CONCEPTUAL DESIGN AND AERODYNAMIC STUDY OF BLENDED WING BODY BUSINESS JET

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Abstract

A Conceptual Design and Aerodynamic Study of Business Jet BWB Aircraft is carried out focusing on BWB Aerodynamics, including Wing Planform Configuration and profiles, and their relationship to the Design Requirements and Objectives. Possible Configuration Variants, Mission profile, Flight Envelope requirements, performance, stability, as well as the influence of propulsion configuration and noise considerations of BWB aircrafts are considered and elaborated. Parametric study performed on wing planform, thickness, and twist optimization, with design variables including overall span plus chord, sweep, thickness, and twist at several stations along the span of the wing prior to more structured optimization scheme. Considerations are also given to range, trim, structural design, maximum lift, stability, control power, weight and balance. A statistical study and review on prevailing market demand lead to the choice of a candidate of conventional Subsonic Business Jet, which will be used as a baseline for the aerodynamic and configuration conceptual design. The chosen business jet accommodates 10 passengers as a baseline. Some aerodynamic and performance improvement is then carried out through parametric study to arrive at the best solution meeting the design requirements and objectives.

1 Introduction

The Blended-Wing-Body (BWB) aircraft concept blends the fuselage, wing, and the engines into a single lifting surface, allowing the aerodynamic efficiency to be maximized. The largest improvement in aerodynamic efficiency, when compared to a conventional aircraft, comes from the reduced surface area and thereby reduced skin friction drag (Liebeck, [1]) while maintaining the payload and other relevant performance. This reduction comes mainly from the elimination of tail surfaces and engine/fuselage integration (Leifsson and Mason, [2]). Further performance improvement of the BWB can be achieved by using distributed propulsion. In addition, the BWB aircraft has the potential for significant reduction in environmental emissions and noise (Liebeck, [1]; Fielding & Smith, [3]; Kroo et al,[4]). Locating the engines on the upper surface of the aircraft allows shielding of the forward-radiated engine fan noise by the center-body, and the engine exhaust noise not to be reflected by the lower surface of the wing. The absence of slotted trailing edge flaps allows the elimination of a major source of airframe noise. Further, the use of trailing edge flaps can be eliminated by obtaining high lift and longitudinal control through the use of distributed propulsion and deflection of the trailing edge jet. Furthermore, lower total installed thrust and lower fuel burn imply an equivalent reduction in engine emissions, using the same engine technology, while relatively larger fuselage allows BWB to carry relatively larger amounts of fuel. Therefore, BWB aircraft offers a significant advantage over a conventional aircraft in terms of performance and weight. Studies have also demonstrated that the BWB is readily adaptable to cruise Mach numbers as high as 0.95. Although BWB concept has emerged due to limitation encountered in designing large aircrafts, the advantages offered by BWB as identified above should also be applicable to smaller aircrafts, provided due considerations of relevant factors are taken into account. In this conjunction, another class of aircrafts, i.e. business jets, which offer attractive market, could benefit from various advantages offered by BWB. It is therefore of interest to look into BWB Business jet configuration, which then lead to the present study. For this purpose, the conceptual design of BWB for Business Jets is carried out to look into the feasibility of such application, focusing on the aerodynamic aspects as a prime driver, taking into account that aircraft designs are the result of the integration of several technologies, such as propulsion, structures and flight control.

Market potential and demand of Subsonic Business jets (SBJ's) is reviewed, and statistical studies is performed to select a Business Jet candidate for the study. The significance of the present study is believed to be related to the fact that SBJ comprises a significant segment of aircraft fleet that contributes to the global economy and economic growth. In the Aerodynamic Design Study for Conceptual Design of Business Jet BWB Aircraft, attention is focused on BWB Aerodynamics, including Planform Configuration and profiles, and their relationship to the Design Requirements and Objectives. Possible Configuration Variants, Mission profile, Flight Envelope requirements, performance, stability, as well as the influence of propulsion configuration and noise considerations of BWB aircrafts are considered and elaborated. Parametric study in this regard will be required, prior to some optimization scheme. Parametric study is performed on wing planform, thickness, and twist optimization, with design variables including overall span plus chord, sweep, thickness, and twist at several stations along the span of the wing. Considerations are also given to range, trim, structural design, maximum lift, stability, control power, weight and balance. A statistical study and review on prevailing market demand lead to the choice of a candidate of conventional SBJ, which will be used as a baseline for the aerodynamic and configuration design of the present study. The chosen business jet accommodates 10 passengers as a baseline. Then following a chosen design procedure evaluated from those offered in the literature, a conceptual design study of a business jet BWB is carried out to arrive at some candidate solutions. Care is exercised to meet performance and stability criteria, selected structural and propulsion considerations. Some aerodynamic and performance improvement is then carried out through parametric study and optimization, to arrive at the best solution meeting the design requirements and objectives.

The conceptually designed BWB candidates are then assessed by comparison to the chosen baseline aircraft in terms of the aerodynamics and performance improvements. Particular assessment is elaborated regarding the viability of Business Jet BWB, passenger requirements and multifold performance indicators. Following Bradley (2004), a generalized BWB configuration is synthesized by utilizing a sizing methodology based on the center-body part of the wing that has to fit inside the wing, by reference to the generic configuration already developed in earlier studies (Liebeck, [1]; Wakayama et al, [5]). The aft spar will serve as the rear pressure bulkhead for the pressurized compartment as well as taking bending and shear loads from the wing.

To gain aerodynamic advantages through reduced wetted area, structurally efficient use of wing span, relaxed static stability and optimum span loading, the inboard portion of the wing configuration that contains the passenger cabin and cargo areas is chosen to be relatively thick with large chord. Parametric study on various airfoil candidates were carried out. To verify the advantages, computational aerodynamic codes are utilized for investigating the detailed fluid dynamic characteristics. The design issues for choosing the best airfoil for the center-body are, among others, height of cabin where allow passenger to travel along the cabin with comfort, the radius of leading edge to comfortably and ergonomically fit-in the pilot with ease and comply with the 15 degree of visible angle to the ground from the cockpit, as well as the ability to produce highest lift at lowest possible drag. From the aerodynamic design study on a series of airfoils, the most suitable airfoil for the body of BWB was chosen.

