

Numerical Study of Aerodynamic Characteristics on Blended Wing Body Aircraft with Small Canard

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ABSTRACT

The blended wing body (BWB) aircraft has a unique design. The main body and wing of BWB are merged to increase the lift force on the aircraft. However, BWB has poor stability arising from the absence of the tail. Hence, a small horizontal stabilizer called as canard has been incorporated in front of the main wing to improve BWB's stability. Computational Fluid Dynamics (CFD) simulations conducted to obtain the aerodynamics parameters of the BWB i.e. lift, drag and moment coefficients, showed that overall, the canard is beneficial to the BWB aerodynamics performance.

Keywords: Aerodynamics, blended wing body (BWB), canard, Computational Fluid Dynamics (CFD)

INTRODUCTION

The blended wing body (BWB) is specifically designed to meet the objectives of greater internal volume, aerodynamics and structural efficiency, noise reduction and significant improvement on cost-per-seat-mile (Ordoukhanian & Madni, 2014). The numerical study on the canard is difficult due to the need to identify, re-design and model the viscous flow area. The fluid flow over a BWB aircraft complicated by the rounded trailing edge and canard surfaces.

Many researches in numerical study examine the possibility of using Navier-Stokes equations to predict the aerodynamics characteristics of BWB or an aircraft with

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canard at best developed an unsteady three-dimensional Navier-Stokes analysis for circulation control wing (CCW) configurations. The solver can be used in a 2-D and a 3-D mode, and thus model air foils as well as finite wings. The Spalart Almaras, one-equation turbulence model was used by Mamat et al. (2011) to calculate the flow around the BWB aircraft model. The data obtained from the study confirmed the experimental result. Nangia et al. (2006) investigates the design of conventional and unconventional wings with winglet. The BWB research team from Universiti Teknologi MARA (UiTM) had studied BWB incorporated with canard since 2005.

The canard is a small wing located in front of the main wing and used as a longitudinal stabilizer and increase lift (Nasir et al., 2010). A CFD simulations and wind tunnel experiment on the BWB aircraft by Wisnoe et al. (2010), Reduan et al. (2010) and Mohamad et al. (2010) found that higher stall angle and maximum lift to drag (L/D) ratio is observed on BWB-Baseline II. However, in computational fluid dynamic CFD study by Nasir et al. (2011) show small differences of aerodynamic parameters between CFD and wind tunnel experiment at the linear lift region. To simulate flight conditions beyond the linear lift region, different turbulence model is proposed by Nasir et al. (2011).

The study of BWB with a small rectangular canard using CFD at Mach number 0.1 was studied by Ali (2012). The differences from the maximum lift coefficient, C_{Lmax} between CFD and wind tunnel is small (9%). Adding the canard surface at certain setting angle will increase the moment at zero lift, C_{M0} . This paper will extend the findings of previous studies by investigating the canard-setting angle to the aerodynamics of BWB subjected to variation canard setting angles.

METHOD

Numerical Methods

The geometry in this study (Figure 1) is based on the wind tunnel model (one-sixth scaled from the real BWB configuration). Two lifting bodies (wings and body) are blended together to form the BWB geometry. As BWB is symmetrical where only half body is generated, thereby saving computer memory space as well as time spent on modelling and simulation.

The rectangular canard is attached to the wing-body and acts as a horizontal stabilizer. The canard's aspect ratio, ($AR = \text{span wise}/\text{chord}$) was designed, and incorporated to the wing body. The ratio of canard size area, S_c to wing-body area, S is 13.6 % (0.005 m^2), following the same canard size used in Nasir et.al (2010). Theoretically, the higher aspect ratio, the slimmer and thinner the body will be. The canard is a control canard, so it is free to rotate. The deflected canard rotates about the span wise axis at the 1/4 of the canard's chord. Canard deflection angles δ are calculated relative to the wing-body axis, with positive δ indicates a canard is pitching upwards and negative δ is pitching downward as shown in Figure 2.

