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CONCEPTUAL DESIGN OF A BUSINESS JET AIRCRAFT

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ABSTRACT
The modern jet transport is considered as one of the finest integration of technologies. Its economic success depends on performance, low maintenance costs and high passenger appeal and design plays a vital role in summing up all these factors. Conceptual design is the first step to design of an aircraft. In this paper a business jet aircraft is designed to carry 8 passengers and to cover a range of 2000 NM with maximum Mach No of 0.7 and with maximum ceiling of 29,000 ft. The conceptual design consisted of initial sizing, aerodynamics and performance analysis. Through trade studies and comparison with other business jet aircrafts a final model of the aircraft was built to achieve the requirements.

Key Words: Business jet, Conceptual design, Initial Sizing, Aerodynamics, Aircraft performance, Trade study.

1. Introduction

Airplane design is an art with scientifically approach. It requires both the intellectual engineering and sensible assumptions. Aircraft design is actually done to meet certain specifications and requirements established by potential users or pioneer innovative, new ideas and technology. Now-a-days business jet aircraft is one of the most popular forms of transport aircraft. A business jet is a jet aircraft designed to transport passenger and goods. It is also known as biz jet, executive jet or private jet. Biz jet is used by public bodies, government bodies and armed forces and used to parcel deliveries, transporting people and evacuation in case of casualties. This paper will illustrate about the conceptual design of a business jet.

Aircraft design has three distinct phases that are carried out in sequence. In chronological order, conceptual design, preliminary design and detail design. Conceptual design is the first step of designing aircraft. The main focus of this paper is to design a business jet transport aircraft conceptually. In conceptual design the configuration arrangement, size and weight and performance parameters will be calculated. The first thing required in a conceptual design is the design requirements which guide and evaluate the development of the overall aircraft configuration arrangement. In this paper we have tried to design gross weight, wing and tail geometry and some performance parameters with trade study.

Conceptual design is a series of activities which includes some basic question and answers. What requirements drive the design, what should it look like, what tradeoffs should be considered, what technologies should be used and do these requirements sale a viable and salable plane all these sums up conceptual design in a nutshell. This paper covers every aspects of conceptual design.

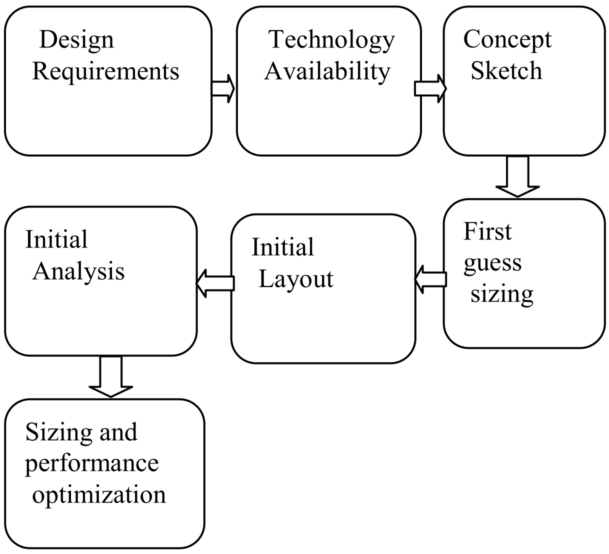

Fig 1: Block Diagram of Conceptual Design

2. Design Requirements

Mach no	0.7
Range	2000 NM
Maximum Ceiling	29,000 ft
Payload	8 pax
Endurance	30 min
Max g	+2.5, -1.2

3. Initial Layout Analysis

The actual design effort usually started with a conceptual sketch. This is the 'Back of a Napkin' drawing which gives a rough indication of what the design may look like. It first starts with a conceptual sketch.

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3.1 Concept Sketch

A conceptual skecth is a rough skecth to show how the future design will look like. In this design a rough hand made skecth was first drawn as a initial sketch.

