DESIGN OF COMMERCIAL PASSENGER AIRCRAFT

AEB4341 AIRCRAFT DESIGN PROJECT REPORT-I

Submitted by Team 9

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BACHELOR OF TECHNOLOGY

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BONAFIDE CERTIFICATE

Certified that this project report titled “**COMMERCIAL PASSENGER AIRCRAFT”** is the BONAFIDE work of “**Ajin Antony(19101069), Ashwin Manoharan(19101067), Varun Vinayachandran(19101077)”** who carried out the project under authorized supervision. Certified further to the best of my knowledge that the work reported here does not form a part of any other project/research work on the basis of which a degree or reward was conferred on an earlier occasion on this or any other candidate.

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The Project Viva – Voice Examination is held on______________

INTERNALEXAMINER

EXTERNALEXAMINER

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We wish to express my heartfelt gratitude to Dr. R. Ashokan, Head of Department, School of Aeronautical Science for much of his valuable support and encouragement in carrying out this work.

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Table of Content

List of Symbols & Abbreviations

- ❖ AR - Aspect Ratio
- ❖ b - Wingspan(m)
- ❖ C - Chord of the Aerofoil(m)
- ❖ C_{root} - Chord at Root(m)
- ❖ C_{tip} - Chord at Tip(m)
- ❖ C_d - Drag Co-efficient
- ❖ C_{do} - Zero lift Drag co-efficient
- ❖ 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)
- ❖ Re - Reynolds number
- ❖ s - Wing area(m^2)

- S_{ref} - Reference surface area
- S_{wet} - Wet surface area
- S_a - Approach distance(m)
- S_f - Flare distance(m)
- S_{fr} - Free roll distance(m)
- S.C - Service ceiling(ft)
- 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(fpm)
- η - Kinematic viscosity (m^2/s)

INTRODUCTION TO DESIGN

Modern aircraft are a complex combination of aerodynamic performance, lightweight durable structures and advanced systems engineering. Air passengers demand more comfort and more environmentally friendly aircraft. Hence many technical challenges need to be balanced for an aircraft to economically achieve its design specification. Aircraft design is a complex and laborious undertaking with a number of factors and details that are required to be checked to obtain the optimum final envisioned product. The design process begins from scratch and involves a number of calculations, logistic planning, design and real-world considerations, and a level head to meet any hurdle head on.

Every airplane goes through many changes in design before it is finally built in a factory. These steps between the first ideas for an airplane and the time when it is actually flown make up the design process. Along the way, engineers think about four main areas of aeronautics: *Aerodynamics, Propulsion, Structures and Materials,* and *Stability and Control.*

Aerodynamics is the study of how air flows around an airplane. In order for an airplane to fly at all, air must flow over and under its wings. The more aerodynamic, or streamlined the airplane is, the less resistance it has against the air. If air can move around the airplane easier, the airplane's engines have less work to do. This means the engines do not have to be as big or eat up as much fuel which makes the airplane more lightweight and easier to fly. Engineers have to think about what type of airplane they are designing because certain airplanes need to be aerodynamic in certain ways. For example, fighter jets maneuver and turn quickly and fly faster than sound (supersonic flight) over short distances. Most passenger airplanes, on the other hand, fly below the speed of sound (subsonic flight) for long periods of time.

Propulsion is the study of what kind of engine and power an airplane needs. An airplane needs to have the right kind of engine for the kind of job that it has. A passenger jet carries many passengers and a lot of heavy cargo over long distances so its engines need to use fuel very efficiently. Engineers are also trying to make airplane engines quieter so they do not bother the passengers on-board or the neighborhoods they are flying over.

Another important concern is making the exhaust cleaner and more environmentally friendly. Just like automobiles, airplane exhaust contains chemicals that can damage the earth's environment.

Structures and Materials is the study of how strong the airplane is and what materials will be used to build it. It is really important for an airplane to be as lightweight as possible. The less weight an airplane has the less work the engines have to do and the farther it can fly. It is tough designing an airplane that is lightweight and strong at the same time. In the past, airplanes were usually made out of lightweight metals like aluminum, but today a lot of engineers are thinking about using composites in their designs. Composites look and feel like plastic, but are stronger than most metals. Engineers also need to make sure that airplanes not only fly well, but are also easy to build and maintain.

Stability and Control is the study of how an airplane handles and interacts to pilot input and feed. Pilots in the cockpit have a lot of data to read from the airplane's computers or displays. Some of this information could include the airplane's speed, altitude, direction, and fuel levels as well as upcoming weather conditions and other instructions from ground control. The pilot needs to be able to process the correct data quickly, to think about what kind of action needs to be taken, and to react in an appropriate way. Meanwhile, the airplane should display information to the pilot in an easy-to-read and easy-to-understand way. The controls in the cockpit should be within easy reach and just where the pilot expects them to be. It is also important that the airplane responds quickly and accurately to the pilot's instructions and maneuvers.

When you look at aircraft, it is easy to observe that they have a number of common features: wings, a tail with vertical and horizontal wing sections, engines to propel them through the air, and a fuselage to carry passengers or cargo. If, however, you take a more critical look beyond the gross features, you also can see subtle, and sometimes not so subtle, differences. This is where design comes into play. Each and every aircraft is built for a specific task, and the design is worked around the requirement and need of the aircraft. The design is modeled on the aircraft role and type and not the other way around. Thus, this is why airplanes differ from each other and are conceptualized differently. Aircrafts that fall in the same category may have similar specifications and performance parameters, albeit with a few design changes.

Design is a pivotal part of any operation. Without a fixed idea or knowledge of required aircraft, it is not possible to conceive the end product. Airplane design is both an art and a science. In that respect it is difficult to learn by reading a book; rather, it must be experienced and practiced. However, we can offer the following definition and then attempt to explain it. Airplane design is the intellectual engineering process creating on paper (or on a computer screen) a flying machine to (1) meet certain specifications and requirements established by potential users (or as perceived by the manufacturer) and/or (2) pioneer innovative, new ideas and technology. An example of the former is the design of most commercial transports, startingatleastwiththeDouglasDC-1in1932,which was designed to meet or exceed various specifications by an airplane company. (The airline was TWA, named Transcontinental and Western Air at that time.) An example of the latter is the design of the rocket-powered Bell X1, the first airplane to exceed the speed of sound in level or climbing flight (October 14, 1947). The design process is indeed an intellectual activity, but a rather special one that is tempered by good intuition developed via experience, by attention paid to successful airplane designs that have been used in the past, and by (generally proprietary) design procedures and databases (handbooks, etc.) that are a part of every airplane manufacturer.

1.1 DEFINING A NEW DESIGN

The design of an aircraft draws on a number of basic areas of aerospace engineering. These include aerodynamics, propulsion, light-weight structures and control. Each of these areas involves parameters that govern the size, shape, weight and performance of an aircraft. Although we generally try to seek optimum in all these aspects, with an aircraft, this is practically impossible to achieve. The reason is that in many cases, optimizing one characteristic degrades another.

There are many performance aspects that can be specified by the mission requirements. These include:

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

- The purchase cost

1.1.1 Aircraft Purpose

The starting point of any new aircraft is to clearly identify its purpose. With this, it is often possible to place a design into a general category. Such categories include combat aircraft, passenger or cargo transports, and general aviation aircraft. These may also be further refined into subcategories based on particular design objectives such as range (short or long), take-off or landing distances, maximum speed, etc. The process of categorizing is useful in identifying any existing aircraft that might be used in making comparisons to a proposed design. With modern military aircraft, the purpose for a new aircraft generally comes from a military program office. For example, the mission specifications for the X-29 pictured in figure 1.1 came from a 1977 request for proposals from the U.S. Air Force Flight Dynamics Laboratory in which they were seeking a research aircraft that would explore the forward swept wing concept and validate studies that indicated such a design could provide better control and lift qualities in extreme maneuvers. With modern commercial aircraft, a proposal for a new design usually comes as the response to internal studies that aim to project future market needs. For example, the specifications for the Boeing commercial aircraft (B-777) were based on the interest of commercial airlines to have a twin-engine aircraft with a payload and range in between those of the existing B-767 and B-747 aircraft. Since it is not usually possible to optimize all of the performance aspects in an aircraft, defining the purpose leads the way in setting which of these aspects will be the “design drivers.” For example, with the B-777, two of the prominent design drivers were range and payload.

1.2 DESIGN MOTIVATION

Fundamentally, an aircraft is a structure. Aircraft designers design structures. The structures are shaped to give them desired aerodynamic characteristics, and the materials and structures of their engines are chosen and shaped so they can provide needed thrust. Even seats, control sticks, and windows are structures, all of which must be designed for optimum performance. Designing aircraft structures is particularly challenging, because their weight must be kept to a minimum. There is always a trade-off between structural strength and weight. A good aircraft structure is one which provides all the strength and rigidity to allow the aircraft to meet all its design requirements, but which weighs no more than necessary. Any excess structural weight often makes the aircraft cost more to build and almost always makes it cost more to operate. As with small excesses of aircraft drag, a small percentage of total aircraft weight used for structure instead of payload can make the difference between a profitable airliner or successful tactical fighter and a failure. Designing aircraft structures involves determining the loads on the structure, planning the general shape and layout, choosing materials, and then shaping, sizing and optimizing its many components to give every part just enough strength without excess weight. Since aircraft structures have relatively low densities, much of their interiors are typically empty space which in the complete aircraft is filled with equipment, payload, and fuel. Careful layout of the aircraft structure ensures structural components are placed within the interior of the structure so they carry the required loads efficiently and do not interfere with placement of other components and payload within the space. Choice of materials for the structure can profoundly influence weight, cost, and manufacturing difficulty. The extreme complexity of modern aircraft structures makes optimal sizing of individual components particularly challenging. An understanding of basic structural concepts and techniques for designing efficient structures is essential to every aircraft design.

1.3 DESIGN PROCESS

The process of designing an aircraft and taking it to the point of a flight test article consists of a sequence of steps, as illustrated in the figure. It starts by identifying a need or capability for a new aircraft that is brought about by (1) a perceived market potential and (2) technological advances made through research and development. The former will include a market-share forecast, which attempts to examine factors that might impact future sales of a new design. These factors include the need for a new design of a specific size and performance, the number of competing designs, and the commonality of features with existing aircraft. 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 a new aircraft that are determined in a market survey go to define the mission requirements for a conceptual aircraft. These are compiled in the form of a design proposal that includes (1) the motivation for initiating a new design and (2) the "technology readiness" of new technology for incorporation into a new design. It is essential that the mission requirements be defined before the design can be started. Based on these, the most important performance aspects or "design drivers" can be identified and optimized above all others. Following the design proposal, the next step is to produce a conceptual design. The conceptual design develops the first general size and configuration for a new aircraft. It involves the estimates of the weights and the choice of aerodynamic characteristics that will be best suited to the mission requirements stated in the design proposal.

The conceptual design is driven by the mission requirements, which are set in the design proposal. In some cases, these may not be attainable so that the requirement may need to be relaxed in one or more areas. This is shown in the iterative loop in the flow chart. When the mission requirements are satisfied, the design moves to the next phase, which is the preliminary design.

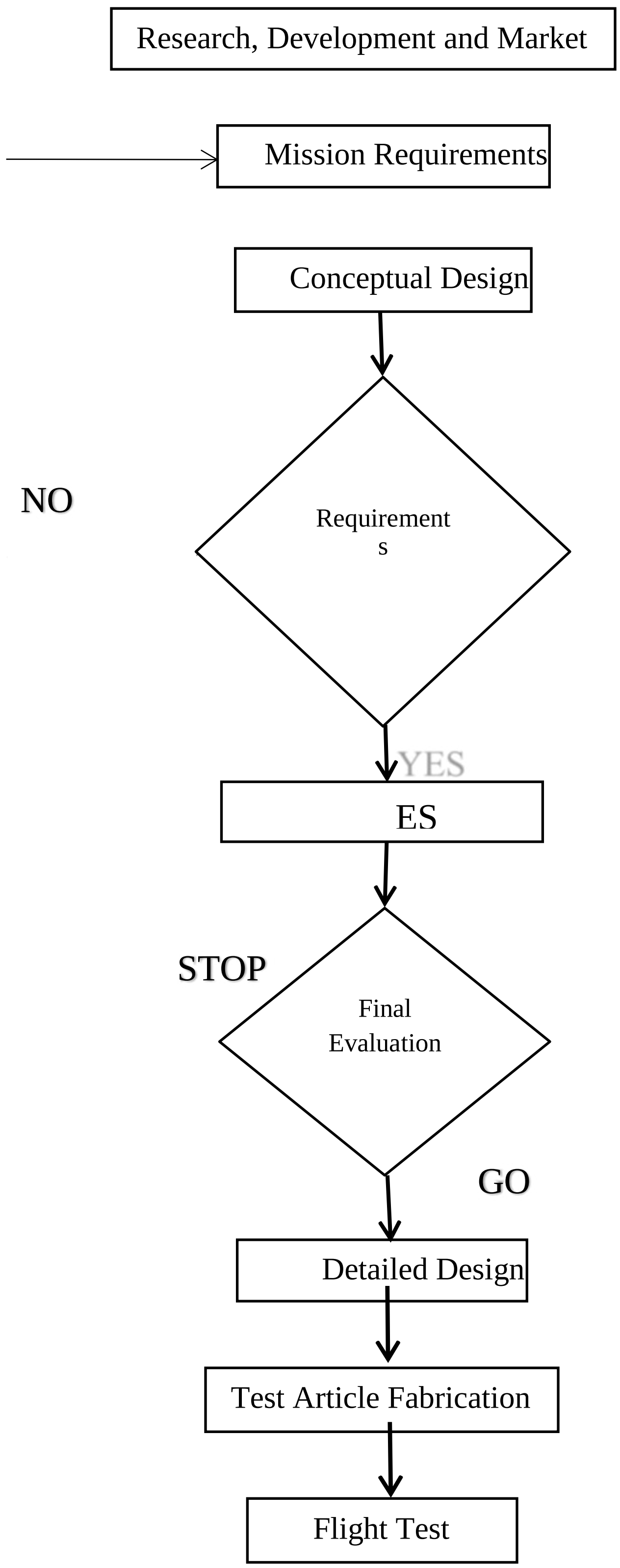


Figure. 1.1 Design Process flow chart

1.3 CONCEPTUAL DESIGN

This article deals with 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
    a. Maximum take-off Weight
    b. Empty weight of the aircraft
    c. Weight of the fuel
    d. Fuel tank capacity
4. Estimation of critical performance parameters
    a. Wing area
    b. Lift and drag coefficients
    c. Wing loading
    d. Power loading
    e. Thrust to weight ratio
5. Engine Selection

1. DESIGN PROCESS BREAKDOWN

Table 1.1 Design Process Breakdowns

Conceptual Design: • Competing concepts evaluated • Performance goals established • Preferred concept selected	What drives the design? Will it work/meet the requirements? What does it look like?
Preliminary Design: - Refined sizing of preferred concept Tests - Design examined data/establish parameters - Some changes allowed	Do serious wind tunnel tests Make actual cost estimate
Detail Design: - Final detail design - Drawings released - Detailed performance Only "tweaking" of design allowed	Certification process Component/systems tests Manufacturing Flight control system design

Introduction to Passenger Aircraft

- **What is a Passenger Aircraft?**

An airliner is a type of aircraft for transporting passengers and air cargo. Such aircraft are most often operated by airlines.

- **Who built Passenger Aircraft?**

The Wright brothers' indispensable helper got a ride as a ward. Just before 8a.m. on May14, 1908, Wilbur Wright made an easy landing on the beach at Kitty Hawk. He had covered about 2,000 feet in just over 28 seconds, figures that by this point in his career were routine , even underwhelming.

- **What are Passenger Aircraft made of?**
-

Most airplanes are made out of titanium, steel, aluminum, and many other materials, including composites. Composites can contain a variety of different materials, usually including polymers, carbon fiber, and more. These metals are stiff and strong as well as resistant to corrosion and light in weight.

- **How many passenger vehicles are there in the fleet?**

While the active global commercial fleet currently stands at 25,368 aircraft, the next 10 years will see 3.4% net annual growth, increasing the number to 35,501.

Types of aircraft

Narrow body aircraft

The most common airliners are narrow-body aircraft, or single-aisles. The earliest jet airliner were narrow bodies: the initial de Havilland Comet, the

Boeing 707 and its competitor the Douglas DC-8.

Currently produced narrow-body airliners include the Airbus A220 and A320 family, Boeing 737 and Embraer E-Jet family, generally used for medium-haul flights.

***Wide body aircraft**

The larger wide-body aircraft, or twin-aisle as they have two separate aisles in the cabin, are used for long-haul flights. The first was the Boeing 747 quad jet, followed by the tri jets: the Lockheed L-1011 and the Douglas DC-10, then its MD-11 stretch. Other quad jets were introduced: the Ilyushin Il-86 and Il-96, the Airbus A340 and the double-deck A380. Twin Jets were also put into service: the Airbus A300/A310, A330 and A350; the 767, 777 and 787.

***Regional aircraft**

Regional airliners seat fewer than 100 passengers. These smaller aircraft are often used to feed traffic at large airline hubs to larger aircraft operated by the major mainline carriers, legacy carriers, or flag carriers, often sharing the same livery. Regional jets include the Bombardier CRJ100/200 and Bombardier CRJ700 series, or the Embraer ERJ family. Currently produced turboprop regional airliners include the Dash-8 series

***Commuter aircraft**

Light aircraft can be used as small commuter airliners, or as air taxis. Twin turboprops carrying up to 19 passengers include the Beechcraft 1900, Fairchild Metro, Jetstream 31, DHC-6 Twin Otter and Embraer EMB 110 Bandeirante. Smaller airliners include the single-engined turboprops like the Cessna Caravan and Pilatus PC-12; or twin piston-powered aircraft made by Cessna, Piper, Britten-Norman, and Beechcraft. They often lack lavatories, stand-up cabins, pressurization, galleys, overhead storage bins, reclining seats, or a flight attendant.