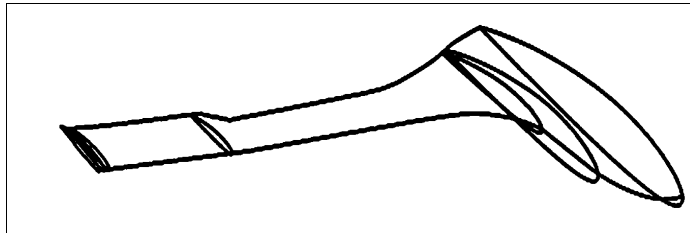


Figure 1. BWB-Baseline layout

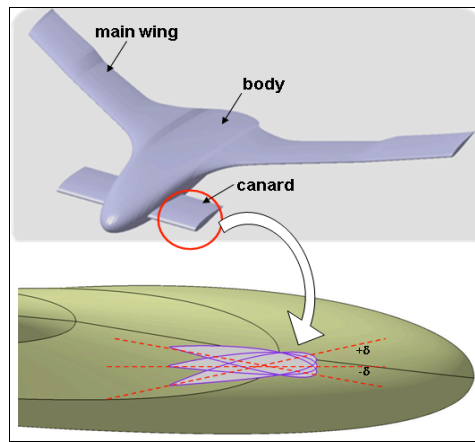


Figure 2. Sign convention for canard deflection

The centreline plane was modelled as a symmetry plane and the BWB surface as a solid wall with no slip condition. The symmetrical plane for flow domain and BWB half body is coincide. The distribution of all flow variables needs to be specified at inlet boundaries. The incoming and outgoing flow was set as an inlet and outlet. The BWB described as a wall are located at 0.468 m from inlet boundary, respectively.

The domain bounded by BWB is covered using mesh or grid. Mesh was used to convert the partial differential equations into algebraic equation. The advantage of unstructured mesh is its flexibility in handling complex geometries. In this grid generator, three-dimensional (3D) unstructured hexahedral meshes was used to compute flow around the aircraft configuration. The finer mesh was created near the aircraft model, to ensure the accuracy of the results.

In a mathematical model, turbulence-Navier Stokes flow model was selected as a flow model, which means the turbulence was taken into account through a turbulence models such as; Spalart Allmaras, extended wall function $k-\epsilon$, $k-\omega$ and many more. Turbulence is generated above a critical Reynolds number that may range in values from 400 to 2000 depending on the specific case. In the current work, the Spalart-Allmaras (SA), one equation model was selected due to the low Reynolds number, 3×10^5 . The advantage of this model is its robustness and the lower CPU and memory usage. Besides, the SA turbulent model has also been successfully

implemented in previous BWB aircraft analysis. The reference length was 0.114 m, taken from mean aerodynamic chord (MAC). The turbulent eddy viscosity μ_t is equal to $\rho\nu_t$, and ν_t state by Liu (2003) is given by:

$$\nu_t = \tilde{\nu} f_{v1}, f_{v1} = \frac{1-\chi^3}{\chi^3 + c_{v1}^3}, \chi = \frac{\tilde{\nu}}{\nu} \quad [1]$$

Where ν is the molecular viscosity. The working variable, $\tilde{\nu}$, is governed by the transport equation.

$$\frac{D\tilde{\nu}}{Dt} = c_{D1}(1 - f_{t2})\tilde{S}\tilde{\nu} + \frac{1}{\sigma}[\nabla \cdot ((\nu + \tilde{\nu})\nabla\tilde{\nu} + c_{b2}(\nabla\tilde{\nu})^2)] + [c_{w1}f_w - \frac{c_{b1}}{K^2} f_{t2}][\frac{\tilde{\nu}}{d}]^2 + f_{t1}\Delta U^2 \quad [2]$$

Here, $\tilde{S} = S + \frac{\tilde{\nu}}{K^2 d^2} f_{v2}, f_{v2} = 1 - \frac{\chi}{1-\chi f_{v1}}$

S is a magnitude of the vortices and d is distance to the closest wall.

