CONCEPTUAL DESIGN AND AERODYNAMIC STUDY OF JOINED-WING BUSINESS JET AIRCRAFT

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Abstract

The concept of joined-wing aircraft with nonplanar wings as conceived and patented by Wolkovitch is attractive due to various advantages such as light weight, high stiffness, low induced drag, high trimmed C_{Lmax} *, reduced wetted area and parasite drag and good stability and control, which have been supported by independent analyses, design studies and wind tunnel tests. With such foreseen advantages the present work is carried out to design joined-wing business-jet aircraft and study and investigate its advantages and benefits as compared to the current available conventional business jet of similar size, passenger and payload capacity. In particular, the work searches for a conceptual design of joined-wing configured business-jet aircraft that possesses more superior characteristics and better aerodynamic performance in terms of increased lift and reduced drag, and lighter than the conventional business jet of similar size. Another significant objective of this work is to prove that the added rigidity possessed by the joined wing configuration can contribute to weight reduction.*

1 Introduction

The joined-wing[1, 2] is an innovative aircraft configuration with a rear wing that has a tip that sweeps forward to join the trailing edge of the main wing. The rear wing (aft wing or tail) is used both for pitch control and as a structural support for the forward wing. When compared to a conventional wing-tail configuration, several advantages have been predicted for joined-wings [3 - 9]. The potential for lower structural weights and less drag are perhaps the most important of these advantages. The business jets promising market could benefit from various advantages offered by such benefits derived from joined-wing technology.

Joining the tail to the wing allows the tail to act as a strut, relieving wing bending moments inboard of the wing-tail joint. The induced buckling on the aft wing structure, however, must be resisted with a stiffer structure, which could lead to weight increase and need further meticulous design compensation. Cuerno-Rejado et al [10] evaluates the capabilities of joined-wing medium-sized aircraft with tandem wings having positive and negative sweep and dihedral, and establishes a comparison with respect to a reference conventional wing-plus-horizontal tail aircraft and with the same medium-/long-range transport mission. The topics considered include structural arrangement, weights and aerodynamic characteristics, as well as operational issues, such as performance and direct operating costs. The conclusions drawn in this preliminary study are very positive, but further research is required in order to confirm some hypotheses regarding the structural arrangement.

In line with modern concern on efficiency, energy and environment, the objectives of the present work is to contribute to the concept of “Better, Lighter, Faster, Cheaper and Greener” Joined-Wing Business-Jet aircraft. “Better” means the aircraft to be conceptually designed should possesses superior aerodynamic performance such as considerably good rate of climb and endurances, takeoff and landing distances, lower stalling velocity, and reduced drag, among others. “Faster” means that the aircraft is able to fly at a high speed, getting from one point to another in a much shorter time. In consequence, the aircraft should be able to fly in high-subsonic or transonic cruising speeds. If the joined-wing aircraft conceived should have considerably good aerodynamic performance, more fuel saving and economical engines with reduced thrust will be required, thus saving the aircraft's operating cost, hence the word "Cheaper" comes into place. Greener aircraft objectives could be gained by all the previous advantages, as well as novel concept in the holistic design approach. Various authors [3-9] have established and verified the advantages of Joined Wing Aircraft as compared to conventional Cantilevered Wing-Tail Design, such as lighter weight wing structure, better directional stability and controllability, lower induced drag, improved aeroelastic characteristics and improved space for fuel, which motivates the present work as well as poses a challenge for the conceptual design efforts. In summary, the objectives of the present work are to carry out conceptual design and aerodynamic study of a joined-wing configuration aircraft that possesses better aerodynamic performance in terms of increased lift and reduced drag and lighter as compared to conventional business jet of similar size, passenger and payload capability, and to arrive at a structurally robust joined wing configuration.

2 Statistical Studies for Reference Aircraft

A comprehensive statistical study is carried out to search for some candidate business jets to be utilized as reference in establishing design requirements and objectives (DR&O), in-lieu of market study. The design parameters and performance specifications of several business jet were obtained from online literatures. One of these candidate business jets is selected as the conceptual design target, subject to further overriding considerations, and reflects the specific DR&O based on customer requirements, certification and other requirements. For such purpose, a host of business jet aircraft data has been compiled and summarized in Table 1. Based on such statistical analysis on trends and state of the art, a Business Jet with specifications is described in Table 2 is obtained.

Table 1. A sample of Selected Business Jets Statistics (detailed analysis is elaborated in [11])

