FLYING WING CONCEPT FOR REGIONAL TRANSPORT

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ABSTRACT

The flying wing is regarded as an alternate configuration to reduce drag and structural weight. This paper presents the design process of a medium size Blended-Wing-Body airplane, which in essence is a flying wing configuration. Because of the rapid changing of thickness and chord distribution, it requires special design tools. In the present study the wing surface is generated using RAPID method. Takanashi's inverse design method is utilized to obtain the airfoil shape. The required target pressure distribution is specified using constrain target pressure specification techniques. The present study shows that the design difficulties can be overcome by using the proposed design tools.

1. Introduction

To have more efficient airplanes and to meet the changing of the airplane mission many airplane's configurations have been designed by the aeronautical engineers. Many of their designs have flown successfully and others are still in the drawing tables. Some of their design concepts are different from the conventional airplane. One of the design concepts is the *flying wing* configuration. The flying wing and the tailless airplane are different. Although they both do not have horizontal plane, the tailless airplane still has the typical cylindrical fuselage, which carries a large part of the load. However in this paper the flying wing referees to both types of airplanes.

The flying wing is regarded as an alternate configuration to reduce drag and structural weight. Since flying wing possesses no fuselage it may have smaller wetted area than the conventional airplane. In the conventional airplane the primary function of the wing is to produce the lift force. In the flying wing configuration the wing has to carry the payload and provides the necessary stability and control as well as produce the lift. The fuselage has to create lift without much penalty on the drag. At the same time the fuselage has to keep the cabin size comfortable for passengers.

In the past years several flying wings have been designed and flown successfully. The Horten, Northrop bombers and AVRO are among of those examples. However the application of the flying wing concepts were so far only for sport and military airplanes. A review on the flying wing histories is given in reference [1]. The flying wing concept for the civil transport airplane has not been built or still only in the drawing table such as a short-haul airplane designed by Lee around 1965.

Nowadays the flying concept comes again into attention, especially for very large transport airplane configuration as shown in references [2,3,4]. Reference [5] describes a concept of flying wing for 300 passengers. The constraints implied by the required cabin height for the human payloads imply an interesting application for high capacity airplane. However the advantages of the flying wing concept may also be useful for regional transports such as for 200 or even for 50 passengers. The flying wing usually has larger reference area that reduces the wing loading. With its lower loading the required takeoff fields length can be shorten without complicated high-lift devices. This aspect is attractive and important for the regional airplanes.

A Blended-Wing-Body (BWB) airplane is a conceptual transport airplane, which in essence is a flying wing airplane. The inboard wing of the BWB airplane is usually very thick because it is used to carry the payload. The outboard wing is similar to the one of the conventional airplane. It is a challenging task to design the inboard wing under severe constraints. The inboard wing should have enough space for the passengers and should have also a good aerodynamic performance.

More challenging is to design medium or small size BWB airplane because the geometrical requirements are stricter. The space requirements to give the passengers enough comfort may also contradict with the constraint on the wetted area, so that some trade-off may be required. Other potential problem is the blending from the thick inboard wing into the thin outboard wing. The blending should be done as smooth as possible.

In this paper the design process of BWB airplane for maximum of 224 passengers and its current results will be described. The emphasis is on the aerodynamic design and to establish the required design tools in achieving the geometry constraints.

2. Conceptual design

In general aircraft design process can be divided into three major processes, conceptual design, preliminary design and detail design. This study focuses on the

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conceptual design process. The conceptual design phase is an iteration process. In the conceptual design phase the configuration arrangement, size, weight, performance and technology availability are studied to meet the requirements. If the requirements cannot be met then some relaxing of the requirements might be required.

The purpose of this study is to design a regional transport airplane for 200 passengers with takeoff and landing distance shorter than the current available airplane. The maximum cruise speed is at Mach number of 0.8 and range of 2500 nm.

