# DESIGN OF BUSINESS JET WITH MORPHING WINGS

## ASB4341 - DESIGN PROJECT-1 REPORT

***Submitted by***

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# BONAFIDE CERTIFICATE

Certified that this project report titled **" DESIGN OF BUSINESS JET WITH MORPHING WINGS "** is the bonafide work of **" SI DHANIYALAKSHMI (19103025), LAURA MERIN D (19103031) and DIVYA R (19103037) "** who carried out the project work 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 on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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**INTERNAL EXAMINER**

**EXTERNAL EXAMINER**

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# ABSTRACT

The modern jet transport is considered as one of the finest integration of technologies. Its economic success depends on performance, low maintenance costs and high passenger appeal and design plays a vital role in summing up all these factors. Conceptual design is the first step to design of an aircraft. In this paper a business jet aircraft is designed to carry 4 passengers and to cover a range of 5800 km with maximum Mach No of 0.78 and with maximum ceiling of 14000m. The conceptual design consisted of initial sizing, aerodynamics and performance analysis. Through trade studies and comparison with other business jet aircrafts a final model of the aircraft was built to achieve the requirements.

The aim of this project is to design and conceptualize a corporate/business jet that can cater to a wide range of clientele ranging from business conglomerates to private organizations and individual parties. Business jet, private jet or, colloquially bizjet is a term describing a jet aircraft, usually of smaller size, designed for transporting groups of business people or wealthy individuals. The project involves the design of a business jet that can accommodate about 4 passengers at full seating layout, providing the amenities and level of comfort that a business jet is expected to provide while incorporating the design specifications and performance parameters of a long-range commercial airliner. The aircraft allows for long range transport with better efficiency and reduced fuel consumption and noise levels owing to a state-of-the-art engine and design features.

Aircraft flight performance can be increased by optimizing the wing design. However fixed wing design has disadvantages since the aircraft's wing unable the to achieve maximum flight performance in all flight condition. Thus, the wing shape demanded to evolve or change with view to adapt with different flight condition. This method recently known as morphing wing. Morphing wing surfaces change its geometry during flight with view to improve the aerodynamics performances of aircraft. The concept is inspired from bird flight which able to change its wing depends on different situation. Such wing will enable the aircraft to accommodate multiple flight regimes and obtain better flight performance. The method offers simpler mechanism to replace those active control devices implementation on actual aircraft design.

An efficient mission profile which comes as a result of a well-engineered aircraft is expected in the market. The input to the concept Mission profile is a flight profile of the aircraft defined by the customer. Wing profile and vertical tail configurations have direct impact on lift, drag, stability, performance and manoeuvrability of the aircraft. A propulsion system directly influences the performance of the aircraft. By combining the wing profile and the propulsion system, two important parameters, known as wing loading and thrust to weight ratio can be calculated. In this work, conceptual design procedure given by Jan Roskam is applied to calculate wing loading and thrust to weight ratio.

**Keywords:** *Luxurious, Business conglomerate, Long range, Private, Mission profile, Manoeuvrability, Wing loading, Thrust – Weight ratio, Morphing wings, Lift characteristics, Bizjet.*

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## 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 Co-efficient
- $C_{D,0}$ - Zero lift Drag co-efficient
- $C_P$ - Specific fuel consumption (lbs / hp / hr)
- $C_L$ - Lift Co-efficient
- 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$^2$)
- $\rho$ - Density of air (kg/m$^3$)
- $\mu$ - Dynamic viscosity (Ns/m$^2$)
- $\lambda$ - Tapered ratio
- R/C - Rate of Climb
- $\eta$ - Kinematic viscosity (m$^2$/s)

# CHAPTER 01

# INTRODUCTION TO DESIGN

## 1.1 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 optimum the 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.

***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 it’s 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*.

***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 onboard 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 modelled about 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 of 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, starting at least with the Douglas DC-1 in 1932, 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.

## 1.2 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

## *1.3* 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.

## 1.4 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

## 1.5 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.

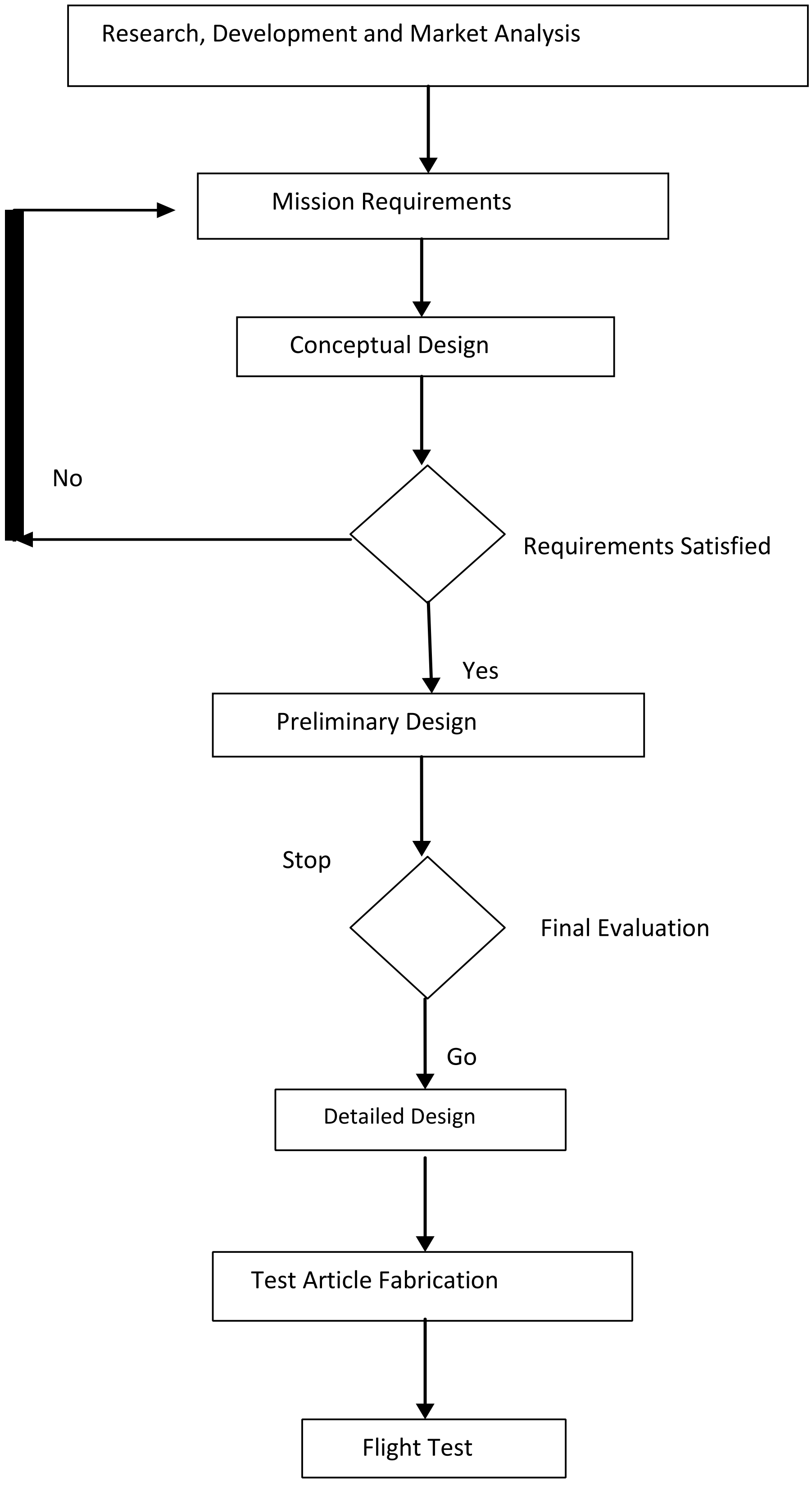


*Figure 1.1 Design flow process*

## 1.6 CONCEPTUAL DESIGN

This article deals with the steps involved in the conceptual design of an aircraft. It is broken down in to 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
6. Performance curves
7. 3 View diagram

## 1.7 DESIGN PROCESS BREAKDOWN

*Table 1.1 (Design Process Breakdown)*

| | |
|---|---|
| •**Conceptual Design:**<br>- Competing concepts evaluated<br>- Performance goals established<br>- Preferred concept selected | What drives the design?<br>Will it work/meet requirement?<br>What does it look like? |
| • **Preliminary Design:**<br>- Refined sizing of preferred concept tests<br>- Design examined data/establish parameters<br>- Some changes allowed | Do serious wind tunnel tests<br>Make actual cost estimate |

| | |
|---|---|
| • **Detail Design:** | Certification process |
| - Final detail design | Component/systems tests |
| - Drawings released | Manufacturing |
| - Detailed performance | Flight control system design |
| - Only “tweaking” of design allowed | |

# CHAPTER 02

# STUDY OF DIFFEENT BUSINESS JETS

## 2.1 Cessna Citation X

The **Cessna Citation X** is an American business jet produced by Cessna and part of the Citation family. Announced at the October 1990 NBAA convention, the Model 750 made its maiden flight on December 21, 1993, received its type certification on June 3, 1996, and was first delivered in July 1996. The updated **Citation X+** was offered from 2012 with a 14 in (360 mm) cabin stretch and upgraded systems. Keeping the Citation III fuselage cross section, it has a new 37° swept wing with an area of 527 $ft^2$ (49 $m^2$) for a fast Mach 0.935 MMo and a 36,600 lb (16.6 t) MTOW for a 3,460 nmi (6,408 km) range, a T-tail and two 7,034 lbf (31.29 kN) AE3007 turbofans. After 338 deliveries, production ended in 2018

*Figure 2.1 Cessna Citation X*

## 2.2 Embraer EMB-500 Phenom 100

The **Embraer EMB-500 Phenom 100** is a very light jet developed by Brazilian aircraft manufacturer Embraer, type certificate is EMB-500. As of April 2017, 350 were in service in 37 countries. The Phenom 100 has an oval fuselage with a 7.985 $m^3$ (282 $ft^3$) passenger cabin, a 1.47 m-high by 0.74 m-wide (4.5'x2.1') door and 1.2'x1' windows. Its unpressurized cargo hold is 1.56 $m^3$ (54.9$ft^3$).Its structural life is 28,000 flight cycles or 35,000 hours, and it is built of 20% composite materials.

*Figure 2.2 Embraer EMB-500 phenom 100*

It has capacity for four passengers in its normal configuration, but it can carry up to seven passengers with a single crew, with an optional side-facing seat and belted toilet. The cabin interior is designed by BMW Design works USA.

The aircraft is fitted with two rear-mounted Pratt & Whitney Canada PW617-F turbofan engines rated at a take-off thrust of 7.2 kN (1,695 lb) to ISA+10 °C. The engines have dual full authority digital engine control (FADEC). An automatic performance reserve (APR) feature boosts engine output to 1,777 lb in the event of engine failure on take-off. Later model PW 617 F-E models have a ten-minute thrust rating at 1,820 lb. It has a maximum flying range of 1,178 nmi (2,182 km) with four occupants and NBAA IFR Reserves.

## 2.3 DASSAULT FALCON 7X

The **Dassault Falcon 7X** is a large-cabin, 5,950 nautical miles (11,020 km) range business jet manufactured by Dassault Aviation, the second largest of its Dassault Falcon line. Launched at 2001 Paris Air Show, its first flight was on 5 May 2005 and it entered service on 15 June 2007. The **Falcon 8X** is derived from the 7X with a longer range of 6,450 nautical miles (11,950 km) afforded by engine optimizing, aerodynamic refinements and an increase in fuel capacity. Featuring an S-duct central engine, it and the Falcon 900 are the only two trijets in production.

*Figure 2.3 Dassault Falcon 7X*

### 2.4 Embraer Legacy 600 Executive Jet

*Figure 2.4. Embraer Legacy 600 Executive Jet*

Legacy 600 is a super midsize aircraft developed by Embraer. The aircraft entered into service in April 2002. The aircraft is currently being operated in more than 24 countries across the world. It is available in two versions, which include the Legacy Executive and Legacy Shuttle. The Legacy 600 aircraft incorporated most of the design features from the Embraer ERJ 145 and 135 families. The aircraft features added range and extra fuel tanks. It has wingtips for improved aerodynamic performance. The aircraft dimensions include 26.33m length, 6.76m height and 21.17m wingspan. The aircraft features a large cockpit with a spacious flight deck. It also features integrated stand-by instruments system, electronic flight bag and central maintenance computer, coupled vertical navigation (VNAV), data loader 1000 with SD card and USB ports, RNP 0.3 and XM weather capabilities.

### 2.5 Bombardier Challenger 300

The Challenger 300, originally known as the Continental Business Jet BD-100, is medium size trans-continental business jet from Bombardier Aerospace of Canada. The aircraft carries up to eight passengers in a cabin with stand-up headroom over a non-stop range of 3,100nm, i.e. coast-to-coast range across America, using a take-off airfield length of less than 5,000ft. The Challenger 300 entered service with Flexjet in January 2004. The Challenger 300 has a conventional all-metal airframe. Winglets reduce lift-induced drag. Canadair is responsible for building the forward section of the fuselage including the cockpit and primary flight controls. Mitsubishi Heavy Industries builds the wings. Bombardier Aerospace in Belfast is responsible for construction of the centre fuselage. The rear fuselage and tail are built by AIDC of Taiwan. The component sections are transported to the Bombardier Aerospace Montreal Dorval facility for final assembly.