EXAMPLES OF PASSENGER AIRCRAFTS

The **Airbus A380** is a wide-body aircraft manufactured by Airbus. It is the world's largest passenger airliner. Airbus studies started in 1988 and the project was announced in 1990 to challenge the dominance of the Boeing 747 in the long haul market.

The full-length double-deck aircraft, sometimes nicknamed the superjumbo, has a typical seating capacity of 525, though it is certified for up to 853 passengers. It is powered by four Engine Alliance GP7200 or Rolls-Royce Trent 900 turbofans providing a range of 8,000 nmi

The **Boeing 757** is an American narrow-body airliner that was designed and built by Boeing Commercial Airplanes. The then-named 7N7, a twinjet successor for the 727 (a tri jet), received its first orders in August 1978

Major customers for the 757 included U.S. mainline carriers, European charter airlines, and cargo companies. It was commonly used for short and mid-range domestic routes, shuttle services, and transcontinental U.S. flights.

PREPARATION OF COMPARATIVE DATA SHEETS OF DIFFERENT AIRCRAFTS

Dimensions:

S.No	AIRCRAFT NAME	LENGTH(m)	HEIGHT(m)	WING SPAN(m)	WING AREA (m^2)
1	A318	31.4	11.76	34.1	122.6
2	A319	33.84	11.76	35.8	122.6
3	A320	37.57	11.76	35.8	122.6
4	A321	44.51	11.76	35.8	122.6
5	B737-100	29	11.13	28	91.04
6	B737-200	30.53	11.13	28	91.04
7	B737-300	31	11.13	28.88	91.04
8	B737-400	35	11.13	28.88	91.04
9	B737-500	37	11.13	28.88	91.04
10	B737-600	31	12	35.79	124.6
11	A220	35	11.5	35.1	112.3
12	B737-700	35	11.13	35.79	124.6
13	B717	37.8	12	28.47	93
14	B727-100	40.6	11.13	32.92	153
15	B737-800	40	12	35.79	124.6
16	B737-900	42	12	35.79	124.6
17	B727-100C	47.3	12	32.92	153
18	B727-200	48.5	11.5	32.92	153
19	DH Comet 3	33.99	12	35	187.2
20	B377	33.63	8.19	43.05	164.3
21	B737-MAX 10	43.8	12.29	35.92	127
22	MD-87	39.75	8	32.82	112.3

23	DH Comet 4	33.99	8	35	197
24	MD-90	46.51	8.75	32.86	115
25	MD-81	45.06	8.75	32.82	112.3
26	HS-121 Trident 2E	34.98	8.5	30	135.8

Weight Configuration:

S.No	AIRCRAFT NAME	EMPTY WEIGHT (kg)	MAXIMUM TAKEOFF WEIGHT (kg)	payload (kg)
1	A318	39,500	68,000	3612
2	A319	40,800	75,500	18000
3	A320	42,600	78,000	150000
4	A321	48,500	93,500	15545
5	B737-100	28,000	50,000	13600
6	B737-200	29,600	58,100	41600
7	B737-300	31,950	60,600	18335
8	B737-400	32,000	64,000	46040
9	B737-500	34,820	68,000	51250
10	B737-600	36,378	65,500	30688
11	A220	63,100	63,100	50850

12	B737-700	38,000	66,000	50850
13	B717	30,617	49,900	16600
14	B727-100	39,800	77,000	17400
15	B737-800	41,145	71,000	10890
16	B737-900	44,677	85,100	15000
17	B727-100C	40,500	115,680	24700
18	B727-200	45,720	142,800	14380
19	DH Comet 3	40,000	68,000	14380
20	B377	37,875	67,132	9000
21	B737-MAX 10	45,070	88,300	30500
22	MD-87	33,200	67,800	25000
23	DH Comet 4	42,000	71,000	70000
24	MD-90	40,007	70,760	45000
25	MD-81	36,200	63,500	11242
26	HS-121 Trident 2E	33,200	64,600	8629

Performance:

S.No	AIRCRAFT NAME	CRUISE VELOCITY (km/hr)	MAXIMUM RANGE (km)	RATE OF CLIMB (m/s)	SERVICE CEILING (m)
1	A318	890	5,750	7.62	11000
2	A319	890	6,950	15.24	12100
3	A320	890	6,100	7.62	13000
4	A321	890	5,950	7.62	11300
5	B737-100	876	2,850	19.1	11300
6	B737-200	876	4,800	14.224	12800
7	B737-300	876	3,815	11.684	13000
8	B737-400	876	4,000	9.14	12500
9	B737-500	876	4,398	7.62	13100
10	B737-600	838	5,436	15.24	12000
11	A220	870	6,390	2.54	13100
12	B737-700	838	5,450	12.7	13100
13	B717	822	2,645	30.48	11887
14	B727-100	960	4,170	6.09	11277
15	B737-800	838	5,500	10.16	10668
16	B737-900	838	5,575	5.62	12100
17	B727-100C	960	4,170	16.783	11887
18	B727-200	953	4,720	12.7	11300

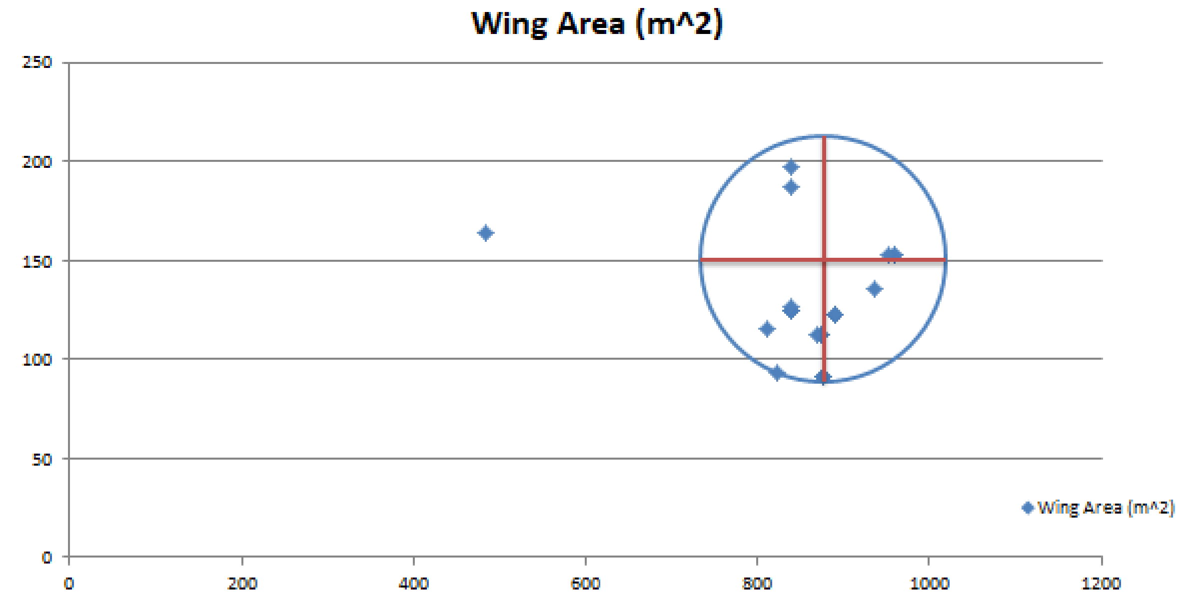
19	DH Comet 3	840	4,300	10.16	12500
20	B377	484	6,800	10.16	12200
21	B737-MAX 10	838	7,130.00	17.272	12000
22	MD-87	873	5,400	18	12000
23	DH Comet 4	840	5,190	10	12527
24	MD-90	812	3,787	10.16	12527
25	MD-81	873	3,300	4.64	11000
26	HS-121 Trident 2E	937	4,350	20.32	10700

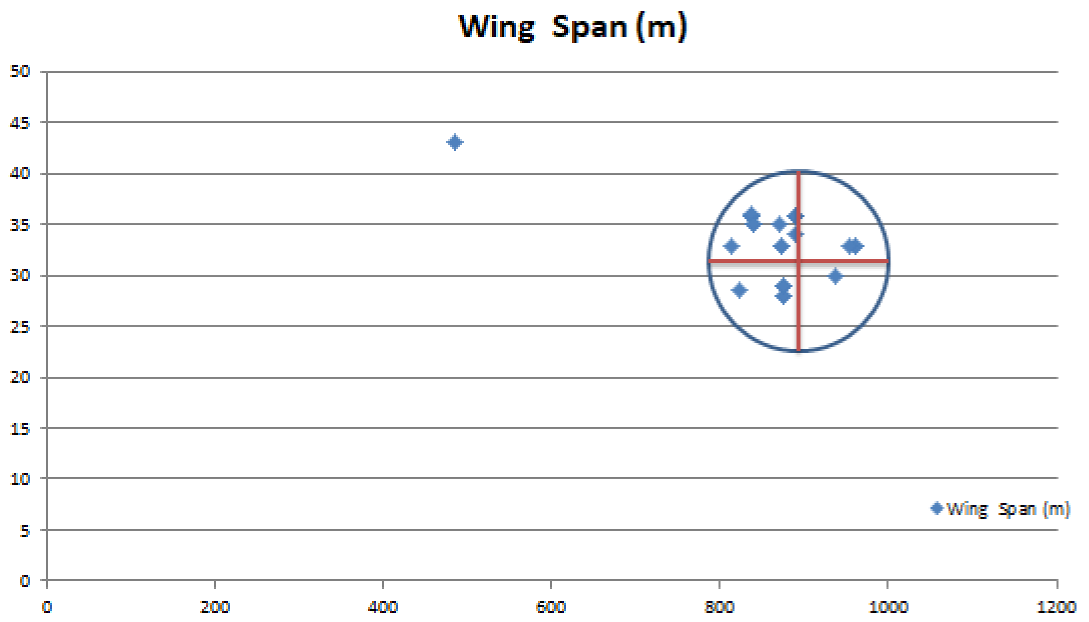
Engine Configuration:

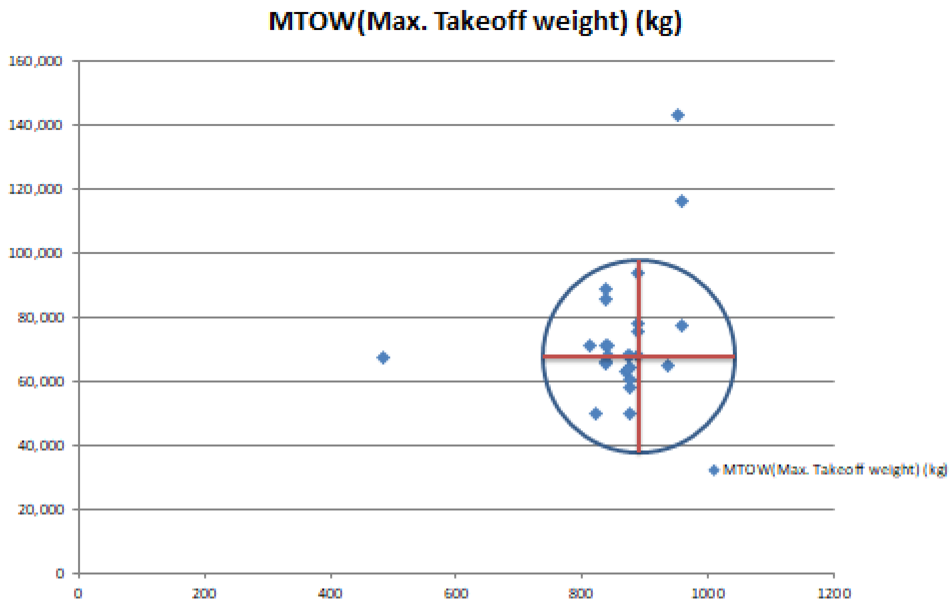
S.No	AIRCRAFT NAME	ENGINE TYPE	MAXIMUM THRUST (kN)
1	A318	turbofan	105
2	A319	turbofan	120
3	A320	turbofan	120
4	A321	turbofan	147
5	B737-100	turbofan	62
6	B737-200	turbofan	73
7	B737-300	turbofan	105
8	B737-400	turbofan	105
9	B737-500	turbofan	105

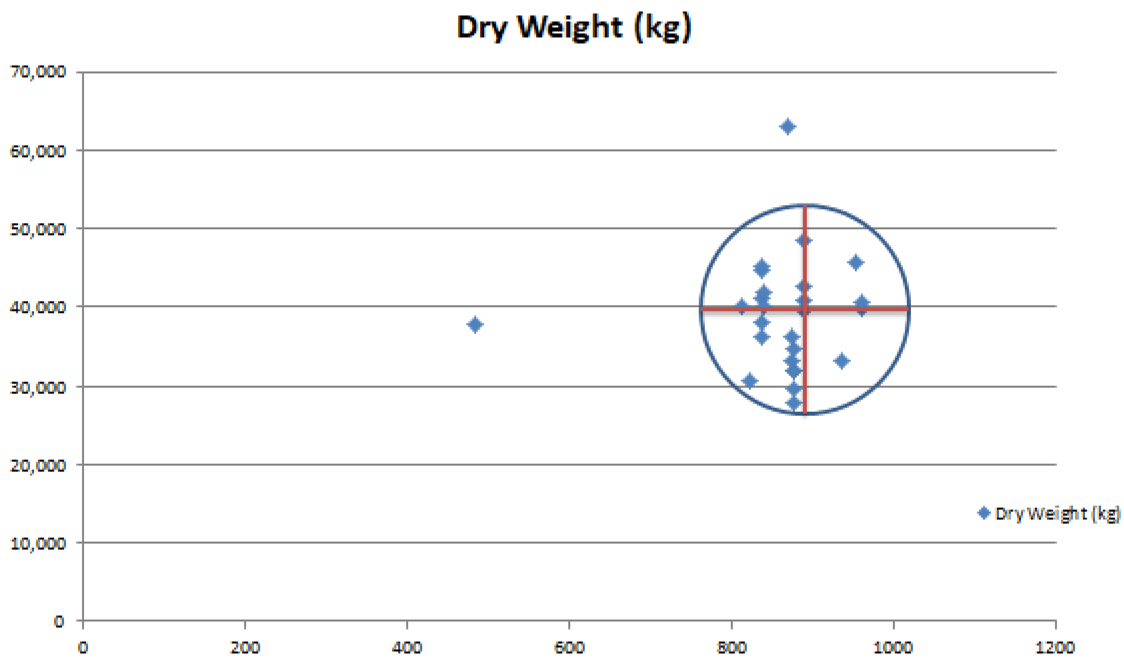
10	B737-600	turbojet	120
11	A220	turbofan	103.6
12	B737-700	turbofan	120
13	B717	turbofan	168
14	B727-100	turbofan	64
15	B737-800	turbofan	120
16	B737-900	turbofan	120
17	B727-100C	turbofan	64
18	B727-200	turbofan	77
19	DH Comet 3	turbofan	44
20	B377	turboprop	3500 hp
21	B737-MAX 10	turbojet	130
22	MD-87	turbofan	93
23	DH Comet 4	turbofan	47
24	MD-90	turbofan	111.21
25	MD-81	turbofan	93
26	HS-121 Trident 2E	turbofan	53.2

