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Shape Optimization of Blended-Wing-Body Configuration- An Experimental Approach

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Abstract**:** ***In the recent years alternative aircraft configurations, such as Blended – Wing- Body(BWB) aircraft, are being studied and researched with the intention to develop more effectual aircraft configurations, in particular for very large transport that are more efficient and environmental friendly. In addition to the removal of the tail for this specific kind of aircraft and the substantial decline in equivalent weight, drag force, and radar cross-section, the accessible space for mounting equipment inside the wing and the operational range have also been augmented. Regardless of all these stated advantages, instability is the negative outcome of removing the tail. Revising this imperfection requires designing a combination of control surfaces and reflexed wing sections and using complex computer control systems. Hence, the aerodynamic shape optimization of BWBs, along with the need to meet the design necessities, has encouraged numerous investigators to overwhelm its challenges. In this project an experimental approach was adopted to optimize the shape of a basic design of a BWB using an experimental approach. The flow simulation using wind tunnel was carried out for a basic model of BWB. Then the aerodynamic efficiency of the basic design was compared with a conventional aircraft B747 using the same experimental conditions. The three models such as the basic BWB, B747 and the 787 were compared in terms of their*** $(C_L)_{max}$, $(C_D)_{min}$ ***and*** $(L/D)_{max}$ ***values. The results were presented with the BWB with 45% efficient shape when the above-mentioned parameters are compared***.

Index Terms**:** ***Blended Wing Body, Shape Optimization, Gradient-less Optimization, Experimental Approach***

I. INTRODUCTION

The BWB configuration entitles an unconventional aircraft configuration where the wing and fuselage are incorporated which results in a hybrid flying wing shape. A few of the significant attempts by early researchers in the areas of shape optimization of a BWB are mentioned here . Wayne Mastiny Robert Eetal. (1996)carried out on a parametric model and have presented their results for the unconventional airplane, one idea being projected for the subsequent generation of huge subsonic transports.

In scrutinizing the variances in geometry and Computational Fluid Dynamics results with the CAD and rapid models, it was distinguished that this practice was proposed for aerodynamic analysis at the conceptual phase of the design process .Mart.A.Potsdam et al. (1997) investigated on a novel aircraft configuration offering significant performance advantages over conventional transonic transport with the aim of designing an aerodynamically viable BWB configuration. The design recommended was highly integrated and offers performance improvements of significant proportions .N. Qin etal. (2004) carried out aerodynamic study of a unconventional configuration. It was an outline of numerous BWB airplane design projects in connection to their aerodynamic behavior. After a theoretical valuation of the ideal aerodynamic performance for the baseline configuration, viscous flow simulation were completed to examine the aerodynamic performance of the baseline design of 3D aerodynamic surface optimization of BWB has been carried out. In 2012, M. Zhang, A. Rizzi, P. Meng, R. Nangia, R. Amiree and O. Amoignon have worked on the optimization work for the transonic flying wing: the blended wing body transport. The work was then straight forward and easy to understand. It was recommended that engineer must be engaged in the design loop to attendant the course of the optimization work. The optimized results showed that it was converged towards the design goal. It showed that the results could be upgraded by familiarizing additional design parameters and more strict limits. C. Thomas A. Reist and David W. Zingg (2013) revealed that BWB signifies a potential revolution in effectual aircraft design. These drag declines were realized while both trimming and stabilizing the baseline design.

In 2015, Payam Dehpanah, Amir Nejat worked on the aerodynamic design evaluation of a BWB configuration .It was an underlying scaled BWB airframe utilizing computational investigates in early conceptual design stage. Then, a revised airframe was developed based on assessment of the initial airframe. In 2017Chunya Sun et al. worked on the shape optimization of BWB underwater glider by using gliding range as the optimization target.

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In 2018 Parviz MOHAMMAD ZADEH and Mohsen SAYADI worked on an efficient aerodynamic shape optimization of blended wing body UAV using multi-fidelity models. The work on conceptual design of a Blended Wing Body MALE UAV in 2018 by P. Panagiotou et al. was quite useful for the shape optimization study.

