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(DEEMED TO BE UNIVERSITY)

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PADUR, CHENNAI - 603103

DESIGN OF TWENTY SEATER BUSINESS JET

ASB4341 - DESIGN PROJECT 1

In partial fulfillment for the award of the degree of

BACHELOR OF TECHNOLOGY

In

AEROSPACE ENGINEERING

Submitted by

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DECLARATION

This is to hereby declare that this project entitled "DESIGN OF TWENTY SEATER BUSINESS JET" has been carried out by our efforts and facts arrived by our observation and under the guidance and motivation of Dr. Ravi Ranjan Kumar. For the partial fulfillment of the award of the degree of Bachelors in Aerospace engineering. We hereby declare that this project has not been previously submitted to any other university.

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BONAFIDE CERTIFICATE

Certified that this project report titled "DESIGN OF COMMERCIAL TWENTY SEATER BUSINESS JET" is the bonafide work of ANNUNJAYA VERMA (19103074), SADHVI GUPTA (19103068), and G. DINESH (19103073) who carried out the project under my supervision. Certified further that to the best of my knowledge the work reported here does not form part of any other project/ research work based on which a degree or award was conferred on an earlier occasion on this or any other candidate.

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Contents

CHAPTER NO.	TITLE	PAGE NO.
	Abstract	8
	List of tables List of figures and graphs List of symbols and abbreviation	9
1.	**1. Introduction to Design** 1.1. Introduction 1.1.1. Aircraft purpose 1.2. Design process 1.3. Conceptual design 1.4. Design process breakdown	
2.	**2. Introduction to business jets** 2.1. Business jets 2.2. Types of business jets 2.2.1. Very light jets 2.2.2. Light jets 2.2.3. Mid-size jets 2.2.4. Super midsize jets 2.2.5. Large jets 2.3. Need for business jets 2.4. Aircraft selection 2.4.1. Lancair IV 2.4.2. Boeing 777 2.4.3. Antonov AN-70 2.4.4. Gulfstream G550 2.4.5. F-16 2.4.6. Airbus A340 Prestige 2.4.7. Boeing B77 VIP 2.4.8. Embraer Lineage 1000	
3.	**3. Preparation of comparative data sheet** 3.1. Common Aircrafts	

	3.2. Business jets	
4.	**4. Preparation of comparative graphs** 4.1. Cruise speeds vs Range 4.2. Cruise speeds vs Altitude 4.3. Cruise speeds vs Wing loading 4.4. Cruise speeds vs Gross weight 4.5. Cruise speeds vs Aspect ratio 4.6. Range vs Aspect ratio 4.7. Wing loading vs Aspect ratio 4.8. Wing loading vs Takeoff run 4.9. Wing loading vs R/C_{max} 4.10. Aspect ratio vs R/C_{max}	
5.	**5. Selection of tentative design parameters** 5.1. Tentative design parameters 5.1.1. General characteristics 5.1.2. Weight configuration 5.1.3. Performance	
6.	**6. Weight estimation** 6.1. Flight profile 6.2. Gross weight 6.3. Maximum fuel capacity 6.4. Conclusion	
7.	**7. Aerofoil and wing selection** 7.1. Wing selection 7.1.1. Number of wings 7.1.2. Wing support 7.1.3. Wing location 7.1.4. Wing planform 7.1.5. Wing angle 7.1.6. Wing loading 7.2. Airfoil selection 7.2.1. Geometry 7.2.2. NACA series 7.2.3. Calculations 7.3. Winglets	

	7.4. Selected wing parameters	
8.	**8. Tailplane selection** 8.1. Conventional tail 8.2. T-Tail 8.3. V-Tail 8.4. Cruciform Tail 8.5. Inverted Tail 8.6. Tail-less 8.7. Selection	
9.	**9. Fuselage selection** 9.1. Monocoque 9.2. Semi-monocoque 9.3. Geodesic truss 9.4. Selection	
10.	**10. Landing gear selection** 10.1. Types 10.2. Different configurations 10.3. Calculations	
11.	**11. Engine selection** 11.1. Reciprocating engine 11.2. Turbojet engine 11.3. Turbofan engine 11.4. Turboprop engine 11.5. Ramjet engine 11.6. Scramjet engine 11.7. Pulsejet engine 11.8. Engine selection	
12.	**12. Lift and drag estimation** 12.1. Lift estimation 12.2. Drag estimation	

13.	**13. Performance calculations** 13.1. Take off performance 13.2. Climbing 13.3. Gliding	
14.	**14. v-n diagram** 14.1. Choosing load factors 14.2. Finding maximum velocity 14.3. Finding corner velocity 14.4. Die velocity 14.5. Coordinates 14.6. v-n diagram	
15.	**15. Final design specifications**	
16.	**16. 3-view diagrams** 16.1. Front view 16.2. Side view 16.3. Top view	
17.	Conclusion	
18.	Reference	

Abstract

The demand for people to be transported from one location to another has risen dramatically in recent years. Businessmen and the wealthy demand a more rapid and luxury form of transportation. A commercial aircraft cannot provide an exclusive and elegant mode of transportation; hence, a Business jet, often known as a private jet, is required.

The goal of this project is to build and conceptualize a corporate/business aircraft that can serve a diverse variety of clients, from large corporations to small businesses and individuals. A business jet, often known as a private jet or bizjet, is a type of jet aircraft that is meant to transport groups of business people or rich individuals. The project entails the creation of a business jet that can seat approximately 20 passengers in a full seating layout, while also incorporating the amenities and level of comfort that a business jet is expected to provide, as well as the design specifications and performance parameters of a long-range commercial airliner. The aircraft allows for long-distance travel with improved efficiency, lower fuel consumption, and lower noise levels.

The aircraft's state-of-the-art engine and design features enable long-range travel with improved efficiency, lower fuel consumption, and lower noise levels. In the market, a mission profile that is efficient as a result of a well-engineered aircraft is expected. The concept's contribution The customer defines the mission profile, which is the flight profile of the aircraft. The lift, drag, stability, performance, and maneuverability of an aircraft are all affected by the wing profile and vertical tail layout. The performance of an airplane is directly influenced by its propulsion system.

Two crucial factors, wing loading and thrust to weight ratio, may be determined by integrating the wing profile and the propulsion system. In this paper, the Jan Roskam conceptual design approach is used to determine wing loading and thrust to weight ratio.

This aircraft's Supercritical airfoil provides high lift characteristics and better take-off and landing performance. The use of a supercritical airfoil in a Bizjet results in a higher lift coefficient.

List of tables

TABLE NO.	TITLE	PAGE NO.
3.1	Common aircrafts comparative datasheet	38
3.2	Business jets comparative datasheet	39
6.1	weight estimation	57
6.2	final weight measured	58
7.1	Selected Wing Parameters	82
11.1	Comparison of turbofan Engines	100
14.1	velocity coordinates	113
15.1	Finalized Design Parameters	114

List of Figures

FIGURES	CONTENT	PAGE NO.
	Design process breakdown	118
2.1	Honda jet	21
2.2.	Cessna citation mustang	21

2.3	Embraer phenom	22
2.4	Bombardier Learjet 30	23
2.5	Beechcraft premier	23
2.6	Hawker 400	24
2.7	Bombardier Learjet 45	25
2.8	Hawker 800	25
2.9	Cessna Citation XLS	26
2.10	Cessna Citation X	26
2.11	Bombardier Challenger 300	27
2.12	Gulfstream G250	27
2.13	Bombardier Challenger 600	28

2.14	Dassault Falcon 2000	28
2.15	Embraer legacy 600	29
2.16	Lancair IV	30
2.17	Boeing 777	31
2.18.	Antonov An - 70	32
2.19	Gulfstream G550	33
2.20	F-16	34
2.21	Airbus A340 Prestige	35
2.22	Boeing B77 VIP	36
2.23	Embraer lineage 1000	37
4.1	Graph:Cruise speed vs. Range	41
4.2	Graph:Cruise speed vs. Altitude	42

4.3	Graph:Cruise speed vs. Wing loading	43
4.4	Graph:Cruise speed vs. Gross weight	44
4.5	Graph:Cruise speed vs. Aspect ratio	45
4.6	Graph: Range vs. Aspect ratio	46
4.7	Graph:Wing loading vs. Aspect ratio	47
4.8	Graph:Wing loading vs. Takeoff run	48
4.9	Graph: Wing loading vs. R/C_{max}	49
4.10	Graph: Aspect ratio vs. R/C_{max}	50
6.1	Flight profile	53
7.1	Monoplane	59

7.2	Biplane	60
7.3	Triplane	61
7.4	Cantilever and semi cantilever wings	62
7.5	High wing	63
7.6	Mid wing	63
7.7	Low wing	64
7.8	Shoulder wing	64
7.9	Parasol wing	65
7.10	Rectangular wing	66
7.11	Elliptical wing	66
7.12	Tapered wing	67
7.13	Swept forward wing	68
7.14	Swept backward wing	68

7.15	Delta wing configurations	69
7.16	Wing angle	71
7.17	Elements of an airfoil	73
7.18	Angle of attack	74
7.19	NACA 63-415 airfoil	76
7.20	NACA 63-512	77
7.21	NACA 63A-514	77
7.22	Maximum Thickness	78
7.23	Sweep angle	78
7.24	Winglets	82
8.1	Types of T-tail	84
8.2	Inverted tail	84
8.3	Tailless	85
9.1	Monocoque and semi monocoque	86

9.2	Geodesic truss	87
10.1	Single wheel	89
10.2	Bicycle wheel	90
10.3	Tricycle wheel	90
10.4	Quadricycle	91
10.5	Multi Bogey wheel	92
11.1	Reciprocating engine	95
11.2	Turbojet engine	96
11.3	Turbofan engine	97
11.4	Turboprop engine	97
11.5	Ramjet engine	98

11.6	Diagram Ramjet engine	98
11.7	Pulse jet	99
11.8	Pratt & Whitney PW1000G	101
14.1	v-n diagram	113

Symbols and Abbreviation

- $A.R$ Aspect Ratio
- B Wing span(m)
- C Chord of the Aerofoil (m)
- C_{Root} Chord at Root (m)
- C_{Tip} Chord at Tip (m)
- C_d Drag Coefficient
- $C_{D,0}$ Zero lift Drag coefficient
- C_P Specific fuel consumption (lbs / hp / hr)
- C_L Lift Coefficient
- D Drag(N)
- E Endurance (hr)
- e Oswald efficiency factor
- L Lift (N)
- $(L/D)_{Loiter}$ Lift-to-drag ratio at loiter
- $(L/D)_{Cruise}$ Lift-to-drag ratio at cruise
- M Mach number of aircraft
- M_{FF} Mission fuel fraction
- R Range (km)
- R_e Reynolds number
- S Wing area (m^2)
- S_{Ref} Reference surface area
- S_{Wet} Wetted surface area
- S_a Approach distance (m)
- S_f Flare distance (m)
- S_{fr} Freeroll distance (m)

- $S.C$ Service ceiling
- $A.C$ Absolute ceiling
- T Thrust (N)
- T_{Cruise} Thrust at cruise (N)
- $T_{Take\text{-}off}$ Thrust at take-off (N)
- $(T/W)_{Loiter}$ The thrust-to-weight ratio at Loiter
- $(T/W)_{Cruise}$ The thrust-to-weight ratio at cruise
- $(T/W)_{Take\text{-}off}$ The thrust-to-weight ratio at take-off
- V_{Cruise} Velocity at cruise (m/s)
- V_{Stall} Velocity at stall (m/s)
- V_t Velocity at touch down (m/s)
- W_{Crew} Crew weight (kg)
- W_{empty} Empty weight of the aircraft (kg)
- W_{Fuel} Weight of fuel (kg)
- $W_{Payload}$ Payload of the aircraft (kg)
- W_0 Overall weight (kg)
- W/S Wing loading (kg/m^2)
- ρ Density of air (kg/m^3)
- μ Dynamic viscosity (Ns/m^2)
- λ Tapered ratio
- R/C Rate of Climb
- η Kinematic viscosity (m^2/s)

1. Introduction to design

Modern aircraft are a complex combination of aerodynamic operations, robust non-heavy structures, and advanced systems engineering. Passengers want more luxury and environmentally friendly flights. Many technical challenges, therefore, need to be balanced for the aircraft to achieve the specificity of its design. Aircraft construction is a complex and difficult task with many features and details needed to test before determining the final product. The design process starts from scratch and involves arithmetics, planning, design, and imagination of the real world, and a level head to meet any direct obstacle.

The entire aircraft goes through many changes in its design before it is finally built in the factory. These steps from the original ideas of the aircraft to the time of takeoff from the design process. Along the way, engineers consider four major areas of aeronautics: Aerodynamics, Propulsion, Structures and Materials, and Strength and Control.

Aerodynamics is the study of how air flows around a plane. The stronger the plane, or simplified, the less resistance it has to the air. If the air can move easily in an airplane, the aircraft engines have little work to do. This means that the engines do not have to be large or fuel-efficient to make the plane easier and more efficient. Engineers have to figure out what kind of aircraft they are designing because some aircraft require a certain amount of flight. For example, military jets move and turn faster and fly faster than noise (very high aircraft) at shorter distances. Most passenger planes, on the other hand, fly at low speeds (low plane) for long periods.

Propulsion is a study of what type of engine an aircraft needs. An airplane needs to have the right kind of engine for the type of job it has. The passenger plane carries a lot of passengers and heavy loads over long distances so its engines need to use more fuel. Engineers are also trying to silence the aircraft engines so that they will be silent and not harass passengers onboard or at their destinations. Another important concern is to keep the exhaust clean and environmentally friendly. Like cars, airplane fumes contain chemicals that can damage the earth's environment.

Structures and Materials is a study of how strong the aircraft is and what materials will be used to build it. The plane must be as light as possible. If the aircraft is lightweight, the work of the engines would be less and it'll be able to fly long distances. It is difficult to design a lightweight and sturdy aircraft at the same time. In the past, airplanes were usually made of lightweight materials such as aluminum, but today many engineers consider using composites in their designs. The compound looks and feels like plastic but is stronger than most metals. Engineers also need to make sure that the aircraft is not only efficient but also easy to build and maintain.

Stability and Control The study of how the aircraft manages and participates in pilot installation and supply. Pilots in the cockpit have a lot of data they can read on computers or a plane screen. Some of this information may include flight speed, altitude, route, and fuel levels as well as future weather conditions and other instructions from ground control. The pilot should be able to process the necessary data quickly, think about the type of action to be taken, and respond appropriately. In the meantime, the aircraft should display information to the pilot in a way that is easy to read and understand. The controls in the cockpit should be easily accessible and where the pilot expects them to be. It is also important that the aircraft responds quickly and accurately to the pilot's direction and direction.

When you look at an aircraft, it is easy to see that it has several similar features: wings, tail-shaped, horizontal tail, air-conditioning engine, and fuselage for passengers or cargo. However, if you look deeper beyond the basics, you can also see subtle, and sometimes huge differences. That's where the design comes in. Each aircraft is designed for a specific task, and the design is tailored to the needs and requirements of the aircraft. The design is based on the role and type of aircraft and not the other way around. So, that's why planes are different from each other and are thought of differently. Airlines that fall into the same category may have similar specifications and operating parameters, but with a few design changes.

Design is an integral part of any project. Without a fixed vision or knowledge of the required flight, it is impossible to conceive the final product. Aircraft construction is an art of science.

However, we can give the following explanation and try to explain it. Aircraft design is the process of intelligent design on paper of a flying machine to

(1) meet specific specifications and requirements established by potential users

(2) to innovate, new ideas and technologies.

The design process is a really clever, but very specialized operation influenced by a well-developed sense of knowledge, paying attention to successful aircraft designs used in the past, as well as (usually related) design processes and websites (manuals, etc.) that are part of all aircraft manufacturers.

1.1. Defining a new design

Aircraft design draws on a few basic areas of aerospace engineering. These include aerodynamics, propulsion, lightweight structures, and controls. Each of these areas includes parameters that control the size, shape, weight, and performance of the aircraft.

Many performance aspects can be specified by the mission requirements. These include:

- The aircraft's purpose or mission profile
- The type(s) and amount of payload
- The cruise and maximum speeds
- The normal cruise altitude
- The range of radius with normal payload
- The endurance
- The take-off distance at the maximum weight
- The purchase cost

1.1.1. Aircraft purpose

The start of any new aircraft is to see its purpose. With this, it is often possible to put the design in the standard category. Such categories include fighter jets, passenger or cargo aircraft, and standard aircraft. This can also be developed in small categories based on specific design objectives such as width (short or long), departure or arrival distances, high speed, etc. The classification process is useful in identifying any existing aircraft that could be used to make comparisons with the proposed design. With modern fighter jets, the purpose of a new aircraft usually comes from the military program office. With modern commercial airlines, a new design

proposal often comes as a response to in-house studies aimed at highlighting future market needs. For example, the details of the Boeing (B-777) commercial aircraft were based on the interest of commercial aircraft with dual-payable aircraft and the distance between the existing B-767 and B-747 aircraft. Since it is not always possible to fully perform all aspects of aircraft operation, defining a purpose leads to set which of these features will be the "design pilots." For example, with the B-777, two prominent design drivers were distance and payload.

1.2. Design motivation

A plane is a structure. The structures are designed to provide the desired aerodynamic features, and the materials and structures of their engines are selected and constructed to provide the required momentum. Even chairs, controls, and windows are buildings, all of which must be built to function properly. Designing aircraft buildings is especially challenging since their weight must be kept to a minimum. There is always a trade-off between building power and weight. Like a small overhaul of a plane, a small percentage of the total plane weight used by the building instead of the payload can make the difference between a profitable aircraft or an effective fighter for strategy and failure. The careful layout ensures that parts of the building are installed to carry the required loads effectively and do not interfere with the placement of other parts and the payload within the space. The choice of building materials can greatly affect the weight, cost, and complexity of production. The extreme complexity of modern aircraft structures makes the perfect balance of individual parts a challenge. Understanding the basic design concepts and techniques for designing efficient buildings is essential to all aircraft construction.

1.2.1. Design process

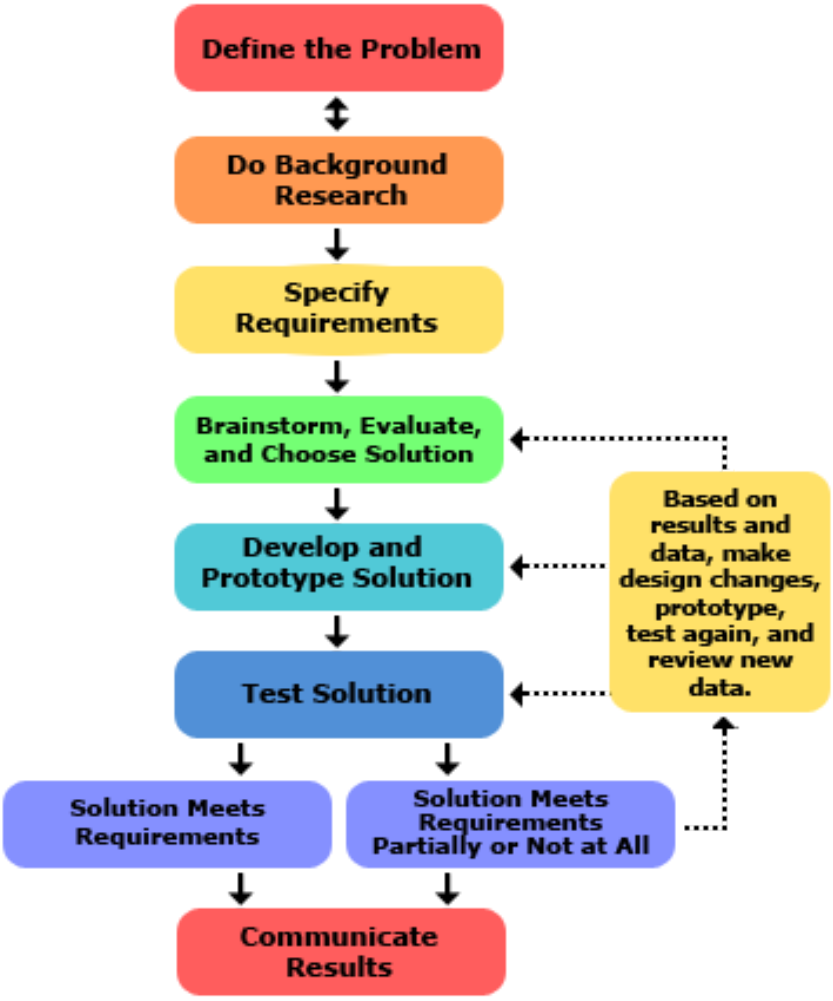
The process of designing a plane and taking it to the test site of the aircraft article contains a sequence of steps, as shown in the diagram. It begins by identifying the need or capacity of a new aircraft delivered by

(1) perceived market power

(2) technological advances made through research and development.