*Figure 2.5 Bombardier Challenger 30*

## 2.6 Honda HA-420 Business Jet

*Figure 2.6 Honda HA-420 Business Jet*

The Honda HA-420 is a twin-engine business jet designed and manufactured by US-based Honda Aircraft Company (HAC) to operate on domestic and international air routes. It is the first general aviation aircraft built by HAC. HondaJet obtained type certification from the US Federal Aviation Administration (FAA) in December 2015. The aircraft was granted type certification by the Civil Aviation Safety Authority of Mexico in March 2016. The sleek and aerodynamic design of the HA-420 is claimed to accomplish 35% higher fuel efficiency than conventional business jets. An over-the-wing podded engine configuration of the aircraft reduces drag during flight and maximises cabin space. The fuselage is made up of lightweight carbon composite or honeycomb sandwich materials to decrease the overall weight of the aircraft. The wings are built with reinforced single sheets of aluminium, which provide a smoother surface compared to the wings of conventional business jets.The HA-420 features the first touchscreen controlled all-digital glass flight deck integrated with a Garmin G3000 avionics system.

### 2.7 Bombardier Global 7500 Business Jet

*Figure 2.7. Bombardier Global 7500 Business Jet*

Global 7500 is a high-speed business jet developed by Bombardier Aerospace. It entered service in December 2018. It was initially named as Global 7000 business jet and was rebranded as Global 7500 at the European Business Aviation Convention and Exhibition (EBACE2018) held at Geneva, Switzerland, in May 2018. The final assembly of the aircraft began in Bombardier’s Toronto site in Canada in September 2011. The aft fuselage of the aircraft is built at the Queretaro site in Mexico. Global 7500 features an improved design, while the length of the aircraft is 33.71m, overall height is 8.14m and wingspan is 31.79m. The aircraft is produced with a new high-speed transonic wing, which significantly optimises its aerodynamic efficiency. It is fitted with a Global Vision flight deck and a Rockwell Collins avionics system. The cockpit features four large liquid crystal display (LCD) screens, head-up display system (HUD), enhanced vision system (EVS) and synthetic vision system (SVS)

## 2.8 Legacy 650:

*Figure 2.8 Legacy 650*

Legacy 650 is a large business jet developed by Embraer. Following completion of its maiden flight in September 2009, the aircraft entered into service in late 2010. The Legacy 650 aircraft is a longer-range version of the Legacy 600. Its range is 500nm higher than that of the Legacy 600. The 650 also provides higher altitude take-off and climb thrust than the Legacy 600 aircraft. The aircraft has 38.5in compound swept-fan blades and features a new bypass vane and core vane. It has a length of 26.33m, height of 6.76m, and wingspan of 21.17m. The first Legacy 650 aircraft was delivered to Amsair Aircraft in November 2010. The aircraft has three spacious cabin zones, which provide seating for up to 14 people. The aircraft has a total of 22 windows, which provide abundant natural light in the cabin. The cabin features fully berthing seats, as well as a spacious and fully equipped galley, and the largest lavatory in its class. An optional forward lavatory can also be included. The cabin has a baggage compartment with a space of 240$ft^3$ (6.8$m^3$) and an internal storage space of about 46$ft^3$ (1.3$m^3$).

## 2.9 Bombardier Global Express

High speed business/corporate aircraft with a range of 6,700 nmi at Mach 0.80, 51,000 ft maximum altitude and a 14 hours endurance. The semi monocoque airframe is made of lightweight aluminum alloys and composite materials.It has a low wing, tricycle landing gear and fuselage mounted engines.Business jet with the largest cabin.It can accommodate 12 to 16 passengers in three cabin sections: mostly a forward four-chair club section, a central four-seat conference grouping and an aft three-place divan facing two chairs.The cabin has an unobstructed length of 14.6 m while the floor is dropped by 51 mm from the Challenger to increase width at shoulder level, while the windows have been repositioned and enlarged by 25%.

*Figure 2.9 Bombardier Global Express*

## 2.10 Hawker 400

Fig*ure* 2.10 Hawker 400

The Hawker 400 is a small, low-winged twin-turbofan aircraft of all metal construction, flown by a crew of two pilots and accommodating eight passengers in a pressurized cabin. Its wings use a computer-designed supercritical airfoil in order to minimize drag. Two turbofans are mounted on the rear fuselage. The 400 can fly 1,351 nmi with four passengers, cruising at Mach 0.71–0.73, and most pilots are comfortable flying it over three hours, about 1,175 nmi cruising at Mach 0.73–0.76. Basic operating weights range from 11,000 to 11,100 lb, full tanks payload is less than 500–600 lb with an average passenger load of three, however its full capacity is six passengers 1,100 nmi.

## 2.11 North American Sabreliner

*Figure 2.11 North American Sabreliner*

The civilian production version, or Series 40, was slightly refined over the prototype, with more speed and a roomier cabin. North American then stretched the design by 3 feet 2 inches (0.97 m), providing greater cabin space, and marketed it as the Series 60.The cabin was made taller for the Series 70 and general electric CF700 turbofans were installed for the Series 75A The resulting Raisbeck Mark V wing was the first supercritical wing in service in the United States. The Mark V wing was combined with GARRETT AIRESEARCH TFE-731-3R-1D engines, to create the Series 65. Sabreliner models 60 and 80 were retrofitted with the Mark V wing as the Series 60A and Series 80A

## 2.12 SYBERJET SJ30

*Figure 2.12 SYBERJET SJ30*

The SJ30 can seat up to six passengers plus one pilot. A unique feature of this aircraft is that it maintains a 'sea level cabin up to 41,000 ft, thereby reducing fatigue due to high cabin altitude on long journeys. The SJ30 was the first aircraft designed around a 12 psi cabin for more comfort in the cabin. The 12 psi cabin results in a sea level cabin through 41,000 ft and less than a 1,800 ft cabin at its ceiling of 49,000 ft.

### Aircrafts Selection

We have chosen to design a Mid-size jet which is a 10 seater aircraft with jet engine. We have also studied similar aircrafts in order to collect data in the following chapters. The following are the aircrafts chosen for study,

*Table 2.1 Aircrafts chosen for study*

| S.No. | Aircrafts |
|---|---|
| **1** | Cessna CitationX |
| **2** | Embraer EMB-500 Phenom 100 |
| **3** | Dassault Falcon |
| **4** | Embraer Legacy 600 |
| **5** | Bombardier Challenger 300 |
| **6** | Honda HA-420 |
| **7** | Bombardier Global 750 |
| **8** | Legacy 650 |
| **9** | Bombardier Global Express |
| **10** | Hawker 400 |
| **11** | North American Sabreliner |
| **12** | Syberjet SJ30 |

# CHAPTER 03

# PREPARATION OF COMPARATIVE DATA SHEET OF DIFFERENT AIRCRAFTS

## General Characteristics

The following table gives the general characteristics of the selected aircrafts

*Table 3.1 General Characteristics*

| **Aircraft\Data** | **Cruising speed,** *kmph* | **Crew** | **Length,***m* | **Height,** *m* | **Wing area ,** $m^2$ | **Wing span ,** *m* | **Aspect ratio** |
|---|---|---|---|---|---|---|---|
| Cessna Citation X | 978 | 2 | 22.43 | 5.86 | 48.96 | 21.09 | 9.08 |
| Embraer EMB-500 Phenom 100 | 750 | 2 | 12.82 | 4.35 | 14.87 | 12.3 | 10.17 |
| Dassault Falcon 7X | 850 | 3 | 23.38 | 7.83 | 70.7 | 26.21 | 9.7 |
| Embraer Legacy 600 | 829 | 2 | 26.33 | 6.76 | 51.2 | 21.17 | 8.75 |
| Bombardier Challenger 300 | 871 | 2 | 20.92 | 6.20 | 48.5 | 19.46 | 7.8 |
| Honda HA-420 | 682 | 2 | 12.99 | 4.54 | 17.28 | 12.12 | 8.5 |
| Bombardier Global 7500 | **902** | 4 | 33.88 | 8.2 | 116.5 | 31.7 | 8.62 |
| Legacy 650 | **829** | 2 | 26.33 | 6.64 | 51.2 | 21.17 | 8.7 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bombardier Global 5000 | 907 | 3 | 29.5 | 7.8 | 105.6 | 28.7 | 7.8 |
| Hawker 400A | 828 | 2 | 14.75 | 4.19 | 22.43 | 13.25 | 7.83 |
| North American Sabreliner 60 | 800 | 4-5 | 13.41 | 4.88 | 31.79 | 13.56 | 5.7 |
| Syberjet SJ30 | 882 | 1 | 14.3 | 4.3 | 17.65 | 12.9 | 9.4 |
| Learjet 45 | 804 | 2 | 17.68 | 4.3 | 28.95 | 14.58 | 7.4 |
| Bombardier Learjet 85 | 829 | 2 | 20.76 | 6.08 | 37.25 | 18.75 | 9.4 |
| Cessna Citation II | 746 | 2 | 14.542 | 4.57 | 31.83 | 15.913 | 7.9 |

# WEIGHT CONFIGURATION

The following table gives the weight configuration of the selected aircrafts.

*Table 3.2 Weight Configuration*

| **Aircraft\Data** | **Cruising speed,** *kmph* | **Empty weight**, *kg* | **Maximum Takeoff weight,** *kg* | **Loaded weight/ operating weight,** *kg* |
|---|---|---|---|---|
| Cessna Citation X | 978 | 8618 | 16375 | 10025 |
| Embraer EMB-500 Phenom 100 | 750 | 3275 | 4800 | 4000 |
| Dassault Falcon 7X | 850 | 14548 | 31,751 | 16601.5 |
| Embraer Legacy 600 | 829 | 13675 | 22500 | 17000 |
| Bombardier Challenger 300 | 871 | 10590.92 | 17622.06 | 10818.17 |
| Honda HA-420 | 682 | 3267.23 | 4808.08 | 3,379 |
| Bombardier Global 7500 | 902 | 28349.52 | 48194.19 | 40764.04 |
| Legacy 650 | 829 | 14546.18 | 24299.85 | 20000 |
| Bombardier Global 5000 | 907 | 4,199 | 41957.29 | 23,070 |
| Hawker 400A | 828 | 4588 | 7302.84 | 4950.96 |
| North American Sabreliner 60 | 800 | 5,148.278 | 9149.87 | 5488.467 |
| Syberjet SJ30 | 882 | 4044.68 | 6327.61 | 4082.33 |

| | | | | |
|---|---|---|---|---|
| Learjet 45 | 804 | 5,829 | 9,752 | 6300 |
| Bombardier Learjet 85 | 829 | 10,977 | 15,195 | 10976.94 |
| Cessna Citation II | 746 | 3655.95 | 6849.245 | 3923.574 |

## PERFORMANCE

The following table gives the performance of the selected aircrafts.