	Passenger (Upper Average)	Range [nm]	Max. TOGW [lb]	Cruise Speed	Empty Weight	Service Ceiling [ft]	Price [USD]	Length [ft]	Height [ft]	Wingspan [ft]
Learjet 60	10.00	2409	23500	484	14,640	51,000	13,000,000	58.67	14.67	43.75
Cessna Citation Columbus	8.00	4000	n/a	n/a	n/a	45000	n/a	77.00	27.58	80.00
Cessna Citation X	10	3,250	36,400	594	21,700	51,000	22,000,000	72.30	19.00	63.60
Cessna Citation Excel	9	1,858	20,200	506.41	12,800	45,000	n/a	52.50	17.17	56.33
Cessna Citation Sovereign	10	2,847	30,300	n/a	17,700	47,000	n/a	61.08	19.17	63.08
Dassault Falcon 50	9	6480	40,780	624.19	20,170	49,000	n/a	60.77	22.88	61.88
Embraer Legacy 450	9	2,300	n/a	n/a	n/a	45,932	15,250,000	62.83	22.08	66.42
Embraer Legacy 500	8	3,000	n/a	n/a	n/a	45000	18,400,000	67.33	22.08	66.42
Gulfstream G100	10.00	2563.47	24,900	529.35	14,400	45,000	11,750,000	55.58	18.17	54.58
Gulfstream G200	13	3,400	35,450	528	19,200	45,000	11,735,000	62.25	21.42	58.08
Gulfstream G250	10.00	3,400	39,600	560	24,150	45,000	n/a	66.83	21.33	63.00
Hawker 800	11	2,642	28,000	463	15,670	41,000	n/a	51.17	18.08	54.33
Learjet 40	7.00	1,692	21,000	526	n/a	51,000	n/a	55.56	14.13	47.78
Learjet 45	9.00	1,710	20,200	500	12,850	51,000	11,500,000	58.00	14.08	47.83
Cessna CitationJet	5.00	1,300	10,700	447.38	6,765	41,000	n/a	42.58	13.75	46.92

Table 2. Business Jet Specifications as outcome from the statistical analysis

Parameters	Unit	Baseline	Intended Improvement
No. of Passengers	Person	9	9
Range	n mile	2,104.00	2,500.00
Maximum Takeoff Gross Weight	lb	21,270.18	20,000.00
Cruise Speed	mph	520.70	600.00
Empty Weight	lb	14,420.00	13,000.00
Service Ceiling	ft	46,218.25	48,000.00
Price	USD	10,959,115.50	10,500,000.00
Length	ft	53.87	52.00
Height	ft	17.44	16.00
Wing span	ft	54.72	54.00
Wing area	ft	354.84	350.00
Rate of Climb	ft/min	3568.32	3,600.00
Takeoff Distance	ft	4,285.91	4,000.00
Landing Distance	ft	3,086.21	3,000.00

For the interest of objectivity, this reference Business Jet will be referred to in the present study as Reference Conventional Business Jet (RCBJ). It may be noted that the specification parameters of selected RCBJ has a range of values between Learjet 45 and Learjet 60, which for further assessment of the design study, will be referred.

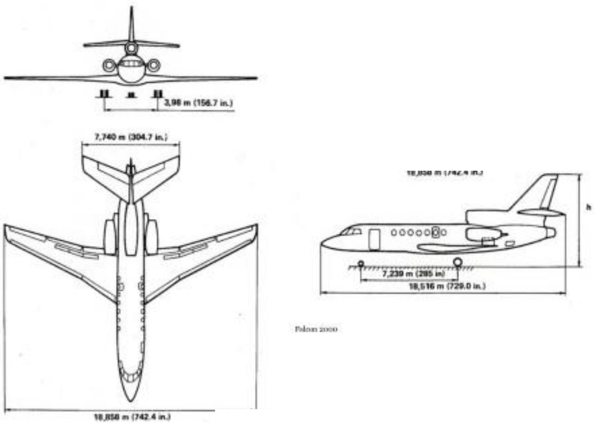

Fig. 1. Learjet 60 as reference aircraft [12]

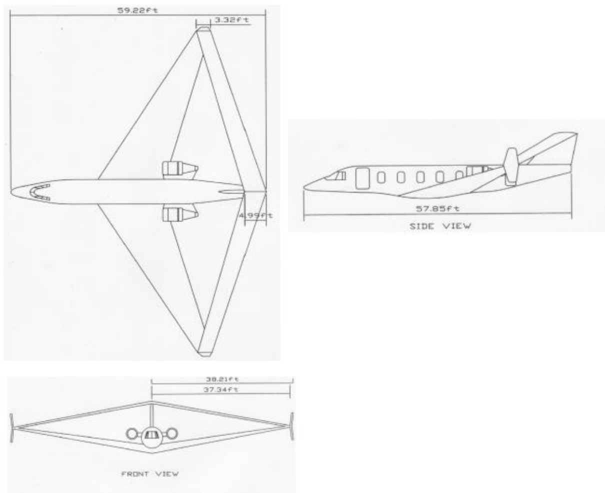

Fig. 2. Schematic of the Joined-Wing Business Jet Aircraft

3 Systematic and Methodology: Conceptual Design Approach.

This work is organized systematically to cover the authors' design philosophy of that of Raymer [13]. The state of the art and progress of the joined-wing aircraft technology and development are considered. Following a statistical analysis, performance and design parameters of various business jet aircrafts are carefully assessed and analyzed to arrive at an acceptable target aircraft DR&O and design specifications, which is then referred to as the RCBJ. The DR&O of this RCBJ will guide the present conceptual design to arrive at performance and design parameters of the desired Joined-Wing Business Jet (JWBJ). The design considerations include mission profile, weight and weight fraction and wing loading determination, airfoil selection, thrust loading, engine selection, forewing sizing, centre of gravity determination, aft wing (horizontal tail) and fuselage sizing, and landing gear/undercarriage configuration determination.