The first will include market share forecasts, which attempt to explore the factors that may influence the future sale of a new design. These factors include the need for a new design for a specific size and function, the number of competing designs, and the similarity of existing aircraft features. As a rule, a new design with competitive performance and cost will have an equal share of new sales with existing competitors. The needs and capabilities of the new aircraft are determined by a market survey that will determine the requirements for sensible aircraft equipment. This is integrated into a design proposal that includes (1) the motivation to start a new design and (2) the “technical readiness” of the new technology to be incorporated into the new design. The requirements of the equipment must be explained before the project is started. Based on this, the most important performance features or "design drivers" can be identified and developed above all others. Following the design proposal, the next step is to produce a conceptual design. The conceptual design enhances the original standard size and configuration of the new aircraft. It includes weight scales and a selection of aerodynamic features that will best fit the mechanical requirements specified in the design proposal. The design of the concept is driven by the requirements of the equipment, set out in the design proposal. In some cases, this may not be possible so the requirement may be relaxed in one or more areas. This is shown in the recurring loop in the flow chart. When the equipment requirements are met, the design progresses to the next stage, which is the first design.

1.2.2. Design process breakdown



1.3. Conceptual design

The steps involved in the conceptual design of an aircraft. It is broken down into several elements, which are followed in order. These consist of :

1. Literature survey
2. Preliminary data acquisition

3. Estimation of aircraft weight

- 3. a. Maximum take-off weight
- 3. b. The empty weight of the aircraft
- 3. c. Weight of the fuel
- 3. d. Power loading
- 3. e. Thrust to weight ratio

4. Engine selection

5. Performance curves

6. 3 View diagrams

2. Introduction to business jets

2.1 Business jets

A business jet, private jet, or bizjet is a plane designed to transport small groups of people. Business jets may be adapted to other roles, such as wound removal or parcel delivery, and some are used by civil society organizations, government officials, or armed forces. Business jets are also designed comfortably for special clients, the interior is designed differently compared to other bizjets.

2.2. Types of business jets

These are mainly classified based on their size and the number of passengers and crew. They are classified as

1. Very Light Jets (VLJ)
2. Light Jet
3. Mid-size Jets
4. Super midsize Jets
5. Large jets

2.2.1. Very light jets

It is less than 45 meters high. It can carry up to 7 people and staff. Its wings do not exceed 50 feet. These types of commercial aircraft came into existence with the release of the Eclipse 500 Aircraft. These widgets are authorized for single-driver operation. Some popular Jet Lights,

1. Honda Jet
2. Embraer Phenom
3. Cessna Citation Mustang



Fig 2.1. Honda jet



Fig 2.2. Cessna citation mustang



Fig 2.3. Embraer phenom

2.2.2. Light jets

It is a system where the aircraft is lightweight but heavier than VLJs. It is less than 55 meters high. It can carry up to 10 passengers and crew. It has a wingspan of up to 55 ft. These aircraft are being introduced in the commercial aviation industry with the release of Learjet 23. These jets provide access to smaller airports and enable the customer to travel faster to become an efficient air travel tool. Some famous Light Jets are :

1. Bombardier Learjet 30
2. Beechcraft Premier
3. Hawker 400



Fig 2.4. Bombardier Learjet 30



Fig 2.5. Beechcraft premier



Fig 2.6. Hawker 400

2.2.3. Mid-size Jets

Mid-size Jets is a system in which aircraft are built as long as cross-country aircraft. It can carry up to 10 passengers and crew. It has a wingspan of 73 ft. These planes are designed for longer flights with more passengers than the previous two jet categories. Some famous mid-size Jets are

1. Bombardier Learjet 45
2. Hawker
3. Cessna Citation XLS



Fig 2.7. Bombardier Learjet 45



Fig 2.8. Hawker 800



Fig 2.9. Cessna Citation XLS

2.2.4. Super Mid-size jets

Super mid-size jets is a system where the aircraft has large cabinet space, high altitude, long-distance range, and can travel at high speeds. It is less than 75 meters high. It can carry 12 passengers and crew. These jets provide the comfort of a wide-rise and high-performance aircraft. Some famous Jets are super super-size,

1. Cessna Citation X
2. Bombardier Challenger 300
3. Gulfstream G250



Fig 2.10. Cessna Citation X



Fig 2.11. Bombardier Challenger 300



Fig 2.12. Gulfstream G250

2.2.4. Large jets

Large Jets is a system where the aircraft has a large house space, long distances, and can travel at high speeds. It is less than 95 meters high. It can carry up to 20 passengers and crew. It has a maximum density of 70 ft. on average. Some of the most famous Big Jets are

1. Bombardier Challenger 600
2. Dassault Falcon 2000
3. Embraer Legacy 600



Fig 2.13. Bombardier Challenger 600



Fig 2.14. Dassault Falcon 2000



Fig 2.15. Embraer legacy 600

2.4. Need for Business Jets

The following is a summary of some of the most common reasons businesses use business aviation to solve transportation problems.

- Gaining access to areas where airline service is limited or non-existent. The number of towns served by business aviation is ten times more than that of commercial airlines. This means that businesses can locate plants or facilities in small towns or rural areas where commercial airplane service is limited or non-existent. This is crucial given the loss of aeroplane service in roughly 100 locations.
- Multiple destinations can be reached fast and efficiently. Companies that need to go to several locations in a single day may use business aviation because other means of transportation may be difficult or impossible to perform.

2.3. Aircraft selection

. The following are the aircraft chosen for study

2.3.1. Lancair IV:

The Lancair IV and IVP are a family of four-seat, retractable gear, compound, low-wing monoplanes powered by a 550 cubic inch Continental TSIO550 twin-turbo piston engine. Aircraft kit production ended in 2012. The Lancair IV and IVP were designed by Lancair around the Continental TSIO550, a twin-turbo engine capable of developing and developing 350 hp (261 kW) at sea level. Operating altitude up to 29,000 feet. By the fall of 2011, 110 Runcare IVs and 250 IVPs had been completed and were in flight. In July 2016, the company announced that it would sell Lancair's old aircraft line. Lancair IV will focus on Lancair Evolution instead. After the migration was completed, the company changed its name to Evolution Aircraft Company. Buyers of the old aircraft line continued to operate as Lancair International



Fig 2.16. Lancair IV

2.3.2. Boeing 777:

The Lancair IV and IVP are a family of four-seat, retractable gear, compound, low-wing monoplanes powered by a 550 cubic inch Continental TSIO550 twin-turbo piston engine. Aircraft kit production ended in 2012. The Lancair IV and IVP were designed by Lancair around the Continental TSIO550, a twin-turbo engine capable of developing and developing 350 hp (261 kW) at sea level. Operating altitude up to 29,000 feet. By the fall of 2011, 110 Runcare IVs and 250 IVPs had been completed and were in flight. In July 2016, the company announced that it would sell Lancair's old aircraft line. Lancair IV will focus on Lancair Evolution instead. After the migration was completed, the company changed its name to Evolution Aircraft Company. Buyers of the old aircraft line continued to operate as Lancair International



Fig 2.17. Boeing 777

2.3.3. Antonov An-70:

The Antonov An-70 (Ukrainian: Антонов Ан-70) is a four-engine medium-range transport aircraft, and the first aircraft to take flight powered only by propfan engines. It was developed in the late 1980s by the Antonov Design Bureau to replace the obsolete An-12 military transport aircraft. The maiden flight of the first prototype took place in December 1994 in

Kyiv, now independent Ukraine. Within months the prototype had suffered a mid-air collision. A second airframe was produced to allow the flight-test program to proceed. Both prototypes were produced by the Kyiv Aircraft Production Plant. Following the dissolution of the Soviet Union in the early 1990s, the program became a joint development between Russia and Ukraine. The former compounded the issue of a reduced market with its intermittent commitment to the project. Repeated attempts to start production have had limited success. Western European countries, including Germany, at one stage, assessed the aircraft for procurement, but many later decided against it.



Fig 2.18. Antonov An - 70

2.3.4. Gulfstream G550:

The Gulfstream G550 is a business jet manufactured by General Dynamics' Gulfstream aerospace unit in Savannah, Georgia, USA. The authentication specification is GVSP. As of January 2016, 450 G550s were in operation. The last commercially available G550 unit is the, which will be delivered in 2021. A reduced fuel capacity version of the aircraft was sold as the G500. Compared to the Gulfstream V, drag reduction details boost the range by 250 nmi (460 km) and increase fuel efficiency. Maximum takeoff weight (MTOW) is increased by 500 lb (230

kg) and takeoff performance is enhanced. The seventh pair of windows is added and the entry door is moved 2 ft (0.61 m) forward to increase usable cabin length. The Plainview flight deck features cursor control devices, Honeywell Primus Epic avionics, a standard head-up guidance system by Rockwell Collins, and an enhanced vision system by Elbit, improving situational awareness in reduced visibility conditions.



Fig 2.19. Gulfstream G550

2.3.5. F-16:

General Dynamics The F16 Fighting Falcon is a single-engine multirole fighter originally developed by General Dynamics for the United States Air Force (USAF). Designed as an air superiority fighter, the was a successful all-weather utility aircraft. More than 4,600 aircraft have been built since production began in 1976. But no more The improved version purchased by the US Air Force is designed for export by customers. In 1993, General Dynamics sold its aircraft manufacturing business to Lockheed Corporation. It became part of Lockheed Martin after the merger of Martin Marietta in 1995. The main features of the Fighting Falcon are a frameless canopy for improved visibility, a side-mounted joystick for easy control during maneuvering, and 30 degrees from the vertical to reduce the impact of G-force on the pilot. The first deployment of the tilted ejection seat, relaxed static stability/fly-by-wire flight control system will help make

the aircraft agile. F16 It features an internal M61 Vulcan cannon and 11 positions for mounting weapons and other mission gear. The official name of the F16 is "Fighting Falcon", but "Viper" is often used. Pilots and crew are perceived to resemble Viper Snakes as well as Colonial Vipers. The starfighter of the space carrier Galactica that was aired when the F16 was commissioned.



Fig 2.20. F-16

2.3.6. Airbus A340 Prestige:

The A340600 is the largest member of the Airbus A340 family, with a total length of 75.36 meters and a seating capacity of 320-370 (or 475 with high-density seats). The aircraft is capable of effective commercial, enterprise, or government operations, with cutting-edge features such as a pilot-friendly cockpit, flight control, and as well as lightweight composite construction, and fuel-efficient aerodynamic design. Incorporates technology. System. The Super Stretch A340600 is Airbus' longest jet airliner, with a total fuselage of meters of 75.36 meters. Aircraft capacities range from 320 to 370 seats in a typical layout and can accommodate up to 475 passengers in a

high-density configuration. The provides operators around the world with the ideal blend of capacity and efficiency.



Fig 2.21. Airbus A340 Prestige

2.3.7. Boeing B77 VIP:

Boeing has new options. The next 777X business jet version. The long-range, fuel-efficient aircraft can accommodate 350, and 425 passengers in two variations, providing a stunning canvas when configured for personal or corporate use. Boeing Business Jet released three interior concepts on Monday, VIP version of its largest and longest-range twin-engine aircraft. Reserving seats for hundreds of passengers is a Middle Eastern design Turkish style called Shaheen (Royal Whitehawk Arabic) by the Swiss interior company Jet Aviation, a luxurious lounge, games, and cinema area, and give way to the steam room Presented in Dubai at the Middle East Business Aviation Association show. Reducing the weight of these passengers and their luggage increases the range of the BBJ 7778 from 11,645 nautical miles by approximately 33% and the larger 7779 by 44% to 11,000 nautical miles. Enough to travel non-stop from Seattle to Dubai. From London to Sydney



Fig 2.22. Boeing B77 VIP

2.3.8. Embraer Lineage 1000:

Embraer Lineage 1000 is a private jet variant of the Embraer 190 regional jet airliner, which was introduced on May 2, 2006. The Lineage, manufactured by the Brazilian aerospace firm Embraer, is marketed as an "ultra-large" business jet with comfortable seating for 19 passengers. The Lineage 1000 is based on the Embraer 190 airliner, but with additional fuel tanks in the lower deck cargo hold space, which nearly doubles the jet's range. It has a luxurious interior that is divided into up to five sections, including an optional bedroom, a washroom with running water, and a walk-in cargo area at the back. Its fuselage cross-section is larger than that of comparable-priced business jets such as the smaller than other airline conversions the $50.4 million Global 5000, $53.8 million Falcon 7X, or $54.5 million Gulfstream G600 other airliner modifications are the Sukhoi Superjet 100, B737-based $71.4M Boeing Business Jet-1 or A320-based $87.0M Airbus Corporate Jet A319. The Lineage 1000 received its certification from Brazil's ANAC and from EASA in December 2008. It was certified by the USA Federal Aviation Administration on 7 January 2009. The first Lineage 1000 was delivered to Aamer Abdul Jalil Al Fahim on May 7, 2009.



Fig 2.23. Embraer lineage 1000

3. Preparation of comparative datasheet

3.1. Common aircrafts

Parameters	**Lancair IV**	**Boeing 777**	**Antonov An-70**	**Gulfstream G550**	**F-16**
Dimensions					
Length	7.62 m	63.7 m	40.7 m	29.39 m	15.06 m
Height	2.44 m	18.51 m	16.38 m	7.87 m	4.88 m
Wing span	9.93 m	60.93 m	44.06 m	28.50 m	9.96 m
Aspect ratio	9.3	8.7	8.2	7.7	3.2
Wing area	9.1 m^2	427.8 m^2	394 m^2	105.63 m^2	27.86 m^2
Specifications					
Empty weight	907 kg	134800 kg	66230 kg	17917 kg	8570 kg
MTOW	1610 kg	247200 kg	145000 kg	41277 kg	19200 kg
Fuel weight	703 kg	94210 kg	38000 kg	18819 kg	7797 kg
Performance					
Max. speed	595 kph	950 kph	780 kph	1086 kph	2120 kph
Range	2494 km	9700 km	6600 km	12501 km	4220 km
Max. (R/C)	13.2 m/s	26.33 m/s	24.9 m/s	21 m/s	254 m/s
Max. (W/S)	176.9kg/ m^2	536.5kg/ m^2	498 kg/m^2	390.8kg/ m^2	431 kg/m^2
Service ceiling	8840 m	13140 m	12000 m	15545 m	15240 m
Takeoff run	457 m	2440 m	1800 m	1801 m	-

3.2. Business jets

Parameters	**Airbus A340 Prestige**	**Boeing B777 VIP**	**Embraer Lineage 1000**
Type	Long range corporate jet	Wide body business jet	Long range business jet
Dimensions			
Length	63.68 m	73.86 m	36.24 m
Height	16.74 m	18.49 m	10.28 m
Wing span	60.3 m	60.9 m	28.72 m
Aspect Ratio	10.1	8.7	8.9
Wing area	361.6 m^2	427 m^2	92.5 m^2
Wing			
Sweep angle	30^0	31.6^0	25^0
Root chord	10.6 m	9.57 m	4.76 m
Tip chord	2.6 m	2.29 m	1.22 m
Mean chord	7.26 m	7.01 m	3.22 m
Flaps	Single slotted	Double slotted	Double slotted
Taper ratio	0.25	0.24	0.2
Wing loading	760.5 m^2	699.8 m^2	594.6 m^2

Weights			
Payload	50900 kg	59422 kg	12400 kg
Empty weight	130900 kg	167800 kg	280 80 kg
MTOW	275000 kg	299370 kg	550 00 kg
Fuel weight	114615 kg	135845 kg	218 71 kg

Powerplant			
Name	CFM56-5C3	GE90-115B	GE CF3 4-10E
Thrust rating	145 kN (x4)	514 kN (x2)	82.3 kN (x2)
SFC	0.58	0.55	0.65
Dry weight	3990 kg	8283 kg	170 0 kg
Performance			
Max speed	914 kph	927 kph	890 kph
Cruise speed	880 kph	895 kph	847 kph
Max R/C	23 m/s	24.38 m/s	16.1 9 m/s
Service ceiling	12500 m	13140 m	124 96 m
Range	14300 km	18700 km	833 4 km
Takeoff run	3125 m	3045 m	1852 m

