Experimental result analysis for scaled model of UiTM tailless blended wing-body (BWB) Baseline 7 unmanned aerial vehicle (UAV)

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Abstract. Blended wing-body (BWB) aircraft having planform configuration similar to those previously researched and published by other researchers does not guarantee that an efficient aerodynamics in term of lift-to-drag ratio can be achieved. In this wind tunnel experimental study, BWB half model is used. The model is also being scaled down to 71.5% from the actual size. Based on the results, the maximum lift coefficient is found to be 0.763 when the angle is at 27.5° after which the model starts to stall. The minimum drag coefficient is 0.014, measured at zero angle of attack. The corrected lift-to-drag ratio (L/D) is 15.9 at angle 7.8°. The scaled model has a big flat surface that surely gives an inaccurate data but the data obtained shall give some insights for future perspective towards the BWB model being tested.

1. Introduction
Blended wing-body (BWB) aircraft, through its unique configuration and potential benefits, is well-suited for the role of environmental-friendly, long range, high capacity airliner [1]. However, there are issues of flight stability and control that need to be addressed and solved. The BWB tends to have poor departure characteristics due to its lower maximum lift coefficient, which results from the absence or limited number of high lift devices and also tails with long moment arm [2]. The tailless nature of the BWB aircraft with multiple elevons as control surfaces requires understanding of the impact of these elevons have towards stability. Such BWB aircraft often requires an active flight control system [3].

The study on the BWB unmanned aerial vehicle (UAV) has begun in Universiti Teknologi MARA (UiTM) since 2005, which is focused on the design, fundamental aerodynamics and flight dynamics of small BWB [4]. It is found from previous studies that a BWB aircraft having planform configuration just like the one previously being researched and published by other researchers somehow does not guarantee it to have efficient aerodynamics in terms of lift-to-drag ratio (L/D) [5]. Studies conducted by UiTM have found that each variation of BWB aircraft design has its own advantages and disadvantages [6]. The Baseline 7 BWB design, as shown in Figure 1, has been introduced to study the behavior of the control surfaces, given four elevons and without vertical stabilizer and wingtip. The challenge is that this aircraft design will have to fly with improved stability solely depending on airfoil selection and four control surfaces to stabilize the aircraft [6-7]. The tailless design shall simplify the mechanism while improving the design characteristics of Baseline 7. However, this paper only focuses on the aerodynamic
behavior and characteristics of the Baseline 7 scaled model analysis inside the wind tunnel with a closed system configuration.

2. Model and Wind Tunnel Setup
The experimental test is performed in Universiti Pertahanan Nasional Malaysia (UPNM) Wind Tunnel as shown in Figure 2. The wind tunnel is a suction-type tunnel with a test section area of 0.2m x 0.2m and it is equipped with three-component force balance equipment that able to measure lift and drag. For this wind tunnel experimental setup, half model of the BWB is used. The model is scaled down to 1:7 from the actual size. The dimensions and concept of the scaled half model are shown at Figure 3 and Figure 4.

The experiment is conducted at a speed of 49.58m/s, which represents 15 m/s for full-scaled model wind tunnel test. The wing span of the scaled model had been minimised and that is 0.021m². The pitching angles being tested are between -10° to +30° with fixed elevator. The experiment is done from angles of attack of -10° up to +30°. The increment of 2° interval is chosen to identify the best configuration of each aerodynamic coefficient for the model. The test location has an ambient temperature of 300K with the density of air around 1.155kg/m³.

Since the experiment is done in the wind tunnel with a closed-loop system, some corrections have to be made to achieve true values of aerodynamic coefficient [8]. The values obtained in the closed-system wind tunnel must be corrected to eliminate several effects of interference [9]. Influence of the tunnel walls and interaction between tunnel wall and model will affect the aerodynamic characteristics results [9].
The first correction is for the blockage correction. Solid blockage correction is a simple velocity correction in which the flow of air inside the wind tunnel will be in the freestream condition [10]. The solid blockage sometimes can be neglected because of its minimal correction to the velocity of the airflow affected during solid blockage correction. This is done using Equation 1 and Equation 2 where $\Delta V$ is the corrected velocity of the airspeed, $\varepsilon_{sb}$ is the solid blockage factor, $V_u$ is uncorrected velocity of the airflow at the leading edge, $V_b$ is the Volume of the model, $K_1$ for vertical model is 0.52 and $S$ is the working section area.

$$\Delta V = \varepsilon_{sb} V_u$$  \hspace{1cm} (1)

$$\varepsilon_{sb} = \frac{K_1 V_b}{S^{3/2}}$$ \hspace{1cm} (2)

The wake correction, on the other hand, carries out a handful of corrected parameters such as wake correction factor and velocity of airflow at trailing edge of the model. This is done using the following Equation 3 and Equation 4 where $c_d u$ is the uncorrected drag coefficient, $c$ is the model’s length and $h$ is the height of working section.

$$\Delta V = \varepsilon_{wb} V_u$$ \hspace{1cm} (3)

$$\varepsilon_{sb} = \frac{c}{2h} c_d u$$ \hspace{1cm} (4)

