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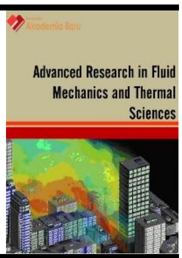

Aerodynamic Performance of a Tail-less Blended Wing-Body Small Transport Aircraft

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ABSTRACT

Blended wing-body (BWB) is a concept with promising future for transport aircraft. Many studies have been conducted on blended wing body concept, each with different ideas and designs. The search of the perfect BWB design is still on going around the world with the hope of applying the design to the conventional aviation industries. This paper proposes a tail-less BWB-type aircraft design to be used as transport aircraft with similar payload capacity as the popular conventional DHC-6 Twin Otter aircraft. An experimental investigation is conducted to obtain aerodynamic characteristics and performance of the proposed BWB aircraft design, known as Baseline-IX, and its conventional counterpart. Both aircrafts have the same wing span and cargo-passenger volume in the fuselage. The models are both 1:30 scale with experiment conducted at 36 m/s in LST-1 wind tunnel at Flight Technology & Test Centre laboratory. Discussions on aerodynamic characteristics comparison between Baseline-IX BWB and DHC-6 concluded that although the former is only 8.25% better in term of lift-to-drag ratio than the latter, the C_L^3/C_D^2 of Baseline-IX is 31.7% higher than DHC-6's. This means that for a given take-off weight, the Baseline-IX will have 8.25% better range and 31.7% better endurance than its conventional counterpart. At maximum endurance, the Baseline-IX also flies slower indicating that it may also be used surveillance or maritime patrol aircraft that requires long hours of flight.

Keywords:
Blended-wing body; lift to drag ratio; transport aircraft

1. Introduction

A Blended Wing-Body (BWB) is a fixed-wing aircraft having wings and its fuselage (or body) are smoothly merged together that some designs almost resemble pure flying wing. The main target of many of the designs is focused on drag reduction – to get the best performance out of an aircraft especially related to range and endurance. Ultimately, this leads to savings in terms of fuel consumption for similar flying weight as its conventional design.

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Studies on BWB design and aerodynamics in Flight Technology and Test Centre (FTTC), UiTM began in 2005 with the first Baseline-I design that resembles a popular flying wing bomber. However, due to many shortcomings in the design itself, Baseline-II was introduced later with prevalent body smoothly blended with rear wing and canard foreplanes giving lift-to-drag ratio (L/D) of 15.0 against 7.5 for the former [1]. However, canard configuration is dynamically unstable thus a stability augmentation system is proposed to trim the canard automatically to ensure its phugoid and short-period mode are stable and stay within ac-acceptable [2]. Various other designs were explored later on from Baseline-III bird-inspired planform and Baseline-IV delta-planform BWB and found that L/D around 14.0 and 11.5 respectively. Performance wise, in terms of range and endurance, Baseline-II still came at the top L/D = 24 for the canard-less configuration [3]. Baseline-V was designed based on Baseline-II planform but with wing located forward while canard was replaced with integrated tail at the rear. Various tail sweep angles were studied and the best was found to give maximum L/D of 18.0 [4]. Later on, similar studies were conducted BWB design (Baseline-7) based on cranked-wing flying-wing configuration and the experiment found that its L/D reached 21.9 at its peak [5]. However, such design may not have large usable volume to be expedited as a proper transport aircraft.

The BWB offers increased range and payload capacity due to 27% reduction in fuel consumption [6]. Various BWB designs are produced especially for large passenger airliner that accommodates at least 400 passengers such as NASA-800, Boeing-450, TsAGI’s FW (flying wing), IWB (Integrated wing-body) and Lifting body, ACFA2020, SAX-40 and MOB BWB among others. Maximum L/D of these aircrafts are measured or computed to be around 14.0 to 21.0 at Mach 0.8 to 0.8 [7]. Achieving such high L/D at high Mach number is not impossible since their conventional designs with wing aspect ratio between 8.0 to 10.0 can achieve L/D around 17.0. Li *et al.,* suggest an optimization to the existing BWB design and found the expected fuel consumption per passenger to be 2.15 L per 100 km per passenger compared to 2.48, 3.39 and 3.20 for B787-3, B747-4 and A330-3 respectively [8].

Another type of BWB design is known as lifting body aircraft is studied and compared with a standard BWB design and conventional design. According to Reist and Zingg [9], BWB can only offer 5.5% reduction is fuel consumption while lifting body air-craft can do better at 10.3% saving compared with conventional aircrafts. Despite improvements on designs, BWB aircrafts must also be optimized for other requirements such as structural strength, stability and control that computational aerodynamic method may assist in finding the balance between these requirements [10].

So far, there is lack of study on BWB design for small trans-port aircrafts with wing span less than 20 metres and payload capacity of 20 passengers or two tons of cargo. If wing span is fixed to around 20 metres plus minus 2 metres (20±2 m) with cargo volume inside the fuselage to be around 10.0m^3 then the approach to BWB aircraft design is different. Firstly, it cannot have lifting body as it will make the body unnecessarily long and putting its pusher propeller far behind. Secondly, to have the benefit of high lift-to-drag ratio, the BWB shall be tail-less and closely resembles a flying wing with near-conventional fuselage optimized for single pusher-propeller installation.

Until recently, the team at FTTC UiTM has only focused on BWB design for small unmanned aerial systems (UAS). The latest design, known as Baseline-IX (Figure 1) is a mini UAS-sized aircraft at around 2.0 metre wing span but it is designed to be scalable up to five times wider without the need for major changes in the design to suit to i.e. compressibility or different Mach number regime and high Reynold’s number difference.