*Table 3.3 Performance*

| **Aircraft\Data** | **Cruising speed ,** *kmph* | **Maximum speed,** *Mach* | **Maximum altitude ,** *m* | **Range,** *Km* | **Rate of climb,***mpm* | **Wing Loading, kg/m$^2$** |
|---|---|---|---|---|---|---|
| Cessna Citation X | 978 | 0.935 | 15,545 | 6,408 | 1112.5 | 339.1 |
| Embraer EMB-500 Phenom 100 | 750 | 0.7 | 12,496 | 2182 | 932.99 | 322.798 |
| Dassault Falcon 7X | 850 | 0.9 | 15,545 | 11,019 | 626.364 | 449 |
| Embraer Legacy 600 | 829 | 0.8 | 12,497 | 6,297 | 926.6 | 439.5 |
| Bombardier Challenger 300 | 871 | 0.82 | 13,716 | 5,741 | 1036.3 | 481.6 |
| Honda HA-420 | 682 | 0.63 | 13,107 | 2,661 | 21 | 278.25 |
| Bombardier Global 7500 | 902 | 0.925 | 15,545 | 14,260 | 1066.8 | 413 |
| Legacy 650 | 829 | 0.8 | 12496.8 | 7200 | 972.92 | 474 |
| Bombardier Global 5000 | 907 | 0.89 | 15,545 | 9,639 | 1478 | 397.32 |
| Hawker 400 A | 828 | 0.69 | 13,716 | 5375 | 1,225 | 320 |
| North American Sabreliner 60 | 800 | 0.71 | 12,200 | 4020 | 1432.56 | 287 |

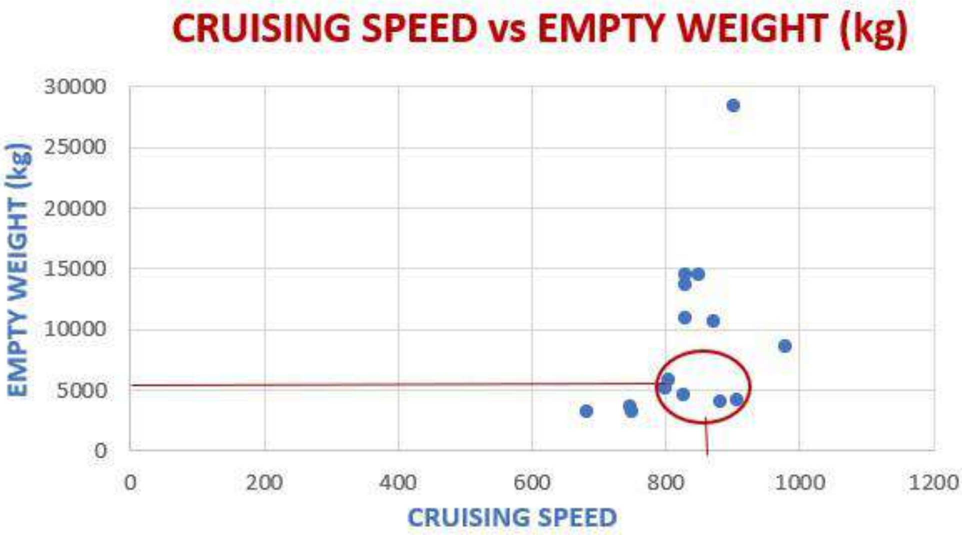
| | | | | | | |
|---|---|---|---|---|---|---|
| Syberjet SJ30 | 882 | 0.72 | 14935.2 | 4600 | 1116.48 | 358 |
| Learjet 45 | 804 | 0.81 | 15,545 | 3,167 | 685.8 | 379.2 |
| Bombardier Learjet 85 | 829 | 0.70 | 15000 | 4800 | 762 | 407 |
| Cessna Citation II | 746 | 0.721 | 13716 | 3,700 | 1175 | 215 |

# CHAPTER 04

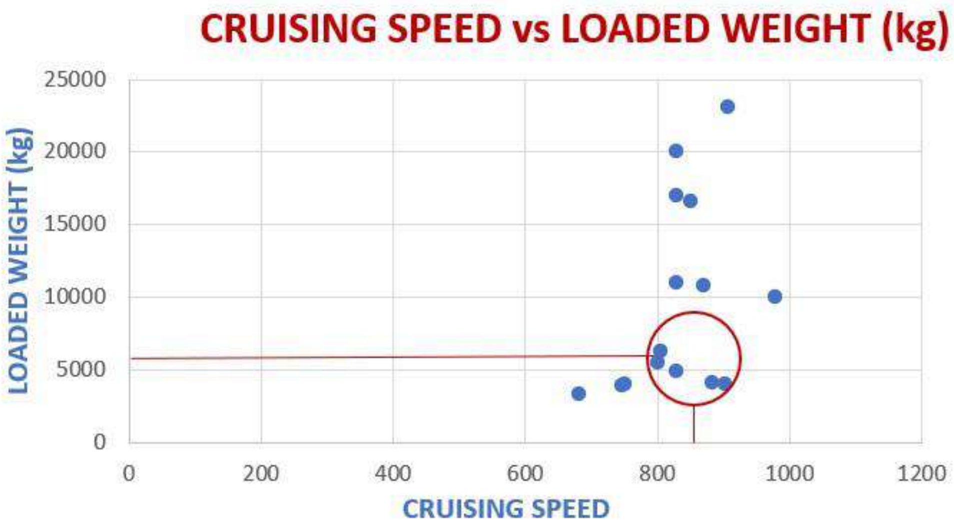
# PREPARATION OF COMPARATIVE GRAPHS

## 4.1 GRAPH PLOTTING

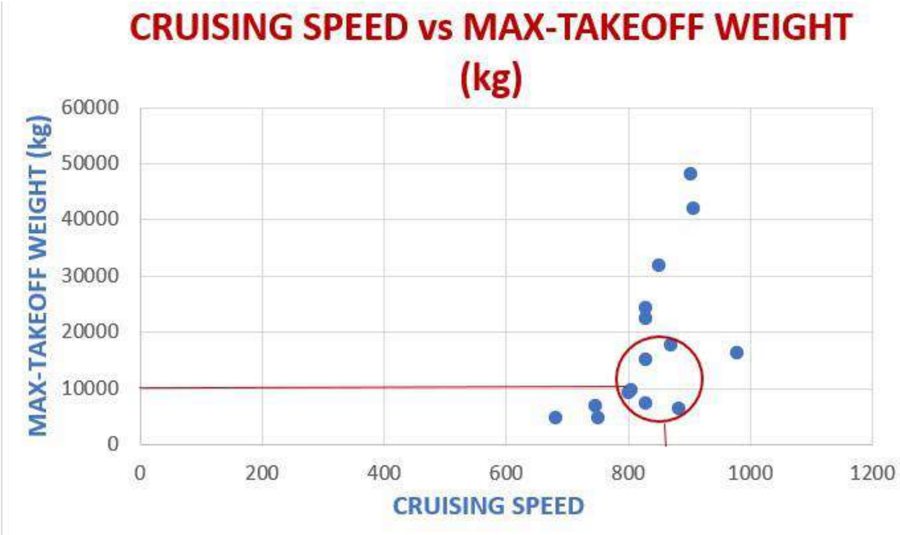
The graphs are plotted for the tabulated data from the previous section. The inference from these graphs will give us the tentative design parameters



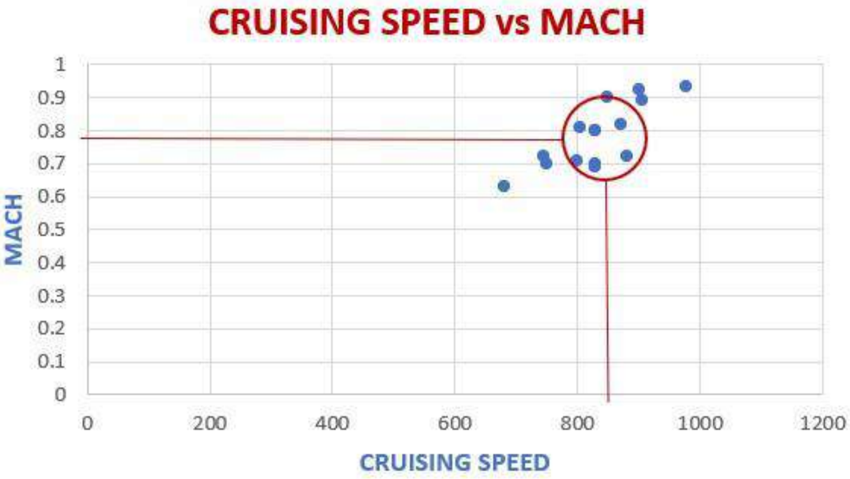
*Graph 4.1 Cruising speed vs Empty weight*



*Graph 4.2 Cruising speed vs loaded weight*

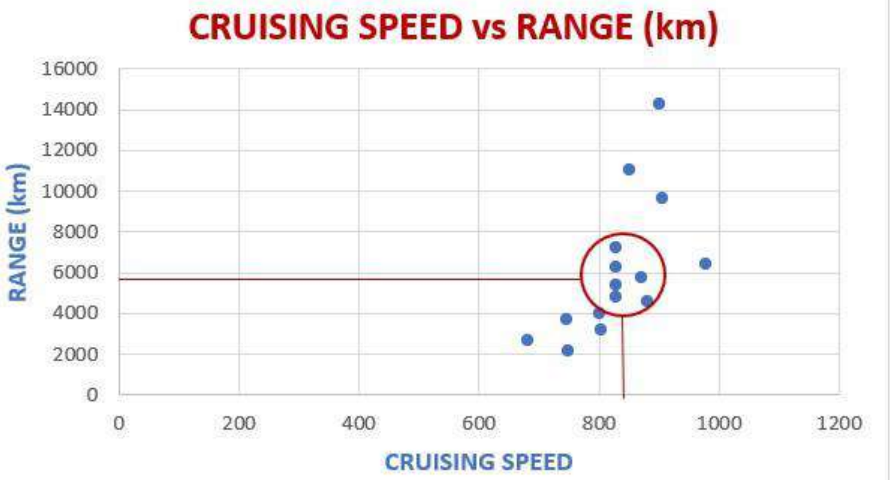


*Graph 4.3 Cruising speed vs Max- take-off weight*



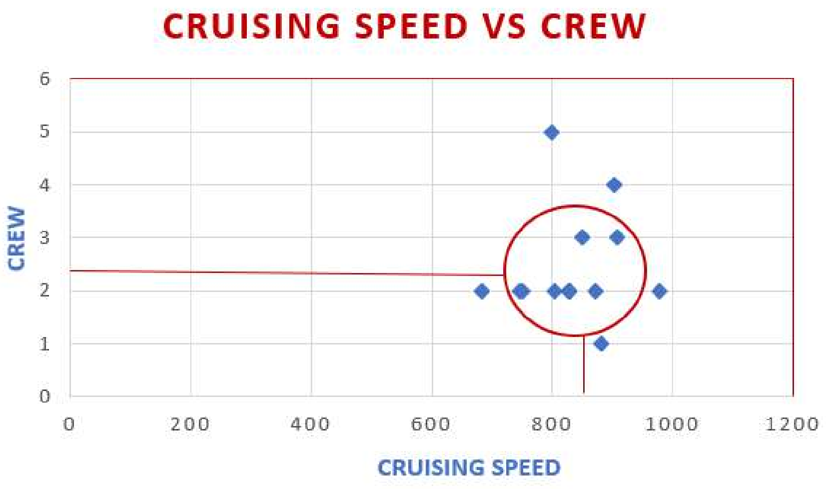
*Graph* 4.4 Cruising speed vs Mach

*Graph 4.5 Cruising speed vs Maximum Altitude*

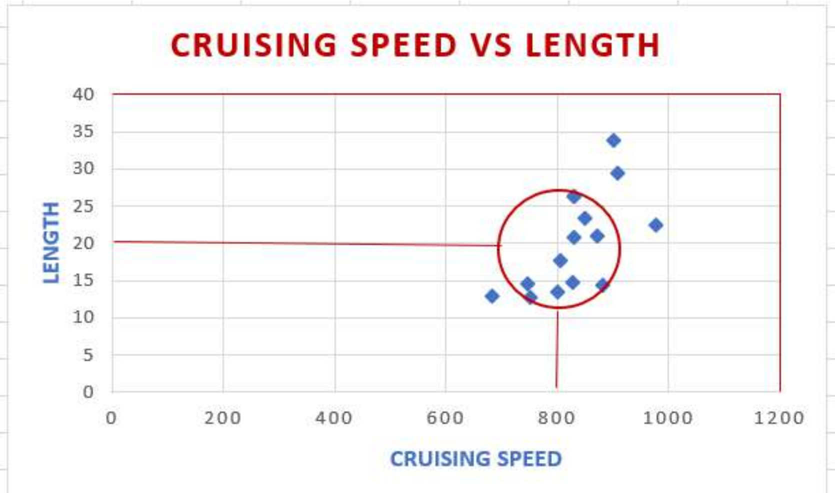


*Graph* 4.6 Cruising speed vs Range

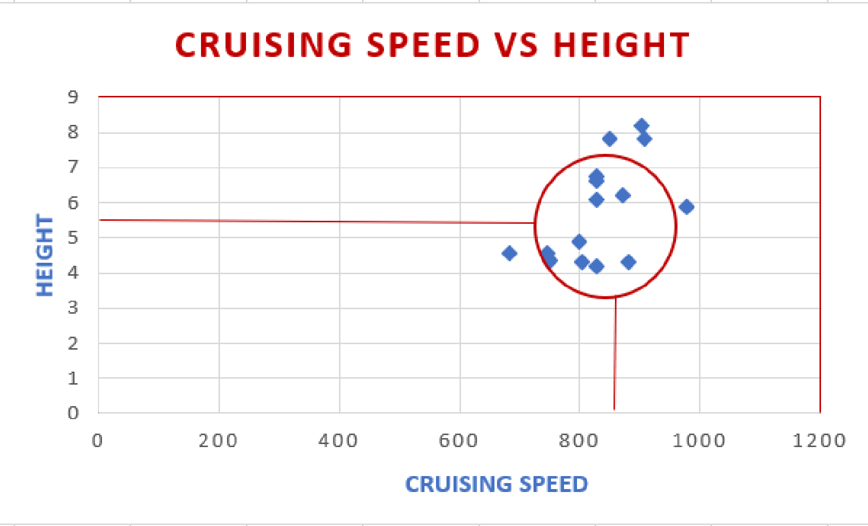
*Graph 4.7 Cruising speed vs Rate of climb*



*Graph 4.8 Cruising speed vs Crew*

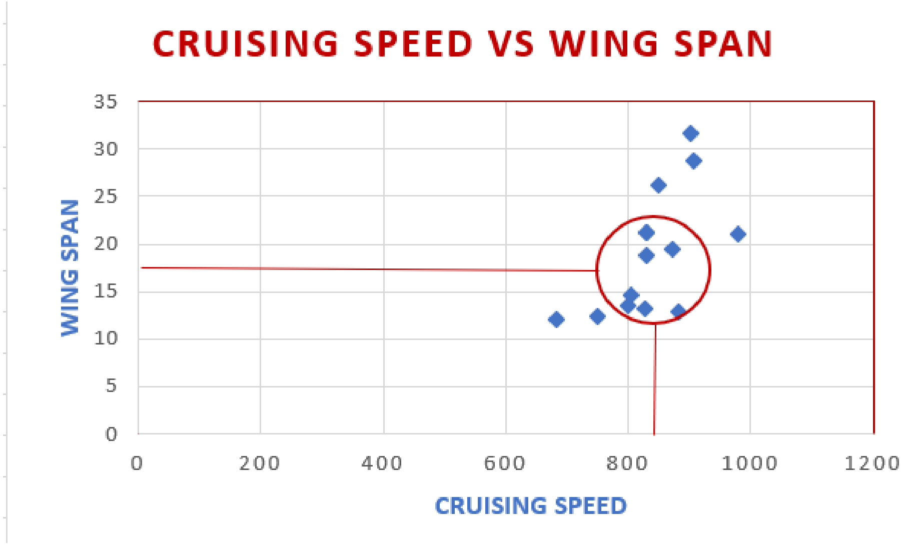


*Graph* 4.9 Cruising speed vs Length



*Graph 4.10 Cruising speed vs Height*

*Graph 4.11 Cruising speed vs Wing Area*



*Graph 4.12 Cruising speed vs Wing span*

*Graph* 4.13 Cruising speed vs Aspect ratio

# CHAPTER 05

# 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 5 aircrafts, we have selected the tentative design parameters for out aircraft. These parameters will be used to proceed with the design steps and weight estimation processes.