A BWB's lift-to-drag ratio is greater than the conventional airplane. The streamlined shape between fuselage and wing intersection reduces interference drag. By incorporating the functions of wing and fuselage, the Blended-Wing-Body accomplishes a clean aerodynamic and effective structural design that offers great potential for reduced fuel burn, weight, and cost .In the present study it is proposed to consider a candidate conventional commercial aircraft configuration and CFD analysis will be carried out on this candidate configuration by considering various flight conditions .In this project, a CFD analysis of a conventional aircraft was carried out using commercially available ANSYS® Fluent – a CFD solver. A basic BWB model was tested in subsonic wind tunnel to measure its aerodynamic efficiency. A comparison of the key parameters were made between the experiment and numerical simulation.After the necessary number of experiments were conducted and results were compiled it was proposed to compare the results with that of a B787 model using numerical method. So, a numerical simulation of a B787 model was done using RANS-solver only for comparison with BWB and B747.The results were analyzed and compared with the results of the same model tested in subsonic wind tunnel. The aerodynamic characteristics of the both methods (numerical and experimental) were plotted.

II. METHODOLOGY

A basic configuration of BWB (called as BWB1), shown in Fig.1, was initially made and aerodynamic characteristics were measured through wind tunnel simulation. The details of the configuration were mentioned above. The results of the wind tunnel were compared with the existing results of conventional aircraft such as a Boeing 747 aircraft. The key dimensions of all the models used in both the experiments and numerical simulations are summarized. The aspect ratio of both B747/B787 is almost 3 times of a BWB. The flow used for the testing of BWB was turbulent (above 10^5) in wind tunnel. The initial span and other dimensions of the basic BWB-1 were adopted, with certain assumptions as per capacity of the available equipment, for two reasons: (i) the wind tunnel test section maximum width is 600 mm and (ii) dimensions mentioned in the literature, Ref[22]. The Fig. 2 shows C_L versus AOA plots for 3 different Reynolds numbers of the flow past the BWB. The linearly proportional behavior of C_L with respect to AOA is observed from an AOA of -5° to 10° for all the 3 different Reynolds numbers with a 20% rise in C_L at 3.8E+05 at AOA 10° after the stalling began and C_L started dropping from each of the cases. Beyond the AOA =17°, C_L for these cases started picking up. The AOA chosen for the experiment varies between -5° and 20°. The variation of C_L for three different Reynolds numbers was not significant except between 8° and 15°.

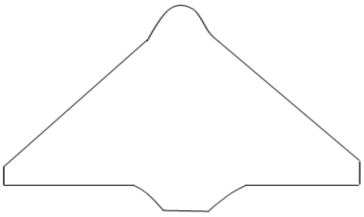


Fig. 1: A basic BWB configuration (BWB1)

III. RESULTS AND DISCUSSION

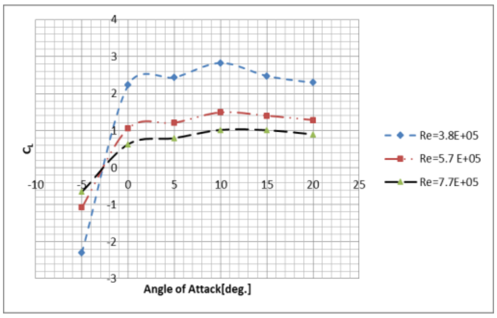


Fig. 2: C_L versus AOA for 3 different Reynolds numbers of the flow past BWB

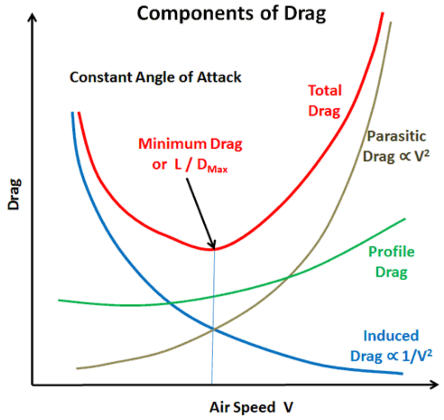


Fig.3(a) Drag and Speed variation

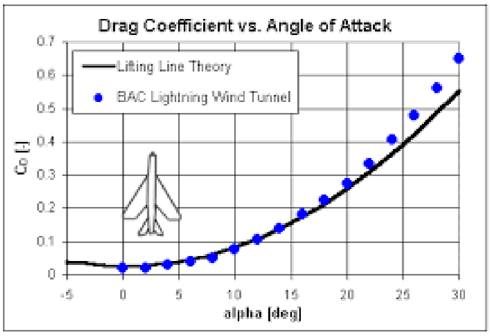


Fig.3(b) C_D versus AOA variation [Lifting Line Theory]