As an example of the design study results, the passenger cabin extends forward to the leading edge (also the front spar), which must also take into account the internal pressure load in addition to bending and shear loads. Passenger bays are located between ribs, which serve as the walls of each bay, and the outer ribs of the center-body have to be designed to take the internal pressure load of the cabin. The general configuration and performance characteristics of the *BWB Business Jet (BWB-BJ)* will be compared to the *Baseline Conventional Business jet (BCBJ)*. Further configuration optimization can be carried out.

2 Motivation and objectives

One of the well known Blended Wing body prototypes was studied by McDonnell Douglas Company (Currently is Boeing Company) and NASA which is design to carry 800 passengers over a range of 7000 nautical miles at a cruse mach number of 0.85. It is a revolutionary transport aircraft configuration with large performance advantages compared to the current conventional aircraft. Preliminary design studies on the BWB indicate the following improvement:

Table 1. Improvement of Performance for BWB

Lift to Drag Ratio	+20.6%
Maximum Takeoff Gross Weight	-15.2%
Overall Empty Weight	-12.3%
Fuel Burn	-27.5%
Thrust	-27%

Aerodynamic advantages are achieved through reduced wetted area, structurally efficient use of wing span, static stability and optimum span loading. Most of the present studies are focus on super big size, long range commercial transport jet. There is limited study on application of Blended Wing Body for business jet. Hence, the present conceptual design study Business Jet Class Blended-Wing-Body Configuration will be challenging.. It is well known that the BWB configuration is efficient for large airplane configuration due to the expansion of its configuration in spanwise direction. The design of medium or small size BWB configuration airplane will face stricter geometrical constraints. The space requirements to give the passengers enough comfort may also contradict with the wetted area constraint, so that some trade-off may be required. Other potential problem is the blending from thick inboard wing into the thin outboard wing. The blending should proceed as smooth as possible to produce least possible drag.

The objectives of the present work are conspicuous. Firstly, a conceptual BWB configuration is sought which can meet the design requirements and objectives (DR&O) as well as mission profile for business jet BWB that offer great comfort to the passengers. Secondly, the work aims to achieve an improvement in performance and aerodynamics over the conventional business jet configuration by offering significant margin of improvement compared to the chosen BCBJ baseline aircraft.

3 Design Mission

To reach our mission statement goals, the idea of a ***long range business aircraft*** was chosen. By looking at long range business aircraft currently in production and choosing attributes that are believed will contribute to improvements, the design missions are identified:

- 12 – 19 Passengers + 4 Crew
- Cruise Altitude > 40,000 ft
- Cruise Speed 0.85 Mach
- Still-air Range of 7,100 nmi
- Takeoff Field Length 4,700 – 5,000 ft
- Landing Field Length 2,500 – 3,000 ft

A high operating ceiling has many benefits. By choosing a cruise altitude of greater than 40,000 feet (although within green aircrafts altitude requirements), the business jet will operate above the majority of air traffic allowing for higher speeds and a cruise/climb method, increasing altitude as the aircraft becomes lighter from burning fuel. This method improves the overall efficiency of the engines and decreases fuel usage. Timely flights are a desirable characteristic that consumers desire in a business jet. High cruise speed directly correlates to the flight duration. Therefore, a cruise speed of 0.85 Mach is chosen as a baseline based on statistical data of combined high speed and fuel efficiency. A range of 7,100 nmi, a conservative distance from Los Angeles to Hong Kong with a 60 kts headwind, is a typical design mission range for the aircraft. Destination flexibility is also important for a desirable business jet solution. With a takeoff field length of 4,700 – 5,200 feet and a landing field length of 2,500 – 3,000 feet, these aircrafts will have access to many small airports; this reduces the aircraft design's reliance on larger and more congested terminals and, thereby, improves turnaround time and decreases wait times.

Sequence	Operation
0 – 1	Warm up
1 – 2	Taxi
2 – 3	Take off
3 – 4	Climb
4 – 5	Cruise
5 – 6	Loiter
6 – 7	Descent
7 – 8	Land and taxi

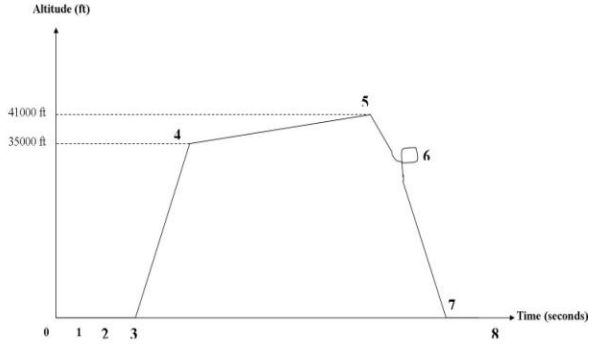


Fig. 1 , Mission Profile for BWB Configuration

It is not reasonable to expect the designed aircraft to operate at the full design mission at all times. Therefore, the typical operating mission could be to carry 6 – 8 passengers, with 3 crew, over approximately 2,500 nmi. This mission allows for travel between many transcontinental cities. As a reference, a flight from New York to Los Angeles is 2,139 nmi. While this mission does not fully utilize the aircraft's capabilities, the short takeoff and landing capacity will allow for more opportunities for shorter range flights in a given time frame. Typical Mission Profile is illustrated in Fig. 1.

4 Statistical Studies for the search of Reference Aircraft Configuration and Design Specification

A statistical study is carried out to find a plausible candidate to be utilized as a reference and for post assessment of the conceptual design efforts. For such purpose, a host of business jet aircraft data has been com\piled and summarized in Table 1.

