International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:7, No:5, 2013

The Effect of Canard Configurations to the Aerodynamics of the Blended Wing Body

Zurriati Mohd Ali, Wahyu Kuntjoro, and Wirachman Wisnoe

***Abstract*—**The aerodynamics characteristics of a blended-wing body (BWB) aircraft were obtained in Universiti Teknologi MARA low speed wind tunnel. The scaled-down of BWB model consisted of a canard as its horizontal stabilizer. There were four canards with different aspect ratio used in the experiments. Canard setting angles were varied from -20° to 20°. All tests were conducted at velocity of 35 m/s, with Mach number 0.1. At low angles of attacks, the increment of lift slope for various canards' aspect ratio is small and almost constant. Higher canard aspect ratio will cause higher drag. However, canard has a high effect to the moment at zero lift, $C_{M,0}$. The visualization using mini tuff was performed to observe the airflow at the upper surface of canard.

***Keywords*—**Aerodynamics,blended-wing body, canard, wind tunnel.

I. Introduction

CANARD is a secondary wing which is located in front of the main wing. It is used as a horizontal stabilizer, controlling the longitudinal movement of an aircraft. From aerodynamic point of view canard is added to increase the maximum lift and flow control over a main wing. For the stability and control ability, canard is often used when the reduction of static margin and pitch control trimming is required.

The effect of canard to the aircraft/wing-body has been studied by many researchers. Tu [1] carried out a numerical study on the effect of canard deflection and canard-wing vortex interaction. The canard aspect ratio that has been used is 4.12, with Mach numbers of 0.85 and 0.9. The lift is increases from -0.07 to 0.24 when canard is deflected from -10° to 10°, at α =4.27°. The moment slope is about 0.16 per degree.

The effect of canard shape on the center of pressure of a generic missile configuration has been experimentally studied by Guy et al. [2]. The canard has constant area while the aspect ratio, taper ratio and sweep angle has been varied. From the experiment results, the efficacy of canard in shifting the center of pressure is greatly increase as aspect ratio increase, especially in low angle of attack region. At higher angle of attack, the efficacy of the canard decreased.

The effect on lift enhancement when both delta-wing and canard varied from low to high sweep angle was studied by Ma et al [3]. The study was done with the wind tunnel experimental, where 72 configurations were made by 9 canards and 8 wings. Wing and canard are co-planar and longitudinal distance is zero. It can be observed that the canard configurations were only effective at higher angle of attack.

The study about the effect of canard position on wing surface pressure has been studied by Soltani et. al [4]. Six different wing canard configurations had been tested using a close return type wind tunnel. From the experiment, they found out that the downwash of canard reduces the effecting angle of attack at the inboard section of the wing near the apex, which prevent flow separation on the wing.

UiTM's BWB is an unmanned aerial vehicle, where the research started since 2005. A series of wind tunnel experiment has been done. A higher stall angle and maximum lift to drag (L/D) ratio is observed on BWB-Baseline II by Wisnoe et al. [5], Reduan et al.[6] and Mohamad et al. [7]. The study of BWB through computational fluid dynamic CFD by Nasir et al.[8] shows small differences of aerodynamic parameters between CFD and wind tunnel experiment in linear lift region. Different turbulence model is proposed by Nasir et al. to simulate flight conditions beyond linear lift region.

The BWB-Baseline without and with a rectangular canard was studied by Z.M Ali et al. [9-10]. In computation simulation, the maximum lift of BWB without canard has a difference of 9% and for the drag force, the CFD predicts lower when compare to the experimental result. The wind tunnel experiment of BWB with a rectangular canard has been carried out with a Mach number of 0.1. The canard has a rectangular shape with an aspect ratio of 2. Experimental result shows that the increment of lift caused by the canard setting angle is small and drag is higher as the canard angle is increased and decreased from zero setting. The L/D_{max} is reducing as the canard setting angle is increased. Canard has a high effect to the C_{Mo} as well as to $C_{M,CG}$ versus C_M curve.

II. Experimental Setup

The experiments were conducted in Universiti Teknologi MARA subsonic wind tunnel. The tunnel is an open-circuit type and has a closed test section. The size of the rectangular-shaped test section is 0.5m x 0.5 m x 1.25m. The maximum speed is 45 m/s, with a Mach number of 0.13. In the test section, the freestream turbulent intensity is about 0.32%. An aerodynamics loads are measured using six components external balances. The basic components of open circuit wind tunnel are intake section, honeycomb intake, contraction section, test section, diffuser, fans and delivery section. The photographic image of the wind tunnel is shown in Fig. 1

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ISSN: 2517-9950
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Fig. 1 Low Speed Wind Tunnel

The model used was a one-sixth scaled BWB equipped with canard. Only half- body used since the BWB is symmetrical in shape. The shape of the canard is rectangular. There are four canards used in the experiments and have the same area, but different aspect ratio, ARc. Canard aspect ratio that has been selected was 2, 4, 6 and 8. The longitudinal position of the canard in relation to the wing-body is fixed. The models were made from aluminum. It was fabricated closely match to the real BWB in order to provide correct result of the wind tunnel testing. Inaccuracy in fabrication of the scaled model will not yield exact full-scale condition. The canards and the BWB wind tunnel model are shown in Fig. 2. The model was mounted on the turntable wind tunnel floor, inside the test section. Table I shows the geometric characteristic of the BWB with canard model.