## 5.2 GENERAL CHARACTERISTICS:

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

1. Crew : 2
2. Length : 20 *m*
3. Height : 5.5 *m*
4. Wing area : 38 $m^2$
5. Wing span : 17.5 *m*
6. Wing chord : *2.1 m*
7. Aspect ratio : 8
8. Cruising speed: : 850 *km/h*

## 5.3 WEIGHT CONFIGURATION:

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

1. Empty weight : 5500 *kg*
2. Take-Off weight : 10,000 *kg*
3. Loaded Weight : 6500 *kg*

## 5.4 PERFORMANCE:

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

1. Maximum speed : 0.78 Mach
2. Maximum Altitude : 14000 *m*
3. Range : 5800 *km*
4. Wing Loading : 420 $kg/m^2$

# CHAPTER 06

# WEIGHT ESTIMATION

## 6.1 FLIGHT PROFILE

Flight profile can be defined as the trajectory of flight or the flight plan which consists of the altitude, speed, distance of flight and the maneuvers to be performed and the number of stops etc. A flight plan plays a very important role as it helps us to be prepared in advance. The following is the flight profile of our aircraft.

I 🟧 Engine Start and Warm up
II 🟥 Taxiing
III 🟨 Take-Off
IV 🟨 Climb
V 🟧 Cruise
VI 🟧 Descent
VII ⬛ Loiter
VIII 🟨 Landing
VIII 🟥 Taxiing

**FLIGHT PROFILE**

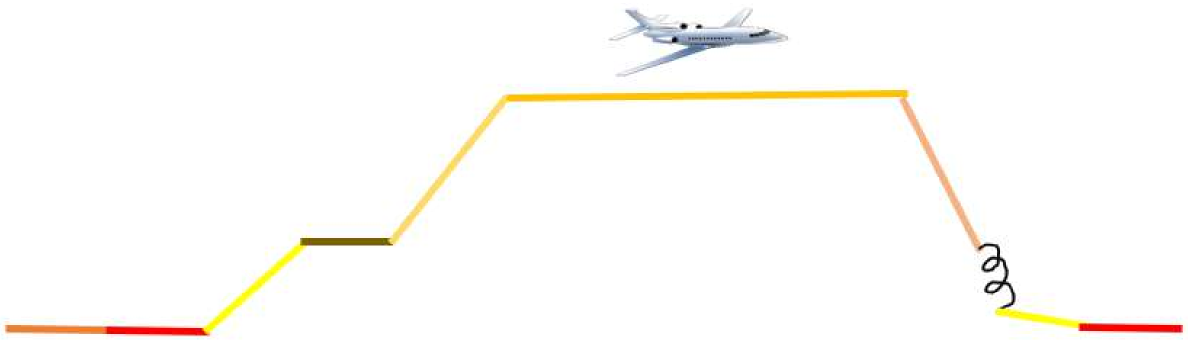


*Figure 6.1 FLIGHT PROFILE*

I. **ENGINE START & WARM UP:**

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

II. **TAXIING:**

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

III. **TAKE-OFF**:

The aircraft takes off into air from the ground surface.

IV. **CLIMB**:

The aircraft climbs to reach its maximum altitude.

V. **CRUISE**:

The aircraft travels in the maximum altitude in the cruising speed.

VI. **DESCENT**:

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

VII. **LOITER**:

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

VIII. **LANDING & TAXIING**:

The aircraft completes the journey and lands. After landing, the aircraft is taxied to the warehouse.

## 6.2 WEIGHT ESTIMATION

The following are the steps involved in weight estimation of the designed aircraft.

## 6.3 PAYLOAD WEIGHT

The following is the calculation for the maximum payload weight of the aircraft. Considering the maximum weight of 1 passenger as 175 lbs and maximum allowable baggage weight for each passenger as 30 lbs, For 4 passengers along with baggage, $W_{pl} = (W_{passenger} + W_{Baggage}) * (\text{No. of passengers})$

1. $W_{pl} = (175 * 4) + (4 * 30)$
2. $W_{pl} = 700 + 120$
3. $W_{pl}$=820lbs.

### 6.4 CREW WEIGHT

The following is the calculation for the maximum weight of the crew in the aircraft. Considering the maximum weight of 1 crew member as 175 lbs and maximum allowable baggage weight for each crew member as 30 lbs. For 2 crew members along with their baggage,

$W_{cr} = (W_{crew} + W_{Baggage}) * (\text{No. of crew members})$

$W_{cr} = (175 + 30) * 2$

$W_{cr} = 205*2$

$W_{cr}$=410lbs.

### 6.5 WEIGHT RATIO CALCULATIONS

The weight ratio are used to obtain the weight of the aircraft at various stages. It is then used to calculate $M_{ff}$ which is used in calculation of $W_{used}$. The below calculations are made considering $W_{To\ Guess}$ as Take-off weight i.e. 20,000 kgs or 44092.4 lbs.

The following tables are used to obtain the weight ratios of respective phases along with cruise and loiter,

**ENGINE START & WARM UP:**

The following calculation gives the weight of the aircraft in the engine start and warm up phase,

$$\frac{W_1}{W_{To\ Guess}} = 0.990$$

$W_1 = W_{To\ Guess} * 0.990$

$W_1 = 22046.23 * 0.990$

$W_1$=21825.54lbs.

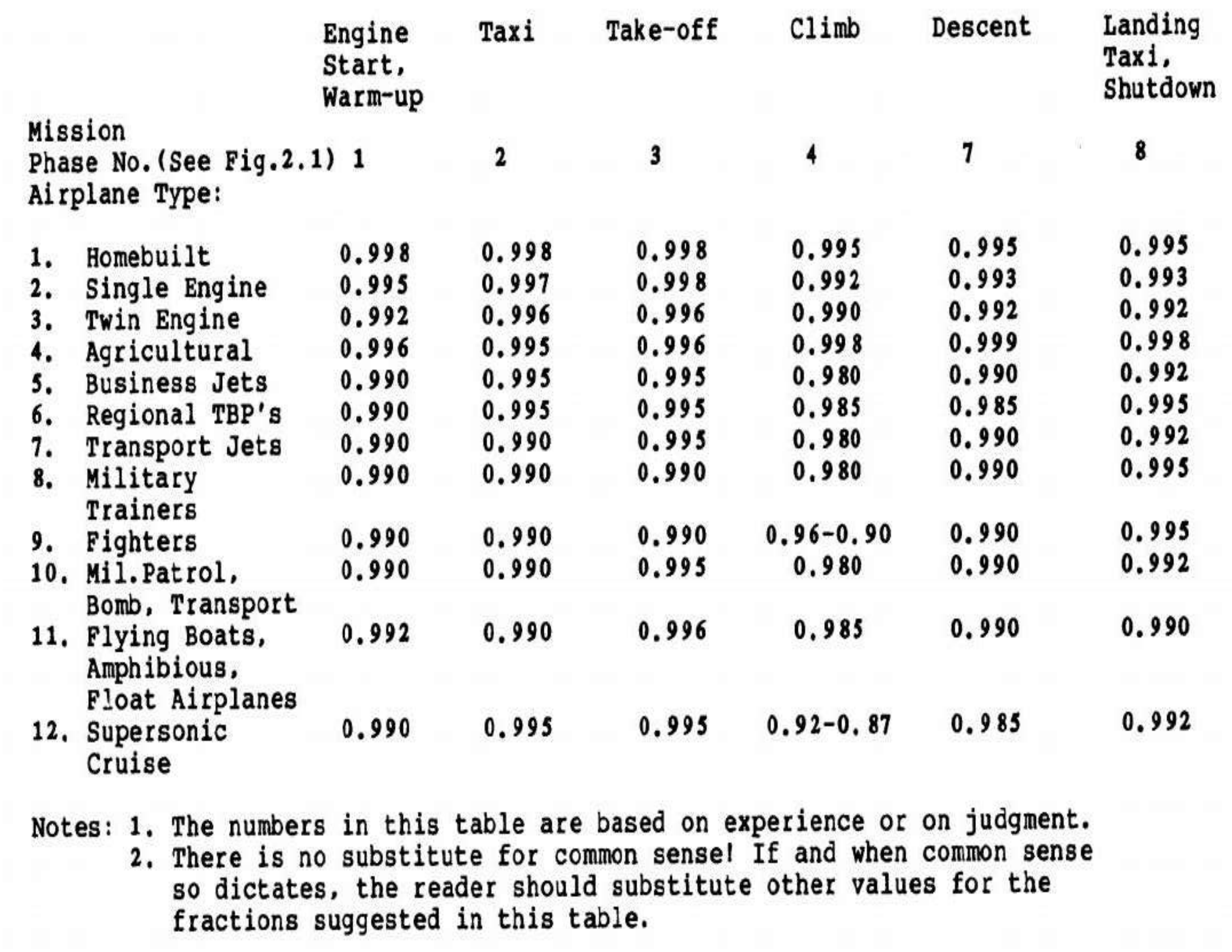
**I. TAXIING:**

The following calculation gives the weight of the aircraft in the taxiing phase,

$$\frac{W_2}{W_1} = 0.995$$

1. $W_2 = W_1 * 0.995$
2. $W_2 = 21825 * 0.995$
3. $W_2$=21716.4123lbs.

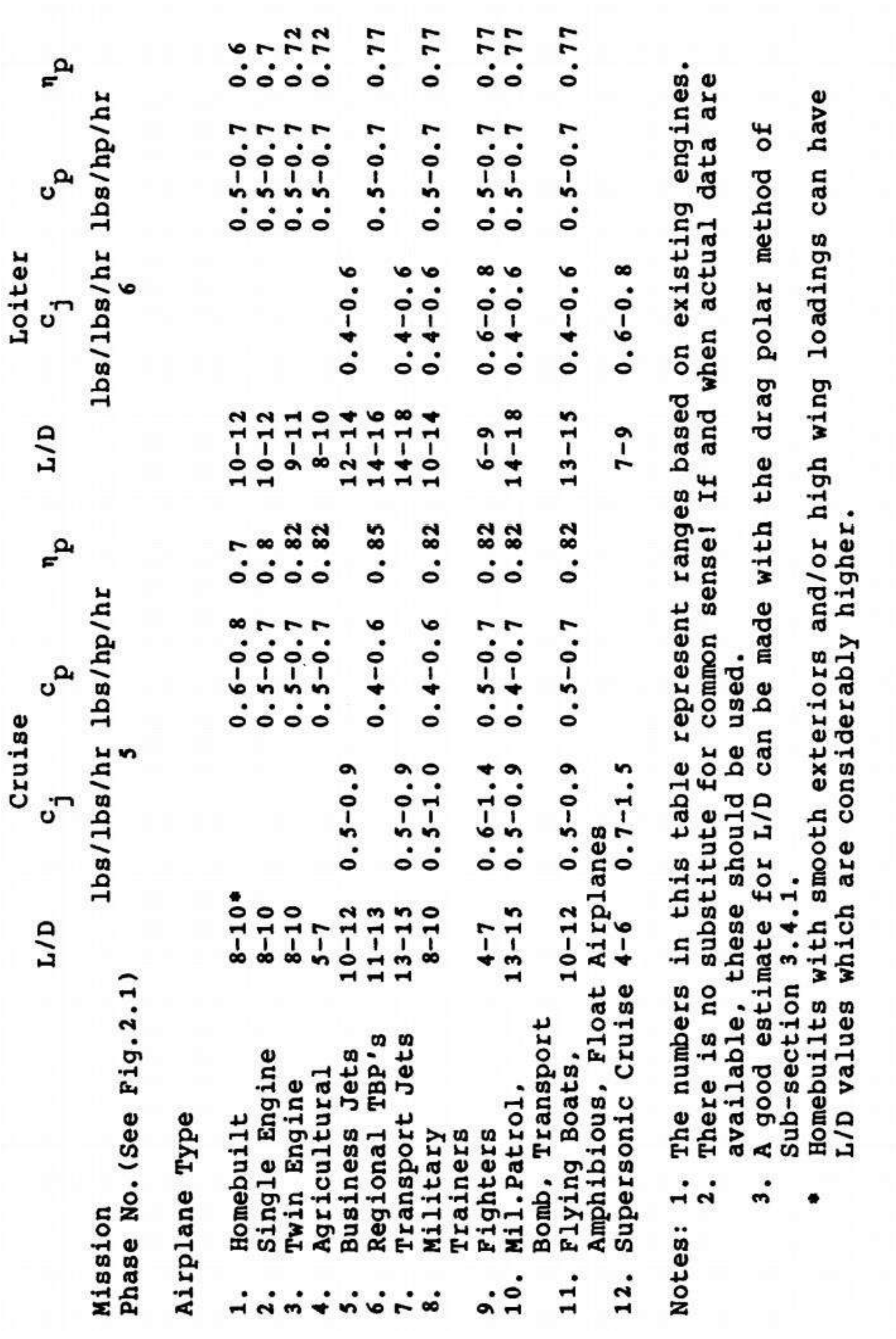
*Table 6.1 Fuel –Fraction for Several Mission Phases*



| Mission Phase No.(See Fig.2.1) | Engine Start, Warm-up | Taxi | Take-off | Climb | Descent | Landing Taxi, Shutdown |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 7 | 8 |
| Airplane Type: | | | | | | |
| 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.

