AERODYNAMIC DESIGN FOR WING-BODY BLENDED AND INLET

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Abstract

A wing-body blended configuration for transport and three wing-body blended flying wings for unmanned air vehicle are designed using box complex search approach optimization method and inverse design method. The twists of wing sections are optimized using composite method, and the airfoils on wing sections are designed using iterative residual correction method. The designed blended wing-body is analyzed using CFD method and its aerodynamic characteristic is obtained in detail. The embedding inlet of engine is designed and integrated into the wing-body blended configuration to investigate the influence of inlet on the aerodynamic performance. Numerical simulation shows that the inlet results in a favorable effect on the lift and pitching moment but unfavorable effect on the total drag. The stall characteristic becomes better due to the embedding inlet.

1 Introduction

The wing-body blended configuration is widely investigated in recent years due to its advantage of higher cruise efficiency [1][2][3], larger loading space for civil aircraft, and also better electromagnet-ism stealth performance for military aircraft. The European transport solution VELA is a good example for civil usage. B2 is a well-known success in military application. Nevertheless, the stability and maneuverability difficulty is the disadvantage of thus configuration. In this paper twists of wing sections are optimized using box complex search approach to get maximum ratio of lift to drag and desired pitching moment characteristic. The "iterative residual correction" concept is used as inverse design method that modifies the profile of wing section according to the target pressure desired for special purpose. The natural laminar flow on the wing surface is desired. The embedding inlet and power system of blended wing-body (BWB) is designed to enhance drag performance and stealth characteristics.

2 Methods

2.1 Optimization Method

Box complex search (M.J. Box, 1965) approach is a direct search procedure to solve constrained nonlinear problems. The procedure is initiated by randomly placing a set of N+2 <=K <= 2N search points in the feasible region, where N is the number of search variables. A "worst point" is identified and replaced by a "reflection" point according to the given relation. This procedure is iterated, in each step discarding the least desirable point and replacing it with a new, and hopefully superior, search point, within the constrained bounds. The search is terminated and the best solution is taken as the optimal solution. The target function and constraints are aerodynamic characteristics computed using a CFD solver. Due to the large number of search variables, a fast working CFD analysis code is required, thus the full potential solver with three-dimensional boundary layer correction is chosen as CFD tool. The maximum ratio of lift to drag and minimum pitching moment at cruise situation is desired target.

2.2 Inverse Design Method

The Takanashi[4] "iterative residual correction" concept is used for geometry modification according to the difference between initial pressure and target pressure on the wing surface. This method is based on the assumption that the correction is small, and the residuals of pressure between initial and target surfaces are also small, thus the correction flow satisfies the small perturbation equation. This assumption is reasonable for instance of subsonic and transonic flow with weak shocks. If the residuals are not small enough, they can be relaxed. In order to reach the target pressure the design procedure is iterated several times. As improvement, the geometry smooth procedure is applied and upper wind equation is introduced for instance of supersonic flow occurs on wing surface[5][6].

For (BWB) configuration, original airfoils for all section are laminar airfoil, but the analysis shows that the transition takes place much earlier since the three-dimensional flow effect on wing surface. So the target pressure is specified to keep a constant pressure along span-wise in middle part of the wings so that span-wise flow on middle sections is limited and the laminar boundary layer last longer in chord-wise.

2.3 Inlet Design

Normally there are more than one engines distributed aside the body of BWB configuration which looks like a bomber. For smaller unmanned aircrafts, the inlet of single engine can be installed inside the body like a fighter, or back on the body at symmetry plane. An embedding inlet of single engine flying wing is designed as a S-shaped channel for air breath jet engine. The geometry of the inlet is also optimized for the best pressure recovery on geometrically confined condition.

3 Results and Analysis

3.1 Case 1

The VELA is designed by DLR(see Fig.1 (a)). The detailed investigation shows that the pressure distribution on inner sections is not so good that lift coefficient of inner is quite small, and pressure distribution show that complex intersected shocks appear on up surface. One design purpose is to change the target pressure distribution on inner sections, and let design code change the airfoils. The design results are shown in Fig.3, where the geometry and pressure distribution on inner sections is modified slightly.

