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PRELIMINARY DESIGN FOR A LOW REYNOLDS NUMBER BWB UAV DEMONSTRATOR

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Abstract

The preliminary design of the low Reynolds number Blended Wing Body (BWB) Unmanned Aerial Vehicle (UAV) demonstrator, which is dorsal inlet and exhaust, V-type tail and 6 control surfaces, is carried out, and the aerodynamic design, structure design and flight test are presented in this paper.
Through 2D airfoil design, the S5010-15 airfoil is chosen, of which the maximum lift coefficient is about 1.33, and the stall angle of attack (alpha) is around 13°. When the alpha is below 12°, the drag coefficient is below 0.02. The maximum lift-drag ratio can reach 103 at 6.5°. 3D aerodynamic analysis of take-off, cruise and landing configurations shows that all the requirements can be satisfied. Take-off lift coefficient can reach 1.0 at -6° elevators & elevons deflection and 12° angle of attack, and the drag coefficient is about 0.07. Cruise lift coefficient can reach 0.4 at 4° angle of attack with clean wing, and the drag coefficient is about 0.028. For this demonstrator, landing is similar to take-off.
Laser-cutting wood plates are used for the spars, ribs and frames, and glass fiber composite for the skin.
The flight test results prove that the BWB configuration is feasible, the analysis is reliable, and the design is successful.

1 General Introduction

The preliminary design process of the BWB UAV demonstrator is shown in Fig.1. The concept of the UAV is shown in Fig.2.