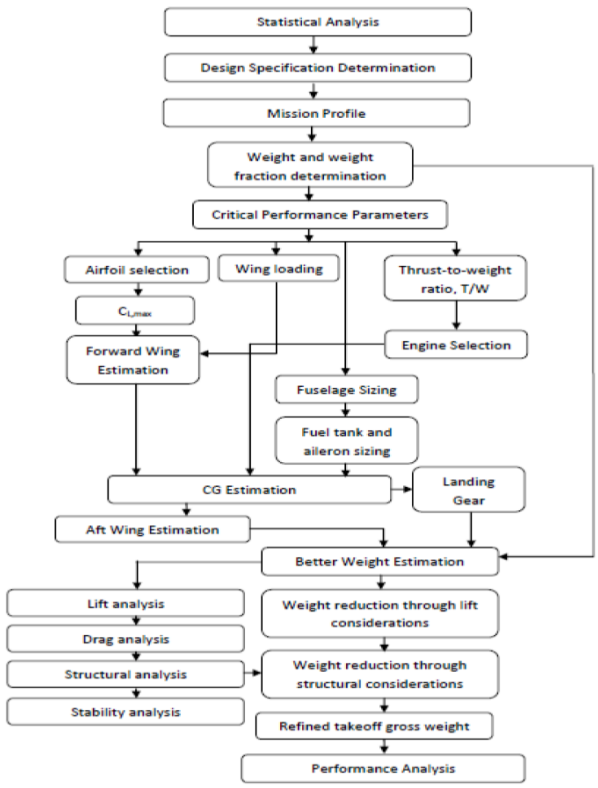

Fig. 3. Summary of Conceptual Design Approach

Further computational iterations and analysis follow to obtain better estimation of aircraft weight, lift and drag. In addition, structural and stability analysis are also carried out in subsequent iterative cycles. A performance analysis is then carried out followed by comprehensive assessment of the design specifications outcome. This design philosophy is summarized in Figure 3. Following such design philosophies as a preliminary step toward CDIO, Lean Aircraft Initiatives, and "Better, Lighter, Faster, Cheaper and Greener" aircraft demanded by global energy and environmental concerns, the problem statement of this work is to conceptually design a joined-wing business jet aircraft that produces more lift and less drag, but yet is lighter than the conventional business jet of similar size.

Mission profile determination and Flight envelope of the joined-wing configuration aircraft

The flight envelope, or V-n diagram, is determined following FAR's regulations and mission profile. The regulations provide a method to determine the maximum load factor limit. The structure is designed to the ultimate load factor with a factor of safety of 1.5 above the limit load. Basically the V-n diagram is based on two limitations, namely aerodynamic and structural limits. Some of the parameters are incorporated in the V-n diagram calculations. The improved and refined values are used instead of the initial estimate.

Table 3. Parameters considered in flight envelope calculations

Parameters	Units	Value	Remarks
$\left(\frac{L}{D}\right)_{max}$		17.5	Initial estimate
$(C_L)_{max}$		1.512	Obtained from airfoil
Forewing Area, S	ft^2	743.5649	
K *(forewing)*		0.07423	From Oswald span efficiency method
Oswald Span Efficiency Factor, e *(forewing)*		0.4549	Oswald span efficiency method
C_{D_0} *(total aircraft)*		0.0100094	Component buildup
Cruise altitude	ft	35000	
Cruise density	$\frac{slugs}{ft^3}$	0.0007382	
Cruise velocity	$\frac{ft}{s}$	806.6667	
Weight at mid-cruise	lb	20019.0179	Improved value through lift and structural considerations
Wing loading $\left(\frac{W}{S}\right)$	$\frac{lb}{ft^2}$	30.5073	Improved value

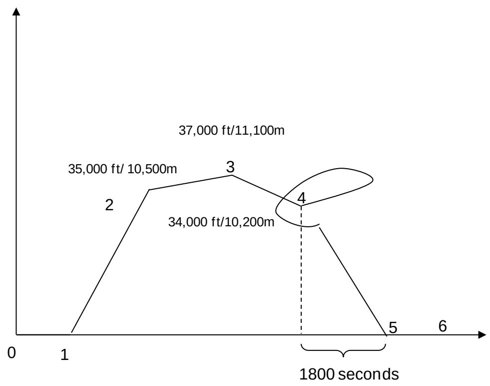

Fig. 4. Mission Profile of the Target JWBJ

4 Conceptual Design Work Progress and Outcome

4.1 Aircraft Sizing; Weight and Weight Fraction Determination

The detail of the design calculation is comprehensively described in Kim[11]. The total weight of the payload, $W_{payload}$ was determined to be 1635.00kg (3604.56lbs), the range 4630 km and cruise velocity 550 mph. The typical maximum lift-to-drag ratio, $\left(\frac{L}{D}\right)_{Max}$ of RCBJ is 14. An improvement in $\left(\frac{L}{D}\right)_{Max}$ of 25% is desired. Assuming the JWBJ should acquire $\left(\frac{L}{D}\right)_{Max}$ =1.75, its Lift-to-drag ratio during cruise will be 15.155.

The wing loading is computed based on two constraints: (a) Stall velocity, v_{stall} and (b) landing distance. Assuming an approach speed of similar to Learjet 60 , the velocity is estimated to be 155.9km/hr. Typical cruise altitude of h_{cruise} of 35000ft and cruise Mach number of 0.8290 can be assumed.

Wing loading based on Stall velocity

To search for the desired C_{Lmax}.value and C_L , appropriate selection of airfoil has to be made. Other parameters are estimated using those applicable to RCBJ.

5 Airfoil selection

In order to start selecting a suitable airfoil for conceptual design purposes, airfoil analysis are carried out using basic principles and available simple computer program (for example designFOIL). Following historical trends, the NACA 5-digit series were used extensively in business jets. Thus, the NACA 5-digit series airfoils were selected. NACA 66013-43 airfoil was selected due to its conventionality and as a baseline.