3.2 Case 2

A flying wing configuration of BWB is analysed using CFD and the section geometry is redesigned to improve its pitching moment performance, the initial flying wing has good lift-drag performance, but separation flow occurs early on up surface. Thus the pitching moment performance becomes worse at attack angle 8 degree and Mach number 0.2, which is exactly in taking off/landing case. The detailed analysis shows that the initial airfoil is a typical higher subsonic laminar supercritical airfoil. Although it has good performance at Mach number 0.6, at the higher angle of attack and/or the lower speed case the cross flow on middle sections is much strong, the boundary layer transition and separation occur very early. In order to solve this problem, the pressure distribution on upper surface is modified to decrease the pressure peak, and the design code corrects the airfoils of the wing sections. The pressure distribution on upper surface becomes more uniform along span-wise (see Fig.3).

Finally, the new BWB and initial one are analysed in detail with RANS code. Fig.4 gives comparison of aerodynamic characteristics between initial BWB, designed BWB and the configuration of new BWB with the embedding inlet. It shows that the new configuration has higher maximum lift coefficient but poorer linearity. Fig.5 shows that the new BWB has smaller drag coefficient at lower lift coefficient. The drag coefficient of the BWB configuration with embedding inlet is larger at lower lift coefficient but becomes smaller at higher lift coefficient. It means that the flow separation situation at higher lift coefficient is improved.

Fig.6 shows the new configuration of BWB with embedding inlet has the better linearity of pitching moment coefficient, it validates further that flow separation is improved.

Comparison of Fig.1(a) and Fig.1(b) shows that the embedding inlet changes Mach number contour distribution on up surface of BWB, it decreases the Mach number of up surface, specially on inner wing sections. The pressure distribution on up surface is also changed, lower pressure region become smaller near the body (see Fig.3 (a) and (b)). Moreover the lift coefficient of the BWB with embedding inlet is increased compared with alone BWB (see Fig.4), and the drag coefficient is increased at lower lift coefficient and decreased near maximum lift coefficient. To analyse the influence of embedding inlet on aerodynamic characteristics of BWB, the pressure contour on symmetry plane is shown if Fig.7 (a) and (b). It is shown that the embedding inlet increases the pressure of up and low side on symmetry plane section, i.e. decreases the flow velocity on this section. The same results can be observed from streamline distributions (see Fig.8 (a) and (b)). Fig.9 and Fig.10 show that the streamlines are displaced less due to the inlet.

3.3 Case 3

Although the stall angle becomes greater and linearity looks better than the old BWB due to the embedding inlet, the absolute value of pitching moment coefficient is larger and the static stability is relative too larger for flying wing configuration. Generally pitching moment value is a key design parameter for the flying wing. It must be small enough because thus type aircraft can provide only small control efficiency of pitching moment. In order to decrease the value of pitching moment coefficient, a newer BWB configuration is designed. Its swept angle is decreased so that the pitching moment can be smaller. Meantime the aerodynamic focus may change more slowly with the angle of attack. The geometry and surface pressure distribution of the newer BWB are show in Fig.10. The airfoil of every section is the same as case 3, but the platform is different. The design purpose of the newer BWB is to get better performance of pitching moment. The detailed RANS analysis results are given out. Fig.11 shows the pressure contour and oil stream picture on upper surface in this case. The oil stream is strongly influenced by the embedding inlet. It is evident that the flow separation is improved due to the embedding inlet influence. The aerodynamic characteristic of the newer BWB is given out in Fig.12-fig.14. They show that the embedding inlet increases the maximum lift coefficient and stall angle of the BWB. The drag characteristic become much better at higher lift coefficient, i.e. higher angle of attack, but the ratio of lift to drag is decreased due the inlet influence.

4 Conclusion

The numerical analysis is down for 3 BWB configurations in this paper, it shows some interesting results.