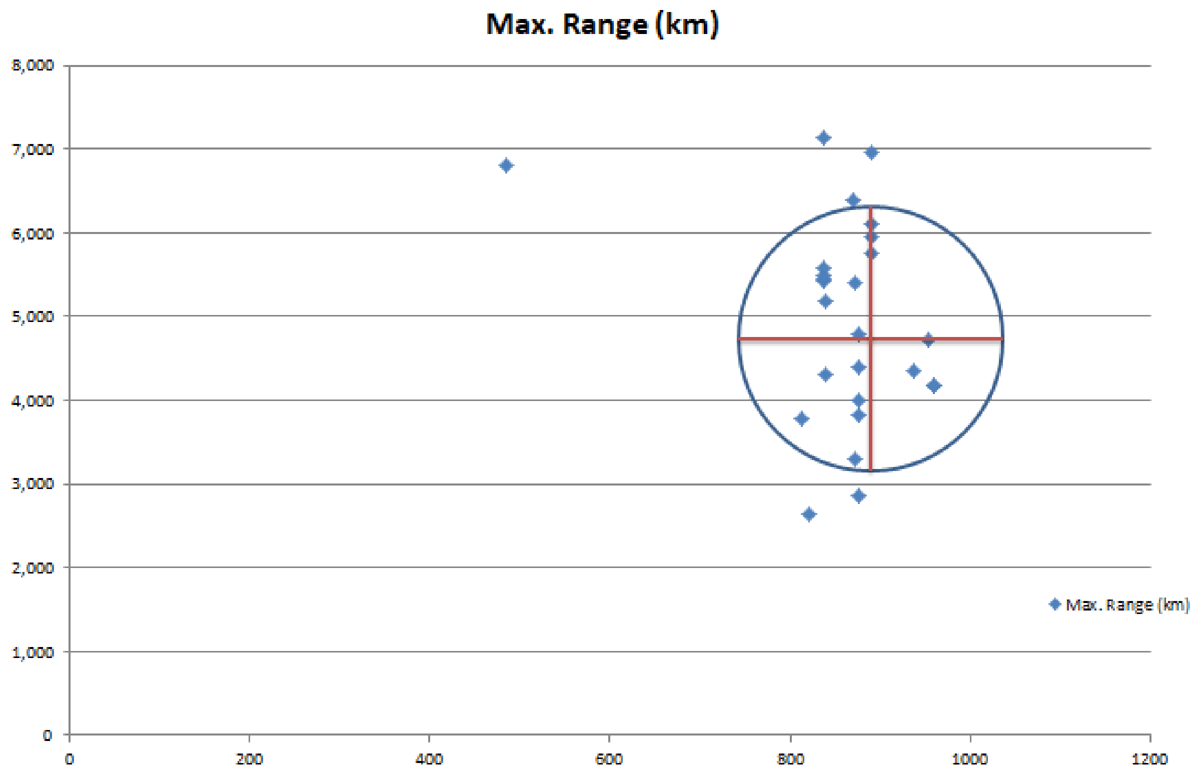
PREPARATION OF COMPARATIVE GRAPHS

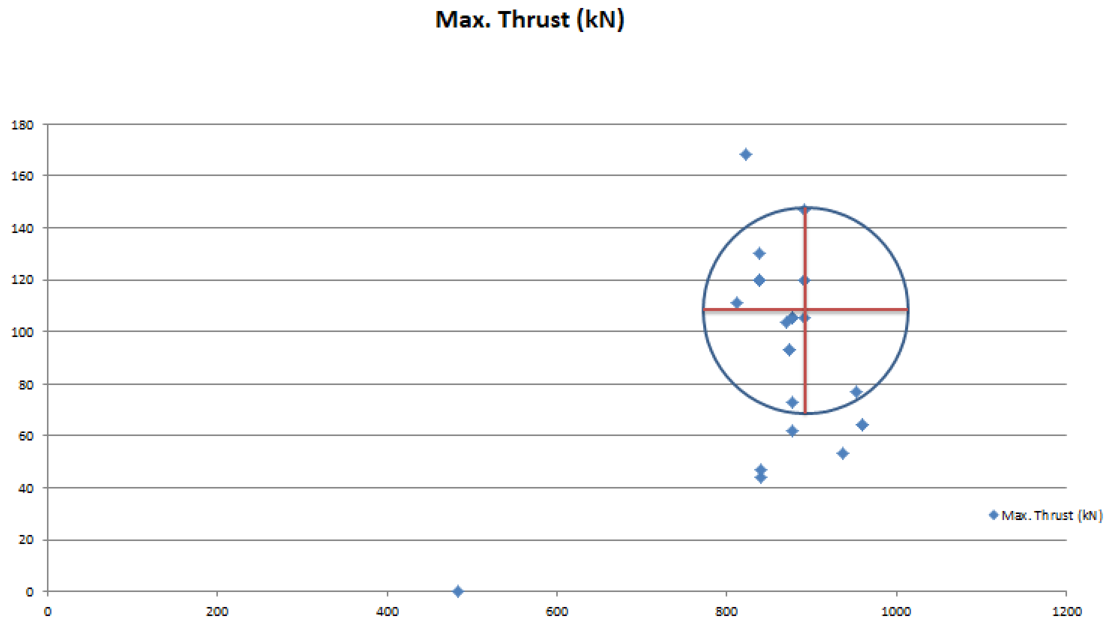


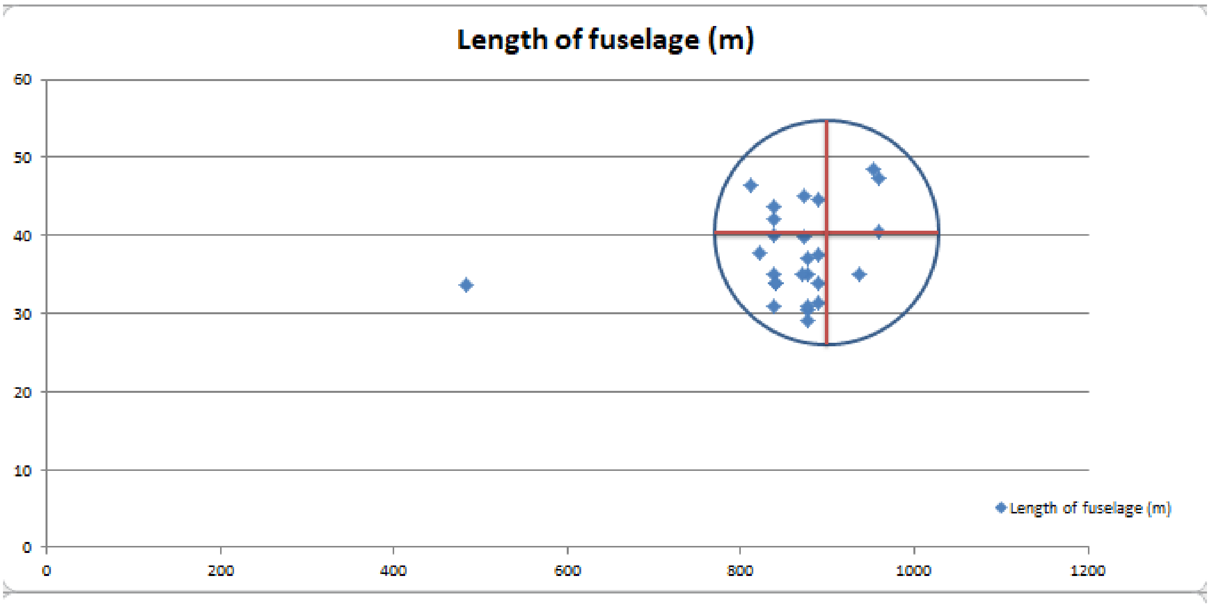


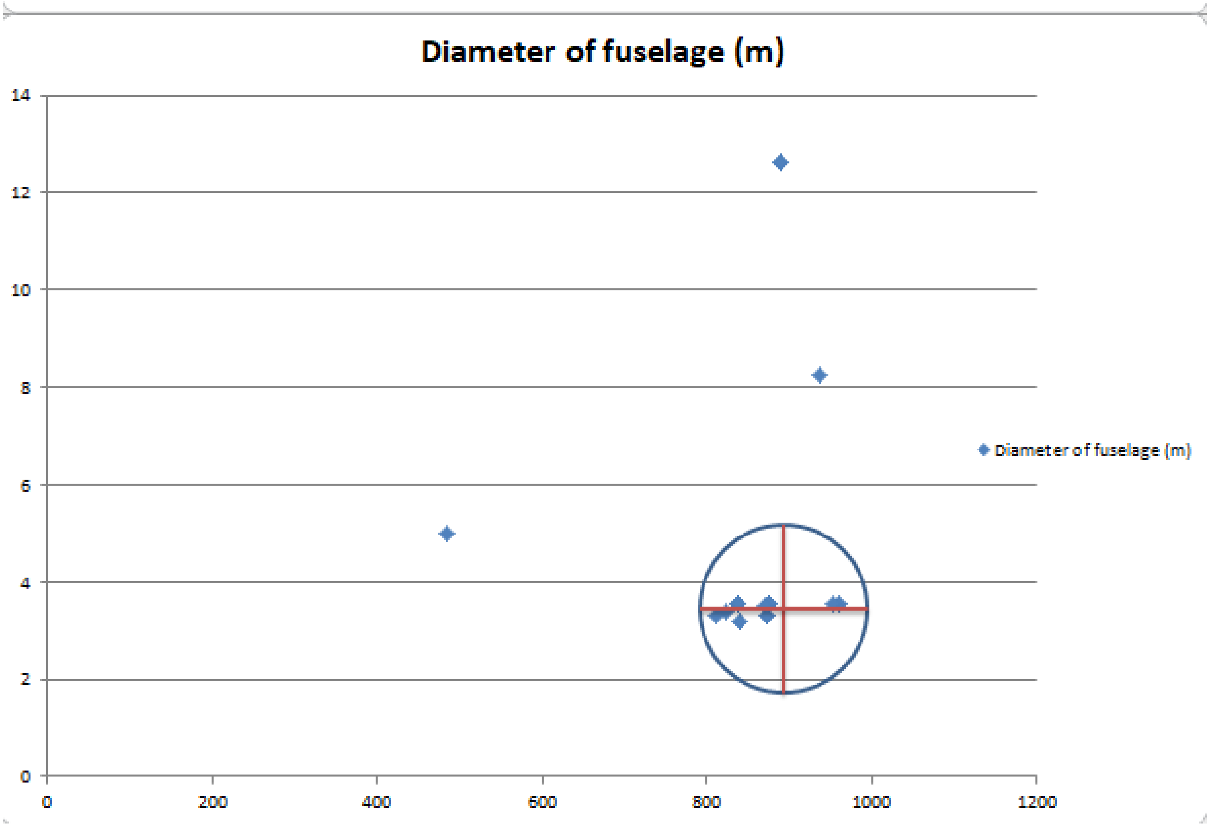

MTOW(Max. Takeoff weight) (kg)
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
200
400
600
800
1000
1200
MTOW(Max. Takeoff weight) (kg)


Dry Weight (kg)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
200
400
600
800
1000
1200
Dry Weight (kg)


Max. Range (km)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
200
400
600
800
1000
1200
Max. Range (km)


Max. Thrust (kN)
180
160
140
120
100
80
60
40
20
0
0
200
400
600
800
1000
1200
Max. Thrust (kN)


Length of fuselage (m)
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
Length of fuselage (m)


Diameter of fuselage (m)
14
12
10
8
6
4
2
0
0
200
400
600
800
1000
1200
Diameter of fuselage (m)

SELECTION OF TENTATIVE DESIGN PARAMETERS

S. No.	Design Parameters	Value	Unit
1.	Aspect Ratio	6.023	-
2.	Height	11	m
3.	Length	40	m
4.	Maximum Takeoff Weight	70000	Kg
5.	Payload	20000	Kg
6.	Maximum Range	4900	Km
7.	Rate of Climb	14	m\s
8.	Service Ceiling	11800	m
9.	Wing Span	32.5	m
10.	Maximum Thrust	105	kN
11.	Wing Area	150	m^2
12.	Wing Loading	588	Kg/m^2
13.	Empty Weight	40000	Kg
14.	No. of. Crews	2	-

WEIGHT ESTIMATION

To find the weight of the following parameters of the aircraft.

- Take-off weight (W_{TO})=70,000 kg
- Empty weight (We)=40,000 kg
- Weight of crew= 9,600 kg

The following are the data which is obtained from the graph to proceed for the weight estimation.

- Cruise speed = 239m/s (860 km/hr)
- Service ceiling = 11,800 m
- Range = 4,900 km
- Take off distance = 1.005 km
- Landing distance = 1.851 km
- Payload = 13,125 kg

Mission Phase No. (See Fig.2.1) / Airplane Type:	Engine Start, Warm-up 1	Taxi 2	Take-off 3	Climb 4	Descent 7	Landing Taxi, Shutdown 8
1. Homebuilt	0.998	0.998	0.998	0.995	0.995	0.995
2. Single Engine	0.995	0.997	0.998	0.992	0.993	0.993
3. Twin Engine	0.992	0.996	0.996	0.990	0.992	0.992
4. Agricultural	0.996	0.995	0.996	0.998	0.999	0.998
5. Business Jets	0.990	0.995	0.995	0.980	0.990	0.992
6. Regional TBP's	0.990	0.995	0.995	0.985	0.985	0.995
7. Transport Jets	0.990	0.990	0.995	0.980	0.990	0.992
8. Military Trainers	0.990	0.990	0.990	0.980	0.990	0.995
9. Fighters	0.990	0.990	0.990	0.96-0.90	0.990	0.995
10. Mil.Patrol, Bomb, Transport	0.990	0.990	0.995	0.980	0.990	0.992
11. Flying Boats, Amphibious, Float Airplanes	0.992	0.990	0.996	0.985	0.990	0.990
12. Supersonic Cruise	0.990	0.995	0.995	0.92-0.87	0.985	0.992

Notes: 1. The numbers in this table are based on experience or on judgment.
2. There is no substitute for common sense! If and when common sense so dictates, the reader should substitute other values for the fractions suggested in this table.

	Cruise				Loiter			
	L/D	c_j	c_p	η_p	L/D	c_j	c_p	η_p
Mission		lbs/lbs/hr	lbs/hp/hr			lbs/lbs/hr	lbs/hp/hr	
Phase No. (See Fig.2.1)		5				6		
Airplane Type								
1. Homebuilt	8-10*		0.6-0.8	0.7	10-12		0.5-0.7	0.6
2. Single Engine	8-10		0.5-0.7	0.8	10-12		0.5-0.7	0.7
3. Twin Engine	8-10		0.5-0.7	0.82	9-11		0.5-0.7	0.72
4. Agricultural	5-7		0.5-0.7	0.82	8-10		0.5-0.7	0.72
5. Business Jets	10-12	0.5-0.9			12-14	0.4-0.6		
6. Regional TBP's	11-13		0.4-0.6	0.85	14-16		0.5-0.7	0.77
7. Transport Jets	13-15	0.5-0.9			14-18	0.4-0.6		
8. Military Trainers	8-10	0.5-1.0	0.4-0.6	0.82	10-14	0.4-0.6	0.5-0.7	0.77
9. Fighters	4-7	0.6-1.4	0.5-0.7	0.82	6-9	0.6-0.8	0.5-0.7	0.77
10. Mil.Patrol, Bomb, Transport	13-15	0.5-0.9	0.4-0.7	0.82	14-18	0.4-0.6	0.5-0.7	0.77
11. Flying Boats, Amphibious, Float Airplanes	10-12	0.5-0.9	0.5-0.7	0.82	13-15	0.4-0.6	0.5-0.7	0.77
12. Supersonic Cruise	4-6	0.7-1.5			7-9	0.6-0.8		

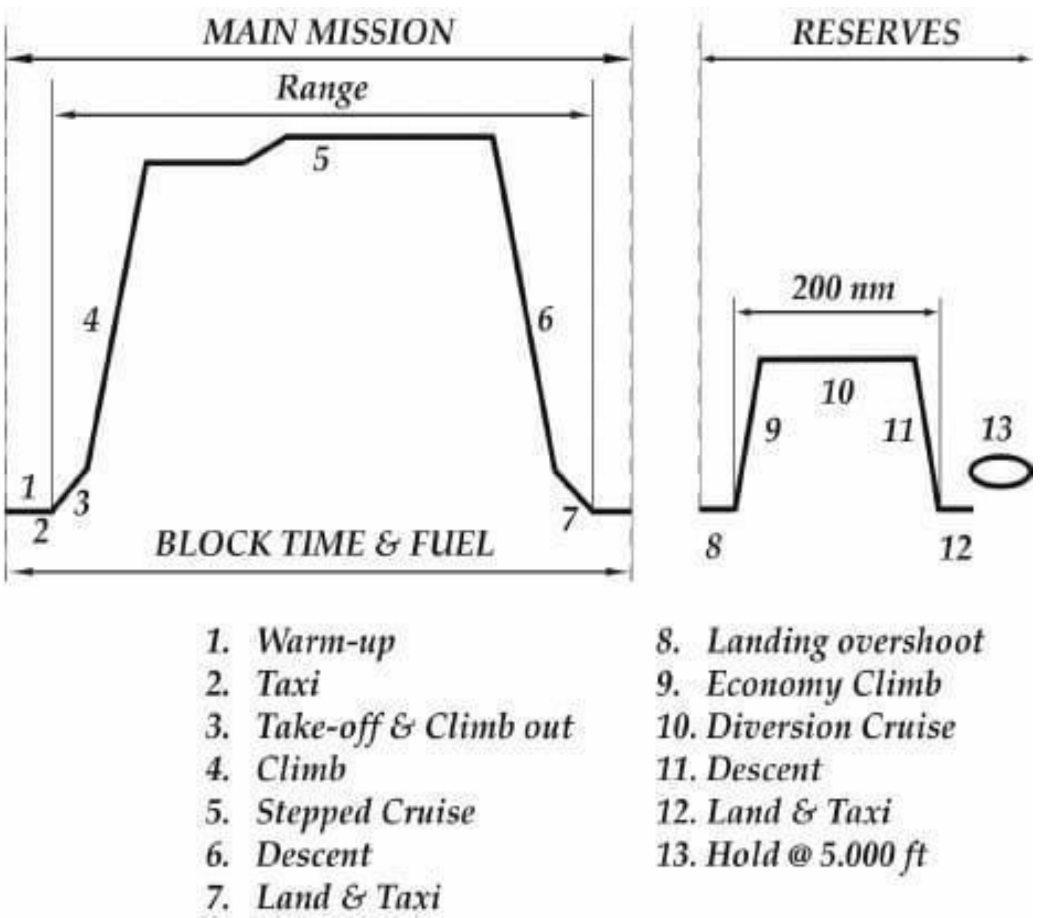
Notes: 1. The numbers in this table represent ranges based on existing engines.
2. There is no substitute for common sense! If and when actual data are available, these should be used.
3. A good estimate for L/D can be made with the drag polar method of Sub-section 3.4.1.
* Homebuilts with smooth exteriors and/or high wing loadings can have L/D values which are considerably higher.

Calculation:

Phases:

1. ENGINE
2. TAXING
3. TAKE OFF
4. CLIMB
5. CRUISE
6. LOITER
7. DESCENT
8. LANDING
9. TAXING
10. SHUT DOWN

MISSION PROFILE:



Phase 1: Engine start and Warm-up

Begin weight is W_{TO} End weight is W_1 . The ratio W_1/W_{TO} is typically 0.990.

Phase 2: Taxi

Begin weight is W_1. End weight is W_2. The ratio W_2/W_1 is typically 0.990.

Phase 3: Take-off

Begin weight is W_2. End weight is W_3. The ratio W_3/W_2 is typically 0.995.

Phase 4: Climb to cruise altitude and accelerate to cruise speed

Begin weight is W_3. End weight is W_4. The ratio W_4/W_3 is typically 0.980.