The Baseline-IX is actually an improvement from Baseline-V and Baseline-7 in which both lack volume capacity in their body. The BWB Baseline-IX offers simpler planform with wing design extracted from Baseline-V and tail-less configuration like Base-line-7, shorter and large-volume fuselage in the middle with moderate blending to the wing, and slightly higher wing aspect ratio compared to its predecessor.

The Baseline-IX nose design is highly influenced around a CCTV camera which is to be carried in its UAS version. The team also envisioned that perhaps future cargo transport aircraft shall be unmanned and flown automatically. Following its predecessors, Baseline-IX have airfoil shaped wings where the air moves smoothly over the top which causes power pressure to develop with less drag and high lifts [18,21]. The wings are generated from MH60 airfoil which is then blended moderately with its near boxy fuselage. Access to the cargo area is via complete opening of the nose which does not have pilots' cockpit. At the other extreme end, the flat fuselage end is designed to mount rear engine – either turboprop, radial-type piston engine or electric motor connected to propellers that is 25% percent wider in terms of diameter than conventional transport aircraft's twin propellers of similar wing span.

The purpose of this case study is to imagine the Baseline-IX not just to serve the purpose of a UAS but to serve as a transport airplane in the future. A comparison will be made to a popular transport airplane; a DHC-6 Twin Otter which has very good track records. It is one of the most reliable to fly and flexible to be used as either passenger or cargo transport aircraft. Its less than 20 metre wing span and rugged landing gear allows it to operate at remote, unprepared air strips while its good fuel economy enables it to be used as reconnaissance and surveillance purposes for nations which cannot afford to have sophisticated long-range UAS. In the meantime, the proposed Baseline-IX design offers practicality, improved flight performance, namely range and endurance at low cruising speed. It is to achieve long flight hours with enhanced spaces in its large wings to store fuel, or batteries or PEM fuel cells generators.

In this paper, aerodynamic performance of the Baseline-IX is investigated via wind tunnel experiments using small model fabricated by a 3D printer using fused deposition method (FDM) (Figure 2). The performance especially important aerodynamics ratios are compared with results of DHC-6 transport aircraft tested with wind tunnel model of similar scale at the same airspeed.

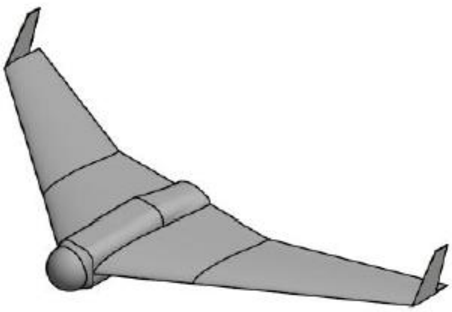

Fig. 1. Baseline-IX BWB design

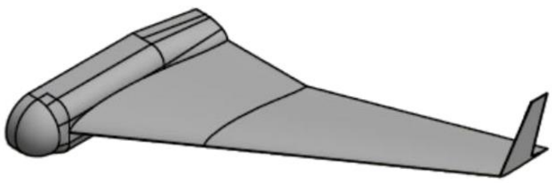

Fig. 2. Baseline-IX BWB half model of 1:30 scale for the purpose of printing wind tunnel model

2. Baseline-IX and DHC-6 Specifications

Figure 3 and 4 drawings of both aircrafts; the Baseline-IX and the Twin Otter. The DHC-6 Twin Otter has served the aviation industries since its first flight in 1965. The Twin Otter is well known for its capability in short take-off and landing, which does not require long runway like most transport airplanes. Twin otter can also be equipped to land on water. Due to its versatility and manoeuvrability, twin otters are popular in areas with difficult flying environment such as Papua New Guinea, Maldives and Alaska. Those areas with short-field airport and short connect from rural areas with larger towns demand the service of aircraft like the DHC-6 [11].

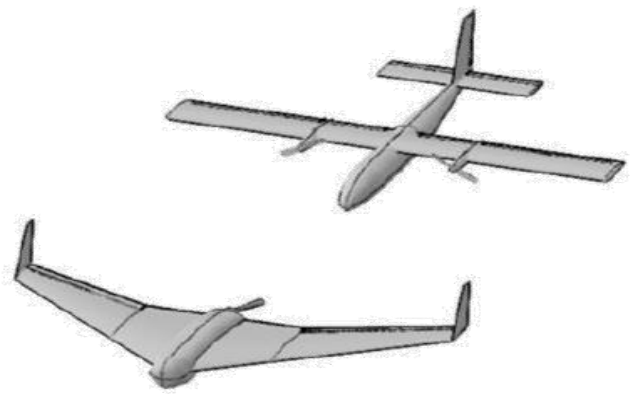

Fig. 3. A sketch-up of BWB Baseline-IX (front) and DHC-6 transport aircraft (rear)