- Body embedding inlet can improve lift characteristic of BWB configurations, it improves separation flow at higher lift coefficient and increases the maximum lift coefficient.
- Body embedding inlet can increase the stall angle of BWB about 2 degree, thus the pitching moment coefficient curve can last long linearity region.
- The friction drag of body embedding increases the total drag of BWB+inlet configuration, thus the ratio of lift to drag is decreased.
- The influence of BWB planform shape on pitching moment performance is quite complex. The stall angle can be enlarged and linearity become better when swept angle become smaller.

References

[1] B. Mialon, ONERA Chatillon, France; M. Hepperle. Flying Wing Aerodynamics Studies at ONERA and DLR *Proc of CEAS/KATnet Conference on Key*

Aerodynamic Technologies. Bremen Germany, 20-22 June 2005.

[2] Richard L. Campbell, Melissa B. Carter and Odis C. Pendergraft, Jr. Design and Testing of a Blended Wing Body with Boundary Layer Ingestion Nacelles at High Reynolds Numbers. *Proc Conference of the 43rd AIAA Aerospace Sciences Meeting,* AIAA-2005-0459.

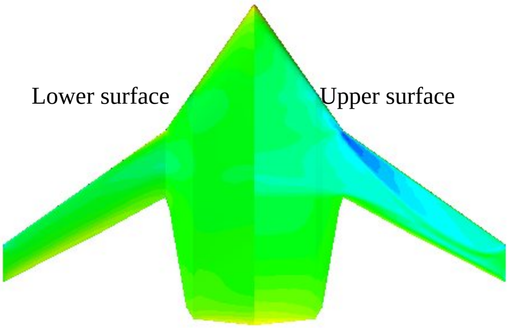
[3] JOSÉ JIMÉNEZ-VARONA.Design of Blended-wing-body Configurations using a Constrained Numerical Optimisation Method. *Proc of CEAS/ KATnet Conference on Key Aerodynamic Technologies.* Bremen Germany, 20-22 June 2005.

[4] S. Takanashi: An Iterative Procedure for Three-Dimensional Transonic Wing Design by the Integral Equation Method. *AIAA-84—2155,1984.*

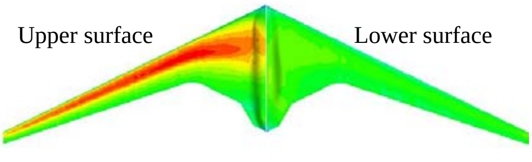
[5] J. Hua, F. M. Kong, J. J. Wang, H. Zhan, R. Z. Sun, D. Qiu: Recent Examples on Design Aerodynamics for Transport Aircraft. *ICAS 2002 Congress.*

[6] Q.Z. Yang, Th. Streit and G. Wichmann. Aerodynamic Design Study for Multi-lifting Surfaces. *Proc of CEAS/KATnet Conference on Key Aerodynamic Technologies.* Bremen Germany, 20-22 June 2005.

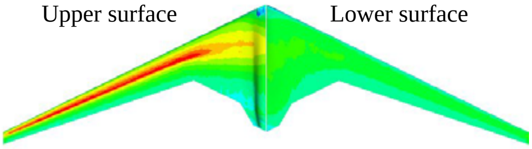
Figures



(a) (VELA, α =4°，Ma=0.85)



(b) (Blended wing body α =4° ， Ma=0.6)



(c) (Blended wing body + embedding inlet α =4° ， Ma=0.6)

Fig.1 Mach number contour of BWB surface

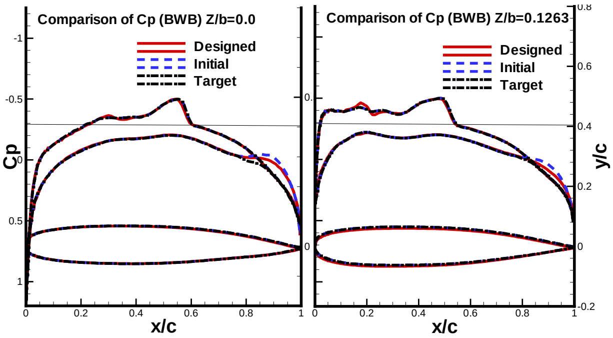
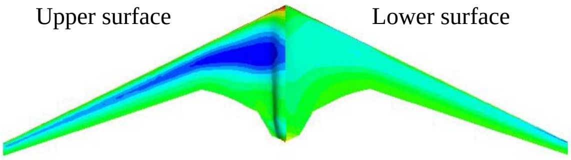
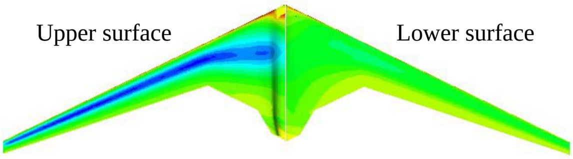