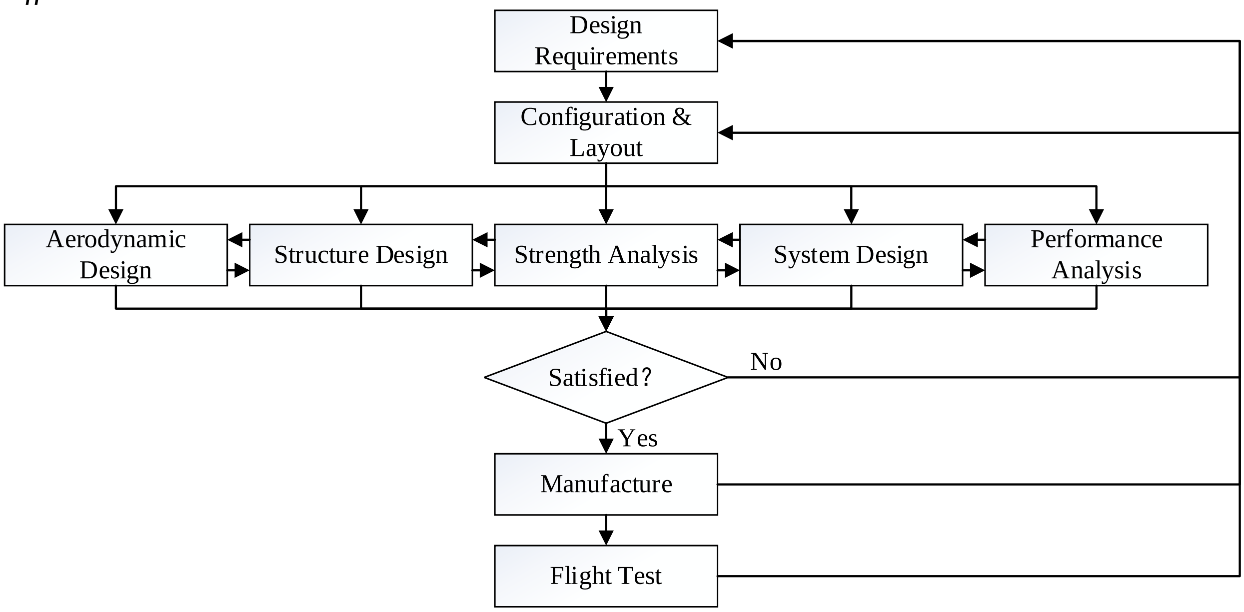

Fig.1 The Preliminary Design Process of the Demonstrator

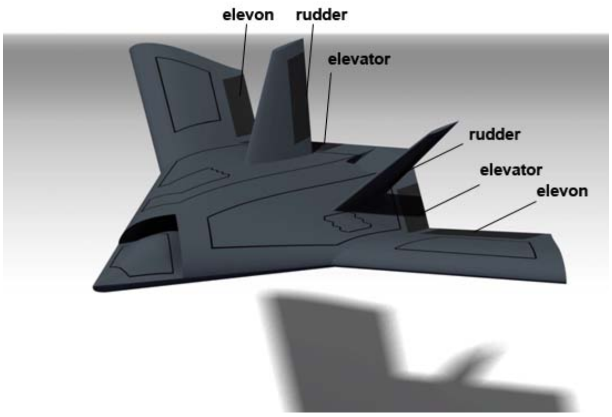

Fig.2 Concept of the UAV

2 Aerodynamic Design

2.1 2D Airfoil Design

The principles of airfoil design are as follows:

- The maximum lift coefficient should be as large as possible;
- Near the design lift coefficient, the drag coefficient would better be almost the same, in case of drag increase due to velocity variation;
- The range of available angle of attack (alpha) should be wide in case of early stall, and the cruise alpha should be far away from stall angle so that the stall is gentle;
- The airfoil would better not be too thin to reduce structure weight;
- The zero-lift moment coefficient should not be too large, in case of large trim moment. [1] [2]

Because the cruise velocity is relatively low, we choose software XFOIL to design the airfoils. Initially, according to experience, S airfoils are more suitable for BWB configuration. The S5010 and S5010-98 airfoils are chosen to analysis, but they seem too thin for structure and manufacture. So we increase the airfoil thickness to 15%, named S5010-15 and S5010-98-15. The cruise Reynolds number is about 750000, so the Cl vs. Cd, Cl vs. alpha, Cd vs. alpha, lift-drag ratio Cl/Cd vs. alpha and pitch moment Cm vs. alpha curves are shown in Fig.3 to Fig.5. Cl, Cd and Cm are airfoil lift, drag and pitch moment coefficient respectively and the unit of alpha is degree.