*Table 6.2 Mission Cruise and loiter parameter for Several Phases*



| Mission Phase No. (See Fig.2.1) | Cruise L/D | Cruise $c_j$ lbs/lbs/hr | Cruise $c_p$ lbs/hp/hr | Cruise $\eta_p$ | Loiter L/D | Loiter $c_j$ lbs/lbs/hr | Loiter $c_p$ lbs/hp/hr | Loiter $\eta_p$ |
|---|---|---|---|---|---|---|---|---|
|  |  | 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.

### **II. TAKE-OFF**:

The following calculation gives the weight of the aircraft in the take-off phase,

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

4. $W_3 = W_2 * 0.995$
5. $W_3 = 21716.4123 * 0.995$
6. $W_3$=21607.83lbs.

### **III. CLIMB**:

The following calculation gives the weight of the aircraft in the take-off phase,

$$\frac{W_4}{W_3} = 0.980$$

$W_4 = W_2 * 0.980$

$W_4 = 21607.83 * 0.980$

$W_4$=21175.6734lbs.

### **IV. CRUISE**:

The Range of the jet aircraft is given by the following equation and $W_5$ is calculated from the same,

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

The following values are taken from the table,

$R_{cr}$ = 3603.953 miles

V = 528.16 mph

$C_j$ = 0.7

L/D = 11

⇨ $3603.953 = \left(\frac{528.16}{0.7}\right) * 11 * \ln\left(\frac{W_4}{W_5}\right)$

⇨ $\frac{3603.953}{8299.65} = \ln\left(\frac{W_4}{W_5}\right)$

⇨ $0.4342 = \ln\left(\frac{W_4}{W_5}\right)$

⇨ $0.960 = \frac{W_5}{W_4}$

⇨ $W_5$ = 13717.043 lbs

## V. DESCENT:

The following calculation gives the weight of the aircraft in the descent phase,

$$\frac{W_6}{W_5} = 0.990$$

- ⇨ $W_6 = W_2 * 0.990$
- ⇨ $W_6 = 13717.043 * 0.990$
- ⇨ $W_6 = 13580.2557$ lbs.

## VI. LOITER:

The Loiter time of the jet aircraft is given by the following equation and $W_7$ is calculated from the same,

$$E_{ltr} = \left(\frac{1}{C_j}\right)_{ltr} * \left(\frac{L}{D}\right) * \ln\left(\frac{W_7}{W_6}\right)$$

The following values are taken from the table 6.2,

$E_{ltr} = 1$ hour

$V = 528.16$ mph

$C_j = 0.5$

$L/D = 11$

- ⇨ $1 = \left(\frac{1}{0.5}\right) * \ 11 * \ln\left(\frac{W_7}{W_6}\right)$
- ⇨ $0.0227 = 11 * \ln\left(\frac{W_7}{W_6}\right)$
- ⇨ $1.023 = \frac{W_7}{W_6}$
- ⇨ $W_7 = 1.023 * 13580.2557$
- ⇨ $W_7 = 13892.601$ lbs

## VII. LANDING & TAXIING:

The following calculation gives the weight of the aircraft in the landing and taxiing phase,

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

⇨ $W_8 = W_2 * 0.990$

⇨ $W_8 = 13892.601 * 0.990$

⇨ $W_8 = 13{,}781.46$ lbs.

Calculation of $M_{ff}$ :

The $M_{ff}$ is given by the following formula,

$$M_{ff} = \left(\frac{W_8}{W_7}\right) * \left(\frac{W_7}{W_6}\right) * \left(\frac{W_6}{W_5}\right) * \left(\frac{W_5}{W_4}\right) * \left(\frac{W_4}{W_3}\right) * \left(\frac{W_3}{W_2}\right) * \left(\frac{W_2}{W_1}\right) * \left(\frac{W_1}{W_{To\ Guess}}\right)$$

⇨ $M_{ff} = (0.992) * (1.0229) * (0.990) * (0.6477) * (0.980) * (0.995) * (0.995) * (0.990)$

⇨ $M_{ff} = 0.625$

### 6.2.4 WEIGHT OF FUEL

The weight of the fuel, $W_f$ is calculated using the following formula, $W_f = (W_{used} + W_{res})$

Where, $W_{used} = (1 - M_{ff}) * W_{To\ Guess}$

$W_{res}$ = 10-25% of $W_{used}$

⇨ $W_{used} = (1 – 0.6283) * 22046.23$

⇨ $W_{used} = 8267.33$ lbs.

⇨ $W_{res}$ = 10% of $W_{used}$

⇨ $W_{res} = 8267.733$ lbs.

⇨ $W_f = (W_{used} + W_{res})$

⇨ $W_f = 8267.733 + 8267.733$

⇨ $W_f = 9094.063$ lbs.

### 6.2.5 $W_{OE\ Tentative}$

The $W_{OE\ Tentative}$ is calculated using the following formula, $W_{OE\ Tentative} = W_{To\ Guess} - W_f – W_{pl}$

Where, $W_{To\ Guess} = 44092$ lbs.

$W_f = 9094.063$ lbs.

$W_{pl} = 820$ lbs.

⇨ $W_{OE\ Tentative} = 22046.23 – 9094.063 – 820$

⇨ $W_{OE\ Tentative}$ = 12132.167 lbs.

### 6.2.6 $W_{E\ Tentative}$

The $W_{E\ Tentative}$ is calculated using the following formula, $W_{E\ Tentative} = W_{OE\ Tentative} - W_{TFO} - W_{crew}$

Where, $W_{OE\ Tentative}$ = 12132.167 lbs.

$W_{TFO}$ = NA for smaller aircrafts

$W_{crew}$ = 410 lbs.

⇨ $W_{E\ Tentative}$ =12132.167 - 0 – 410

⇨ $W_{OE\ Tentative}$ = 11722.167 lbs.

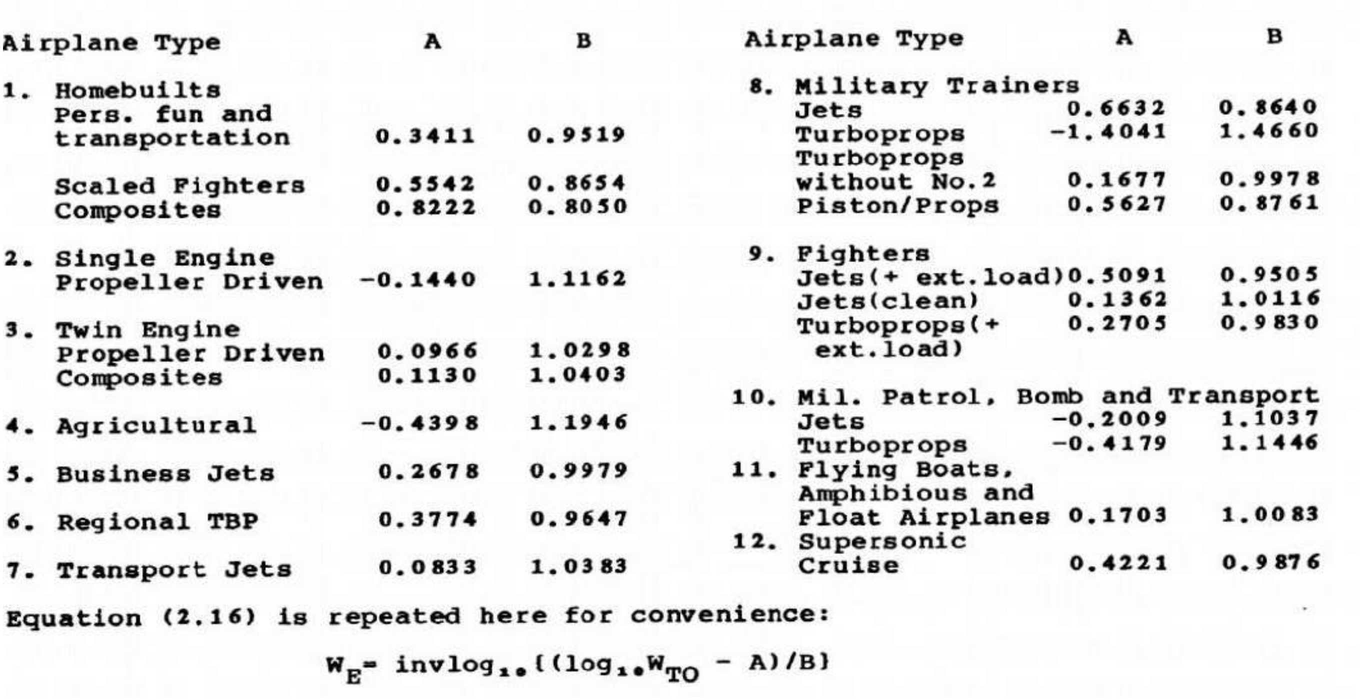
### 6.2.7 $W_{E\ Actual}$

The $W_{E\ Actual}$ is calculated using the following formula,

$$W_{E\ Actual} = inv\ \log_{10}\left[\frac{\log_{10} W_{To} - A}{B}\right]$$

The values of A and B are obtained from the following table,

*Table 6.3 $W_E$ Values*



| Airplane Type | A | B |
|---|---|---|
| 1. Homebuilts | | |
| Pers. fun and transportation | 0.3411 | 0.9519 |
| Scaled Fighters | 0.5542 | 0.8654 |
| Composites | 0.8222 | 0.8050 |
| 2. Single Engine Propeller Driven | -0.1440 | 1.1162 |
| 3. Twin Engine Propeller Driven | 0.0966 | 1.0298 |
| Composites | 0.1130 | 1.0403 |
| 4. Agricultural | -0.4398 | 1.1946 |
| 5. Business Jets | 0.2678 | 0.9979 |
| 6. Regional TBP | 0.3774 | 0.9647 |
| 7. Transport Jets | 0.0833 | 1.0383 |
| 8. Military Trainers | | |
| Jets | 0.6632 | 0.8640 |
| Turboprops | -1.4041 | 1.4660 |
| Turboprops without No.2 | 0.1677 | 0.9978 |
| Piston/Props | 0.5627 | 0.8761 |
| 9. Fighters | | |
| Jets(+ ext.load) | 0.5091 | 0.9505 |
| Jets(clean) | 0.1362 | 1.0116 |
| Turboprops(+ ext.load) | 0.2705 | 0.9830 |
| 10. Mil. Patrol, Bomb and Transport | | |
| Jets | -0.2009 | 1.1037 |
| Turboprops | -0.4179 | 1.1446 |
| 11. Flying Boats, Amphibious and Float Airplanes | 0.1703 | 1.0083 |
| 12. Supersonic Cruise | 0.4221 | 0.9876 |

Equation (2.16) is repeated here for convenience:

$$W_E = \text{invlog}_{10}\{(\log_{10} W_{TO} - A)/B\}$$

Where, A = 0.2678

B = 0.9979

⇨ $W_{E\ Actual} = inv\ \log_{10}\left[\frac{\log_{10}(22046.23)-0.2678}{0.9979}\right]$

⇨ $W_{E\ Actual} = inv\ \log_{10}\left[\frac{22046.23}{0.9979}\right]$

⇨ $W_{E\ Actual} = 12{,}136.9892\ lbs.$

### 6.2.8 Error percentage

The Error is given by the following formula,

$$Error\ \% = \left[\frac{W_{E\ Actual} - W_{E\ tentaive}}{W_{E\ Actual}}\right] * 100$$

Where, $W_{E\ Actual}$ = 12136.9892 lbs.