A parametric study is then carried out starting with NACA66013-43 series, and its values are varied to find the best airfoil. Such parametric study is carried out varying the first, second and third, fourth and fifth digits, and other variations. Typical finding is illustrated by Table 4.

Table 4. Typical Outcome of airfoil parametric study result

Variation of the lift coefficient indicated by the first digit [α=0°]			
Type of airfoil	**Lift Coefficient**	**Drag Coefficient**	**Moment Coefficient**
NACA46013-43	0.436	0.0070	-0.064
NACA56013-43	0.544	0.0072	-0.080
NACA66013-43	0.653	0.0073	-0.097
NACA76013-43	0.724	0.0074	-0.113
NACA86013-43	0.766	0.0076	-0.129

For the example displayed in Table 4, the most suitable airfoil is NACA66013-43 because it has a considerably high lift coefficient and also a drag coefficient that is not too large. At the present stage, only parametric study for design iteration and optimization has been carried out; further structured optimization will be carried out incorporating wing twist and other structural considerations. Wing loading study is exemplified in Table 5.

Table 5, Wing Loading estimates

Constraints	Wing loading, W/S [lb/ft2]	Remarks
Stall Velocity	30.2390	Lower wing loading
Landing Distance	85.9830	Higher wing loading

Based on such parametric study, forewing sizing is carried out, followed by the computation of wing area and aspect ratio. Trade-off study is made to choose the appropriate aspect ratio, taking into considerations the effect of aspect ratio on lift curve slope due to wing tip (trailing) vortices as qualitatively exhibited in Fig. 5.

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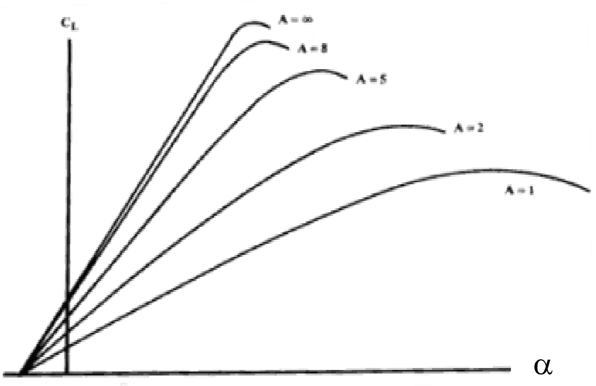

Fig.5. The effect of aspect ratio to lift

The figure above shows the relation between $\left(\frac{L}{D}\right)_{Max}$ and the wetted aspect ratio. From such graph and others available on various data bases, a first estimate on the wingspan and aspect ratio can be made.

The choice of wing dihedral angle should also be made, guided by dihedral angle guidelines as given by Raymer [13]. Since this joined-wing configuration is of low wing and it is a subsonic swept wing, the dihedral angles should be within 3 to 7 degrees.

The forewing is placed in such as way that the aerodynamic centre of the wing is in line with the centre of gravity of the fuselage, as schematically illustrated by Fig.6..

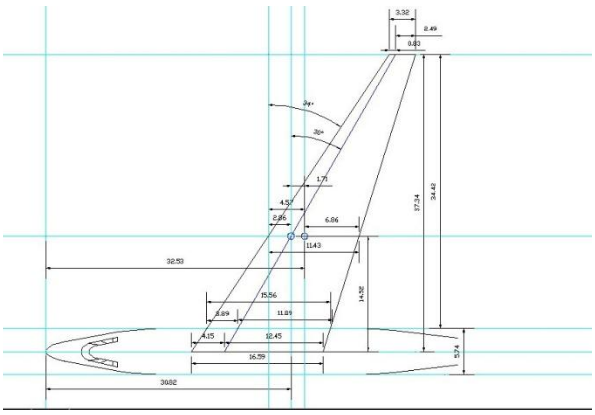

Fig. 6. Schematic Diagram of Forewing Placement

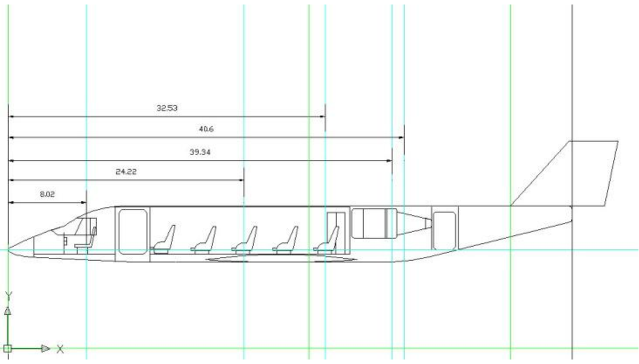

Fig. 7: Schematic Diagram **of** Fuselage Design and dimensioning

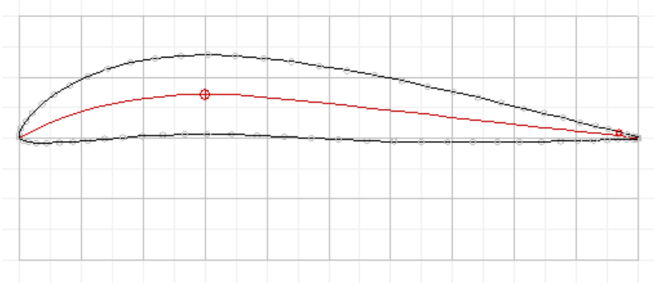

Fig. 8. NACA 66013-43 airfoil

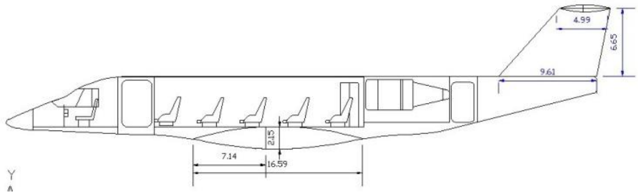

Fig. 9. Airfoil Maximum Thickness at Root Chord (dimensions in feet)

