

# Conceptual Design of Blended-Wing-Body Business Jet

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**Blended wing body (BWB) business jet is a new concept of business jet aircraft which give an alternative solution to solve the fuel efficiency problem of long range jet aircraft. The longer range of an aircraft, it means aircraft must have higher velocity to cut the time deficiency, and it means more fuel to burn up and more cost to pay. In the present work, conceptual design of BWB business jet was carried on to solve the Design Requirement and Objectives (DRO) of a business jet aircraft which mainly based on long range aircraft requirement. The design calculation of the present work was mainly based on empirical formulas from the references and doesn't involve any experimental simulation or advance computational simulation such as CFD and FEM. The DRO itself, consist of the demand to design business jet aircraft of 6-12 passengers which can fly nonstop from Jakarta to Los Angeles ( 7800 nm). In the present work, BWB business jet design is high subsonic speed (0.85 M) with 3 high bypass turbofan engines. This design mainly construct to have high aerodynamic efficiency (high maximum lift to drag ratio) to get high fuel efficiency. To solve stability and control problem, present BWB design consist of reflexed camber airfoil, split rudder and winglet as vertical stabilizer. With this advance design, the present BWB design also mainly construct to have not quite far purchase price compare with the competitor.**

## I. Introduction

Flying wing aircraft concept is one of the thing that always be the aircraft designer's dream. This concept eliminates the fuselage that known as zero-lift component which produce biggest portion of aircraft drag. With this concept, it is hoped that the aircraft can have a very high aerodynamic efficiency. This concept had been long become concept that keep on developed for all kind of aircraft from military type to civilian transportation. B2-Spirit aircraft is one of the legendary military (bomber) aircraft that succeed enough using this concept on it's time.

Civilian aircraft adopt this concept to make benefit of fuel efficiency as logical consequence of high aerodynamic efficiency. But, for the civilian aircraft's application one of the main problem such as cabin placement for passengers (payload), then show up. That reason leads modification of flying wing concept to blended wing body (BWB) concept. BWB concept is actually pretty similar with flying wing concept, but it's just that there is less fuselage effect given on this concept that integrated smoothly (blended) with the wing for cabin placement.

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However, it is hoped that BWB concept still have the same benefit as flying wing, like high aerodynamic concept. Although up to this moment, civilian transport aircraft with BWB concept can't be commercially made yet, but prototype of this concept has built and developed, such as prototype of Boeing X-48, a civilian transport aircraft with BWB concept.

In the present work, BWB concept applied on long range business jet aircraft. It is related with market need on business jet aircraft which is able to go through pretty far distance by considering the business's need on time and cost efficiency. BWB configuration propose the solution by provide aerodynamic efficiency on high subsonic speed. However, the objective of the present work limited on the conceptual design that only determine whether the determined configuration is feasible to make and able and able to fulfill the determined DRO.



Figure 1. Boeing X-48 (left) and B2-spirit (right)

## II. Design Requirement and Objectives (DRO)

To get the boundary of the present design work, list of DRO are shown in table 1.

Table 1. DRO Specification

Specification	DRO
Type	Business jet
Cabin capability	6-12 passengers
Range	
Maximum Range	Nonstop fly from Jakarta-Los Angeles ( 7800 nm)
Range with maximum payload	3500 nm
Cruise altitude	Above 41000ft
Requirements based on FAR 25	
Engine numbers	2 or more
Minimum flight crew	2 or more (per 10 hours)
Minimum cabin crew	1 or more ( 10 passengers per 10 hours)
Flight performance	Calculated based on FAR 25

## III. Initial Weight Sizing

Initial weight sizing process is initial step to guess the weight of an aircraft that will be design based on the mission profile of the aircraft. This process is an iterative process to determine initial weight parameters such as:

- Take-Off Gross Weight ( $W_{TO}$ ),
- Empty Weight ( $W_e$ ),
- Mission Fuel Weight ( $W_f$ ).