Phase 5: Cruise

Begin weight is W_4. End weight is W_5. Consider the cruise Mach-number to be 0.80 at an altitude of 11800m. This amounts for a cruise speed of 940km/h. The amount of fuel used during cruise can be found from Briquet's range equation mentioned below.

$$R_{cr}= (V/C_j)_{cr} * (L/D)_{cr} * \ln(W_4/W_5)$$

Where,

R_{cr} - Range covered during cruise.

V - Velocity of aircraft

$(L/D)_{cr}$ - Lift to drag ratio during cruise

The (L/D) value is taken to be **14** at cruise and an optimistic value of **CJ=0.7**. Also take a range of;

R_{cr} = R-[T+L+2SC]

Where,

R - Range of aircraft

T - Take-off distance

L - Landing distance

SC - Service ceiling

R_{cr} = 4900– [2*7.332+1.005+1.8] = 4890 km

$R_{cr}= (V/C_j)_{cr} * (L/D)_{cr} * \ln(W_4/W_5)$

$4900=(860/0.6)*14*\ln(W_4/W_5)$

$(W_4/W_5) = e(0.244)$

$(W_4/W_5) = 1.41$

$(W_5/W_4) = 0.709$

Therefore, the Weight Ratio (W_5/W_4) is 0.833.

Phase 6: Loiter

Begin weight is W_5. End weight is W_6. The ratio W_6/W_5 can be estimate from the Brequet's endurance equation which is mentioned below.

$E_{ltr} = (1/C_j)_{ltr} * (L/D)_{ltr} * \ln(W_5/W_6)$

Where,

E_{ltr} - Endurance

C_j - Jet velocity

It is assumed that the transport will be able to loiter at a **(L/D) value of 16** and a value of **C_j=0.5.** The mission profile assumes no range credit during loiter. Loiter time is 3 minutes.

$$E_{ltr} = (1/C_j)_{ltr} * (L/D)_{ltr} * \ln(W_5/W_6)$$

$$= (1/0.5) * 14 * \ln(W_5/W_6)$$

$E_{ltr=}$ 1.16(R_{cruise}/V_{cruise}) ($C_{cruise/}$ C_{loiter})

=1.16(2467.021/571.661)(0.7/0.5)

=7.008/min or 0.1168/hr

(4900/860)=(1/0.5)*14*ln(W5/W6)

$\ln(W_5/W_6) = 0.203$

(W5/W6) = e^(0.203)

$(W_5/W_6) = 1.59$

$(W_6/W_5) = 0.628$

Therefore, the Weight Ratio (W_6/W_5) is 0.9855.

Phase 7: Descent

Begin Weight is W_6. End Weight is W_7. No credit is taken for range. However, a penalty for fuel used during descents from high altitudes needs to be assessed. Typically, the ratio W_7/W_6=0.990

Phase 8: Fly to alternate and descent

Begin weight is W_7. End weight is W_8. The ratio W_8/W_7 can be estimated from the Brequet's range equation. This time however, because of the short distance to fly, it will not be possible to reach an economical cruise altitude. It will be assumed that for the cruise to alternate, a value for (L/D) of only 10 can be achieved. For Cj a value of only 0.9 will be used. Because the flight to alternate routes will probably be carried out at or below 10,000 ft, the cruise speed can be no more than 250 knots in accordance with FAA regulations.

Therefore, the Weight RatioW_8/W_7=0.992.

Phase 9: Landing, Taxi, Shutdown Begin weight is W_8. End weight is W_9.

The ratio W9/W8 is assumed to be 0.992.

The Overall mission fuel-fraction, M_{ff} can now be computed as:

$M_{ff}=$
$(W_8/W_7)*(W_7/W_6)*(W_6/W_5)*(W_5/W_4)*(W_4/W_3)*(W_3/W_2)*(W_2/W_1)*(W_1/ W_{TO})$

M_{ff} = 0.99 * 0.99* 0.995 * 0.98 * 0.709 * 0.628 * 0.99 * 0.992 *

M_{ff} = 0.418

Payload (W_{pl})

$$W_{pl}=13125 \text{ kg}$$

Crew

$$W_C=9600\text{kg}$$

Fuel weight (W_f)

$$W_f= (1-M_{ff})\, W_{TO}$$
$$= (1-0.77)100000$$
$$W_f = 40740\text{kg}$$

Empty weight

$$W_{E(tentative)} = W_{OE(tent)} - W_{TFO} - W_C$$
$$W_{OE(tent)} = W_{TO} - W_f - W_{pl}$$
$$W_E= 40000\text{kg}$$

From 6th iteration,
W_{TO} = 150000kg
W_{TFO} = 0.5% of W_{TO} = 750kg
W_f = 12000kg

Actual weight (W_{ac})

$$W_{ac} = inv\,log\left[\frac{log\,W_{TO} - A}{B}\right]$$
$$W_{ac}= 80340\text{kg}$$

$$\%\boldsymbol{Error} = \frac{W_{ac} - W_{Empty}}{W_{Empty}} \times 100 \quad \%\boldsymbol{Error} = 3.5\%$$

Result:

M_{ff}	*0.418*
W_f	40740*kg*
W_E	40000*kg*
W_{ac}	*50340kg*
Error %	*3.5%*

AEROFOIL AND WING SELECTION

1. Selection of Number of wings:

There are three types of wings that exist based on the number of wings of an aircraft.

- Monoplane,
- Biplane,
- Triplane

i. Monoplane:

A monoplane is a fixed-wing aircraft with a single main wing plane, in contrast to a biplane or other multiplane, each of which has multiple planes. A monoplane has inherently the highest efficiency and lowest drag of any wing configuration and is the simplest to build. The monoplane has been the most common form for a fixed-wing aircraft.

ii. Biplane:

A biplane is a fixed-wing aircraft with two main wings stacked one above the other. The Biplanes offer several advantages over conventional cantilever monoplane designs: they permit lighter wing structures, low wing loading and smaller span for a given wing area. However, interference between the airflow over each wing increases drag substantially, and biplanes generally need extensive bracing, which causes additional drag.

iii. Triplane:

A Triplane is a fixed-wing aircraft equipped with three vertical stacked wing planes. Tail planes and canard fore planes are not normally included in this count, although they may be occasionally. A Triplane arrangement has a narrower wing chord than a biplane of similar span and area.

Selected Type:

Monoplane. A monoplane is very efficient and less heavy than a biplane, especially when the aircraft has higher cruise speeds. The monoplane design eliminates lift induced drag and it also eliminates extra structural support mass needed to support an extra set of wings.

a. Wing support:

To support itself a wing has to be rigid and strong and consequently may be heavy. By adding external bracing, the weight can be greatly reduced. Two types of wing support are available: Cantilever and semi-cantilever.

i. Cantilever support:

Self-supporting, All the structure is buried under the aerodynamic skin, giving a clean appearance with low drag.

ii. Semi-Cantilever support:

Many high-wing airplanes have external braces, or wing struts, which transmit the flight and landing loads through the struts to the main fuselage structure. Since the wing struts are usually attached approximately halfway out on the wing, this type of wing structure is called a semi-cantilever.

Selected Type:

Cantilever. The wings of most naval aircraft are of all metal, full cantilever construction. The wing can be fastened to the fuselage without the use of external bracing, such as wires or struts. A complete wing assembly consists of the surface providing lift for the support of the aircraft.

a. Wing location:

The wing may be mounted at various positions relative to the fuselage:

- **Low wing:** mounted near or below the bottom of the fuselage.

- **Mid wing:** mounted approximately halfway up the fuselage.

- **Shoulder wing:** mounted on the upper part or "shoulder" of the fuselage, slightly below the top of the fuselage. A shoulder wing is sometimes considered a subtype of high wing.

- **High wing:** mounted on the upper fuselage. When contrasted to the shoulder wing, it applies to a wing mounted on a projection (such as the cabin roof) above the top of the main fuselage.

- **Parasol wing:** raised clear above the top of the fuselage, typically by carbon struts, pylon(s) or pedestal(s).

Selected Type:

Low Wing. A low wing enhances take-off performance of an aircraft. It lowers the drag of the aircraft as its low wing design has a lower cross-sectional area than a high wing design. Low wing design is also lighter as the wing need not to be as structurally reinforced as in a high wing design, struts are also eliminated. The landing gear can be housed inside the wing box 0allowing more cabin space which is essential for a light business jet. A low wing design also gives the aircraft a more premium look which customers of business jets expect.

b. Wing plan-form:

The wing plan-form is the silhouette of the wing when viewed from above or below.

i. Elliptical:

Leading and trailing edges are curved such that the chord length varies elliptically with respect to span. Theoretically the most efficient, but difficult to make. Famously used on the Super-marine Spitfire. (Note that in aerodynamics theory, the term "elliptical" describes the optimal lift distribution over a wing and not its shape).

1. Delta:

Triangular plan-form with swept leading edge and straight trailing edge. Offers the advantages of a swept wing, with good structural efficiency and low frontal area. Disadvantages are the low wing loading and high wetted area needed to obtain aerodynamic stability. Variants are:

1. **Tailless delta:** a classic high-speed design, used for example in the Dassault Mirage III series.

2. **Tailed delta:** adds a conventional tail plane, to improve handling. Used on the Mikoyan- Gurevich MiG-21.

3. **Cropped delta:** wing tips are cut off. This helps avoid tip drag at high angles of attack. The Fairey Delta 1 also had a tail. At the extreme, it merges into the "tapered swept" configuration.

4. **Compound delta or double delta:** Inner section has a (usually) steeper leading edge sweep as on the Saab Draken. This improves the lift at high angles of attack and delays or prevents stalling. By contrast, the Saab Viggen has an inner section of reduced sweep to avoid interference from its canard fore-plane.

5. **Ogival delta:** A smoothly blended "wineglass" double-curve encompassing the leading edges and tip of a cropped compound delta. Seen in tailless form on the Concorde supersonic transports.

1. Swept:

Wings may be swept back, or occasionally forwards, for a variety of reasons. A small degree of sweep is sometimes used to adjust the center of lift when the wing cannot be attached in the ideal position for some reason, such as a pilot's visibility from the cockpit. Other uses are described below.

1. **Straight:** extends at right angles to the line of flight. The most structurally-efficient wing, it has been common for low-speed designs since the very first days of the Wright Flyer.
2. **Swept back (aka "swept wing"):** The wing sweeps rearwards from the root to the tip. In early tailless examples, such as the Dunne aircraft, this allowed the outer wing section to act like a conventional empennage (tail) to provide aerodynamic stability. At transonic speeds swept wings have lower drag, but can handle badly in or near a stall and require high stiffness to avoid aeroelasticity at high speeds.
3. **Forward swept:** the wing angles forward from the root. Benefits are similar to backwards sweep; also it avoids the stall problems and has reduced tip losses allowing a smaller wing, but requires even greater stiffness to avoid aeroelastic flutter as on the Sukhoi Su-47.

ii. Tapper wings/Tapered Wings:

Not all wings are rectangular. Another way to reduce drag while increasing strength is with a trapezoid-shaped wing. Another name for this wing is a tapered wing. "To taper" means to make something gradually smaller at one end.

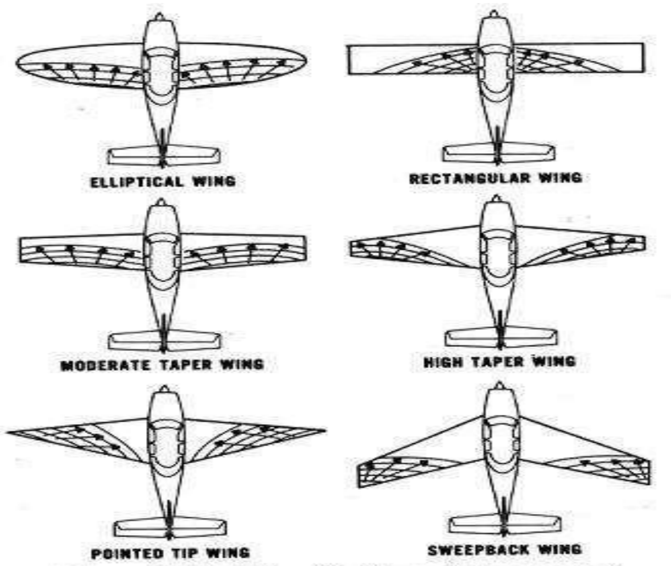


Figure 17–13 Wing Planforms (Exaggerated)

Selected Type:

Tapered Wing. The wing is tapered at the end to avoid creation of high vortices which causes drag and reduces the efficiency of the wing.

c. Selection of Angle:

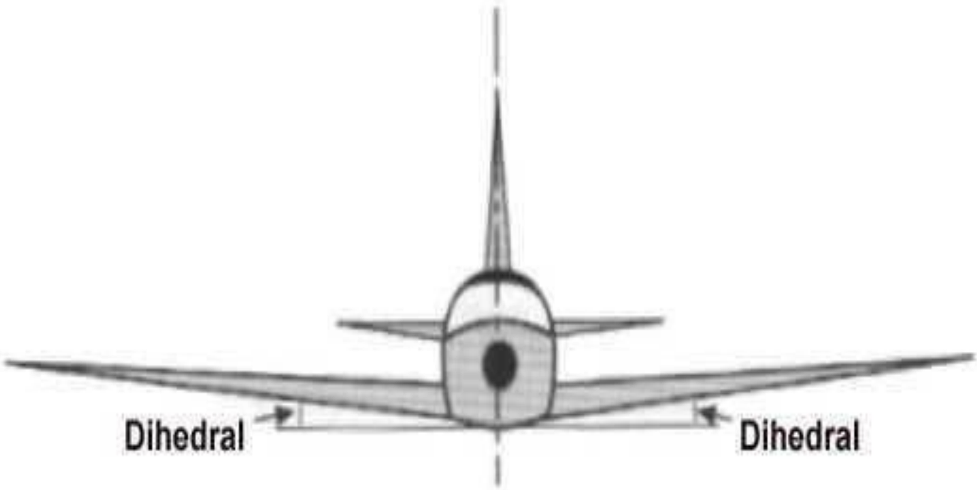
Angling the wings up or down spanwise from root to tip can help to resolve various design issues, such as stability and control in flight.

Dihedral: the tips are higher than the root as on the Santos-Dumont 14- bis, giving a shallow 'V' shape when seen from the front. Adds lateral stability.

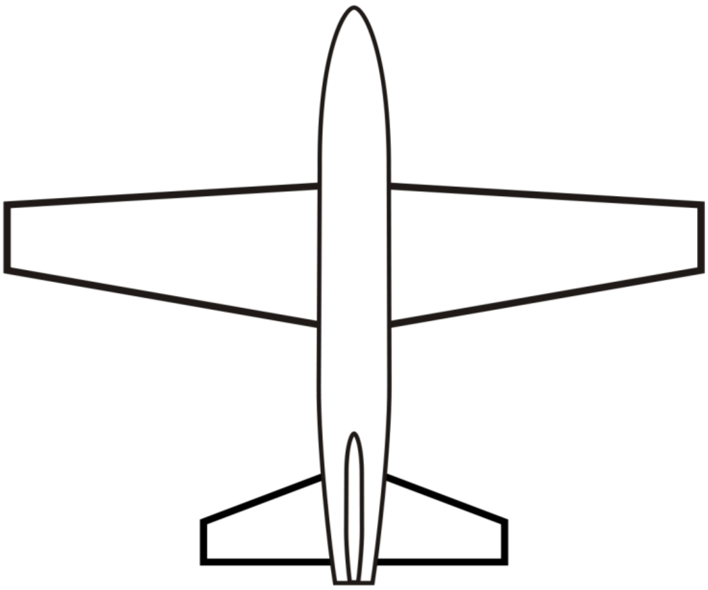
Anhedral: the tips are lower than the root, as on the first Wright Flyer; the opposite of dihedral. Used to reduce stability where some other feature results in too much stability.

Selected Type:

Dihedral. Dihedral improves lateral (roll) stability of the aircraft. The placement of wings at the lower side decreases the lateral stability to a small extent, this is to be compensated by dihedral and additional lateral stability is to be provided, as for a civil aviation aircraft stability is a desired feature.



Low Wing Dihedral Monoplane



Tapered Wing

Figure 7.1 Wing Configuration

d. Auxiliary Control Surfaces:

i. Chime:

In aircraft design, a chime is a longitudinal line of sharp change in the cross-section profile of the fuselage or similar body. The term chine originates in boatbuilding, where it applies to a sharp profile change in the hull of a boat. In a flying boat hull or float plane float, the longitudinal line of sharp change in cross- section where the bottom plane meets the sidewall is an example of a chime.

7.6.2 Canards:

A canard is an aeronautical arrangement wherein a small forewing or foreplane is placed forward of the main wing of a fixed-wing aircraft. Rather than use the conventional tail plane configuration found on most aircraft, an aircraft designer may adopt the canard configuration to reduce the main wing loading, to better control the main wing airflow, or to increase the aircraft’s maneuverability, especially at high angles of attack or during a stall.

ii. Levcons :

A levcon is a small extension to an aircraft wing surface, forward of the leading edge. The primary reason for adding an extension is to improve the airflow at high angles of attack and low airspeeds, to improve handling and delay the stall. A dog tooth can also improve airflow and reduce drag at higher speeds.

Selected Type:

Canard. The aircraft uses canards for pitch control. A lifting canard is used which distributes the load between the wing and canard. The canard helps in allowing the aircraft to have an apt center of gravity and the main advantage of the canard is its favorable stall recovery characteristics. The canard is of the same profile as the wing and is set at a slightly higher angle of incidence than the wing such that during onset of stall the canard shall drop the nose down and help in stall recovery. The canard is also more efficient than a conventional tail as it does not produce downward force.