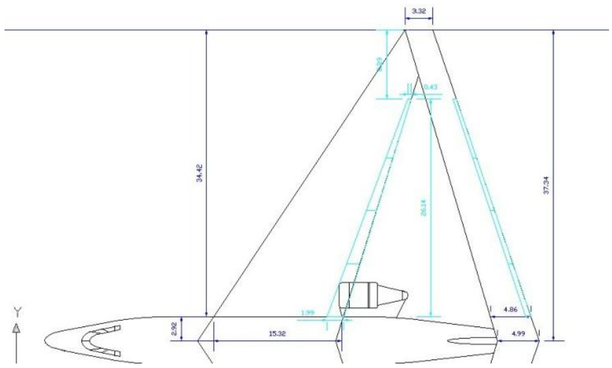

Fig. 10. Aileron sizing and placement

Table 6. Calculation of CG (without forewings)

Type of Weight	**Unit Weight [kg]**	**Quantity**	**Total [kg]**	**Total [lbm]**	**Distance from nose datum [ft]**	**∑**
Air crews	80	2	160	352.739619	8.02	2828.972
Passengers	80	9	720	1587.32856	24.22	38445.1
Cabin crew	80	2	160	352.73968	24.22	8543.355
Cabin crew unchecked baggage	30	2	60	132.27738	39.34	5203.792
Passenger unchecked baggage	5	9	45	99.208035	24.22	2402.819
Air crew luggage	40	2	80	176.36984	8.02	1414.486
Passenger checked luggage	30	9	270	595.24821	39.34	23417.06
Engine	448.1492	2	896.29	1976.00034	40.6	80225.61
				5271.91166		162481.2

Forewing Airfoil

The airfoil chosen for the forewing is . NACA 66013-43 airfoil, shown in Fig. 8.

Through computation using strip theory, on-line simple airfoil computational method and panel method, wing lift and its parametric optimization is carried out. The spanwise sectional lift distribution of the Conceptual JWBJ is exhibited in Figs. 11 and 12..

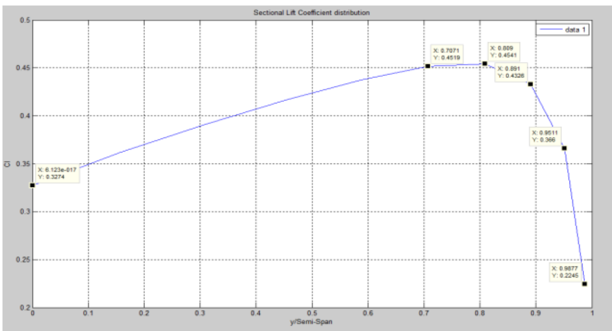

Fig. 11 Distribution of Sectional Lift Distribution along forewing mid-span

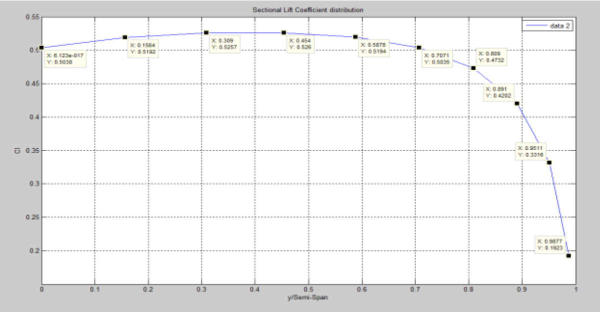

Fig. 11 Sectional lift coefficient distribution of the joined-wing configuration aircraft along forewing mid-span

Determination of Thrust and Engine Selection

The determination of the thrust loading is based on three constrains: Takeoff Distance, Rate of Climb and Maximum velocity at mid-cruise. The computational results are tabulated in Table 7.

Table 7. Engine selection

Constrain Parameters	Thrust Required [lbf]	Ratio (T/W)
Takeoff distance	1241.0472	0.09326
Rate of Climb	4782.6760	0.35940
V_{max} at $W_{mid\text{-}cruise}$	1661.5284	0.13070

Thrust loading based on Rate of Climb has been selected because the engines that will be selected later should produce the thrust required at all points in the flights, which is critical during takeoff which requires largest thrust (5265.9072 lbf.).

The maximum thrust is required occurs during rate-of-climb just after liftoff. T_{RMax} 5265.9072 lbf. The intended range for this aircraft is 2500 nautical miles (4630km) is considered long range and the type of aircraft falls under the transport aircraft category.
According to the design requirements laid down 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 is selected to fulfill this requirement. It is also the trend that a business jet size aircraft have 2 engines. Thus, the thrust required per engine is (5265.98072lbf/2)=2632.9536lbf.
Since the Federal Aviation Regulation states that two engines are required for long distance cruising, hence one engine must at least provide 2632.9536lbf during takeoff.