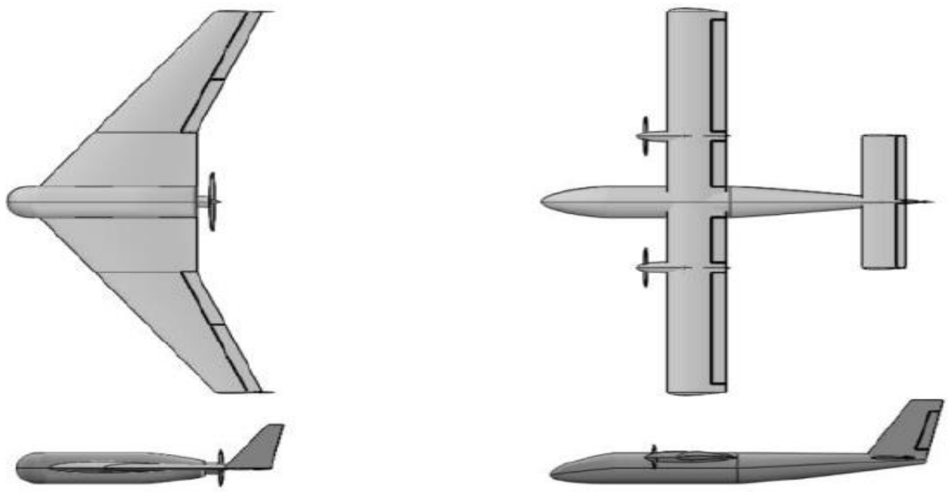

Fig. 4. BWB Baseline-IX (left) versus DHC-6 Twin Otter transport aircraft (right)

Based on Table 1, the wingspan of Baseline-IX is 21.75 meters including its wing tip vertical stabilizer while DHC-6 is 19.8 meters. The small difference in the wingspan is the reason the DHC-6 is the chosen aircraft as comparison to the Baseline-IX in this case study. Even though the wingspan of Baseline-IX surpasses the DHC-6, the length of Baseline-IX is shorter compared to Twin Otter. With a total length of 10.13 meters, the BWB Base-line-IX is 33 percent shorter than the Twin Otter. Although Base-line-IX has shorter length than DHC-6, its cabin volume of 17.9 m^3 is 39.3% larger than DHC-6's if the thick wing root is included but only slightly larger at 11.0 m^3 if only fuselage is counted. Currently, the DHC-6 is able to carry up to 21 people including pilot and cabin crew [11] as shown in

Figure 5. The aspect ratio for Baseline-IX is 6.49 while for Twin Otter is 8.58. Aspect ratio between six to ten falls under low subsonic transport category [12].

A blended wing body aircraft has an advantage through the blended wing to body design. The advantage is the extra usable area in the thick inboard wings which helps to provide more space for smaller cargo and extra fuel to be stored for longer flying time purpose (Figure 6). BWB Baseline-IX's inboard wings itself provide another 6.90 m^3 of cargo space for the aircraft, which is 62.7% extra on top fuselage or equivalent to 4,830 litres of fuel based on inboard wings volume times 0.7 (only 70% of the volume for occupied by fuel).

Table 1
Baseline-IX & Twin Otter Original Size Specifications

Specifications	Aircrafts	
	BWB Baseline-IX	DHC-6 Twin Otter
Wing span (m)	21.75	19.80
Length (m)	10.13	15.77
Cabin Volume (usable) (m^3)	17.90 (incl. inboard wing), 11.0 (fuselage only)	10.87
Aspect Ratio	6.49	8.58

Fig. 5. Seating arrangement inside a DHC-6 Twin Otter aircraft

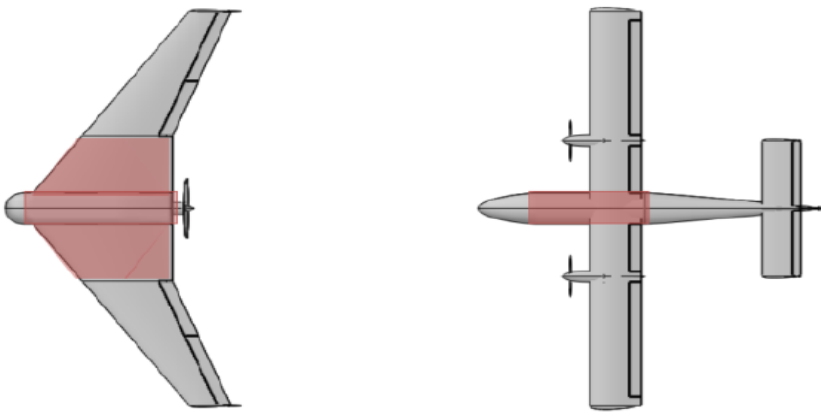

Fig. 6. BWB Baseline-IX usable area (left) compared to DHC-6 Twin Otter transport aircraft usable area (right), shaded in red

3. Experimental Setup

The experiments had been carried out in LST-1 low speed, suction, open type wind tunnel in Flight Technology and Test Centre laboratory (FTTC), Universiti Teknologi Mara, Shah Alam. This wind tunnel (Figure 7) has a test section area of 0.5 X 0.5 X 1.25 meters and is equipped with six-component external balance for force and moment measurement. Maximum wind speed provided by this wind tunnel facility is up to 45m/s.However, this study only utilizes only three components of longitudinal forces (X, Z and M) as both Baseline-IX and DHC-6 wind tunnel models are of half-model type.

Fig. 7. UiTM low speed wind tunnel

These models are 1:30 scaled-down size from the original air-craft. The wind tunnel models are drafted in commercial CAD suites converted to ".stl" files, turned into G-Code in CURA soft-ware and 3D-printed using Creatbot D600 3D printer. The completed wind tunnel model underwent finishing process of smoothing its surface from rough edges and then sprayed with black matte paint.