$W_{E\ Tentative}$ = 11722.167 lbs.

⇨ $Error\ \% = \left[\frac{12136.9892 - 11722.167}{12136.9892}\right] * 100$

⇨ $Error\ \% = \left[\frac{414.8222}{12136.9892}\right] * 100$

⇨ $Error\ \% = 0.034 * 100$

⇨ Error % = 3.4 %

### 6.2.9 RESULT

Thus, the weight estimation for the aircraft has been calculated and all the values can be observed from the above steps. The weight estimation has been done with an error percentage of 1.5% which ensures the accuracy of the calculations done. The following data are obtained from the calculations,

*Table 6.4 Weight Parameters*

| Name | Parameters |
|---|---|
| Take Off Weight | 44092 lbs. |
| Fuel Weight | 9094.063 lbs. |
| Actual weight | 12,1369892 lbs. |

# CHAPTER 07

# WING AND AEROFOIL SELECTION

## 7.1 WING SELECION:

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.

## 7.2 NUMBER OF WINGS

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

- Monoplane
- Biplane
- Triplane

### 7.2.1MONOPLANE:

A **monoplane** is a fixed-wing aircraft configuration with a single mainplane, in contrast to a biplane or other types of multiplanes, which have multiple planes.

A monoplane has inherently the highest efficiency and lowest drag of any wing configuation and is the simplest to build. However, during the early years of flight, these advantages were offset by its greater weight and lower manoeuvrability, making it relatively rare until the 1930s. Since then, the monoplane has been the most common form for a fixed-wing aircraft.

*Figure 7.1 Monoplane*

### 7.2.2 BIPLANE

A **biplane** is a fixed- wing aircraft with two main wings stacked one above the other. The first powered, controlled aeroplane to fly, the wright flyer, used a biplane wing arrangement, as did many aircraft in the early years of aviation. While a biplane wing structure has a structural advantage over a monoplane, it produces more drag than a monoplane wing. Improved structural techniques, better materials and higher speeds made the biplane configuration obsolete for most purposes by the late 1930s.

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.

*Figure 7.2 Biplane*

### 7.2.3 TRIPLANE

A triplane arrangement has a narrower wing chord than a biplane of similar span and area. This gives each wing-plane a slender appearance with higher aspect ratio, making it more efficient and giving increased lift. This potentially offers a faster rate of climb and tighter turning radius, both of which are important in a fighter. The Sopwith triplane was a successful example, having the same wing span as the equivalent biplane, the Sopwith pup. Alternatively, a triplane has reduced span compared to a biplane of given wing area and aspect ratio, leading to a more compact and lightweight structure. This potentially offers better manoeuvrability for a fighter, and higher load-capacity with more practical ground handling for a large aircraft type.

*Figure 7.3 Triplane*

### 7.3 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.
- Mono plane has lower span and chord, reducing the structural forces and allowing it to be lighter.

### 7.4 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

### 7.4.1 CANTILEVER

A cantilever is a rigid structural element, such as a beam or a plate, anchored at one end to a usually vertical support from which it protrudes; this connection could also be perpendicular to a flat, vertical surface such as a wall. Cantilevers can also be constructed with trusses or slabs. These types of wings are mostly preferred in modern aircrafts.

*Figure 7.4 Cantilever*

### 7.4.2 SEMI-CANTILEVER

The semi-cantilever usually has one, or perhaps two, supporting wires or struts attached to each wing and the fuselage. 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 semi-cantilever.

*Figure 7.5 Semi-Cantilever*

## 7.5 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 arm.

## 7.6 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,

- High wing
- Mid wing
- Low wing
- Shoulder
- Parasol

### 7.6.1 HIGH WING

A high wing is a configuration with the wings set on the top of the airplane's body, called the fuselage. By design they provide both shade in the sun and an "umbrella" in the rain for passengers during boarding or debarking. On the ground they offer clearance over many fences.

*Figure 7.6 High Wing*

### 7.6.2 MID WING

A mid-wing configuration places the wings exactly at the midline of the airplane, at half of the height of the fuselage. The mid-wing also has neutral roll stability, which is good from the perspective of combat and aerobatic aircraft as it allows for the performance of rapid roll manoeuvres with minimum yaw coupling.

*Figure 7.7 Mid Wing*

### 7.6.3 LOW WING

Fuelling a low wing airplane usually does not involve a step ladder, and neither does checking the security of the fuel caps. The low wing being closer to the ground may allow for a shortened take-off roll and faster acceleration because of ground effect.

*Figure* 7.8 Low Wing

### 7.6.4 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.

*Figure 7.9 Shoulder Wing*

### 7.6.5 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.

*Figure 7.10 Parasol Wing*

### 7.7 SELECTION:

The **low wing** configuration is chosen for the wing location. The reason for the selection are 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 effect than high-wing.

### 7.8 WING PLANFORM

The wing planform allows the aircraft to have more control for stability and maneuverability. Wings are classified based on their planform as follows,

- Rectangle
- Elliptical
- Tapered
- Swept
  - Swept forward
  - Swept backward
- Delta
  - Ogival
  - Cranked
  - Compound

- Cropped
- Tailed
- Tailless

### 7.8.1 RECTANGLE WING

Arguably the simplest wing planform from a manufacturing point of view, the rectangular wing is a straight, untapered wing.

*Figure 7.11 Rectangle Wing*

### 7.8.2 ELLIPTICAL WING

Aerodynamically, the elliptical plan form is the most efficient as elliptical span wise lift distribution has the lowest possible induced drag (as given by thin aerofoil theory). However, the most important disadvantage of the elliptical wing is that its manufacturability is poor.

*Figure 7.12 Elliptical Wing*

### 7.8.3 TAPERED WING

This is a modification of the rectangular wing where the chord is varied across the span to approximate the elliptical lift distribution. While not as efficient as the elliptical lift distribution, it offers a compromise between manufacturability and efficiency.

*Figure 7.13 Tapered Wing*

### 7.8.4 SWEPT WING

A swept wing is a wing that angles either backward or occasionally forward from its root rather than in a straight sideways direction. Wing sweep has the effect of delaying the shock waves and accompanying aerodynamic drag rise caused by fluid compressibility near the speed of sound, improving performance. The swept wings are classified as,

- Swept forward
- Swept backward

#### 7.8.4.1Swept forward:

Forward-swept wings make an aircraft harder to fly, but the advantages are mainly down to maneuverability. Wing sweep has the effect of delaying the shock waves and accompanying aerodynamic drag rise caused by fluid compressibility near the speed of sound, improving performance. They maintain airflow over their surfaces at steeper.

*Figure 7.14 Swept forward*

#### 7.8.4.2 Swept backward:

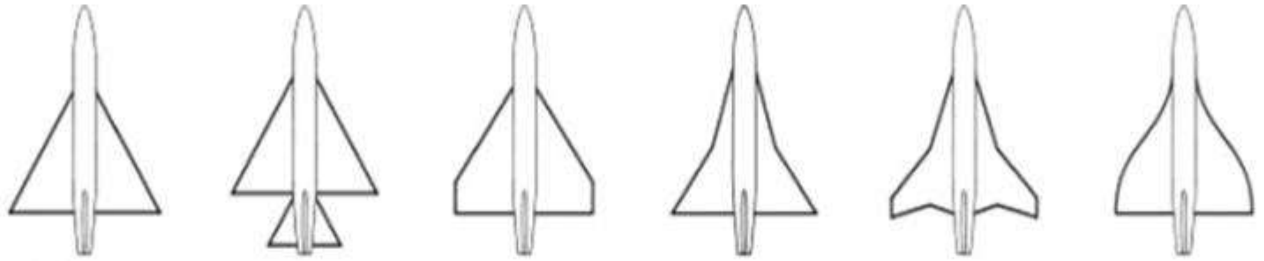
The leading edges of these wings are swept back. This is done order to reduce drag in transonic speeds, which is determined by the velocity normal to the wind. A swept wing is a wing that angles either backward.

*Figure 7.15 Swept Backward*

### 7.8.5 DELTA WING

The delta wing is a wing shaped in the form of a triangle. It is named for its similarity in shape to the Greek uppercase letter delta. Although long studied, it did not find significant applications until the jet age, when it proved suitable for high-speed subsonic and supersonic flight. The delta wings are classified as,

a. Tailless
b. Tailed
c. Cropped
d. Compound
e. Cranked
f. Ogival



(a) Tailless delta (b) Tailed delta (c) Cropped delta (d) Compound delta (e) Cranked arrow (f) Ogival delta

*Figure 7.16 Delta Wing*

**a. Tailless delta:**

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.

**b.Tailed delta:**

A conventional tail stabilizer allows the main wing to be optimized for lift and therefore to be smaller and more highly loaded.

**c.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, merges into the "tapered swept" configuration.

**d.Compound 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 foreplane.

**e.Cranked delta:**

The goal of the cranked arrow was to have a high sweep inboard panel for low drag at supersonic speeds, and a low sweep outboard panel to provide better handling and maneuverability at subsonic speeds.

**d.Ogival delta:** The Ogive is a type of supersonic wing used in high-speed aircraft. This is a complex mathematical shape derived for minimizing drag, especially at supersonic speeds. They offer excellent supersonic performance, with minimal drag.

## 7.9 SELECTION:

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

- Wing sweep has the effect of delaying the shock waves and accompanying aerodynamic drag rise caused by fluid compressibility near the speed of sound, improving performance.
- Swept-back wing can be longitudinally stable on its own, without needing a horizontal tail plane.

## 7.10 WING ANGLE

The angle of the wing plays a major role in generating lift for the aircraft. The angles in a wing are classified as follows,

- Anhedral
- Straight
- Dihedral

### 7.10.1 ANHEDRAL

Anhedral angle, the downward angle from horizontal of the wings or tail plane of a fixed-wing aircraft. Anhedral angles are also seen on aircraft with a high mounted wing.

*Figure 7.17 Anhedral*

### 7.10.2 STRAIGHT

The straight wing does not have any angle between the base of root chord and tip chord. These wings are naturally stable and generate enough lift in straight conditions.

*Figure 7.18 Straight*

### 7.10.3 DIHEDRAL

Dihedral angle is the upward angle from horizontal of the wings or tail plane of a fixed-wing aircraft. It has a strong influence on dihedral effect.

*Figure 7.19 Dihedral*

## 7.11 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.
- Dihedral effect is a critical factor in the stability of an aircraft about the roll axis so it is also present little.

## 7.12 REYNOLDS NUMBER

The Reynolds number for our working conditions of the aircraft can be found by using the following formula,

$$R_e = \frac{\rho * V * l}{\mu}$$

Where, $\rho = 0.193\ \text{kg/m}^3$

$\mu = 1.4*10^{(-5)}$ Ns/m^2

l = 2.1 m

V = 236.11 m/s

Re $=0.193 * 236.11 * 0.00889416$

$=0.193 * 236.11 * 1.70.000014322$

Re =68.35*10^ (5)

Thus, the Reynolds number for our conditions is found to be 68.35*10^ (5).

## 7.13MORPHING WINGS:

### 7.13.1 Introduction:

Morphing wing technology has been a part of the aviation industry since the Wright Brothers used morphing wing technology for the Wright Flyer, and the type of morphing wing used back then was twisting wing, which was done with the help of bicycle tubes and cardboard, but in order to improve morphing wing technology to produce more effective results aerodynamically, as well as increase lift and lower drag performances, better materials with better mechanisms had to be used.

The aviation industry has been researching techniques to improve aerodynamic performance and maximise lift-to-drag ratio in all flight circumstances. Currently, mainly fixed wings are widely utilised throughout the world, but the outcomes are not what researchers and designers had hoped for. To address this, researchers looked back to when the Wright Flyer used twist morphing and came up with a way to use and improve morphing wing technology. The morphing wing is the best approach to obtain high aerodynamic performance and also boosts lift to drag ratio in all flying scenarios by altering its shape depending on the situations, while the fixed wing cannot be used properly and efficiently in all flight conditions.

### 7.13.2History:

Since the Wright Brothers, morphing wings have been used in the aviation business. During that time, the Wright Brothers decided to utilise a twist morphing wing, which is an out-of-plane sort of morphing wing, to roll the plane, and it worked. As time went on, more and more aeronautical engineers became interested in morphing wing concepts and began to experiment; the challenge they encountered was finding materials that could be used efficiently and at a reasonable cost. The aircraft X-5 was flown in 1951 with a variable sweep wing that could change shape depending on speed and was quite efficient, and later aircrafts such as the F14 and F111 used the same design geometry, but this time the material was Titanium, which was very strong and light and is still used in the aviation industry. Designers were confronted with the issue of weight, which is still an issue for morphing wing aircraft, but they didn't let it stop them. Many designers developed morphing wing technology and applied it to smaller scale aircraft, which included chord changing, leading and trailing edge changing, and flaps changing.

