. Component Weight Estimation*. Roskam Aviation, Ottawa (KA, USA), 1985.

[5] Martinez-Val, R and Hedo, JM. Analysis of Evacuation Strategies for Design and Certification of Transport Airplanes. *Journal of Aircraft*, Vol. 37, No. 3,pp.440-447, 2000.