The wind tunnel model (Figure 8) of Baseline-IX has the half wing span of 0.35 metres with a reference area of 0.0405 m^2 while DHC-6 model (Figure 9) has the slightly shorter wing span but with smaller reference wing area of 0.0296 m^2. This shows that Baseline-IX has 36.8% larger wing area compared to DHC-6. Table 2 shows the specifications of both BWB Baseline-IX and the DHC-6 models. Baseline-IX has greater chord length com-pared to DHC-6 mainly due to Baseline-IX broader chord by 1.8 times. The experiment is done under Reynold number of 2.60 X 10^5 at airspeed of 36 m/s. For both models, the wingtip vertical stabilizer on Baseline-IX and vertical tail on DHC-6 are not fabricated and are assumed to be too thin to affect longitudinal forces.

Fig. 8. BWB Baseline-IX wind tunnel model

Fig. 9. Transport Airplane Twin Otter wind tunnel model

The pitch angle (angle of attack) is varied from -10 degree until 25 degree or until stall angle of attack with increment of one or two degree each. The Mach number used for this experiment is 0.105 and results from this airspeed can be assumed to represent the whole low subsonic flight regime (until Mach 0.3) where compressibility effect is neglected. The specifications for Baseline-IX and DHC-6 are simplified in Table 2.

Table 2
Baseline-IX & Twin Otter wind tunnel model specifications

Specifications	Wind Tunnel Models	
	BWB Baseline-IX	DHC-6 Twin Otter
Chord Length (m)	0.148	0.083
Wingspan (m)	0.362	0.356
Wing area (m^2)	0.0405	0.0296

Once data from wind tunnel experiments are recorded, blockage correction is executed before final values are tabled. The uncorrected aerodynamics coefficients then are corrected by using these formulas below [4].

Solid blockage

$$\Delta V = \varepsilon_{sb} V_U \tag{1}$$

$$\varepsilon_{sb} = \frac{K_1 V_b}{S^{3/2}} \tag{2}$$

where V_U is the uncorrected airspeed, K_1 for vertical model is 0.52, for horizontal model is 0.74 and S is the working section area. The half 1:2.4 scale model is a vertical model.

Wake blockage

$$\Delta V = \varepsilon_{wb} V_U \tag{3}$$

$$\varepsilon_{sb} = \frac{c}{2h} c_{d_u} \tag{4}$$

where c_{d_u} is the uncorrected coefficient of drag, c is the model's length and h is the height of working section. Streamline curvature correction

$$\alpha = \alpha_u + \frac{57.3\sigma}{2\pi}\left(C_{lu} + 4C_{m\frac{1}{2u}}\right) \tag{5}$$

$$\mathrm{C_l} = \mathrm{C_{lu}}(1 - \sigma - 2\varepsilon) \tag{6}$$

$$\mathrm{C_{m\,1/2}} = \mathrm{C_{m\frac{1}{2u}}}(1 - 2\varepsilon) + \frac{\sigma \mathrm{C_l}}{4} \tag{7}$$

$$\sigma = \frac{\pi^2}{48}\left(\frac{c}{h}\right)^2 \tag{8}$$

Total corrected airspeed,

$$\varepsilon_{sb} = \frac{c}{2h} c_{d_{uV=V_u(1+\varepsilon)}} \tag{9}$$

Total corrected drag,

$$C_{d0} = C_{d0u}(1 - 3\varepsilon_{sb} - 2\varepsilon_{wb}) \tag{10}$$

The total corrected data of lift, drag and moment of both Baseline-IX and DHC-6 transport aircrafts are plotted in graphs and discussed in the next subsection.

4. Results

The measured coefficients of both aircraft are plotted in the same graph for comparative purposes. These plots are coefficient of lift against angle of attack (C_L vs α), coefficient of drag against angle of attack (C_D vs α), coefficient of drag against coefficient of lift (C_D vs C_L), pitching moment coefficient against coefficient of lift (C_M vs C_L), lift to drag ratio against angle of attack (C_L/C_D vs α) and cubic lift to squared drag ratio against angle of attack as below.

4.1 Lift Coefficient (C_L)

Figure 10 shows the lift coefficient versus angle of attack (α). Based on the figure above shows that both Baseline-IX and trans-port airplane have similar shape curves. The lift coefficient in-creases as angle of attack increases. Lift coefficient at zero angle of attack (C_{L0}) for Baseline-IX is just slightly above zero while for DHC-6 is around 0.25. Meanwhile, angle of attack at zero lift (α_{0L}) of Baseline-IX is -0.65°. For DHC-6 model, the angle of attack at zero lift is -3.0°. This is possibly due to the choice of airfoil – DHC-6 uses conventional cambered thick (above 15% chord) airfoil while Baseline-IX uses reflex type MH60 airfoil with t/c of only around 10%. Cambered airfoils are known to have C_{L0} of around 0.2 to 0.3 while reflex type airfoil specifically for flying wing has C_{L0} = 0.

The gradient below the graph ($C_{L\alpha}$) for Baseline-IX is 0.067 per degree or 3.82 per radian while DHC-6 model has gradient of 0.086 per degree or 4.91 per radian. From the slope values, it shows that the DHC-6 has steeper slope than its BWB counterpart due to its higher wing aspect ratio and zero sweep angle.

The lift coefficient is at its maximum ($C_{L\ max}$) at an angle of at-tack of 9.8° for transport airplane model and 16.7° for Baseline-IX. Beyond these angles, both aircraft show decrease in lift coefficient and begin to stall. However, maximum lift coefficient for Baseline-IX is 1.01 while Twin Otter's $C_{L\ max}$ is 0.90 which shows that the Baseline-IX is able to fly at a higher angle of attack thus having 20% lower stall airspeed due to 12.2% higher $C_{L\ max}$ and 36.8% higher wing area.