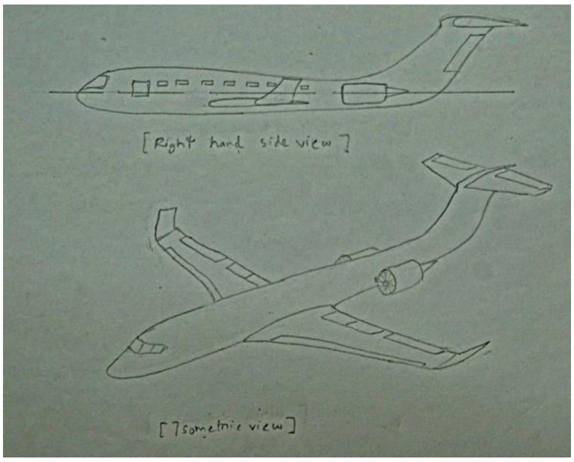

Fig.2: Initial Sketch

3.2 Initial Sizing

The conceptual design is used to estimate aerodynamics and weight fractions by comparison to previous design. In this paper first we estimated the required total weight and fuel weight to perform the design mission by 'Sizing' process.

3.3 Sizing from the Conceptual Sketch

Sizing is the most important calculation in aircraft design. It determines size of the aircraft, specially the take off-weight. Design take off gross weight can be calculated using the following equations,

$$Wo = \frac{Wcrew + Wpayload}{1 - \left(\frac{We}{Wo}\right) - \left(\frac{Wf}{Wo}\right)}$$

In this paper a jet for 8 passengers each of approximate 200 lbs, 2 crew members and 40 lbs of luggage for each passenger is considered. Fuel fraction is calculated based on the mission to be using approximations of the fuel consumption and aerodynamics.

3.4 Mission Profile

In this paper a simple cruise mission profile is considered as most transport and general aviation design use this profile. So there are five legs including takeoff, climb, cruise, loiter and landing. For warm up and take off, climb and landing we have taken weight fractions from the historical data.

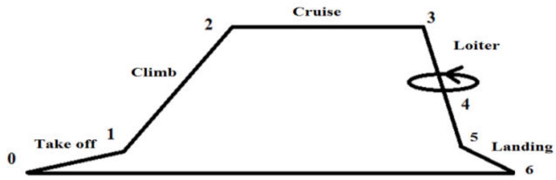

Fig 3: Mission Profile

Table.1: Historical mission segments weight fractions [1]

Mission Segment	Weight Fraction
Warm up and takeoff	0.970
Climb	0.985
Landing	0.995

For calculating weight fractions for cruise and endurance a Lift-to-Drag ratio which is a measure of the design's overall aerodynamic efficiency is needed .Using aspect ratio of 10.67 and from analyzing different business jet we have taken maximum Lift-to-Drag ratio as 23. Thus fuel fraction for cruise is 0.995 and for endurance is 0.991is found. An overall weight fraction of 0.8055is found and from this, takeoff gross weight is calculated 11035.624 lb. So it is a mid-sized business jet. Here the empty weight is 6439.16 lb and 2275.2146 lb of fuel is needed.

3.5 Engine Selection:

Design mach no is 0.7 and so analyzing both historical data and different jet aircraft High Bypass Turbofan engine. High BPR turbofan engine is used for high thrust and good fuel efficiency. Rolls-Royce/MAN Turbo RB193 .

4. Aerodynamics

Before designing layout, a number of parameters including aerofoil(s), the wing and tail geometries, wing loading as it affects the cruise speed, takeoff speed and landing distances, stall speed, handling qualities during all flight phases,

4.1 Aerofoil selection

(1)Camber aerofoil allows the airflow to remain attached have to be calculated. Thus it increases lift and reduces drag and also it produces lift at zero angle of attack. A five digit aerofoil analyzing different types of wing used so we used 65-2XX series is selected where last two digits define position of maximum camber. From calculation we have got the position of mean camber at .12 of mean chord i.e. 12%. Thus our aerofoil is NACA 65-212.

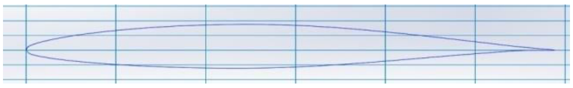

Fig 4: NACA 65-212 Aerofoil

4.2 Wing Geometries

(1)From different business jet and other transport aircraft historical trend the wing loading is 120 is found but considering different aerodynamic facts a wing loading of 80 is taken and so our wing area becomes 137.94 square feet. The relevant aspect ratio is 10.67 and so wing span is 38.35 ft.

(2)The maximum co-efficient of lift is 1.5. As wing sweep increases lateral stability, a leading edge sweep of 20 degree is taken. A twist angle of 3 degree to prevent tip stall is taken. Wing incidence angle is given 2 degree to minimize drag during cruise. As it is a subsonic aircraft so a positive dihedral of 5 is taken.

