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Blended Wing-Body Unmanned Aerial Transport Aircraft: A conceptual design

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Abstract
UAVs have advantages for tasks like aerial surveillance, agriculture, and transportation because of their low operating costs and the ability to automate the work. This paper introduces a conceptual design of a parcel transport UAV called Baseline-X BWB that carries two kilogrammes of payload for inter-city transport. The scope of discussion is limited to aerodynamic estimation, flight performance, and monetary cost. This UAV prototype has a longer battery charge range, a larger and heavier payload capacity, and a lower operating cost-per-mile and fleet cost per route than conventional designs of the same size, making it feasible and profitable for operators.

Keywords: Air Transport; Blended Wing-Body; Unmanned Aerial Vehicle

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1.0 Introduction

Air transport industry in Malaysia is worth USD10.3 billion in 2017 and is expected to grow to USD23.4 billion (average, current trend) in 2037 (IATA, 2022). The volume of goods using air transport in and out of Malaysia is worth USD225 billion while attracting USD140 billion worth of foreign direct investment (FDI). The volume of air cargo in Malaysia is on average 250,000 metric tonnes per quarter year or around 1.0 million metric tonnes per year from 2017 to 2019. There 116 companies with courier licence transporting 93 million and 123 million documents and parcels, respectively in 2019 and big majority of them are local transport. This is expected to grow tremendously post Covid-19 pandemic. These facts show great potentials in inter-city courier air transport in Malaysia in years to come.

Nomenclature

BWB	Blended Wing-Body
UAV	Unmanned Aerial vehicle
VTOL	Vertical Take-Off and Landing

Unmanned aerial vehicles (UAVs) are products of deep integration of aviation technology and Information technology (IT). The core factor of why the UAV industry can become a relatively independent industry and experience rapid development is the full penetration of IT into the aviation industry. Under the networked environment, UAVs are now becoming data driven mobile agents (Fan et. al., 2020). UAVs have advantages in assisting works such as aerial surveillance, agriculture and transport with minimal risk, low operating costs,

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relatively inexpensive price and ability to automate the work (Kille et. al., 2019). Currently the UAV technology is expanding to include unconventional designs and configurations to suit to their purposes.

Other than agriculture, the fast-growing sector that mulls the use of UAV is courier or parcel transportation service industry. Many courier companies are focusing on the short-range, last-mile delivery using mutirotor or helicopter drones such as the one developed by UPS in conjunction with Matternet with their M2 quadcopter (Takahashi, 2021) and DHL Malaysia-PEN Aviation collaboration with PEN55 Helicopter UAV (DHL Express Malaysia And Pen Aviation Signs MoU For Cargo Drone Delivery, 2021). The former is of multirotor electric vehicle that is simple and popular amongst drone industry players, but such UAV configuration has limited range to only within a city (10 kilometers) while the latter is a huge UAV powered by turboshaft engine thus having highly complex operation that requires highly competent crews (PEN55, 2022). Both have VTOL capabilities which is advantageous for operations within congested city, but it is this capability that makes it consume more energy (battery or fuel), inefficient to fly thus having poor performance. Their cruising speed is normally around 10 m/s or 36 km/h which is slower than motorcycles. Their range is limited to only 10 kilometres if they were to return to its base safely with battery capacity for obstacle avoidance and climbing maneuvers to spare.

There is a need for transportation of parcels between cities. With growing online shopping economies, inter-city domestic parcel delivery has becoming more important than ever. The people nowadays also want short delivery time in which delivery from a city to another within a state or inter states usually takes three to seven days. Many are also willing to pay premium price for same-day delivery service which is possible between cities of not more than 50 kilometres apart. There is no point of having fast last-mile parcel delivery via multirotor drones if parcel transport between cities is still slow. Currently, the inter-city or inter-state transport of parcel and goods are done using land transportation such as cars, vans, lorries and trains. These land vehicles are susceptible to 1) traffic congestion due to accidents, peak hours, holiday season or other reasons, and 2) road inaccessibility due to floods, landslides and other natural disasters.

Straight line distance between major cities in Peninsular Malaysia is, on average, 60 kilometres but if one to consider the some retricted areas to fly such as Putrajaya and KLIA aerodome region then the practical flying distance will be around 100 kilometres. This is out performance capabilities of all small multirotor drones. There is also a hybrid of fixed wing and multirotor UAVs such as Alphabet by Wing Inc. that combines VTOL capability of multirotor drone with flight performance of a fixed wing UAV but this type of UAV is often a compromise – Jack of all trades but master of nothing (Aphabet Wing, 2022). It is often too large to operate within a city due to its wide wingspan but also having slightly better range than mutirotor drone and not good enough for longer range, inter-city transport. With its complex propulsion and control systems, it consumes as much energy as multirotor drones while its airframe is often heavy limiting its payload carrying capability.

2.0 Literature Review

Fixed-wing UAV is preferred for such transportation in Africa such as the Rwanda-based Zipline UAV service specifically to transport medicine, vaccines, blood and medical kits (Zipline , 2022). Its 150-kilometre flying range enbles it to cover cities or villages within 75 kilometre radius. In addition, the service is commercially successful that it has now expanded to American continents and The Philipines. No such service is offered in Malaysia. If such transport service is to be offered here then the UAV must be customized to suit local terrains, flying limitations, CAAM air regulations and with better flight performance. Conventional fixed wing UAV consists of wing-fuselage-tail configuration in which the fuselage is usually long and slender that hampers it from carrying bulky items. The lifting surface (wing) area of conventional UAV is small for a given wingspan hence its ability to lift heavy payload is limited or can only be possible by increasing its take-off airspeed. This conventional UAV configuration, therefore, requires high amount of thrust from a more powerful engine that increases energy consumption. Powerful engine or electric motor is often heavy and bulky leading to increased mass of the UAV and larger drag force. In addition, the more power a motor needs, the larger battery capacity is needed for a given targeted range because it consumes more current or electrical charge per time. Other than making the UAV even heavier, larger battery then occupies more space in the fuselage thus reducing payload space.