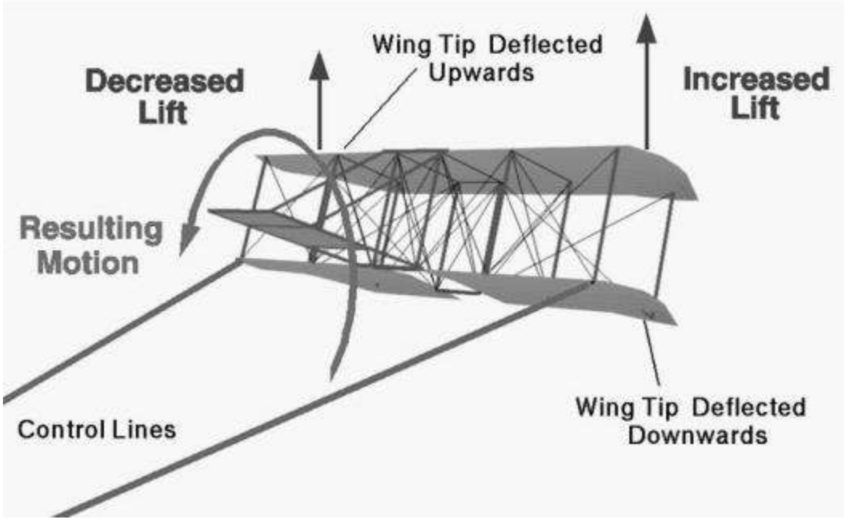


*Figure 7.20 Wright brothers having twist morphing*

### 7.13.3 Birds Know Best:

The best example of morphing at work is birds. Researchers have known for a long time that birds adjust their wing structures in flight to perform various manoeuvres based on observations. When a peregrine falcon dives for its prey, its wing form changes to move from economical cruise to aggressive manoeuvre. The shift in wing structure allows the bird to reduce drag, enhancing its energy efficiency in catching prey - which translates to fuel economy in planes. Airplanes can behave more like birds thanks to wing-morphing technology, which improves their performance in a variety of flight scenarios.

Humans have been fascinated and envious of birds from the ground for thousands of years. Humans' urge to fly, and ultimately the development of aeroplanes, stems from their curiosity about how birds are able to soar in the air. Because birds serve as a source of inspiration for aeroplane design, planes should reportedly resemble birds in order to be more energy efficient. In many ways, though, aeroplanes today resemble birds in appearance. In reality, experts have discovered that aeroplanes can achieve greater efficiency if they can "behave" more like birds in flight, and morphing technology allows them to do so.

### 7.13.4 Adaptive wing:

Morphing wings can be incorporated into adaptive wings, which increases lift and reduces stall speed during take-off and landing. In order to execute morphing and adjust aerodynamics according to the given scenario, devices are fitted in the leading and trailing edges.

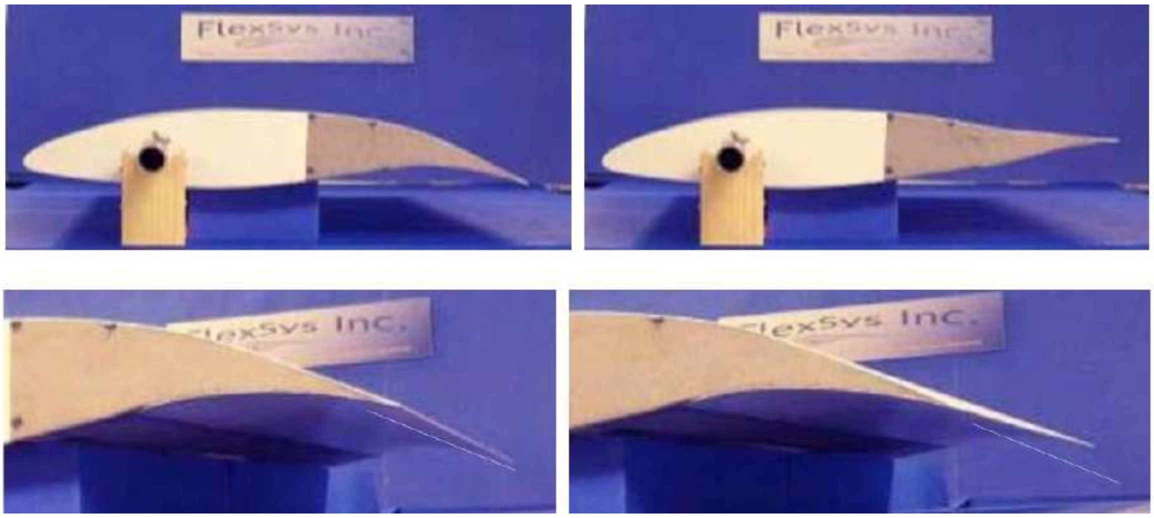


*Figure 7.21 Adaptive Wing*

### 7.13.5 Multidisciplinary Approach:

The interdisciplinary method is a passive morphing technique that reduces the amount of energy required for actuation, resulting in increased energy efficiency. In reality, this is quite similar to a bird's flight mechanism. According to Fausz, it can be split down into three processes: sensing, computation, and actuation.

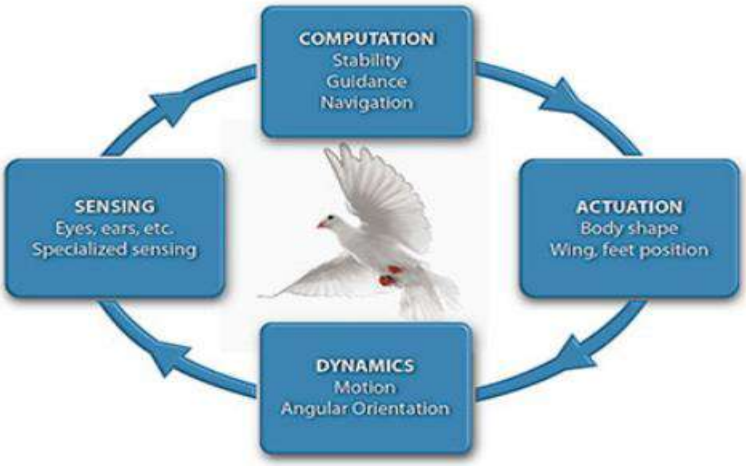


*Figure 7.22 Multidisciplinary Approach*

### 7.13.6 Sensing:

A bird must be able to detect and sense the air conditions around it, as well as its own position, in order to take the appropriate action in a particular situation. Sensor equipment is also required for a morphing aeroplane to react accurately to the surrounding environment, such as air pressure, altitude, air speed, and its position relative to other object

### 7.13.7Computation:

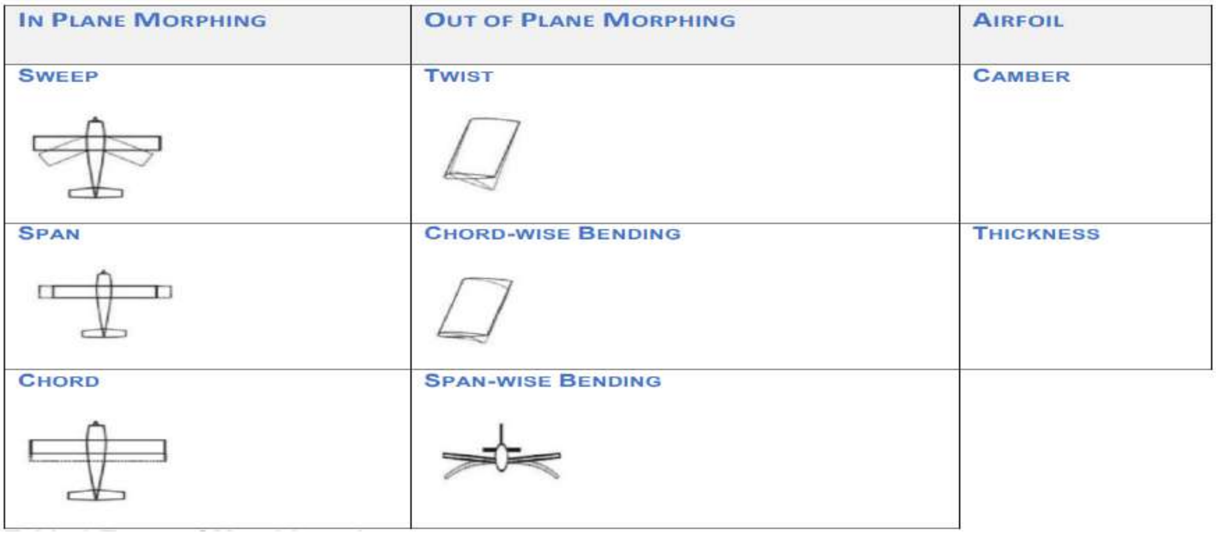
The sensor inputs will be integrated and analysed in the brain of the bird, or alternatively, the flight computer of a morphing aeroplane, after enough data has been collected. Flight stability is critical as the plane morphs and changes shape, and it must be maintained throughout the flight. As a result, the control system must receive the inputs from the sensors, compute the necessary responses using finite element software, and output commands that activate actuation with the least amount of energy.

### 7.13.8 Actuation:

Not only does morphing flight necessitate specific structures, but it also necessitates specialised actuators to move and position those structures. To optimise an airplane's performance, the actuator components receive commands from the control system and adjust the wing shape accordingly.

### 7.13.9 Types of Morphing wings:

Morphing wing technology is a vast subject in aviation industry. Since it is such an extraordinary technology there are many varieties in morphing wing too. Morphing wing is divided into these categories as shown in table below:



| In Plane Morphing | Out of Plane Morphing | Airfoil |
|---|---|---|
| Sweep | Twist | Camber |
| Span | Chord-wise Bending | Thickness |
| Chord | Span-wise Bending | |

*Figure 7.23 Types of Morphing wings*

### 7.14.SELECTION:

It’s a symmetric wing with trailing edge shape morphing, that has the ability to change to an under cambered air foil. It can also act as a controlling surface as well as a hyper lift mechanism.

The prototype is a model of 3D printed using flexible PLA and normal PLA. As by the name, the wing ribs are replaced with spokes that allows the wing to change its shape, as well as retain its structural strength.

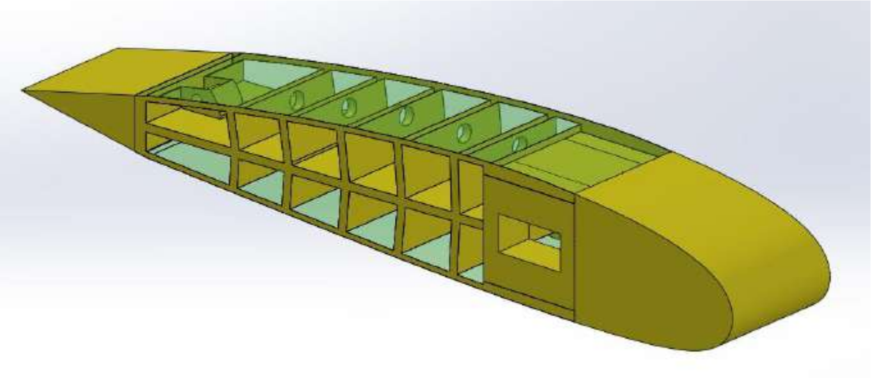


*Figure 7.24 Morphing Wing*

All of the spokes in the middle of the wing are exactly angled parallel to the lift force at that specific point.