Statistical analysis is carried out to find the spread of data and determine favorable capabilities by inspection.

The design of BWB configuration for business jet will start with the survey of the current medium size business jet available in the market. A statistical analysis is carried out en lieu of market study to determine an acceptable target aircraft design specification, whereby various performance and design parameters of business jet aircrafts were determined and listed so that the performance and design parameters of the baseline aircraft can be determined. The state of the art and progress of conventional Business Jets as found in the market are considered.

A comprehensive statistical study produced some candidate business jets to be utilized as reference design requirements and objectives, in-lieu of market study. The design parameters and performance specifications of several business jet were compiled and organized systematically. One of these candidate business jets is selected as the conceptual design target, subject to further overriding considerations.

The analysis includes the review, classification and structured grouping of the aircrafts' specification and performance such as number of passengers, maximum range, takeoff gross weight, empty weight, cruise speed, service ceiling, takeoff distance and landing distance. The specification and performance of these aircrafts was plotted in graphs to facilitate identification of potentially appealing characteristics or performance. A tolerance of 25% was set for the potential points. Aircrafts with the specification and performance within the tolerance point are tabulated. By inspection, the baseline aircraft or aircrafts to be chosen as a reference can be identified. Statistical analysis for the search of the baseline or reference aircraft is carried out by considering various relevant parameters such as Passenger capacity, Range, TOGW, Take-off and Landing distance, Wing Loading, L/D, Engine Power, Service Ceiling and rate of climb. From such statistical analysis, a list of baseline parameters for the reference aircraft(s) are tabulated in Table 1. , which is adopted as the characteristics of *Baseline Conventional Business jet (BCBJ)*. To be used as having the reference Design Requirements and Objectives (DR&O) in the present conceptual design of *BWB Business Jet (BWB-BJ)*. The conventional Business jet that has close characteristics to the BCBJ is Beechcraft Hawker 4000, which will be referred to also in the present work.

Table 2. Statistical Analysis Outcome for Reference Aircraft Performance

Parameter	Unit	Baseline	Target
No of Passenger [pax]	Person	10	10
Range [nmile]	nm	2500	2800
TOGW [lbs]	lbs	39000	35000
Empty Weight [lbs]	lbs	20000	20000
Cruise Speed [ft/s]	ft/s	776.67	780
Service Ceiling [ft]	ft	45000	45000
Takeoff Distance [ft]	ft	5000	4500
Landing Distance [ft]	ft	2700	2300

3 Systematic and Methodology: Conceptual Design Approach.

This work is organized systematically to cover the design philosophy of the authors and Raymers [6], taking into considerations the relevance, motivation and the importance of the Blended-Wing-Body configured aircraft for business jet. The conceptual design of the Blended-Wing-Body configuration aircraft includes the mission profile, weight and weight fraction determination, wing loading determination, airfoil selection, thrust loading determination, engine selection, comprehensive wing sizing, centre of gravity determination, and landing gear /undercarriage configuration determination.

To arrive at plausible design configuration, the procedure is carried out iteratively with careful judgment. Better estimation of aircraft design configuration follows through meticulous analysis. Structural and stability analysis are considered as well. A performance analysis is then carried out followed by the summary of the reassessed design specifications. The Conceptual Design Approach is summarized in Fig. 2.

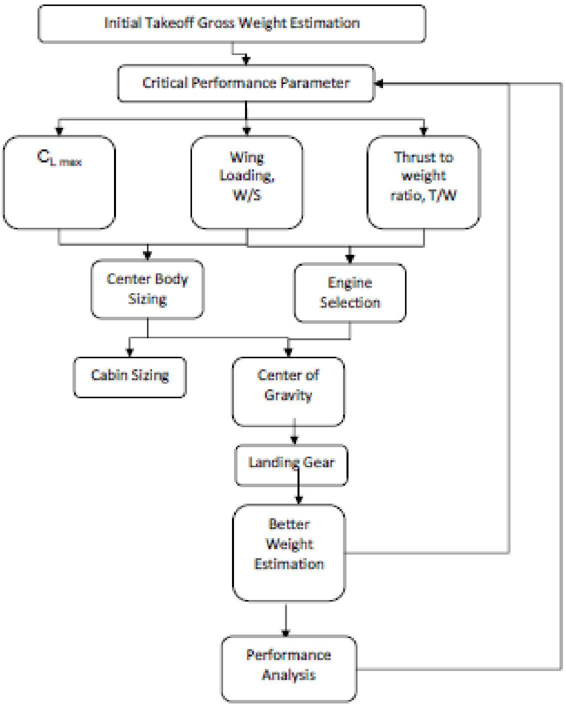


Fig. 2. Conceptual Design Philosophy

The appeal of BWB aircraft technology is the promise of improved performance because of a higher L/D than can be obtained with a conventional “tube and wing” aircraft. Using the fuselage structure as both a passenger compartment and part of the wing has the potential to decrease the wetted area, and improve L/D.

3.1 Airfoil Selection

For 2D airfoil selection in the conceptual design, a basic and simple approach was adopted by analyzing chosen airfoil using Airfoil Investigation Database [7] and on-line

DesignFOIL software, which are interactive database and programs. Eppler, Liebeck, GOE, Lockheed and NACA airfoil series were analyzed for the BWB conceptual design. The airfoil selection process was focused on the airfoil components to achieve favorable pressure distribution, maximum lift and minimum drag coefficients. As a baseline, three different airfoils should be chosen for the center body, inner and outer wing.

3.2.1 Center Body

Through careful analysis and comparison, the center body airfoil chosen should be thick, with large leading edge radius, high lift and high lift to drag ratio. The present conceptual design work selected Liebeck LA2573A as the most suitable airfoil for the center-body of the BWB-BJ.