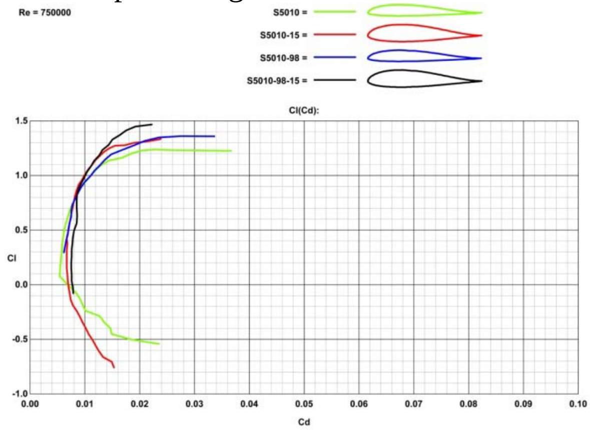

Fig.3 Cl vs. Cd Polar Curves

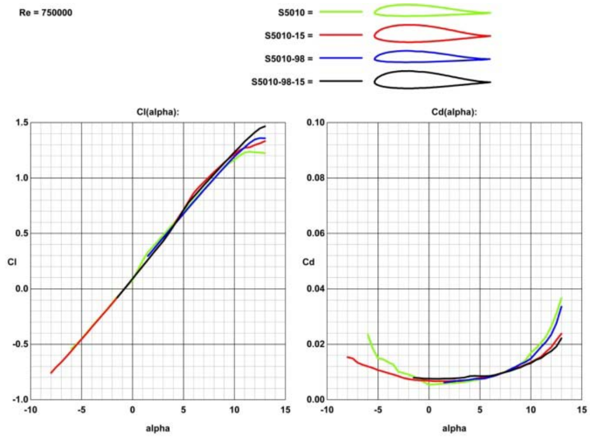

Fig.4 Cl vs. alpha and Cd vs. alpha

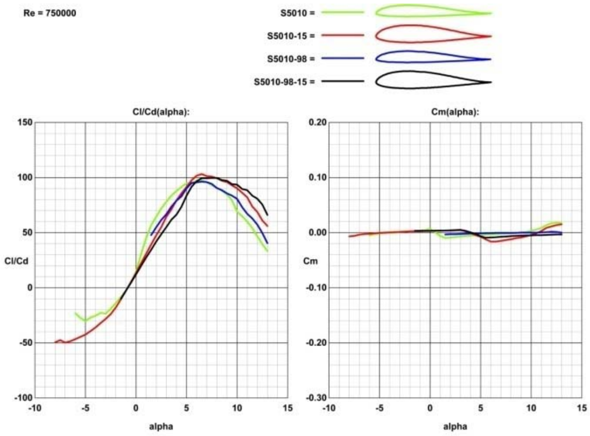

Fig.5 Cl/Cd vs. alpha and Cm vs. alpha

We found that the curves of S5010-15 are smoother, the drag is smaller and the lift-drag ratio is biggest, even though the maximum lift coefficient (Cl_{max}) is a little bit smaller. So the S5010-15 is chosen, of which the thickness is 15% at 29.7% chord and camber 2.17% at 29.7% chord. The Cl_{max} is about 1.33, and the stall

alpha is around 13°. When the alpha is below 12°, the drag coefficient (Cd) is below 0.02. The maximum lift-drag ratio can reach 103 at 6.5°. The pitch moment coefficient is relatively flat. All the parameters show that it's quite good to satisfy the design requirements.
Then the aerodynamic characteristics of the S5010-15 airfoil at different Reynolds numbers (Re) are analyzed, see Fig.6 to Fig.8. We found that the curve shapes just have small differences, which means the aerodynamic characteristics would not change a lot at low Reynolds number.