The tests were run at a velocity of 35m/s with Mach number 0.1. All measurements were performed at a Reynolds Number of 3.0 x 10^5 based on mean aerodynamic chord (MAC) length. During the experiments, the angles of attack range was varied from -16˚ to 50˚ angles of attack. The canard surface was deflected from -20˚ to 20˚ at 5° intervals relative to the axis of BWB's body. The model was fixed in the vertical of the test section. The nose up is taken as a positive angle and nose down as a negative angle.

Fig. 2 Canards with different aspect ratio (left), BWB with canard (right)

TABLE I
MODEL GEOMETRIC CHARACTERISTIC

Reference area (S)	0.03995 m^2
Mean Aerodynamic Chord (MAC)	0.114 m
Body length	0.348 m
Half wing span	0.348 m
Canard area	0.005 m^2
Canard aspect ratio	2, 4, 6, 8

III. RESULT AND DISCUSION

A. Lift Coefficient

Fig. 3 (a) shows the lift coefficient, C_L with respect to wide range angles of attack, α. Generally, lift curves trend for each canard aspect ratio are similar. It can be observed that lift coefficient is increases as angles of attack increased. However, the sudden change in lift is observed between 8° to 10° angles of attack, depending on canard aspect ratio. After that, lift continues to increases until it stalls between 34° to 44° angles of attack. BWB without canard has a stall angle, α_{stall} at 44°, and maximum lift coefficient, $C_{L,max}$ of 0.922. By adding canard, the flow was deteriorated earlier than without canard, which is around angle of attack of 34° to 40°.

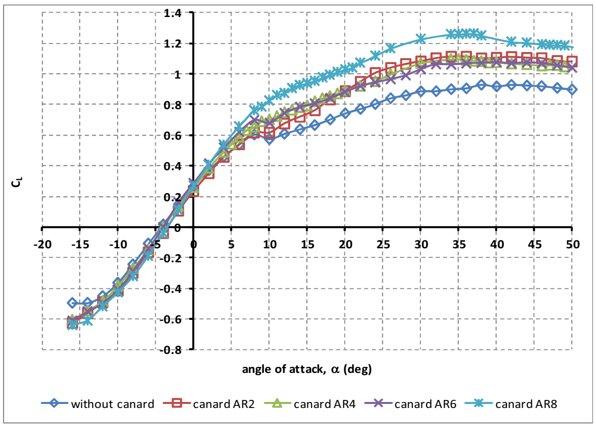


Fig. 3 (a) Lift Coefficient versus angle of attack at δ = 0°

Fig. 3 (b) show the lift curves at low angles of attack region, -8° ≤ α ≤ 8°. This is the region where the lift is linearly increased. From close observation, the higher canard aspect ratio, the higher lift will be as the angles of attack increased. The range of the lift coefficient is within -0.322 ≤ C_L ≤ 0.762. The lift slope, ($C_{L\alpha} = dC_L/d\alpha$) is affected as canard is added to the wing-body. The higher canard aspect ratio, the higher lift slope will be and it is within 0.053 to 0.069 per degree.

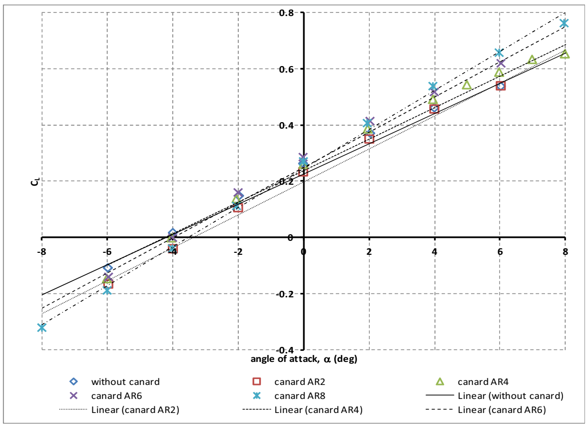
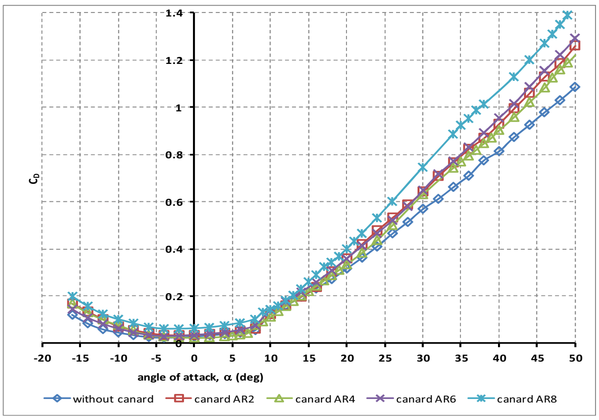