The ground performance of an airplane including takeoff and landing distance is affected by the wing loading. The lower wing loading will give shorter takeoff field length. The other factor is the engine power and lift coefficient at lift off speed. To achieve lower wing loading the weight should be as small as possible and the wing area is increased. The lower wing loading is one of the advantages of the flying wing. For this reason this study chooses the flying wing concept to be applied for the regional transport airplane.

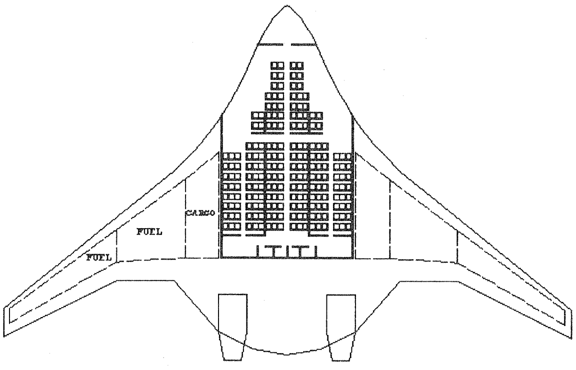


Figure 1. Design configuration

Wing span	50 m
Total Length	31 m
Wing Area (trap)	325 m
Wetted Area	1164 m
Aspect Ratio	7.7

Table 1. Configuration's properties

The first step of the design process is to specify the required space to carry the payload. The required space is based on the human measurement, which will affect their comfort during the flight. The minimum height at the corner of the passenger's cabin is set to 2 meters, while the maximum height depends on the airfoil contour. These requirements result in thick airfoil for the inboard section. The maximum thickness reaches around 15% and it is located in the wing section that connects the passenger's cabin and cargo space. In this section the chord length is shorter than the center chord length while the required cabin height is the same, which result in thick airfoil. The center chord length is chosen in such way that the location of the passengers cabin is limited up to 75% chord length. This is done to avoid the excessive thick airfoil.

The required cabin floor area is 0.929 m^2 area per passenger includes volume required for each passenger's share of galley, lavatories. Weight per passengers is 80 kg with luggage of 20 kg per passenger. First the fuselage is design to meet those space requirements then the wing is added. The outer wing should have enough space to carry the fuel. Figure 1 shows the design result. Some of its properties are displayed in table 1.

The layout consists of 8 eighteen-abreast seats, 1 twelfth-abreast seats, 2 ten-abreast seats, 2 six-abreast seats and 3 four-abreast seats. The passenger's seat pitch is set at 90 cm, which is comparable to the business class or even first class in many aircraft configurations. However the cabin is also designed to allow more passengers. At seat pitch of 80 cm the total passenger becomes 224. Two galleys and four lavatories are located at the most aft position, which give clear forward view for the passengers. Reference 6 describes the necessary methods to compute the required spaces.

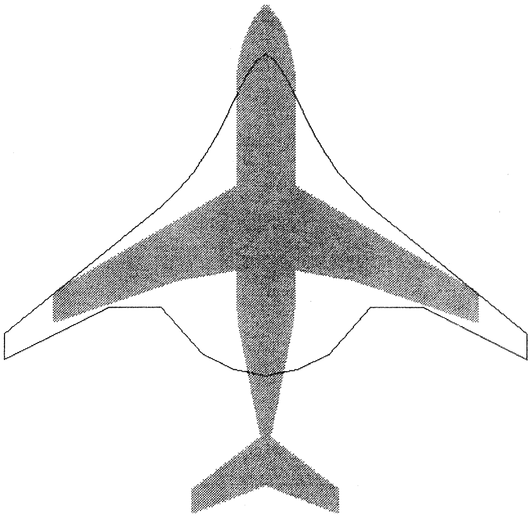


Figure 2. Design configuration in comparison to conventional airplane

Figure 2 shows the comparison between a BWB airplane and the typical conventional airplane with the same payload. The designed BWB airplane will have 2 engines at the aft center part of the wing. The configuration will also utilize the winglet, which also serves as the vertical tails.