Aspect Ratio:

For hang glider = 4 to 8
For sail plane= 20 to 40
For home or UAV= 4 to 7
For private business jet= 5 to 9
For low speed aircraft= 6 to 9
For high speed aircraft= 8 to 12
For supersonic aircraft = 2 to 5
For single engine utility 6 to 9

Reynolds Number:

$$Re = (\rho * v * l) / \mu$$

ρ = Density of air at max altitude = 0.3108 Kg/m^3

v = Cruising Velocity = 255 m/s

l = length of chord = 5.31 m

μ = Kinematic viscosity of air = $4.57*10^{-5}$ m^2 /s

$$Re = (239 * 40) / (5.57*10^{-5})$$

$$Re = 17.1 *10^7$$

Wing Area(S):

S = 150 m^2(From the graph)

Aspect Ratio A.R:

$AR = b^2 / S$

$$AR = (32.5 * 32.5) / 150$$

$$AR = 7.04$$

7.8.1 Chord Length c:

$$AR = b / c$$

$$c = b / AR$$

$$c=32.5/7.04$$

$$c = 4.616 \text{ m}$$

Root Chord C_{root}:

C_{root} = c = 4.616m

Tip Chord C_{tip}:

$\lambda = C_{tip} / C_{root}$

For the Tapered Wing,

$\lambda = 0.4$

$C_{tip} = 0.4 * 4.616$

$C_{tip} = 1.154$ m

Mean Aerodynamic Chord MAC(ĉ):

$\hat{c} = [\{(2/3)*C_r * (1+\lambda+\lambda^2)/(1+\lambda)\}]C_{root}$

$\hat{c} = 4.846$ m

Structural Weight Volume:

$= W_F / \rho_F$

=8.216 m3

Chord Thickness Ratio(t/c):

20% of wt. volume = $(t/c) * \hat{c} * (0.5 * C_r) * (0.5 * b) * 2$

t/c = (0.2*8.216*2)/(4.846*4.616*32.5*0.75)

(t/c) = 0.0371

Root Thickness t_r:

$t_r = (t/c) * C_{root}$

$t_r = 0.0371 * 4.616$

$t_r = 0.171$ m

Tip Thickness t_t:

$t_t = (t/c) * C_{tip}$

$t_t = 0.0371 * 1.154$

$t_t = 0.04$ m

Wing Lift Coefficient C_L:

$C_L = [(2*W_{TO}*g)/(\rho*v^2_{cruise}*S)]$

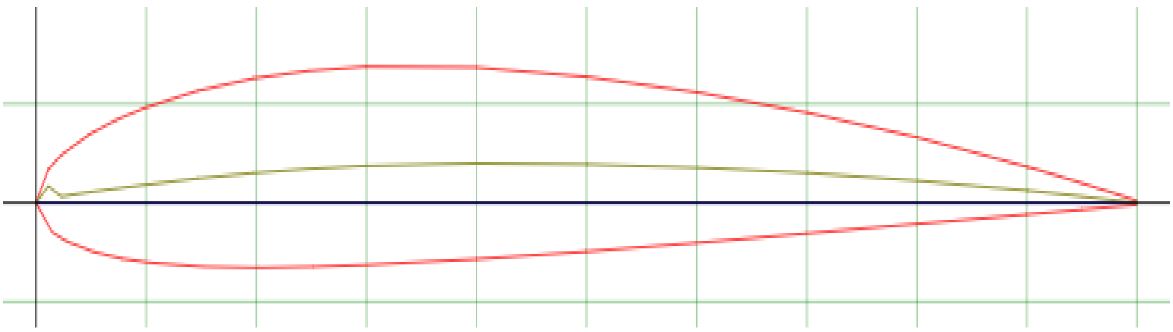
$C_L=$

[(2*11350*9.81)/(1.225*239^2*150]

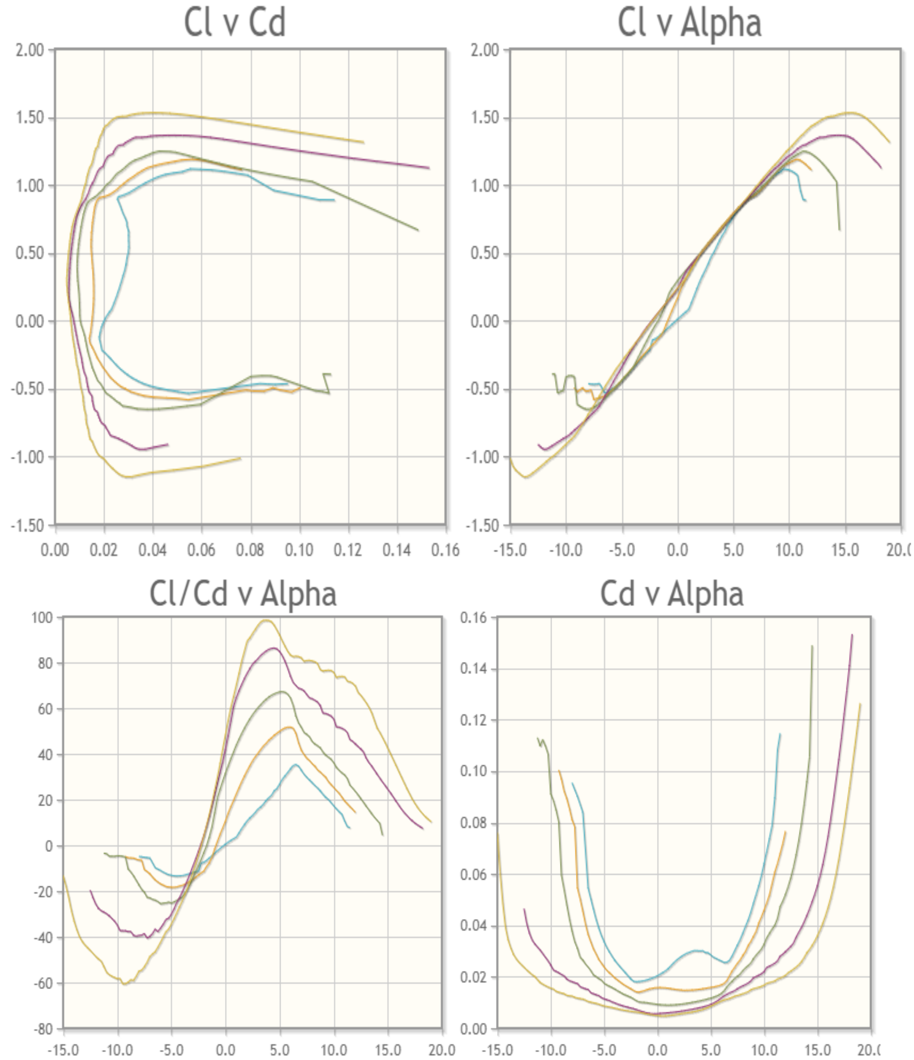
$C_L = 0.0206$

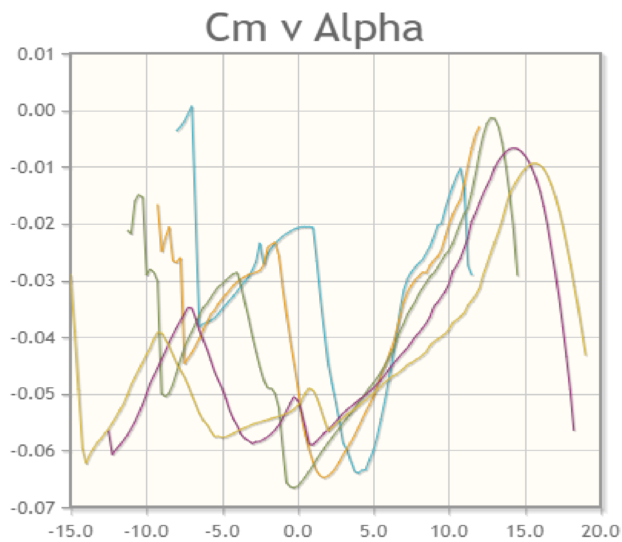
AIRFOIL SELECTION:

The airfoil selected according to the calculations is **NACA 2418**



Performance Curves:





Cruise speed	239m/s
Wing area(s)	150m^2
Aspect Ratio (AR)	7.205
Wing span(b)	32.5m
Taper Ratio (Λ)	0.4
Root chord (C_{root})	4.857m
Tip chord (C_{tip})	1.943m
Mean chord (C_{mean})	3.403m
Design C_L	0.168

Table 3.1 Typical Values For Maximum Lift Coefficient

Airplane Type	$C_{L_{max}}$	$C_{L_{max_{TO}}}$	$C_{L_{max_L}}$
1. Homebuilts	1.2 - 1.8	1.2 - 1.8	1.2 - 2.0*
2. Single Engine Propeller Driven	1.3 - 1.9	1.3 - 1.9	1.6 - 2.3
3. Twin Engine Propeller Driven	1.2 - 1.8	1.4 - 2.0	1.6 - 2.5
4. Agricultural	1.3 - 1.9	1.3 - 1.9	1.3 - 1.9
5. Business Jets	1.4 - 1.8	1.6 - 2.2	1.6 - 2.6
6. Regional TBP	1.5 - 1.9	1.7 - 2.1	1.9 - 3.3
7. Transport Jets	1.2 - 1.8	1.6 - 2.2	1.8 - 2.8
8. Military Trainers	1.2 - 1.8	1.4 - 2.0	1.6 - 2.2
9. Fighters	1.2 - 1.8	1.4 - 2.0	1.6 - 2.6
10. Mil. Patrol, Bomb and Transports	1.2 - 1.8	1.6 - 2.2	1.8 - 3.0
11. Flying Boats, Amphibious and Float Airplanes	1.2 - 1.8	1.6 - 2.2	1.8 - 3.4
12. Supersonic Cruise Airplanes	1.2 - 1.8	1.6 - 2.0	1.8 - 2.2

* The Rutan Varieze reaches 2.5, based on stall speed data from Ref.9.

Notes: 1. The data in this table reflect existing (1984) flap design practice.
2. Considerably higher values for maximum lift coefficient are possible with more sophisticated flap designs and/or with some form of circulation control.
3. Methods for computing $C_{L_{max}}$ values are contained in Ref.6.

Selection of High lift devices:

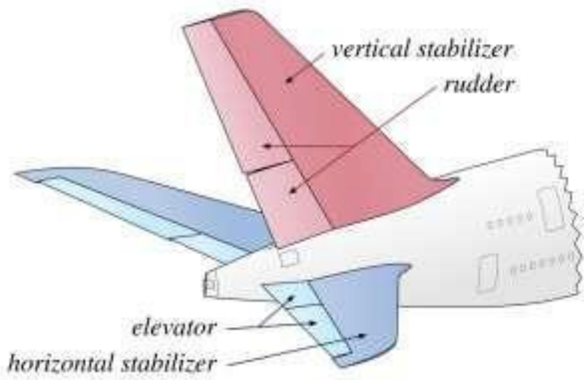
Flaps - single slotted, Slats Reason: Addition of slats and flaps to the wing increases the performance of the wing. Deployment of slats and flaps decreases the stalling speed of aircraft by a significant margin. The lift coefficient is increased by as much as 80 percent. This transforms to lower takeoff and landing speed. These devices enhance the lower speed performance of the wing.

CHAPTER 08

TAIL PLANE SELECTION

1. **Conventional-Tail:**

The conventional tail design is the most common form. It has one vertical stabilizer placed at the tapered tail section of the fuselage and one horizontal stabilizer divided into two parts, one on each side of the vertical stabilizer. For many airplanes, the conventional arrangement provides adequate stability and control with the lowest structural weight. About three-quarters of the airplanes in operation today, including the Airbus A300, the Boeing 777 and 747, and the Beech Bonanza A-36, use this arrangement.

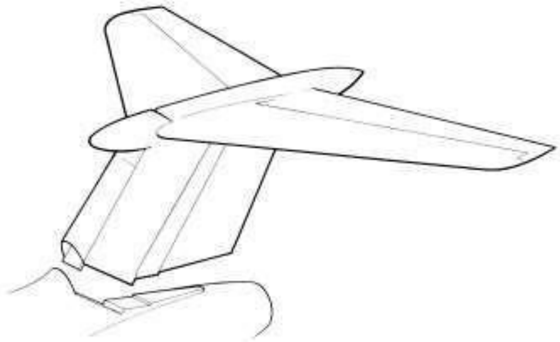


1. **Cruciform-Tail:**

The horizontal stabilizers are placed midway up the vertical stabilizer, giving the appearance of a cross when viewed from the front. Cruciform tails are often used to keep the horizontal stabilizers out of the engine wake, while avoiding many of the disadvantages of a T-tail. Examples include the Hawker Sea Hawk and Douglas A-4 Skyhawk.

1. **T-tail:**

The horizontal stabilizer is mounted on top of the fin, creating a "T" shape when viewed from the front. T-tails keep the stabilizers out of the engine wake, and give better pitch control. T-tails have a good glide ratio, and are more efficient on low speed aircraft. However, T-tails are more likely to enter a deep stall, and are more difficult to recover from a spin. T-tails must be stronger, and therefore heavier than conventional tails. T-tails also have a larger radar cross section.



1. **V-Tail:**

The V-Tail, sometimes called the “butterfly” tail, has had limited application in airplane design, the most significant of which has been by the Beech Company in the Beech-craft Bonanza V35. Clearly, the usual definition of horizontal and vertical stabilizers has no application to the V tail. The intended advantage of the V-tail design is that two surfaces might serve the same function as the three required in the conventional tail and its variants. Removal of one surface then would reduce the drag of the tail surfaces as well as the weight of the tail region.

1. **Triple-Tail:**

The triple-tail design, with two vertical stabilizers placed at the ends of the horizontal stabilizers and one mounted on the fuselage, is attractive when the height

of the vertical stabilizer must meet certain restrictions, such as hangar-door height. Certainly, this was the important consideration in the design of the Lockheed Constellation, one of the most significant passenger airplanes of the late 1940′s. Another well-known example of the triple-tail design is the Grumman E-2 Hawkeye.

1. **Twin boom:**

A twin-boom aircraft is characterized by two longitudinal booms (extended nacelle-like bodies) fixed to its main wing on either side of its centre line. The booms may contain ancillary items such as fuel tanks and/or provide a supporting structure for external ancillary items. Typically, twin tail booms provide mounting points for one or more tail surfaces, although on some types such as the Rutan Model 72 Grizzly the booms run forward of the main wing.

1. **H-Tail:**

The vertical tail end-plate effect improves the aerodynamic performance of the horizontal tail. The H-tail allows the twin vertical tail span to be shorter. The aircraft ―Lockheed constellation‖ had to employ an H-tail configuration to be able to park inside short height hangars.

1. **Tailless:**

A tailless aircraft has no tail assembly and no other horizontal surface besides its main wing. The aerodynamic control and stabilization functions in both pitch and roll are incorporated into the main wing. A tailless type may still have a conventional vertical fin (vertical stabilizer) and rudder. Theoretical advantages of the tailless configuration include low parasitic drag as on the Horten H.IV soaring glider and good stealth characteristics as on the Northrop B-2 Spirit bomber.

1. Y-Tail:

Keeps the prop off the ground and the propwash from interfering with the optics. The outer ends of the horizontal stabilizers are lower than the ends attached to the fuselage.

Selected Type:

T-tail. Since T-tails keep the stabilizers out of the engine wake, and give better pitch control. T-tails have a good glide ratio, and are more efficient on low speed aircrafts.

Fig 8.1: Aircraft With T-tail Configuration

CHAPTER 9
LANDING GEAR SELECTION

1. Types

1. Fixed

Landing gear employing a rear-mounted wheel is called a fixed landing gear. Fixed gear is designed to simplify design and operation. The advantages are that it is always deployed and its initial installment cost is low. Whereas its disadvantage is that it produces constant drag.

1. Retractable

A retractable gear is designed to streamline the airplane by allowing the landing gear to be stowed inside the structure during cruising flight. The primary benefits of being able to retract the landing gear are increased climb performance and higher cruise airspeeds due to the resulting decrease in drag. Retractable landing gear systems may be operated either hydraulically or electrically, or may employ a combination of the two systems. Warning indicators are provided in the cockpit to show the pilot when the wheels are down and locked and when they are up and locked or if they are in intermediate positions. Systems for emergency operation are also provided.

Selected Type:

Retractable. The retractability adds to the overall efficiency of the aircraft. The retractable gear produces lower drag than fixed ones and also permits aircraft to cruise at high speeds.

1. Landing Gear Configuration

1. Single wheel landing Gear

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

1. Bicycle

A relatively uncommon landing gear option is the bicycle undercarriage. Bicycle gear features two main gears along the centreline of the aircraft, one forward and one aft of the centre of gravity. Preventing the plane from tilting over sideways are two small outrigger gears mounted along the wing.

1. **Tricycle**

The most commonly used landing gear arrangement is the tricycle-type landing gear. It is composed of main gear and nose gear. Tricycle-type landing gear is used on large and small aircraft. It allows more forceful application of the brakes without nosing over when braking, which enables higher landing speeds.

1. **Quadricycle**

Quadricycle gears are also very similar to the bicycle arrangement except there are four main gears roughly equal in size and mounted along the fuselage. Like bicycle gear, the quadricycle undercarriage also requires a very flat attitude during take-off and landing. This arrangement is also very sensitive to roll, crosswinds, and proper alignment with the runway. The most significant advantage of quadricycle gear is that the plane's floor can be very close to the ground for easier loading and unloading of cargo. However, this benefit comes at the price of much higher weight and drag than bicycle gear.

1. **Multi-bogey**

A final variation that is worth mentioning is the use of multiple wheels per landing gear strut. It is especially common to place two wheels on the nose strut of the tricycle arrangement to provide safety and steering control in case of a tire blowout. This additional tire is particularly useful on carrier-based aircraft where two nosewheels are a requirement. Multiple wheels are also often used on main gear units for added safety, especially on commercial airliners.

