Wind Tunnel Tests of UiTM Blended Wing Body - Unmanned Aerial Vehicle (BWB-UAV) Prototype

Wirachman Wisnoe, Rizal E. M. Nasir,*
Wan Aizad Musyamel Saarani, Nornashiha Mohd Saad,
Mohd Amirul Afiq Mamud

Aviation Technology Research Group,
Flight Technology & Test Centre (FTTC),
Faculty of Mechanical Engineering,
Universiti Teknologi MARA,
40450, Shah Alam, Selangor, Malaysia

wira_wisnoe@salam.uitm.edu.my

ABSTRACT

In 2014 Universiti Teknologi MARA (UiTM) Malaysia has been granted a research project under Prototype Research Grant Scheme from the Ministry of Higher Education Malaysia to build a prototype of Blended Wing Body - Unmanned Aerial Vehicle for aerial surveillance. In this paper the aerodynamic characteristics of the prototype in the longitudinal direction are presented in terms of lift coefficient, drag coefficient, and pitching moment coefficient obtained from wind tunnel tests. The tests are conducted on a ¼ scaled half model aircraft placed in UiTM Low Speed Tunnel at wind speed of 20 m/s, 25 m/s, 30 m/s, 35 m/s and 40 m/s representing Reynolds number in the order of 10^5. For each wind speed, the angle of attack is varied from -10º to 64º to observe the full capability of the aircraft. Visualisation using thread tufts is also executed to see the flow pattern on the surface of the aircraft at certain angles. The results show that the maximum lift coefficient is around 0.65 at 28º angle of attack, the minimum drag coefficient is below 0.03 at zero angle of attack, and the maximum lift-to-drag ratio is about 20 at 3º angle of attack. The pitching moment curve indicates a static stability with negative slope between -7º to 10º angle of attack. Visualisation shows the flow separation progress on the surface of canard, wing and fuselage.

Keywords: *Blended Wing Body (BWB), Aerodynamics, Wind Tunnel Test, Thread Tuft Visualisation.*

ISSN 1823- 5514, eISSN 2550-164X

Received for review: 2017-02-12
Accepted for publication: 2017-05-12
Published: 2017-10-15

Introduction

In 2014 Universiti Teknologi MARA (UiTM) Malaysia has been granted a research project under Prototype Research Grant Scheme (PRGS) from the Ministry of Higher Education (MOHE) Malaysia to build a prototype of Blended Wing Body - Unmanned Aerial Vehicle (BWB-UAV) for aerial surveillance. BWB is known to be aerodynamically efficient which means it can have a long endurance. It can fly at a wide range of speed. This makes the aircraft suitable for aerial surveillance at remote area as the aircraft can reach the targeted area faster and loiter at low speed with sufficient time to perform surveillance.

With a good shape and configuration, a BWB aircraft can burn 27% lower fuel, have 15% lower take-off weight, 12% lower empty operating weight, 27% lower total thrust, and 20% higher lift-to-drag ratio. These are among the advantages that BWB offers over conventional aircraft [1]. The high lift-to-drag ratio is due to the fact that the integration of body and wings minimizes the aerodynamic interference among them which reduces the overall drag, and when coupled with high lift provided by the wings and the body combination, the aircraft can produce high lift-to-drag ratio.

Aerodynamic characteristic of an aircraft can be obtained through simulation as well as experiments. Qin et al. used high-fidelity RANS solvers and grid by assuming turbulent boundary layer to assess the aerodynamic performance of their 80-m span BWB. The simulation was conducted at M = 0.85 and 0.92. From the simulation at M = 0.85, the design lift was obtained at incidence of about 3° [2]. Shim and Park conducted wind tunnel tests on their 70-mm wingspan BWB-UCAV model with airspeed of 50 m/s. Six-component internal balance was used to measure various aerodynamic force and moment coefficients. They obtained maximum lift coefficient of 0.868 at 20° angle of attack and zero lift angle of attack was about 0.75°. The curve of pitching moment coefficient shows a large unstable region [3]. Wind tunnel tests on UiTM BWB-UAV Baseline II gave maximum lift coefficient of 1.1 at 40° angle of attack. The maximum lift-to-drag ratio is 16.5 at 3° angle of attack. The curve of pitching moment coefficient shows static instability beyond 8º angle of attack [4].

