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Flow Analysis of Blended Wing Body (BWB) Using CFD Technique

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Abstract—*Blended wing body (BWB), as the name suggests has a combined body comprising both the wings and the body of the aircraft, unlike conventional configurations where wings are attached to the fuselage and is a separate entity in the aircraft's structure. The advantages of such configuration vary from reduction of drag, high lift coefficient of overall body to enhanced fuel efficiency, more seating capacity as well as less space being occupied at the airport. The problems currently being faced regarding BWB design is that it is not feasible for manufacturing due to the limiting constraints of structures, aero-structural integration, issues pertaining to pressurizing of the cabin, as well as the large frontal area of the wing that would in turn increase the drag coefficient.*
To overcome the aeromechanical issues the flow analysis over the BWB is done. The geometry developed on trial and error and by trying to keep it as close as possible to the real design from the public literature survey. To get an accurate geometry, co-ordinates were stored in an excel sheet, and the 2-D geometry was created using ANSYS Workbench 14.0 after importing the points from the excel sheet. This was followed by meshing, and flow analysis was carried out in FLUENT 14.0 for the given set of suitable boundary conditions. The results obtained are quite expected and it can be safely said that they comply with the theoretical standards. A smooth, uniform and detached shock wave is obtained in front of the BWB body. The contours obtained clearly show the changes in the flow regime around the BWB body for good aeromechanical features.

Keywords: *BWB, FLUENT, Mach, Analysis.*

1. INTRODUCTION

BWB- Blended Wing Body is the configuration of the aircraft in which the wing is not a separate body attached to the fuselage as in conventional aircrafts, which have "tube-wing" configuration, instead the fuselage and the wings comprise a single entity thus nullifying the "interference drag" – the drag which is caused when two separate bodies are combined together.

BWB is a revolutionary concept and probably the future of aviation because of certain reasons. First is the reduction of drag coefficient of the entire aircraft because, in the conventional configurations, fuselage contributes to very less lift and as a major source of drag. In BWB, the overall body will provide high lift coefficient and minimal drag. Second, reduced surface area again contributes to less drag and also it will reduce the space occupied at the airport, thus minimizing the problems like congestion etc. Third is the increased seating capacity due to uniform distribution of seats and payload over the entire aircraft surface. And last, enhanced fuel efficiency due to reduction in weight of the aircraft.

At present, BWB is facing certain problems pertaining to the design itself. The feasibility of the BWB to replace the present fleet of aircrafts is quite less because of the difficulties faced in the manufacturing of such design due to limiting constraints of the structure, reduced stability and control due to absence of tail surfaces, issues such as pressurization of cabin and limiting the drag due to large frontal area to accommodate the engine in the wing-body.

2. COLLECTED WORKS ON BWB AIRCRAFT

Aerodynamically, BWB is much better than conventional aircrafts as it has at least 20% more "lift to drag ratio" because of a single body creating uniform lift and no other surfaces attached to the body, thus reducing the drag considerably [1,2]. The BWB has been tested so far for the transonic conditions, for M= 0.9 and the conclusions have been made on that basis. We have tried to improvise by doing the flow analysis for supersonic conditions, say M=2 and 3 and we made certain conclusions pertaining to the results obtained which adhere to the theoretical standards [3, 4].

Few papers have been collected and literature survey has been done by studying the papers. Blended Wing Body (BWB) aircraft does not have a clear distinction between the body and wing. The aircraft body system is combination of distinct and separate wing structural parts. In general the BWB wings are smoothly blended into the main body. Such configurations of aircraft have an aero foil like cross section along the span of the body, giving an optimum lift, and the blended wings contribute to the balance. Main advantages of the BWB are efficient high lift wing and wide wing airfoil designed body. This gives maximum lift generation also resulting in enhanced fuel efficiency and range [5, 6]. A BWB can have about 50 percent higher maximum lift to drag ratio than any other conventional aircraft. Considering these factors as motivation, the results and methodology of flow analysis over the Blended

Wing Body (BWB) has been explained in this paper. The results obtained were convincing enough and were in accordance to the existing BWB research literature.

