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Trends in Wing Design and Role of Blended Wing Body (BWB) in the Performance Characteristics of Aircraft

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ABSTRACT

Wings prove as the major factor in any design considerations for an aircraft, as it is the essential parameter which helps the designers for the calculation of lift generated for that particular design. The wing design has undergone slow but steady changes throughout the phase development of aircraft designs from the early days to the present. This seminar deals with the various trends the wing design has faced throughout the paces of aircraft development and testing. The early stages of wing design included the positioning and number of wings along with the degree of twist provided on it to increase the aerodynamic characteristics. Later on we came to see much more radical wing design, as the likes of delta wing, canard wing etc. The increasing demand for the aerodynamic efficiency led to the present stage realization of blend wing body. A BWB is a fixed wing aircraft having no clear dividing line between the wings and the main body of the aircraft. In this the wing is effectively and smoothly blended into the housing of the fuselage. Here the role of BWB to increase the performance characteristics is evaluated and it can be generally found to be about 50% more lift to drag ratio than conventional aircrafts. The BWB design can be extensively employed in aircrafts and underwater gliders.

Keywords- Aerodynamic Analysis, BWB, Design Constraints, Heavy Rain.

1. INTRODUCTION

An aircraft major contributing factor for its flight performance is the design parameter of wing and its functions. The first aircraft was designed and flown by the Wright brothers in the year 1903. After a span of 44 years relative to how you look at it, came the swept-wing Boeing B-47 and took flight [1, 2]. If we take into consideration the design parameters of these two flights there is remarkable engineering accomplishment within a period of slightly more than four decades and the design changes have been so rapid and predominant that with each significant and insignificant changes the performance characteristics have been greatly enhanced.

Embodied in the B-47 are most of the fundamental design features of a modern subsonic jet transport [3-5]. The Airbus A330 designed much after is essentially another equivalent change in the design parameter which led to the rapid evolution and booming of the aviation industry.

In an important historic keynote, in the year 1988, when NASA Langley Research Center's Dennis Bushnell asked the question: "Is there a renaissance for the long haul transport?"[1] there was cause for reflection and led to the conduction of a preliminary design study by McDonnell Douglas to create and evaluate alternate configurations which led to the development of the interesting concept of Blended Wing Body (BWB) [6].

2. EVOLUTION

A wing is a type of fin with a surface that produces aerodynamic force for flight or propulsion through the atmosphere or through another gaseous or liquid fluid. Thus it has a streamlined cross sectional shape to produce lift as shown in Fig.1.

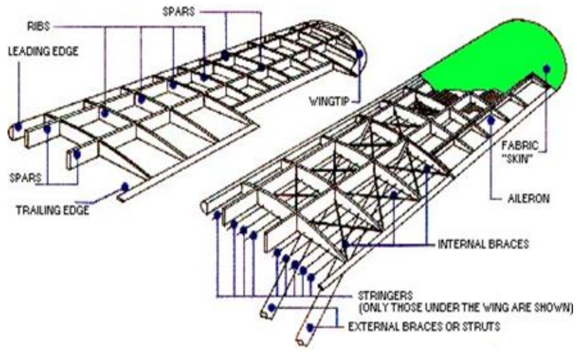

Fig. 1 Cross section of a wing section

2.1 Classification of Aircraft Wing

1. Conventional Configuration
2. Blended Wing Body
3. Hybrid Flying Wing
4. Flying Wing
5. Boeing C Wing

2.1.1 Conventional Configuration

It is essentially the fundamental design that we have been following for a long while till the much more risqué design was brought into limelight. This type of conventional configuration varied based on the type and number of wings along with its positioning on the fuselage.

2.1.2 Hybrid Flying Wing/Flying Wing

It is quintessentially similar to Blended Wing Body and the design parameter of the wing is made in such a way that the major focal point is in the reduction of drag and also to increase the performance efficiency which is greatly seen by the fact that this type of planes use 50% less fuel than its contemporary natives.

3. FORMULATION OF THE BWB CONCEPT

The performance potential implied by the BWB concept provided the incentive for NASA Langley Research Center to fund the study conducted by McDonnell Douglas to develop and compare advanced technology subsonic transports for the design mission of 800 passengers and a 7000 mile range at a Mach 0.85 [1].

In the preliminary design the pressurized passenger compartment consisted of adjacent parallel tubes, a lateral extension of the double-bubble concept [7].

On comparison with the conventional aircraft design configuration the newly formulated concept by Douglas was found to be significantly lighter, had a higher lift to drag ratio and a substantially lower fuel burn [8].

3.1 Design Challenges

The BWB concept based on the double-bubble concept when introduced posed various design challenges which was not only aerodynamically inaccurate but also proved to be major hurdle in the successful employing of this design.