4. Comparative graphs

4.1. Cruise speed vs. Range

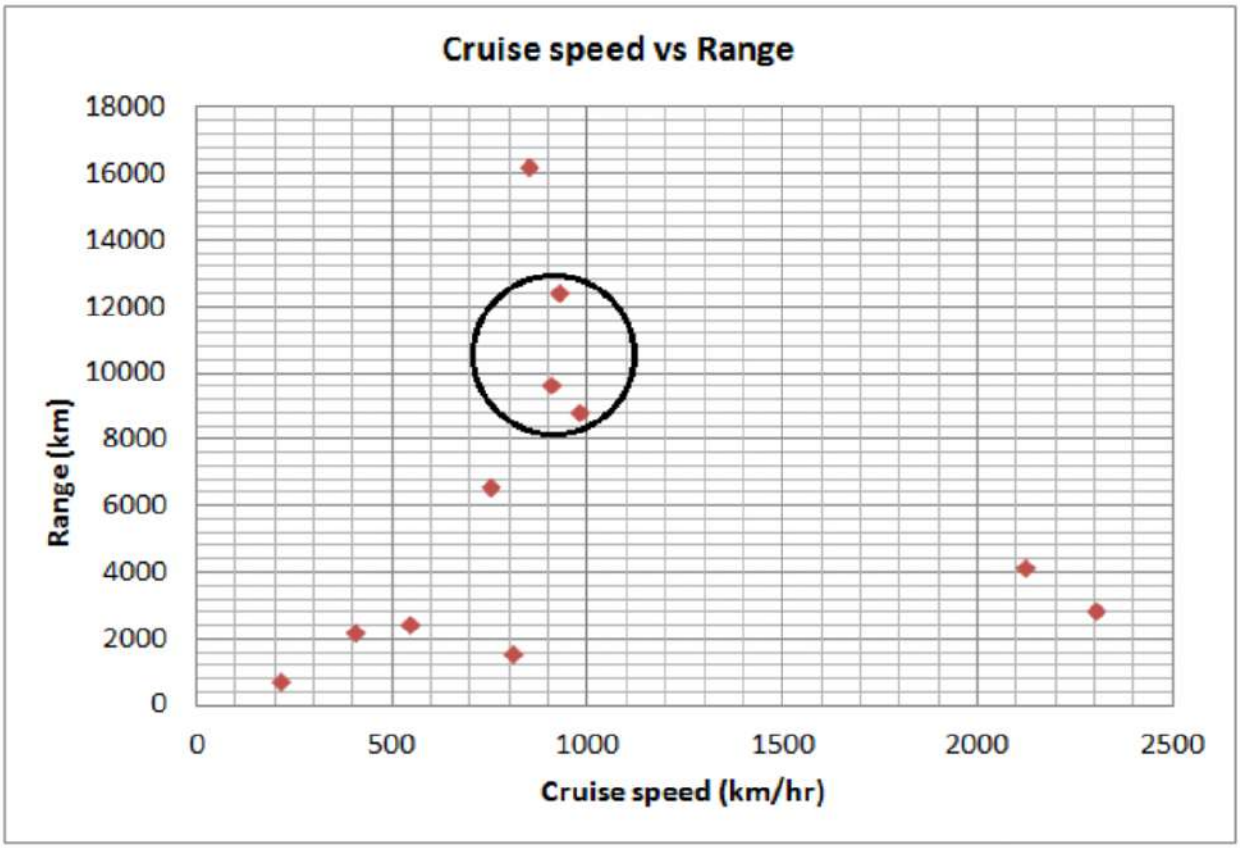


Fig 4.1. Graph:Cruise speed vs. Range

4.2. Cruise speed vs. Altitude

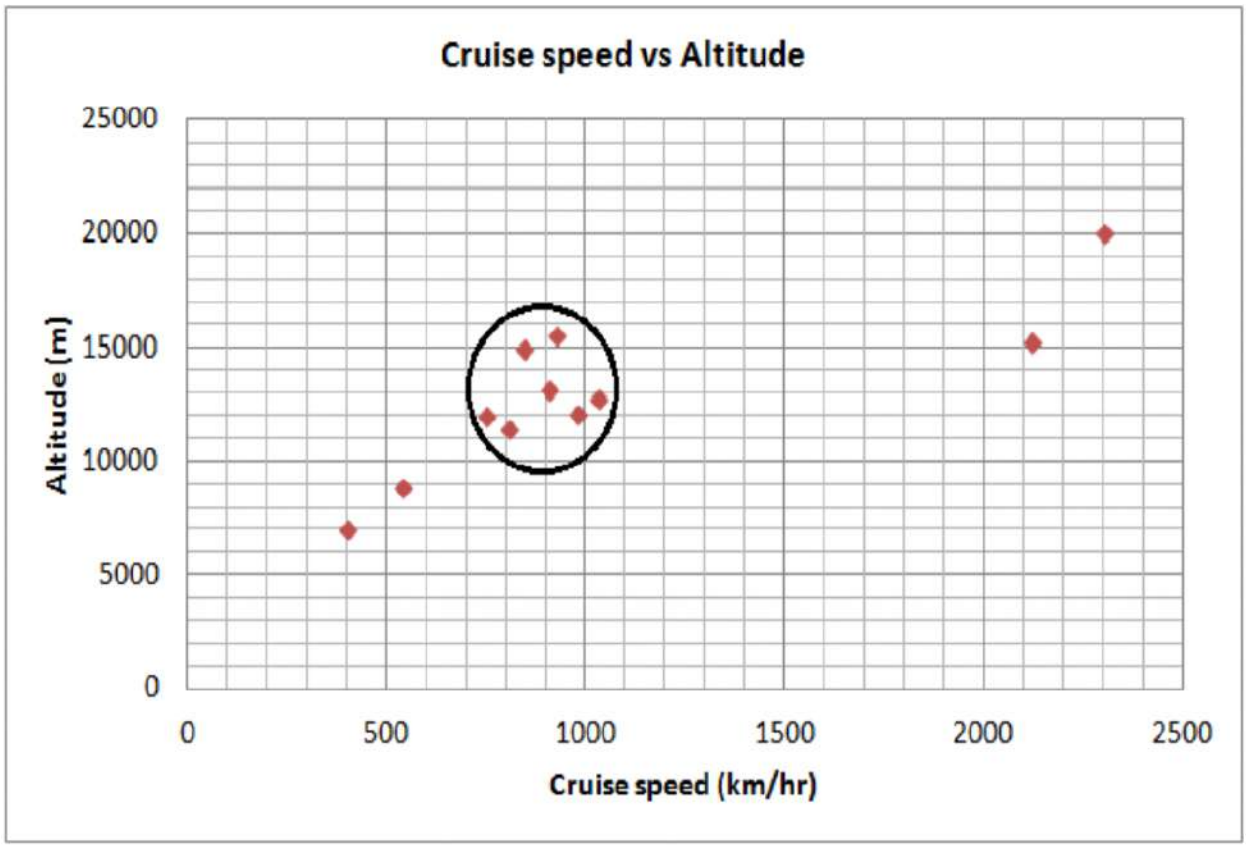


Fig 4.2.Graph:Cruise speed vs. Altitude

4.3. Cruise speed vs. Wing loading

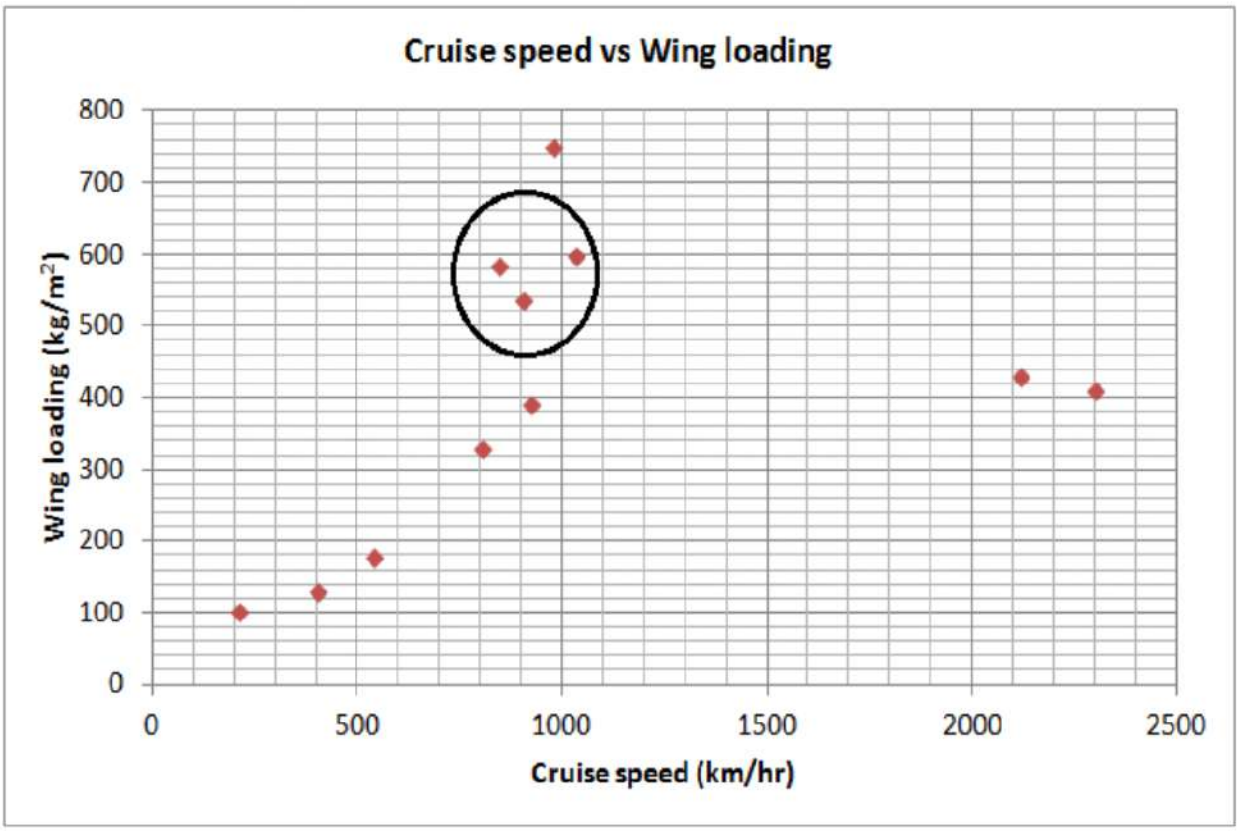


Fig 4.3.Graph:Cruise speed vs. Wing loading

4.4. Cruise speed vs. Gross weight

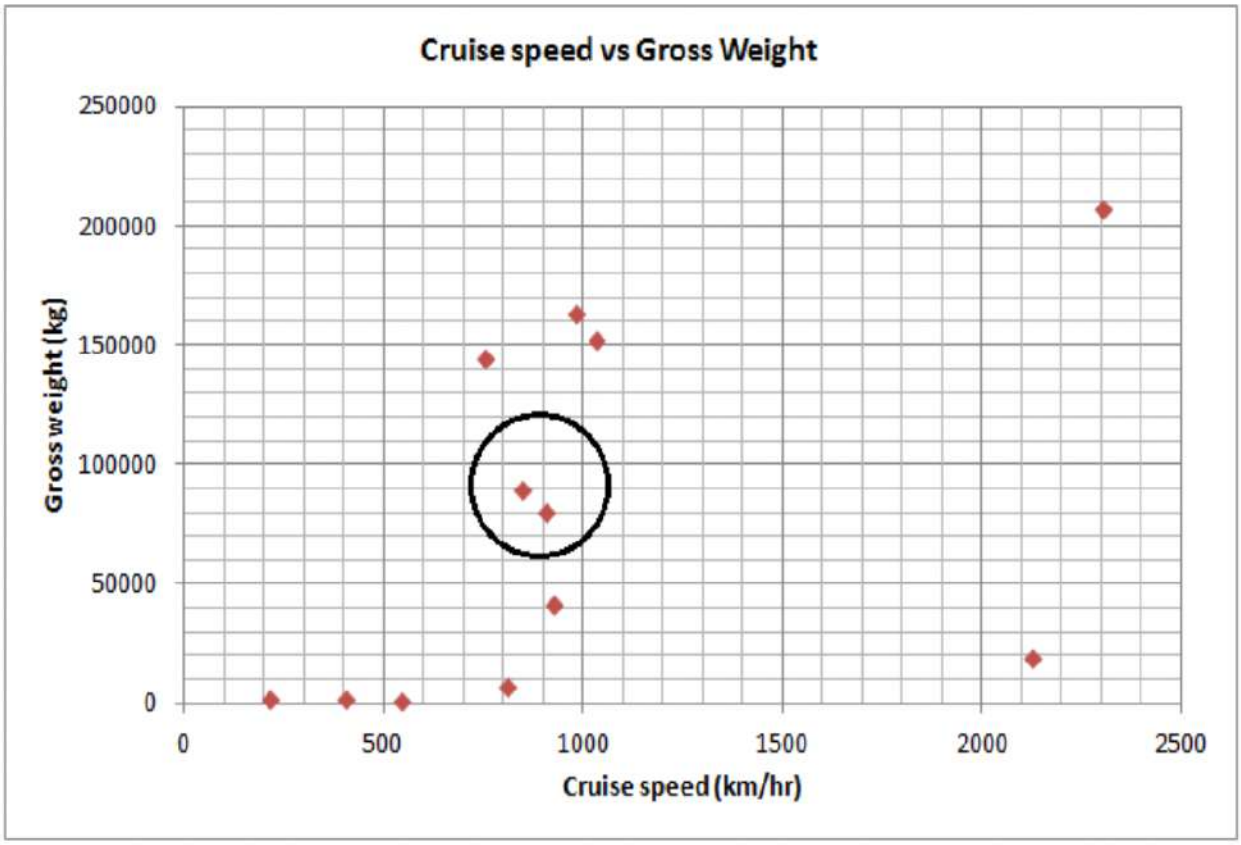


Fig 4.4.Graph:Cruise speed vs. Gross weight

4.5. Cruise speed vs. Aspect ratio

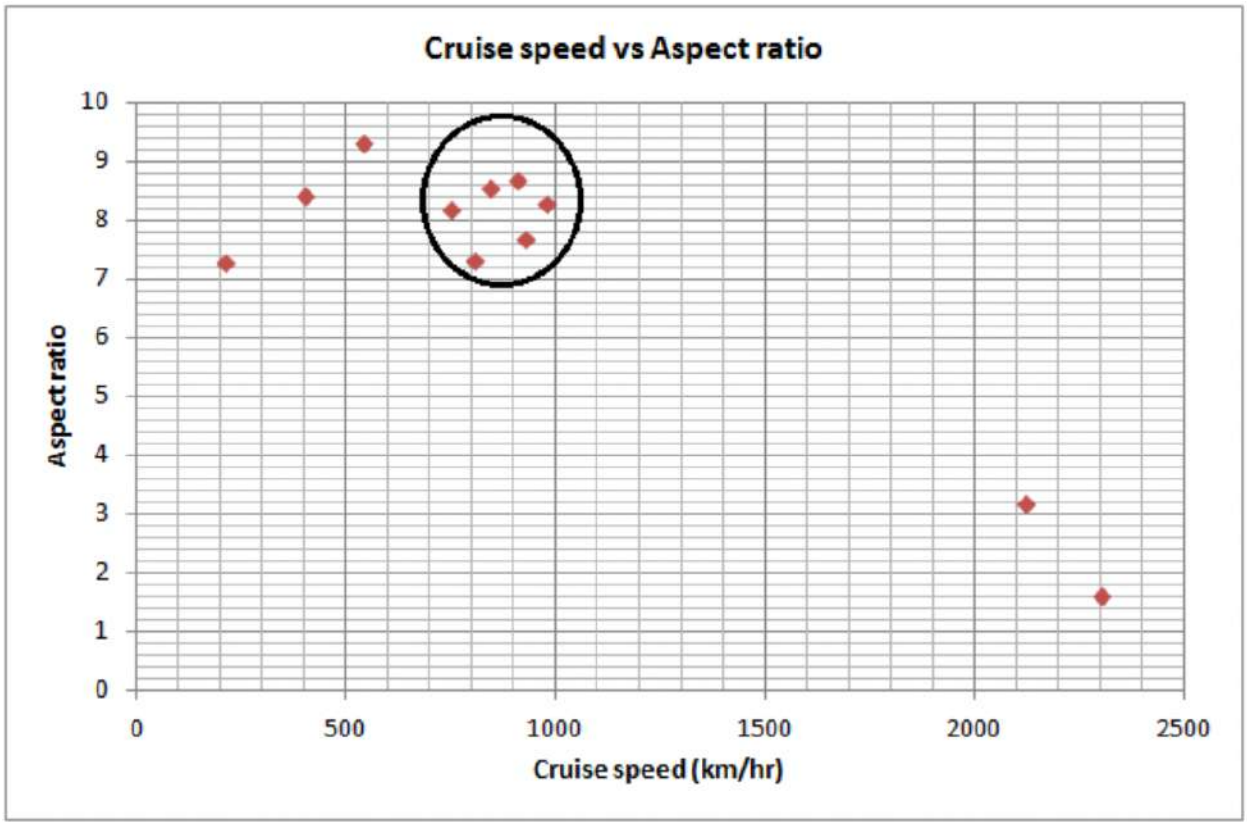


Fig 4.5.Graph:Cruise speed vs. Aspect ratio

4.6. Range vs. Aspect ratio

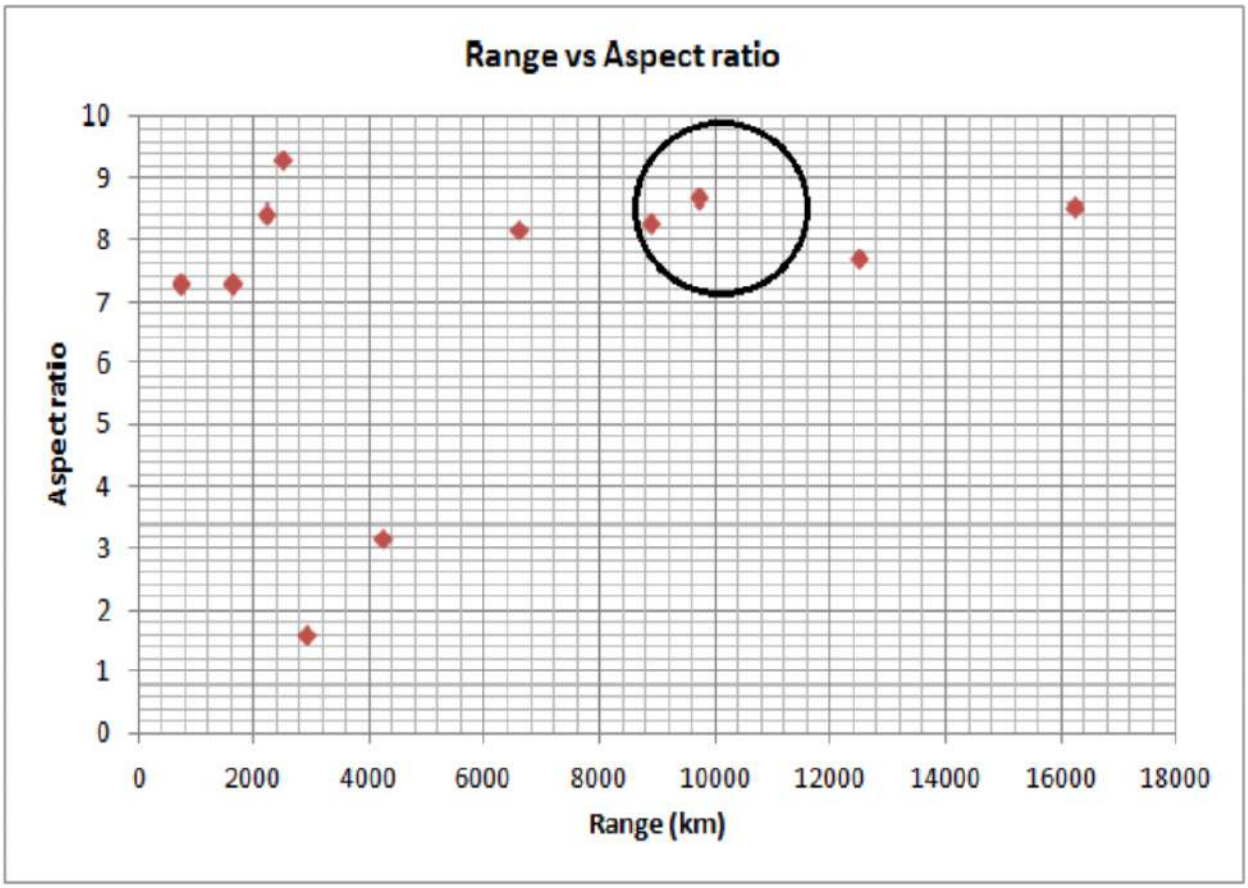


Fig 4.6.Graph: Range vs. Aspect ratio

4.7. Wing loading vs. Aspect ratio

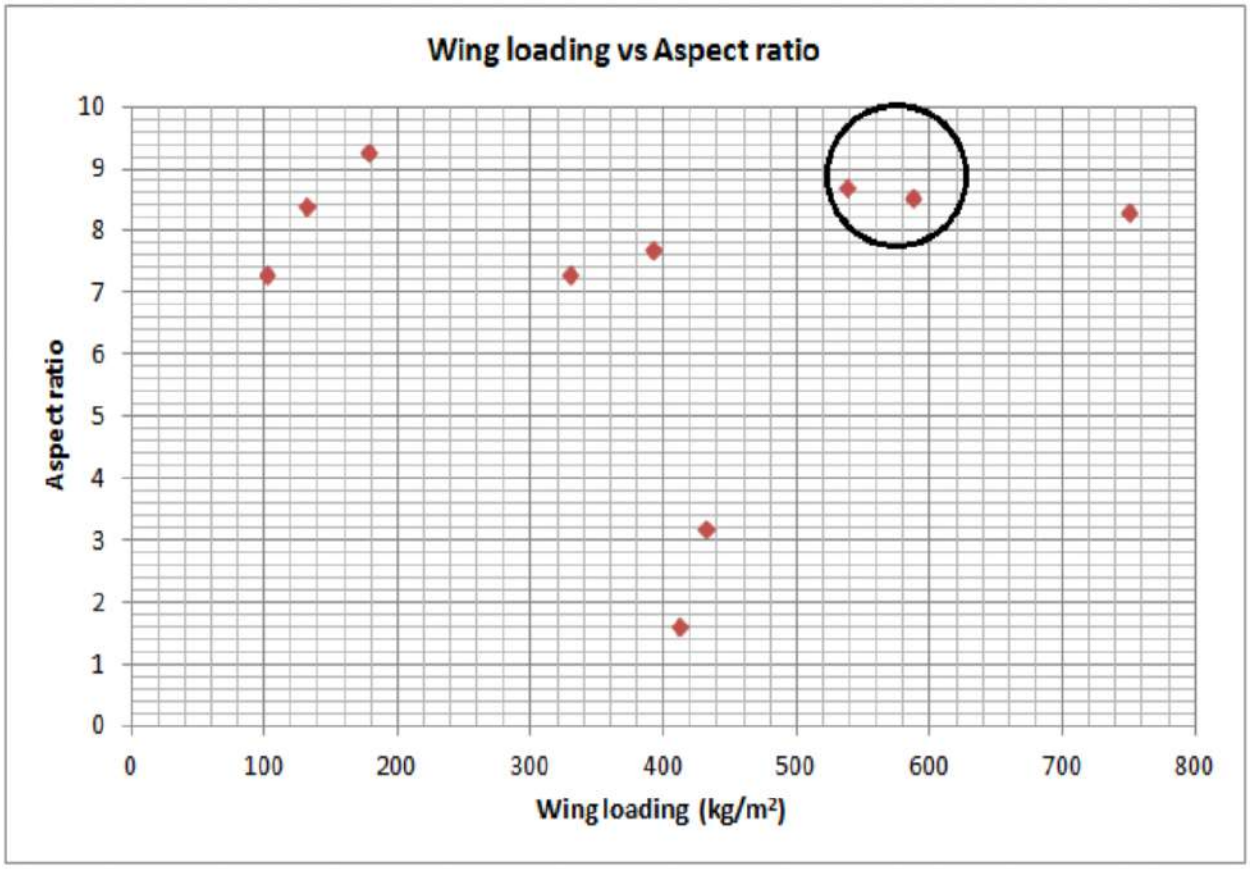


Fig 4.7.Graph:Wing loading vs. Aspect ratio

4.8. Wing loading vs. Takeoff run

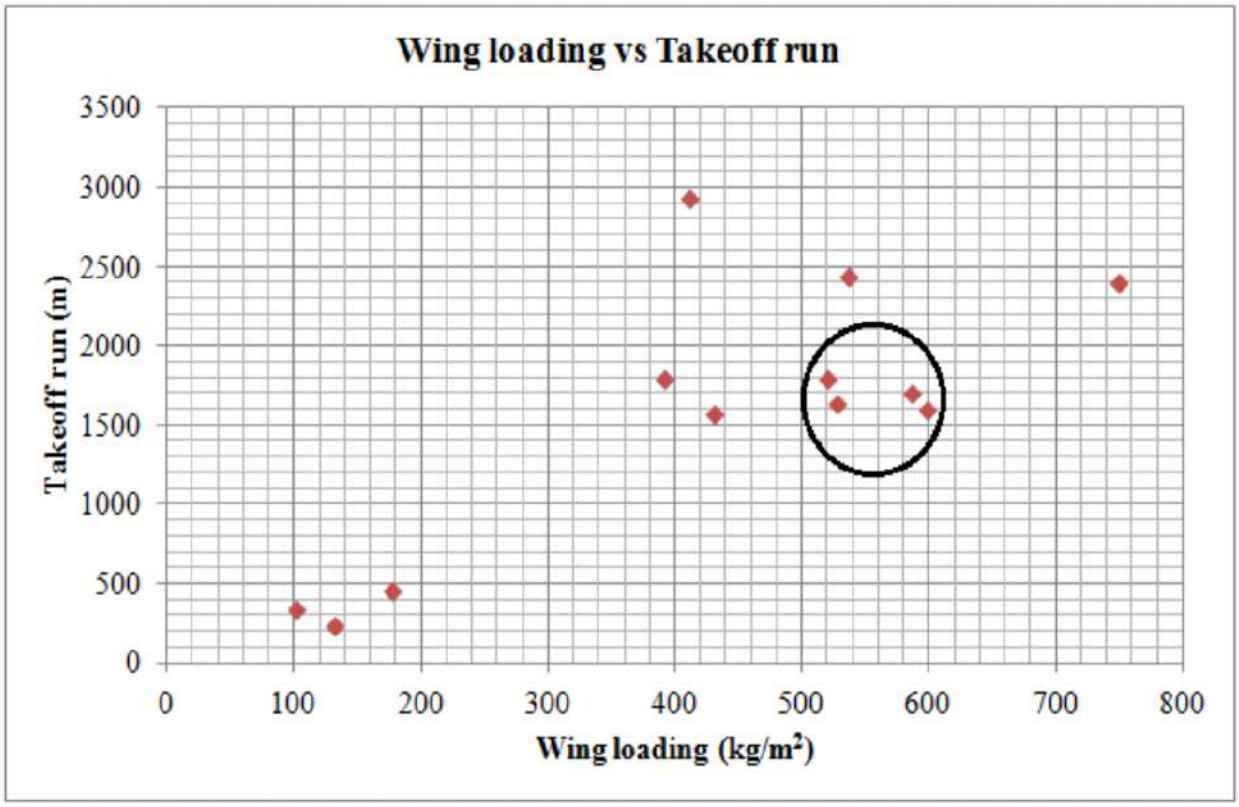


Fig 4.8.Graph:Wing loading vs. Takeoff run

4.9. Wing loading vs. R/C_{max}

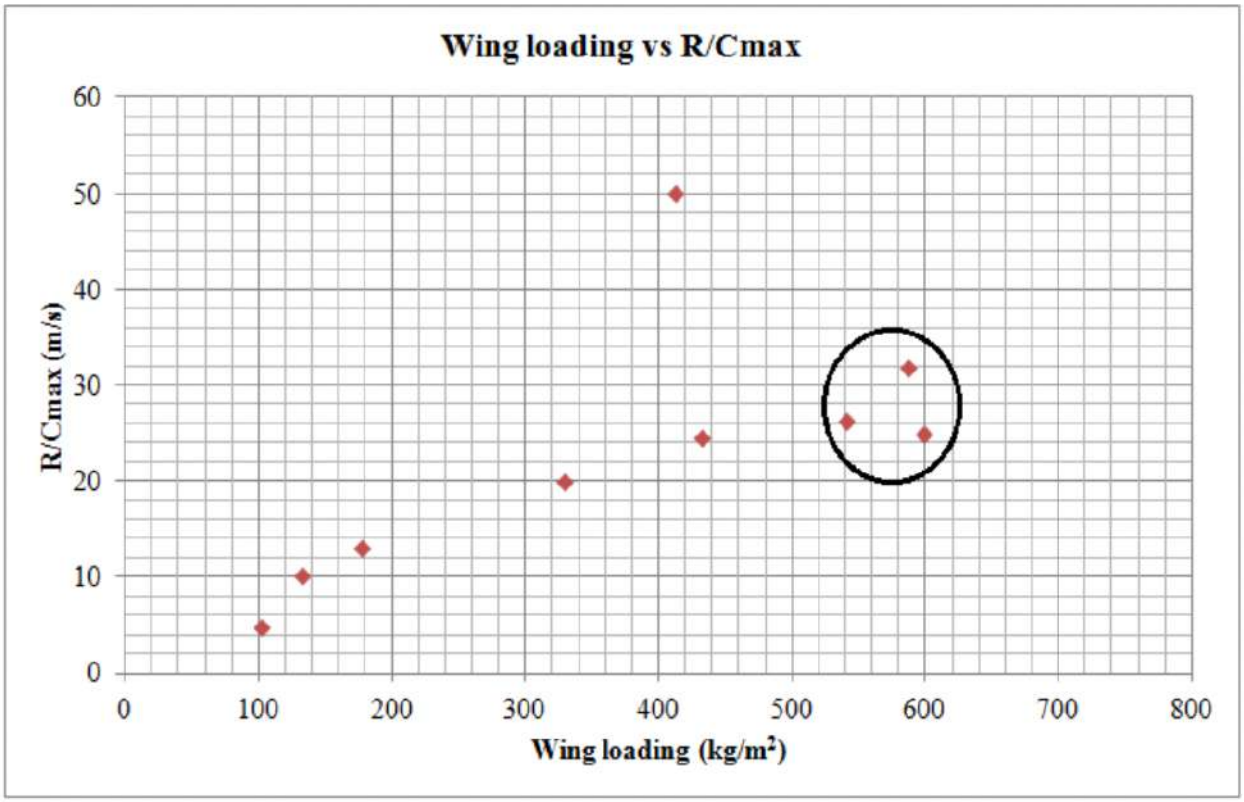


Fig 4.9.Graph: Wing loading vs. R/C_{max}

4.10. Aspect ratio vs. R/C_{max}

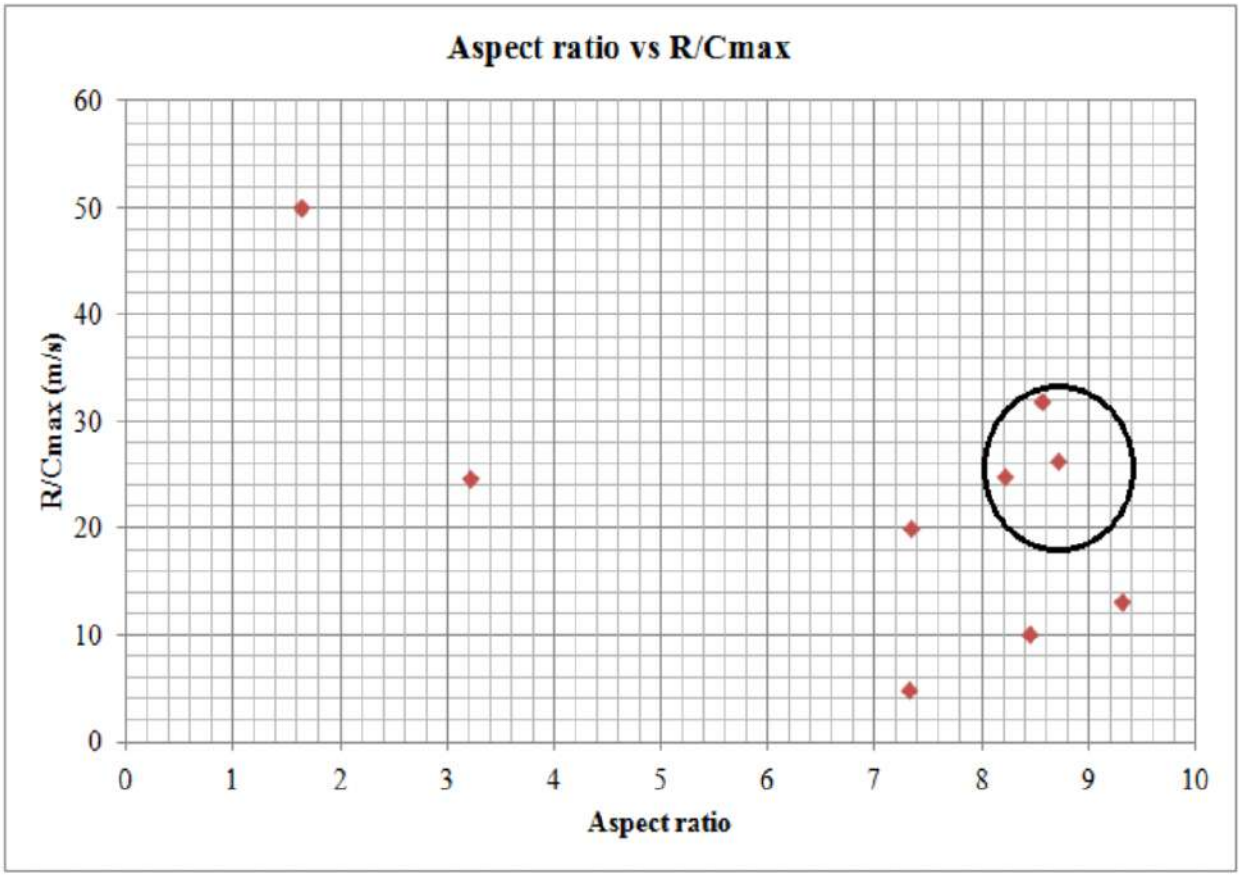


Fig 4.10.Graph: Aspect ratio vs. R/C_{max}

5. Selection of tentative design parameters

5.1. Tentative design parameters

Based on the comparative study from the literature survey as well as the graphs plotted from the tabulated data of the selected 10 aircraft, we have selected the tentative design parameters for our aircraft. These parameters will be used to proceed with the design steps and weight estimation processes.

5.1.1. General characteristics

The tentative parameters for the general characteristics of the design are listed as follows,

1. Crew : 2
2. Length : 22 m
3. Height: 7 m
4. Wing area : 50 m^2
5. Wing span : 20 m
6. Wing chord: 1.7 m
7. Aspect ratio: 8.5
8. Cruising speed: 850 km/h

5.1.2. Weight configuration

The tentative parameters for the weight configuration for the design are listed as follows,

1. Empty weight: 11000 kg
2. Take-Off Weight: 20000 kg
3. Loaded Weight: 14000 kg
4. Thrust to Weight ratio: 0.35

5.1.3. Performance

The tentative parameters for the performance of the design are listed as follows,

1. Maximum speed: 0.84 Mach

2.Maximum Altitude:15500 m

3.Range: 6000km

4. Wing Loading : 450 kg/m

6. Weight estimation

6.1. Flight profile

The flight profile can be defined as the flight path or flight plan which includes altitude, speed, the distance of flight, manoeuvres and stop number, etc. The flight system plays a very important role as it helps us to be prepared prior to the flight.



Fig 6.1. Flight profile

6.1.1. Engine start and warm-up

The engine is started and it is allowed to run for some time so that system warms up before the actual flight.

6.1.2. Taxing

The aircraft is taxied in order to align with the runway before taking off.

6.1.3. Take-off

The aircraft takes off into the air from the ground surface.

6.1.4. Climb

The aircraft climbs to reach its maximum altitude.

6.1.5. Cruise

The aircraft travels at the maximum altitude at cruising speed.

6.1.6. Descent

After the aircraft has traveled 60% of its course, it starts to descend for landing.

6.1.7. Loiter

The aircraft is diverted for loitering when the runway in the airport is engaged.

6.1.8. Landing

The aircraft completes the journey and lands.

6.2. Gross weight

Gross weight $W_0 = W_{crew} + W_{payload} + W_{fuel} + W_{empty}$

W_{crew} = 800 kg (2 pilots + 6 cabin crew)

$W_{payload}$ = 40000 kg (20 passengers + baggage)

Gross weight,

$$W_0 = W_c + W_p + W_f + W_e$$

$$W_0 = W_c + W_p + \frac{W_f}{W_0} W_0 + \frac{W_e}{W_0} W$$

$$W_0 = \frac{(W_c + W_p)}{\left(1 - \frac{W_f}{W_0} - \frac{W_e}{W_0}\right)}$$

$W_0 = W_{crew} + W_{payload} / [1- (W_f / W_0) – (W_e / W_0)]$

6.2.1. Empty weight fraction (We / W0)

$W_e / W_0 = AW_0^c$

$= 1.0595 * W_0^{-0.0598}$

6.2.2. Estimation of fuel fraction (W_f/W_0)

$W_f / W_0 = K_{tf} * (1- W_n/W_0)$

$$W_x/W_0 = \frac{W_i}{W_0} = \frac{W_1}{W_0}\frac{W_2}{W_1}\frac{W_3}{W_2}\frac{W_4}{W_3}\cdots\frac{W_i}{W_{i-1}}$$

6.2.2.1. Fuel fraction for warm up, taxing and take -off (W_1/W_0)

$(W_1/W_0) = 0.98$

6.2.2.2. Fuel fraction for climb (W_2/W_1)

$(W_2/W_1) = 0.98$

6.2.2.3. Fuel fraction for crusie (W_3/W_2)

From Breguet range equation:

$W_3/W_2 = \exp\{-R \text{ X } TSFC / (3.6 \text{ x } V \text{ x } L/D)\}$

6.2.2.3.1. To calculate L/D

$(L/D)\ max = 1/\sqrt{(4\ Cd_0 k)}$

$Cd_0 = 0.005\ \tau\ R_w\ T_f\ S^{-0.1}\ \{1-(C_{lf}/ R_w)\}\ [1-0.2\ M + 0.12\{ M\ (\cos \Lambda_{1/4})^{1/2} / Af - t_1c\}^{20}]$

We have,

M=0.79

AR=9.45

$t_1c = 0.14$

Taper ratio , $\lambda = 0.25$

Sweep angle , $\Lambda_{1/4} = 25^0$

$N_e = 0$ [number of engines present on top of the wings]

$C_{lf} = 0$ [considering no laminar flow over the wing while cruising]

$R_w = S_{wet} / S = 5.5$

$T_f = 1.1$

$A_f = 0.93$ [airfoil factor]

τ=1.013 [wing thickness ratio correction factor]

$f(\lambda) = 0.00592$