Fig.2 Pressure distribution on inner sections of VELA



(a) Initial fly wing



(b) Designed flying wing

Fig.3 Comparison of pressure distribution(Ma=0.6)

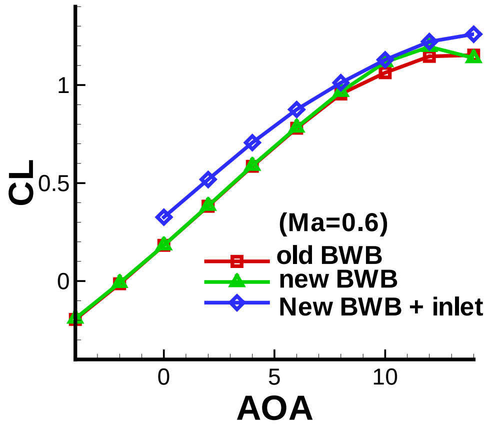


Fig.4 Comparison of lift coefficient

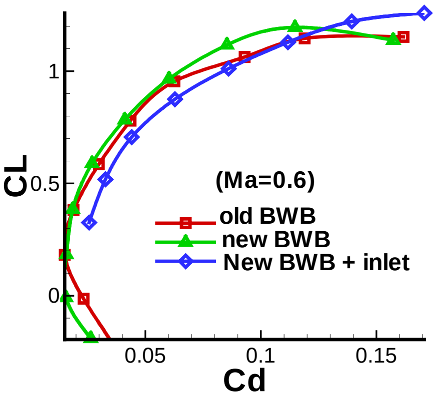


Fig.5 Comparison of polar curves

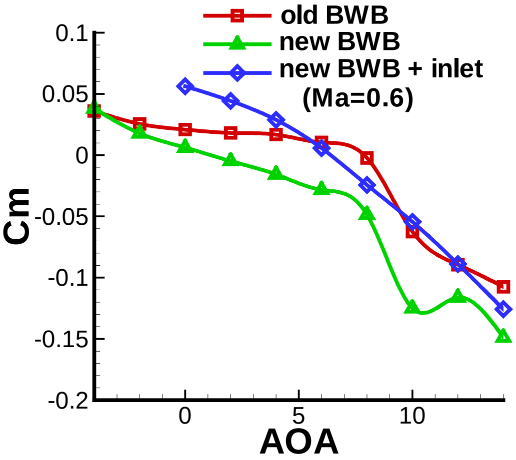
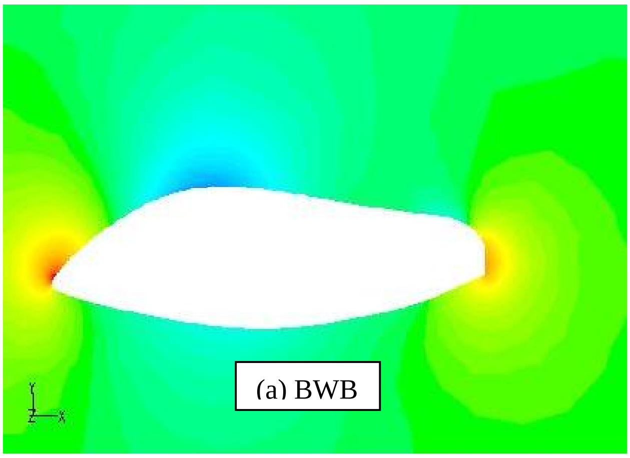


Fig.6 Comparison of pitching moment coefficient.