A solution is needed to have such a small UAV carrying significant amount of parcel payload between a city to another with a flight range of a hundred kilometers that offers feasible operation within Civil Aviation Authority Malaysia (CAAM) jurisdiction and regulation, and commercially attractive to potential UAV operators or courier services (CAAM, 2021).Please make sure that you use as much as possible normal fonts in your documents. Special fonts, such as fonts used in the Far East (Japanese, Chinese, Korean, etc.) may cause problems during processing. To avoid unnecessary errors you are strongly advised to use the 'spellchecker' function of MS Word. Follow this order when typing manuscripts: Title, Authors, Affiliations, Abstract, Keywords, Main text (including figures and tables), Acknowledgements, References, Appendix. Collate acknowledgements in a separate section at the end of the article and do not include them on the title page, as a footnote to the title or otherwise.

Previous research (Figure 1) aimed at characterizing flight behavior of a tail-less Blended Wing-Body UAV being stabilized and controlled by a set of four elevons (elevator-aileron combination). It was commonly understood that most BWB aircrafts are of tailless configuration thus their flight stability may not be sufficient to ensure safe flight. Wind tunnel experiments had been executed on a model of BWB aircraft with four elevons that could be deflected at different angles independently or in unison (Nasir et. al, 2017). The lift, drag, side force and moments at all pitch, roll and yaw axes were measured and analyzed. Then plots are made to evaluate all 31 elevon mixing cases that represented the function of elevator to control pitch, function of aileron to control roll, function of rudder to control yaw, function of flaps to increase lift and function of air brake to slow down its speed. It was found that those elevons could be deflected in mixed angles and directions to achieve satisfactory stability and good flying quality (Ahmad, 2018). There were still some minor issues with aileron reversal phenomenon that occurred at high-speed flight as simulated in the experiment but that was the case when the flight airspeed was beyond the capability of its propulsion system.

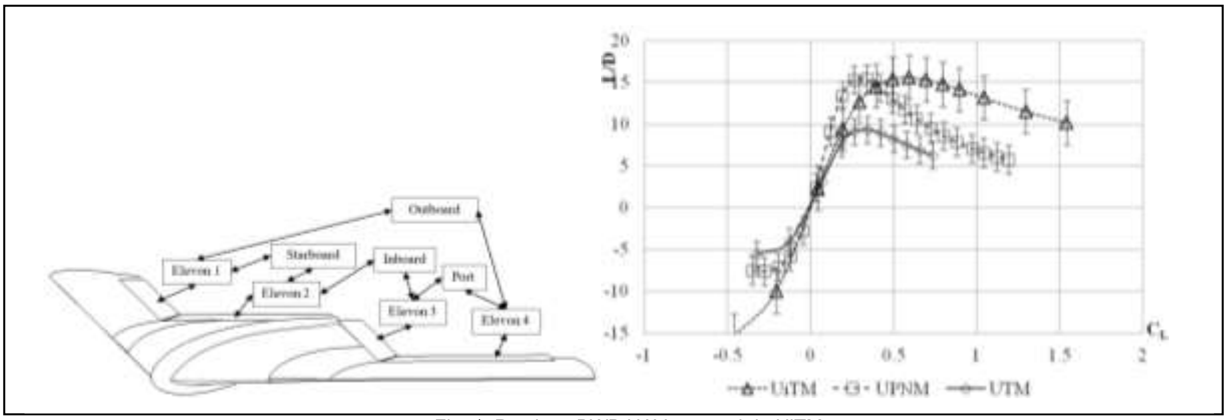


Fig. 1: Previous BWB UAV research in UiTM

The study (Ahmad, 2018) then leads to optimization of BWB UAV design that ensured positive stability and good controllability while also improving aerodynamic efficiency that lowers energy consumption and cost (Figure 2). It has been known by BWB aircraft research community that BWB aircraft design enables around 20 percent improvement in flight range over conventional airplanes of the same wingspan and class (Dakka & Johnson, 2019). However, achieving this requires careful attention to the planform shape, spanwise chord distribution, aspect ratio, wing sweep angle, airfoil selection and centre of gravity location. The BWB UAV studied in (Ahmad, 2018) has evolved into a more "blended" and smooth planform shape inspired by the planform shape of a manta ray fish. Blended Wing-Body technology is an advancement of flying-wing design. Unlike flying wing, which is purely a wing, BWB has a proper body (fuselage) but the body also produces lift and the gradual change from body section at the centre to wing at the outer span reduces interference drag. In fact, a proper BWB design has almost no border between body and wing. In short, almost all parts of the wing-body generate lift unlike conventional airplanes that have much smaller lift force from its relatively smaller wing. Airfoil profile of the body also has lower drag than conventional tubular fuselage on conventional aircraft. Combination of all these produces large lift but low drag on the BWB aircraft (Muta'ali, 2020).