substituting the values for Cd_0

$Cd_0 = 0.01875[0.8868]$

6.2.2.3.2. Calculating value of K

$K = 1/\pi\ AR\ \{ 1+ 0.12M^6\ [\ ((1+\ \{\ 0.142 + f(\lambda)A(10\ t_1c)^{0.33}\})/(\cos\Lambda_{1/4})^2)\{0.1(3Ne +1)/(4+ AR)^{0.8}\}]$

$K= 0.03368\{1.029(1.249+0.0125)\}$

$K=0.04372$

$(L/D)_{max} = 1/(4Cd_0k)^{1/2}$

$(L/D)_{max} = 18.56$

$(L/D)_{cruise} = 86.6\ \%\ (L/D)_{max}$

$(L/D)_{cruise} = 16.07$

$W_3/W_2 = \exp\ \{-R \times TSFC / (3.6 \times V \times L/D)\}$

$W_3/W_2 = \exp\ \{-1100 \times 0.51 / (3.6 \times 236.67 \times 16.07)\}$

$W_3/W_2 = 0.663$

6.2.2.4. Fuel fraction for loiter (W_4/W_3)

$W_4/W_3 = \exp\ \{-E \times TSFC /(L/D)\}$

$W_4/W_3 = \exp\ \{-0.5 \times 0.41 /18.56\}$

$W_4/W_3 = 0.989$

6.2.2.5. Fuel fraction for descent , landing and taxing (W_5/W_4) = 0.98

$W_5/W_0 = W_1/W_0 \times W_3/W_2 \times W_4/W_3 \times W_5/W_4$

$W_5/W_0 = 0.98 \times 0.98 \times 0.663 \times 0.989 \times 0.98$

$W_5/W_0 = 0.617$

$W_f/W_0 = K_{tf} \times (1- W_n/W_0\ )$

$W_f/W_0 = 1.06 \times (1 – 0.617)$

$W_f/W_0 = 0.406$

Gross weight $W_0 = W_{crew} + W_{payload} / [1-(W_f /W_0) – (W_e/W_0)]$

$W_0 = 4800 /[1 – 0.406 – 1.0595(W_0)^{-0.0598}]$

W_0 Guessed (kg)	W_e / W_0	W_0 calculated (kg)
80000	0.539	87272
85000	0.537	84210
84500	0.5378	85257
84800	0.53749	84995
84900	0.53746	84907

Estimated gross weight = 84907 kg

6.3. Maximum fuel weight W_f

W_f = 0.406 x 84907 = 34472 kg

6.4. Maximum fuel capacity

$V_f = W_f / \rho_{fuel}$

We have ρ_{fuel}=0.809 kg/l

V_f= 34472/0.809

V_f = 42610 L

6.5. Conclusion

The flight weight ratio is therefore calculated and all values can be seen from the above steps. The weight measurement was made with a 1.5% error rate confirming the accuracy of the calculations made. The following data is available in statistics,

Name	Parameters
Gross weight	84907 kg
Fuel weight on Board	17860.79 lb
Max fuel capacity	42610 L

7. Airfoil and Wing selection

7.1. Wing selection

We will select the wing and its configuration in this chapter. We have also given the appropriate reason for the selection of our components respectively.

7.1.1. Number of wings

There are different configurations of wings based on the number of wings present in the fuselage of the aircraft. They are predominantly classified as,

7.1.1.1. Monoplane

A monoplane is a fixed-wing plane with only one main wing. A monoplane is the simplest to manufacture and has the maximum efficiency and lowest drag of any wing arrangement. However, its larger weight and lower maneuverability during the early years of flight negated these advantages. The monoplane was the most prevalent form of aircraft until the 1930s when it became a relatively rare fixed-wing.



Fig 7.1. Monoplane

7.1.1.2. Biplane

A biplane is a fixed-wing plane with two primary wings stacked on top of each other. The Wright Flyer, the first powered, controllable aircraft to fly, used a biplane wing arrangement, as did many other aircraft in the early days of aviation. While a biplane wing construction offers structural benefits over a monoplane, it also has a structural disadvantage. A similar unbraced cantilever monoplane wing produces higher drag.



Fig 7.2. Biplane

7.1.1.3. Triplane

The wing chord of a triplane is narrower than that of a biplane of a similar span and area. This gives each wing plane a more slim appearance and a larger aspect ratio, increasing efficiency and lift. This could result in a faster rate of climb and a smaller turning radius, which are both vital in a fighter. A fixed-wing aircraft with three vertically stacked wing planes is known as a triplane



Fig 7.3. Triplane

7.1.1.4. Selection

The Monoplane wing configuration has been selected for the following reasons,

- A high or low wing cabin monoplane is readily adapted to carry additional petrol tanks, probably more readily adapted than any other class of aircraft.
- It has minimum weight compared to other configurations.
- The Monoplane has a lower span and chord, reducing the structural forces and allowing it to be lighter.

7.1.2. Wing support

The type of support of a wing can determine the strength of the aircraft during flight. Wings are also classified based on their type of support, they are

- Cantilever
- Semi-Cantilever

7.1.2.1. Cantilever

A cantilever is a rigid structural element, such as a beam or plate, that is connected at one end to vertical support from which it protrudes; this connection can also be perpendicular to a flat, vertical surface, such as a wall. Trusses or slabs can also be used to create cantilevers. In modern airplanes, these varieties of wings are commonly used

7.1.2.2. Semi-Cantilevers

A cantilever is a rigid structural element, such as a beam or plate, that is connected at one end to vertical support from which it protrudes; this connection can also be perpendicular to a flat, vertical surface, such as a wall. Trusses or slabs can also be used to create cantilevers. In modern airplanes, these varieties of wings are commonly used.