Table 3. Comparison of several Airfoils considered for Center Body Airfoil Selection

	LIEBECK LA2573A	EPPLER 403	EPPLER 407	EPPLER 417	GOE 493	LOCKHEE D L-188	LOCKHEE D C-141
Thickness (%)	13.7	14.958	14.431	14.188	14.932	13.985	12.994
Camber (%)	3.2	3.314	3.498	3.183	3.369	1.997	1.095
Trailing Edge Angle (deg)	7.0	13.435	13.598	15.345	16.336	16.923	22.736
Lower Surface Flatness	56.1	29.663	23.774	30.863	70.310	34.630	35.916
Leading Edge Radius (%)	3.2	2.253	0.756	2.106	3.605	2.337	2.468
Maximum C_L	1.182	1.421	1.451	1.282	1.452	1.254	1.114
Max Lift Angle of Attack (deg)	15.0	7.500	7.000	5.500	15.000	15.000	15.000
Max L/D	18.556	63.250	42.493	66.188	47.366	43.781	40.902
Lift at Max L/D	0.897	1.104	1.362	1.090	1.169	0.792	1.007
Angle of Attack at Max L/D	10.5	4.500	5.500	4.000	5.500	5.000	7.500

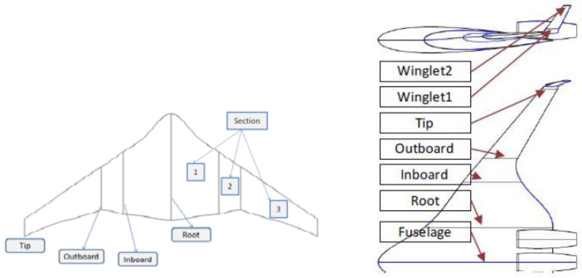
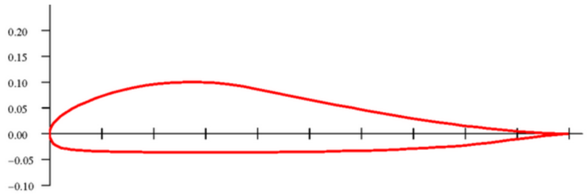
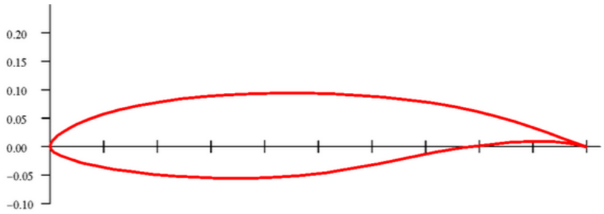


Fig. 3. Wing Components of BWB



Parameter	Dimension (% of chord)	Parameter	Dimension (% of chord)
Thickness	13.7%	Max C_L	1.183
Camber	3.2%	Max C_L angle	15.0°
Lower flatness	56.1%	Max L/D	18.556
Leading edge radius	3.2%	Max L/D angle	10.5°
Trailing edge angle	7.0°	Stall angle	1.0°
Max L/D C_L	1.104	Zero lift angle	0.0°



Parameter	Dimension (% of chord)	Parameter	Dimension (% of chord)
Thickness	14.958%	Max C_L	1.421
Camber	3.314%	Max C_L angle	7.5°
Lower flatness	29.663%	Max L/D	63.250
Leading edge radius	2.253%	Max L/D angle	4.5°
Trailing edge angle	13.435°	Stall angle	-0.5°

Fig. 4. Liebeck LA2573A Airfoil (top) and Eppler 403Airfoil (below) considered for Center Body

3.2.2 Outboard and Tip Airfoil

The outboard and tip wing sections are the crucial parts of wing design since most of the lift, stability and control are produced in this section. The inboard section will also be used to store the fuel tank and main landing gear. Thus, a relatively thick airfoil but capable to produce high possible lift should be selected for this section. Identical airfoil types will be utilized for the inboard to the tip of the wing to facilitate initial lift estimation for the aircraft, which could be refined further. By comparing four different airfoils at 0 deg and 15 degrees angle of attack, the criterion that should be considered in the airfoil selection for the inboard wing section must have balanced performance in both lift and drag. To simplify, airfoil with the highest lift and lowest drag will be chosen. The airfoil chosen is **NACA 64216**.

3.3 Sizing the Pressurized Cabin

The design study conducted by Liebeck[1] showed that for a BWB configuration the center-body could be treated as a ruled surface in the spanwise direction. The center-body is composed of a pressurized cabin section and an aft center-body section, which is non-pressurized. As the number of passengers increases, the center-body is expanded laterally by adding passenger bays. This lateral expansion automatically increases or decreases wing span and planform area with passenger capacity. The study determined that it was possible to design a family of aircraft with identical outer wing panels and the aircraft sizing will be based entirely on the center-body.

3.4 Initial Weight Estimation

Table 4. Weight Distribution for BWB Configuration

	No	Weight (kg)	Weight (lb)	Total weight (kg)	Total weight (lb)
Pilot	2	80	176.3697981	160	352.7395962
Flight Crew	1	75	165.3466857	75	165.3466857
Crew handCarry	3	7	15.43235733	21	46.297072
Crew luggage	3	30	66.13867428	90	198.4160228
Passanger	10	100	220.4622476	1000	2204.622476
Passenger Hand Carry	10	7	15.43235733	70	154.3235733
Passanger luggage	10	30	66.13867428	300	661.3867428
			TOTAL	**1716**	**3783.132169**

Table 5. Weight Fraction for BWB Mission

Mission	Fraction	Weight Fraction
warm up	W1/Wo	0.99
taxi	W2/W1	0.995
take off	W3/W2	0.995
climb	W4/W3	0.98
cruise	W5/W4	0.804987299
loiter	W6/W5	0.988636487
descent	W7/W6	0.99
land and taxi	W8/W7	0.992
	W8/W0	**0.750723415**