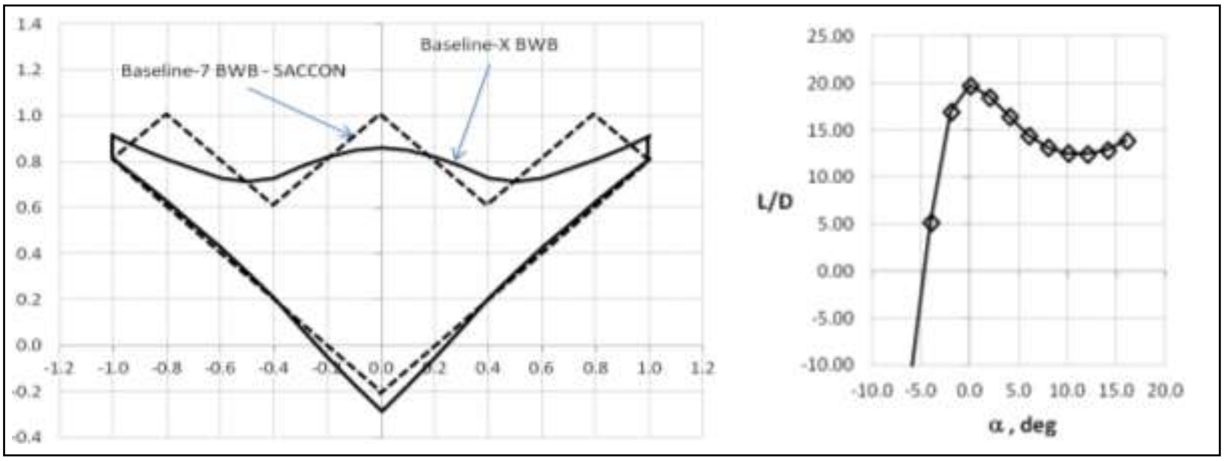


Fig. 2: Improvement to BWB planform design

3.0 Methodology

The Baseline-X BWB aerial transport UAV is an innovative solution to support small, urgent, fast inter-city parcel transport with maximum range of five to ten times the range of currently-operated multirotor drones. While the latter is used for the last-mile parcel delivery within a city or town, the proposed prototype is designed to solve inter-city parcel transport which is currently covered by land transport. This solution will be proven to provide faster arrival to destination by avoiding road congestion, traffic lights and other obstacles. Fig. 3 shows the proposed flight plan for case study here. It is a route of fixed-wing type UAV from Shah Alam to Seremban avoiding two no-fly zones at Putrajaya and KLIA Aerodome. The simulated flight distance is 95.2 kilometres and if climb distance to altitude and landing approach maneuvers are taken into account, estimated total range shall linger around 100 kilometres.

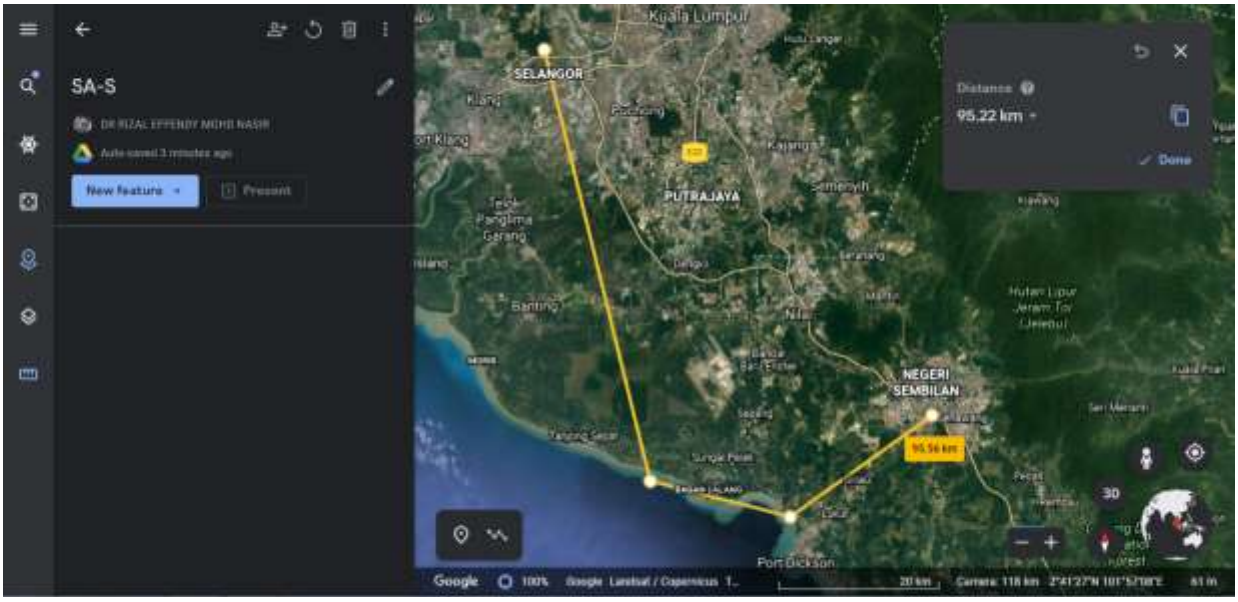


Fig. 3: Case study flight plan for inter-city parcel delivery transport UAV

Figure 4 shows 3D model drawings of the proposed aerial transport UAV called Baseline-X (ten) BWB. Its primary mission is to transport parcels, documents, or medical supplies from one city, town or village to another within 100-kilometre radius from its take-off location. It will be only 2.0 metres in wing span, 1.2 metres in length and 0.3 metres in height including its retractable landing gears. Its maximum take-off mass is 9.0 kilograms which also includes 2.0 kilograms of payload within its 11.5 litres internal cargo bay (0.36 m L x 0.46 m H x 0.07 m H) and 2.4 kilograms of 6-cell, 22.2-Volt 18650 Lithium-ion batteries with 20 Ah capacity. The battery will power up either a single unit of 90-mm or two units of 64-mm electric ducted fans (EDF) rated at 22.2V with maximum of 40 A of current to produce a total of 2.0 kg-f of thrust. It shall take off conventionally on runway less than 100-metre long (length of football field) to an allowable altitude of 400 feet above ground and cruise on preset route with maximum total flying distance of 100 km at constant airspeed of 100 km/h.