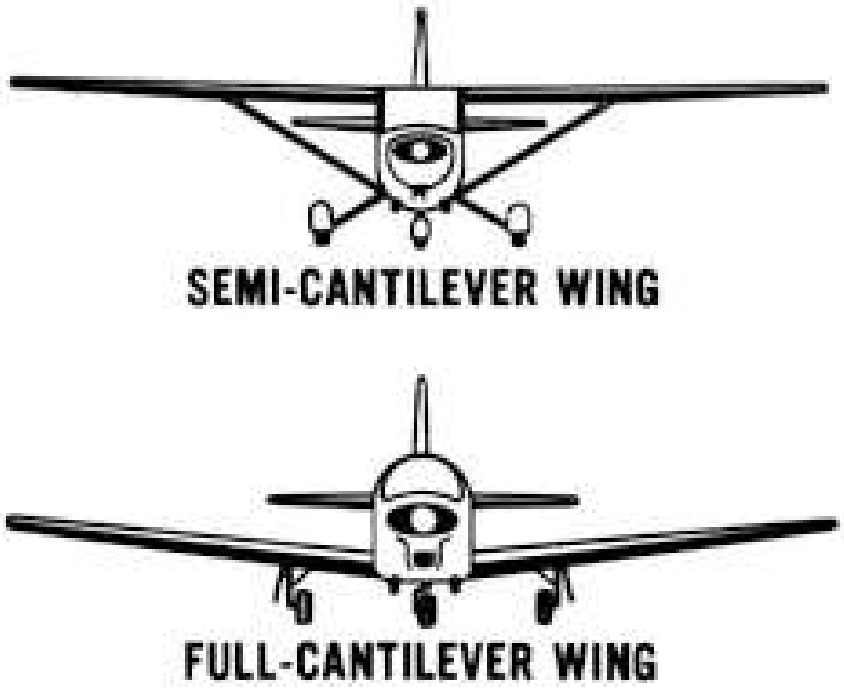


Fig 7.4. Cantilever and semi cantilever wings

7.1.2.3. Selection

The Cantilever type wing support is selected for the following reasons,

- Cantilever arms are very rigid, because of their depth.
- The span can be greater than that of a simple beam because a beam can be added to the cantilever

7.1.3. Wing location

The location of the wing also plays a major role in an aircraft. Wings are classified based on their location in the fuselage as follows

7.1.3.1. High wing

A high wing is a layout in which the wings are attached to the fuselage, which is the plane's main body. They are designed to provide passengers with shade in the heat and an "umbrella" in the rain when boarding or disembarking. They provide clearance over numerous fences on the ground.



Fig 7.5. High wing

7.1.3.2. Mid-wing

A mid-wing arrangement positions the wings at half the height of the fuselage, exactly in the middle of the plane. The mid-wing also offers neutral roll stability, which is advantageous for combat and aerobatic aircraft since it allows for quick roll maneuvers with minimal yaw coupling.



Fig 7.6. Mid wing

7.1.3.4. Low wing

Checking the security of the fuel caps and fueling a low-wing airplane normally do not require a step ladder. Because the low wing is closer to the ground, the ground effect may allow for a shorter take-off roll and faster acceleration.



Fig 7.7. Low wing

7.1.3.5. Shoulder wing

A monoplane with a wing-mounted near the top of the fuselage but not on the top; the wing is between the middle and the high position.



Fig 7.8. Shoulder wing

7.1.3.6. Parasol wing

A parasol wing aircraft is essentially a biplane without the lower pair of wings. The parasol wing is not directly attached to the fuselage but is held above it, supported either by cabane struts or by a single pylon.



Fig 7.9. Parasol wing

7.1.3.7. Selection

The low wing configuration is chosen for the wing location. The reason for the selection is as follows,

- Low-wing aircraft can offer better visibility above the aircraft, as the wing remains mostly out of the field of view.
- Landing characteristics are different, as low-wing aircraft can incur more ground effects than high-wing.

7.1.4. Wing planform

The planform of the wing is nothing but the shape of the wing in the top view. On most airplanes, the planform of the wing is composed of a set of straight lines defining the leading and trailing edges.

7.1.4.1 Rectangular

Simplest wing planform in terms of design and easy to fabricate.



Fig 7.10. Rectangular wing

7.1.4.2 Elliptical

The elliptical wing planform is the most efficient as the elliptical spanwise lift distribution has the lowest possible induced drag. But manufacturing this planform without any flaw is a major challenge.



Fig 7.11. Elliptical wing

7.1.4.3. Tapered

This is a modified rectangular wing, where the chord is varied across the span to approximate the lift distribution.

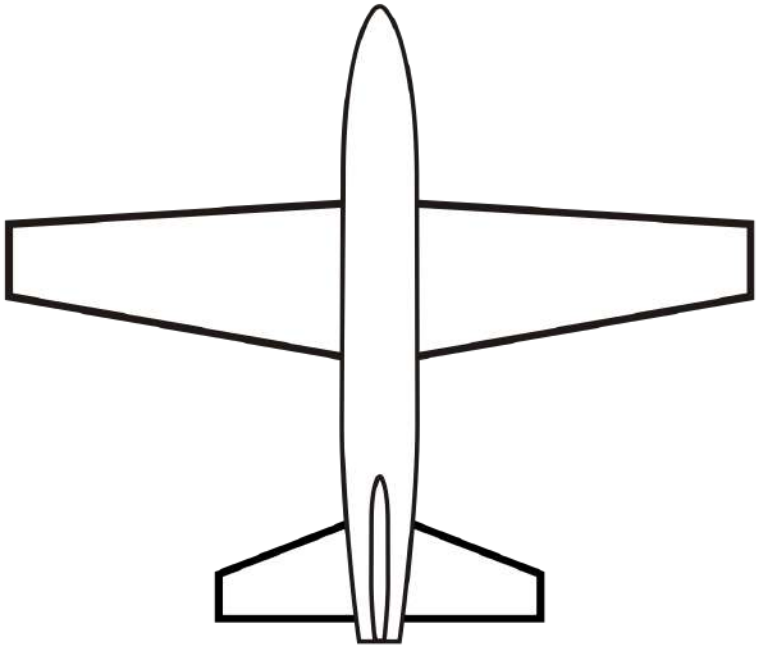


Fig 7.12. Tapered wing

7.1.4.4. Swept wing

7.1.4.4.1. Swept forward wing

The leading edges of these wings are swept forward. The main problem with swept forward wing is that it produces wing twisting as it bends under load, resulting in greater stress on the wing root.



Fig 7.13. Swept forward wing

7.1.4.4.2. Swept backward wing

The leading edges of this planform are swept back. This is done to reduce drag in transonic speeds, which is determined by the velocity normal to the wing. Used in high-speed commercial airliners.



Fig 7.14. Swept backward wing

7.1.4.5 Delta wing

The delta is a very low aspect ratio wing used in supersonic aircraft. It is efficient in all flight regimes

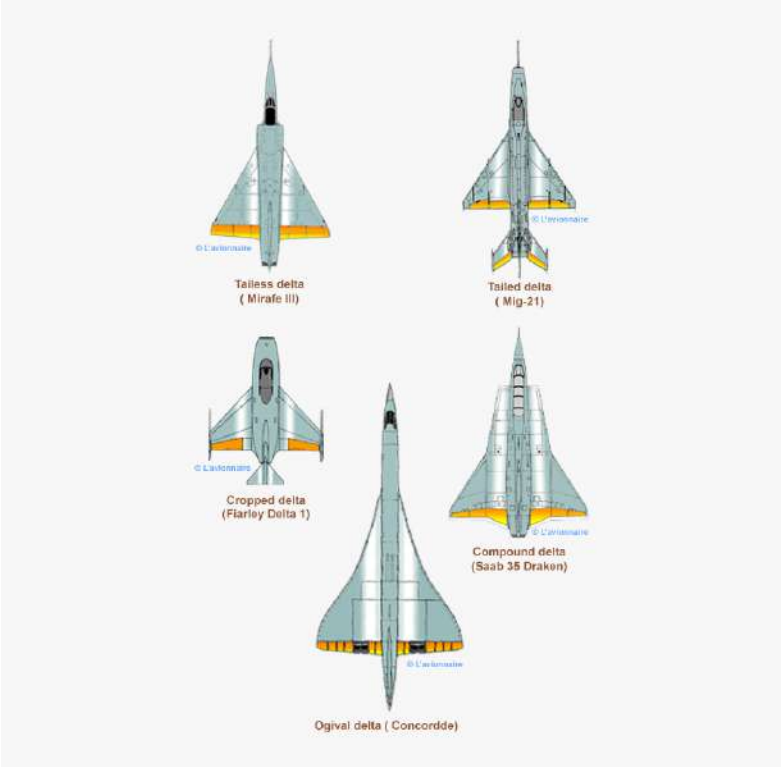


Fig 7.15. Delta wing configurations

7.1.4.5.1 Tailless delta

The tailless delta wing is not suited to high wing loadings and requires a large wing area for a given aircraft weight. The main advantages of the tailless delta are structural simplicity and lightweight, combined with low aerodynamic drag.

7.1.4.5.2 Tailed delta

A conventional tail stabilizer allows the main wing to be optimized for lift and therefore to be smaller and more highly loaded. To improve handling, a traditional tailplane with horizontal tail surfaces is added. Common on Soviet types such as the Mikoyan-Gurevich MiG 21.

7.1.4.5.3. Cropped delta wing

The tip has been snipped. At high angles of attack, this helps sustain lift outboard and reduce wingtip flow separation (stalling). Most deltas are clipped to some extent.

7.1.4.5.4. Compound delta wing

In a compound delta wing, the inner part of the wing has a very sharp angle, while the outer part has a wider angle, which makes it look like a thin and thin and then fat triangle. This helps the pilot to control the lift, reduce drag, and land better.

7.1.4.5.5. Ogival delta

In high-speed aircraft, the Ogive is a form of the supersonic wing. This is a complicated mathematical design created to reduce drag, particularly at supersonic speeds. They provide outstanding supersonic performance while generating very little drag.

7.1.4.5.6. Selection

The Swept-back planform will be implemented on the aircraft. The wing will also have a taper. The reason for the selection is as follows,

- Wing sweep improves performance by delaying shock waves and the associated aerodynamic drag rise induced by fluid compressibility at the speed of sound.
- Without the use of a horizontal tailplane, a swept-back wing can be longitudinally stable on its own.

7.1.5. Wing angle

7.1.5.1. Dihedral wing angle

It is the angle the wing plane makes with the horizontal. Provides the airplane with roll stability and counters the severity of dynamic modes such as Dutch roll.

7.1.5.2. Anhedral wing angle

It is also called a negative dihedral angle when there is a downward angle from the horizontal of the wings or tailplane of a fixed-wing aircraft.

7.1.5.3. Straight wing

This type of wings extends at a right angle to the line of flight. The most structurally efficient wing is commonly used for low-speed aircraft.

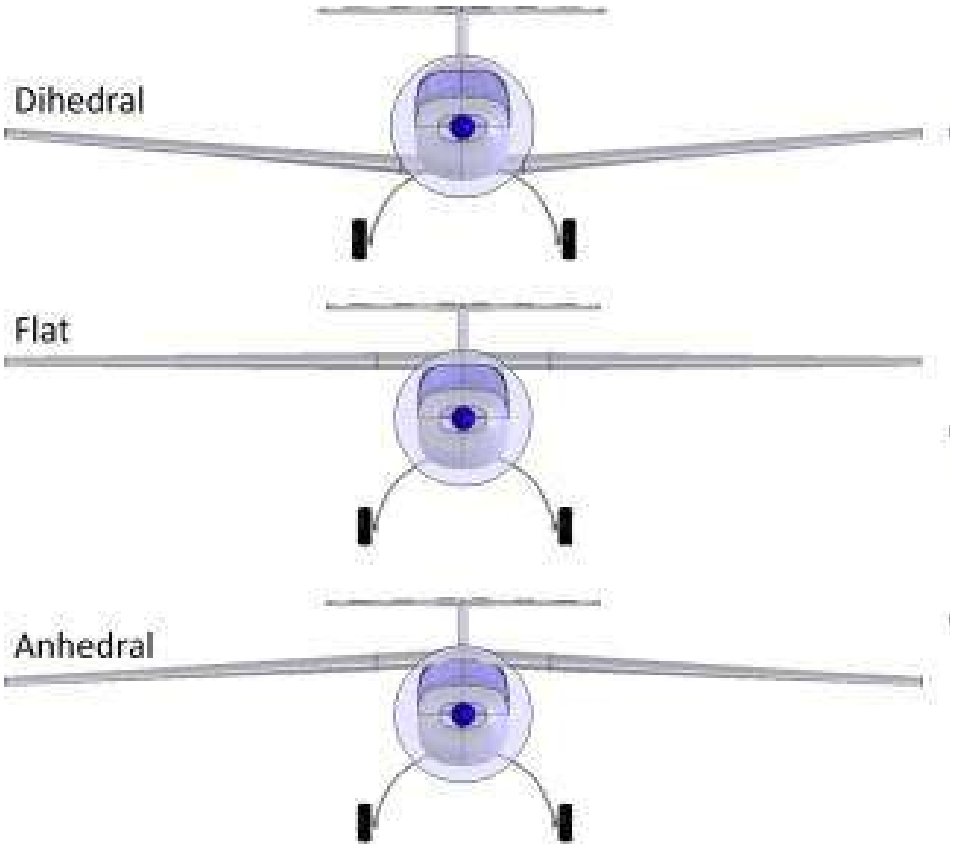


Fig 7.16. Wing angle

7.1.5.4 Selection

The Straight wings with a small dihedral angle will be implemented on the aircraft. The reason for the selection is as follows,

- The aircraft seems to generate enough lift with the existing straight wing configuration.
- The Dihedral effect is a critical factor in the stability of an aircraft about the roll axis so it is also present little.

7.1.6. Wing loading

7.1.6.1. Thrust loading (T/W)

$T/W_0 = AM^c_{max}$

$= 0.267\ (0.82)^{0.363}$

$(T/W)_{takeoff} = 0.248$

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

$(T/W)_{cruise} = 0.0622$

7.1.6.2. Wing loading (W/S)

7.1.6.2.1. Stall

$V_{stall} = V_{approach}/1.3$

$= 72.5/1.3$

$V_{stall} = 55.7$ m/s

$C_{Lmax} = C_{L\,\Lambda=0} \cos\Lambda_{1/4}$

$= 3.4 \cos 25^0$

$= 3.08$

$W/S = (\rho V^2_{stall}\, C_{Lmax})/2$

$= [1.225 \times (55.7)^2 \times 3.08]/2$

$W/S = 598.12$ kg/m^2 [at sea level]

7.1.6.2.2. Landing

Ground roll distance , $S = 80\,(W/S)/(\sigma C_{Lmax})$

$(W/S) = S(\sigma C_{Lmax})/80$

$= 662 \times 0.82 \times 3.08 /80$

$(W/S)_{landing} = 21$ kg/m^2

7.1.6.2.3.Cruise

Skin friction coefficient, $C_{fe} = 0.003$ [subsonic]

Assuming $S_{wet}/S = 5.5$

Parasite drag $C_{D0} = C_{fe}\,(S_{wet}/S_{ref})$

$C_{D0} = 0.0165$

7.1.6.2.4. Oswald efficiency factor

$1/e = 1/e_{wing} + 1/e_{fuselage} + 0.05$

$e_{wing} = 0.84$ for an unswept wing of $A = 9.45$ and $\lambda = 0.25$

e_{wing} for a swept wing is given by

$e_{wing\Lambda} = e_{wing\Lambda=0} \cos(\Lambda\text{-}5)$

$= 0.84 \cos(25\text{-}5)$

$= 0.7893$

$1/e_{fuselage} = 0.1$

$1/e = 1.267 + 0.1 + 0.05$

Therefore, $e = 0.707$

At 10000 m altitude, $V = 236.67$, $\rho = 0.41$ kg/m^2

$Q_0 = l V^2 /2 = 1170.5$ kg/m^2

$(W/S)_{optimum\ cruise} = q_0 (\pi e A R C_{D0}/3)^{0.5}$

$= 1170.5\ (0.432)$

$(W/S)_{optimum\ cruise} = 506.2$ kg/m^2

$(W/S)_{takeoff} = (W/S)_{optimum\ cruise} \times (W_1/W_0)^{-1} \times (W_2/W_1)^{-1}$

$= 506.2 \times (0.98)^{-1} \times (0.98)^{-1}$

$(W/S)_{takeoff} = 527$ kg/m^2

7.2. Airfoil selection

An airfoil is a surface designed to obtain a desirable reaction from the air through which it moves.

7.2.1. Geometry

An airfoil has a leading edge, trailing edge, a chord, and a camber.

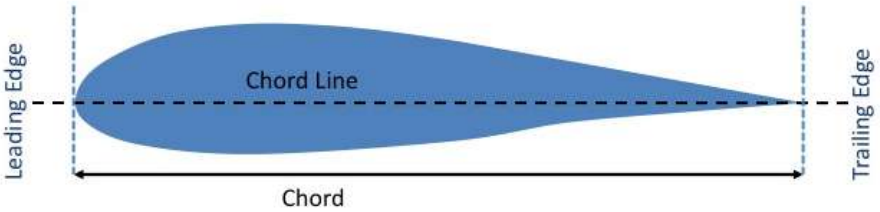


Fig 7.17. Elements of an airfoil

7.2.1.1. Leading-edge

The leading edge is the front of the airfoil, which meets the air first.

7.2.1.2. Trailing edge

The trailing edge is the back of the airfoil, where the airflow over the upper surface joins the airflow over the lower surface.

7.2.1.3. Chord line

An imaginary straight line connecting the leading edge and trailing edge. Thickness: Measured perpendicular to chord line as a % of it.

7.2.1.4. Camber

The Curvature of section. It is a perpendicular distance of section mid-points from chord line as a % of it. The curve is measured by the amount of departure from the chord of the airfoil.

7.2.1.5. The angle of attack (α):

It is the angle between the free stream and the chord line.

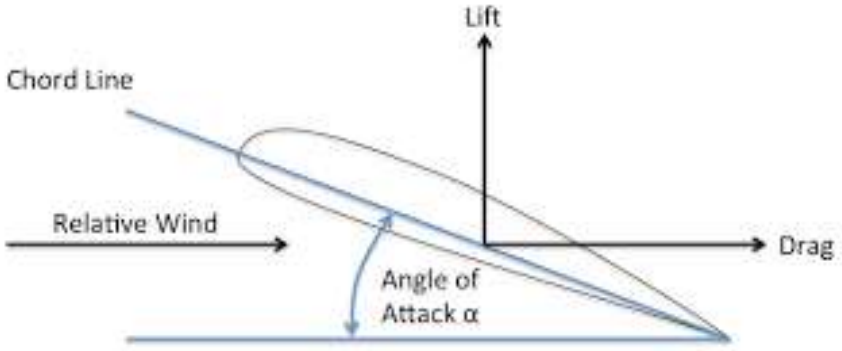


Fig 7.18. Angle of attack

7.2.2. NACA series

The 4-digit, 5-digit, and modified 4-/5-digit NACA airfoil series were created using mathematical equations that described the camber (curvature) of the mean-line (geometric centerline) of the airfoil section as well as the thickness distribution of the section throughout its length. Later families, such as the 6-Series, include more complex shapes that were created using theoretical rather than geometrical methods. Airfoil design used to be quite arbitrary until the National Advisory Committee for Aeronautics (NACA) produced these series, with nothing to assist the designer except previous experience with recognized shapes and experimenting with alterations to those designs.

With the publication of a NACA paper titled The Characteristics of 78 Related Airfoil Sections from Tests in the Variable Density Wind Tunnel in the early 1930s, this methodology began to shift. The authors of this seminal paper noticed that the most successful airfoils have many commonalities and that the slope of the airfoil mean camber line and the thickness distribution above and below this line are the two key variables that impact those forms. They then offered a set of equations that could be utilized to build an entire family of related airfoil forms using these two variables. This basic approach was extended to include other variables as airfoil design became more sophisticated, but these two essential geometrical values remained constant.

- NACA 4 digit was introduced during the 1930's
- NACA 5-digit is aimed at pushing the position of max camber forwards for increased Cl_{max}.
- NACA 6-digit is designed for lower drag by increasing the region of laminar flow.

The modern airfoil is mainly based upon the need for improved aerodynamic characteristics at speeds just below the speed of sound.

7.2.2.1. NACA 4 Digit

- 1st digit: maximum camber (as % of the chord).
- 2nd digit(x10): location of maximum camber
- 3rd & 4th digits: maximum section thickness (as % of the chord).