Furthermore, streamline curvature correction will correct the drag coefficient, lift coefficient, angle of attack and also moment coefficient. The wind tunnel wall is artificially curved to form a curvature streamline inside the system and because of this condition, the correction is required to achieve better results from wind tunnel closed system experimental procedure [11]. Equation 5 up to Equation 10 are involved in this correction procedure. In these equations, $\alpha$ is the corrected angle of attack, $\alpha_{uc}$ is the uncorrected angle of attack, $C_l$ is corrected lift coefficient, $C_{tu}$ is uncorrected lift coefficient, $C_{m1/2u}$ is the uncorrected moment coefficient halved, $\varepsilon$ is the summation of solid blockage factor and wake blockage factor, $C_{dc}$ is corrected drag coefficient and $C_{du}$ is uncorrected drag coefficient.

$$\sigma = \frac{\pi^2}{4h} \left( \frac{c}{h} \right)^2$$ \hspace{1cm} (5)

$$\alpha = \alpha_{uc} + \frac{57.3 \sigma}{2 \pi} (C_{tu} + 4 C_{m1/2u})$$ \hspace{1cm} (6)

$$C_l = C_{tu} (1 - \sigma - 2\varepsilon)$$ \hspace{1cm} (7)

$$C_{m1/2} = C_{m1/2u}(1 - 2\varepsilon) + \frac{\sigma C_l}{4}$$ \hspace{1cm} (8)

$$V = V_u (1 + \varepsilon)$$ \hspace{1cm} (9)

$$C_{dc} = C_{du}(1 - 3\varepsilon_{wb} - 2\varepsilon_{wb})$$ \hspace{1cm} (10)

3. Results and Discussion

Figure 5 shows the plot of lift coefficient versus angle of attack (i.e. from -10° to +30°). The lift coefficient is at maximum with 0.822 when the angle is at 27.5°. The model then starts to stall after the angle of maximum lift coefficient based on the plot. Nonetheless, after the wind tunnel data has been corrected, the maximum lift coefficient value is changed to 0.763 though it occurs at the same angle of attack as before. A small change in lift coefficient is observed throughout the data correction analysis. When the angle of attack is at 0°, the lift coefficient is 0.036 as shown in Figure 6.
In the meantime, Figure 7 shows the drag coefficient versus angle of attack plot. Drag coefficient is at its maximum at about 27.5° angle of attack whereas its minimum value of around 0.014 is observed at the angle of attack of 2.2°. The corrected drag coefficient data shows a slight decrease in value as it approaches the higher angle of attack. A clearer graph is observed from Figure 8 to identify the linear trendline obtained for the drag coefficient versus angle of attack plot.

Figure 5: Lift coefficient versus angle of attack

Figure 6: Lift coefficient versus angle of attack with trendline

Figure 7: Drag coefficient versus angle of attack

Figure 8: Drag coefficient versus angle of attack with trendline

The L/D versus angle of attack graph is presented in Figure 9. The maximum value of L/D from this experiment is achieved at angle 7.74° with a value of 16. However, the corrected L/D results in a just slightly lower value of 15.9 at angle 7.8°. At zero angle of attack, the L/D obtained is 2.6 with the corrected value. These values indicate that L/D value for Baseline 7 BWB is not that as high as L/D = 21 recorded for previous Baseline II design [5]. The higher the value of L/D of an aircraft, the better is the aerodynamic efficiency of the aircraft. In this experiment, the value of L/D for this design airplane is somewhat average compared to other previous baseline models. From the graph, the change of L/D value between uncorrected and corrected is negligible.

4. Conclusion
Data obtained from the wind tunnel experiments in this study are analyzed to obtain the aerodynamic performance characteristics for the BWB Baseline 7. The maximum lift coefficient is 0.822 at angle of attack 27.5° for uncorrected value and 0.763 at angle of attack 27.5° for corrected value. Value of drag coefficient gives a promising value of 0.014 at angle 0° for both corrected and uncorrected values. L/D value obtained from this experiment indicates a promising and good corrected value of 15.9, which is among the top of UiTM’s BWB Baseline series. Table 1 shows the BWB Baseline UiTM models dated from 2005 to 2014 [4-9].

Several recommendations can be made to improve the evaluation of data in this experiment. The wind tunnel model should be fabricated with a smoother finishing such that the flow does not experience
any major wake exerted at the skin of the model. In addition, the wind tunnel should be equipped with more data evaluator such as speed sensor, density sensor and more accurate force balance. The scaled model has a big flat surface that certainly gives an inaccurate data but the data obtained in this study can be used to shape the future perspective towards the model being tested.

![Figure 9: L/D versus angle of attack](image)

Table 1: L/D of BWB baseline model being designed in UiTM

| Year | Model      | L/D Max |
|------|------------|---------|
| 2005 | Baseline-I | 14.0    |
| 2009 | Baseline-II| 24.0    |
| 2012 | Baseline-III| 13.0   |
| 2013 | Baseline-IV| 15.0    |
| 2014 | Baseline-V | 32.0    |
| 2017 | Baseline 7 | 15.9    |

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