The Baseline-X BWB is equipped with BVLOS flight capability in which our previous research grant had enabled us to develop a 4G Internet-based UAV-ground control communication, control and navigation system (Kuntjoro et. al. 2019). BVLOS (beyond visual line-of-sight) UAV operation is now legally allowed by the Civil Aviation Authority of Malaysia (CAAM) under the Civil Aviation Directives CAD 6011 (CAAM, 2021). This directive put such UAV under Special Category without requiring the aircraft to obtain Type Certificate (TC) and Certificate of Airworthiness (CA). With unmanned traffic management system (UTMS) currently being tested by CAAM and service providers, this prototype can finally be integrated into such system. The proposed prototype will be the first aerial transport UAV incorporating tail-less BWB configuration in Malaysia that offers various special features that will be explained next.

Its design originality lies in its formulation in getting its distinct aerodynamic shape. The prototype incorporates Blended Wing-Body tail-less design and technology based on our own formulation in shaping ("softening" or gradual change in chord, airfoil and sweep angle) the planform from the original SACCON-inspired straight, cranked planform. The design has lifting area of 1.0 metre squared and aspect ratio of only 4.0.

Aerodynamics of this UAV will be estimated by using Lifting Line Theory (LLT) at all of its 21 cross-sectional spanwise locations on its wing-body with Lift Reduction Approximation (LRA) empirical equation to come up with sectional lift coefficient. Then the total lift of the whole wing-body is computed by integrating/summating all sectional lift coefficient times local chords. The summation is then divided with the total wing-body planform area to determine its lift coefficient at given angle of attack. The process is repeated for range of angle of attack from -5 deg. Until +15 deg. For drag coefficient and pitch moment coefficient computation, similar approach is applied but with Drag/Moment Estimation equations used for each spanwise section instead.

Lift, lift-to-drag ratio and pitch moment coefficients versus angle of attack shall be plotted to find its optimal flight conditions and to ensure positive longitudinal static stability. These coefficients, together with other aircraft specifications are used to approximate and compute its flight performance characteristics at near sea level altitude to find out how much thrust, power and battery capacity needed for its 100-km journey, its stall, maximum and optimal airspeeds, its maximum rate of climb.

Flight simulator of Baseline-X BWB UAV is developed for the purpose of simulating the flight based on the planned Shah Alam-Seremban route shown in Fig. 3. It is in this simulation that its flying quality is assessed (and will be discussed further in another publication) and its flight performance is validated. Based on the previous fundamental study on flight dynamic characterization of a BWB UAV with four elevons, the proposed transport UAV design incorporates similar control surface (elevon) setup and control strategy to Zainurin et. al. (2021). Figure 5 shows flight simulation pictures and performance plots. The geometry, aerodynamics, mass, powerplant system and other systems were modelled in X-Plane flight simulator suit to evaluate its flight stability and flying quality. The benchmark of flying quality is based on MIL-F-8785C standard (USAF, 1980). The flight control algorithm in the flight simulator does not incorporate any artificial stability augmentation. The flight simulation shows that the proposed BWB transport UAV has good stability and flying quality in both longitudinal and lateral-directional modes. It is commonly known that a tail-less flying wing requires artificial stability augmentation in order to achieve good stability and flying quality. However, in the proposed BWB transport UAV case, this happens without stability augmentation. In simple terms, it is naturally stabilized.