The first family of airfoils designed using this approach became known as the NACA Four-Digit Series

7.2.2.2. NACA 5 Digit

- 1st digit (x0.15): design lift coefficient.
- 2nd & 3rd digits (x0.5): location of maximum camber (as % of chord
- 4th & 5th digits: maximum section thickness (as % of the chord).

The NACA Five-Digit Series uses the same thickness forms as the Four-Digit Series but the mean camber line is defined differently and the naming convention is a bit more complex

7.2.2.3. NACA 6 Digit

- 1st digit: identifies series type.
- 2nd digit(x10): location of minimum pressure
- 3rd digit: indicates acceptable range of CL above/below design value for satisfactory low drag performance (as tenths of CL).
- 4th digit (x0.1): design CL.
- 5th & 6th digits: maximum section thickness(%c)

Although NACA experimented with approximate theoretical methods that produced the 2-Series through the 5-Series, none of these approaches was found to accurately produce the desired airfoil behavior

7.2.2.4. Comparison between various airfoil models

It becomes necessary to use high speed airfoils, i.e., the 5x series, which have been designed to suit high subsonic cruise Mach numbers.

- NACA 63A-514

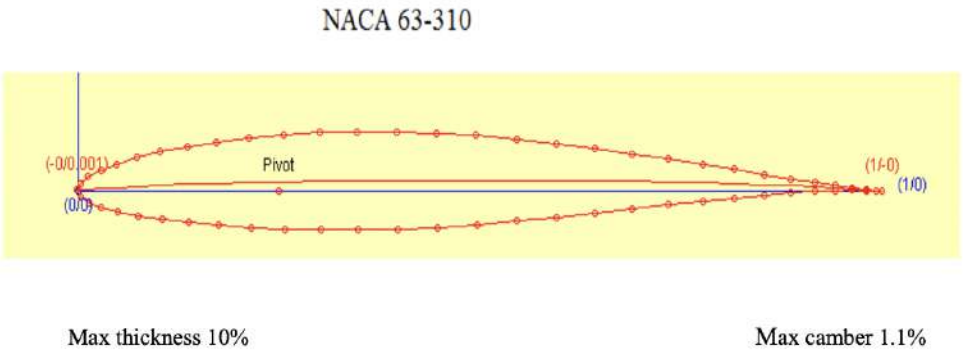


Fig 7.19. NACA 63-415 airfoil

- NACA 63-512

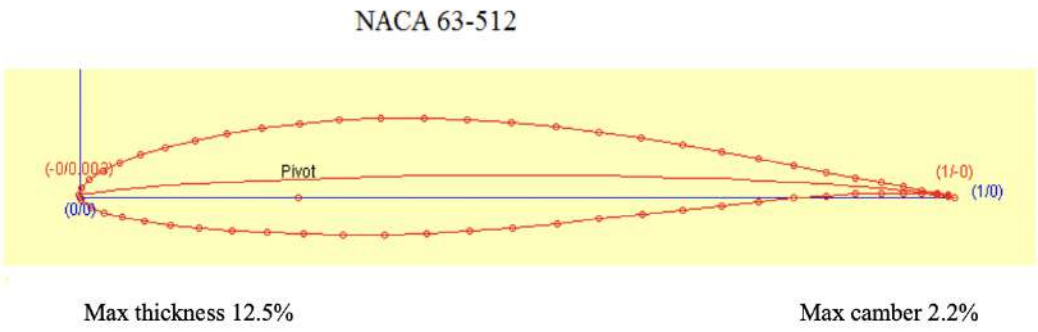


Fig 7.20. NACA 63-512

- NACA 63A-514

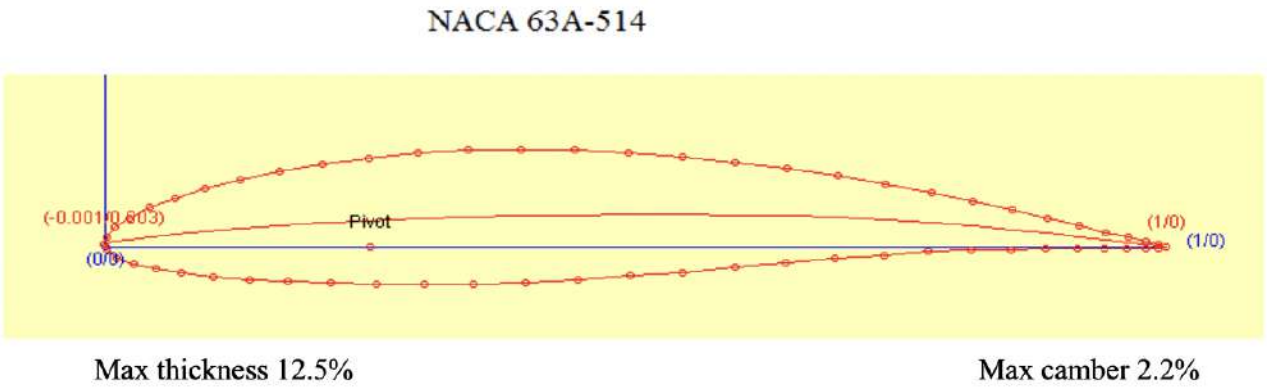


Fig 7.21. NACA 63A-514

7.2.3. Calculations

7.2.3.1. Maximum thickness (t/c)

It is the ratio between the vertical thickness of a wing to its chord. It is a key factor determining the factor g the wing planform when it is operating at transonic speeds.

The maximum thickness of the airfoil desired to produce max Cl is 14%

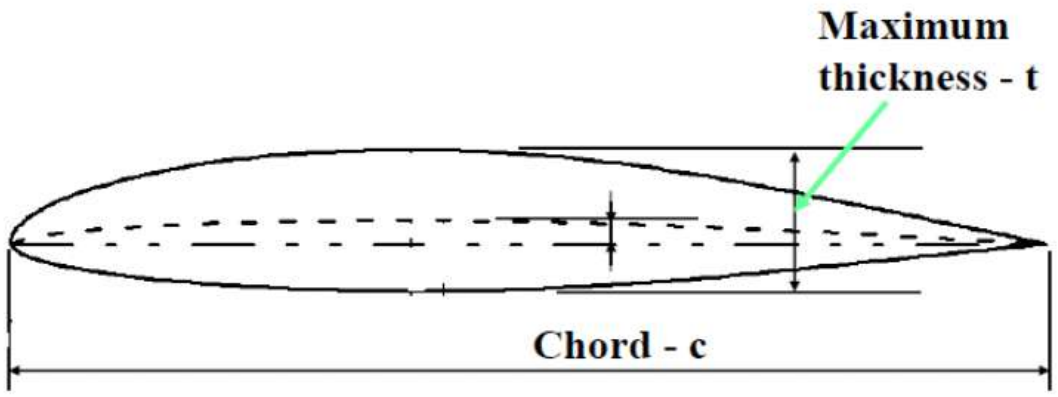


Fig 7.22. Maximum Thickness

7.2.3.2. Wing sweep angle (Λ)

The angle by which the wing is translated backward (or forward in case of swept forward wing) relative to the root chord is called the sweep angle.

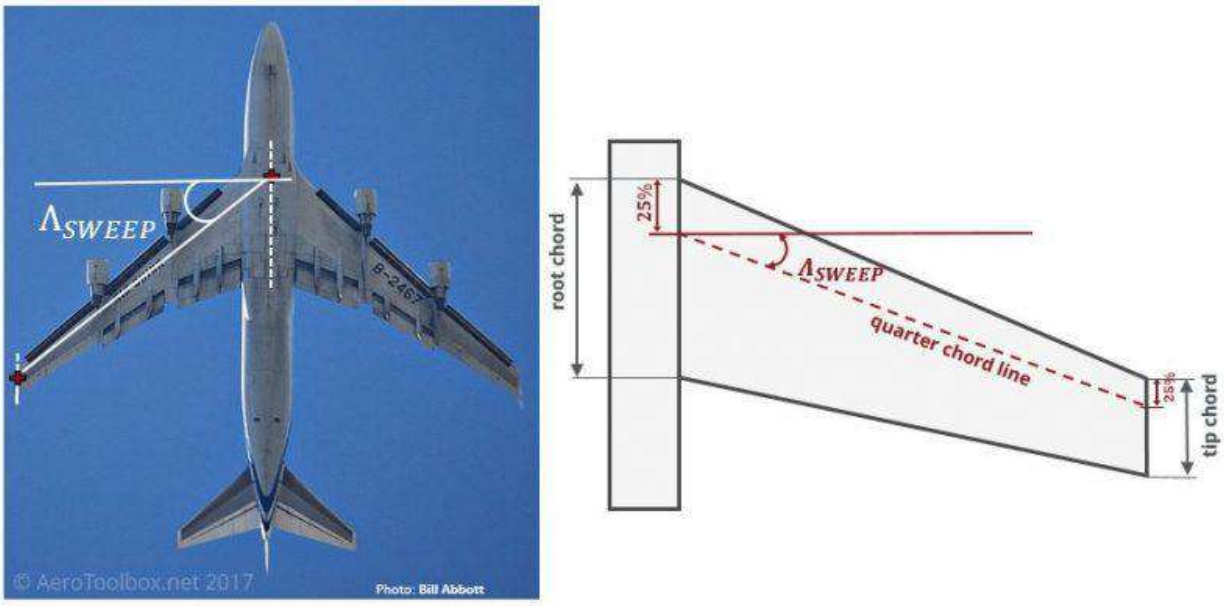


Fig 7.23. Sweep angle

7.2.3.2. maximum lift coefficient (Cl_{max})

Cl_{max} = $Cl_{\Lambda=0}$ cos $\Lambda 1/4$ = 3.4 cos 25^0

= 3.08 (at 40^0 flap settings)

Cl_{cruise} = 2W/ (ρV2S)

= 2 x 598 x 9.81 / 0.41 x 236.672)

= 0.511

$Cl_{req,takeoff}$ = 1.5 (at 12^0 angle of attack) (From the plots above)

7.2.3.3. Taper ratio (λ)

Ratio of the tip chord c_T to the root chord c_R

$$\lambda = \frac{c_T}{c_R}$$

Straight wings: λ = 0.4 - 0.5

Swept wings: λ = 0.2 - 0.3

7.2.3.4. Wing area (S)

$$S = \frac{W}{W/S}$$

S = 84907 / 598.12 = 142 m^2

7.2.3.5. Wingspan (b)

$$b = \sqrt{A \cdot S}$$

b = (9.45 x 142) = 36.63 m

7.2.3.6. Root chord c_R

$$c_R = \frac{2 \cdot S}{[b \cdot (1+\lambda)]}$$

c_R = 2 x 142 / [36.63 x (1 + 0.25)] (λ= 0.25)

= 6.2 m

7.2.3.7. Tip chord c_T

$$c_T = \lambda \cdot c_R$$

c_T = 0.25 x 6.2 = 1.55 m

7.2.3.8. Mean aerodynamic chord (m_{ac})

The mean aerodynamic chord cMAC is the chord of an equivalent untwisted, unswept rectangular wing that achieves the same lift and the same pitching moment as this wing

$$MAC = \frac{2}{3} \cdot c_r \cdot \left(\frac{1+\lambda+\lambda^2}{1+\lambda} \right)$$

M_{ac} = (2/3) [(1++2)/(1+)] c = 4.34 m

7.2.3.9. Wing sweep at leading edge (Λ_{LE})

$$\tan \Lambda_{LE} = \tan \Lambda_{c/4} + \frac{4n}{A} \left(\frac{1-\lambda}{1+\lambda} \right)$$

$\Lambda_{LE} = \Lambda_{c/4} + [(1-\lambda) / AR (1+\lambda)]$

$= 25^0 + 0.75 / (9.45 \times 1.25) = 25.06^0$

7.2.3.10. M_{eff}

$M_{eff} = M_{\infty} \cos_{LE}$

$= 0.79 \cos 25.06_0$

$= 0.715$

7.2.3.11. B

$$\beta = \sqrt{1 - M_{eff}^2}$$

$\beta = \sqrt{(1-M^2_{eff})} = 0.7$

7.2.3.11. $dC_L/d\alpha$

$$\frac{dC_L}{d\alpha} = \frac{2\pi A}{2 + \sqrt{4 + (A\beta)^2 \left(1 + \frac{\tan^2(\Lambda_{t/c})}{\beta^2}\right)}}$$

$dCL/d\alpha = 2.\pi.AR / [2+ \sqrt{\ } \{4+(AR.\beta)^2. (1+\tan^2 \Lambda t/c / \beta^2)\}]$

$= 2 \times \pi \times 9.45 / [2+ \{4+(9.45 \times 0.7)2 \times (1+\tan 225 / 0.72)\}]$

$= 59.376 / 5.269$

$= 11.27$

7.2.3.12. Dihedral angle Γ

The angle from horizontal of the wings or tail, when measured upwards, of a fixed-wing aircraft is termed as dihedral angle.

A value of $\Gamma = 50$ is chosen.

7.3. Winglets

Blended winglets are used in this heavy business jet. The Blended Winglet has a broad radius and

a smooth chord variation where the wing meets the winglet. This provides for optimal aerodynamic loading while also avoiding drag-producing vortex concentrations.

The purpose of a blended winglet is to reduce interference drag at the wing/winglet junction by attaching it to the wing with a smooth curve rather than a sharp angle.



Fig 7.24. Winglets

7.4. Selected Wing Parameters

Design Parameters	Values
Wing loading (W/S)	598 kg/m^2
Wing area (S)	142 m^2
Aspect ratio (AR)	9.45
Wing span (b)	36.63 m
Taper ratio (λ)	0.25
Root chord (c_R)	6.2 m
Tip chord (c_T)	1.55 m
Mean chord (c_m)	4.34 m
Design CL	0.511
Sweepback angle (Λ)	25^0
Dihedral angle (Γ)	5^0

8. Tailplane selection

A tailplane, also known as a horizontal stabilizer, is a small lifting surface located on the tail (empennage) behind the main lifting surfaces of a fixed-wing aircraft. The tailplane of an aircraft is classified as follows

8.1. Conventional Tail

The most popular tail design is the traditional one. One vertical stabilizer is located in the fuselage's tapered tail portion, and one horizontal stabilizer is separated into two pieces, one on each side of the vertical stabilizer. The standard layout provides adequate stability and control for many airplanes.

8.2. T - Tail

When viewed from the front, the horizontal stabilizer is positioned on top of the fin, forming a "T" shape. T tails help pitch control by keeping the stabilizers out of the engine's wake. T-tails have a favorable glide ratio and are more efficient while flying at low speeds.

8.3. V - Tail

A V-tail can be lighter than a conventional tail in some situations and produce less drag. It may also have a smaller radar signature.

8.4. Cruciform Tail

When viewed from the front, the horizontal stabilizers are positioned halfway up the vertical stabilizer, creating the impression of a cross. Cruciform tails are frequently used to keep the horizontal stabilizers clear of the engine wake while avoiding many of the drawbacks of t tail



Fig 8.1. a) Conventional Tail b) T-Tail c) Cruciform Tail d) V-tail

8.5. Inverted Tail

The inverted V-tail is similar to V-tail but it is inverted and it provides more stability and maneuverability. It is mostly used in Unmanned Aerial Vehicles.



Fig 8.2. Inverted tail

8.6. Tailless

A tailless plane has no tail and no horizontal surfaces other than its primary wing. The main wing incorporates aerodynamic control and stabilization functions in both pitch and roll. A traditional vertical fin (vertical stabilizer) and rudder may still be present on a tailless design.



Fig 8.3. Tailless

8.7. Selection

The T – Tail empennage is selected for the aircraft due to the following advantages,

- It gives better pitch control; smoother and faster airflow over elevators.
- It has high aerodynamic performance and an effective glider ratio

9. Fuselage selection

Fuselage construction plays a major role in reducing the total weight of the aircraft. The fuselage construction of an aircraft is classified as follows,

9.1. Monocoque

The major loads are carried mostly by the skin or covering of the monocoque (single shell) fuselage. Monocoque architecture, like an aluminum beverage can, relies on strained skin to support practically all weights. The requirement for internal bracing was avoided or decreased because most twisting and bending forces are handled by the external skin rather than an open framework, conserving weight and optimizing space.

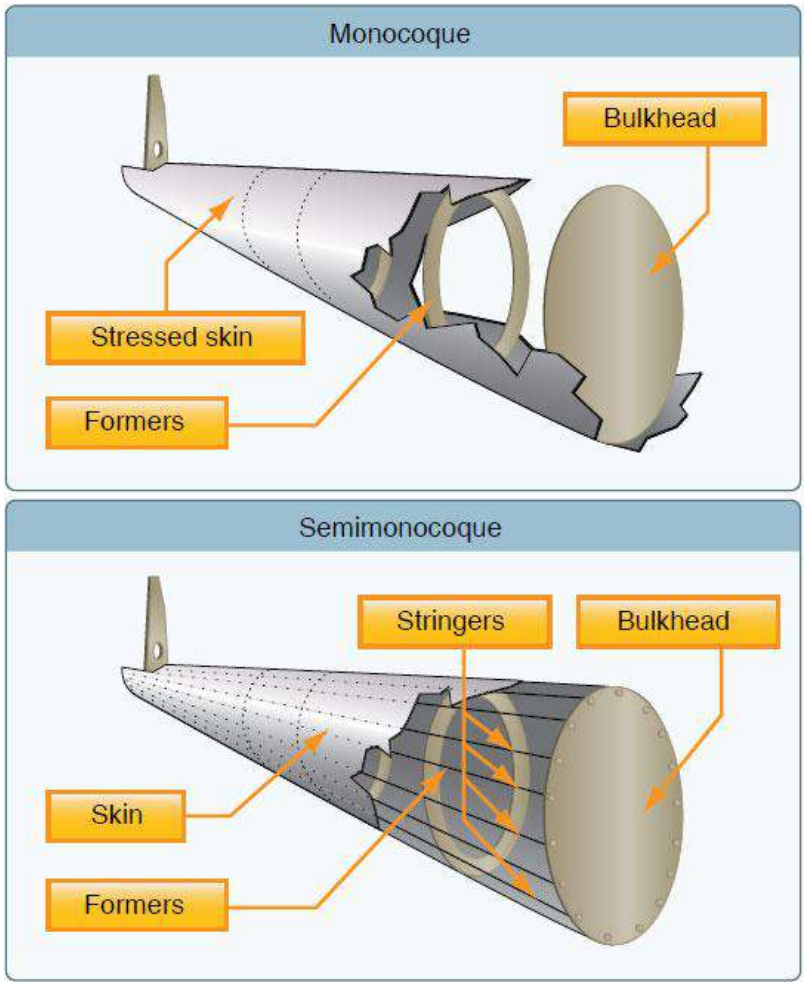


Fig 9.1. Monocoque and semi monocoque

9.2. Semi-Monocoque

A modification known as semi Monocoque construction was created to solve the strength/weight problem of Monocoque construction. It has the same frame assembly, bulkheads, and formers as the Monocoque design, but the skin is reinforced by longerons, which are longitudinal components.

9.3. Geodesic Truss

In the 1930s, British aeronautical engineer Barnes Wallis devised a method of construction for aircraft airframes called the geodesic airframe. It makes use of a space frame made up of load-bearing components that are spirally crossed. The premise is that two geodesic arcs can be formed on the fuselage to intersect in such a way that the torsional loads on each cancel out.

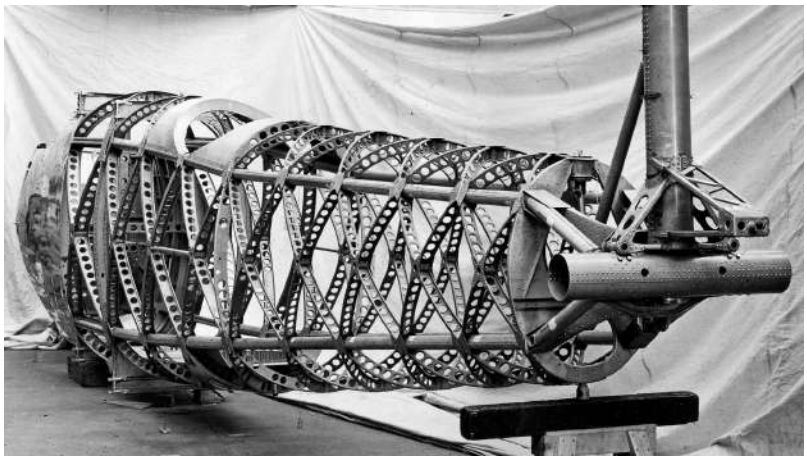


Fig 9.2. Geodesic truss

9.4. Selection:

The Semi-Monocoque fuselage is constructed for the following advantages,

- The Semi-Monocoque structure is less in weight compared to Truss structures.
- The stringers and longerons are light in weight while it provides high strength.
- The skin of the fuselage is supported by bulkheads and other structures.