3.5 Wing Loading Determination

The wing loading is computed based on two Constraints:

i. Stall velocity, v_{stall}
ii. Landing distance

The typical stall for Hawker 4000 is 155.47 ft/s

Cruise altitude, h_{cruise} = 41000ft
Temperature at 41000ft, $T_{41000ft}$ = 389.99˚R
Atmospheric pressure at 41000ft, $P_{41000ft}$ = 3.7475 lb/ft^2
Air density at sea level, ρ_{0ft}= 0.0023769 slugs/ft^3
Air density at 41000ft, $\rho_{41000ft}$ = 0.00055982 slugs/ft^3

Wing Loading Based On Stall Velocity

$$\frac{W}{S} = \frac{1}{2}\rho_\infty v_{stall}^2 C_{Lmax} = \frac{1}{2}(0.0023769)(138^2)(1.119825) = \frac{25.344lb}{ft^2}$$

Wing Loading Based On Landing Distance

$$\frac{W}{S} = \frac{39.5956lb}{ft^2} \; and \; \frac{82.9921lb}{ft^2}$$

Table 6. Wing Loading Determination using from Stall Velocity and Landing Distance

Constraints	Wing loading, W/S (lb/ft^2)	Remarks
Stall Velocity	25.344	Low
Landing Distance	39.5956	High
	82.9921	Higher

The lowest wing loading is chosen in order to obatin the maximum wing area for maximum takeoff gross weight. Thus, the wing loading for the BWB business jet design is taken to be 25.344.

3.6 Thrust Loading Determination

The determination of thrust loading is base on the following Constraints:

i) Takeoff distance
ii) Rate of Climb
iii) Maximum velocity at midcruise weight

Table 7. Thrust Loading Determination using various considerations

Constraints	Thrust Required (lb)	Remarks
Takeoff distance	1601.45	Lowest
Rate of Climb	4913.5339	Highest
V_{max} at mid cruise	2475.32	Mid

3.7 Engine Selection

From previous section, the maximum thrust required by the aircraft,

$$T_{required} = 4913.5339lb$$

The design range for this aircraft is based on the Beechcraft Hawker 4000 (as reference) which is R = 4630 km. Transport aircraft which travel in this range is categorized as long haul aircraft and it falls under the transport aircraft category. According to the design requirements regulated by FAR, the number of engines required for aircraft which falls under the transport aircraft category must be more than 1 engine. Hence, 2 engines are selected to meet this requirement, which incidentally similar to the number of engines of Beechcraft Hawker 4000. The Beechcraft Hawker 4000 uses two Pratt & Whitney Canada PW308A turbofan engine. The present work arrives at the thrust required per engine to be 2456.8 lbf.

The wing sweep for blended wing configuration will be made by section where each section will be designed with different sweep angle. An example is shown in Fig. 5, where the sweep angle for the wing root to inboard (section 1) is approximately 50 to 55 degree. Taking this as starting point, the sweep angle of section for this blended wing configuration will be 55 degree.

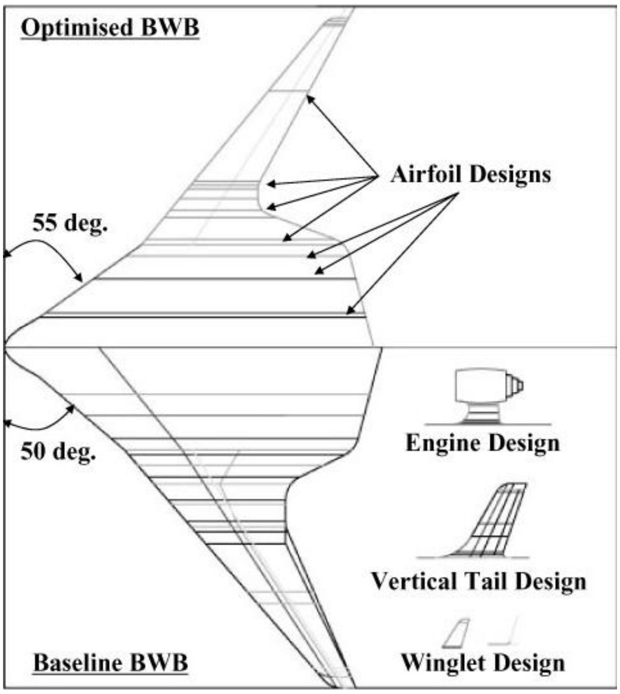


Fig. 5. Example of Blended Wing Configuration with Sweep Angle (Ikeda, [8])

From inboard to tip (section 2 and 3), the wing configuration is more likely similar to conventional wing. The sweep angle in these sections will be designed based on the historical trend as impled by Raymer [6]. Wing sweep improves stability because a swept wing has a natural dihedral effects. From this BWB design, the leading edge sweep angle is taken to be 25 degree which measure start from the in board.

Using equation, $\tan \Lambda_{LE} = \tan \Lambda_{\frac{c}{4}} + \frac{(1-\lambda)}{AR(1+\lambda)}$ (Raymer, [6]. Page 48), the quarter chord sweep angle can be calculated. Wing sweep and wing twist will be considered at further iterations for optimized performance.