Selected type:

Tricycle. The Tricycle landing gear gives the aircraft more stability than a unicycle or bicycle landing gear and it is also more comfortable for occupants than taildraggers. The tricycle is such that the main landing gear takes almost most of the force of landing. This configuration is also less complex and cheaper than fixed ones and also permits aircraft to cruise at higher speeds.

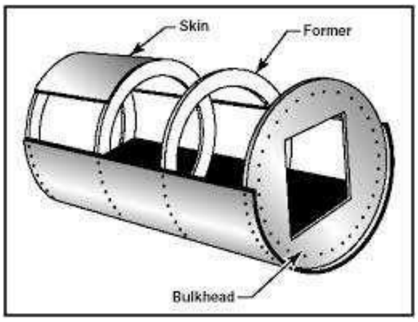
Fig 9.1: Retractable Tricycle Landing Gear

CHAPTER 10
FUSELAGE SELECTION

1. Construction Type:

1. Monocoque

The Monocoque (single shell) fuselage relies largely on the strength of the skin or covering to carry the primary loads. Monocoque construction uses stressed skin to support almost all loads much like an aluminum beverage can. Because most twisting and bending stresses are carried by the external skin rather than by an open framework, the need for internal bracing was eliminated or reduced, saving weight and maximizing space.

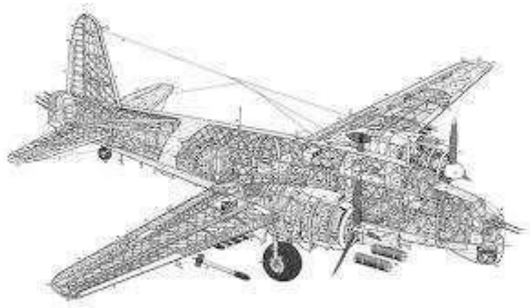


1. Semi-Monocoque

To overcome the strength/weight problem of Monocoque construction, a modification called semi Monocoque construction was developed. It also consists of frame assemblies, bulkheads, and formers as used in the Monocoque design but, additionally, the skin is reinforced by longitudinal members called longerons. They usually extend across several frame members and help the skin support primary bending loads. Stringers are also used in the semi-monocoque fuselage. These longitudinal members are typically more numerous and lighter in weight than the longerons.

1. Geodesic Truss Construction

Geodesic airframe is a type of construction for the airframes of aircraft developed by British aeronautical engineer Barnes Wallis in the 1930s. It makes use of a space frame formed from a spirally crossing basket-weave of load-bearing members. The principle is that two geodesic arcs can be drawn to intersect on the fuselage in a manner that the torsional load on each cancels out that on the other.



Selected type:

Semi-Monocoque Structure. Semi-Monocoque structure offers a higher strength to weight ratio than other forms of aircraft structure. It distributes the load between the skin and the structure; it is lighter than the Monocoque aircraft structure and it is the most preferred aircraft structure.

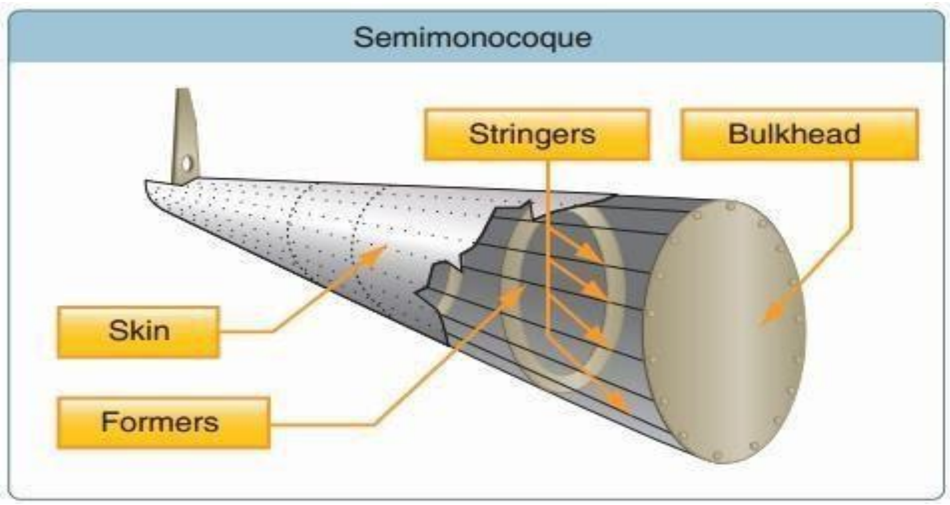


Figure 10.1 Semi-Monocoque Fuselage structure

1. Length of Fuselage:

Length of Fuselage = 16 m

Justification: The fuselage dimensions and shapes of different aircraft that are similar in design to that of the aircraft and study is analyzed and the tentative fuselage dimensions of the aircraft are arrived at. The fuselage dimension is such that it is comfortable to accompany 10 passengers with 3 crew members with a lot of legroom and storage. The dimension is also finalized such that the fuselage is able to carry sufficient fuel and other mission essentials.

CHAPTER 11

ENGINE SELECTION

1. Types of Engine:

1. Reciprocating

The reciprocating engine, also often known as a piston engine, is typically a heat engine (although there are also pneumatic and hydraulic reciprocating engines) that uses one or more reciprocating pistons to convert pressure into a rotating motion.

1. Turbofan

Turbofan engines, which power the majority of Turbofan commercial aircraft, are turbine engines that have been fitted with a powerful front-end fan. The fan sends air into the combustor, similar to a turbojet engine. However, the fan also sends a second stream of air through a larger cylinder entirely outside (and around) the engine core. This second stream of air provides additional thrust, cools the engine, and also serves to reduce engine noise. Turbofans are interchangeably referred to as bypass engines, in reference to this airflow that bypasses the combustor.

1. Turbojet

Turbojets are jet engines that depend exclusively on Turbojet, the thrust of jet exhaust expelled by the engine for propulsion. Turbojet engines are extraordinarily powerful and only efficient at extremely high speeds. As such, they are more likely to be found in a missile, although the now defunct Concorde jet is an example of a turbojet powered commercial aircraft.

1. Turboprop

Like turbojet and turbofan engines, Turboprop engines rely on a gas turbine for power. However, in the case of a turboprop aircraft, the turbine drives a rotating shaft, which in turn drives a reduction gear, which ultimately drives a propeller. The reduction gear is necessary to convert the high-speed shaft rotation into slower, functional propeller speed. Most of the power generated in a turboprop aircraft is used to drive the propeller.

1. Ramjet

The Ramjet uses the open Brayton cycle. No rotating machinery is used and compression is achieved by the intake and diffuser. As such they require speed to compress air enough that good efficiency can be achieved. Ramjets are inefficient at subsonic speeds and their efficiency improves at supersonic speeds.

1. **Scramjet**

The scramjet ("supersonic combustion ramjet") is a variant of a ramjet air-breathing jet engine in which combustion takes place in supersonic airflow. As in ramjets, a scramjet relies on high vehicle speed to compress the incoming air forcefully before combustion (hence ramjet), but whereas a ramjet decelerates the air to subsonic velocities before combustion, the airflow in a scramjet is supersonic throughout the entire engine. That allows the scramjet to operate efficiently at extremely high speeds

1. **Pulsejet**

A pulsejet engine (or pulse jet) is a type of jet engine in which combustion occurs in pulses. A pulsejet engine can be made with few or no moving parts and is capable of running statically (i.e. it does not need to have air forced into its inlet typically by forward motion). Pulsejet engines are a lightweight form of jet propulsion, but usually have a poor compression ratio, and hence give a low specific impulse.

1. **Turboshaft**

A turboshaft engine is a form of gas turbine that is optimized to produce shaft power rather than jet thrust. In concept, turboshaft engines are very similar to turbojets, with additional turbine expansion to extract heat energy from the exhaust and convert it into output shaft power.

Selected Type:

Turbofan. Turbofan engines are the most efficient aircraft engines for high subsonic speeds. They are fuel efficient and have lower emission than other types of jet engines. They also have less acoustic signature, well within the current airport standards.

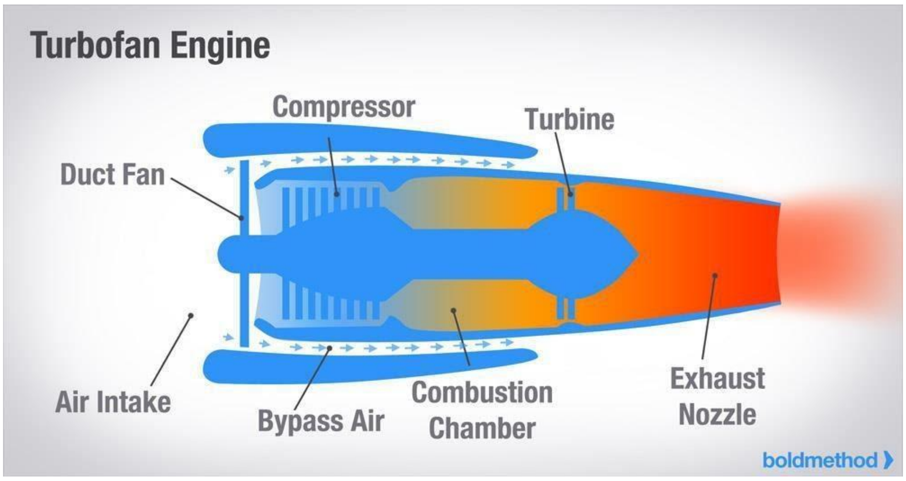


Figure 11.1 Turbofan Engine

1. **Location of Engine:**

1. **Nose mounted**

These engines are mounted to face the local flow of air, and the local airflow at the airplane's tail is typically descending with respect to the centreline of the aircraft's fuselage.

2.**WING MOUNTED BELOW THE WING:**

A podded engine is a jet engine in a pod, typically attached below the wing or to the tail of the aircraft. The pod itself is called a nacelle. Placing engines on the wing provides beneficial wing bending relief in flight. The further the engines are away from the fuselage the greater the wing bending relief so engines buried in the wing root provide little relief. Almost all modern large jet airplanes use engines in pods located a significant distance from the wing root for substantial wing bending relief. The pods are in front of the wing to help avoid flutter of the wing which, in turn, allows a much lighter wing structure.

Above the wing

Unusual designs that deviate from the norm are the VFW-614, Hondajet and the Softex Aero V24L, which place the podded engines clear above the wings to maximize the distance between ground and engine and therefore minimize the likelihood of foreign object damage. The Antonov An-72 and the Boeing YC-14 also place their engines above the wings, but very close 56 to the wing. This placement utilizes the Coandă effect allowing a lower minimum flight speed and decreasing the amount of runway needed for take-off and landing.

Close to Fuselage

Helps to prevent debris from entering the engine, allows for more room for flaps on the wing, and lighter, more aerodynamic wings since they are not holding up engines, generally allowing for slower approach speeds, also the thrust is closer to the center of the aircraft. Fuel lines near the back of the aircraft have to be a T-tail, as well as reinforced. And center of gravity issues.

Center of the Wing

Well centered with the center of gravity, allows for more weight shifting in the cabin, and with the bags. The fuel is also kept away from the cabin, and the noise is better spread out through the cabin. In the event that something goes wrong, debris is also less likely to enter the cabin. Much easier to get debris swept into the engine, wings have to be reinforced, lose some area for flaps and slats, raising approach speed.

1. **Tail mounted**

Aft-mounted engines require that the horizontal stabilizer be above the engines, usually resulting in a T-tail. There are some handling considerations with T- tail airplanes during stalls that must be addressed. Aft-mounted engines put a significant amount of weight aft, causing weight and balance considerations. Under- wing engines are near the center of lift of the wing.

1. **Engine mounted**

An engine mounting configuration ensures the transmission of loads between the engine and the aircraft structure. The loads typically include the weight of the engine, thrust, aerodynamic side loads, and rotary torque about the engine axis. The engine mount configuration must also absorb the deformations to which the engine is subjected during different flight phases and the dimensional variations due to thermal expansion and retraction.

Selected Type: Engine Mounted. The twin turbofan engine is mounted at the rear of the aircraft and is buried inside the fuselage. This eliminates the need for a wing pylon or other external engine mounting fitting or extensions. This in turn reduces cross sections of the aircraft and also reduces the drag. The inline engine mounting also eliminates the need to have a nonzero thrust angle which prevents loss of power due to engine thrust angle offset.

1. **Number of Engines:**

Twin Engine

ENGINE SELECTION

ENGINE THRUST REQUIRED:

T = {Total Thrust (from graph) +10% of Total

Thrust}/No. of Engines

T = (90+90*10/100)/2

T = 105 KN per engine

Total Thrust = 105 * 2 = 210 KN

POWER TO WEIGHT RATIO:

P/W=(T*Vcruise)/Wo in newton

=(210*1000*239)/(11356*9.81)

=451

S.no	Engine Name	Maximum Thrust (kN)	Length (m)	Diameter (m)	Weight (kg)
1.	**CFM International LEAP (1B25)**	130	3.147	2.256	2780
2.	**IAE V2500 (V25 27E-A5)**	110	3.2	2.2	2404

Result:

IAE V2500 Engines mounted on the wing with submerged or pylon support.It is turbo fan engine

V2500

The V2500-A5/D5/E5 has 1 fan; 4 LP and 10 HP compressor stages; 2 HP and 5 LP turbine stages

Type	Turbofan
Manufacturer	International Aero Engines

LEAP

Mockup of a LEAP-X, the early code name of the engine

Type	Turbofan
Manufacturer	CFM International

LIFT AND DRAG CALCULATIONS

$$L = 1/2 \times \rho \times v^2 \times S \times c_L max$$
$$D = 1/2 \times \rho \times v^2 \times S \times c_D max$$

Where,
L = lift at that altitude N.
D = Drag at that altitude N.
ρ= Density at that altitude kg/m3.
V = Velocity at different phases m/s.
S = Surface area of the wing m2.
CL = Coefficient of lift.
CD = Coefficient of drag.

Take-off, lift and drag

$$L = 1/2 \times \rho \times v^2 \times S \times C_L max$$

Density = 1.225kg/m^3
C_{Lmax} = 1.5
$V_{take\text{-}off}$ = 50.81 m/s
L = 450.6 kN

$C_D = C_{Do} + C_{Di}$

$C_{Di} = \frac{C_L^2}{\pi e AR}$

C_{Di} = 0.056

$$C_{Do} = C_{fe} \frac{S_{wet}}{S_{ref}}$$
$$C_{fe} = \frac{0.664}{\sqrt{Re_{sea\ level}}}$$

Where,
V = Velocity at take-off = 50.81 m/s
L = max chord = 5.31m
ν = kinematic viscosity at sea level = 1.46×10^{-5}m^2/s

$Re_{sea\ level} = \frac{V \times l}{\nu}$ = 2.92×10^7

$C_{fe} = 1.23 \times 10^{-4}$

$\frac{S_{wet}}{S_{ref}} = \left[1 + 0.2\frac{t}{c_{mean}}\right]$ = 1.00632

$C_{Do} = 1.02 \times 10^{-4}$

$C_D = C_{Do} + C_{Di}$
C_D = 0.095

$$D = 1/2 \times \rho \times v^2 \times S \times c_D max$$

D = 29.9 kN

Landing, lift and drag

$$L = 1/2 \times \rho \times v^2 \times S \times c_L max$$

Density = 1.225kg/m^3

C_{Lmax}= 2.3

$V_{landing}$ = 57 m/s

L = 355.9 kN

$C_D = C_{Do} + C_{Di}$

C_{Di} = 0.095

$$C_{Do} = C_{fe} \frac{S_{wet}}{S_{ref}}$$

$$C_{fe} = \frac{0.664}{\sqrt{Re_{sea\ level}}}$$

Where,

V = Velocity at landing = 80.681m/s

L = max chord = 5.31m

v = kinematic viscosity at sea level = 1.461×10^{-5}m^2/s

$Re_{sea\ level} = \frac{V \times l}{v}$ = 3.59 × 10^7

C_{fe}= 1.108×10^{-4}

C_{Do}= 1.02×10^{-4}

C_D = 0.296

$$D = 1/2 \times \rho \times v^2 \times S \times c_D max$$

D = 45.86 kN

Cruise, lift and drag

$$L = 1/2 \times \rho \times v^2 \times S \times c_L max$$

Density = 0.122 kg/m^3

C_{Lmax}= 1.3

$V_{landing}$ = 239 m/s

L = 679.45 kN

$C_D = C_{Do} + C_{Di}$

C_{Di} = 0.14

$$C_{Do} = C_{fe} \frac{S_{wet}}{S_{ref}}$$

$$C_{fe} = \frac{0.664}{\sqrt{Re_{sea\ level}}}$$

Where,

V = Velocity at cruise = 239 m/s

L = max chord = 5.31m

v = kinematic viscosity at 6,000m = 2.416×10^{-5} m^2/s

$Re_{at\ 6000m} = \frac{V\times l}{v}$ = 9.02×10^6

C_{fe}= 2.21×10^{-4}

C_{Do}= 1.02×10^{-4}

C_D = 0.094

$$D = 1/2 \times \rho \times v^2 \times S \times c_D max$$

D = 49.5 kN

Final lift and drag values

Phases	Lift (kN)	Drag (kN)
Take-off	**450.6**	**29.9**
Cruise	**679.45**	**49.5**
Landing	**355.9**	**45.86**

CHAPTER 13

PERFORMANCE CALCULATIONS

Take-off Performance:

Lift-off Distance:

S_{LO}=[(1.21 *WTO) / (g* ρ*s*$C_{L\ max}$* (T/W))]