Those parameters are calculated based on ref-1 with input parameter such as:

- 1<sup>st</sup> mission (3500 nm):
  - Maximum payload = 12 person (1200 kg)
  - Flight crew = 4 person (400 kg)
  - Cabin crew = 2 person (200 kg)
- 2<sup>nd</sup> mission (8000 nm):
  - Maximum payload = 8 person (800 kg)

- Flight crew = 4 person (400 kg)
- Cabin crew = 2 person (200 kg)
- Cruise altitude for both mission is 43000 ft with speed of 0.85 Mach.
- Specific fuel consumption (Ci) for cruise is 0,5 lb/lbT/hr
- Maximum lift-d

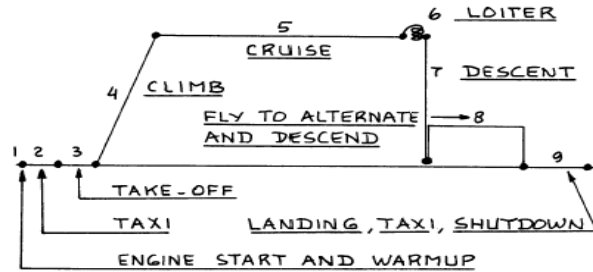


Figure 2. Aircraft Mission

With those input parameters, then give:

- $W_{TO} = 8451$  kg (3500 nm)
- $W_{TO} = 47723.5$  kg (8000 nm).

To comply the maximum range requirement, so the chosen values are:

- $W_{TO} = 47723.5$  kg
- $W_e = 26315$  kg
- $W_f(8000 \text{ nm}) = 20207$  kg (42 %  $W_{TO}$ )
- $W_f(3500 \text{ nm}) = 13032$  kg (27 %  $W_{TO}$ )

#### IV. Design Point Determination

In this process, some more detail parameters are determine, such as:

- Maximum thrust at take-off ( $T_{TO}$ ),
- Wing reference area ( $S_{ref}$ )
- Maximum lift coefficient for clean configuration ( $CL_{max}$ ),
- Maximum lift coefficient for take-off ( $CL_{maxTO}$ ),
- Maximum lift coefficient for landing ( $CL_{maxLD}$ ).

Those parameters are summarize in one design point that chosen from matching chart calculation based on ref-1. Input parameters for these calculation are the  $W_{TO}$  and the flight condition parameters based on the initial weight sizing process. These are the design point result of the matching chart calculation with the comparison with others flying wing or BWB jet aircraft.

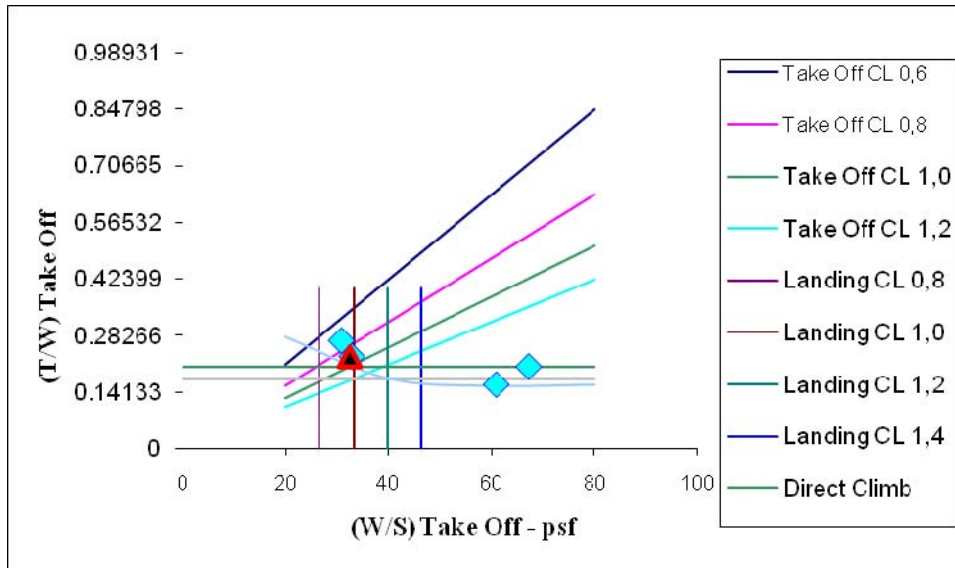


Figure 3. Matching Chart of Present BWB Business Jet

From fig.3, the design point values are:

- Thrust to weight ratio at take off  $(T/W)_{TO} = 0,23$
- Wing loading at take of  $(W/S)_{TO} = 32.48$  psf
- Maximum lift coefficient for clean configuration  $(CL_{max}) = 0.19$
- Maximum lift coefficient for take-off  $(CL_{maxTO}) = 0.9$
- Maximum lift coefficient for landing  $(CL_{maxLD}) = 0.98$

## V. General Specification

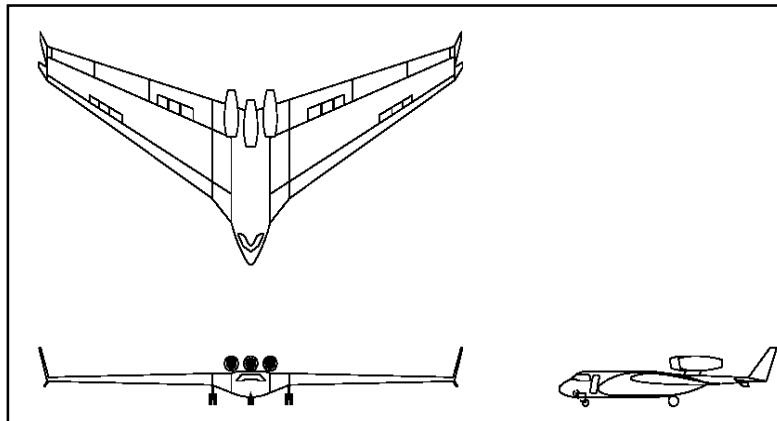


Figure 4. Three View Drawing of Present BWB Business Jet

From initial weight sizing calculation and design point determination, initial general specification of the aircraft can be determine. General specification of the present BWB business jet are shown in table 2.

Table 2. General Specification

Specification	Value
Cruise Performance Cruise speed Cruise altitude	0,85 Mach (448 kts) 43000 ft
Design Mission 1. Payload Range 2. Payload Range	12 passengers + 6 crew and baggage (18000 kg) 3500 nm (6482 km) 8 passengers + 6 crew and baggage (14000 kg) 8000 nm (14816 km)
Mass Max Take-Off Empty Fuel (design mission 1) Fuel (design mission 2)	47723.5 kg (105212 lbs) 26315 kg (58014 lbs) 13032 kg (28730 lbs) 20207 kg (44548 lbs)
Wing Geometry Wing reference area ( $S_{ref}$ ) Wing span (b) Root chord ( $c_r$ ) Aspect Ratio (A)	3232.5 ft <sup>2</sup> (300.31 m <sup>2</sup> ) 139.27 ft (42.45 m) 35.71 ft (10.88 m) 6
Power plant Thrust needed (at Take Off) Specific Fuel Consumption (at cruise)	24148.12 lbT 0,5 lb/lbT/hr

## VI. Engine & Fuel

To fulfill thrust requirement, present BWB business jet use 3 engines of Sam 146 which has been scaled down. 3 engines are required to make sure that present aircraft can fly over the ocean without fulfill ETOPS regulation. Scaled down process is process to modify the default engine, so it not fulfill the thrust requirement excessively. The scaled down process are calculated based on Ref-2. Table 3 gives the comparison between the original engine and the modified engine. Based on Ref-2, it also able to calculate the engine nacelle dimension, figure 5 shows the engine nacelle configuration.

Table 3 Scaled down engine

Engine specification	Original Sam 146	Scaled down Sam 146
Maximum thrust	17500 lbs	12100 lbs
Take off thrust	15400 lbs	8100 lbs
Maximum climb thrust	3740 lbs	10000 lbs
Bypass ratio	4.43	4.43
Cruise specific fuel consumption	0.37 lb/lbT/hr	0.32 lb/lbT/hr
Fan diameter	48.2 inches	42.68 inches
Engine length	81.53 inches	78.03 inches