Unlike the conventional airplane, the BWB airplane does not have cylindrical fuselage. It is assumed that a structural concept can be developed for BWB configuration. An alternate structure concept for BWB is described in reference [3]. The partitions between the cabin bays are the wing ribs that are the primary structure. Reference [2] shows that bending moment and shear on the BWB is half of that of a conventional configuration

3. Design tools

The BWB configuration is characterized by thick wing section in the inboard section, while the outer wing is similar to the one of the conventional airplane. To have lower drag it is required that the blending from the thick wing section into the thin wing section should be done as smooth as possible.

The wing surface between two known wing sections can be created by linear lofting method. This is especially true in the case of straight taper wing as commonly used in the conventional airplanes. However this method will be more difficult to be implemented in the BWB configuration design, especially for the inboard wing design.

The BWB configuration has thick inboard wing and thin outboard wing. The blending of thick inboard wing into the thin outboard wing will be quite difficult to be realized by the linear lofting method. Therefore another method of surface modeling is required to create smooth curved surface. The curved-surface modeling becomes more important for the medium-size BWB airplane because of the abrupt change from the inboard to outboard wings.

To achieve the smooth wing surface, in this study RAPID(Rapid Airplane Parametric Input Design)[7] method was employed. RAPID methodology generates the smooth surfaces by solving the fourth order differential equation

The wing of the BWB airplane has the function to produce the lift and to provide the required space to carry the payload. To satisfy both requirements a method for wing design is required. One way to solve this problem is by utilizing the inverse design method. One of the most useful inverse design method is the Takanashi's[8] inverse design method.

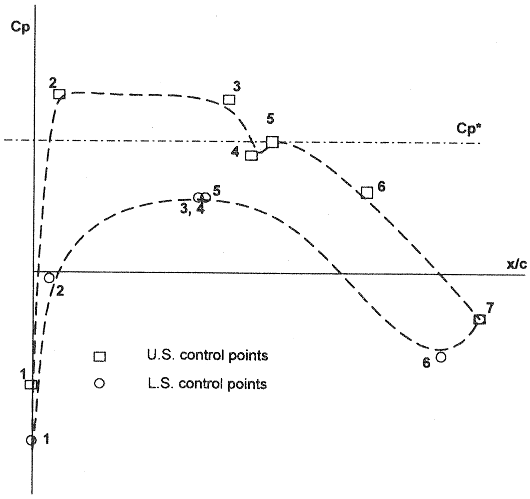


Figure 3. Control points to be used to generated target pressure

To realize the flow constraints and the space requirement, it requires a method to specify the target pressure distribution, which satisfies both requirements. To solve this problem a constrained target pressure specification technique as proposed by Campbell[9] is utilized.

In essence, the inverse design process consists of two primary processes, which are independent each other. One is the analysis process, which consists of grid generation and flow simulation, and the other is the design process itself. The flow simulation solves differential equations, which describes physical phenomena. Any flow simulation can be utilized. The design part consists of the solutions of inverse problem and the smoothing algorithms for designed geometry if necessary. With this arrangement, when a new and more powerful flow analysis becomes available, then only the flow analysis part need to be upgraded.

The first step of the inverse design process is to design the target pressure distribution based on the required aerodynamic performance. The pressure difference between the initial and the target forms an input of the inversely formulated transonic small perturbation equations. The solutions of the equations provide the geometry's correction Δf, which are used to modify the initial geometry to form a new geometry. The flow solutions of this new shape may be obtained by applying the Navier-Stokes equations. If, after having checked the convergence, the design requirements are not satisfied, the design cycle is repeated with the new geometry as the replaced initial geometry. The process is repeated until the pressure difference is minimized.

The target pressure can be generated to realize the required aerodynamic performance such as lift, drag and pitching moment. Here the lift and pitching moment coefficient can be estimated by simply integrating the pressure distribution. On other hand drag cannot be estimated precisely by a direct integration of the pressure distribution. At the present time only wave drag will be considered and it will be discussed briefly later in this section. The requirements from other discipline are usually converted into thickness requirements. An example is a thickness requirement for structural strength or a space requirement to carry enough fuel.