Running through the engine specifications tabulated in [11], two Honeywell TFE731-60 are selected to be installed on this joined-wing configuration because not only both engines can produce the required maximum thrust of 5265.98072lbf, but it is also significantly lighter as compared to other engines listed below.
For the TFE731-60 engine [53], Length, L=1.27m(or 4.1667ft). Inlet Diameter, D_{inlet}=0.787m (2.5820ft); Maximum Diameter, $D_{maximum}$=1.077m (3.5333 ft);

7 Fuselage Sizing

The semimonocoque fuselage design was adopted since the semimonocoque design can enable the installation of any combination of longerons, stringers, bulkheads, and frames to reinforce the skin and maintain the cross-sectional shape of the fuselage. The skin plays a major role in resisting the shear load and together with the longitudinal members to resist tension and bending loads. Longerons help to resist most the fuselage bending loads while stringers on the bending and stabilize the skin in time of compression. Bulkheads are used to overcome the concentrated load which is introduced unto the fuselage especially on the wing, landing gear, and tail surface attach points. This design eventually leads to the rigidity and strength of the aircraft to be distributed evenly on the structure, thus making it stronger. It is also proven that this design may withstand considerable amount of damage and still remain strong and intact.
The aisle have to be large enough based on safety requirement, so that all the passengers can disembark/escape from the aircraft in the case of emergency. Hence, it is important to have wider aisle to ensure that the emergency evacuation of 90 second can be achieved.

The fuselage is usually divided up into three sections: the nose cone, the cabin, and the tail cone. Typically the passengers are all housed in the cabin which tends to be in the shape of a right circular cylinder. This shape is structurally sound, easy to manufacture, permits increases in length by the addition of "plugs", and has reasonable drag characteristics. The length of the cabin then depends upon the number of rows of seats desired and the pitch P of the rows, i.e. the longitudinal distance between adjacent rows. The number of rows is fixed by the number of seats abreast chosen for the design
The fuselage layout is important in the design process as the length of the airplane depends on this. The length and diameter of the fuselage is related to the seating arrangement. The Fuselage of a passenger

airplane can be divided into four basic sections viz. nose, cockpit, payload compartment and tail fuselage. After comprehensive considerations, the nose length of the Learjet 60 is referred to be the nose length of this joined-wing aircraft.

Table 8. Fuselage parameters

Fuselage Length	57.8483ft
Fuselage Height Overall	5.7417ft
Closure angle	6deg
Upsweep Angle	14deg
Nose length	10.9666ft
Upsweep length	16.4213ft

The cabin dimensions are referred to the dimensions of the Learjet 60. These values are adapted to the joined-wing aircraft design.

Table 8. Cabin dimensions

Length (from cockpit divider to end of pressurized compartment	24.04ft
Width (centerline)	5.74ft
Width (floorline)	3.94ft
Height	4.87ft

In the design of the cockpit, the following factors are considered: Glass cockpit, for easy handling and less weight, as well as ergonomic from Pilots' point of view, among others. Other impression on the joined-wing configurations are exhibited in Figs. 12-14.

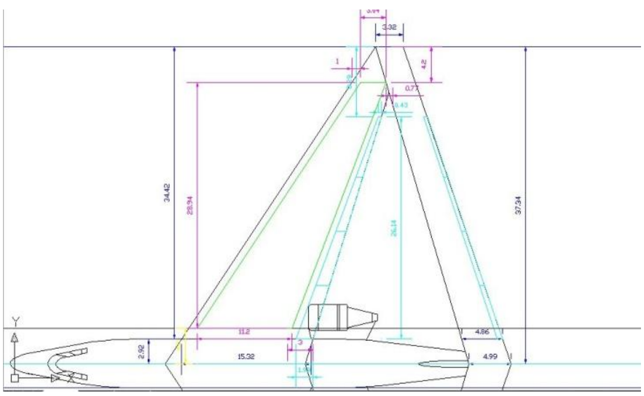

Fig. 12. Fuel tanks sizing and placement (dimensions in feet)

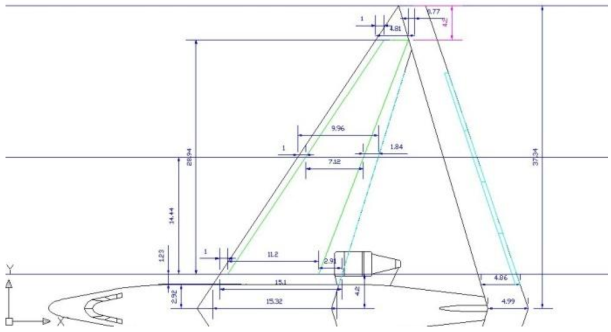

Fig. 13. Fuel tank on forewing (dimensions in feet)

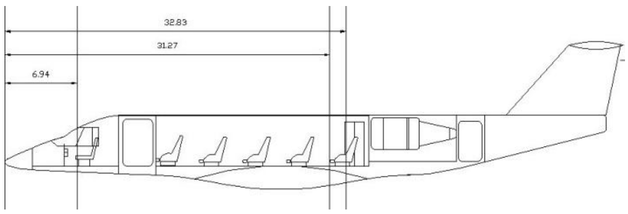

Fig. 14. CG localization for landing gear placement

5 DETAILED CONCEPTUAL DESIGN

5.1 Winglet Effects

Stretching wingspan or increasing aspect ratio certainly reduces induced drag. Designers, though, have to balance the benefits of less induced drag against the costs of structural weight increases, more parasitic drag or cost considerations. For these reasons, aircraft are fitted with winglets during the last two decades. Winglets work because they efficiently produce aerodynamic side forces that divert the inflow of air from the tip vortex. That takes a rather sophisticated small wing, one that is sized, shaped, cambered and canted for a specific application and mounted on the wingtip where it will produce the most benefit and the least drag. A simple, large end plate would block the vortex, but an increase in span produces a much better lift-to-drag improvement because it is a more-efficient lifting surface than a flat sheet of metal or composite.