When we are to define the pressurized passenger cabin for a very large airplane there occurs basically two challenges. First, the square cube law shows that the cabin surface area per passenger available for emergency decreases with increasing passenger count. Second, cabin pressure loads are most efficiently taken in hoop tension [3]. Thus, the early design was such that the engines were buried in the wing root and the passengers could egress from the sides of both the upper and lower levels. The design trend was similar to the earlier tube and wing design and thus the fundamental challenge was revised [7].

The requirement for taking pressure loads in hoop tension was abandoned and an alternate efficient structural concept was developed and this led to the achievement of the much radical design of the BWB concept as in Fig. 2. The represented figure is one of the early design renders which was developed with the then present design constraints in mind and primarily the bubble concept based design was developed to hold a cabin capacity of 800 passengers.

The basic design got evolved from the sphere based canonical forms which was effectively chosen due to the fact that the sphere has minimum surface area thereby effectively ticking the box of every design parameters which was to reduce the effect of flow parameters on the surface area i.e. to reduce overall effect of drag which is one of the major force acting on the aircraft..

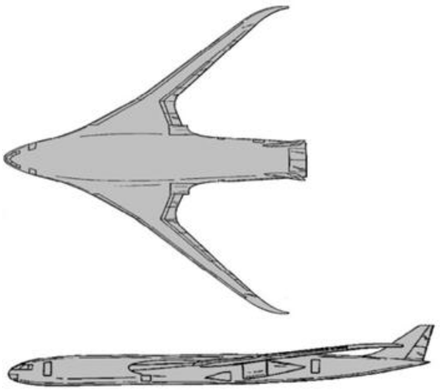

Fig. 2 Early design of BWB

When this design constrain was analyzed for its efficiency it was found that there is a reduction of about 33% in the wetted area as compared to that of a conventional configuration and thus this significant amount of reduction in the wetted area meant there was parallel rise in the overall efficiency of the aircraft due to the drag being reduced as verified by the relation cruise lift to drag ratio is directly proportional to wetted area aspect ratio (b^2/S_{wet}) [10].

Even though sphere which was considered for the formulation of BWB has minimum surface area it was not streamlined so it meant it was not suitable and thus two canonical disks one above the other was considered and thereby an effective fuselage extending into the wing was obtained which was different from the traditional design where the wing was riveted onto the fuselage.

On the canonical disk there came the positioning of power plants which was placed on the end of canonical disks like that of a fighter jet and thus was able to reduce the interference drag which might occur due to the placement of power plants under the wing as in normal design constraint. Then came the design of providing vertical directional stability and thus vertical winglets was provided on the end of the wing to increase the overall dynamic stability. Since in this BWB concept there was no particular wing the span wise lift was to be produced with the help of the wing and canonical shaped fuselage and thus the airfoil was designed with a max of c_l=0.25 in mind [1].

Then came the consideration of the load wise distribution on the body and unlike in conventional configuration where the load can be distributed with the help of longerons and stringers. In BWB the load cannot be handled by the implementation of stressed skin alone and thus a pressure vessel skin which was arched was provided above and below the cabin and this took the tension load and was independent of wing skin thereby ensuring that the design was not only structurally sound and proficient as that of the conventional configuration. But this design had a major flow as the chance of buckling of this independent arched pressure vessel was significantly higher. And this was replaced with a much simpler sandwich structure which meant the independent pressure vessel was replaced by a much broader thick sheet around the cabin to uniformly distribute the load experienced by the air loads.

3.2 Design Constraints

With all the design challenges that was put forward in the designing of the BWB concept a basis design was developed and it was supposed to satisfy a set of design requirements and they were

3.2.1 Volume

Volume available v/s volume required was one of the major design constraints with BWB and passengers, cargo, and systems need to be included within the wing itself.

3.2.2 Cruise Deck Angle

Since the BWB is a unique design and there is the existence of a thin wing attached to the center body a part of the lift production was to be done by the center body and thus a positive camber was used as center body airfoils.

3.2.3 Trim

With the implementation of positive camber as the airfoil of center body there was an increase in the positive static ability which meant the nose down pitching moment was minimized.

3.2.4 Landing Approach Speed

Since BWB has no other control surfaces like flaps to effectively reduce the approach speed and due to the lack of such control surfaces as that of in a conventional configuration the overall lift coefficient is lower and thus the approach speed must be calibrated and it meant there is a greater angle of attack or attitude of approach in play.

3.2.5 Stall

Due to the plan form of center body there is a much greater loading on the wing of the BWB and thus winglets are provided to protect it from low speed stall.