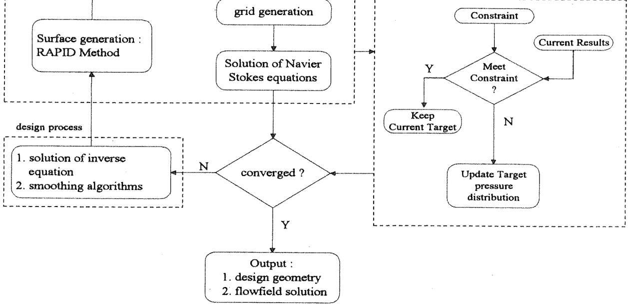


Figure 4. Design process

To translate the geometric constraint into pressure distribution, a method has been developed by Campbell[9] is utilized. To manipulate the pressure distribution during the design process, the pressure distribution is divided into several regions bounded by several control points as shown in figure 3. The location of the control points and their pressure levels are obtained by using two approaches, *empirical estimation approach* and *control point fitting approach.*

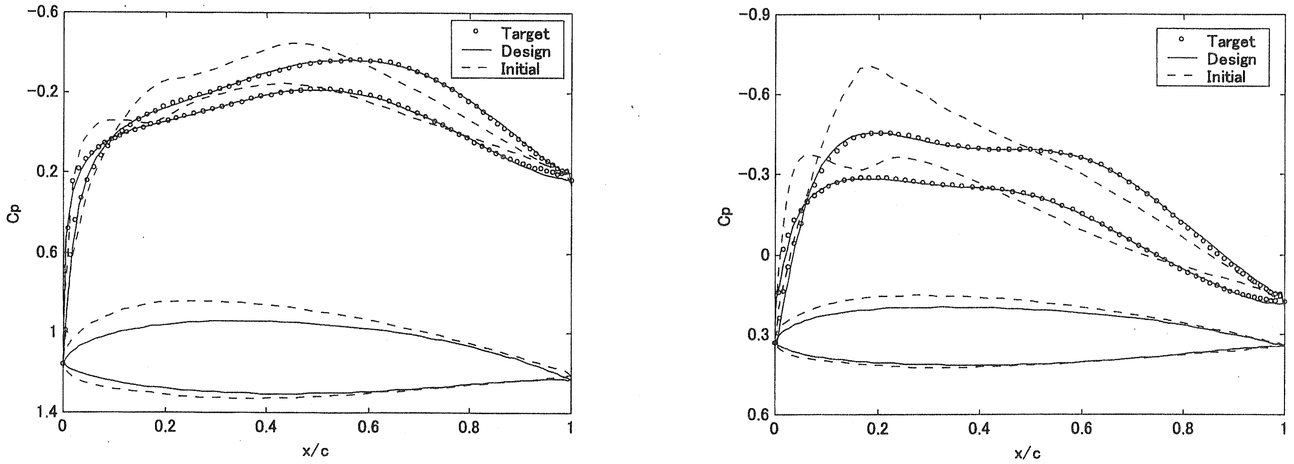
In the empirical estimation approach the controls points are developed by using empirically derived equations. Control point fitting approach is very useful to design target pressure distribution based on the existing airfoil, so the aim of this approach is to modify the existing pressure distribution. In the control point fitting approach, the control points are initially fitted into the existing pressure distribution. Then the pressure level at every control point is modified using the equations from empirical estimation approach.

To design the BWB airplane, the combination of all mentioned methods above are utilized. The integration of constraint target specification and RAPID method into Takanashi's inverse design is shown in figure 4.