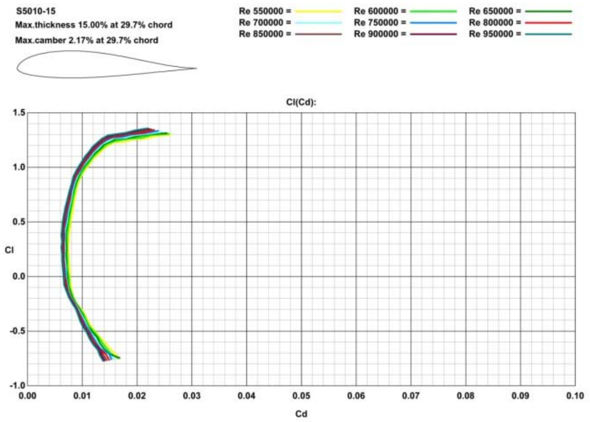

Fig.6 Cl vs. Cd Polar Curves at Different Re

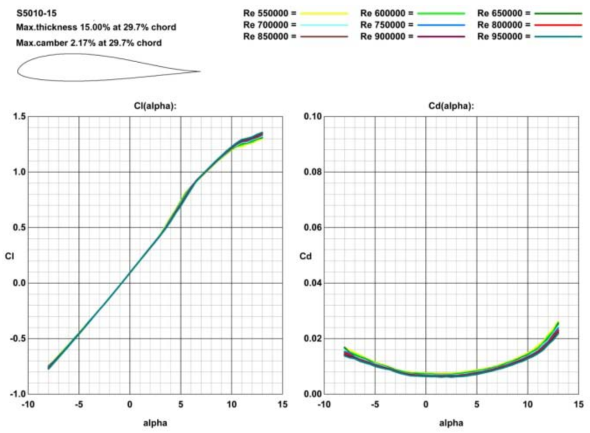

Fig.7 Cl vs. alpha and Cd vs. alpha at Different Re

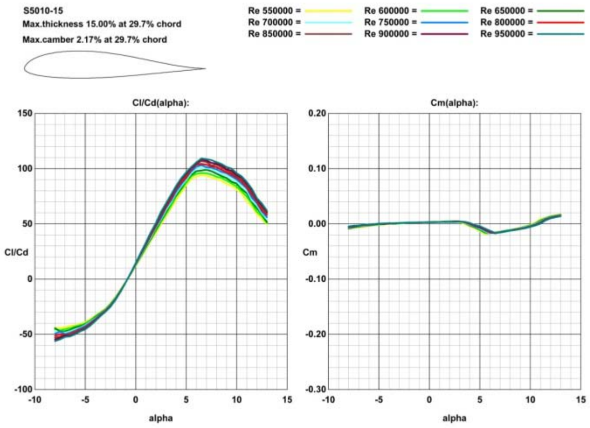

Fig.8 Cl/Cd vs. alpha and Cm vs. alpha at Different Re

2.2 3D Aerodynamic Analysis

After 2D airfoil design, we did the 3D aerodynamic analysis. Considering of the relatively low cruise velocity, we choose software AVL, which is developed by MIT and employs an extended vortex lattice model for the lifting surfaces, to analyze the aerodynamic characteristics. The model built in AVL is shown in Fig.9.

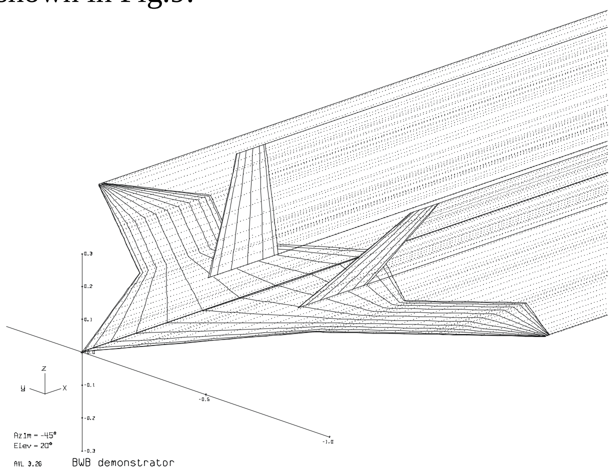

Fig.9 AVL Model

First, take-off configuration is analyzed.
The elevators together with elevons deflect a series of angles (from 0° to -14°, -2° step , minus means deflect upward) at a series of alpha (from 0° to 14°, 2° step). The CL vs. alpha, CM vs. CL and CD vs. alpha curves are shown in Fig.10 to Fig.12. CL, CD and CM are aircraft lift, drag and pitch moment coefficient respectively and the unit of alpha is degree. For the take-off lift coefficient is about 1, from Fig.10 and Fig.11, we found that when the deflection of elevators & elevons is near -6° and the alpha is near 12°, it can be achieved. And at

this point, the drag coefficient is about 0.07, see Fig.12.

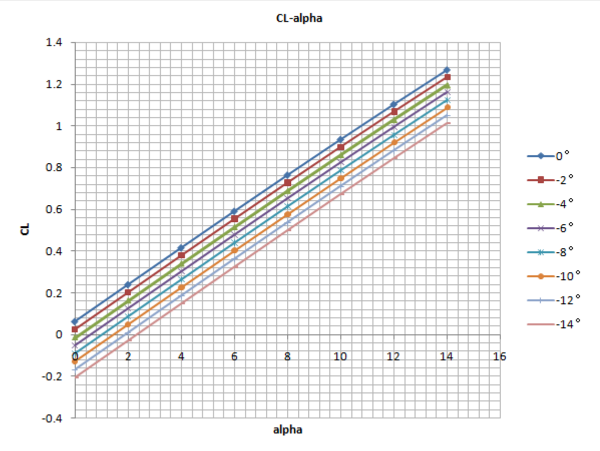

Fig.10 CL vs. alpha (Elevators & Elevons Deflect)

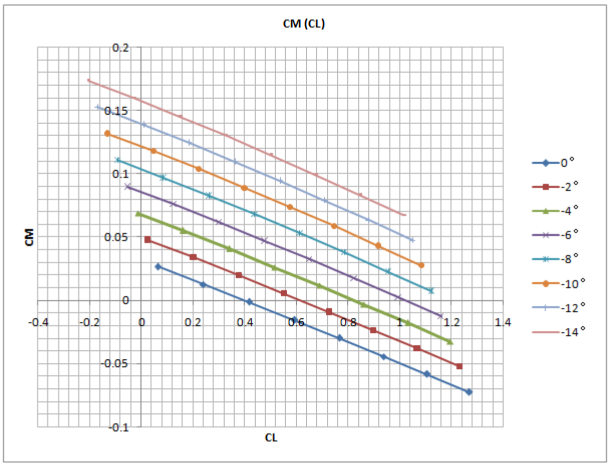

Fig.11 CM vs. CL (Elevators & Elevons Deflect)