3. COMPUTATIONAL FLUID DYNAMICS

The transportation of fluid from one component to other in power/process equipment is described through mass, momentum and energy conservation principles. The Navier Stokes (transport) equations are derived from these principles and are discussed by Hoffman, K.A [1993] which are represented mathematically as-

$$\frac{\partial \rho\varphi}{\partial t} + div(\rho\varphi\vec{u}) = div(\Gamma grad\varphi) + q_{\varphi} \qquad 1$$

The terms on Left Hand Side (LHS) define acceleration of flow over time, while inertia depends on the sum of the external forces, diffusion and sources acting on the fluid element. If the value of φ is 1, the eqn. (1) results in continuity equation. If the value of φ is either u or v or w, the above eqn. describes momentum equation in x, y, z directions. If the value of φ is h then the above eqn. yields to energy equation.

In order to resolve wide spectrum of scales in turbulent eddies, normally two approaches are employed. This requires dense mesh points for proper resolution and its solution depends on heavy computational resources that are expensive, time consuming process and therefore very rarely used simulation technique. The other approach generally used for most of the applications are Reynolds' averaging process wherein flow variables are decomposed into mean and fluctuating components as

$$u_i = \bar{u}_i + u_i' \qquad 2$$

Where, i=1, 2, 3 denotes in x, y, z direction [7]. Likewise the pressure and other scalars can be expressed as

$$\phi = \bar{\varphi} + \phi' \qquad 3$$

Substituting flow variables in this form into the instantaneous continuity and momentum equations and taking a time (or ensemble) average (and dropping the over bar on the mean velocity) yields to

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \qquad 4$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} - \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{i,j}\frac{\partial u_l}{\partial x_l}\right)\right] + \frac{\partial}{\partial x_j}\left(-\overline{\rho u_i' u_j'}\right) \qquad 5$$

Eqn. (4-5) are called RANS equations. The term $\overline{\rho u_i' u_j'}$ in the eqn. (4.5) results from averaging process and is called Reynolds' Stress. With the help of Boussinesq hypothesis to relate the Reynolds stresses, choosing Kronecker delta δ=1 if $i=j$ and $\overline{u_i' u_i'} = 2k$ the Reynolds's stress term in the eqn. (5) is rewritten as -

$$-\overline{\rho u_i' u_i'} = \mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\left(\rho k + \mu_t\frac{\partial u_k}{\partial x_k}\right)\delta_{i,j} \qquad 6$$

Where, μ_t is turbulent viscosity. To resolve turbulence viscosity and Reynolds' stresses, eddy viscosity models based on Boussinesq hypothesis will leads to zero, one and two equation turbulence models and Reynolds's Stress Models (RSM). The strength and weakness of these models for prediction of turbulence effects are extensively studied.

4. METHODOLOGY

Using the trial and error based method the coordinates have been created in the ANSYS workbench. These values, we created for the desired BWB model, domain and mesh it. The lower part of the BWB is same for entire analysis, be it First deg/Second deg/Third deg/ Fourth deg surface model. The finer the mesh is, the more exact is the result we achieve. As this paper is on surface flow analysis, we impregnated the mesh more on the surface part than in other areas of the domain. Few areas were tried out in the process and a couple of them were created to be appropriate for the paper. The end product of the design in Workbench is transferred to FLUENT. Consequences are captured for Mach number, pressure and temperature. The effectiveness and performance of the models are discussed based on Compression efficiency and temperature ratio. The model in this paper is a 2-D model shown from Fig. 1 to 3.

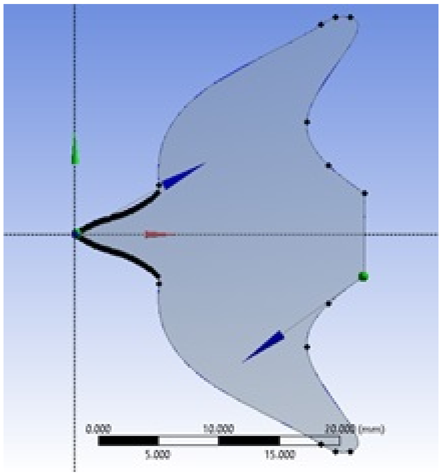

Fig. 1: BWB body surface in Workbench

In workbench the key thing to study is meshing. The meshing was smoothened near the surface of the aircraft as compared to the rest of the domain. For generating the BWB model, the Analysis results have matched well with the theoretical results, as shown in figures from Fig. 4 to 10