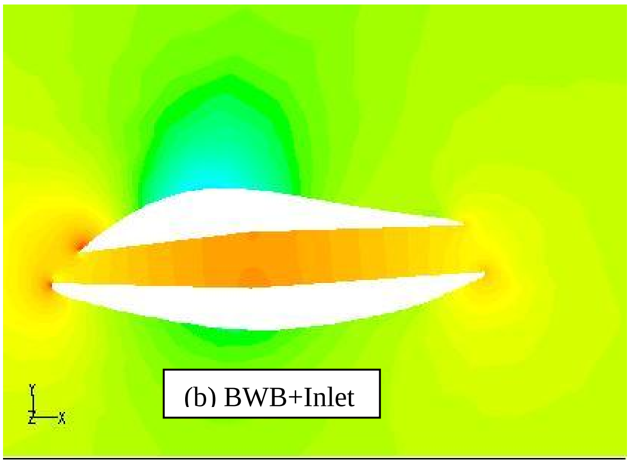
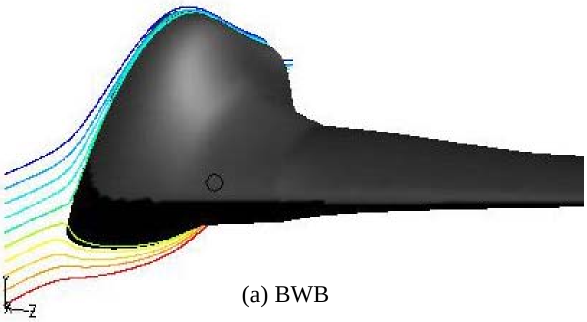
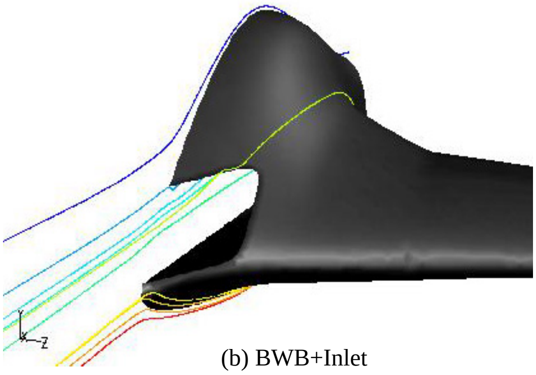