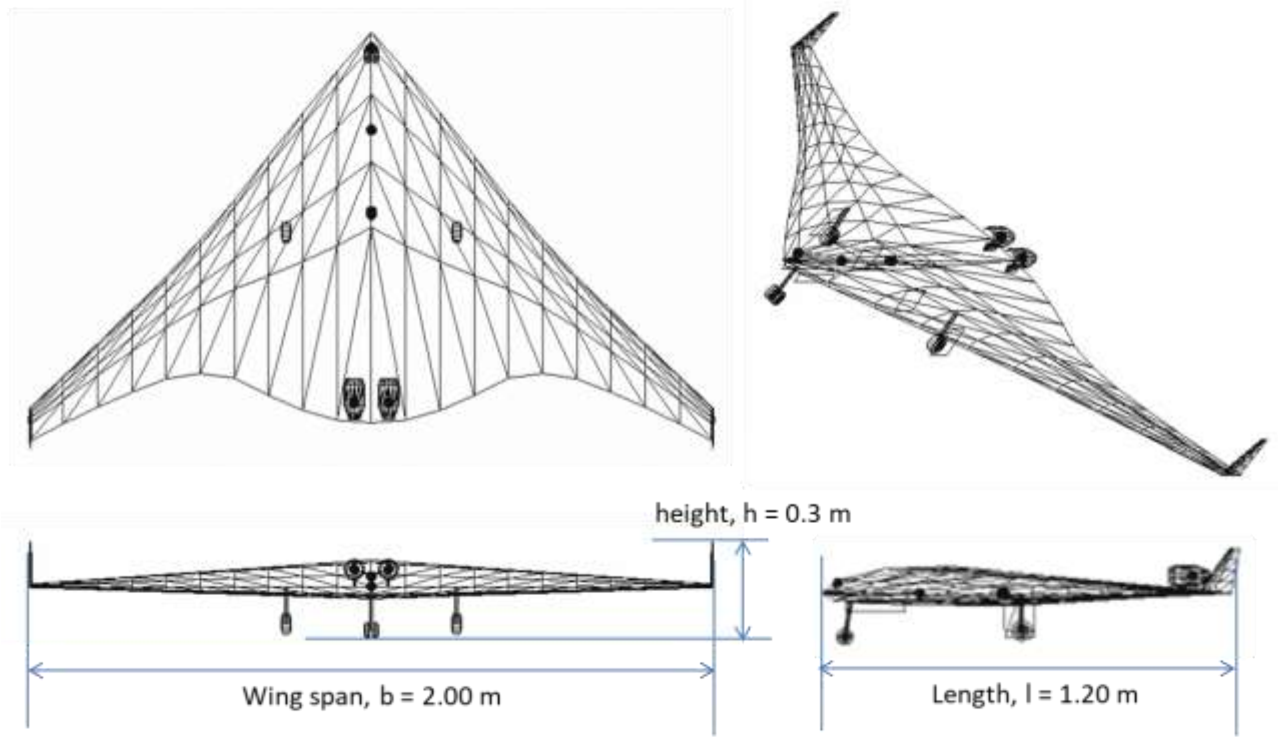


Fig. 4: Baseline-X BWB aerial transport UAV

Fig. 5: Baseline-X BWB UAV flight simulator

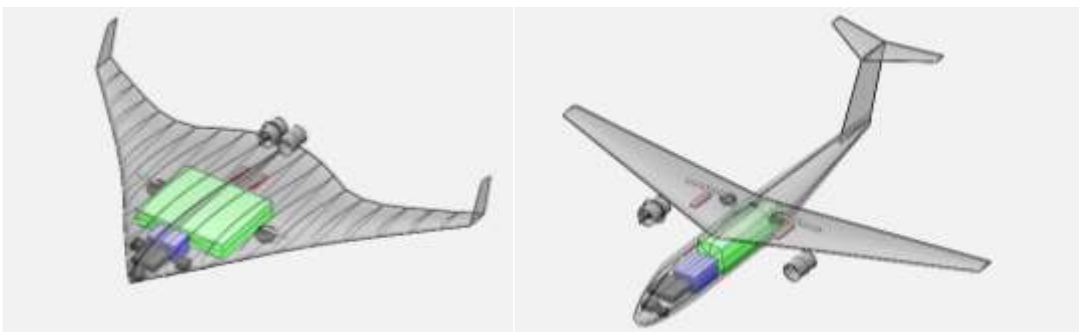


Fig. 6: Baseline-X BWB UAV (left) and Conventional UAV (right) CAD models

As comparison, a conventionally configured transport UAV is also analyzed. The conventional UAV will have the same wingspan as the Baseline-X and has slightly longer fuselage than Baseline-X's body. Fig. 6 shows the comparison. It is obvious that BWB configuration has larger, wider cargo space within its body than within conventional UAV's fuselage. In this case both types are using the same propulsion, navigation and control system. There is difference in empty mass of both aircraft as the BWB type has larger wing thus its empty mass is higher and so does its gross mass (MTOW). Ultimately will all these will be used to estimate the operational cost of flying based on Tenaga National Berhad's maximum tariff rate of RM0.51/kWh for its 20A-h battery charging cost. The rest of the cost is estimated based on method established by Roskam (1990).

4.0 Results and Discussion

Fig. 7 shows aerodynamic coefficient plots for the proposed BWB transport UAV. Despite its low wing-body aspect ratio of only AR = 4.0, it still be able to produce maximum lift coefficient of CL = 0.9 (below left) while having zero-lift drag coefficient of just CD0 = 0.01 (below right). At design lift coefficient of CL = 0.35 representing economical (optimal) cruising condition, its lift-to-drag ratio is L/Dmax = 19.5 (bottom left). Normally a conventional transport aircraft has L/Dmax around 15.0 to 17.0 at AR = 6.0 - 8.0. This 15% BWB transport UAV's L/Dmax improvement over conventional transport design does not sacrifice flight stability and control. The plot of CM versus CL (below right) shows that it has negative slope indicating positive stability with good static margin of 10% mean chord. Its pitch moment coefficient at zero lift is CM0 = 0.0 hence with only small elevon deflection, the BWB transport UAV can easily be "trimmed" to optimal angle of attack where the lift-to-drag ratio is maximum. This is not the case for many BWB UAV design especially previous designs from Flight Technology and Test Centre. The propose BWB transport UAV design is the state-of-the-art when it comes to Blended Wing-Body technology.

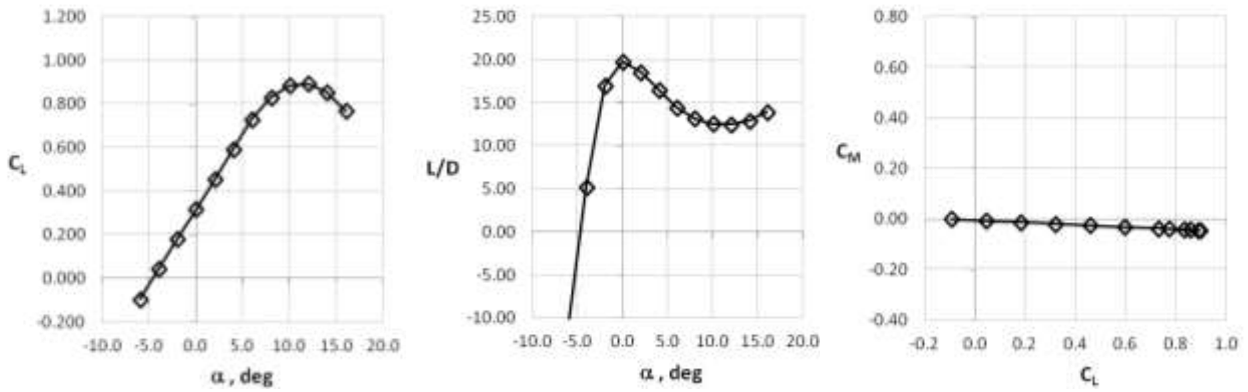


Fig. 7: Aerodynamic characteristics of Baseline-X BWB UAV

Fig. 8 shows thrust, power and rate of climb versus flight airspeed for the proposed BWB UAV and its conventional equivalent. For 100 km/h cruising speed it is obvious that the BWB UAV only requires 5.0 N (0.5 kg-f) of cruising trust at sea level altitude compared with the conventional that requires 60% more. The former has also higher top speed than the latter. In short the former requires less energy to do work, hence less power required for similar maximum rate of climb. It is also found that, performance-wise, in comparison with conventional transport UAV of similar wingspan, Baseline-X BWB UAV has the following advantages;