Max. Take-off Weight WTO = 70000 kg

Acceleration Due to Gravity g = 9.81m/s^2

Density at Sea Level ρ= 1.225kg/m^3

Coefficient of Lift CL max= 1.5

Thrust to Weight Ratio (T/W) = 0.99

Wing Area(S) =150m^2

S_{LO}=[(1.21 * 100000)/ (9.81 *1.225 *150 * 1.5* 0.99)]

S_{LO}= 1004.7 m

Climb Performance:

Thrust Required T_r:

$T_r = D_r = 1/2 * \rho * v^2 * s*(C_{D0}+KC_l\text{^}2_{max})$

$=1/2*0.122*(239*239)*150[0.095]$

$T_r = 49.68$ kN

Power Required P_r:

$P_r = T_r * v$

$P_r = 49.68*10^3*239$

$P_r = 1.2*10^7$ W

Thrust Available T_a:

$T_a = [T_r/(P/\rho)(1+0.7M]$

$T_a = [49.68*10^3/ (0.32079/0.122)(1+0.7*0.7727)$

$T_a = 7456.9$ N

Power Available P_a:

$P_a = W*V\sin 15^o + P_r$

$P_a = 70000 * 239 + 1.2*10^7$

$P_a = 1.57*10^7$ W

Rate of Climb R/C:

R/C=[(Pa –Pr)/W]

R/C= [(**$1.57*10^7$ -$1.2*10^7$**) / 70000]

R/C= 52.85 m/s

$V(R/C)_{max}$:

$$V(R/C)\ max=[\{(2*(W/S)/\rho)*(1/(3*\pi*e*AR*CD0))^{1/2}\}^{(1/2)}]$$

$$\mathbf{V(R/C)_{max} = 319.9\ m/s}$$

$V_{\theta max}$:

$$V_{\theta max}=[\{(2*(W/S)/\rho)*(1/(\pi*e*AR*CD0))^{(1/2)}\}^{(1/2)}]*\cos\theta\ max$$

Oswald's Efficiency e = 0.8 kg/m^2

$\rho = 1.225\ kg/m^3$

$\theta_{max} = 13.47^o$

$V_{\theta\ max}$= 311.1 m/s

Gliding Performance:

Rate of Sink(R/S):

$$R/S=[(2*W/\rho)^{1/2}*(CD/CL)^{3/2}]$$

$$CD=[\{CD0+(\phi CLmax^2)/(\pi e(AR))\}]$$

CD= 0.095

CL = 1.8

$\rho = 1.225\ kg/m^3$

W =70000 kg

R/S=[(2*70000/1.225)1/2*(0.095/1.8)3/2]

R/S = 20.9 m/s

$V(R/S)_{min}$:

$$V(R/S)_{min}= [\{(2 * (W/S)) / (\rho * CL (R/S)_{min})\}^{1/2}]$$

$$CL_{\theta min}= [\pi* e *AR* CD0]^{1/2}$$

$CL_{\theta min}$= 0.043

$CL\ (R/S)_{min}$ = 3^1/2 * $CL_{\theta\ min}$

$CL\ (R/S)_{min}$ = 3^1/2 * 6.9277

$$CL\ (R/S)_{min} = 0.0744$$

$$V(R/S)_{min}=[\{(2*(W/S))/(\rho*CL(R/S)_{min})\}1/2]$$

$$\mathbf{V(R/S)_{min}= 216.9\ m/s}$$

$V_{r\ min}$:

$$V_{rmin}= [\{(2*(W/S))/ (\rho*C_{Lmax})\}^{1/2}]$$

$$\rho = 1.225 kg/m^3$$

$$C_{Lmax}= 1.6$$

$$\mathbf{V_{r\ min} =68.35\ m/s}$$

$V_{\theta\ min}$:

$$V_{\theta min}=[\{(2 *(W/S))/ (\rho* CL_{\theta min})\}^{1/2}]$$

$$\rho = 1.225 kg/m^3$$

$$CL_{\theta\ min}= 0.043$$

$$V_{\theta min}=[\{(13080)/ (1.225*0.047)\}1/2$$

$$\mathbf{V_{\theta min}= 131.84\ m/s}$$

Landing Performance:

Landing Distance S_L:

$$S_L= [\{(1.69* W^2)/(g * \rho* S * CL_{max}* (D+ \mu r\ (W -L)))\}]$$

$$W= 70000\ kg$$

$$CL_{\ max}= 2.3$$

$$\rho = 1.225 kg/m^3$$

$$S = 150 m^2$$

$$\mu r= 0.4$$

$$S_L= [\{(1.69*(536607) \text{^}2)/ (9.81*1.225*150*1.8*(206.926+0.4(536607–711.957)))\}]$$

$$\mathbf{S_L= 1851.6\ m}$$

CHAPTER 14
V-n DIAGRAM

Table14.1 Load factor for various aircrafts

Aircrafts	Max +ve load factor	Max –ve load factor
Home-made	2.5 to 3.8	-1to -1.5
Business Jet	4.4	-1.8
Aerobatic	6	-3
Commercial	3 to 4	-1to -2
High maneuver aircraft	6.5 to 12	-3to -0.6
Bomber	2 to 4	-1to -2

Load factors:

- The positive(+ve) Maximum load factor for Commercial aircraft is **+3**
- The negative (-ve)Maximum load factor for Commercial aircraft is **-1.5**

Maximum velocities

when n=1:

$$\textbf{(+ve)Vmax}=\sqrt{(2wg)}/(\rho S Cl)$$

Where,

W =WTO = 1500 kg =9.81

ρ = Density at sea level =1.225 kg/m^3

S=Wing area=150 m^2

Cl_{max}= 2.3

Vmax={(2*70000*9.81)/(1.225*150*1.8)}^1/2

(+ve)Vmax= 57 m/s

Corner velocities:

$$\textit{(+ve)}V^*=\sqrt{(2wgnmax)}\ /(\rho SClmax)$$

Where,

$n_{max}=+3$

W =WTO = 70000kg

g =9.81m/s

ρ = Density at sea level = 1.225 kg/m^3

$Cl_{max}= 2.3$

$(+ve)V^{*}=\sqrt{((2*70000*9.81*3))/(1.225*150*1.8)}$

(+ve)V= 114 m/s

(-ve)Vmax=$\sqrt{(2wg(-nmax))/\rho S(-Clmax)}$

Where,

$-n_{max}=1.5$

W =WTO = 70000kg

g =9.81m/s

ρ = Density at sea level = 1.225 kg/m^3

S=Wing area= 150 m^2

$^{-}Cl_{max}= 2.3$

$(-ve)V=\sqrt{((2)*70000*9.81*1.5)/(1.225*150*2.3)}$

(-ve)V= 80.62 m/s

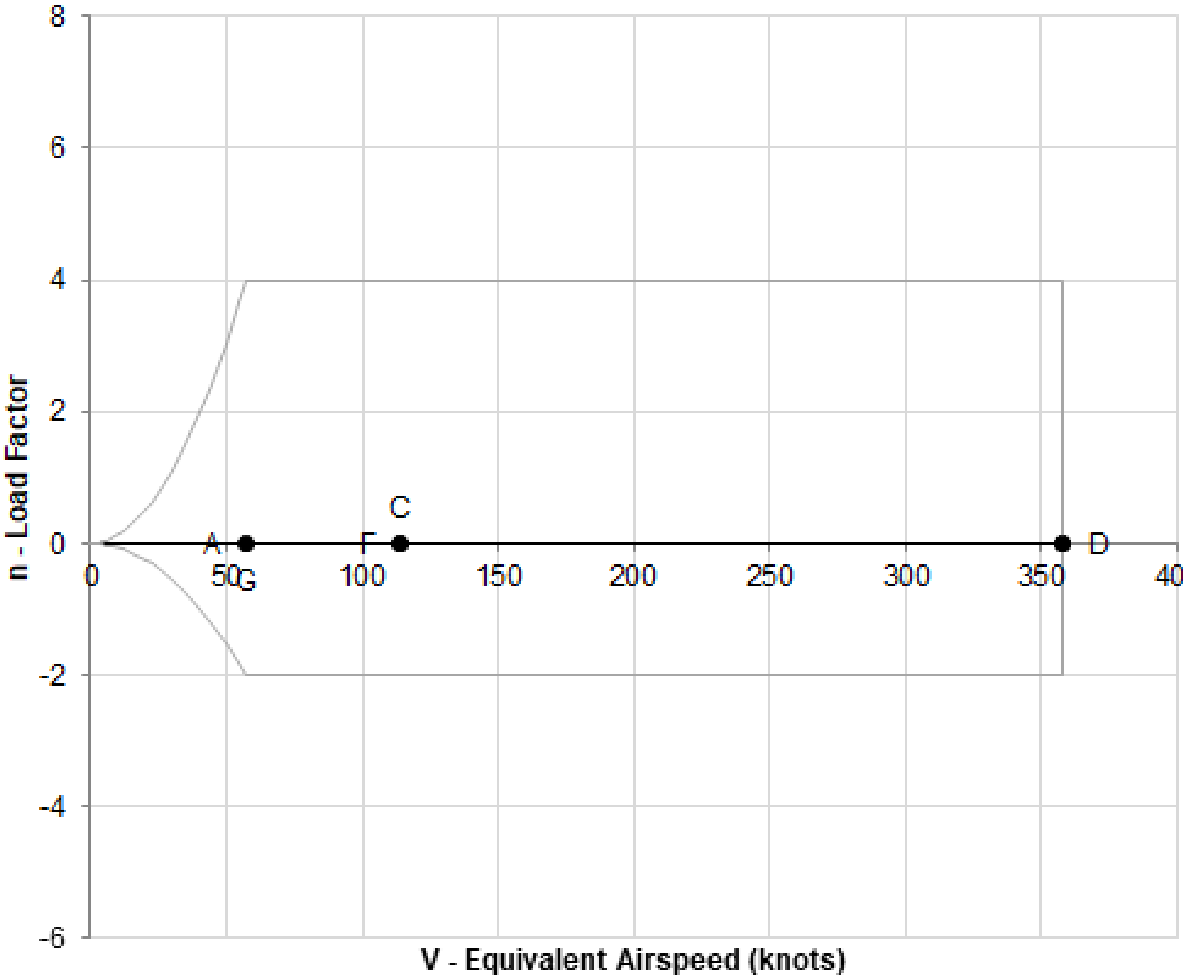
Die Velocity:

V_D= 1.5 * V_C

Where, V_{cruise}=239m/s

V_D=1.5*239

V_D= 358.5 m/s



8
6
4
2
0
-2
-4
-6
n - Load Factor
A
G
F
C
D
0
50
100
150
200
250
300
350
40
V - Equivalent Airspeed (knots)

CHAPTER15

FINAL AIRCRAFT SPECIFICATIONS

Basic parameters:

Table15.1Final Design Parameters

S.no	Main Parameters	Optimum value
1.	CREW	2
2.	LENGTH	40 m
3.	HEIGHT	11 m
4.	WING AREA	150 m^2
5.	WINGSPAN	36 m
6.	ASPECT RATIO	7.205

Weight:

- Take-off weight **W_{TO} =70000 kg**
- Fuel weight **W_F =40000 kg**
- Actual weight **W_E=11350 kg**

✔ *Wing type:*

Tapered wing with **dihedral configuration** mounted as amid-wing.

✔Airfoil chosen:

The airfoil selected according to the calculations is **NACA 2418.**

✔*Fuselage type:*

A **semi-monocoque fuselage** has been constructed.

✔ *Empennage type:*

Conventional configuration is mounted.

✔ *Engine type:*

IAE V2500 Engines mounted on the wing with submerged or pylon support

1.

✔ **Landing Gear:**

Tri-cyclic landing gears are constructed.

✔ *Lift and drag in different phases:*

Phases	Lift kN	Drag kN
Take-off	450.6	29.9
Cruise	679.45	49.5
Landing	355.9	45.86

2.

✔ Performance Calculation:

Rate of climb = 52.85 m/s

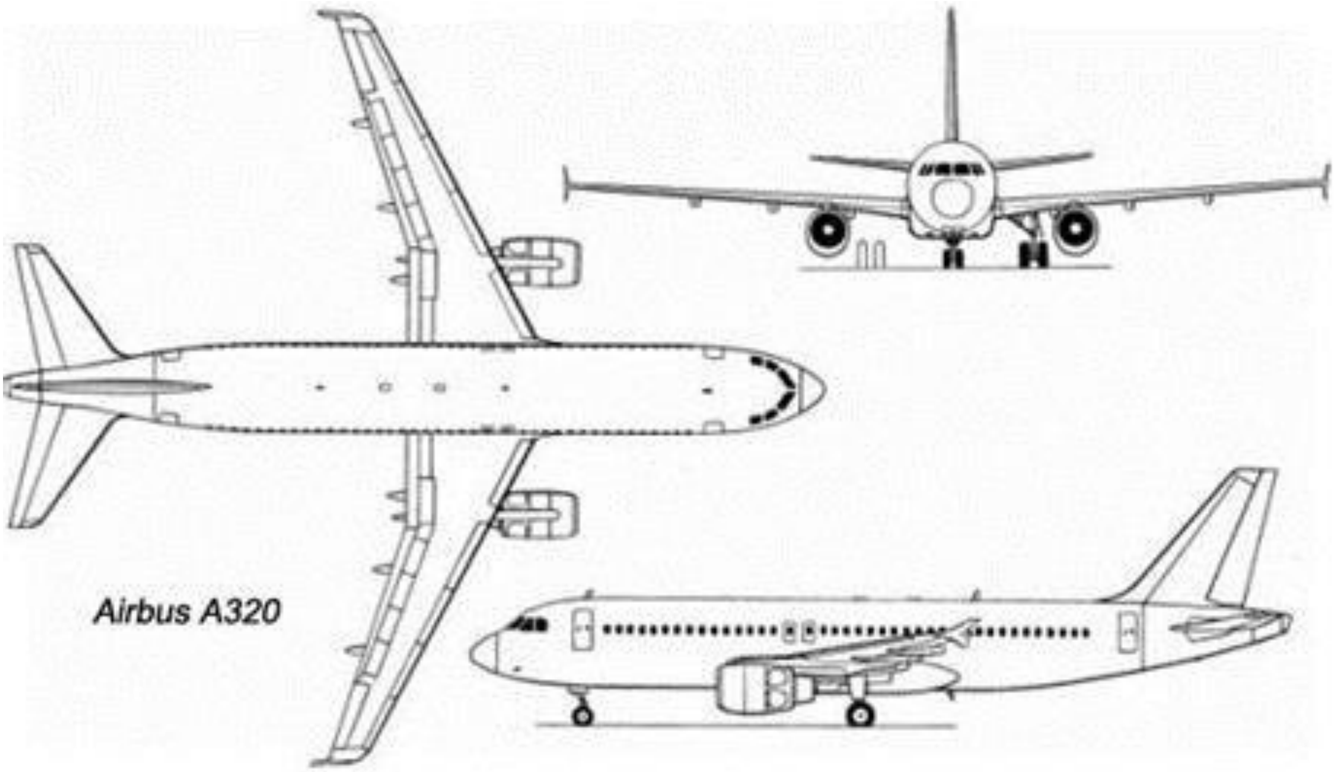
Rate of sink= 20.9 m/s

Take-off distance = 1.005 Km

Landing distance = 1.8 Km

Appendix

3 Views of Aircraft



Handwritten Calculation:

Aircraft Design Project

Commercial Aircrafts

Team : 9

Ashwin Manoharan : 19101067

Ajin Antony : 19101069

Varun Vinaychandran : 19101077

WEIGHT ESTIMATION

Data from graph :

Length	40 m
Height	3.5 m
AR	7.04
S	$150 m^2$
Span	32.5m
W_E	40000 kg
Range	4900 km
W_{TO}	70000 kg
V_{cruise}	860 km/hr
Dry Thrust	210 kN

$$W_{TO} = W_{crew} + W_p + W_f + W_e$$

$$W_{TO} - \left(\frac{W_f}{W_0}\right)W_0 - \left(\frac{W_e}{W_0}\right)W_0 = W_{crew} + W_p$$

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

f → fuel
e → empty
p → payload

$C_{crew} = 120$

$W_{crew} = 120 \times 80 = 9600$ kg

$W_p = (120 \times 80) + (5 \times 80) + (125 \times 25) = 13\,125$ kg

1) Engine Start up.