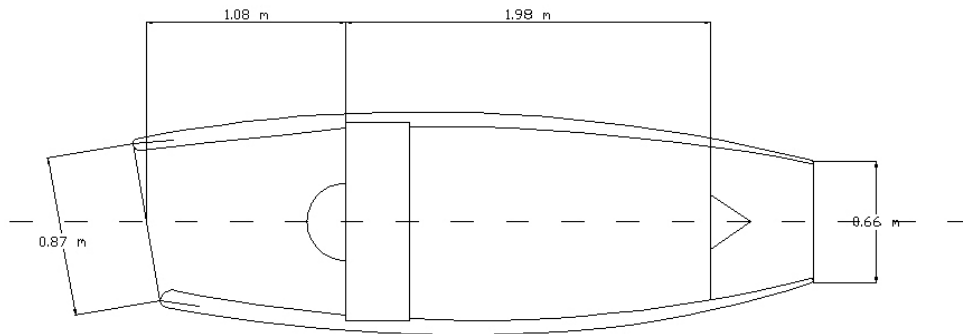


Figure 5. Engine nacelle dimension

Based on the engine performance, it also can be able to calculate fuel volume. The calculation of fuel volume itself, mainly based on the fuel weight required in the flight performance calculation. In conclusion, the fuel volume is  $28.5 \text{ m}^3$  with the type of fuel is aviation gasoline<sup>2</sup>. Figure 6 shows the fuel tank of the aircraft with c.g. of the maximum fuel capacity at 11.15 m from aircraft nose.

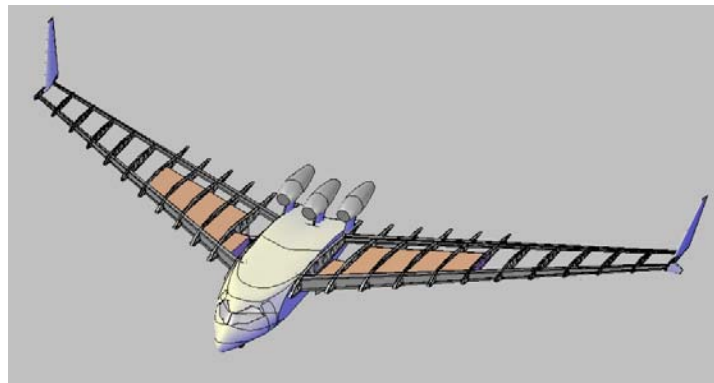


Figure 6. Fuel tank layout

## VII. Structural Layout

Based on some studies about composite materials, it can be concluded that composite materials are suitable for present BWB configuration rather than metal materials. In the present work, although the composite materials have been chosen, the type of composite materials which will be used are still in studies. Figure 7, 8 and 9 shows the structural layout of main component of the aircraft.

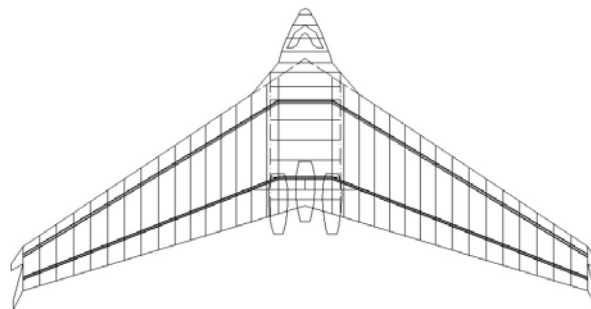


Figure 7. Structural layout concept

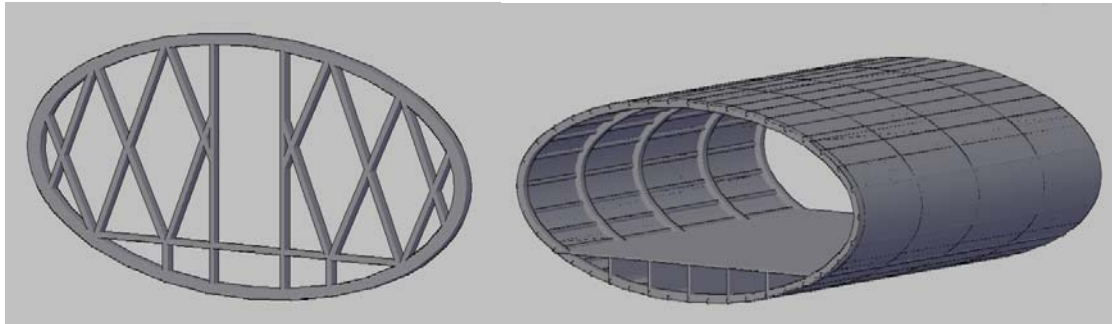


Figure 8. Fuselage structure (left) and cabin strengthener (right)