At the inlet the incoming velocity to the domain is specified at 35 m/s and static temperature of 273 K. The BWB model is set as a solid wall for forces and torque calculation (the lift, drag and moment).

RESULTS AND DISCUSSION

Parameter Validation

Parameter validation is an approach to estimating the reliability of the software in predicting the aerodynamics loads of this study, and set as a benchmark for the CFD results. The lift coefficient of the airfoil profile, NACA 2415 was derived using CFD software NUMECA. Figure 3 illustrates the comparison between CFD and our experiment.

Data is based on the same Reynolds number. As the angles of attack increase, the lift too increases. The trend is all the same. The only noted difference is at higher angles of attack, the differences between the CFD and wind tunnel result was large. However, this can be neglected due to the fact that the case of the study are only limited between -10 to 10 degrees angles of attack.

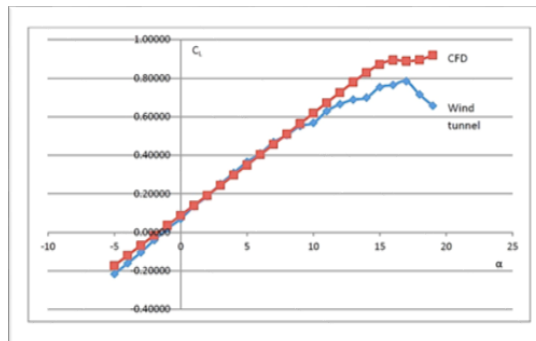


Figure 3. Lift coefficient versus angles of attack (CFD and experimental)

Lift Coefficient

The BWB lift coefficient with respect to angles of attack for various canards' aspect ratio, the AR predicted by CFD is shown in Figure 4. By adding the canard surface on the BWB the lift gradient specifically at low angles of attack is observed. The increase of lift is proportional to higher canard aspect ratio. However, in Figure 5, the result is contrary where all the canards were stall at higher angles of attack. Due to the fact that the canard surface stalled at angles of attack lower than that for wing-body stall, these results, however, do not come as a surprise. This study shows that the main lift contributor comes from the body and wing and that the canard's contribution of lift enhancement to the BWB is not significant due to its size.