(3)Virtually all high-speed commercial transport aircraft are low wing so we have chosen a low wing aircraft as it gives us advantage for landing gear stowage.

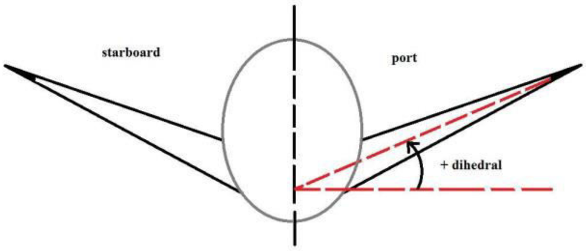

Fig 5: Low wing with dihedral

(4)We have chosen winglet as it increases lift-to-drag ratio by 20%. The following figure explains why winglet is chosen over the conventional wingtip.

4.3 Flap Selection

In this design double slotted fowler flap was used.

Fig 6: Fowler flap

From calculation, leading edge sweep angle is 20 degree. For flap maximum co-efficient of lift was calculated to be 2.82.

4.4 Stall Characteristics

For mach no 0.7, aerofoil thickness ratio of 14% is selected. So it is a moderately thick aerofoil where stall starts from leading edge.

4.5 Tail Geometries

(1)Tails are little wings and it provides for trim, stability and control. Here T-tail is considered as our tail arrangement not because of it is stylish but it allows the use of engines mounted in pods on the aft fuselage.

(2)Leading edge sweep of the horizontal tail is usually set 5 degree more than the wing sweep so it is 25 degree. For T-tail no aspect ratio and taper ratio needed for horizontal tail and for vertical tail taper ratio is 1 and aspect ratio is 0.8.

5. Landing Gear Arrangement

Today’s most commonly used landing gear arrangement is ‘tricycle gear’. So it is used with two main wheels aft of center of gravity, ahead of the main wheels.

As the aircraft is under 50,000 lb(11,036 lb) so two main wheels per strut will be used so we will get advantage in case of flat tire. The tires carries 90% the total weight of the aircraft so it is an important parameter. The diameter of the main wheels as 14.52 in and width is 9.12 in is calculated and the recommended tire pressure is 80 psi.

6. Fuselage Design

For a jet transport, fuselage length is 36.7 ft. Internal cabin system, aerodynamics related calculations etc are required to estimate Fuselage diameter. For rough estimation, taking circular fuselage, fineness ratio is 8 and diameter is 4.58 ft.

7. Vertical Stabilizer

From the historical data taper ratio for vertical stabilizer is 0.6-1.0[2] and the taper ratio considered is 1.0 in this design. T-tail reduces end plate effect by 5 percent. So tail volume coefficient is calculated 0.0855. From historical data, tail arm for aft mounted engine is about 45-50 %.[3] For a better design a tail arm should be as big as possible 50 % of fuselage length was taken and it was calculated to be 18.35 ft. Vertical stabilizer surface area was calculated to be 24.66 ft. square feet. Typical aspect ratio is 0.7-1.2. In this design a aspect ratio of 0.8; a higher aspect ratio was not chosen as increase in aspect ratio increases span which needs a stronger structure. Thus the weight will be increased so a lower aspect ratio was chosen.

8. Horizontal Stabilizer

Leading edge sweep for horizontal stabilizer is 5 degree greater than the sweep angle for wing. So it was taken as 25 degree. From statistical data tail volume coefficient for horizontal stabilizer is 1.00 but for clean air it was reduced 5% and taken as 0.95. Horizontal stabilizer surface area was calculates 27.25 square feet.

9 .Performance Analysis

Thrust-to-weight ratio directly associates the performance of the aircraft. It is not constant and it varies during flight as fuel burns. By analyzing historical data we estimated it for takeoff is 0.35 and for cruise is .0434[4] and it was calculated using the following equation:

$$\frac{T}{W} = \frac{1}{(\frac{L}{D})_{cruise}}$$

From Oswald efficiency as .8[5] and using aspect ratio we calculated our co-efficient of drag is 0.1344. For a jet propelled aircraft to maximize range it has to fly at $C_l^{0.5}/C_d$ and the associated velocity can be calculated as 655 ft/sec and maximum range is 1975 NM which was calculated. Maximum climb angle calculated is 17 degree using the following equation:

$$sin\theta_{max} = \frac{T}{W} - \sqrt{4kC_{Do}}$$

And for maximizing this angle velocity needed is 310 ft/sec. The maximum rate of climb is,

$$V_{(\frac{R}{C})max} = \left(\frac{2}{\rho_\alpha}\sqrt{\frac{k}{3C_{Do}}}(\frac{W}{S})\right)^{.5} = 60\ ft/sec$$