4. Design results

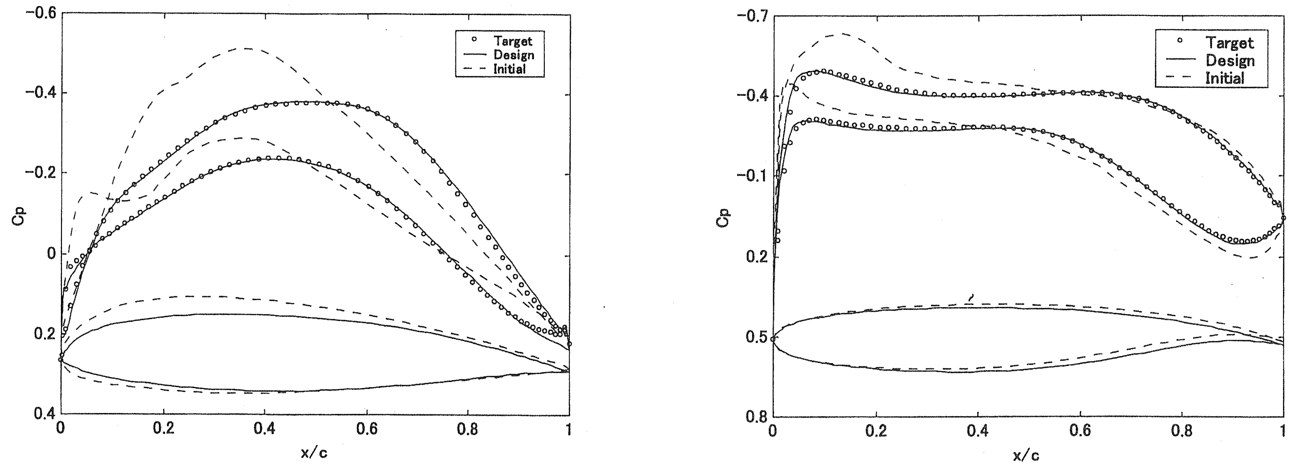
Inverse design

The authors would like to focus on the result of the inboard wing design because inboard wing design is much more difficult than outboard wing. The inboard wing is created using four wing sections at several design locations. Those design locations are at 0%, 12%, 24% and 40% semispan. At those locations the wing sections are obtained by using Takanashi's inverse design method, then the RAPID generates the wing surfaces.



a. 0% semispan

c. 24% semispan



b. 12% semispan

d. 40% semispan

Figure 5. Inverse design results

The target pressure distribution has been defined based on the design requirement. The aim here is to obtain the thickness distribution which lead to the geometry requirement of the inboard wing, which can carry the payload. Thickness requirements regarding the structural strength are not considered in the present study. The other aim is to have drag and pitching moment coefficient as small as possible.

Figure 5 shows the results of the inverse design process at several design locations. It shows that the design processes converge to the specified target pressure distribution, although there are still small discrepancy near the leading edge and trailing edge.

Table 2 shows the aerodynamic performance of the design compare to the initial wing. The drag coefficient is lower than the initial one; this might come from a result that the thinner airfoil in the inboard section has been designed. However the pitching moment (reference point is leading edge of the center airfoil) is slightly higher than the initial one because of the higher aft loading in the inboard section. It can be improved if the target pressure distribution is well adjusted for aerodynamic forces to desirable feature.

	Design	Initial
Lift coefficient, CL	.5124	.5136
Drag coefficient, CD	.0272	.0312
Pitching moment coefficient, Cm	-.3563	-.3353
Lift to Drag ratio, L/D	18.8700	16.4630

Table 2. Aerodynamic performance

Figure 6 shows the airfoils at the three design locations in the fuselage. The passenger's cabin is placed inside those three airfoils. In this figure the passenger's cabin is also represented as the rectangle. The figure shows that the present method can achieve the aerodynamic target with satisfying the geometry constrains to obtain wide space for the passenger's cabin.