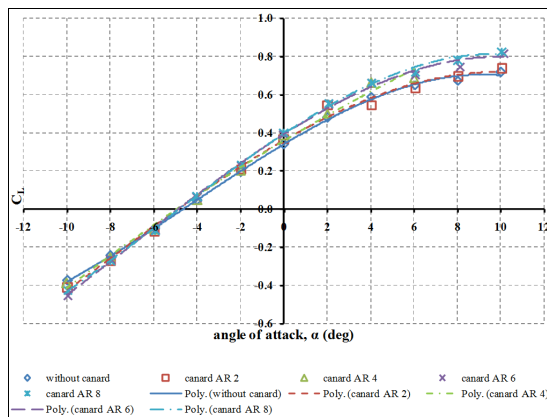


Figure 4. Lift curves of BWB at setting angles, $\delta = 5^\circ$

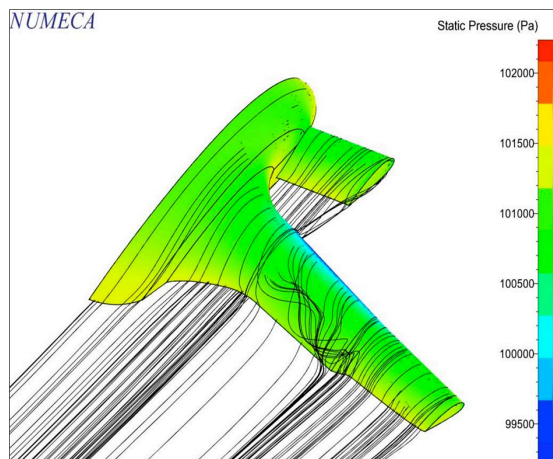


Figure 5. BWB with canard AR 2 at $\alpha = 4^\circ$, $\delta = 0^\circ$

Lift to Drag Coefficient

The lift-to-drag ratio i.e. L/D versus angles of attack α , is shown in Figure 6. A higher L/D means better flight performance, where the drag of aircraft decreases as L/D is increased. In an airplane, T_R is generated to overcome drag and maintain the flight condition. The L/D curves show that as angles of attack increase L/D increases. The point where α reaches the maximum L/D is denoted as $\alpha_{(L/D) \max}$. With L/D a function of α , lift and drag coefficient is also a function of α . The BWB without canard has the maximum lift-to-drag ratio while with canard the maximum L/D of the BWB decreases. The BWB with canard AR 2 and 4 have maximum L/D compared to situations when the canard-setting angle is not deflected. Depending on the canard aspect ratio, the L/D reduces when the setting angle of the canard is increased.

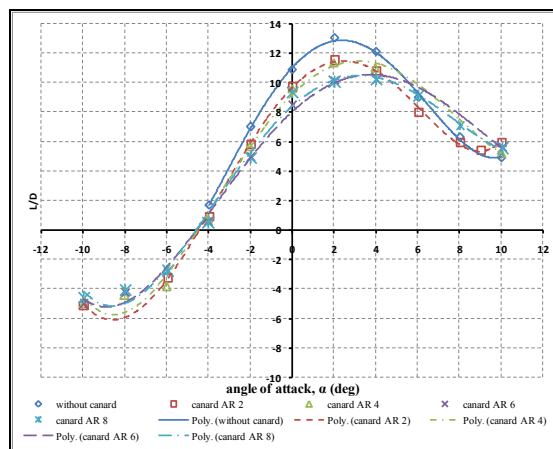


Figure 6. Lift- to-Drag curves of BWB with different canard aspect ratio at setting angles, $\delta = 5^\circ$

Moment Coefficient

The essential criteria that qualifies an aircraft to be statically stable during flight is the pitching moment curve must have a negative slope. By convention, negative moment refers to moment that causes the aircraft nose down, while positive moment gives opposite effect. The pitching moment at zero lift, C_{M0} must be positive. Figure 7, Figure 8 and Figure 9 show the pitching moments C_{Mref} versus angles of attack, α and C_{Mref} versus coefficient of lift, C_L measured from 19.8 % from mean aerodynamic chord, MAC. The overall trend is similar, where the pitching moment is reduced when the angles of attack and lift increases. Although there are many advantages of BWB configurations for examples lighter, high lift-to-drag ratio, and lower fuel burn, this kind of aircraft is technically unstable. The absence of horizontal tail causes the BWB aircraft to have no longitudinal control, and therefore always tends to diverge from the equilibrium position when disturbed. To correct this behaviour the BWB is usually incorporated with elevons or canard. In the present study, the canard is used to produce positive lift, hence, creating a clockwise moment about the centre gravity. If this moment is strong enough, C_{M0}

for the BWB configuration is positive and balance maintained. The graph below shows by adding canard can lead $C_{M\alpha}$ to change dramatically and moment at zero angle of attack, $C_{M,\alpha=0}$ to increase.

Canard shows a significant effect with the moment coefficient of the BWB. Increasing the canard setting angles increases the trimmed angles of attack and moment at zero lift. The result shows that the BWB with the canard fulfils the static stability criteria, and that the BWB with canard AR 6 and 8 are the most effective ones.