- Due to its lifting body capability, its effective wing planform area is 150% more than conventiona UAV. This means that it can carry heavier mass or having lower pressure on its wing. This imposes less stress on its structure or its structure can be made thinner, lighter and simpler than conventional wing.
- Its wide, thick lifting body can accommodate twice the cargo volume of conventional UAV (11.5 L versus 5.5 L). This means that it can also carry large and wide parcels such as Pos Malaysia's standard prepaid domestic envelope or box pack. Alternatively, it can carry two 500-sheet reams of A4 papers in its cargo bay.
- Its gross and empty mass is heavier by 16% and 39%, respectively, than conventional UAV but remember that it has 150% more lifting area thus it mass is not a disadvantage. In fact, despite its heavy mass, it requires 35% less power to cruise at design speed of 100 km/h than its conventional counterpart. For electric vehicle, this translates to equal percentage of throttle setting and required current consumption reduction. With only 60% of battery capacity is allowed for propulsion while another 10% is used by its avionics, 10% as spare capacity for emergency power needs and the last 20% is unusable (to ensure battery life longevity), the BWB UAV here have 1.15 hours of flight endurance which correspond to 114.5 km cruising range as opposed to 0.7 hours and 73.6 km from conventional UAV. This 55.6% improvement ensures the success of its intended mission.
- Its stall speed is only 45 km/h compared with 51.6 km/h of conventional UAV despite its heavier take off mass. Despite just merely 11% speed reduction, it has strong impact to take off and landing distance. The BWB UAV has take off distance of only 79 metres which is 30 metres shorter than its conventional UAV. The 28% improvement is less impressive than its landing distance improvement – 54.8 metres against 100 metres or 46% shorter than conventional UAV. Eighty metres is really a short distance when it comes to aircraft take off and landing.
- It is also faster than conventional aircraft by considerable margin of 10% - 172 km/h against 157 km/h maximum speed. It also has better rate of climb at 816 feet per minute versus 773 feet per minute with higher ceiling (maximum height) of 2000 metres versus 1800 metres. Therefore, it is not only faster but also also climbs 5% faster and be able to fly 11% higher than conventional UAV.

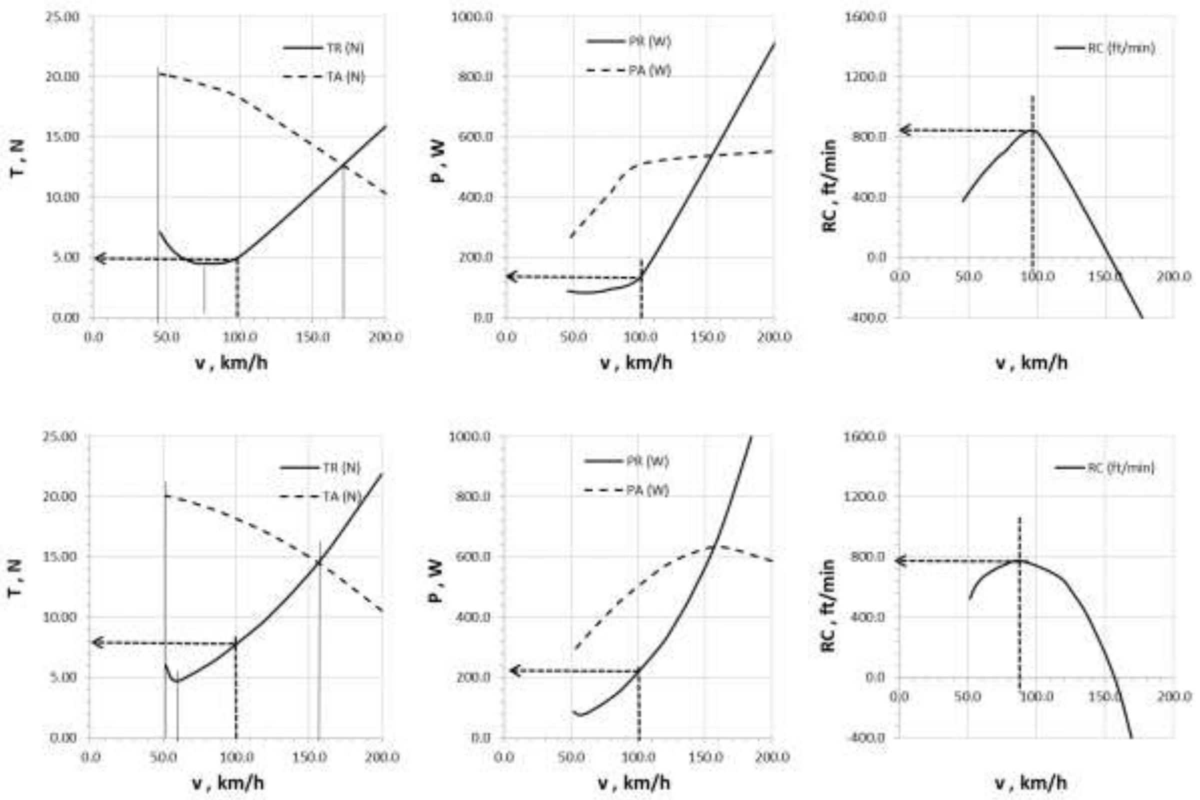
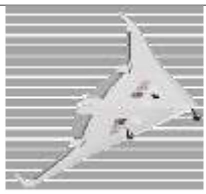


Fig. 8: Flight Performance Comparison between the proposed BWB UAV (top) and its equivalently sized (similar wingspan) conventional UAV (above).