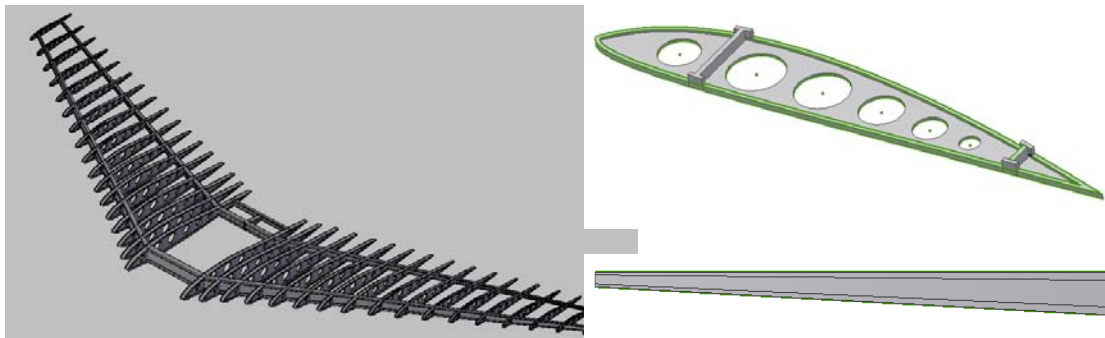


Figure 9. Wing structure (left), ribs and spar structure (right)

### VIII. Weight Breakdown and Center of Gravity (c.g.) Calculation

Weight breakdown are calculated based on Liebeck's method<sup>6,7</sup> and Torenbeek's method<sup>5</sup>. Liebeck's method are used to calculate the fuselage weight, and Torenbeek's method are used to calculate other components. Both methods are mainly based as the function of the geometrical shape of the components. Table 4 shows the weight breakdown calculation results with the estimation of longitudinal location of c.g, components from aircraft nose.

Table 4. Weight breakdown results

Aircraft components	Weight(kg)	Xi(m)
Wing	8371	11.375
Fuselage	4429	7.375
Vertical tail	378	18.375
Nacelle	594	13.7
<i>Main Landing Gear</i>	1573	9.5
<i>Nose Landing Gear</i>	303	2.5
Control Surface	231	13.7
Engine(propulsion)	5939	13.7
Fuel system	241	11
Flight control	550	18
APU	147	12
Instrument	395	3
Hydraulics and pneumatics	330	13.5
Avionics	1233	3
Electrics	905	12
Furnishing	290	7.375

Air Conditioning	177	7.375
Anti icing	95	9.5

From Table 4, it can be calculated with the fuel, crew and payload weight that the aircraft's total weight is 45800 kg. With the c.g. estimation of each component shown in Table 4, c.g. travel of the aircraft can be calculated. The calculation of c.g. travel is mainly based on the weight and location of c.g. components and also fuel, crew and payload weight distribution. Figure 9 shows the c.g. travel in the Potato Diagram. Figure 9 shows that most forward c.g. is on 15 % MAC and most aft c.g. is on 17% MAC.