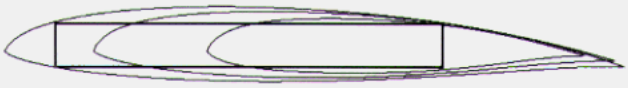


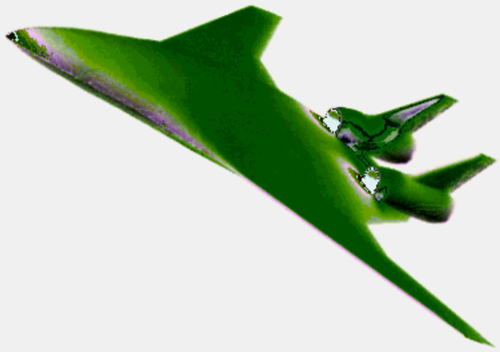
Figure 6. Passenger's cabin

Engine and vertical tails Integration

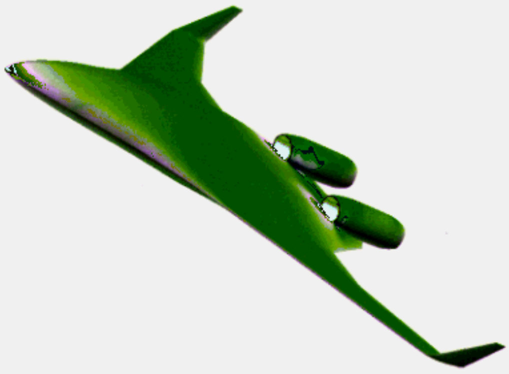
The integration of the engines and vertical tails also requires special attention. The engines are placed in the aft center of the inboard section as shown in figure 2. Two locations of the vertical tails are considered. First, the vertical tails are placed on top of each engine. Second, the vertical tails are placed in the wing tip, which also has a function as winglets.

The presence of engines in the aft center section creates an area with high-speed flow. The placement of vertical tails on top of the engines makes the condition worst. The shockwave appears in the vertical tails as shown in figure 7a, results in high drag coefficient. For this configuration better results might be achieved if the nacelle shape and/or locations are optimized.

A simpler result is achieved if the vertical tails are placed in the wing tip as shown in figure 7b, which also act as winglets. For this configuration the shockwave does not presence. The flow for the complete configurations is analyzed using Euler solver, which utilize unstructured grid.



a. Without winglets



b. Winglets configuration

Figure 7. Surface pressure distribution on BWB airplane

Takeoff field length

Preliminary analysis of the required takeoff field length is performed using a method described in reference [6]. The takeoff field length is defined as the required distance to reach the screen height. Results of the computation are shown in figure 8, which show the required maximum lift coefficient versus the desired takeoff length for different values of takeoff weight. In the calculation it is assumed that the value of thrust to weight ratio is 0.3. The maximum takeoff weight is estimated using a method described in reference [10]. The estimation is based on the payload and the desired range capability.

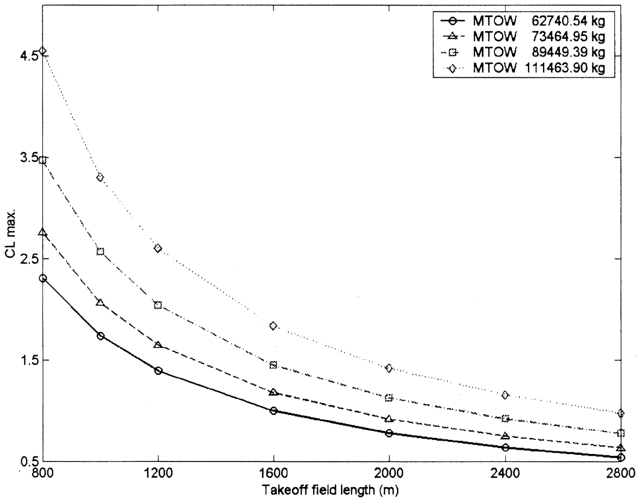


Figure 8. The required $C_{L_{\max}}$ vs. takeoff field length

5. Conclusion

Aerodynamic design of a BWB airplane for maximum of 224 passengers has been performed using the proposed design method. The combination of Takanashi's inverse design method, constrained target pressure specification technique and RAPID method provide a useful design system for BWB configuration airplane. The RAPID method forms a good tool for generating the wing surface. It has more flexibility to create transition from one boundary to the other boundary. Constrained target pressure specification technique as proposed by Campbell is very useful to be used in the inverse design process, which works well together with Takanashi's inverse design method.

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