4 Design of Overall Layout Of BWB Configuration Based on Wing Span and Wing Area

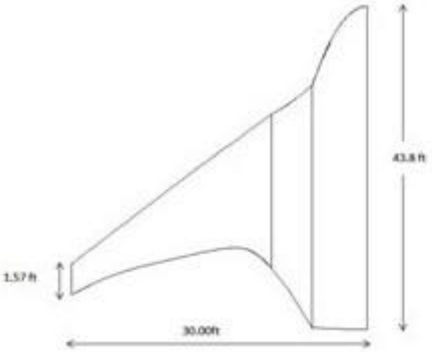


Fig. 6. Half Span of BWB Configuration Layout

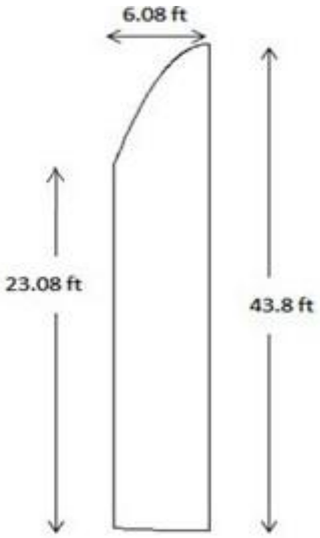


Fig. 7. Center Section of BWB

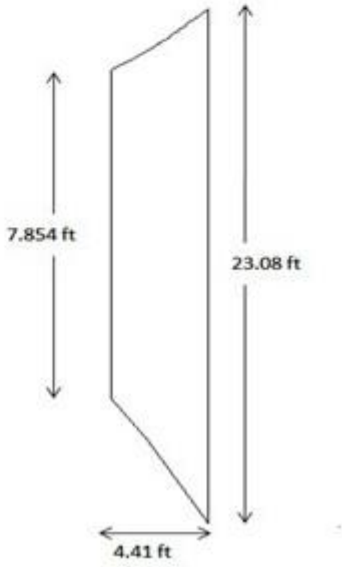


Fig. 8 . Section 2 of BWB Configuration

The wing area for half span is 363.29 ft2. Thus, total area covered for the whole BWB configuration is 726.6 ft2.

5 Wing / Center Body Sizing

In the selection of the airfoil profile for the BWB Center Wing-Body, the Liebeck LA2573A airfoil is modified in order to obtain a maximum thickness at 0.7 chord length as compared to the original which is at 0.25 chord length.

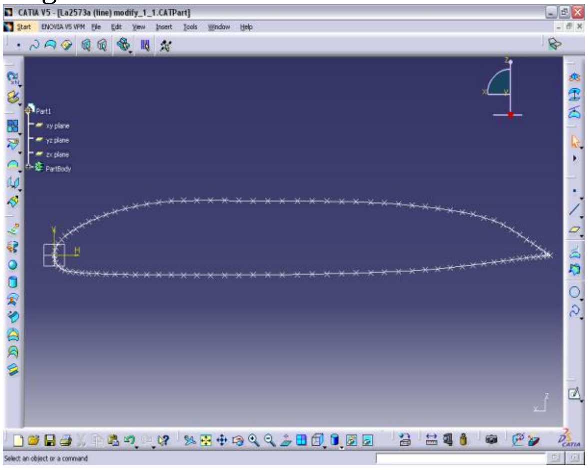


Fig. 9 .The modified Liebeck LA2573A airfoil

This procedure is taken in order to allow convenient and spacious cabin space is to accommodate business passenges. Accordingly, the properties of the airfoil are changed due to different camber line compared to the original airfoil, which is a trade-off to be carefully balanced and analyzed. For conceptual design purpose, it will be assumed that the effect of such modification can be balanced by favorable properties at other wing sections, in particular since the modified center wing-body still delivers lift and offers less drag. Further optimization could be made on the airfoil using Computational Fluid Design. The multi-disciplinary optimization scheme could follow that of Pambagjo et al [9].

5 Cabin Sizing

NASA's methodology as elaborated by Bradley [10] in the conceptual design of BWB uses Finite Element Analysis. The pressurized cabin of the BWB was designed considering combined bending, shear and torsion from aerodynamic loads. In comparison to the conventional circular fuselage, it was predicted that the non conventional fuselage requires higher structural strength because of large bending stresses on the skin [8]. In this regard, there are limited references available for business jet blended wing body research. For cabin passenger compartment sizing, we refer to the Future Requirement and Concepts for Cabins of Blended Wing Body Configuration (Stephan Eelman, [11]). The derivation of key requirements for cabin development follows the methodology as described in the following development.

Taking cabin standards displayed in figure above as a reference, standards for the BWB cabin are tailored according to the requirements of the specific scenario. The main geometric standards are class ratios, seat pitch, seat width, aisle width, toilets per passenger, trolleys per passenger and stowage spaces. These are influenced on the one hand by the relevant characteristics of the different scenarios, but on the other hand by general premises having impact on all of the scenarios as well. These are the continuous growth of human being's dimensions known as acceleration, enhanced in-flight safety and medical facilities (Stephan Eelman, [11]).

Designing the present BWB-BJ configuration for 10 passengers with first class quality, the aisle width, seat pitch and seat width will be based on the typical passenger compartment [6]. For the Aisle height, reference will be made to Beechcraft Hawker 4000 in Fig. 10.

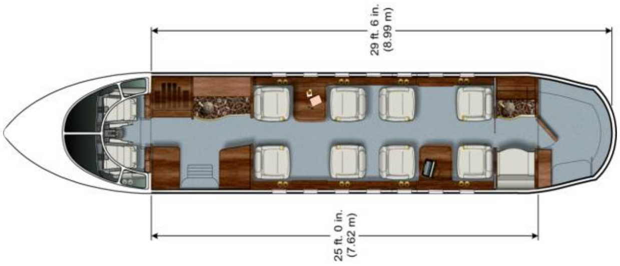


Fig. 10 .Beechcraft Hawker 4000 Cabin Compartment Arrangement (Beechcraft Hawker, [12])

Table 8. Passenger Compartment for Business Jet BWB Configuration

Description	Dimension (in)
Seat Pitch	40 in (1.0160m)
Seat Width	28 in (0.7112m)
Aisle Width	28 in (0.7112m)
Cabin height	72 in (1.8288m)

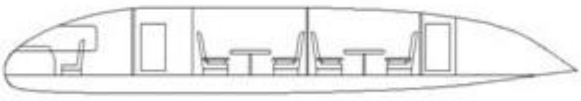


Fig. 11. BWB Cabin Layout (Side)