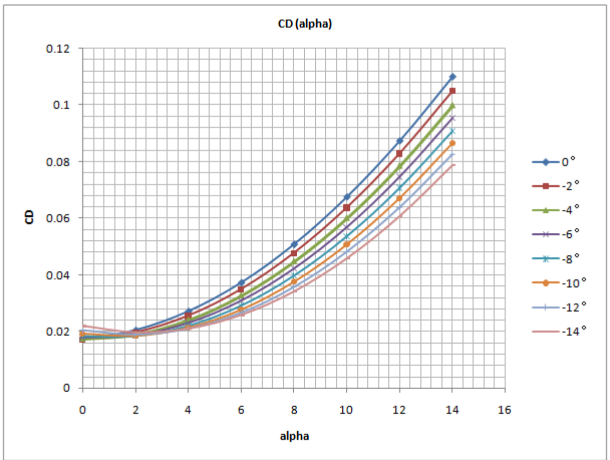

Fig.12 CD vs. alpha (Elevators & Elevons Deflect)

Then, cruise configuration is analyzed.
The elevators deflect to trim the pitch moment. The series of deflection angles and alpha are the same as above. The CL vs. alpha, CM vs. CL and CD vs. alpha curves are shown in Fig.13 to Fig.15. For the pitch moment CM equals 0 at steady flight, from Fig.13 and Fig.14, we found that when the alpha is near 4° with clean wing, the lift coefficient is near 0.4, it is good enough to balance the weight. And at this point, the drag coefficient is about 0.028, see Fig.15.

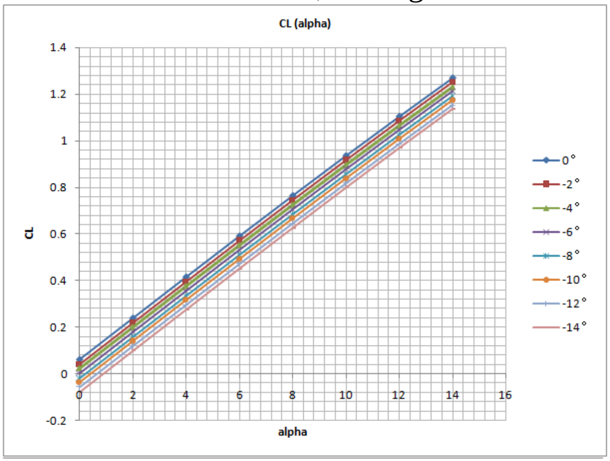

Fig.13 CL vs. alpha (Only Elevators Deflect)

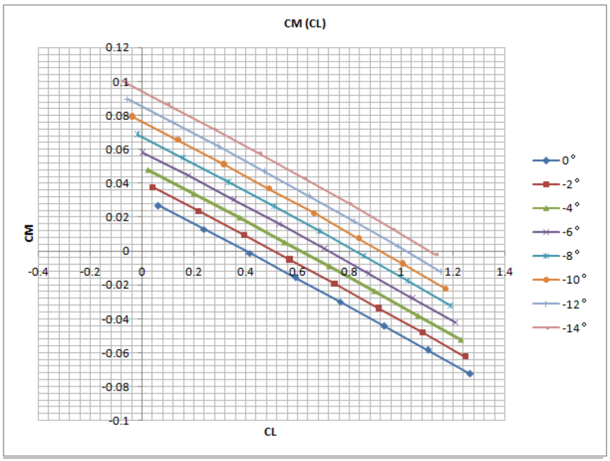

Fig.14 CM vs. CL (Only Elevators Deflect)