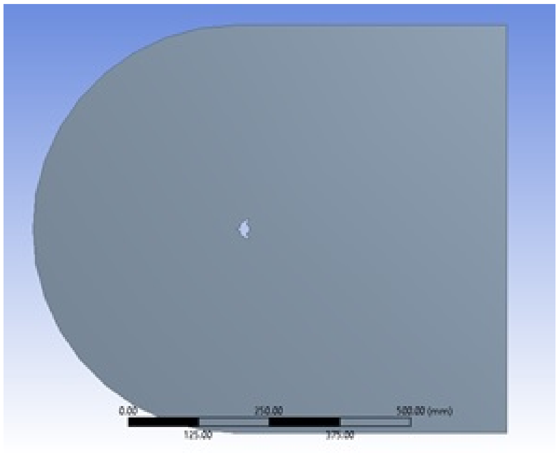

Fig. 2: Far-field around the BWB surface.

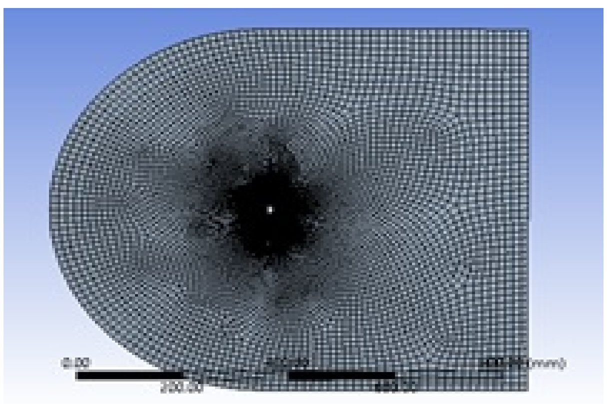

Fig. 3: Meshing on BWB surface

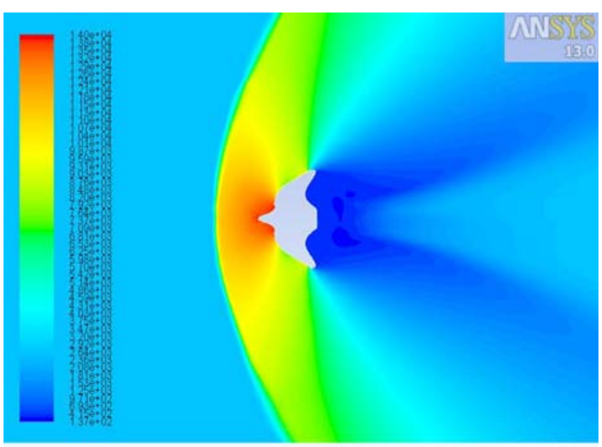

Fig. 4: Static Pressure on BWB surface

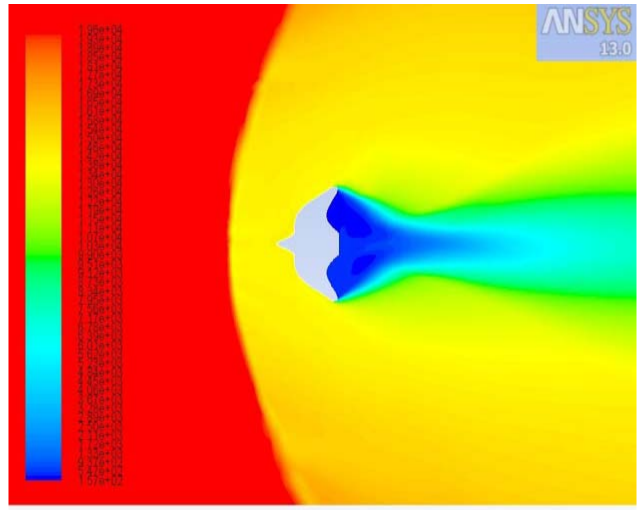

Fig. 5: Total Pressure on BWB surface

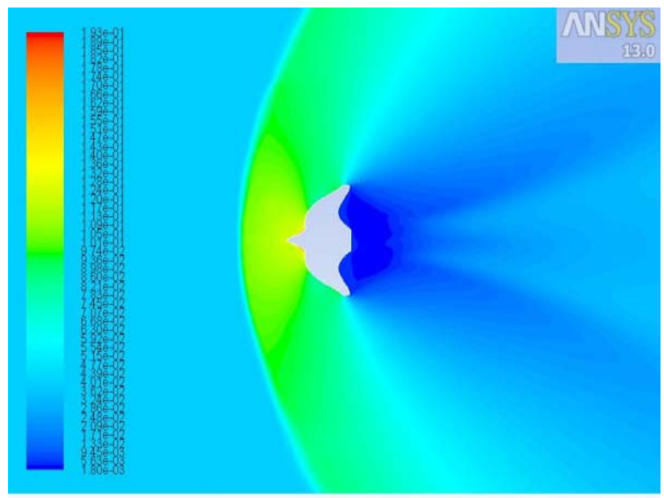

Fig. 6: Density on BWB surface

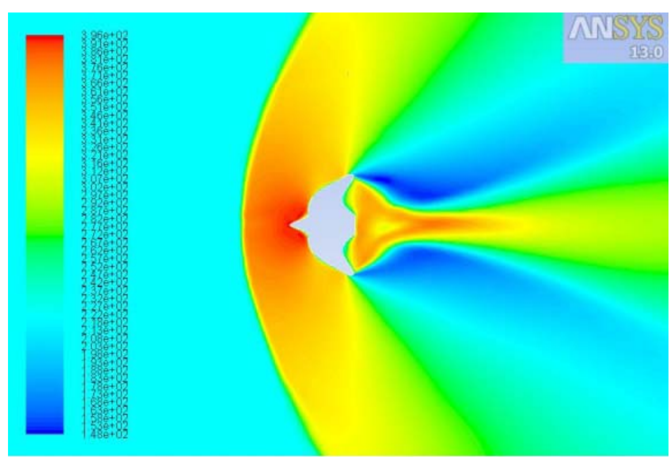

Fig. 7: Static Temperature on BWB surface

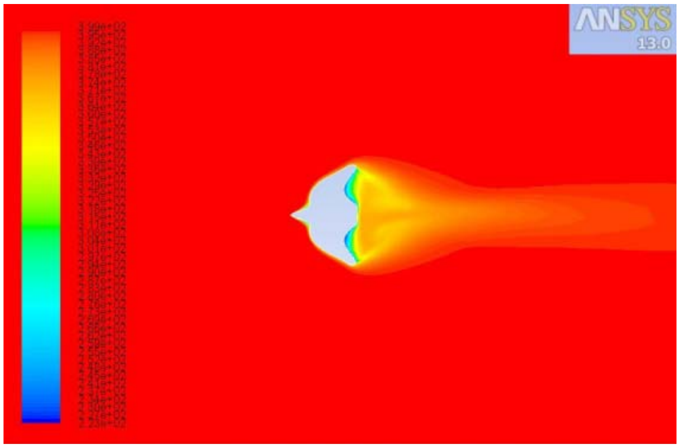

Fig. 8: Total Temperature on BWB surface

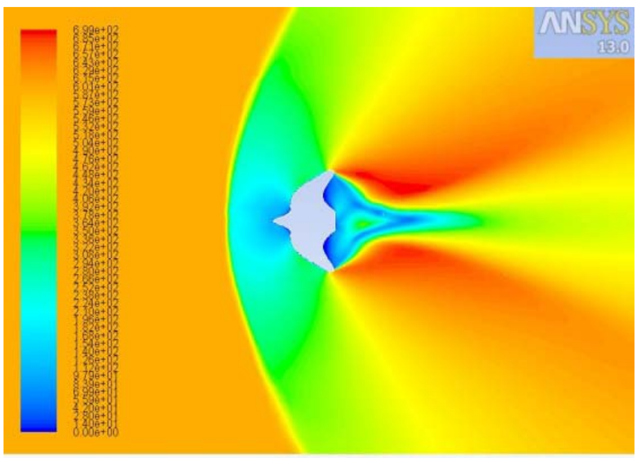

Fig. 9: Velocity magnitude on BWB surface

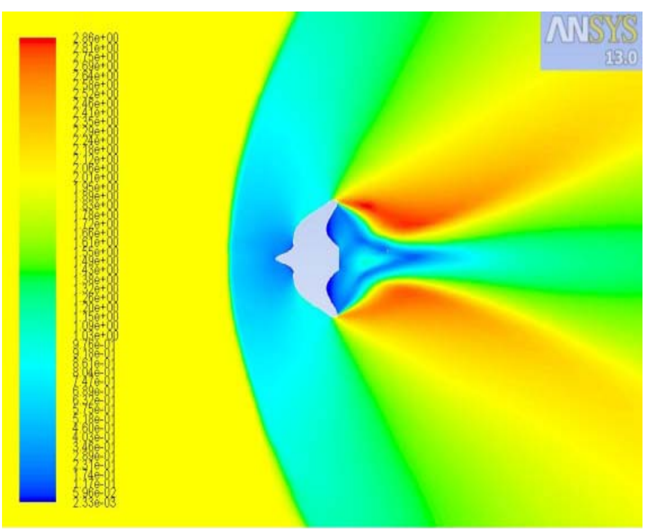

Fig. 10: Mach number on BWB surface

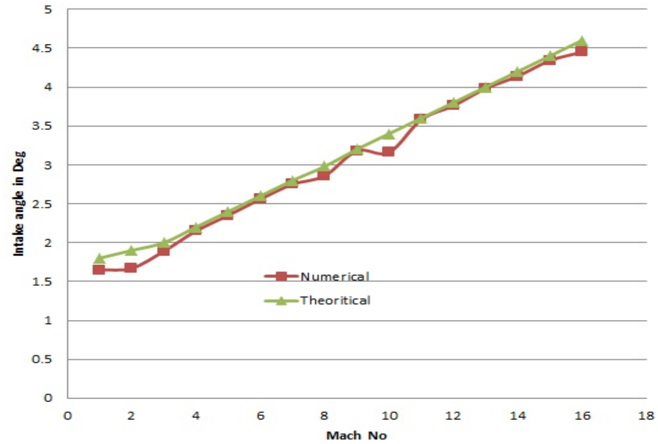

Fig. 11: Comparison results

5. RESULTS AND DISCUSSIONS

The contour obtained for static pressure shows the variation of static pressure across the shock wave. For M=2, supersonic boundary conditions the shock obtained in front of the body is a detached shockwave, with pressure increasing just behind the shockwave and the maximum value obtained at the nose of BWB.

For M=2, the value of the total pressure is maximum before the shock wave and then the value reduces. There is uniformity in the variation in both the front and aft region of the shock wave except behind the BWB body, where the value is minimum which is an indication of flow separation.