Even though the BWB-UAV Prototype was said to be derived from BWB-UAV Baseline II, the modification is considered major. One of the modifications is the airfoil that forms the fuselage. The Baseline II has NACA2415 for the body and the Prototype has NACA0009 which is symmetrical. However, the prototype maintains the same NACA2412 and NACA006 for the wings and the canards respectively as the Baseline II. The wing twist that presents on the Baseline II was removed on the Prototype. The length of the body centreline of the prototype is reduced to 1.2 m from the initial length of 2 m on the Baseline II. The wingspan of the prototype is 2.4

m compared to 4 m for the Baseline II. The BWB-UAV Prototype is shown in Figure 1. For further aerodynamic study of BWB-UAV Baseline II readers may consult references [5-9].

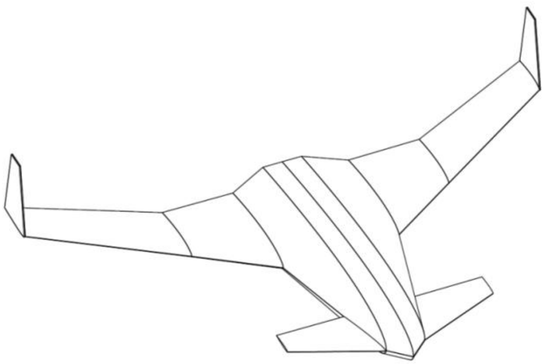

Figure 1: BWB-UAV Prototype

In this paper, the aerodynamics characteristics of the BWB-UAV Prototype are presented in terms of coefficients of lift, drag and pitching moment. Visualisation using thread tufts are presented to show the flow pattern on the surface of the aircraft model at certain angles of attack.

Experimental Setup

The experiment was carried out in UiTM Low Speed Wind Tunnel (Figure 2). It has a test section area of 500 mm x 500 mm x 1250 mm and equipped with 6-component balance. For this study, only 3 components were applied. A half model of the aircraft scaled down at ¼ of the actual size made from aluminium was used (Figure 3). The parameters of the model are presented in Table 1.

The experiment was conducted at five airspeeds: 20 m/s, 25 m/s, 30 m/s, 35 m/s and 40 m/s with angle of attack varying from -10° to +64°. The variables measured are the lift coefficient (C_L), the drag coefficient (C_D), and the pitching moment coefficient (C_M) at various angle of attack and different airspeeds.

For visualisation purpose, thread tufts were arranged and glued on the surface of the wind tunnel model. Visualisation was conducted with airspeed of 20 m/s for certain angles of attack when necessary to observe the flow behaviour around the model.

Figure 2: UiTM Low Speed Wind Tunnel

Figure 3: Wind Tunnel Model

Table 1: Parameters of wind tunnel model

Parameter	Value
Half wing span	0.291 m
Body centreline	0.291 m
Reference area (planform area)	0.035 m^2
Reference Length (MAC)	0.120 m

Results and Analysis

Lift Coefficient (C_L) versus Angle of Attack (α)

The lift coefficient (C_L) versus angle of attack (α) at five different airspeeds is shown in Figure 4. All airspeeds produce almost the same trend where higher airspeed gives higher values of C_L for the same angle of attack. It is observed that the value of C_L increases as the angle of attack increases until it reaches its maximum value of 0.65 at around α = 28°.

A sudden deflection is observable around α = 12°. From the thread tufts visualisation, it can be seen that flow separations occurs on the upper part of the canard and on the upper part of the wing near the wing tip (Figure 5). This indicates the occurrence of stall on these parts of the surface. Hence, the model loses part of its lift, which explains the deflection of the curves.