$$\frac{W_1}{W_{TO}} = 0.99$$

2) Taxing

$$\frac{W_2}{W_1} = 0.99$$

3) Take off

$$\frac{W_3}{W_2} = 0.995$$

4) Climb

$$\frac{W_4}{W_3} = 0.98$$

5) Cruise

$$R_{cr} = \left(\frac{V}{C_j}\right)_{cr} \left(\frac{L}{D}\right) \ln\left(\frac{W_4}{W_5}\right)$$

$$4900 = \left(\frac{860}{0.6}\right) (14) \ln\left(\frac{W_4}{W_5}\right)$$

$$\ln\left(\frac{W_4}{W_5}\right) = 0.244$$

$$\frac{W_4}{W_5} = 1.41 \quad , \quad \frac{W_5}{W_4} = 0.709$$

6) Loiter

$$E_{ltr} = \left(\frac{1}{C_j}\right)_{ltr} \left(\frac{L}{D}\right) \ln\left(\frac{W_5}{W_6}\right)$$

$$\frac{4900}{860} = \left[\frac{1}{0.5}\right) (14] \ln\left(\frac{W_5}{W_6}\right)$$

$$\ln\left(\frac{W_5}{W_6}\right) = 0.203$$

$$\frac{W_5}{W_6} = 1.59 \rightarrow \frac{W_6}{W_5} = 0.628$$

7) Descend

$$\frac{W_7}{W_6} = 0.99$$

8) Landing

$$\frac{W_8}{W_7} = 0.992$$

$$M_{FF} = 0.99 \times 0.99 \times 0.995 \times 0.98 \times 0.709 \times 0.628 \times 0.99 \times 0.992$$

$$M_{FF} = 0.418$$

$$W_F = (1 - M_{FF})\, W_{TO} = (1 - 0.418) \times 70000$$

$$= 40\,740 \text{ kg}$$

1) <u>Payload (W_P) :-</u>

$W_{PL} = 13125$ kg

2) <u>Crew (W_{crew}) :-</u>

$W_c = 120 \times 80 = 9600$ kg

3) <u>Fuel (W_F)</u>

$W_F = (1 - M_{FF}) W_{TO} = 40740$ kg

4) <u>Empty Weight (W_E):</u>

$W_{E\,Tent} = W_{OE\,Tent} - W_{tfo} - W_{crew}$

where $W_{OE\,Tent} = W_{TO} - W_F - W_{payload}$

$W_{tfo} = 0.5\%$ of W_{TO}

$= 0.005 \times 70000$

$= 350$ kg

$W_{OE\,Tent} = 70000 - 40740 - 13125$

$= 16135$ kg

$W_{E\,Tent} = 16135 - 350 - 9600$

$= 6185$ kg

Iterations

i) $W_{act} = \log^{-1}[\log(70000)] - 0.0833/1.0383]$

$= \log^{-1}[\log 154323.6 - 0.0833/1.0383]$

$= \log^{-1}[9.916] = 82413.84$ lbs

$= 37302.3$ kg

$\% \text{ error} = \frac{37302.3 - 6185}{6185} = 504\%$

ii) $W_{act} = \log^{-1}[\log 50000 - 0.0833/1.0383]$

$= \log^{-1}[4.776] = 27081$ kg

$\% \text{ Error} = \frac{27081 - 6185}{6185} = 337\%$

iii) $W_{act} = \log^{-1}[\log 15000 - 0.0833/1.0383]$

$= \log^{-1}[4.77] = 8446.25$

$\% \text{ error} = \frac{8446.25 - 6185}{6185} = 36\%$

iv) $W_{act} = \log^{-1}[\log 13000 - 0.833/1.0383]$

$= \log^{-1}[4.179] = 6704$

$\% \text{ error} = \frac{6704 - 6185}{6185} = 8.4\%$

$W_{act} = \log^{-1}\left[(\log 11350) - 0.0833/1.0383\right]$

$= \log^{-1}[4.159] = 6407\ kg$

$\%\ of\ Error = \dfrac{6407 - 6185}{6185} = 3.5\%$

$W_F = 0.582 \times 11350 = 6605.7\ kg$

Wing And Airfoil Design

i) Reynolds Number

$$R_e = \frac{\rho V L}{m} \quad \rightarrow \rho = 0.218 \ kg/m^3, \quad m = 14.22$$

$$R_e = \frac{0.218 \times 239 \times 4.616}{14.22} = 16.912$$

ii) Aspect Ratio

$$AR = \frac{b^2}{S} = \frac{(32.5)^2}{150} = 7.04$$

iii) Taper Ratio

$$\lambda = \frac{C_{tip}}{C_{root}} \quad , \lambda = 0.25$$

$$C_{root} = b/_{AR} = \frac{32.5}{7.04} = 4.616 \ m$$

$$C_{tip} = \lambda C_{root} = 0.25 \times 4.616 = 1.154 \ m$$

Mean Aerodynamic Chord

$$M_{ac} = C_{mean} = \left[\frac{1 + \lambda + \lambda^2}{1 + \lambda}\right] C_{root}$$

$$= 4.846 \ m$$

4) Structural Weight Volume

$$V = \frac{W_F}{\rho_e} \quad , \rho_e = 804 \ kg/m^3$$

$$= \frac{6605.7}{804} = 8.216 m^3$$

5) Chord Thickness Ratio (t/c) :

$$20\% \text{ of weigh Volume} = \left[\frac{t}{c} \times C_{mean} \times \frac{C_{root}}{2} \times \frac{b}{2} \times 0.75\right] \times 2$$

$$\therefore t/c = \frac{0.2 \times 8.216 \times 2}{4.846 \times 4.616 \times 32.5 \times 0.75}$$

$$t/c = 0.0371$$

6) Root thickness

$$t_r = \left(\frac{t}{c}\right) C_{root} = 0.0371 \times 4.616$$

$$= 0.172 \ m$$

7) Tip thickness

$$t_t = \left(\frac{t}{c}\right) C_{tip} = 0.0371 \times 1.154$$

$$= 0.043 \ m$$

8) Wing Lift Coefficient

$$L = \frac{1}{2} \rho V^2 S C_L \quad , C_L = 2L/\rho V^2 S$$

$$= \frac{2 \times 11350 \times 9.8}{1.225 \times 239^2 \times 150} = 0.021$$

ENGINE SELECTION

i) Engine Thrust Required

$$\text{Single Engine Thrust Req} = \frac{\text{Total thrust} + 10\% \text{ Total thrust}}{\text{No. of Engines Used}}$$

$$= \frac{210 \times 10^3 + 21000}{2} = 115\,500\ N = 115.5\ kN$$

ii) Power to Weight Ratio :

$$P/W = \frac{T\,V_{cruise}}{W_0} = \frac{210 \times 10^3 \times 239}{11356 \times 9.81} = 451$$

ENGINE

CFM Leap [1B25]

Max Thrust : 130.414 kN

By Pass Ratio : 9:1

JAE V2500

Max Thrust : 110.3 kN

By Pass Ratio : 5.4:1

LIFT AND DRAG

Lift, $L = \frac{1}{2} \rho V^2 S C_L$

i) Take off lift , $C_{L max} = 1.5$

$$V_{stall} = \left(\frac{2\ (W/S)}{\rho\ (C_{L max})_{take off}}\right)^{1/2} = \left(\frac{2 \times (70000/150)\ 9.81}{1.225 \times 1.5}\right)^{1/2}$$

$$= 70.58\ m/s$$

$$V_{take off} = 0.6 \times 1.2 \times V_{stall}$$

$$= 50.81\ m/s$$

$$L_{TO} = \frac{1}{2} \rho V_{TO}^2 S C_{L_{TO}} = \frac{1}{2} \times 1.225 \times (50.81)^2 \times 150 \times 1.9$$

$$= 450660.34\ N$$

ii) Cruise Lift , $C_L = 1.3$

$$L = \frac{1}{2} \times ~~1.225~~\ 0.122 \times (239)^2 \times 150 \times 1.3$$

$$= ~~6816684.5 N~~ = 679454.3 N$$

iii) Landing lift

$$V_{stall_{LA}} = \left[\frac{2\ (W/S)}{\rho (C_{L max})_{landing}}\right]^{1/2}$$

$$= \left[\frac{2 \times 70000 \times 9.81/150}{1.225 \times 2.3}\right]^{1/2}$$

$$= \underline{57 \ m/s}$$

$$V_{Landing} = 0.6 \times 1.2 \times V_{stall}$$

$$= 0.6 \times 1.2 \times 57 = 41.04 \ m/s$$

$$L_{Landing} = \frac{1}{2} \rho V_L^2 S C_{L(landing)}$$

$$= \frac{1}{2} \times 1.225 \times (41.04)^2 \times 150 \times 2.3$$

$$= \underline{355909.7 N}$$

10/3/2022

DRAG

$$D = \frac{1}{2} \rho V^2 S \left(C_{D0} + K C_L^2\right)$$

$$K = \frac{1}{\pi e AR} = \frac{1}{3.14 \times 0.8 \times 7.04}$$

$$K = 0.056$$

$$C_{D0} = C_f \left(\frac{S_{wet}}{S_{ref}}\right), \quad C_f = \frac{0.664}{\sqrt{Re}} = \frac{0.664}{\sqrt{17.1 \times 10^3}}$$

$$= \frac{0.664}{13076.7}$$

$$C_f = 5.07 \times 10^{-5}$$

$$\frac{S_{wet}}{S_{ref}} = 2\left[1 + 0.2\,(t/c)\right]$$

$$= 2.0145$$

$$C_{D0} = 5.07 \times 10^{-5} \times 2.0148 = 1.02 \times 10^{-4}$$

1) Take-off Drag

$$D = \frac{1}{2} \rho V_{TO}^2 S \left(C_{D0} + K C_{L_{TO}}^2\right)$$

$$= 0.5 \times 1.225 \times (50.81)^2 \times 150 \left(1.02 \times 10^{-4} + 0.056 \times 1.5^2\right)$$

$$= 29.9\,kN$$

2) Cruise Drag

$$D = \frac{1}{2} \rho V_{cruise}^2 S \left[C_{D0} + K C_L^2\right]$$

$$= \frac{1}{2} \times 0.122 \times (239)^2 \times 150 \left[1.02 \times 10^{-4} + 0.056 \times 1.3^2\right]$$

$$= 49.5\,kN$$

3) Landing Drag

$$D = \frac{1}{2} \rho V_L^2 S \left(C_{D_0} + K C_{L_{landing}}^2\right)$$

$$= \frac{1}{2} \times 1.225 \times (41.04)^2 \times 150 \left(1.02\times10^{-4} + 0.058 \times 2.3^2\right)$$

$$= 45.86\,kN$$

PERFORMANCE CALCULATION

1) Lift Off Distance

$$S_{LO} = \frac{1.21\, W_{TO}}{g \rho S C_{L_{max}} (T/W)}$$

$$= \frac{1.21 \times 70000 \times 9.81}{1.225 \times 9.81 \times 150 \times 1.5 \times \left(\frac{280\times10^3}{70000\times9.81}\right)}$$

$$= 1004.7\, m$$

2. Thrust Required :

$$T_R = D_R = \frac{1}{2} \rho V^2 S \left(C_{D_0} + K C_{L_{max}}^2\right)$$

$$= \frac{1}{2} \times 0.122 \times 239^2 \times 150 \left[1.02\times10^{-4} + 0.058 \times 1.3^2\right]$$

$$= 49.686\, kN$$

3) Power Required :

$$P_R = T_R \times V_{cruise} = 49.686\times10^3 \times 239$$

$$= 1.2 \times 10^7 W$$

4) Thrust Available

$$\frac{T_a}{T_x} = \left(\frac{\rho}{\rho_{SL}}\right)(1+0.7M)$$

$$T_a = T_x\left[\frac{\rho}{\rho_{SL}}\right](1+0.7M)$$

$$= 7456.9\ N$$

5) Power Available

$$P_a = W_{TO} V_{cruise} \sin\theta + P_R$$

$$\text{Climb angle } \theta = \sin^{-1}\left(\frac{T-D}{W_{TO}}\right) = 13.47$$

$$P_a = 3.9\times10^6 + 1.2\times10^2$$

$$= 1.57\times10^7\ N$$

6) Rate of Climb (R/C)

$$R/C = \frac{P_a - P_R}{W_{TO}} = 52.55\ m/s$$

7) $$V_{R/C\ max} = \left\{\frac{2(W/S)}{\rho_{SL}}\left(\frac{1}{\sqrt{3\pi e AR C_{D0}}}\right)\right\}^{1/2}$$

$$= \left[\frac{2(70000\times9.81)}{150\times1.225}\left(\frac{1}{\sqrt{3\times3.14\times0.8\times7.04\times1.1\times10^{4}}}\right)\right]^{1/2}$$

$$= 319.9\ m/s$$

15

8) $V_{\theta max} = \left\{ \frac{2(W/S)}{\rho} \sqrt{\frac{1}{\pi e AR\, C_{D0}}} \right\}^{1/2} \cos\theta$

$= \underline{311.1 m/s}$

9) Rate of Sink (R/S) :

$R/S = \sqrt{\frac{2W}{\rho}} \left(\frac{C_D}{C_L}\right)^{3/2}$

$= 1058.44 \times \left(\frac{0.095}{1.3}\right)^{3/2} = \underline{20.9 m/s}$

10) $V_{R/S\,min} = \sqrt{\frac{2(W/S)}{\rho\, C_{L(R/S)min}}}$

$C_{L(R/S)min} = \sqrt{3}\, C_{\theta min}$

$C_{\theta min} = \sqrt{\pi e AR\, C_{D0}}$

$C_{\theta min} = \underline{0.043}$

$C_{L(R/S)\,min} = \underline{0.0744}$

$V_{(R/S)min} = \underline{316.95 m/s}$

11) $V_{min} = \left(\frac{2(W/S)}{\rho C_L}\right)^{1/2} = \left(\frac{2 \times 70000 \times 9.81}{150 \times 1.225 \times 1.6}\right)^{1/2}$

$= \underline{68.35 m/s}$

12) $V_{\theta min} = \sqrt{\frac{2(W/S)}{\rho\, C_{\theta min}}} = \sqrt{\frac{2 \times 70000 \times 9.81}{150 \times 1.225 \times 0.043}}$

$= \underline{131.84 m/s}$

13) Landing Distance

$$S_L = \frac{1.69\, W^2}{g \rho S C_{Lmax} \left[D + \mu_r (W - L) \right]} \quad , \mu_r = 0.4$$

$$= \frac{1.69 \times (70000 \times 9.81)^2}{1.225 \times 9.81 \times 150 \times 2.3 \left[49500 + 0.4 (70000 \times 9.81 - 35590 \right.}$$

$$= 1851.16 m$$

V-n diagram

1) Load Factor

$n \rightarrow$ from table

Max +ve = 4 $\qquad n_{max} = 4.0$

Max −ve = −2 $\qquad n_{min} = -2$

2) Max Velocity when $n = 1$

$$V_{max} = \sqrt{\frac{2Wg}{\rho S C_L}} = \sqrt{\frac{2 \times 70000 \times 9.81}{1.225 \times 150 \times 2.3}}$$

$$= 57 \; m/s$$

3) Corner Velocity

$$+ve \quad V^* = \sqrt{\frac{2Wg\, n_{max}}{\rho S C_{Lmax}}} = \sqrt{\frac{2 \times 70000 \times 9.81 \times 4}{1.225 \times 150 \times 2.3}}$$

$$= 114 m/s$$

$(-ve)\ V^{+} = \sqrt{\dfrac{2Wg(-n_{max})}{\rho S(C_{Lmax})}} = \sqrt{\dfrac{2\times 70000\times 9.81\times 2}{1.225\times 150\times 1.3}}$

$= \underline{80.62 m/s}$

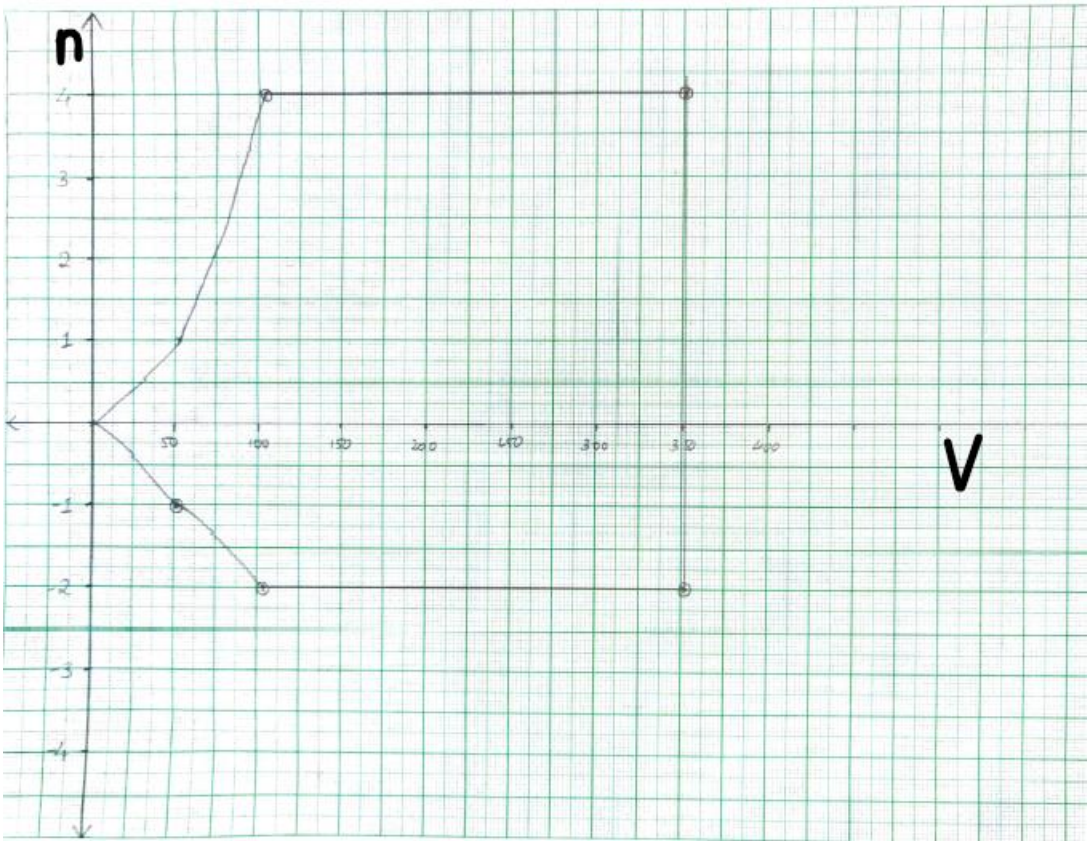
4) Dive Velocity

$V_D = 1.5\ V_{cruise} = 1.5\times 239$

$= \underline{358.5 m/s}$

5) Coordinates for V-n Diagram

1) (0, 0)
2) (57, 1)
3) (114, 4)
4) (358.5, 4)
5) (358.5, -2)
6) (114, -2)
7) (57, -1)



n
V
4
3
2
1
-1
-2
-3
-4
50
100
150
200
250
300
350
400