The density value is low before the shock wave and it increases behind the shock wave. The maximum value is at the surface of the nose tip of BWB. The value subsequently reduces as we approach the rear of the BWB. The minimum value is obtained behind the BWB, indicative of flow separation.

The static temperature value increases as we proceed towards behind the shockwave, with the maximum value attained at the nose region of BWB with subsequent reduction in the value as we reach the end of BWB body. At the trailing edge of the BWB, where flow separation occurs, there is a low value at the boundary of BWB, and quite high value aft of BWB. The least value is obtained in the lateral axis direction adjacent to the flow separation region.

The total temperature value is uniform across the entire region except for the aft of BWB, where the minimum value is at the rear surface of BWB over a very thin region with the value suddenly increasing for a given region and after that region of maximum value is obtained.

The velocity magnitude reduces as we proceed from front to behind the shockwave. The value further reduces in the nose region, with the minimum value obtained at the nose and the rear surface of BWB. There is an increment in the value adjoining the flow separation region in the direction away from BWB body with quite low value for a region behind the BWB body.

The Mach number reduces drastically across the shock wave, with some variation at the boundary layer of the shock wave in the aft region. The value further reduces in the nose region, with the minimum value obtained at the nose and the rear surface of BWB. There is an increment in the value adjoining the flow separation region in the direction away from BWB body with quite low value for a region behind the BWB body.

6. CONCLUSION

After successful completion of the flow analysis over the surface of BWB aircraft all performance parameters were identified clearly with front bow shock. The free stream was observed with strong bow shock at entry of the BWB. Thus the aerodynamic drag which reduces at the rear portion is more because of the high interaction of air molecules. However, the temperature distribution limit also exists but not in off-design values. The theoretical and Numerical simulation is also showing an approximately better performance match. The complete analysis will emphasize the future development and optimization of BWB in both aero mechanical features in advanced air breathing engines.

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