Its associated velocity is 867 ft/sec. Maximum distance covered in a gliding path is 70 NM and associated velocity is 310 ft/sec. Maximum endurance is calculated to be 1.11 hrs and the velocity associated is 500 ft/sec. Maximum velocity is 1600 ft/sec which is much more than our required velocity. Stalling velocity is,

$$V_{stall} = \sqrt{\frac{2W}{\rho S C_L}} = 212 ft/sec$$

Takeoff distance was calculated to be 5100 ft and landing distance is 3445 ft.

10. Trade Study:

Trade study is an important part of conceptual design. It helps the designer to choose the best convenient design parameters. From the above trade study it can be seen that the best thrust to weight ratio will be 0.40 and wing loading will be 80.

Table.2: Trade study

Thrust to weight ratio	Wing Loading	Takeoff distance(ft)	Landing distance (ft)
0.30	80	6100	3444.4
0.35	80	5100	3444.4
0.40	80	5000	3444.4
0.35	85	5800	4255.9
0.35	75	5200	3825.8

11. V-n Diagram

V-n diagram is a very important diagram for both the designers and the pilots. It is actually a graph showing the limiting factors of design and flying. It shows stall region, corner velocity, maximum velocity, maximum and minimum load factor etc.

Table.3: Different factors of V-n diagram

Maximum g	+2.5, -1.95
Maximum velocity	725.9 ft/sec
V_{NE}	871 ft/sec
Maximum lift coefficient for positive load factor	2.82
Maximum lift coefficient for negative load factor	1.5
Ceiling	29,000 ft

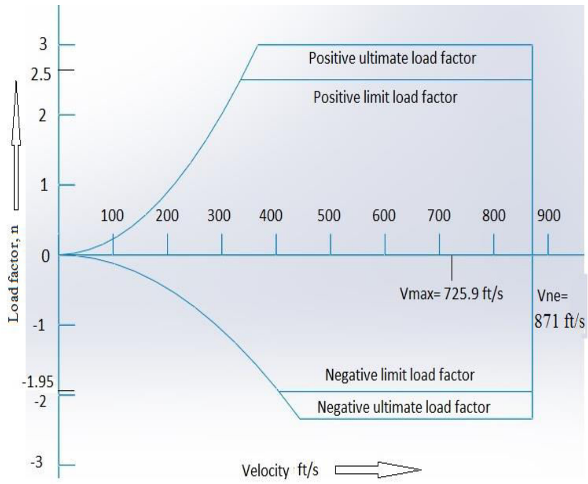

Fig 7: V-n diagram

12. Final Model

After all the calculations and the estimations done a final aircraft model was designd which is shown in the next page with the help of Solid Works software.