The winglet has a tip, just like a wing, so it also produces a tip vortex, although a much weaker one. The winglet's tip vortex is located far above the airflow over the wing, thus it has little influence on the airflow over the main wing, hence Whitcomb reference of winglets as "vortex diffusers."

Table 9. Considerations for winglets.

TYPE OF JOINT	CONSIDERATION POINTS
1. Winglet extended above and below	• Winglet having an airfoil section and being twisted and cambered to minimized induced drag [86]. • Positive forewing dihedral angle allows larger winglets to be employed without ground clearance problems [87]. • Trailing edge of forewing overlaps with leading edge aft wing minimizing interference drag [87]. • Outer portion of forewing acts as slat for the outer portion of aft wing that improves tip-stalling characteristics [87]. • Winglets designed to offset parasitic drag and weight penalties of the connecting structure by reducing the airplane's induced drag [87]. • Winglets designed to develop sideways-acting loads even when the aircraft itself is not side-slipping [87]. • Mutual bracing effect on the other wing due to the fact that a truss structure is formed. Strength to weight ratio, and the stiffness of the aircraft is improved and the aerodynamic drag is reduced [87].
2. Circular cross section fairings	• The fairings are streamlined hence the aerodynamic drag on the fairings are reduced [87]. • Fairing can serve as fuel tank [87]. • Fairing can serve as a container for bombs, missiles or other forms of payload or for landing gear [87].
3. Circular cross section fairings with winglets extended above and below	• The functions are the same as the circular cross section fairings but a reduction in induced drag [87] .

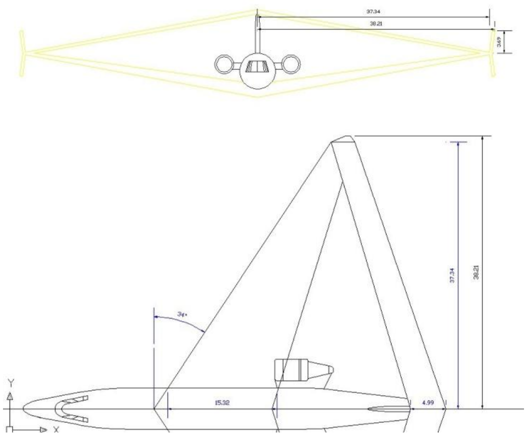

Fig. 15. Plan-view of the joined-wing configuration aircraft - forewing and aftwings are joined with winglet extended above and below (dimensions in feet)

6 Structural Analysis

Further to the study of the aerodynamic performance and weight reduction when all design parameters of the joined-wing configuration aircraft has been determined using RCBJ as a reference and to obtain better overall performance, structural loading on the critical parts of the joined-wing aircraft configuration is analyzed. From such analysis, some modifications may have to be made, bearing in mind that the modified configuration has better performance. These are illustrated in Figs. 16-18.

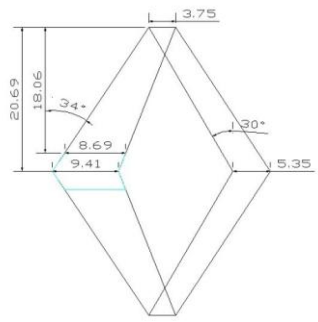

Fig. 16 Forewing and aft wing dimensions when all design parameters of the joined-wing configuration aircraft have been tuned to be comparable or better than the RCBJ, including structural considerations.

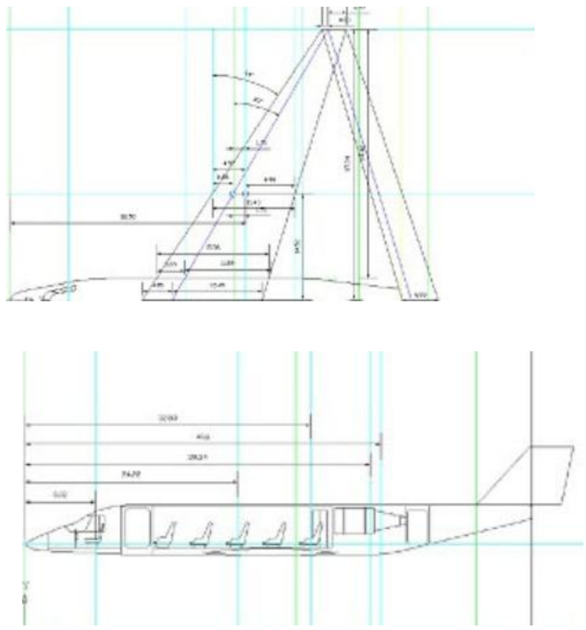

Fig. 17. Vertical Tail Placement pre-adjustment and Placement and sizing of aft-wing Conceptual Design Refinement