10. Landing gear selection

The undercarriage of an aircraft or spacecraft is known as landing gear, and it can be utilised for either takeoff or landing. In most cases, both are true for aircraft. When an aircraft is not flying, the landing gear supports it, allowing it to take off, land, and taxi without harm.

10.1. Types

10.2.1. Fixed landing gear

Fixed landing gear is defined as landing gear with a rear-mounted wheel. Fixed gear is intended to make design and operation easier. It has the advantages of being always deployed and having a cheap initial instalment cost. Its downside is that it generates persistent drag.

10.2.2. Retractable landing gear.

The landing gear on a retractable gear aeroplane can be stowed inside the structure during cruising flight, which helps to streamline the aircraft. Hydraulic or electrically operated retractable landing gear technologies, as well as a combination of the two, are available.

10.2.3. Selection

The Retractable landing gear is implemented in the aircraft due to the following reasons

- There will be less drag during cruise as the landing gear will be retracted.
- It helps in higher cruise speeds and increased climb performance.

10.2. Different configurations

The landing gears have different configurations based on the number of wheels and their arrangement. They are classified as follows,

1. Single wheel
2. Bicycle
3. Tricycle
4. Quadricycle
5. Multi-bogey

10.2.1. Single wheel landing gear

The single-wheel configuration, which consists of a main gear with a total of two wheels, one on each strut, the dual-wheel configuration, which consists of a main gear with a total of four wheels, two on each strut, and the dual-tandem configuration, which consists of two sets of wheels on each strut.



Fig 10.1. Single wheel

10.2.2. Bicycle

The bicycle undercarriage is a relatively unusual landing gear option. Bicycle gear has two major gears, one forward and one aft of the centre of gravity, running parallel to the plane's centerline. Two small outrigger gear installed along the wing prevent the plane from tipping over sideways.



Fig 10.2. Bicycle wheel

10.2.3. Tricycle

The tricycle-type landing gear is the most common landing gear layout. It is made up of two parts: main gear and nose gear. Landing gear that looks like a tricycle is used on both large and small planes. It allows for more vigorous braking without nosing over, allowing for faster landing speeds.



Fig 10.3. Tricycle wheel

10.2.4. Quadricycle

Quadricycle gear is similar to bicycle gear except that it has four primary gears that are about equal in size and are positioned along the fuselage. The Quadricycle undercarriage, like cycling gear, demands a fairly flat attitude during take-off and landing. This design is also extremely vulnerable to roll, crosswinds, and runway alignment.



Fig 10.4. Quadricycle

10.2.5. Multi bogey

The usage of numerous wheels per landing gear strut is a last variation . This extra tyre is especially beneficial on carrier-based aircraft, which are required to have two nose wheels. For extra safety, several wheels are frequently utilised on main gear units, especially on commercial aircraft.



Fig 10.5. Multi Bogey wheel

10.2.6. Selection

Tricycle landing gear configuration is chosen for the following reasons,

- It allows more forceful application of the brakes without nosing over when braking, which enables higher landing speeds.
- It provides the advantage of giving more vision to the pilot.

10.3. Calculation for nose gear and main gear

Main wheels diameter or width (in.) $= A\,W^{B_W}$

For diameter (Business twin)

A = 2.69 ; B = 0.251

For width (Business twin)

A = 1.170 ; B= 0.216

A tire supports a load almost entirely by its internal pressure. The weight carried by the tire (W_W) is simply the inflation pressure (P) times the tire's contact area with the pavement.

$W_W = P A_p$,where A_p – footprint area.

$A_p = 2.3 (wd)^{1/2}[d/2 - R_r]$

10.2.1. Nose gear

Load on nose gear = $0.1 W_0$

= 8490.7 kg

Load on each tire, L_t = 4245.35 kg = 9359.4 lb

Wheel diameter = $2.69 L_t^{0.251}$

= 21.9 in = 0.56 m

Wheel width = $1.17 L_t^{0.216}$

=7.11 in = 0.18 m

Tire size = 27 x 7.75

Tire diameter , d = 27 in = 0.686 m

Tire width ,w =7.75 in = 0.197 m

Rolling radius, R_r = 11.5 in = 0.3 m

Pavement contact area , $A_p = 2.3 \times (wd)^{1/2} \times (d/2 - R_r)$

= 66.54 in^2

Tire pressure = 9359.4/66.54

= 140.6 psi

10.2.2. Main gear

Load on main gear = $0.9 W_0$

= 76416.3 kg

Load on each tire, L_t = 19104 kg = 42117.3 lb

Wheel diameter = $2.69L_t^{0.251}$

= 31.94 in = 0.81 m

Wheel width = $1.17L_t^{0.216}$

= 9.83 in = 0.25 m

Selecting Goodrich tire of size 40 x 14.5

Tire diameter d = 40 in = 1 m

Tire width, w = 14.5 in = 0.37 m

Rolling radius, R_r = 16.3 in = 0.414 m

Pavement contact area , $A_p = 2.3 \times (wd)^{1/2} \times (d/2 - R_r)$

$= 205 \text{ in}^2$

Tire pressure = 205 psi

Wheel base = 17.17 m

Wheel track = 5.71 m

11. Engine selection

The engine in an aircraft plays a major role as it generates thrust for the aircraft to take-off and move forward. The engines are classified based on their working methods as follows,

i. Reciprocating Engine
ii. Turbojet Engine
iii. Turbofan Engine
iv. Turboprop Engine
v. Ramjet Engine
vi. Scramjet Engine
vii. Pulsejet Engine

11.1. Reciprocating engine

A reciprocating engine is also called as a Piston engine. This engine uses one or more pistons to convert pressure into rotational motion. Depending upon variant, it can have single or multi pistons. A connecting rod and a crankshaft, or a swashplate or other suitable device, turn the piston's linear movement into a rotational movement.

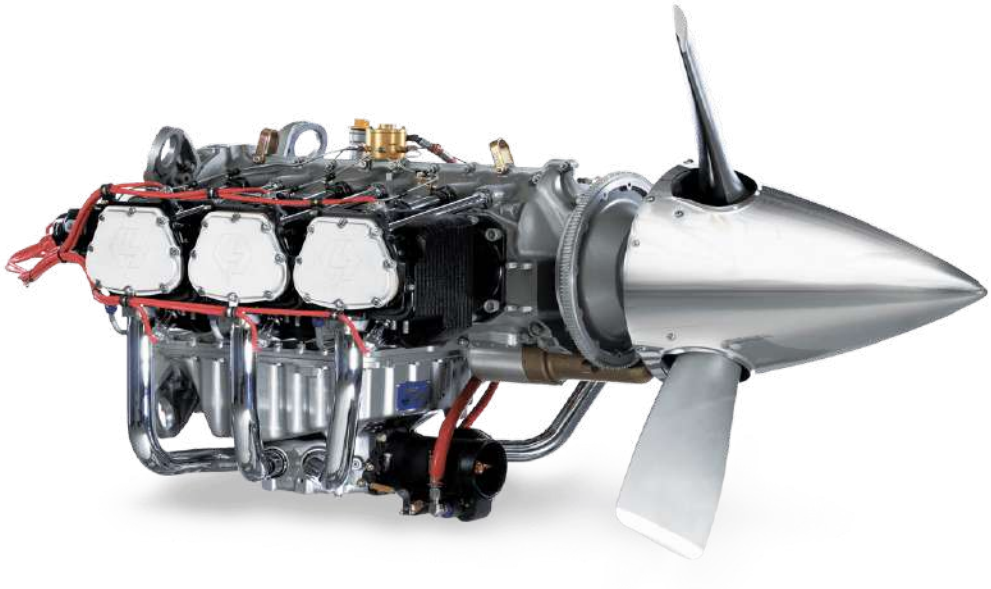


Fig 11.1. Reciprocating engine

11.2. Turbo jet engine

A gas turbine engine is also known as jet engine. A turbine-driven compressor pulls in and compresses air, forcing it into a combustion chamber into which fuel is fed, resulting in a jet engine. When the gas is ignited, it expands and rushes through the turbine, then through a nozzle in the back. Forward thrust is generated as a reaction to the rearward momentum of the exhaust gases.



Fig 11.2. Turbojet engine

11.3. Turbo fan engine

The most contemporary variant of the basic gas turbine engine is the Turbofan engine. There is a core engine, just like other gas turbines. The primary engine of a turbofan engine is encircled by a fan in the front and a second turbine in the back. The fan and fan turbine, like the core compressor and core turbine, are made up of multiple blades and are coupled to a second shaft.

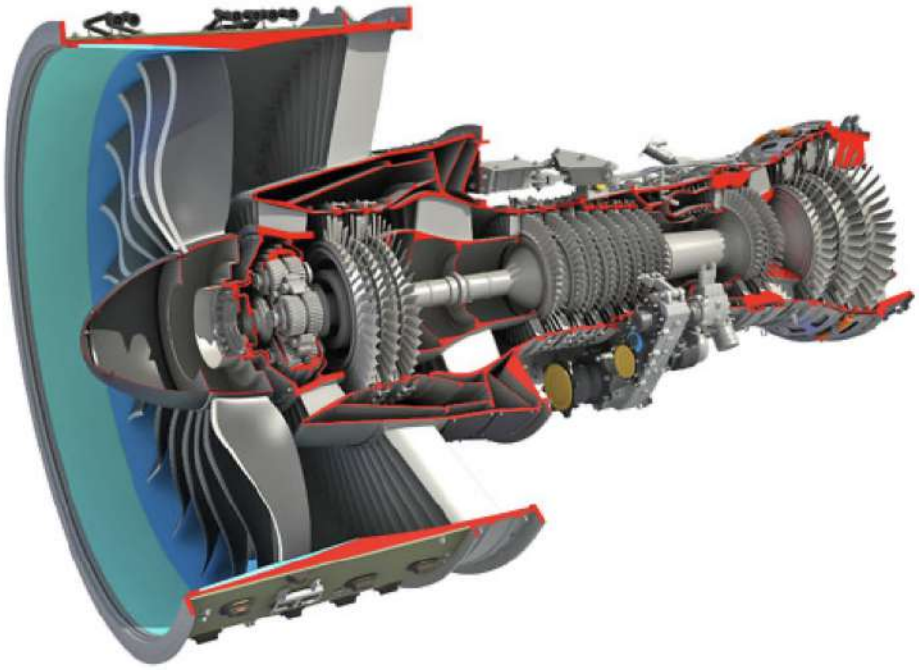


Fig 11.3. Turbofan engine

11.4. Turboprop engine

The turboprop uses a gas turbine core to turn a propeller. A turboprop consists of an intake, compressor, combustor, turbine, and propelling nozzle in its most basic form.



Fig 11.4. Turboprop engine

11.5. Ramjet engine

A ramjet, also known as a flying stovepipe or an athodyd [aerothermodynamic duct], is a type of air breathing jet engine that compresses incoming air using the engine's forward motion rather than an axial or centrifugal compressor.

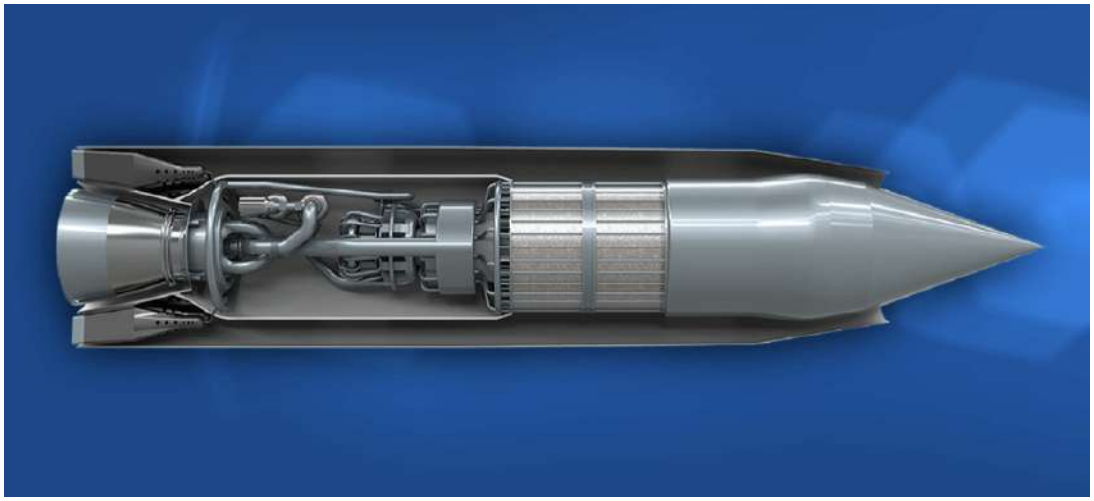


Fig 11.5. Ramjet engine

11.6. Scramjet engine

Scramjet stands for Supersonic Combustion Ramjet. A scramjet is a type of ramjet air breathing jet engine that uses supersonic airflow for burning. Scramjets rely on high vehicle speed to compress incoming air strongly before combustion, however unlike ramjets, which reduce the air to subsonic velocities before combustion, scramjets have supersonic airflow throughout the engine.

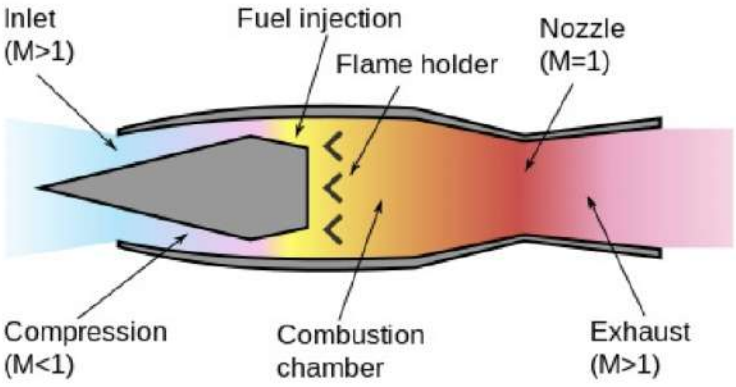


Fig 11.6.diagram

11.7. Pulsejet engine

A pulsejet engine (or pulse jet) is a type of jet engine in which combustion occurs in pulses. A pulsejet engine can be built with minimal or no moving parts and run in a static mode.

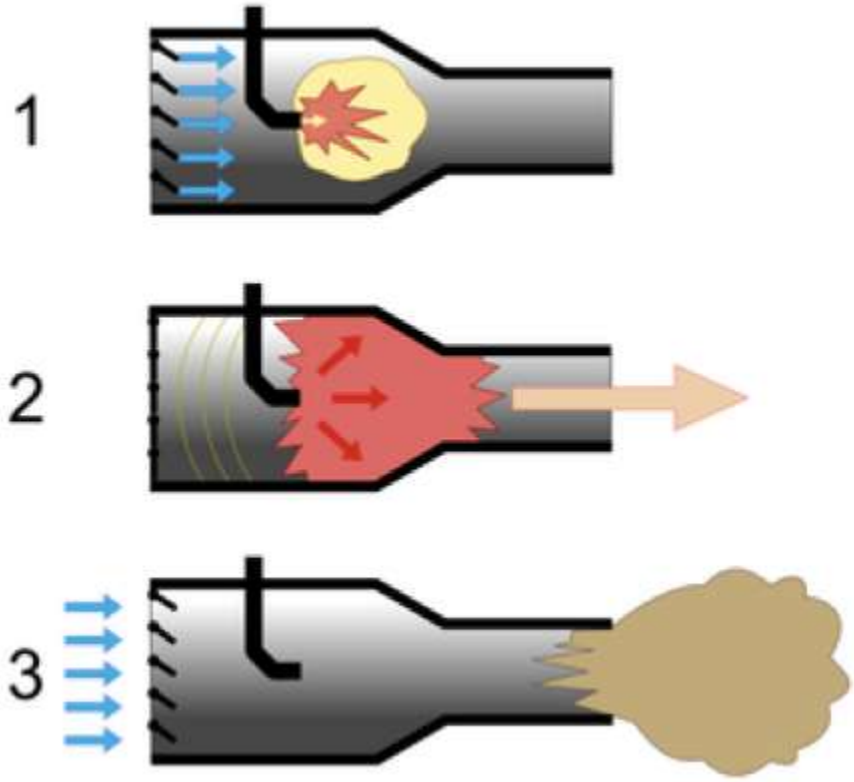


Fig 11.7. Pulse jet

11.8. Engine Selection

The thrust loading based on sea level static thrust is: T/W = 0.248 (from thrust loading calculation)

Thus, the trust required is, T_{req} = 0.248 x 84907 x 9.81 = 206.57 kN

It is observed that the maximum thrust requirements occurs from V_{max} consideration i.e. T_{max} = 206.57 kN.

As a twin engine configuration has been adopted, the above requirement implies a thrust per engine of 103.28 kN.

11.8.1. Comparison of turbofan Engines

Engine	Length (m)	Diameter (m)	Thrust (kN)	Weight (kg)	T/W	Bypass ratio	Pressure ratio	Sfc (hr^{-1})
CFM56-7B	2.5	1.55	86.7	2366	3.7	5.5:1	32.8:1	0.56
PW6000	2.74	1.44	99-106	2289	4.7	5:1	28.2:1	0.68
CFM leap -1A	3.5	1.9	123.5-133.4	3762	3.6	11:1	40:1	0.44
PW1000G	3	2.1	110 - 150	3796	4	10:1 -12:1	38:1	0.39

In the above comparison of high bypass turbofan engines, the CFM LEAP-1C and PW1000-G compete in a number of criteria. Unlike fighter planes, business jets or any airliner in that case aims for a key parameter: the lowest particular fuel consumption.

Though LEAP-1C gives a pressure ratio higher than PW1000-G, it contains a greater number of stages which adds weight to the aircraft. On the other hand, PW1000G has a lowest TSFC of 0.39/hr.

The PW1000-G will have a variable inlet duct and a Gearing system (Geared turbofan) that will allow for adjustments in bypass ratio by adjusting the fan's rpm as needed during flight. A variable-area nozzle, in addition to the geared turbofan, is included in the present design, which reduces noise. According to CAEP, it also promises a 15% decrease in CO2 emissions and a 55% reduction in NO_x margin.

Taking these advantages in consideration, PW1000-G is selected.

Selected Engine series of PW1000-G family

- PW1124G
- PW1127G
- PW1133G

11.8.2. Details Of The Selected Engine

PRATT & W HITNEY PW1000G



Fig 11.8. Pratt & Whitney PW1000G

The Pratt & Whitney PW1000G is a high-bypass geared turbofan engine family, currently selected as the exclusive engine for the Bombardier CSeries, Mitsubishi Regional Jet (MRJ), Embraer's second generation E-Jets, and as an ultra efficient option for the Airbus A320neo.

11.8.2.1.Fan

A large, light-weight fan moves well over 90% of air around the core, delivering a very quiet engine with very low fuel burn.