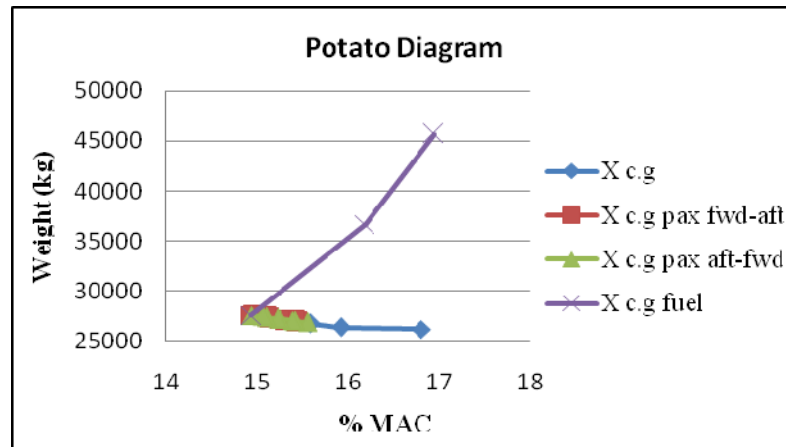


Figure 9.Potato diagram

## IX. Aerodynamic Calculation

The parameters that to be determine in aerodynamic calculation are the airfoil configuration, wing configuration and the aerodynamic characteristics of the aircraft ( $C_L$ ,  $C_D$ ). Process to determine airfoil configuration is an iterative process which is a looping relationship between aerodynamics, stability & balance and flight performance. But the most important thing in determination of airfoil configuration of BWB aircraft is to make sure the airfoil configuration can fulfill the aircraft's balance criteria. Because of the balance criteria that the aircraft must have positive coefficient of moment ( $C_m+$ ), then the airfoil chosen is a reflexed camber airfoil. In the present work, NACA 63a210<sup>3</sup> is modified to become reflexed camber airfoil. The modification process of the airfoil is using the DesignFoil software simulation. The airfoil characteristics are:

- $C_{l_{max}} = 1,571$  (at  $\alpha=14^0$  & reynolds number  $a=9 \times 10^6$ )
- $C_m = +0.13$
- $\alpha_{Cl=0} = 1.12^0$

For the determination of wing configuration, the parameters to be considers are the taper ratio<sup>1,2,4</sup>, swept angle<sup>4</sup>, incidence angle<sup>2</sup> and winglet configuration<sup>2,4</sup>. A special configuration in the present BWB aircraft is the wing planform doesn't use any high lift devices, because from the aerodynamic calculation shows that  $C_L$  of clean wing configuration is enough to make the take off or landing phase. The results of the wing configuration are:

- Taper ratio = 0.33, it's enough to minimize the induced drag,
- Swept at  $c/4 = 30^0$  (Swept at LE =  $34^0$ , Swept at  $t/c_{max} = 28^0$ ), it's able to delay mach drag divergence,
- Incidence angle =  $3^0$ , it's able to give enough  $C_L$  at take off, cruise and landing,
- Winglet configuration besides it's able to handle the tip vortex, it's also able to give enough stability.

Based on the aerodynamic calculation following Ref-2, the aerodynamic characteristics of the aircraft are:

- $C_{D0}$  (0.85 M) = 0.0059
- $C_L$  (cruise at 0.85 M) = 0.2045
- $C_{Di}$  (0.85 M) = 0.0023
- $C_L/C_D$  (0.85 M) = 24.91

## X. Stability & Control

In the present work, the stability criteria calculated are only the static stability coefficients. The calculation itself are based on Ref-2. The results of the calculation are:

- $C_{m\alpha} = -0.564$  per radian
- $C_{n\beta} = 0.092$  per radian
- $C_{l\beta} = -0.049$  per radian

Those static stability coefficients shows that aircraft has fulfill the static stability requirements. It can be concluded that for the present BWB aircraft although it doesn't have horizontal and vertical stabilizer but it still can be stable statically. A special configuration to make this aircraft stable in lateral-directional axis is the winglet configuration that use to substitute the function of the vertical tail as the vertical stabilizer.

For control devices of the aircraft, the present BWB business jet has a special configuration of directional control devices which is the split rudders. The split rudders function are quite much similar with the spoilers at conventional aircraft. When the split rudders are opened, it gives additional drag to the wings, and to make the aircraft yawing it use the drag difference from the split rudders from each wings. Another control devices in the present aircraft is elevon for longitudinal and lateral movements. Sizing of those control devices are calculated based on Ref-2. Figure 11 shows the layout of the control devices on the wings.