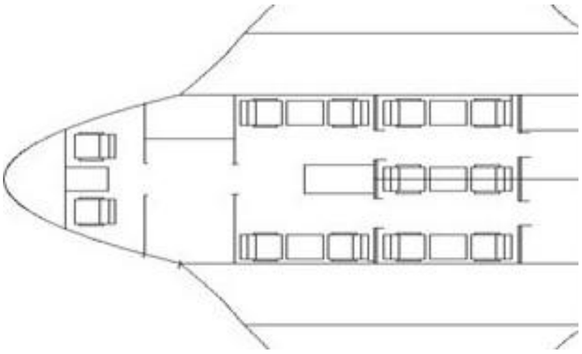


Fig. 12 . BWB Cabin Layout (Top View)

Thus, the passenger compartment for this BWB configuration can be defined as shown in Table 8. Figs. 11 and 12 depicts the cabin lay-out of the present BWB-BJ conceptual design.

5.1 Center Of Gravity

Computation of the center of gravity distance of the center body proper yields a value of 27.144ft from the nose datum. Fig. 13 exhibit the skeleton of the Weight Distribution Along the Center Cabin Body. This center of gravity excludes sections 2 and 3 which are located between the inboard and tip BWB wing sections.

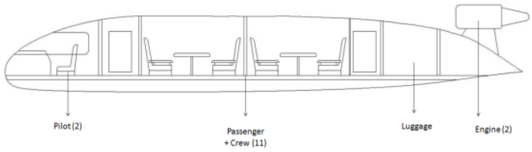


Fig. 13 . Weight Distribution Along the Center Cabin Body

Table 9. Weights Arrangement due to Payload along Center Body

Type of Weight	Quantity	Unit Weight (kg)	Total Weight (kg)	Total Weight (lb)	Distance from nose datum (ft)	Σ
Pilot	2	80	160	352.736	5.209	1837.401824
Passenger	10	100	1000	2204.6	20.7675	45784.0305
Cabin Crew	1	75	75	165.345	20.7675	3433.802288
Cabin Crew Handcarry	3	7	21	46.2966	20.7675	961.4646405
Passenger Hangcarry	10	7	70	154.322	20.7675	3204.882135
Passenger Luggage	10	30	300	661.38	35.2425	23308.68465
Crew Luggage	3	30	90	198.414	35.2425	6992.605395
Engine	2	289	578	1274.2588	40.6159	51755.16799
TOTAL				**5057.3524**		**137278.0394**

The location and length of the Mean Aerodynamic Center (MAC) of the BWB wing is important because the wing incorporate the aircraft cabin (fuselage) so that careful considerations of the relative position (or alignment) of entire wing MAC with the aircraft center of gravity should be taken into account in the conceptual design. This provide first estimate of the wing position to attain the required stability characteristic. For a stable aircraft, the wing should be initially located such that aircraft center of gravity is at about 30% of the mean aerodynamic chord [6].

Further detailed and refined analysis is carried out in [13].

6 Detailed Analysis and Summary

Refined weight Estimation and detailed aerodynamic analysis using CFD are carried out in [13]. Table 10 exhibit the outcome of such refined analysis. The Lift distribution along half-span of the BWB wing as well as the corresponding drag polar are exhibited in Figs. 14 and 15, while the BWB-BJ conceived is exhibited in Fig. 16. Table 11 summarizes the BWB-Business Jet Configuration and compare its performance BCBJ.

Table 10. Better Estimated Weights

TOGW (lb)	Wing Weight (lb)	Vertical Stabilizer Weight (lb)	Landing Gear Weight (lb)	Installed Engine Weight (lb)	Else Empty Weight (lb)	Empty Weight (lb)	Fuel + Crew +Payload Weight (lb)	New TOGW (lb)
23421.88	7266	1798.3	1007.1	2581.8	3981.7	16635	7874.92	24509.92
24509.91	7266	1798.3	1053.9	2581.8	4166.6	16867	7874.92	24741.67
24741.66	7266	1798.3	1063.8	2581.8	4206.0	16916	7874.92	24791.03
24791.02	7266	1798.3	1066.0	2581.8	4214.4	16927	7874.92	24801.54
24801.54	7266	1798.3	1066.4	2581.8	4216.2	16929	7874.92	24803.78
24803.78	7266	1798.3	1066.5	2581.8	4216.6	16929	7874.92	24804.26
24804.26	7266	1798.3	1066.5	2581.8	4216.7	16929	7874.92	24804.36
24804.36	7266	1798.3	1066.5	2581.8	4216.7	16929	7874.92	24804.38
24804.38	7266	1798.3	1066.5	2581.8	4216.7	16929	7874.92	**24804.39**
24804.38	7266	1798.3	1066.5	2581.8	4216.7	16929	7874.92	**24804.39**
24804.38	**7266**	**1798.3**	**1066.5**	**2581.8**	**4216.7**	**16929**	**7874.92**	**24804.39**

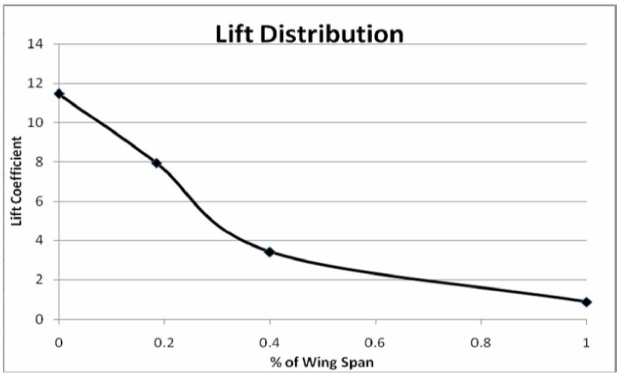
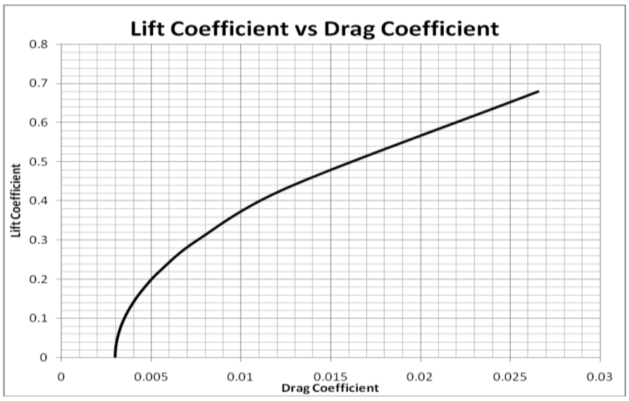