Fig.7 Pressure contour on symmetry plane



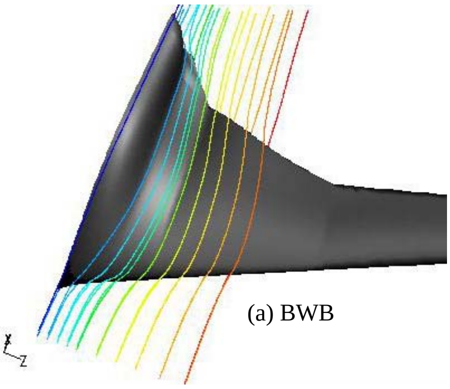
(a) BWB

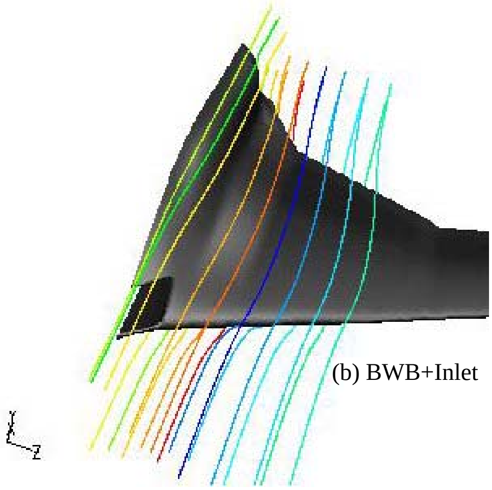


(b) BWB+Inlet

Fig.8 Comparison of streamline near the symmetry

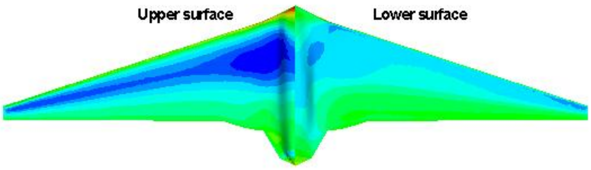
$(M_\infty = 0.6, \alpha = 0^\circ)$



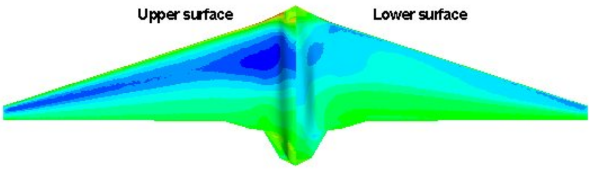


(b) BWB+Inlet

Fig.9 The streamline near inner sections

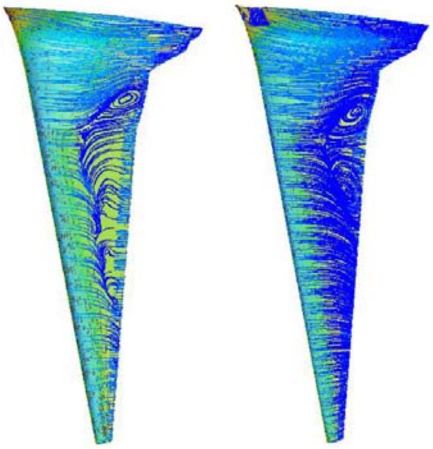


(a) BWB, $M_{\infty} = 0.2, \alpha = 0^{\circ}$



(b) BWB+Inlet, $M_{\infty} = 0.2, \alpha = 0^{\circ}$

Fig.10 The geometry and pressure contour of case 3



(a) BWB (b)BWB+Inlet

Fig11 Comparison of pressure contour and oil stream picture on up surface($M_{\infty} = 0.2, \alpha = 16^{\circ}$)

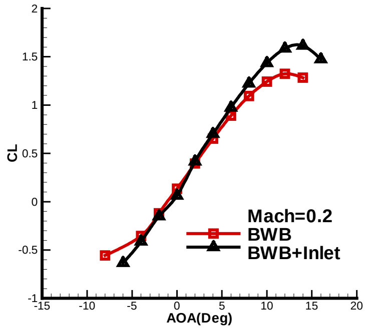


Fig.12 Comparision of lift coefficient

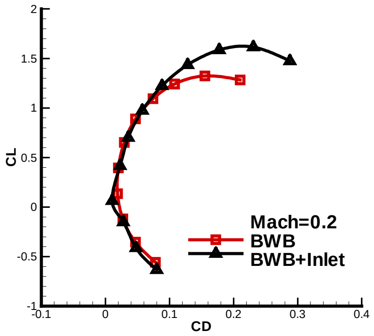


Fig.13 Comparision of drag coefficient

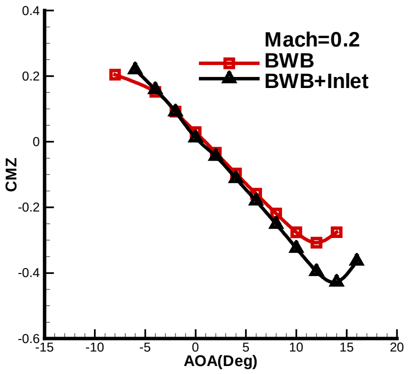


Fig.14 Comparison of pitching moment coefficient

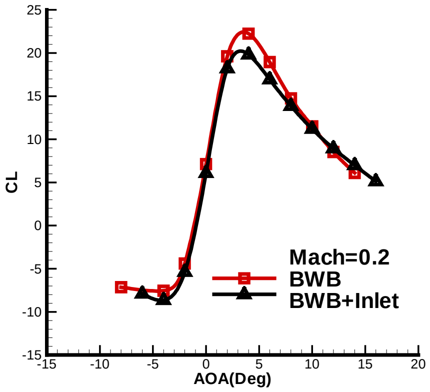


Fig.15 Comparison of ratio of lift to drag