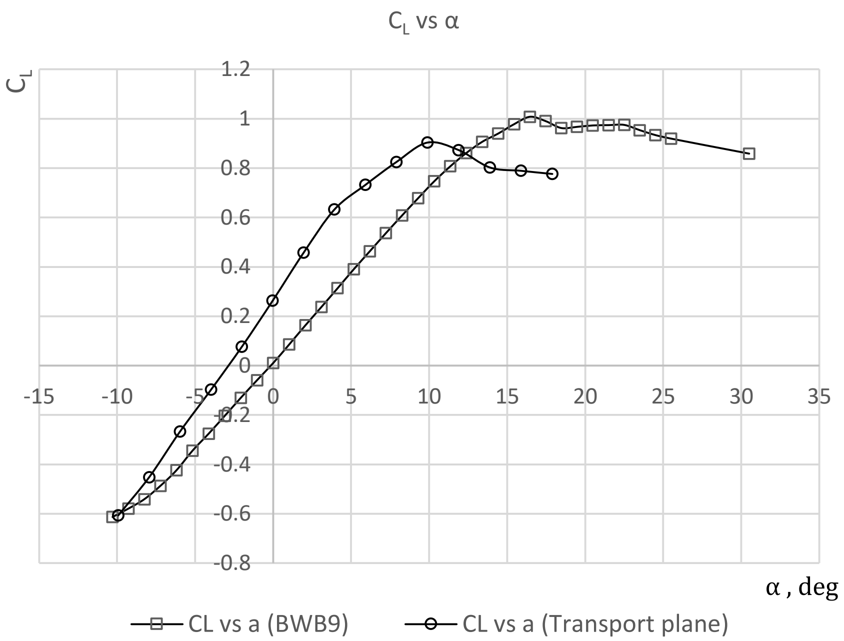

Fig. 10. Lift coefficient (CL) versus angle of attack (α)

4.2 Drag Coefficient (C_D)

Figure 11 shows the drag coefficient (C_D) versus angle of attack (α) for both models. Drag coefficient of Baseline-IX BWB is lower than DHC-6 at almost all range of usable angle of attack. The drag curves of both aircraft are parabolic for angles of attack less than stall angle of attack. Differences between DHC-6 and Baseline-IX drag coefficients changes progressively from 0.0% at near α= - 5.0 degrees to around 100% at DHC-6's stall angle of attack (α = 10 degrees). Beyond stall angle of attack, the drag coefficients increase rapidly for both aircraft.

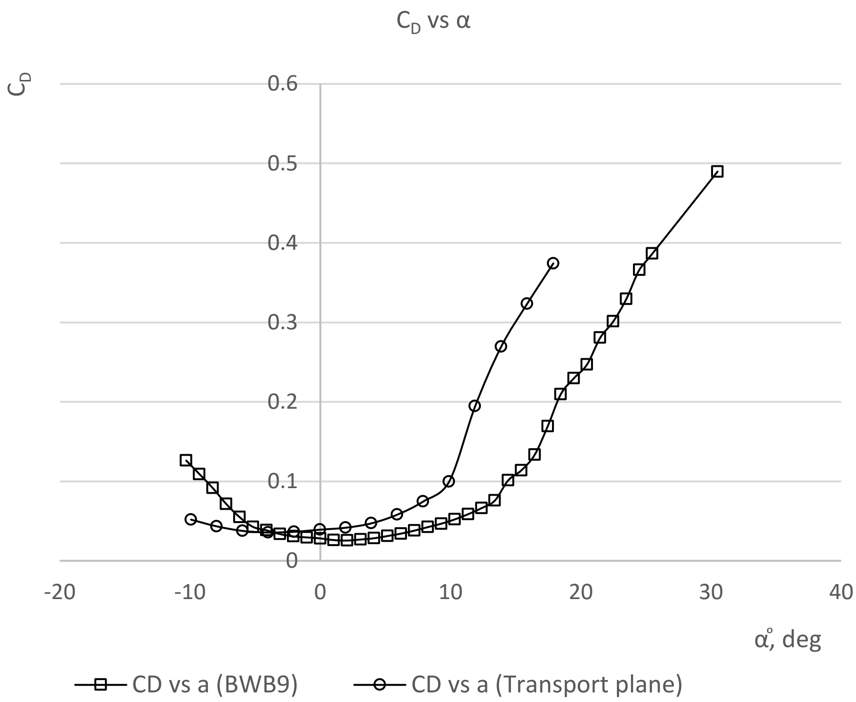

Fig. 11. Drag coefficient (C_D) versus angle of attack (α)

4.3 Drag Polar

Figure 12 shows the drag coefficient (C_D) versus lift coefficient (C_L) plots, or drag polar, for Baseline-IX and DHC-6 models. For DHC-6, shallow parabolic trend is observed at lift coefficient below C_L = 0.7 after which the plots begin to rise rapidly as angle of attack soars towards stall region. Similar observation is found on Baseline-IX BWB drag polar where low drag coefficient is registered at wide range of angles of attack and rises rapidly as approaching stall angle of attack except that there is another steep rise in drag coefficient at lift coefficient lesser than -0.3. Drag at zero lift or parasite drag coefficient C_{D0} is 0.028 and 0.036 for Baseline-IX and DHC-6 respectively meaning that drag coefficient at zero lift of the former is 30% lower that its conventional counterparts. This sounds like a promising result akin to confirming many other studies than BWB can save up to 30% fuel consumption with respect to conventional aircraft. However, Base-line-IX BW has 36.7% larger area of wing than DHC-6's and the real drag force reduction at zero lift (hence thrust required during take-off ground run, for example) is actually only 4.30%. This seems to be too little for any significant improvement on the performance but since Baseline-IX has 20% lower stall airspeed and 12% higher maximum lift coefficient compared with DHC-6, the needed runway length can significantly be reduced by at least 10 to 15 %.