Fig. 3 (b) Lift coefficient vs angles of attack (low region)

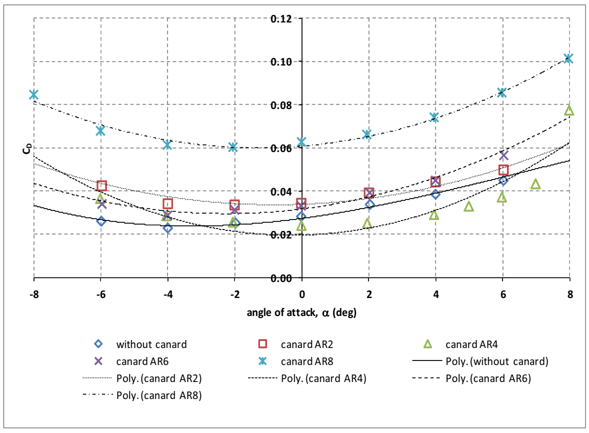
B. Drag Coefficient

Fig. 4 (a) shows a drag coefficient versus angles of attack, for various canard aspect ratios. The curves are in parabolic trend, whereby increasing (positive angles) and decreasing (negative angles) of angles of attack will cause a higher drag. As observed, at angles of attack, $\alpha \geq 8°$, drag coefficient shows a dramatic increase, generally associated with sudden change in lift as mentioned in Fig. 3 (a). The drag continued to increase with angle of attack, even after the stall event taken place.

From close observation in low angles of attack region (Fig. 4 (b)), it shows that the drag is higher compare than without canard depending on canard aspect ratio. The drag is within $0.034 \leq C_L \leq 0.143$.



(a)



(b)

Fig. 4 (a) Drag Coefficient versus angle of attack at $\delta = 0°$ (b) Drag coefficient vs angles of attack (low region)

C. Moment Coefficient

Fig. 5 (a) shows a pitching moment coefficient curves versus angles of attack at various canard aspect ratio (including without canard). The moment reference was measured from 19.8% mean aerodynamic chord (MAC). The change of moment with respect to angles of attack, $C_{M,\alpha}$ ($dC_{M,ref}/d\alpha$) is negative. It was achieved when the BWB is within $-10 \leq \alpha \leq 5°$. However, at $\alpha > 5°$ (except at canard aspect ratio of 8) the moment slope, $C_{M,\alpha}$ ($dC_{M,ref}/d\alpha$) changes from negative (stable) to positive (unstable).

The other criteria for a static stability, moment at zero lift, $C_{M,0}$ must be positive. Fig. 5 (b) shows a plot of moment coefficient with respect to lift coefficient. From observation, the BWB with and without canard cannot produce a positive $C_{M,0}$. The higher aspect ratio, the more unstable aircraft will be.