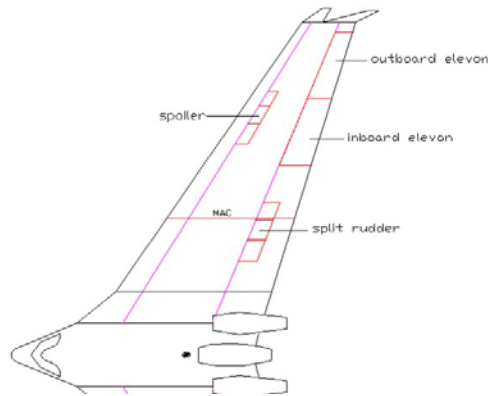


Figure 11. Control devices layout

## XI. Flight Performance

### A. Speed limit based on regulation

Regulation defines the speed limit to ensure safety and controllability of aircraft. Speed limit criteria consist of stall speed, minimum control speed, minimum safe speed, and rotation speed. Table 5 shows the result of speed limit calculation.

Table 5 Resume of Regulation Speed Limit

Speed Criteria	m/s	knots
$V_{stall}$	45.08	87.62
$V_{mc}$	50.5	98.14
$V_R$	56.8	110.4
$V_2 \text{ min}$	59.5	115.6

### B. Take-off distance

Take-off distance is calculated by make assumption that aircraft on maximum take-off weight condition. Take-off distance is divided into ground run distance and airborne distance.

$$\text{Trak take-off distance} = 1.15 \times (\text{ground run distance} + \text{airborne distance})$$

$$= 1.15 \times 688.14$$

$$= 791.4 \text{ m}$$

### C. Landing Distance

Landing distance is calculated by make assumption that aircraft on maximum landing weight and maximum  $Cl_{\text{landing}}$  condition. Calculation gave the result of 1471 m in landing distance.

### D. Resume of all calculation

Table 6. Resume of all calculation for flight performance

Jakarta - LA			
	Distance	Time	Wf
Ground	0,0 m	840 s	807 N
Take-off	1386,2 m	69 s	761 N
Climb	1209931,6 m	6832 s	63777 N
Cruise	12964000,0 m	51645 s	99384 N
Descent	595662,9 m	3643 s	2861 N
Approach landing	1471,1 m	300 s	577 N
total	14772451,9 m	63329 s	168166 N
	7977,13 nm	17,59 hr	

## XII. Cost Analysis

Cost analysis is calculated based on ref-2 using Modified DAPCA IV Cost Model. Component of cost are consist of research, development, test, and evaluating cost, production cost, and operating cost. It is also consider selling strategy, direct operating cost, and fare comparison with competitor. Table 7 shows the selling price per aircraft.

Table 7. Aircraft Pricing

	Production Quantity				
	60	120	180	240	300
<b>Development Cost per Aircraft (US \$)</b>	17.180.988	8.590.494	5.726.996	4.295.247	3.436.198
<b>Production Cost per Aircraft (US \$)</b>	57.119.381	45.152.243	38.606.312	36.026.820	34.271.952
<b>Profit</b>	11.145.055	8.061.411	6.649.996	6.048.310	5.656.222
<b>Purchase Price (US \$)</b>	<b>85.445.424</b>	<b>61.804.148</b>	<b>50.983.304</b>	<b>46.370.377</b>	<b>43.364.372</b>

Table 8 shows the aircraft pricing on 60 units of aircraft production.

Table 8. Aircraft Price Comparison for 60 units Aircraft Production

Business jet	Aircraft Price (US \$)	
	2012	2015
G650	<b>60.014.919</b>	<b>63.215.534</b>
RAYKATO	<b>81.930.100</b>	<b>85.445.424</b>

### **XIII. Conclusions**

On conceptual design calculation, it is feasible to build business jet aircraft with Blended-Wing-Body (BWB) configuration which have ability to nonstop flight from Jakarta to Los Angeles at 7800 nm in distance with 6-12 passengers on board.

BWB configuration provides lower thrust loading and better aerodynamics efficiency than conventional. Good aerodynamic efficiency results low drag and increase fuel efficiency respectively. Also, BWB configuration gives a lot space for passenger cabin and fuel tank.

Stability problem caused by tailless configuration was solved by choosing a reflexed (s-shaped) airfoil. Winglet could be used to increase aerodynamic efficiency and also it is used to replace the function of vertical tail. This aircraft put all of control surfaces, such as elevon and split rudder, on its wing.

### **XIV. Acknowledgment**

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