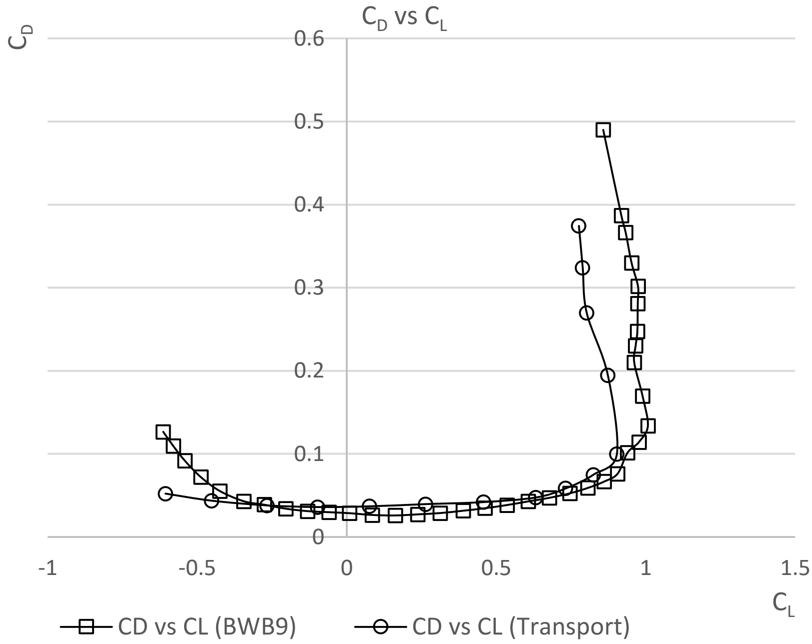

Fig. 12. Drag coefficient (C_D) versus lift coefficient (C_L)

4.4 Lift-to-Drag Ratio (C_L/C_D)

Figure 13 shows plots of lift-to-drag ratios (C_L/C_D). versus angle of attack (α) for both aircrafts. Maximum lift-to-drag ratio is 14.4at α = +9.0 for Baseline-IX and 13.3 at α= +4.0 for DHC-6. This means that for the same take-off weight and fuel capacity, BWB aircraft in study here will have 8.3% more range than its conventional type rival. Baseline-IX must also fly at higher angle of at-tack than DHC-6 and couples with its larger wing area, it is also likely than the BWB aircraft flies at slower cruising airspeed. The lift coefficient at maximum lift-to-drag ratio is 0.67 and 0.62 (8% difference) for Baseline-IX and DHC-6 respectively and the difference in cruising airspeed is only around 4.0% in which the BWB type aircraft will be lagging behind DHC-6 for 2.4 minutes for every hour of flight.

4.5 Lift Coefficient (C^3_L)/Drag Coefficient (C^2_D)

Figure 14 below shows cubic lift coefficient over drag coefficient squared (C^3_L/C^2_D) plots against the Angle of Attack (α) for both aircraft. This is seldomly being discussed in many aerodynamic studies of BWB aircraft as most of them are propelled by turbofan propulsion. For propeller driven aircraft, it is more appropriate to discuss this aerodynamic ratio parameters as it shall affect flight endurance. The parameter will be referred after this as “endurance factor”.

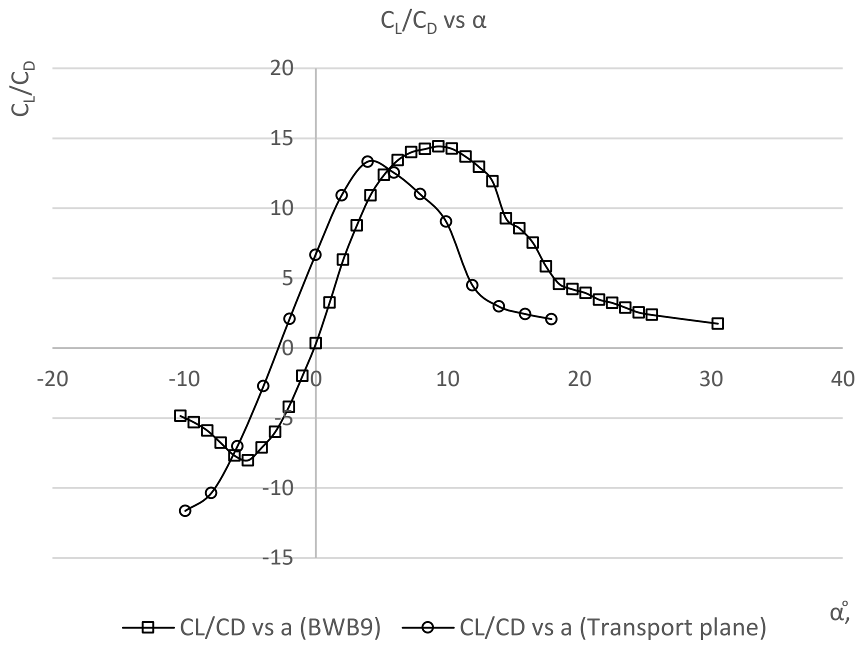

Fig. 13. Lift to drag ratio (CL/CD) versus angle of attack (α)