Table 1 : Performance comparison of various transport UAV designs

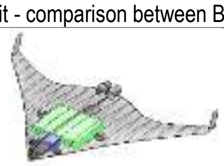
					
UAS	Baseline-X BWB	Zipline	Alphabet Wing	DHL Malaysia PEN55	UPS-Matternet M2
Aircraft type	BWB/flying-wing	conventional fixed wing	VTOL fixed wing	helicopter	quadcopter drone
Origin	Malaysia	Rwanda	Australia	Malaysia/France	USA
Mission	Transport/delivery	Transport/delivery	Transport/delivery	Transport/delivery	Transport/delivery
Secondary role	Surveillance, mapping	-	-	Surveillance, security	-
Payload type	parcel, documents, vaccines, medicines, anything	Vaccines, New treatments, Medicines, Essential medical products and safe blood	Food, Vaccines, blood, small goods	essential supplies to ships	parcel, documents, vaccines, medicines, anything
MTOW (kg)	9.00	10.0	8.0 - 12.0	55.0	11.5
Payload mass (kg)	2.00	1.75	1.50	15.0	2.00
Wing span (m)	2.00	3.00	1.00	2.64	1.28
cruising speed (km/h)	100.0	75.0	60.0	80.0	36.0
maximum speed (km/h)	172.0	128.8	113.0	110.0	43.2
Range (km)	114.5	150.0	20.0	100.0	20.0
Endurance (h)	1.15	2.00	0.33	2.5	0.56
Propulsion	electric ducted fan	twin electric propellers	14 electric propeller	gas turboshaft	4 electric rotor
Launch	short/normal take off	rail launcher	vertical take off	vertical take off	vertical take off
Recovery	normal landing	arrestor	vertical landing	vertical landing	vertical landing

Operations	-	Africa continents, USA, Philipines	Australia, Finland, USA	Malaysia	USA, Europe

There are some oversea competitors in term of transport UAV. Table 1 shows potential competitors to Baseline-X BWB UAV. The most established and closest to the proposed UAV is Zipline UAV that transport medical supplies to rural areas in Africa. However, its mission profile does not suit transport and delivery method for general transportation of good by courier companies. It is launched via catapult - the sudden acceleration during launch may break or spoil items inside the cargo bay - and the goods are air-dropped using parachute. This is not allowed under the Malaysian Civil Aviation Regulation (MCAR) (CAAM, 2021). Although smaller and lighter than Zipline, Baseline-X BWB UAV is faster and carries heavier payload. The only drawback is range and endurance because Zipline has larger batteries. Its mission requires it to come back home thus the radius of operation is limited to only 75 km where as Baseline-X BWB can land 100 km away from its original base and just swap to newly-charged batteries for return flight. The other competitors in shown in figure above do not fit for the inter-city parcel transport.

Table 2 highlights potential cost and revenue from Baseline-X BWB UAV and its conventional counterpart. Baseline-X BWB UAV's proposed selling price is RM40,000 or around USD10,000 with airframe lifecycle usage of 2000 flight hours. Assuming that conventional UAV has the same price and lifespan, the figure compares how the proposed aerial transport UAV can save cost and generate better profit per aircraft. 2000 flight hours at average 100 km/h translates to 200,000 km lifecycle mileage. This is 35 % better than conventional UAV that consume more energy per mile. Assuming that this UAV flies 4 trips a day for 250 days per year, then the airframe lifecycle usage is around two years. Dividing the procurement cost to each one-hour flight, the cost per flight (or per flight-hour) is RM15 and this translates to 15 cents per km in term of procurement cost per mile. This is 26% cheaper than RM20 per hour and 20 cents per km for conventional aircraft. Other important costs are electricity bills (consider maximum tariff of 51 cents per kWh for commercial use), flight crew manhours, MRO (maintenance, repair and overhaul), last-mile rider wage (RM3 per trip within 10 km radius per parcel) and insurance. All these costs including UAV procurement become operation cost of the UAV. Baseline-X BWB UAV has 37 cents per km which translates to RM36.56 per flight-hour and RM18.28 per kg of parcel per flight-hour. The conventional UAV costs 50 cents, RM49.74 and RM24.87, respectively. In short, the proposed prototype can potentially offer 26% operation cost saving over conventional UAV. With premium same-day delivery parcel pack price of RM20 per unit at maximum 0.5 kg items, four packs can be carried per flight or RM80 per flight revenue. The profit per flight is RM43.44 per flight or over RM43,000 per year per aircraft and almost RM87,000 per its lifecycle. The profit per aircraft from Baseline-X BWB UAV is 43.6% more than its conventional counterpart.

Table 2: Procurement and operation cost, revenue and profit per aircraft unit - comparison between Baseline-X BWB and Conventional UAV

Parameter	Symbol (Unit)	 Baseline-X BWB	 Conventional	%Δ
Procurement (Aircraft price)				
UAV selling price (keep constant)	$C_{aircraft}$ (RM)	30,000.00	30,000.00	
airframe structural lifecycle hours	$t_{lifecycle}$ (h)	2,000.00	2,000.00	
flight range per lifecycle	$km_{lifecycle}$ (h)	200000.00	147173.00	35.9
number of flight per year (4 per day for 250 days)	n_{flight} (per year)	1000	1000	
lifecycle year	$t_{lifecycle}$ (year)	2.00	2.00	
procurement cost per flight hour	C_{achour} (RM/h)	15.00	15.00	
procurement cost per flight km	C_{ackm} (RM/km)	0.15	0.20	-26.4
Operation Costs (Energy, manhour, procurement, MRO, last-mile rider cost, insurance included)				
operation cost per km flight	C_{perkm} (RM/km)	0.37	0.50	
operation cost per hour flight	C_{perhr} (RM/hr)	36.56	49.74	
operation cost per kg payload per hour flight	$C_{perkghr}$ (RM/kg-hr)	18.28	24.87	
operation cost per flight	$C_{perflight}$ (RM/flight)	36.56	49.74	-26.5
Revenue				
Price per unit parcel pack	R_{parcel} (RM/unit)	20.00	20.00	
mass of parcel allowed per unit	m_{parcel} (kg)	0.50	0.50	
number of parcel per flight	n_{parcel} (unit/flight)	4.00	4.00	