3.2.6 Control Surface Actuation

In the BWB design concept there is no ordinary control surfaces as that of in conventional configuration and thus the placement of the control surfaces is very important. Thus the power required to actuate the control surfaces comes into play here as the hinge moment of the control surfaces sometimes needs maximum hydraulic power in the system and thus the power requirement becomes a function of rate at which a control surface is moved.

3.2.7 Manufacturing

The design constraints can result in a complex 3D shape which would be difficult to manufacture and produce and thus the aerodynamic efficiency increases with the smoothness of the curved surface but at the same time satisfying the design constraints.

4. AERODYNAMIC ANALYSIS

Once the blended wing body concept was formulated it came down to the fact that it needs to be analyzed for finding out its aerodynamic performance characteristics.

The major aerodynamic advantage of the BWB design are its reduction in wetted area to volume ration which meant greater reduction in interference drag. There is also a theoretical estimation of 20% increase in lift to drag ratio. This is achieved and varied with even subtle changes in the aerodynamic shape.

When considering the aerodynamic performance side the maximum lift to drag ratio depends on the ratio of aircraft span to the square root of the product of the induced drag factor and zero lift drag area which is proportional to the wetted area of the aircraft [8].

This means the smaller the wetted area or lower the skin friction means the lesser the induced drag which means there is a substantial improvement in the aerodynamic performance. The wing span length limitation depends on the design of purpose and also the airport capability during mass production.

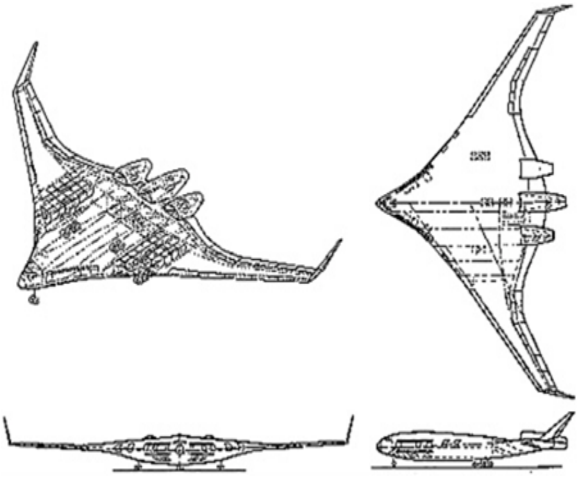

Fig. 3 BWB sectional view along with wing span

4.1 Aerodynamic Design Analysis

When we basically break down the design constraint of the BWB we can see that all the parameters that we seen in the fuselage, wing etc has been squeezed into the unique conical shaped disks of the BWB design. To increase the passenger capacity the design has been in such a way that the passenger cabin is made double deck with single level cargo areas outboard [11].

This basically results in a design as in Fig. 3 a boost over conventional configuration which when analyzed shows a relaxed static stability and optimum span loading as the advantages of BWB design over conventional configuration.

When this design was analyzed with the help of both computational and realistic methods the results obtained where astoundingly similar and shows the clear advantage it has over conventional design configuration. The boundary layer separation that is usually present in the any configuration which shows the lack of aerodynamic efficiency was significantly lower in the case of BWB as verified by both computational analysis methods like CFD and by realistic methods like wind tunnel techniques as in Fig. 4 and 5.

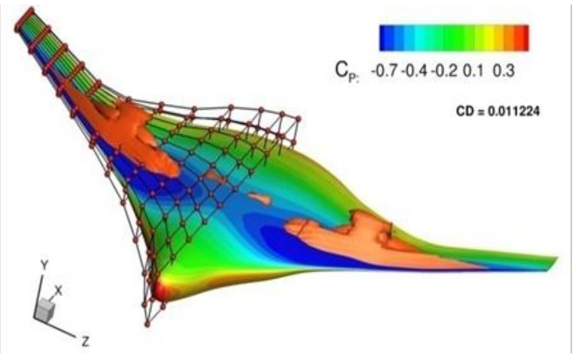

Fig. 4 CFD analysis of BWB

Fig. 5 TUFT analysis of BWB

4.2 Lift Distribution

Generally BWB design has an increase in lift to drag ratio compared to that of conventional configuration aided by its unique design constraints. But this general comparison is proven with the help of experimental methods like CFD which also points to this fact.

But no design is successful unless and until it is analyzed for the efficiency with which the lift is produced and how the lift gets distributed across the span of the design. As mentioned above the maximum lift to drag ratio depends on aspect ratio [12].

This relation in theory is important for the confirmation of the net 20% increase the BWB claims over the conventional configuration. The relation is

$$\left(\frac{L}{D}\right)_{\max} = \sqrt{\frac{\pi A}{(4kC_{D0})}} = b\sqrt{\frac{\pi}{(kS_{D0})}}$$

It is evident from this relation that larger span, smaller wetted area, lower zero lift drag can all improve the aerodynamic performance. Typically k takes about 1.2 as its value when we consider a conventional configuration. And this relation holds true under normal conditions where the excessive strengthening of the shock wave is not taken into account.