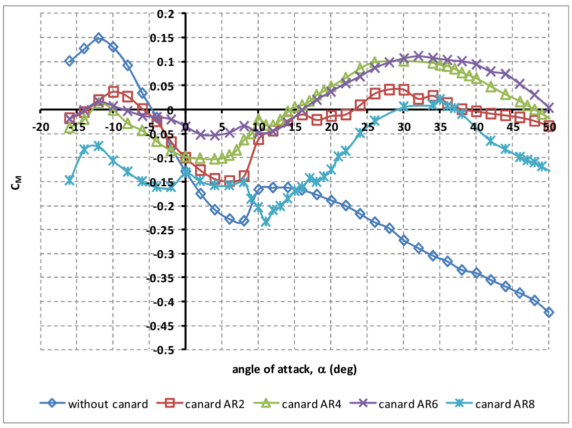


Fig. 5 (a) Moment Coefficient versus angle of attack at $\delta = 0°$

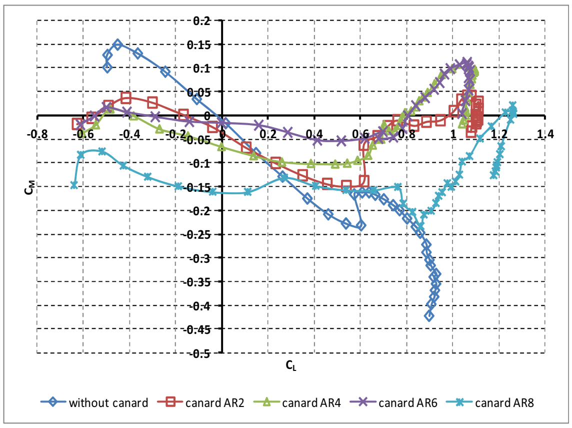
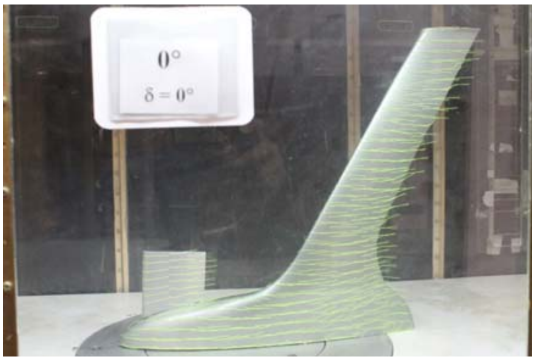


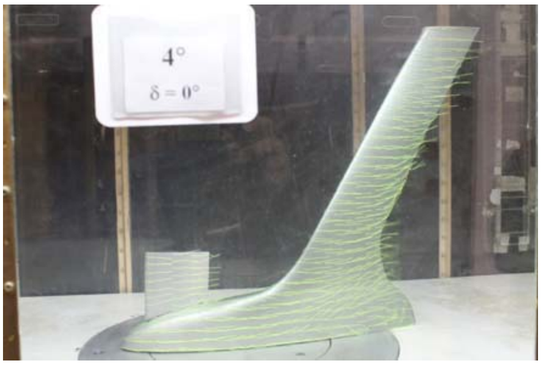
Fig. 5 (b) Moment Coefficient versus Lift Coefficient at δ = 0°

D. Flow Visualization

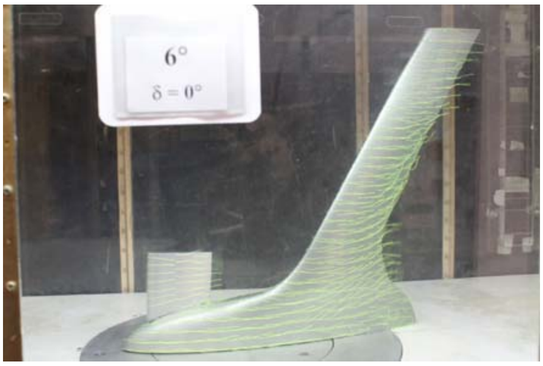
The flow visualization on the upper surface of BWB using a mini tuft is shown in Fig. 6 (a) to (d). From observation, the separation of airflow begins on the upper surface of the inboard wing. As the angle of attack increases, the separation and area of separation flow is spreading toward the outboard wing. This phenomenon continues until almost flow on the whole wing is totally separated, hence no longer producing lift.



(a)



(b)



(c)

(d)

Fig. 6 Flow visualization (a) α = 0° , δ = 0°, (b) α = 4° , δ = 0°,(c) α = 6°   δ = 0°, (d) α = 10° , δ = 0°

IV. Discussion and Conclusion

The series of wind tunnel experiments of BWB with the effect of various canards' aspect ratio has been performed. Lift coefficient increases as the canard is added to the wing-body. At low angles of attacks, the increment of lift slope for various canards' aspect ratio is small and almost constant. The change of lift occurs between angles of attack of 8° to 10° depends on canard aspect ratio. After that, the lift increases significantly. The drag is increase as the positive angles of attack are increasing and negative angles of attack are decreasing. Higher canard aspect ratio will cause higher drag.

The result shows a pronounce effect of canard aspect ratios to the BWB aerodynamics, particularly on the pitching moment. The BWB is statically stable as the change of moment with respect to angles of attack, $C_{M,\alpha}$ ($dC_{M,ref}/d\alpha$) is negative, within -10≤ α ≤ 5°. However, the BWB with and without canard cannot produce a positive $C_{M,0}$ at the c.g location being observed. It was observed that, the higher aspect ratio, the more unstable aircraft will be.

Canard has a high effect to the $C_{M,0}$. It is recommended that more studies which look at the different canard setting angles to be done.

ACKNOWLEDGMENT

We would like to acknowledge that during this work, we had the financial support from Research Management Institute (RMI) Universiti Teknologi MARA (UiTM).We also wish to express a special thanks to all fellow colleagues for their invaluable ideas and critic throughout this work.

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