The Fig.3(a) is a theoretical graph which is presented here is to understand the variation of drag with AOA and Fig.3(b) is a classical example of drag variation taken from the literature to verify the experimental approach for both the measurement of lift and drag for BWB. From the Fig. 4 that shows the variation of C_D with AOA for 3 different Reynolds numbers, it is noted that total drag $(C_D)_{min}$ is the least at an AOA = -0.10^o.

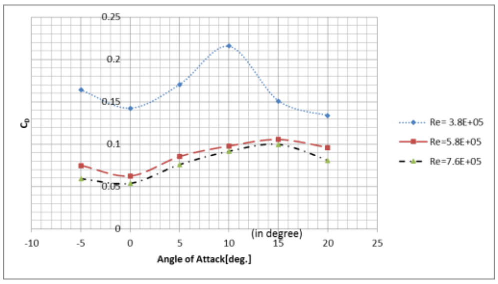


Fig. 4: C_D versus AOA for 3 different Reynolds numbers of the flow past BWB

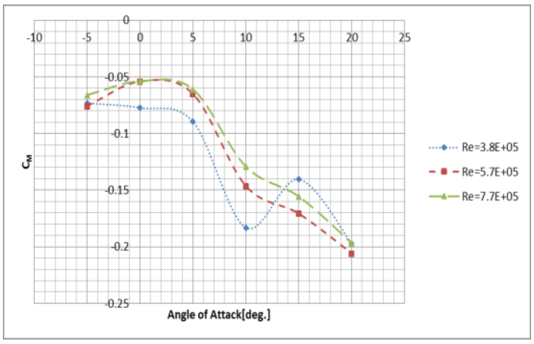


Fig. 5: C_M versus AOA for 3 different Reynolds numbers of the flow past BWB

From the Fig. 5 that shows the variation of C_M with AOA for 3 different Reynolds numbers, it is noted that total drag $(C_M)_{min}$ is observed AOA = 20^o for all three cases.

The basic BWB model (BWB1) will be reshaped after the optimization of its design parameter and then the results of the optimized shape of the BWB (called BWB2) will also be plotted to check if the parameters have made improvement in their values. The numerical simulation of the aerodynamics of the flow was attempted using the commercially available Ansys® Fluent through its Reynolds Averaged Navier-Stokes solver. The reason for doing the simulation on a Boeing 787 was to understand how an attempt in optimization in the shape of BWB has made sense in ascertaining an approach towards optimization of BWB(from its basic design) to qualify for a transport aircraft. Both the 747 (used for experiment) and 787 (used for numerical study but not presented in this paper) have remained as a strong evidence in commercial transport.

The motivation towards optimization came from the set of experiment with a basic shape of BWB. It is learnt for the past studies that most of the previous researchers' very first approach for shape optimization of a BWB has been a numerical one and then the same has be validated with a set of experimental activities or otherwise. The challenge, therefore, is time and accuracy of solving RANS equations [in an approximated method] and then validating it with a set of experiments. In the present research, the approach was simultaneous in nature. Instead of solving the flow past a basic BWB using a CFD solver and then validating it, the flow was experimentally solved (as well as validated) for its flow variables and aerodynamic efficiency parameter in a wind tunnel thus reducing the time to approach for its shape optimization. Experiments were conducted on a B747 aircraft model and results were reported below and afterwards the comparisons were made between the BWB1 and B747 model. In the Fig.6 is shown C_L versus AOA for 3 different Reynolds numbers of the flow past a Boeing 747.