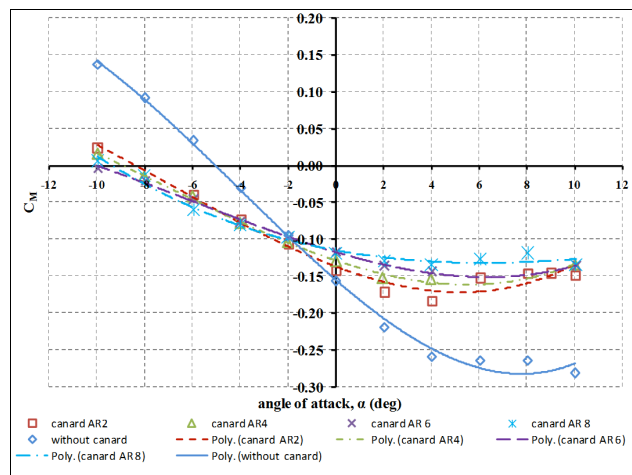


Figure 7. Moment coefficient, $\delta = 0^\circ$

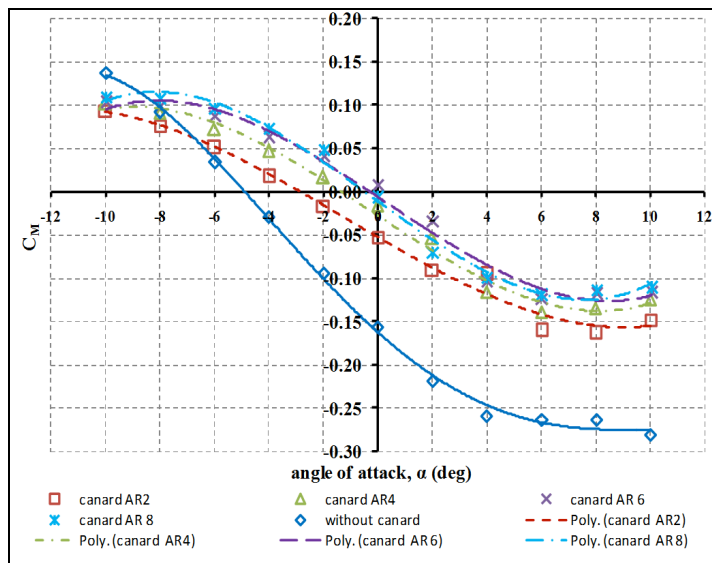


Figure 8. Moment coefficient $\delta = 5^\circ$

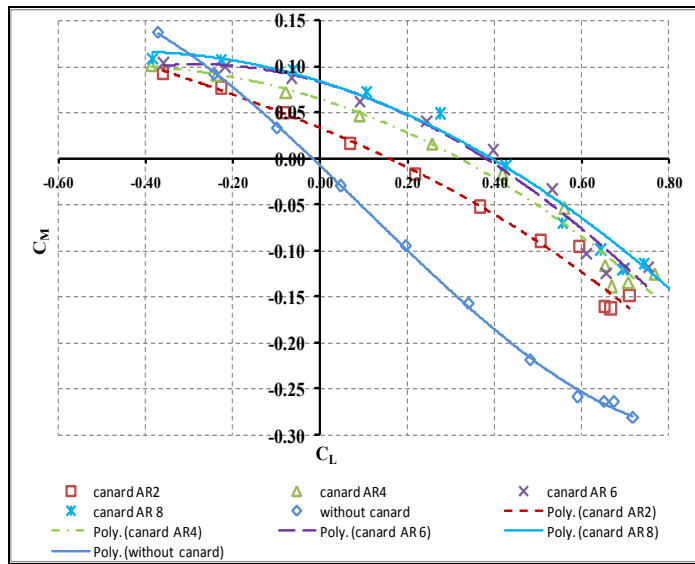


Figure 9. Moment coefficient, $\delta = 10^\circ$

CONCLUSION

A new control surface consisting of a canard located at the front of the major wing of the BWB was studied. It involves the determination of aerodynamics characteristic (C_L , L/D and C_M) of BWB incorporated with the canard. A summary of major findings of this research are:

- i. It is found that BWB has an optimum lift, drag and moment coefficient at lower angles of attack and canard setting angles. The differences of the aerodynamics coefficients between canards aspect ratio are small;
- ii. The canard with aspect ratio 6 and 8 have a significant effect towards the moment coefficient of the aircraft configuration where it improves the trim angle and moment at zero lift. The trim angle is shifted toward the positive angles of attack and moment at zero lift is increases;
- iii. The pitching moment is improved when the canard is deflected to a higher canard setting angles ($\delta = 10^\circ$).

The result shows that these configurations can improve pitching moment of BWB.

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