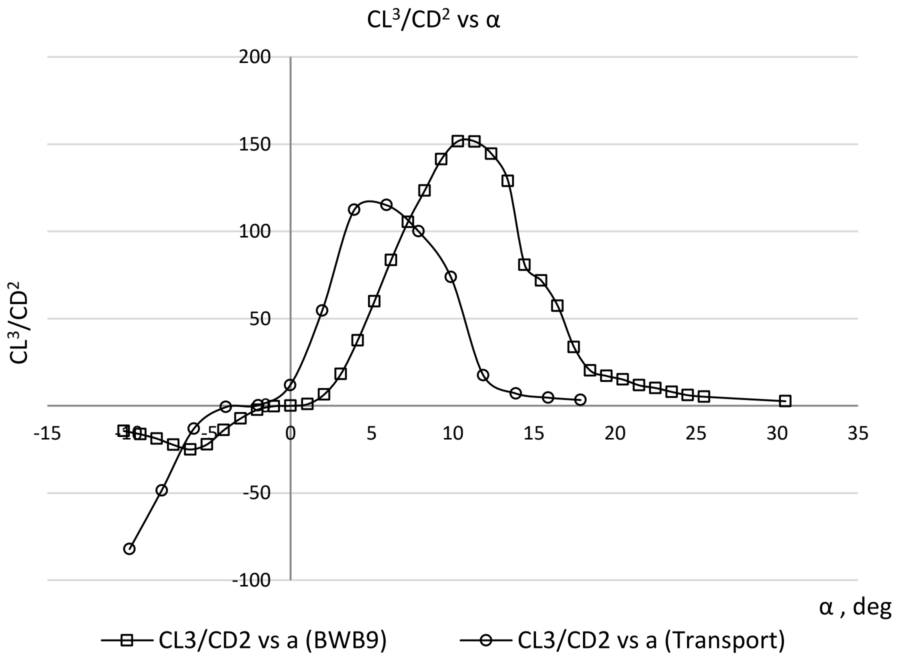

Fig. 14. Lift coefficient (C3L)/drag coefficient (C2D) versus angle of attack (α)

From Figure 14, there is significant difference on the endurance factor (C^3_L/C^2_D) between both aircraft. DHC-6 has a maximum C^3_L/C^2_D of 115.0 at an angle of attack of 6.0 degrees while Baseline-IX has a maximum C^3_L/C^2_D of 151.4 at angle of attack of 11.4 degrees. This means that Baseline-IX BWB can fly 31.7% longer time than its conventional competitor. This extended endurance can be beneficial if the small transport aircraft here also acts as surveillance platform or maritime patrol as its secondary role. In fact, both secondary roles mentioned also requires slower loitering speed and clearly Baseline-IX BWB has it slightly better than DHC-6. At 11.4 degrees angle of attack, the BWB aircraft's lift coefficient is approximately 0.8 compared with 0.72 at 6.0 degrees for the conventional transport aircraft. The 10% higher lift coefficient will result in 5% slower loitering airspeed.

4.6 Pitch Moment Coefficient (C_M)/Lift Coefficient (C_L)

The curves of pitching moment coefficient (C_M) versus Lift Coefficient (C_L) are shown in the graph in Figure 15. The moment coefficient is measured at a location of 129 mm behind Baseline-IX model's nose or at approximately quarter mean chord of its mean reference wing. For DHC-6 model, the moment coefficient (C_M) is measured at 240 mm from nose or around quarter-chord location of its reference wing. From Figure 15, both aircraft models have negative slopes of -0.04 and -0.06 for BWB and conventional aircraft respectively. This indicates that their stick-fixed neutral points are 4.0% to 6.0% mean chord behind the wind tunnel centre or reference point. In other words, these are the static margins K_n of each aircraft.

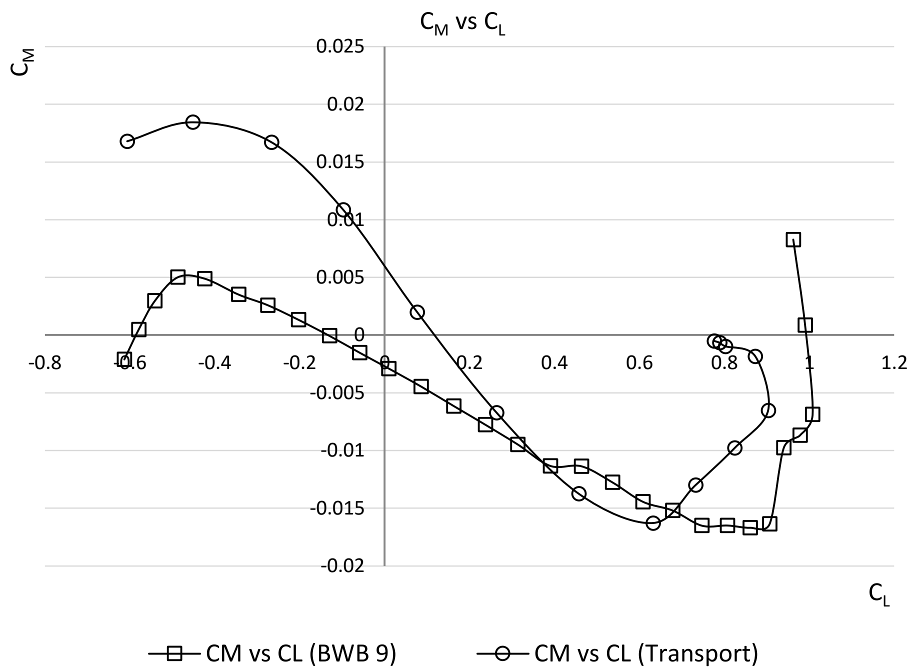

Fig. 15. Pitch moment coefficient (C_M) versus lift coefficient (C_L)

The trend here also correlates to the ideas of having neutral point further back for aircraft with horizontal tail. However, only DHC-6 is able to achieve complete longitudinal static stability by having positive value of C_{M0} or pitch moment at zero lift and positive value of trim lift coefficient. For Baseline-IX BWB, its negative C_{M0} can be made positive by having negative elevon deflection angle (elevons deflect up).