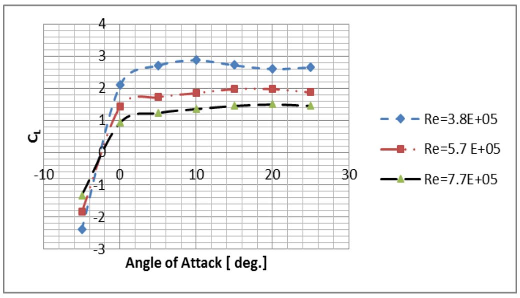


Fig. 6 : C_L versus AOA for 3 different Reynolds numbers of the flow past a Boeing 747

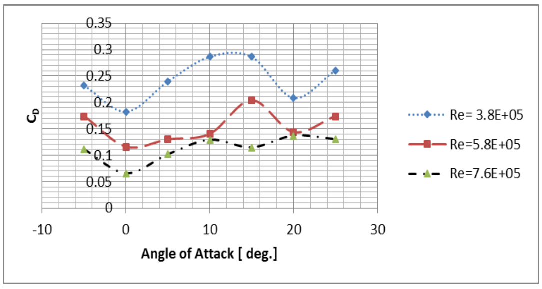


Fig. 7: C_D versus AOA for 3 different Reynolds numbers of the flow past a Boeing 747

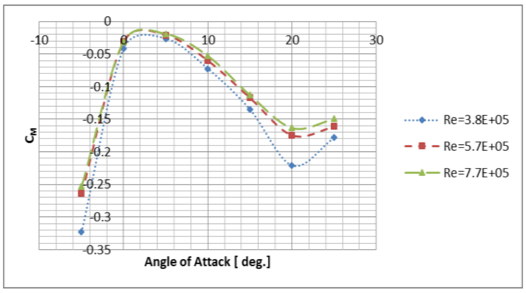


Fig. 8: C_M versus AOA for 3 different Reynolds numbers of the flow past a Boeing 747

The stall is observed at AOA=20^o and the value of $(C_L)_{max}$ is 2.8 for Re=3.8E+05 , the $(C_D)_{min}$ occurs at AOA=0^o as shown in the Fig. 7 and pitching moment is positive [

Fig.8] in the range of AOA from -1^o to 10^o [that means the nose-up pitching is noted during experiment for all three Reynolds numbers) and negative C_M is observed in other AOA range . The variation of C_M indicates that static stability for B747 is significantly to be maintained during the flight.

Comparison between BWB1 (Baseline Model) along with a conventional aircraft (B747)

A comparison was made between the basic design of BWB and B747 at a specific number to ascertain whose aerodynamic efficiency parameters are better. From the Fig. 11 it is observed that, for the same range of AOA, the value of $(C_L)_{maximum}$ for BWB varies within 30-40 % higher that of a B747 and $(C_D)_{minimum}$ is achieved at AOA=0^o as shown in the Fig. 12 and the variation of C_M for a BWB is the least [mostly negative and 10%] thus rending it to be more stable [Fig. 13].The Fig.10 shows a comparison of L/D versus AOA, Fig.11 depicts a comparison of C_L versus AOA and Fig. 12 contains the plot of C_D versus AOA for BWB and a B747 at Re=3.8E+05. L/D ratio for the BWB (baseline design) is close to 40% up from the L/D ratio of B747/B787 and $(C_D)_{min}$ of BWB is 18% lower than that of B747/B787.