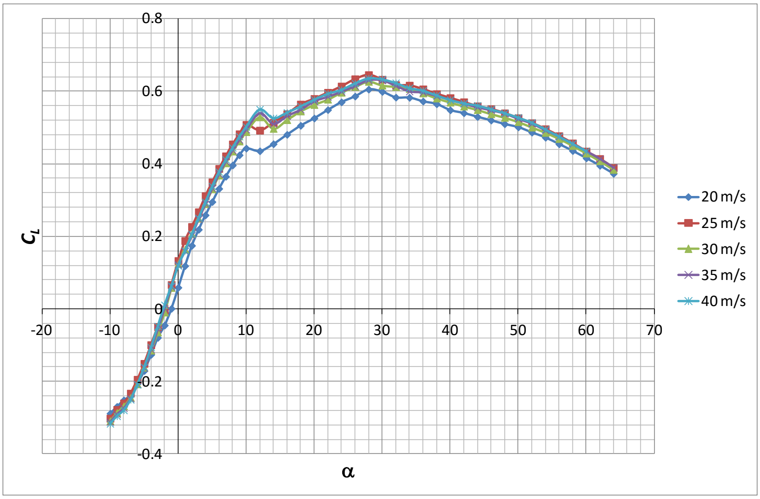

Figure 4: Lift coefficient (C_L) versus angle of attack (α).

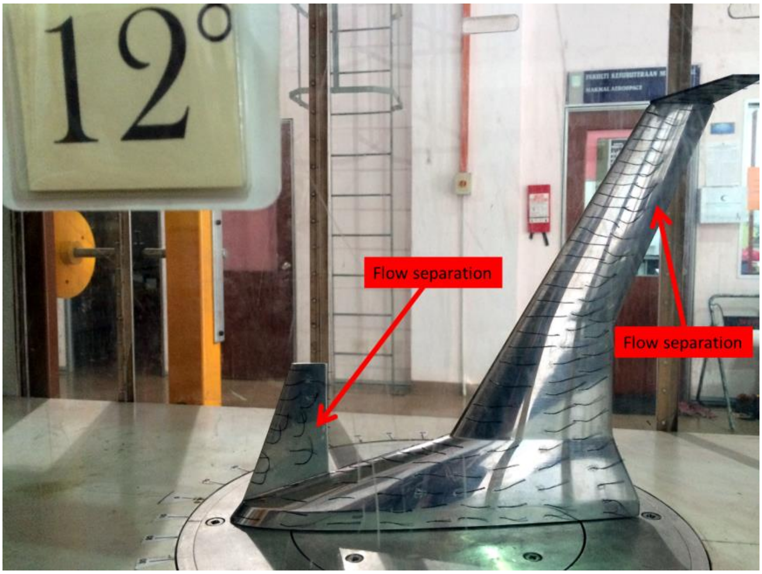

Figure 5: Visualisation at $\alpha = 12°$.

Drag Coefficient (C_D) versus Angle of Attack (α)

Figure 6 shows the variation of drag coefficient (C_D) versus angle of attack (α) taken at five different airspeeds. The curves have the same trends for all airspeeds with small differences among curves. The value of C_D at zero angle of attack is about 0.03. The drag coefficient remains low as long as the flow is attached to the surface of the aircraft. Figure 7 shows the visualisation at $\alpha = 6°$ where the flow is still attached on the model surface. At $\alpha = 12°$, just like the curves of C_L, here also, a sudden deflection is observed where the drag increases suddenly due to the flow separation on some parts of the surface. Beyond this angle the value of C_D grows at higher rate as α increases. Visualisation at $\alpha = 18°$ shows a wider area of flow separation on the upper surface of the canard and the wing.

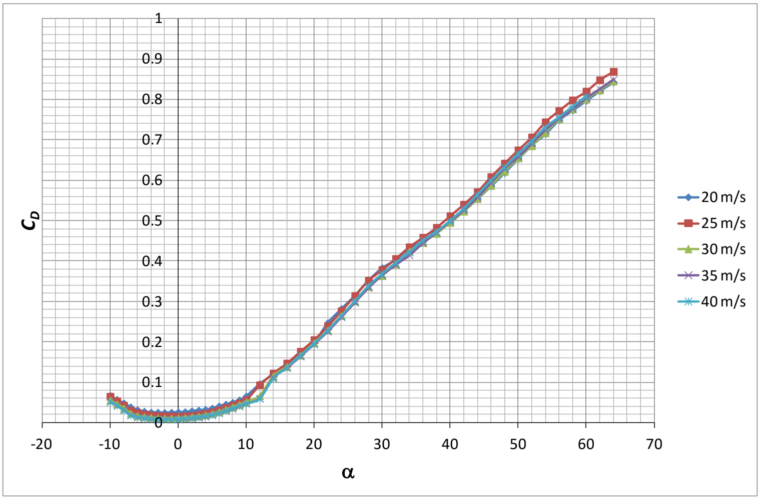

Figure 6: Drag coefficient (C_D) versus angle of attack (α).