Revenue per flight	R_{parcel} (RM/flight)	80.00	80.00	
Profit per unit aircraft				
profit per flight	Profit (RM/flight)	43.44	30.26	
profit per year per aircraft	Profit (RM/year)	43,444.89	30,263.54	
profit per aircraft lifecycle	Profit (RM/lifecycle)	86,889.78	60,527.08	43.6

Table 3: Fleet operation cost, revenue and profit per aircraft unit - comparison between Baseline-X BWB and Conventional UAV

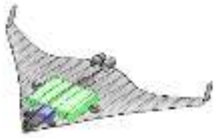
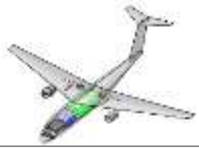
Parameter	Symbol (Unit)	 Baseline-X BWB	 Conventional	%Δ
number of aircraft per fleet	n_{fleet} (unit)	16	16	
procurement cost per fleet	C_{fleet} (RM)	480,000.00	480,000.00	
number of active aircraft	n_{active} (unit)	12	12	
number of spare aircraft	n_{spare} (unit)	4	4	
operation cost per flight per aircraft	$C_{perflight}$ (RM/flight)	36.56	49.74	
number of flight per day	$n_{flight/day}$	48	48	
flight operation cost per day	$C_{Operation}$ (RM/day)	1,754.65	2,387.35	-26.5
number of operational day per year	Op day/year	250	250	
yearly flight operation cost	$C_{Operation}$ (RM/year)	438,661.32	596,837.51	-26.5
yearly spare aircraft possession cost	C_{spare} (RM/year)	60,000.00	60,000.00	
total operation cost per year	C_{year} (RM/year)	498,661.32	656,837.51	-24.1
total operation cost per day (average)	C_{day} (RM/day)	1,994.65	2,627.35	-24.1
Based on Example 2 Mission				
yearly revenue from parcel charge per fleet	R_{parcel} (RM/year)	960,000.00	960,000.00	
lifecycle revenue from parcel charge per fleet	R_{parcel} (RM/lifecycle)	1,920,000.00	1,920,000.00	
Daily profit on operation day per fleet	Profit (RM/day)	1,845.35	1,212.65	52.2
Yearly profit per fleet	Profit (RM/year)	461,338.68	303,162.49	52.2
lifecycle profit per fleet	Profit (RM/lifecycle)	922,677.36	606,324.99	52.2

Table 3 simulates the potential cost and revenue for a fleet of UAV operated between City A and City B which is 100-km flight route apart. Example of route is shown above for Shah Alam-Seremban transport service which avoids Putrajaya airspace and KLIA aerodome region. Although straight line distance between these two cities is merely 60 km, the flight route is almost 100 km. With each UAV permitted flight is 4 times per day, a courier company need 16 of them if it were to launch one UAV every 15 minutes within 9 am to 4 pm flight operation. Eight of them are located at each city with six of them are on active operation and two are stored as back up UAVs and for training purpose. Every time a UAV departs from City A towards City B, another departs from City B towards City A. With a total of 48 flights a day from 12 operational UAVs, operation cost per day for Baseline-X BWB UAV is slightly less than RM2,000 while its conventional UAV operator has to fork out RM2,627.35. Yearly cost for the former is just shy of RM500,000 and this is 24% less than the latter. With yearly revenue of RM960,000 or almost RM2.0 million over its lifecycle, the potential profit from this fleet is RM461,338.68 per year and RM922,677.36 per its two-year lifecycle. This is 52% higher profit than its conventional UAV fleet operation. The profit can be used to procure a new fleet of UAVs while the old fleet can be sold to be overhauled for another 1000 flight hours and repurposed as surveillance UAV carrying light payload such as camera. With huge investment and serious marketing, as many as 40 fleets can be created to cover all major cities in Malaysia each with average of two routes. Potential revenue per year from just this parcel delivery pack product is around RM40 million and this is a case for just one courier company. There are more than 100 licensed courier companies in Malaysia. For UAV design house and manufacturer, potential revenue from 40 UAV fleets or 640 aircrafts is RM25.6 million over its lifecycle of two years and this does not include potential revenue from MRO service around RM2.6 million.

5.0 Conclusions

The proposed Baseline-X BWB UAV a new conceptual parcel air transport UAV based on Blended Wing-Body configuration that is proven to have better flight performance, lower energy consumption and hence lower operation cost-per mile compared with its equivalent conventional UAV. In fact, interm of flight performance and payload carrying capability, Baseline-X BWB is on par with leading operational UAVs on market and also better than many others. Fleet operations for Shah Alam-Seremban flight route avoiding two no-fly zones is simulated and computed in which the potential revenue and profit from Baseline-X BWB UAV operations is higher than its counterpart. In the near future, detail analyses and discussion on flying quality and handling of this UAV will be conducted. The flight performance and stability of this design also allow it to be applied to agricultural purposes such as crop-spraying, monitoring, surveillance and others. New grant has also been secured in which a prototype will be constructed, integrated and flight tested to validate claims made in this paper.

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