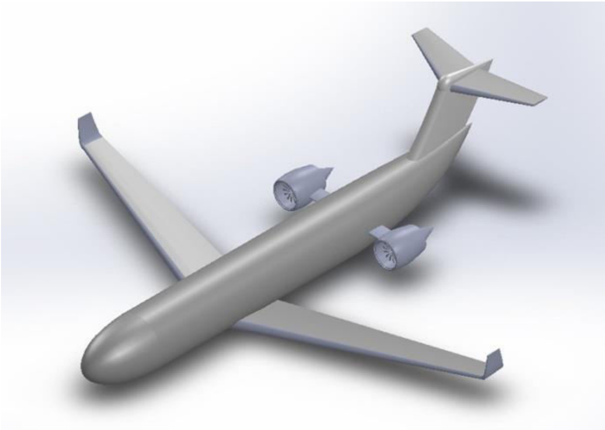

Fig 8: Isometric view

Fig 9: Front view

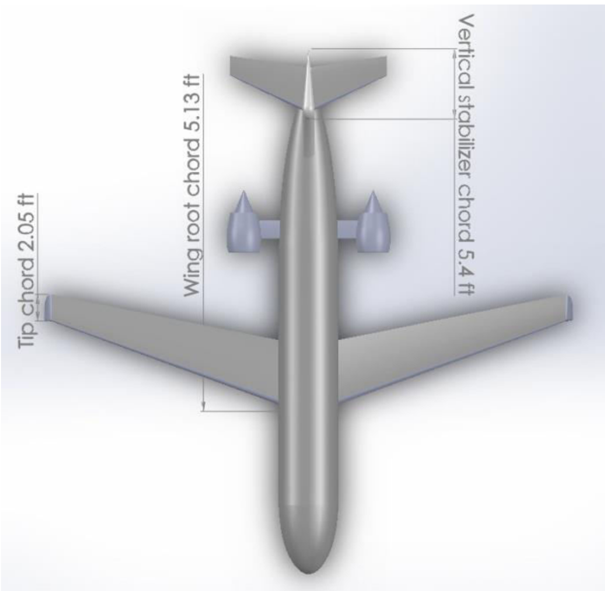

Fig 10: Top view

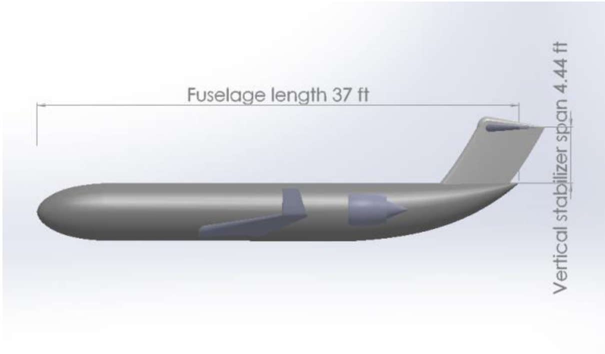

Fig 11: Right hand side view

13. Novel Ideas

During the design process some novel ideas were developed. These are explained in details below:

(1)T-tail was considered not because it is stylish but it allows the use of engines to be mounted on the aft fuselase in pods. Its not only stylish but it also reduces tail area due to endplate effect. Though it is heavier than the conventional wing it reduces buffet on the horizontal tail.

(2)Winglet was chosen as the wing tip as it offers lower drag. It is both cambered and twisted so the rotating vortex flow at the wing tipcreates a forward lift component which reduces total wing drag.

(4)As it is a small aircraft so aft-engine arrangement was used in this desing to maintain adequete wing nacelle and nacelle-ground clearances. As there is no wing-pylon interferance so less drag is created. Less assymetric yaw after engine failure with engine close to fuselage and lower fuselage height are also the advantages of using aft- engine arrangement.

14. Comparison with Similar Aircraft

Parameter	HONDA HA-420 JET AIRCRAFT	Designed Aircraft
Crew	2	2
Passenger	6	6
Fuselage Length	42.6ft	36.7ft
Wing span	39.9ft	38.35ft
Takeoff weight	9200lb	11035.624lb
Engine	GE Honda HF 120 turbofan engine	Rolls-Royce/MAN Turbo RB193 .
Maximum range	1180nmi	1975nmi
Maximum velocity	709.026ft/s	1581.469 ft/s

A comparison is done between the designed aircraft and HondaHA-420 Jet aircraft. Both the aircraft has almost same wing span and same passenger number. But with almost double range the weight increased only 2000 lb. It is a remarkable success in design.

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15. Conclusion

In comparison with other business jet aircraft the total weight of the aircraft that was calculated is a compatible one. Maximum range calculated is almost close to the requirement assumed but the maximum velocity calculated exceeds the required velocity. Comparing with statistical data the takeoff distance and the landing distance calculated is a good one. The aerofoil chosen is a compatible one with the design requirement. Some during the design process some requirements were fulfilled but some were not. But still the calculation of total weight was remarkable one with a higher range thus this design is totally fuel efficient and economical.

NOMENCLATURE

W_o : Total gross Weight, lb
W_f : Fuel weight, lb
W_e : Empty weight, lb
T : Thrust, lb
L : Lift, lb
D : Drag, lb
Θ : Climb angle, degree
C_{D0} : Zero Lift Drag co-efficient
V : Velocity, m/s
R/C : Rate of climb, m/s
$\dot{\rho}$: Density, kg/m^3
W/S : Wing loading
C_L : Lift coefficient
n : Load factor
Vne : Velocity never exceed

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