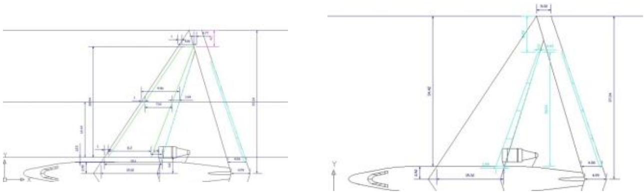

Fig. 18 Fuel Tank on Fore-wing and Aileron Sizing and placement

7 Flight envelope of the joined-wing configuration aircraft

The flight envelope, or V-n diagram, is determined according to regulations in the FAR's and from the mission profile. The regulations provide a method to determine the maximum limit load factor. The structure is designed to the ultimate load factor which has a factor of safety of 1.5 above the limit load. Basically v-n diagram were based on two limitations, namely aerodynamic limits and structural limits. Some of the parameter are involved in the V-n diagram calculations. The improved and refined values are used instead of the initial estimate.

Table 10 Parameters incorporated in flight envelope calculations

Parameters	Units	Value	Remarks
$(L/D)_{max}$		17.5	Initial estimate
$(C_L)_{max}$		1.512	Obtained from airfoil
Forewing Area, S	ft^2	743.5649	
K ***(forewing)***		0.07423	From Oswald span efficiency method
Oswald Span Efficiency Factor, e ***(forewing)***		0.4549	Oswald span efficiency method
C_{D_0} ***(total aircraft)***		0.0100094	Component buildup
Cruise altitude	ft	35000	
Cruise density	Slug/ft^3	0.0007382	
Cruise velocity	ft/s	806.6667	
Weight at mid-cruise	lb	20019.0179	Improved value through lift and structural considerations
Wing loading (W/S)	lb/ ft^2	30.5073	Improved value
Thrust loading (T/W)	lb_f/lb_m	0.2414	Improved value

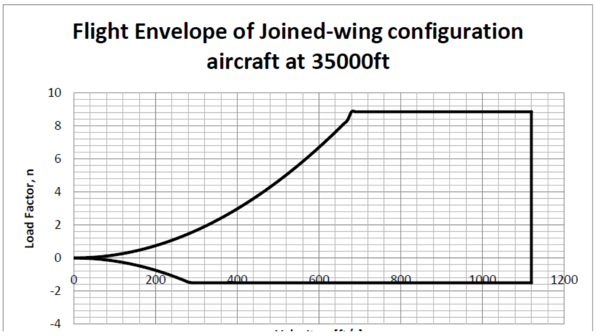

Fig. 18 Flight Envelope of JWBJ at 35000 ft

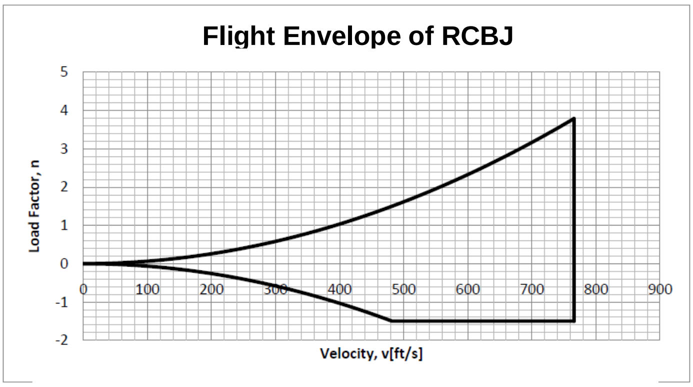

Fig. 19 Flight Envelope of RCBJ at 35000 ft

Table 11. Summary of JWBJ Design Specification as compared to RCBJ.

Parameter	Unit	Joined-Wing Configuration Aircraft	RCBJ
Number of passengers	-	9	9
Range	n mile	2500.6252	2409.0000
Maximum Range	n mile	2601.5674	2450.0000
Maximum Takeoff Gross Weight	lbm	22684.1299	23500.0000
Cruise speed (35000ft)	mph	550.0000	484.0000
Stall velocity at sea-level	ft/s	130.4044	129.8300
Stall velocity at 35000ft	ft/s	180.0000	-
Maximum Operating Speed	ft/s	1030.0000	765.6000
Serving Ceiling	ft	52651.8000	51000.0000
Takeoff Distance	ft	2603.7323	4000
Landing Distance	ft	2339.9544	2660.76
Fuselage Length	ft	57.8483	58.6667
Wing Span	ft	76.4200	47.7500
Wing Area (Forewing)	sq. ft	743.5649	264.5
Wing Area (Aft wing)	sq. ft	310.2954	

6 Conclusions

As concluding remarks, results obtained in both designs will be compared with the aim of concluding if the joined-wing configuration has met the objectives set out in the beginning of this work. To this end, the comparison will be established based on four technological aspects. It is important to note that the conclusions drawn from this study are based on simplistic aerodynamic and structural assumptions that should be more accurately substantiated in future works.

From the analysis carried out in this work, it can be concluded that, the JWBJ joined-wing configuration aircraft is 5.0716 percent lighter than the reference Business Jet (RCBJ) and produces 1.3629 times more lift than the Learjet 60. The total drag of the joined-wing configuration aircraft after considering the reduction of vortex drag due to the joined-configuration is 3.5 percent lower than the Learjet 60. Figs. 18 and 19 and Table 11 exhibit such comparison, which indicate that the objectives have been to a certain extent achieved. However, further study needs to be carried out to elaborate how joined-wing aircraft without any uplift produced by the aft wing will not turn out to be as heavy as the conventional design.

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