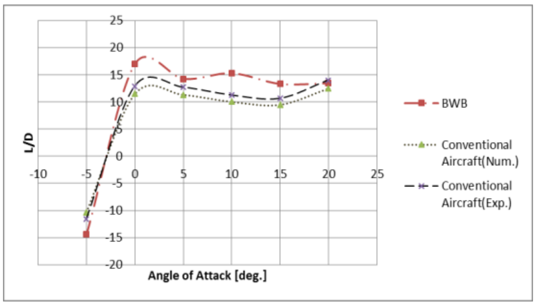


Fig. 10: Comparison of L/D versus AOA for BWB1 and a B747 at Re=3.8E+05

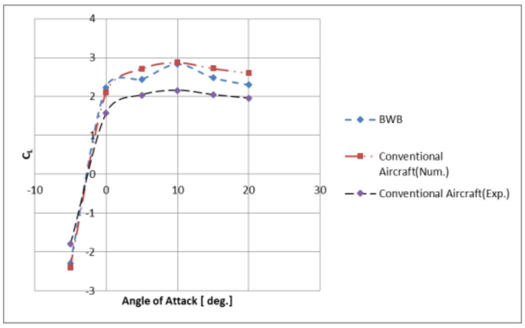


Fig. 11: Comparison of C_L versus AOA for BWB1 and a B747 at a Re=3.8E+05

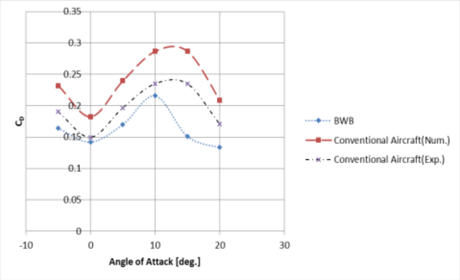


Fig. 12: Comparison of C_D versus AOA for BWB1 and a B747 at Re=3.8E+05

The Drag and Speed plot shown in the Fig. 13 is fundamentally matching with theoretical drag plot shown in Fig. 3(a). Similarly the nature of the plot of C_D versus AOA shown in the Fig. 4 is fairly matching with the fundamental variation of C_D with AOA as shown in Fig. 3(b). The Fig. 13 shows the variation of drag with air speed for models such as BWB1 and two conventional aircrafts, B747 and B787.

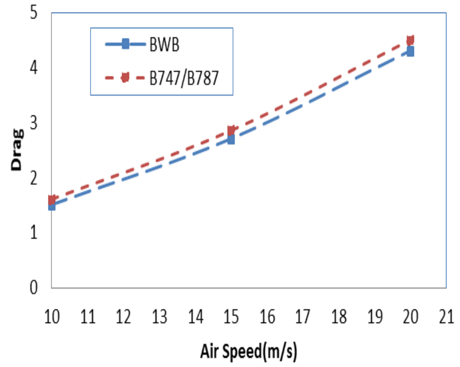
Table 1: (a) Summary of Comparison of BWB with Conventional Configuration (Experimental)

Models	Lift/ Drag $(L/D)_{max}$	$(C_L)_{max}$	$(C_D)_{min}$	% improvement in L/D ratio	% improvement in $(C_L)_{max}$	% improvement in $(C_D)_{min}$
BWB1 (Baseline Model)	18	2.8	0.14	38%	21%	26%
Experimental (conventional)	11	2.2	0.19			

(b) Summary of Comparison of BWB with Conventional Configuration (Computational)

Models	Lift /Drag $(L/D)_{max}$	$(C_L)_{max}$	$(C_D)_{min}$	% improvement in L/D ratio	% improvement in $(C_L)_{max}$	% improvement in $(C_D)_{min}$
BWB1 (Baseline Model)	18	2.6	0.15	33%	20%	23%
Computational (conventional)	12	2.6	0.22			

The plot demonstrates that the most of the drag gets developed due to the shape of aircraft, its skin friction and certain interference of flows when the aircraft moves through the fluid. Hence total drag is predominately parasitic in nature which increases with flight speed (or air speed). It is also noted that the BWB shows the least drag value that is 40% lesser at air speed of 10 m/s and 50% lesser at airspeed of 20 m/s when the comparison is made between BWB and conventional aircrafts (B747 and B787).



The **Table 1** summarizes a comparison of the important design parameter, findings from optimization and the aerodynamic efficiency parameters for the BWB before the optimization. The **Table 1 (a) and (b)** summarizes a comparison of the aerodynamic performance parameter, i.e. the aerodynamic efficiency parameters comparison of the BWB with Computational and Experimental results of conventional aircraft configuration.

IV.CONCLUSION

In the present research work it has been analyzed through Computational Fluid Dynamics and Experiments. The C_L, C_D, C_M and L/D ratio of a conventional aircraft model (Boeing 747) was compared with that of the baseline configuration BWB to understand the need to optimize the shapes. The Lift to Drag ratio increases by 38% when compared with conventional aircraft model (Experimental) and similarly the $(C_L)_{Max}$ also increases with decrease in $(C_D)_{Min}$ .The Lift to Drag ratio increases by 33% when compared with conventional aircraft model (Computational) and similarly the $(C_L)_{Max}$ also increases with decrease in $(C_D)_{Min}$ .Further improvement in optimization study over BWB (Baseline Configuration) is under process, the optimized configuration experimental investigation is also planned for the betterment in the aerodynamics performance characteristics

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