Figure 7: Visualisation at $\alpha = 6°$

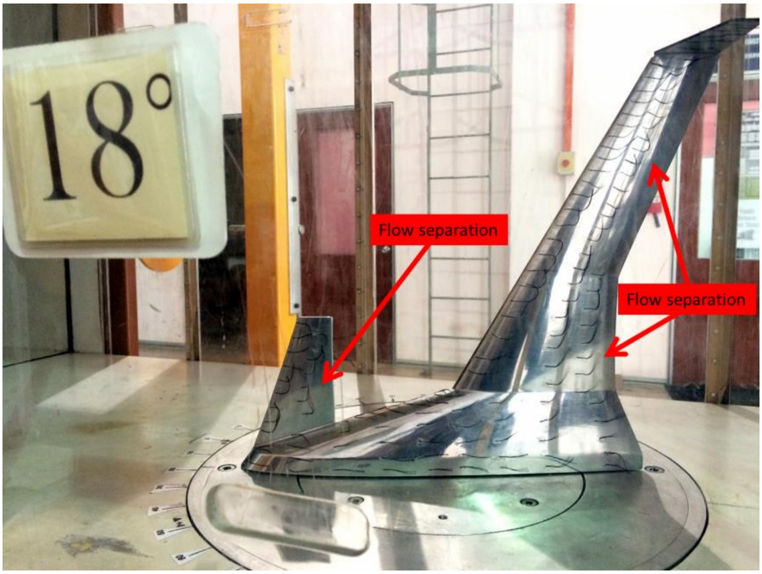

Figure 8: Visualisation at $\alpha = 18°$

Lift-to-Drag Ratio (*L/D*) versus Angle of Attack (α)

The curves of *L/D* versus angle of attack (α) for various airspeeds are plotted in Figure 9. Here the curves show different values for α below 14° and they almost coincide for α above 14°. In general, the *L/D* is higher when the airspeed is higher. However, the maximum value is given when the airspeed is 35 m/s, which is almost 20 at $\alpha = 3°$. This angle of attack indicates the optimum flight configuration for the aircraft. Deflection of curves at $\alpha = 12°$ is also observable on these graphs. Visualisation at $\alpha = 3°$ is presented in Figure 10. The flow is well attached to the surface everywhere at this angle of attack.

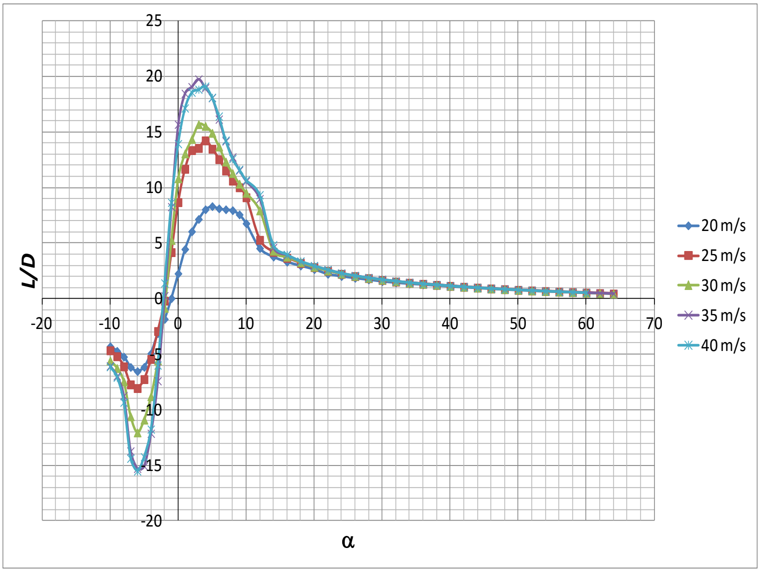

Figure 9: Lift-to-drag ratio (L/D) versus angle of attack (α)

Figure 10: Visualisation at α = 3°

Lift Coefficient (C_L) versus Drag Coefficient (C_D)

The drag polar (C_L versus C_D) curves for five different airspeeds can be seen in Figure 11. The value of C_D at zero lift is obtained approximately equal to 0.01. This is the minimum drag coefficient of the BWB at zero lift (C_{Do}). It is also observed that, at high angles of attack, the aircraft may have larger drag but at the same time it can generate higher lift.