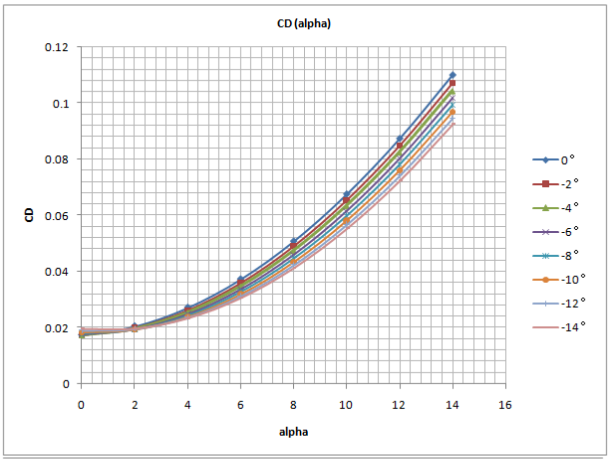

Fig.15 CD vs. alpha (Only Elevators Deflect)

Last, landing configuration is analyzed. It is similar to take-off. Because of the limitation of length, no more tautology here.
After this, high accuracy calculations are also carried out in CFD software CFX, there're not too much differences in the results. Which means the analysis is reliable. The unstructured mesh is shown in Fig.16.

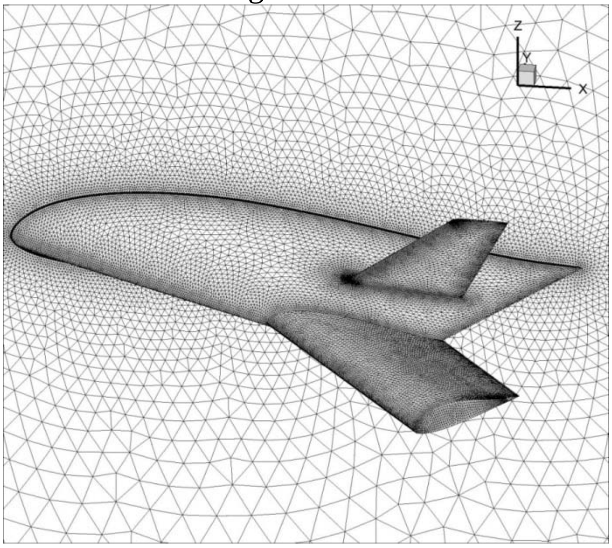

Fig.16 Unstructured Mesh of Half Model

3 Structure Design

After aerodynamic design, structure design is carried on, the outer wing consists of 2 spars and 5 ribs, the inner wing 3 spars and 3 ribs, the center body 9 frames and 3 ribs and the tail 2 spars and 4 ribs. Each control surface structure consists of 1 leading spar and 4 ribs. Laser-cutting wood plates are used for the spars, ribs and frames, and glass fiber composite for the skin, see Fig.17 and Fig.18. Nose landing gear could be retracted forward, and main landing gear inboard. At the current stage, the inlet is not designed in detail.

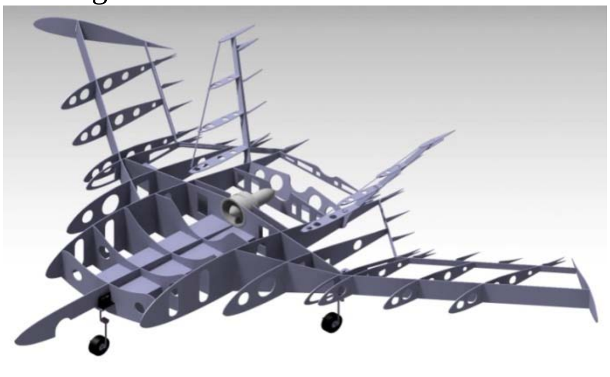

Fig.17 Demonstrator Structure

Fig.18 Demonstrator Glass Fiber Composite Skin

4 Flight Test

After strength analysis, system design, performance analysis and manufacture, flight test is performed, see Fig.19. The take-off and landing distances are short enough for the runway. The straight flight is stable without any sudden pitch or roll. And steady turning is very smooth. The cruise velocity, turning radius and efficiency of control surfaces are fairly consistent with design.

Fig.19 Flight Test

5 Further Work

Further work will be done at next stage, including:

- Optimization of the airfoils deployment, for the moment, all the sections have the same airfoil;
- Optimization of the wing twist angle;
- High accuracy aerodynamic analysis;
- Developing automatic flight control system, for the moment, the UAV is controlled by the remote control.

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[2] Roger D S. *The elements of aircraft preliminary design*. 1st edition. California: Aries Publications, 2000.

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