The basic span wise distribution of lift in the BWB design after considering the parameters is such that it adopts a elliptic distribution in the outer and inner wing and a less loading in the center body. This kind of distribution is similar to that of a conventional configuration which strengthens the fact that the BWB can be effectively employed in all the situations that we use for normal configuration. The other amount of forces acting on the design including the bending moment and rotational elements also take a similar setting as that of a conventional configuration.

4.3 Real World Analysis

Once on the completion of the BWB concept it was mandatory for the complete parametric check of the various aerodynamic effects on these design constraints and as such experiments were carried out. First of all these designs was checked for the parameters with the help of modern age computational methods and as such the results were obtained.

And these results were cross referenced with practical tests carried out at various flight velocities and were found to be accurate and complimenting one another. Then came the practical cases which these design constraint would have to go through and as such test were carried out and they were much broadly termed as real world test scenarios.

4.3.1 Gust Effect on BWB

The effect of gust on BWB plays an important role in two ways. First of all it becomes necessary to verify for the effect of gust on BWB since the gust effect is a common parameter in the real world scenario. Another way the effect becomes important is the case of the BWB in civil aviation.

When we are to consider the design parameter of BWB for a civil aviation vehicle the economy factor takes a back seat since the safety becomes the paramount feature around which the whole design development is centered. It is important for the study of effect of gust on BWB since it’s experienced by any flight in motion during its flight hours.

Mainly two types of gust are predominantly seen in the case of real world scenarios. The vertical gust acting in the z direction and lateral or horizontal gust in y direction. The effect of vertical gust and lateral gust on the BWB is different from one another. The vertical gust which is more rapid and powerful has greater effect on the body of BWB due to its unique shape in the center body and this tends to create pulses like lift which reduces the stability of the craft. But on the other hand the lateral gust has a much sublime effect on the BWB as compared to that of a conventional configuration also aiding to the shape. Due to its flat shape it skims across the gust wind acting on the body and thus effectively helps in keeping it afloat. Thus it is mandatory to reduce the effect of vertical gust on BWB which substantially improves the dynamic stability of the aircraft.

4.3.2 Effect of Heavy Rain

Due to the major changes in the atmospheric patterns around the world there has been varying changes in weather. This changes becomes so extreme that the design constraints of any aircraft or any vehicle for that matter has to be in such a way that the design is made with these extreme weather conditions in mind along with other parameters like efficiency, economy, safety.

Usually when we are to consider the effect of extreme rain we usually think about the wind shear which is accompanied with heavy down pour. This wind shear is so strong that it has enough down force to rip apart the wing from the fuselage if the aircraft gets caught in the wind shear accidentally.

But if the downpour becomes so extreme the effect of it on a conventional configuration can be neglected or becomes significantly less as compared to that of a BWB. This is also due to the fact of the unique design of BWB. The design of the BWB is in such a way that under heavy torrential rain the center body acts us a relative catchment area. That is due to the more surface area of the fuselage as seen from the top, the heavy rain acts as a moderate to high load on the body.

But the wind shear becomes less of an effect as in the case of BWB due to the fact that the wing and fuselage is merged into one and sandwiched with thick pressure vessels. This design structure can withstand wind shear which is accompanied with the torrential rain.

5. CONCLUSION

The advancement of design changes in the field of aeronautics has undergone in a brisk pace and out of that the design concept of BWB was the one which had undergone lot of developments and criticisms. The BWB concept which was originally started as one design concept for a long overhaul transport vehicle has gradually spread onto all design phases due to the unique capabilities the design element brings onto the stage.

The major improvements being a 27% lower fuel burning, 15%lower takeoff weight, 20%higher lift to drag ratio to name a few. This significant improvement led designers to widely exploit the possibility if the BWB concept which originated from NASA Langley research center to the next stage of reworking by Boeing and launched as Boeing C wing.

The usage of BWB concept is not restricted to that of a subsonic transport vehicle or that of a civilian aircraft but it is in its true sense a multipurpose vehicle which can be used for all kinds of aerial activities with minor to no changes in the design constraint.

The design parameter however advantageous has some flaws which accompanies it which directly relates to the stability of the aircraft along with its control and the effects of some of the aerodynamic parameters which is greatly affected by the smoothness of the BWB design during manufacturing which leads to the cost and credibility at pulling of such a design. Thus like the two sides of a coin the advantages balances the disadvantages of the BWB design concept which means that the application level of the concept can be put into practical use and also gives rise to new innovative ideas as that of the C wing by Boeing another tailless concept and also to retract wings by Airbus on supersonic flights.

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