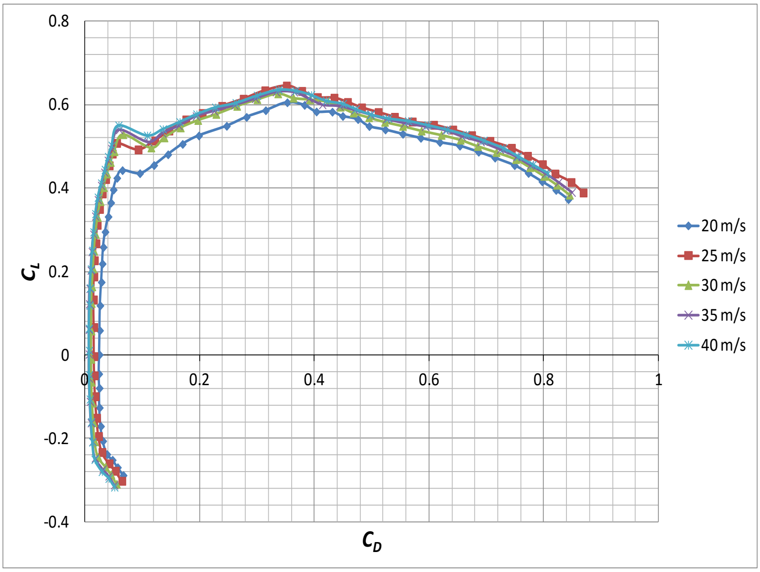

Fig. 11 Lift coefficient (C_L) versus drag coefficient (C_D)

Pitching Moment Coefficient (C_M) versus Angle of Attack (α)

The curve of pitching moment coefficient (C_M) versus angle of attack (α) is presented in Figure 12. The measurement of pitching moment is taken at 145 mm from the nose of the model, corresponding approximately to the mid-point of the body centreline. The curves indicate a trimming angle between -4° and -2° to have zero pitching moment, depending on the airspeed. At α = 0°, the curve shows negative pitching moments which means that the aircraft has a tendency to nose down at zero degree angle of attack. At positive angle of attack, pitching moments are negative (nose down). Up to α = 10° the slopes are negative which implies static stability within this range of α. The slopes become positive between α = 10° and 14° reducing the aircraft's static stability within this range. Between α = 12° and 20° the curves shows almost zero slope which means that the moment is almost independent of α. This implies that the point where the moment is taken represents the aerodynamic centre for this range of α. Beyond this angle of attack, at higher α, the pitching moment curves shows negative slopes, except for the airspeed of 20 m/s where more fluctuations occur with α.

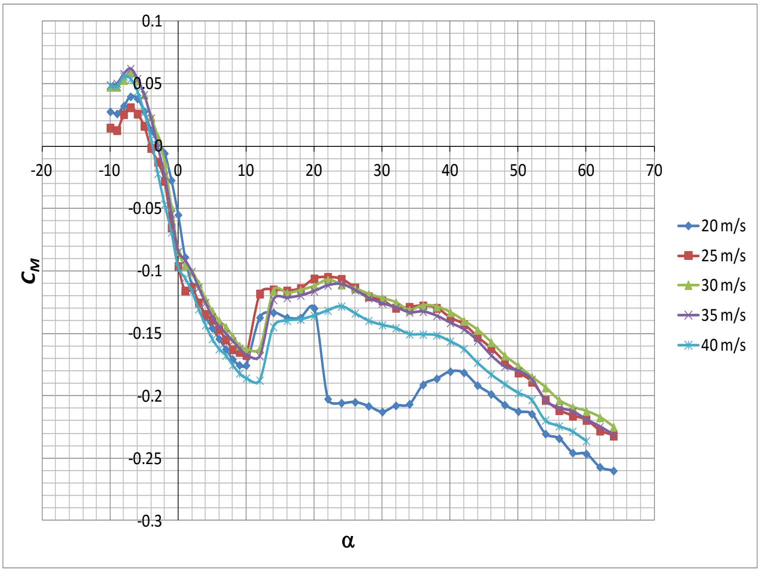

Figure 12: Pitching moment coefficient (C_M) versus angle of attack (α)