Fig. 14 . Lift Distribution along mid-span of BWB-BJ

7 Conclusions

The BWB configuration was compared to the design baseline aircraft, BCBJ, which is similar to the characteristics, specifications and performance to the BCBJfollowing the statistical study. In the aerodynamics analysis, the L/D ratio of the BWB-BJ configuration is 41, which is 2.9 times higher than a typical conventional business jet aircraft represented by the reference BCBJ. In the computational approach, the simulation of flow on both aircraft section by section show that BWB configuration has 2.8 times higher in lift generated over the wing span compared to the BCBJ.



Fig, 15. Drag Polar of BWB-BJ

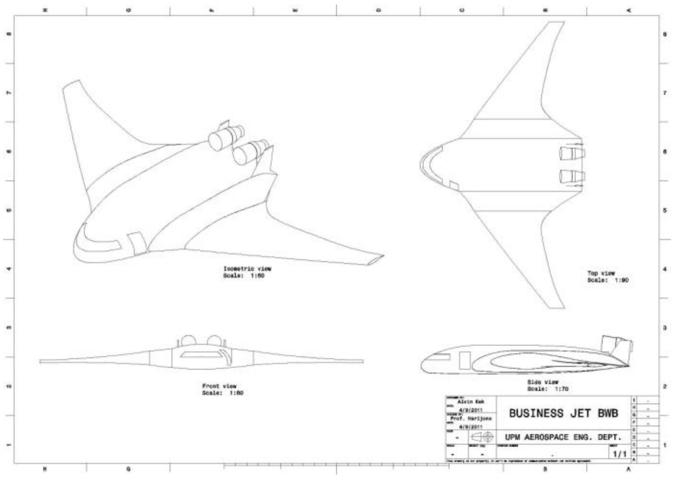
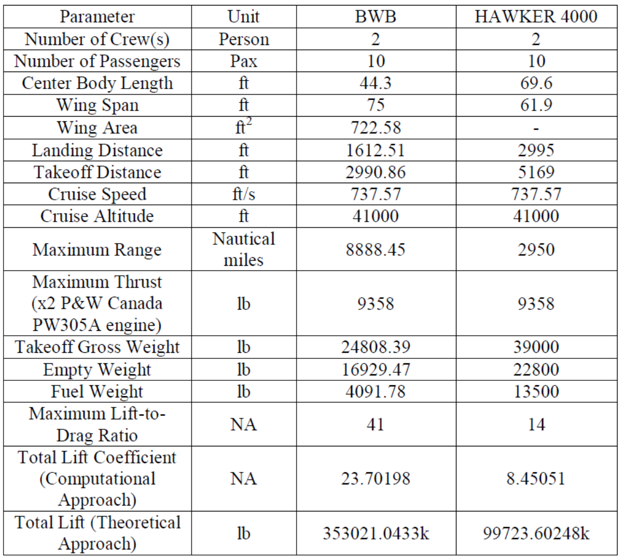


Fig. 16 . BWB-Business Jet Configuration

In the theoretical approach, however, calculations which has been based on strip method on both BWB-BJ and BCBJ planform wing show that lift generated on BWB-BJ wing span is 3.54 times higher than the BCBJ. Hence, it can be concluded that the BWB configuration is able to generate lift over wing span in 2.8 to 3.54 times higher compared to conventional aircraft as represented by the BCBJ. The differences in the conceptual design of the BWB configuration are the cabin and fuselage section compared to the cylindrical one of conventional aircraft. The design of BWB configuration without the fuselage is the major contributor towards low weight of the overall BWB configuration. This is because fuselage contains about 20% to 30% of overall empty weight of an aircraft which produces high drag yet less lift.

Table 11. Summary of BWB-Business Jet Configuration and Performance Comparison with BCBJ.



Parameter	Unit	BWB	HAWKER 4000
Number of Crew(s)	Person	2	2
Number of Passengers	Pax	10	10
Center Body Length	ft	44.3	69.6
Wing Span	ft	75	61.9
Wing Area	ft^2	722.58	-
Landing Distance	ft	1612.51	2995
Takeoff Distance	ft	2990.86	5169
Cruise Speed	ft/s	737.57	737.57
Cruise Altitude	ft	41000	41000
Maximum Range	Nautical miles	8888.45	2950
Maximum Thrust (x2 P&W Canada PW305A engine)	lb	9358	9358
Takeoff Gross Weight	lb	24808.39	39000
Empty Weight	lb	16929.47	22800
Fuel Weight	lb	4091.78	13500
Maximum Lift-to-Drag Ratio	NA	41	14
Total Lift Coefficient (Computational Approach)	NA	23.70198	8.45051
Total Lift (Theoretical Approach)	lb	353021.0433k	99723.60248k

The BCBJ empty weight is 22800 lb while the BWB-BJ is 16929.47 lb. By waiving the fuselage, BWB configuration can save weight up to 5870.53 lb. In other hand, it is shown that the BWB-BJ aircraft is fuel saving whereby the fuel weight required by BWB configuration aircraft is 4091.78 lb while BCBJ is 13500 lb. This implies that the conceived BWB-BJ configuration is 36.4% more weight efficient than the BCBJ for the same flight mission.

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