11.8.2.2. Compressors and Turbines

A compact, high-speed low-pressure system accomplishes the same work in fewer stages. That means fewer airfoils, fewer life-limited parts, and ultimately lower maintenance costs.
Components : Axial flow, 1-stage geared fan, 3-stage LP, 8-stage HP

11.8.2.3. Core

The supercharged low-pressure system allows the advanced PurePower engine core – optimized for high-cycle durability – to run cooler than the closest competition, with fewer stages, and without expensive materials. That means longer time on wing and lower maintenance costs.
Components : Annular combustion chamber

11.8.2.4. Geared Turbofan

In a conventional turbofan engine, a single shaft (the "low-pressure" or LP shaft) connects the fan, the low-pressure compressor and the low-pressure turbine. A second concentric shaft connects the high-pressure compressor and high-pressure turbine. In this configuration, the maximum tip speed for the fan limits the rotational speed for the LP shaft and thus the LP compressor and turbine. At high bypass ratios (and thus high radius ratios) the tip speeds of the LP turbine and LP compressor must be relatively low, which means extra compressor and turbine stages are required to keep the average stage loadings and, therefore, overall component efficiencies to an acceptable level.
A reduction gearbox between the fan and the LP shaft in a geared turbofan allows the latter to rotate at a greater rotational speed, allowing for fewer stages in both the LP turbine and the HP compressor, boosting efficiency and lowering weight. The weight savings on the turbine and compressor stages are partially offset by the gearbox's bulk.
A large, slow fan pushes air into a small, fast turbine in the Pure Power engine, which is more efficient. The end result is a smaller, lighter engine that can deliver the same amount of power as a larger conventional turbofan while using 15% less gasoline and releasing 15% less CO2.
Component : Axial, 2-stage HP, 3-stage LP

12. Lift and drag estimation

12.1. Lift

Component of aerodynamic force generated on aircraft perpendicular to flight direction

12.1.1. Lift Coefficient (CL)

- Amount of lift generated depends on:
    - Planform area (S)
    - air density (p)
    - flight speed (V)
    - lift coefficient (CL)
    - L = ½ ×ρ × V 2 ×S× OPQ
- CL is a measure of lifting effectiveness and mainly depends upon:
    - Section shape,
    - planform geometry
    - angle of attack (α)
    - compressibility effect (Mach number)
    - viscous effects (Reynolds number)

12.1.2. Generation of Lift

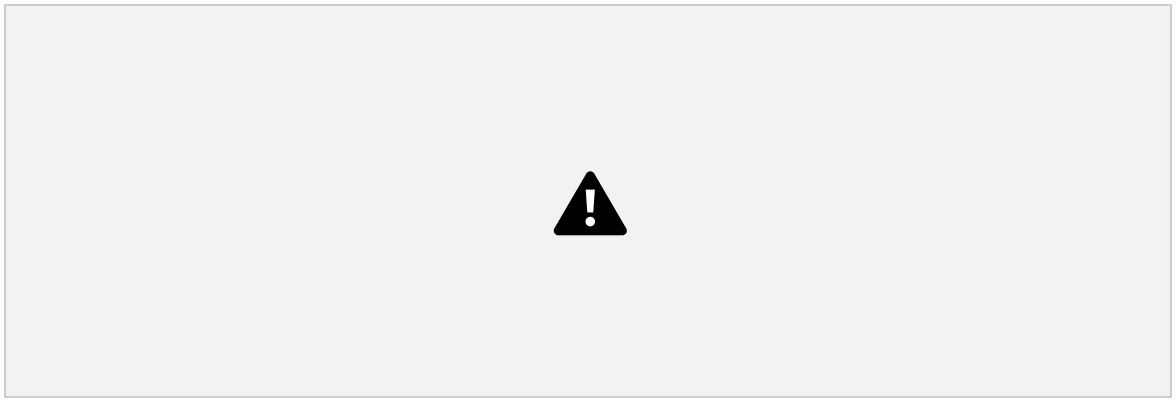


Fig 12.1. Lift generation

Aerodynamic force arises from two natural sources:

- Variable pressure distribution
- Shear stress distribution.
    - Shear stress primarily contributes to overall drag force on aircraft.
    - Lift mainly due to pressure distribution, especially on main lifting surfaces, i.e., wing.
    - Require (relatively) low pressure on upper surface and higher pressure on lower surface.
    - Any shape can be made to produce lift if either cambered or inclined to flow direction.
    - Classical aero foil section is optimum for high subsonic lift/drag ratio.

12.1.3. Pressure variations with angle of attack

- Negative (nose-down) pitching moment at zero-lift (negative α).
- Positive lift at α = 00.
- Highest pressure at LE stagnation point, lowest pressure at crest on upper surface.
- Peak suction pressure on upper surface strengthens and moves forwards with increasing α.
- Most lift from near LE on upper surface due to suction.

12.1.4. Calculation

CL_{cruise} = 2W ρ∗ Vc2 ∗ S [where, ρ = 0.23884 (at 13700 m)]

= 2∗ 12800∗ 9.81 023884∗ (236.11∗023884) 2∗21.84

CL_{cruise} = 0.8636

12.1.4.1. Lift At Take-Off

$CL_{take\text{-}off} = CL_{cruise} \times \Delta CL_{flap}$ [where, take off flap at 200 is 0.5]

$= 0.8636 + 0.5$

$CL_{take\text{-}off} = 1.364$

VR = 1.1 V stall

$= 1.1 \times 59.02$

VR = 64.922 m/sec

$L_{Take\text{-}off} = ½ \times \rho \times V^2 \times S \times CL_{take\text{-}off}$ [where, ρ = 1.225 (at sea level)]

$= ½ \times 1.225 \times (64.922)2 \times 21.84 \times 1.364$

$L_{take\text{-}off} = 76905.4$ N

12.1.4.2. Lift At Landing

$CL_{Landing} = CL_{cruise} + \Delta$ CL flap

$= 0.8636 + 0.9$ CL Landing = 1.7636

VR = 0.7 V stall

$= 0.7 \times 59.02$

VR = 41.314m/sec [where, ρ = 1.225 (at sea level)]

$L_{Landing} = ½ \times \rho \times V^2 \times S \times CL_{landing}$

$= ½ \times 1.225 \times (41.314)2 \times 21.84 \times 1.7636$

$L_{Landing} = 32871.32$ N

12.2. Drag

Drag is the resolved component of the complete aerodynamic force which is parallel to the flight direction (or relative oncoming airflow).

- It always acts to oppose the direction of motion.
- It is the undesirable component of the aerodynamic force while lift is the desirable component.

12.2.1. Drag Coefficient (C_d)

Amount of drag generated depends on:

- Planform area (S)
- Air density
- Flight speed (V)

- Drag coefficient (C_d)

C_d is a measure of aerodynamic efficiency and mainly depends upon:

- Section shape
- Planform geometry
- Angle of attack
- Compressibility effects (Mach number)
- Viscous effects (Reynold's number)

12.2.2. Drag Components

- Skin Friction
- Due to sheer stresses produced in boundary layer
- Significantly more for turbulent than laminar types of boundary layers

12.2.3. Form Drag

Drag is the resolved component of the total aerodynamic force that is parallel to the flight direction (or relative approaching airflow) due to static pressure distribution around the body.
It acts in the opposite direction of motion at all times.
It is the unfavorable part of the aerodynamic force, whereas lift is the preferred part.
The amount of drag produced is determined by:
Planform area (S), air density (V), and drag coefficient (D) (CD)
CD is a measure of aerodynamic efficiency that is primarily determined by the following factors: section shape, planform
Geometry, angle of attack, compressibility effects (Mach number), and viscous effects (Reynolds' number) are all factors to consider.

- Skin Friction.
- Due to sheer stresses produced in boundary layer.
- Significantly more for turbulent than laminar types of boundary layers.
- Due to static pressure distribution around body.
- Component resolved in direction of motion.
- Sometimes considered separately as forebody and rear (base) drag components.

12.2.4. Drag Calculation

12.2.4.1. Drag At Take-Off

$Cd_{Take\text{-}off} = Cd_o + KCl_{takeoff}\text{^}2$

$K = 1 / \Pi\, eAR$

$K = 1 / (3.14*0.7445*7.55)$

$K = 0.057$

where $Cd_o = 0.03$

$Cd_{take\text{-}off} = 0.03 + (0.057 \times (1.364^2))$

$Cd_{take\text{-}off} = 0.136$

$D_{Take\text{-}off} = ½ \times \rho \times V\text{^}2 \times S \times Cd_{Take\text{-}off}$

$= ½ \times 1.225 \times (64.922)\text{^}2 \times 21.84 \times 0.136$

$D_{Take\text{-}off} = 7667.9\ N$

12.2.4.2. Drag At Landing

$CD_{Landing} = Cd_o + K\, CL_{landing}\text{^}2$

where $Cd_o = 0.03$

$CD_{Landing} = 0.03 + (0.057 \times (1.7636)^2)$

$CD_{Landing} = 0.207$

$D_{Landing} = ½ \times \rho \times V\text{^}2 \times S \times Cd_{landing}$

$= ½ \times 1.225 \times (41.314)\text{^}2 \times 21.84 \times 0.207$

$D_{Landing} = 4726.32\ N$

13. Performance characteristics

13.1. Takeoff Performance

Distance from rest to clearance of obstacle in flight path and usually considered in two parts:

- Ground roll - rest to lift-off (Sl_0)
- Airborne distance - lift off to specified height of 50ft

The aircraft will accelerate up to lift-off speed (VL_0 = about 1.2 x Vstall) when it will then be rotated.

Ground roll take-off distance is given by

$Sl_o = 1.21W / g\rho SCL_{max} (T/W)$

(from 'Aircraft Performance & Design' by John. D Anderson)

= 1.21 x 84907x9.81 / (9.81 x 1.225 x 142 x1.5 x 0.248)

(CLmax for takeoff = 1.5, from airfoil selection)

Sl_o = 1587.67 m

13.2. Climbing

Consider aircraft in a steady unaccelerated climb with vertical climb speed of Vc

$$L = W\cos\gamma$$

$$T = D + W\sin\gamma$$

$$V_C = (T - D)Vstall / W$$

13.2.1. R/C_{max}

$$R/C_{max} = VC = (2x206570 – 44210) \times 55.77 / (84907 \times 9.81)$$

$$R/C_{max} = 24.7 \text{ m/s}$$

13.2.2. Level Turn

In the case of a commercial transport aircraft, it is capable of performing only a constant altitude banked turn and not any vertical pull-up or pull-down maneuvers.

In steady condition:

$$T = D$$

Force balance gives:

$$W = L\cos\theta$$

$$F_r = mV^2 / r = L\sin\theta$$

Therefore,

$$\tan\theta = V^2 / Rg$$

So, for a given speed and turn radius there is only one correct bank angle for a coordinate (no sideslip) turn.

In the turn, $n = L/W = \sec\theta > 1$ and is therefore determined by bank angle.

13.2.3. Turn radius (R) and turn rate (ω)

$$V^2 / (Rg) = \tan\theta = \sqrt{(\sec^2\theta - 1)} = \sqrt{(n^2 – 1)}$$

Therefore,

R = V^2 / (g √(n2 - 1))

And ω = V/R = (g √(n2 - 1)) / V

W = Lcosθ

Let θ = 60-degree

N = L/W = 2

R = 236.672 / (9.81 x √(22 – 1))

R = 3296.5 m

ω = V/R

= 236.67 / 3296.5

= 0.072 rad/s

13.3. Gliding

The thrust can be assumed to be zero while the aircraft is gliding.

ϕ = tan-1 [1/ (L/D)]

= tan-1 [1 / 18.57]

ϕ = 3.08^0 degree is the glide angle.

13.3. Landing Performance

13.3.1. Ground roll distance (S_{TD}):

S_{TD} = 1.69 W^2 / *gϱ* SC*Lmax* [D + μ_r (W-L)]

μ_r is higher than for take-off since brakes are applied

μ_r = 0.4 for paved surface.

S_{TD} = 1.69 x (84907 x 9.81)^2 / (9.81 x 1.225 x 142 x 3.08 x [213976 + 0.4(832937.67 – 0.8 x832937.67)]

S_{TD} = 795 m

14. v-n diagram

It is also called a Flight Envelope. It defines the strength limitations of an aircraft. Every airplane has its own V-n diagram. These are developed during the design process either in the conceptual or very early preliminary design stages.

Factors affecting a flight envelope:

- MTOW
- Configuration of airplane
- Symmetry of loading.
- Critical gust – Damaging flutter
- Control/lift surface reversal.

The maximum air loads on an aircraft usually come from the generation of lift during high g-maneuvers.

Load factor n = L/W

14 .1 Choosing load factors

- The positive (+ve) Maximum load factor for Business jets is +4.4
- The negative (-ve) Maximum load factor for Business jets is -4.8

- The chosen (+ve) Maximum load factor is +4.4 and the chosen (-ve) Maximum load factor is -2 .

14.2 Finding maximum velocity in both (-ve) & (+ve) velocities when n=1

The Velocity is given by the formula,

$(+ve)V_{max}=\sqrt{2*W*g/\varrho*S*CL_{max}}$

Where,

ρ	=	Density at sea level
W	=	Take-Off Weight
S	=	Wing Area

(+ ve) V_{max}	=	$(\sqrt{2}* 20000* 9.81/ 1.225 * 142 * 3.08)$
(+ ve) V_{max}	=	$\sqrt{}$ 731.662
(+ ve) V_{max}	=	27.049 m/s

(−ve) V_{max}	=	$\sqrt{}$ $(2*W*g/\varrho*S*(-CL_{max}))$
(− ve) V_{max}	=	$\sqrt{}$ (2*20000*9.81/1.225*142*0.51)
(− ve) V_{max}	=	$\sqrt{}$ 4418.668
(− ve) V_{max}	=	66.473 m/s

14.3 Finding corner velocity at both (-ve) & (+ve) with selected load factor.

The Velocity is given by the formula,

$(+ve)V_{max}$ = $\sqrt{2*W*g*n_{max}/\varrho*S*CL_{max}}$

Where,

ρ	=	Density at sea level
W	=	Take-Off Weight
S	=	Wing Area

(+ ve) V_{max}	=	$\sqrt{}$ (2*20000*9.81*4.4/1.225*142*0.51)
(+ ve) V_{max}	=	$\sqrt{}$3219.315

(+ ve) V_{max} = 56.739 m/s

(−ve) V_{max} = $\sqrt{(2*W*g*n_{max}/\varrho*S*(-CL_{max}))}$

(−ve) V_{max} = $\sqrt{(2*20000*9.81*2/1.225*142*0.51)}$

(−ve) V_{max} = $\sqrt{9014.084}$

(−ve) V_{max} = 94.9425 m/s

14.4 Die velocity

The Die Velocity is given by the formula,

V_D = $1.5* Vc$

Where, Vc = Cruise Velocity

V_D = $1.5 * 270.97$

V_D = 406.455 m/s

14.5 Coordinates

FORMAT	CO-ORDINATES
(0,0)	(0,0)
(V_{max}, 1)	(27.049, 4.4)
(V_c, +nMax)	(270.97, 4.4)
(V_d, +nMax)	(406.455, 4.4)
(V_d, -nMax)	(406.455, -2)
(V_c, -nMax)	(270.97, -2)
(V_{max}, -1)	(27.049, -1)

14.6. v-n diagram

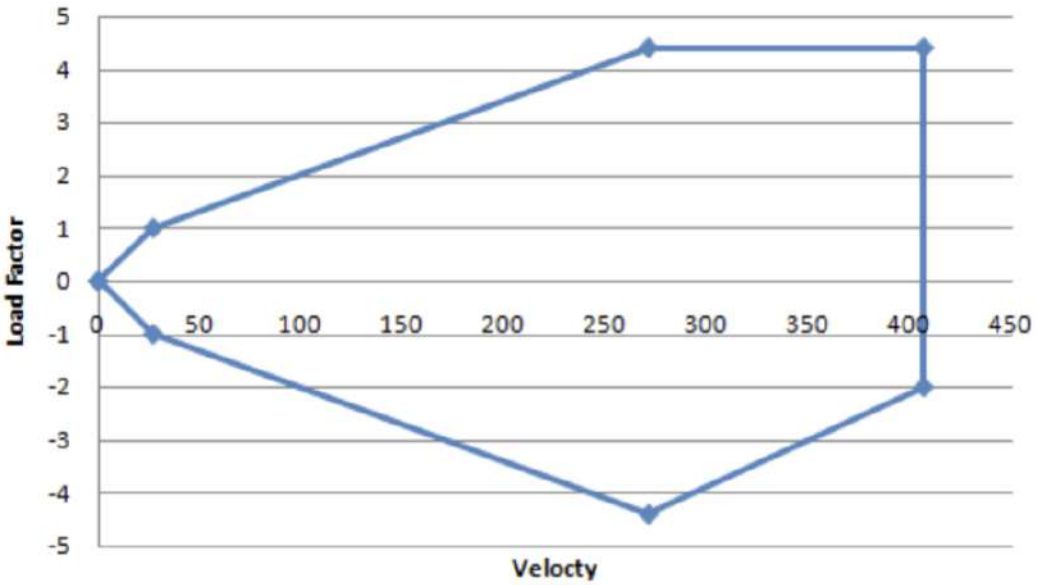


Fig 14. 1. v-n diagram

15. Finalized Design Parameters

Parameter	Values
Seating capacity	20
Length	43.1 m
Height	12.5 m
Wing Span	36.63 m
Wing Area	142 m^2
Wing Sweep Angle	25 degree
Cabin Width	3.53 m
Fuselage Width	3.76 m

Empty weight	45634 kg
Max. Speed	0.82 M
Cruise Speed	0.79 M
Range	11000 km
Service Ceiling	12500 m
Wing Loading	598 kg/m^2
Engines (X2)	PW1000G geared turbofan

17. Conclusion

A heavy business jet's preliminary design is completed, and the many design factors and performance metrics necessary are computed and determined. The derived design values are not necessarily a precise representation of the airplane's genuine and imagined design, but they do provide a foundation for further development.

The final design adheres to the required characteristics of a long-range aircraft with excellent fuel efficiency. There is no such thing as an ideal design, and ongoing adjustments, upgrades, and inventions all contribute to making the design as ideal as possible, while continuously striving for optimum performance.mChanges and implementations are made to the design on a regular basis.

The difficulties we encountered at various stages of the project highlighted the need for experience in the design of any aircraft or aircraft component. This project has taken a lot of time and effort, and we've learned a lot along the way.

17. References

- Anderson, John D. Jr., (2001) Introduction to Flight, McGraw-Hill ,New York
- 3 Perkins, C. and Hage, R. (1949) Airplane Performance, Stability and Control, Wiley, New York
- Raymer, Daniel P. (1992) Aircraft Design: A Conceptual Approach, AIAA Education series, Washington, DC
- http://www.airfoiltools.com
- http://www.airfoildb.com
- http://www.boeing.com/boeing/commercial/737family/specs.page
- www.purepowerengine.com

FIGURES	CONTENT	PAGE NO.
	Design process breakdown	118
2.1	Honda jet	21
2.2.	Cessna citation mustang	21
2.3	Embraer phenom	22
2.4	Bombardier Learjet 30	23
2.5	Beechcraft premier	23
2.6	Hawker 400	24
2.7	Bombardier Learjet 45	25
2.8	Hawker 800	25
2.9	Cessna Citation XLS	26

2.10	Cessna Citation X	26
2.11	Bombardier Challenger 300	27
2.12	Gulfstream G250	27
2.13	Bombardier Challenger 600	28
2.14	Dassault Falcon 2000	28
2.15	Embraer legacy 600	29
2.16	Lancair IV	30
2.17	Boeing 777	31
2.18.	Antonov An - 70	32
2.19	Gulfstream G550	33
2.20	F-16	34
2.21	Airbus A340 Prestige	35

2.22	Boeing B77 VIP	36
2.23	Embraer lineage 1000	37
4.1	Graph:Cruise speed vs. Range	41
4.2	Graph:Cruise speed vs. Altitude	42
4.3	Graph:Cruise speed vs. Wing loading	43
	Graph:Cruise speed vs. Gross weight	44
	Graph:Cruise speed vs. Aspect ratio	45
	Graph: Range vs. Aspect ratio	46
	Graph:Wing loading vs. Aspect ratio	47
	Graph:Wing loading vs. Takeoff run	48

	Graph: Wing loading vs. R/C_{max}	49
	Graph: Aspect ratio vs. R/C_{max}	50
6.1	Flight profile	53
7.1	Monoplane	59
7.2	Biplane	60
7.3	Triplane	61
7.4	Cantilever and semi cantilever wings	62
7.5	High wing	63
7.6	Mid wing	63
7.7	Low wing	64
7.8	Shoulder wing	64
7.9	Parasol wing	65

7.10	Rectangular wing	66
7.11	Elliptical wing	66
7.12	Tapered wing	67
7.13	Swept forward wing	68
7.14	Swept backward wing	68
7.15	Delta wing configurations	69
7.16	Wing angle	71
7.17	Elements of an airfoil	73
7.18	Angle of attack	74
7.19	NACA 63-415 airfoil	76
7.20	NACA 63-512	77
7.21	NACA 63A-514	77
7.22	Maximum Thickness	78
7.23	Sweep angle	78

7.24	Winglets	82
8.1	Types of T-tail	84
8.2	Inverted tail	84
8.3	Tailless	85
9.1	Monocoque and semi monocoque	86
9.2	Geodesic truss	87
10.1	Single wheel	89
10.2	Bicycle wheel	90
10.3	Tricycle wheel	90
10.4	Quadricycle	91
10.5	Multi Bogey wheel	92
11.1	Reciprocating engine	95
11.2	Turbojet engine	96
11.3	Turbofan engine	97

11.4	Turboprop engine	97
11.5	Ramjet engine	98
11.6	Diagram Ramjet engine	98
11.7	Pulse jet	99
11.8	Pratt & Whitney PW1000G	101
14.1	v-n diagram	113