Conclusion

In this paper, the aerodynamic characteristics of UiTM BWB-UAV Prototype have been presented in terms of coefficient of lift, coefficient of drag and coefficient of pitching moment. The data are obtained from wind tunnel tests using ¼ scaled half model at five different airspeeds. Visualisation has been executed by means of thread tufts to clarify flow behaviours on the surface of the model at certain angles of attack.

The aerodynamic curves and visualisation have shown that stall starts to occur at α = 12°, starting on the upper surface of the canard and on the upper surface of the wing close to the wing tip. The flow separation zone is getting wider for higher angle of attack. This BWB-UAV has a maximum value of lift coefficient of 0.65 at α = 28°, a drag coefficient around 0.03 at zero angle of attack and as low as 0.01 at zero lift. The aircraft can produce lift-to-drag ratio of 20 at α = 3° at 35 m/s of airspeed. From the curves of pitching moment, it can be concluded that the aircraft has strong static stability behaviour for angles of attack up to 10°.

Acknowledgement

Authors would like to thank the Malaysian Ministry of Higher Education (MOHE) and the Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM) for providing fund and support for this research under Prototype Research Grant Scheme (PRGS), File No.: 600-RMI/PRGS 5/3 (3/2014).

References

[1] E. Ordoukhanian and A. M. Madni, "Blended Wing Body Architecting and Design: Current Status and Future Prospects", *Procedia Computer Science* 28, 619-625, 2014.

[2] N. Qin, A. Vavalle, A. Le Moigne, M. Laban, K. Hackett and P. Weinerfelt, "Aerodynamic considerations of blended wing body aircraft", *Progress in Aerospace Sciences* 40, 321–343, 2004.

[3] H. J. Shim and S. O. Park, "Low-speed Wind-tunnel Test Results of a BWB-UCAV Model", *Procedia Engineering* 67, 50-58, 2013.

[4] N. F. Reduan, W. Wisnoe, W. Kuntjoro, R. E. M. Nasir, F. Mohamad and Z. M. Ali, "Aerodynamics characteristic of UiTM's BWB UAV Baseline-II at different canard deflection angles at low pitching angle", *Proceeding of 2010 International Conference on Science and Social Research (CSSR 2010)*, 1005-1009, 2010.

[5] W. Wisnoe, R. E. M. Nasir, R. Ramly, W. Kuntjoro and F. Muhammad, "Aerodynamic of UITM's Blended-Wing-Body Unmanned Aerial Vehicle Baseline-II Equipped with One Central Vertical Rudder", *Jurnal Teknologi* 75 (8), 95-99, 2015.

[6] R. E. M. Nasir, F. Mohamed, R. Ramly, A. M. I. Mamat, W. Wisnoe and W. Kuntjoro, "Flight Performance of Various Blended Wing-Body Small UAV Designs, *Jurnal Teknologi* 75 (8), 71-75, 2015.

[7] R. E. M. Nasir, W. Kuntjoro and W. Wisnoe, "Aerodynamic, Stability and Flying Quality Evaluation on a Small Blended Wing-body Aircraft with Canard Foreplanes", *Procedia Technology* 15, 784-792, 2014.

[8] F. Mohamad, W. Wisnoe, R. E. M. Nasir, K. I. Sainan and N. Jenal, "Yaw Stability Analysis for UiTM's BWB Baseline-II UAV E-4", *Applied Mechanics and Materials* 393, 323-328, 2013.

[9] Z. M. Ali, W. Kuntjoro and W. Wisnoe, "The Effect of Canard to the Aerodynamic Behavior of Blended Wing Body Aircraft", *Applied Mechanics and Materials* 225, 38-42, 2012.