4.7 Wind Tunnel Accuracy

It is found out that wind tunnel LST-1 has an accuracy of 0.05% of full-scale measurement of ±200N. This means that the result from wind tunnel has an accuracy tolerance of ±1.0N thus coefficient of lift has an accuracy tolerance of ±0.033. The wind tunnel experiment accuracy is graphically shown in Figure 16 below. The upper and lower limit of the values obtained are referred as C_L+ and C_L- respectively which graphically shown as dotted lines.

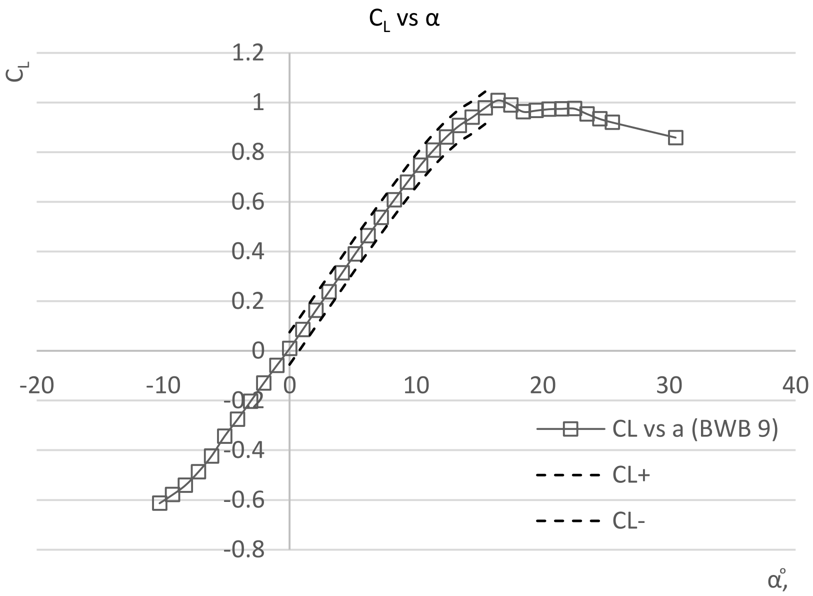

Fig. 16. Graph of lift coefficient versus angle of attack with accuracy tolerance region

4. Conclusions

While DHC-6 has steeper lift slope, Baseline-IX has wider angle of attack range, 36.8% larger wing area and 12.2% higher maxi-mum lift coefficient that stall speed drops 20% than the former's. Baseline-IX BWB has 30% lower parasite drag coefficient than DHC-6 but since its wing area is also larger its actual drop in parasite drag is only 4.3%. Despite small reduction, the take-off distance is expected to be reduced by 10 to 15% by Baseline-IX due to slower take off (stall) airspeed and larger wing area. Based on C_L versus C_D plots, Baseline-IX BWB aircraft has slightly longer flight range by 8.0% but it also cruise at 4.0% slower air speed. The endurance factor for the Baseline IV is 31.7% longer than that of DHC-6.

In the future, more precise calculations can be done, including the longitudinal stability analysis. Implicating a horizontal tail may increase Baseline-IX in terms of longitudinal stability but degrades its flight performance. Further investigation with addition of winglet to the Baseline-IX wind tunnel model will produced a higher lift-to-drag ratio. Adding vortex generators on the wing of Baseline-IX might delay the flow separation and minimize the size of the wake at the end of the wing thus improving its performance [19].

The fuselage design could be improved with its nose mimicking the transport airplane to improve its stability (Figure 17). A pair of elevon may be added to the Baseline-IX blended wings to provide more control surface to the aircraft. Improving the fuselage may even give the Baseline-IX more space for cargo though current comparison has given Baseline-IX an advantage of 39.3% of more usable volume compared to DHC-6 transport airplane.

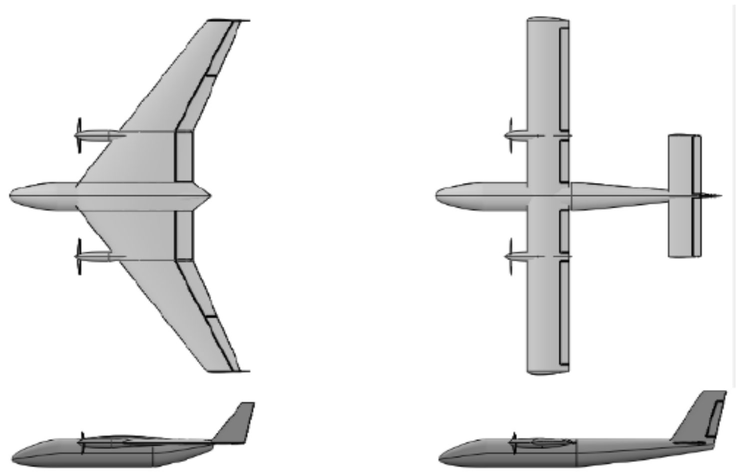

Fig. 17. Recommended improvement to BWB Baseline-IX (left) to mimic typical transport aircraft fuselage

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