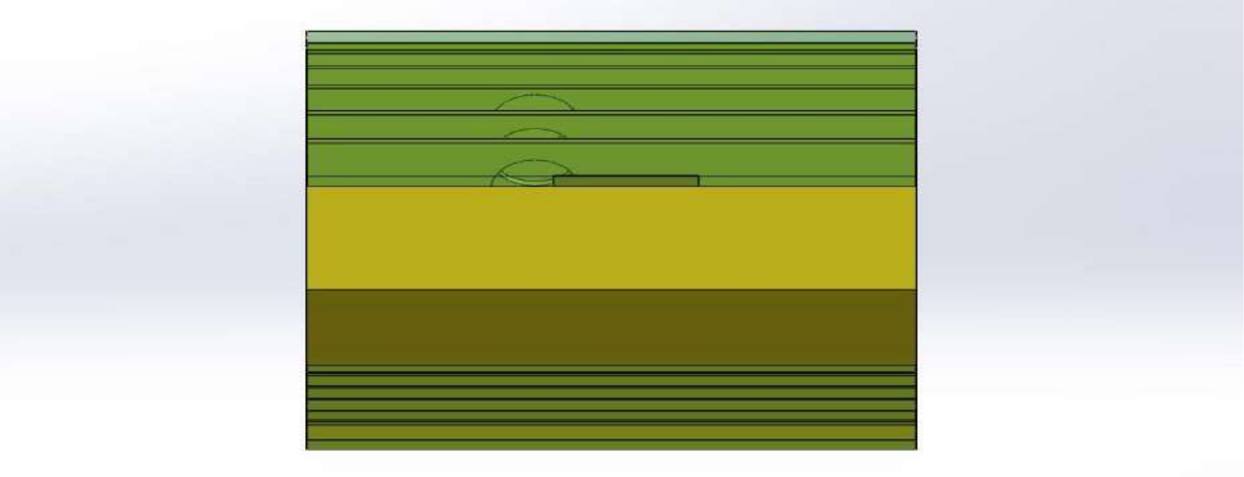


*Figure 7.25 Top View*

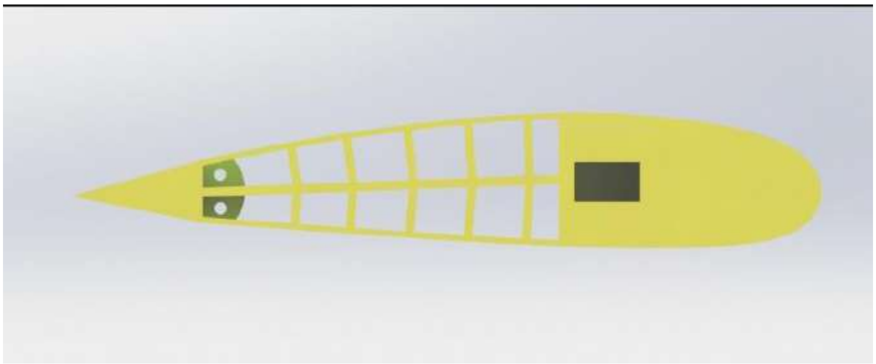


*Figure 7.26 Side view*

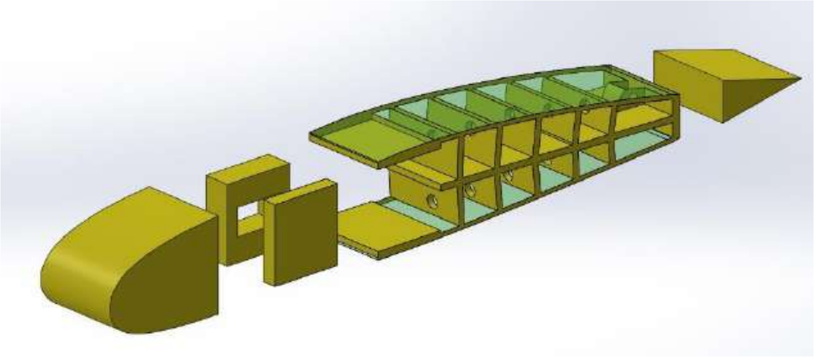


*Figure 7.27  Segmented view*

## 7.15. PARTS USED:

### 7.15.1Flexible Spokes:

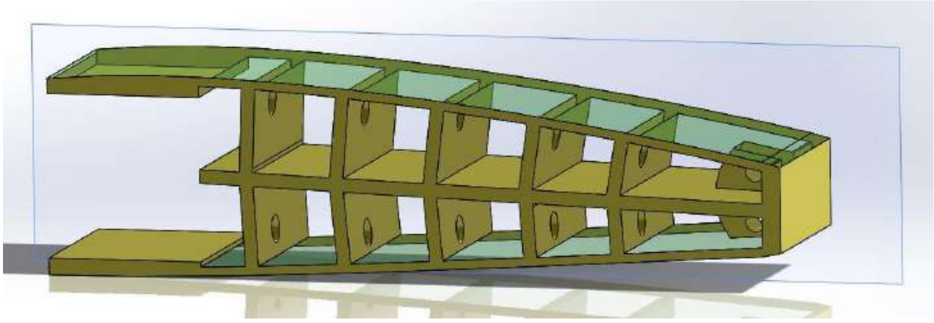


*Figure 7.28 Flexible spokes*

### 7.15.2 Leading Edge:

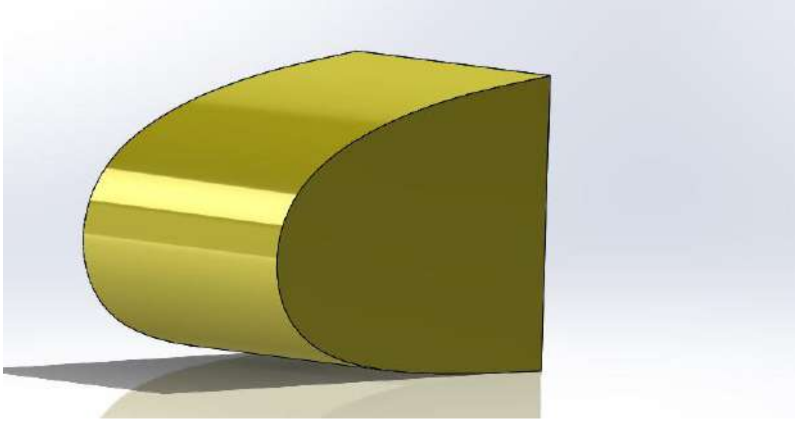


*Figure 7.29 Leading edge*

### 7.15.3 Trailing Edge:

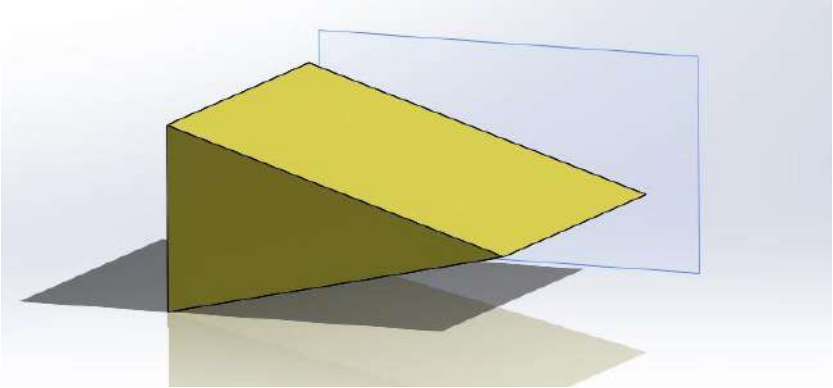


*Figure 7.30 Tail*

### 7.15.4 Servo Holder & Support:

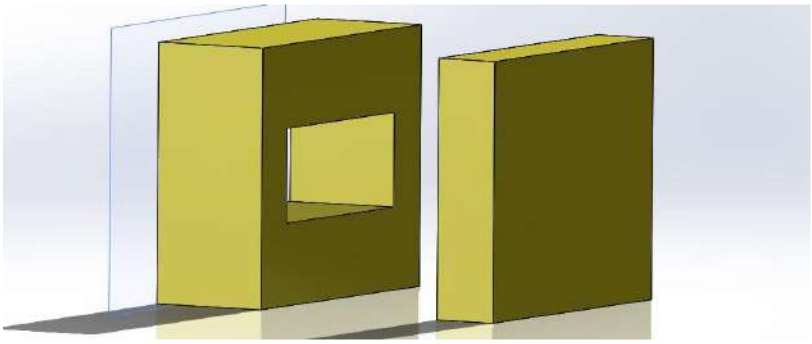


*Figure 7.31 Servo Holder*

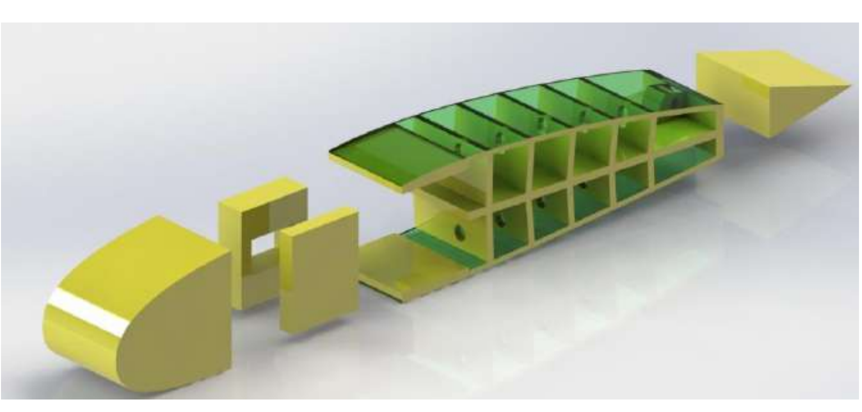


*Figure 7.32 Segmented Parts*

### 7.15.6 ASSEMBLED PART:

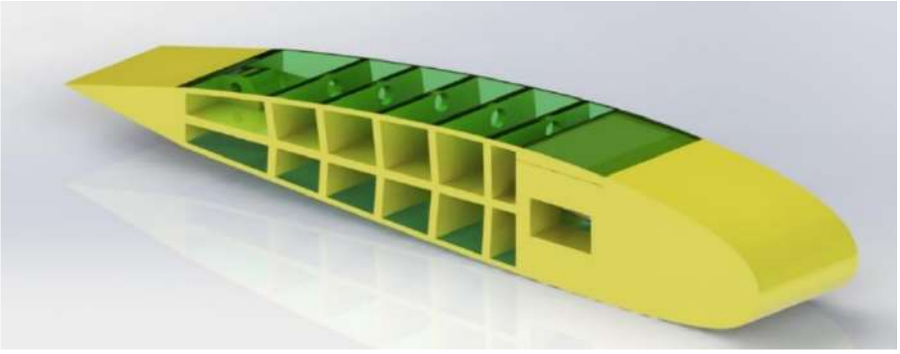


*Figure 7.33 Morphing with Assembly*

These shows the schematic of the Fish BAC design, which was driven by servo motors. Two tendons are attached to the solid trailing edge section, and the torque generated by the servo motors is transferred onto the spine, which will cause the deformation of the spine.

### 7.16 AIRFOIL SELECTION

The below table gives the table of selected airfoils and their respective information,

*Table 7.1 Airfoil Data*

| **Name of Airfoil** | **Thickness %** | **Cambered %** | **Alpha max** | **Cl $_{max}$** | **(L/D) $_{max}$** | **(Cl/Cd) $_{max}$** | **Cd$_{min}$** | **Min Coeff of moment** | **Stall angle** | **Stall quality** |
|---|---|---|---|---|---|---|---|---|---|---|
| **NACA 0015** | 15% AT 30% CHORD | 0 | 19.25 | 1.3972 | 1.17 | 75.1 | 0.0777 | 0.0224 | 3.2 | good |
| **NACA 0008** | 8% AT 30% CHORD | 0 | 15 | 1.0725 | 1.01 | 69.93 | 0.0994 | -0.0178 | 3 | good |
| **EPPLER 520** | 15% AT 36.7% CHORD | 0 | 19.25 | 1.1612 | 0.98 | 67.48 | 0.1052 | 0.002 | 6 | medium |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **NACA 0024** | 24% AT 30% CHORD | 0 | 19.25 | **1.3042** | 1.95 | 90.72 | 0.0717 | 0.0434 | 8 | medium |
| **E 474-Il** | 14.1% AT 21.5% CHORD | 0 | 18.25 | 1.2075 | 1.43 | 88.71 | 0.0852 | 0.0259 | 12 | medium |

### 7.16.2 SELECTION:

The **NACA 0015** airfoil has been selected for the aircraft. The diagram shows the selected airfoil

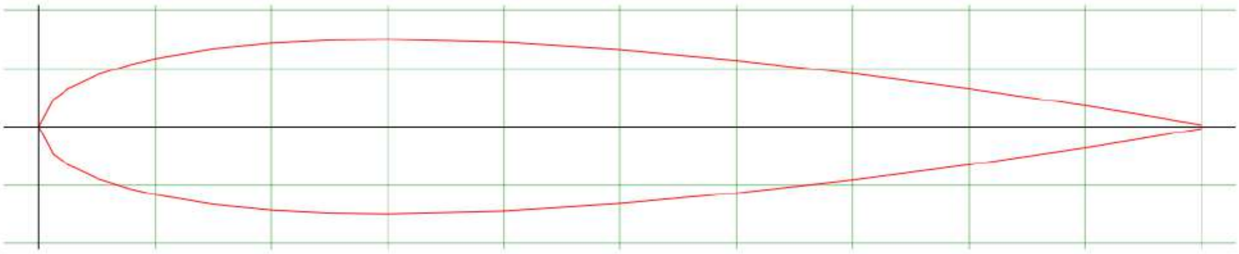


*Figure 7.34 NACA 0015 AIRFOIL*

The NACA 0015 airfoil is symmetrical, the 00 indicating that it has no camber. The 15 indicates that the airfoil has a 15% thickness to chord length ratio: it is 15% as thick as it is long.

The following is the selected airfoil parameters.

*Table 7.2 NACA 0015 Data*

| **NASA SC (2)-0714** | |
|---|---|
| Thickness% | 15 at 30% chord |
| Camber% | 0% |
| $\alpha_{max}$ | 19.250 |
| $Cl_{max}$ | 1.3972 |

|  |  |
|---|---|
| (L/D) max | 1.17 |
| (Cl/Cd) max | 75.1 |
| Stall angle | 3.2 |
| (Cd) min | 0.07771 |
| $C_m$ | 0.0224 |
| Stall quality | Good |

## 7.17 PERFORMANCE CURVES

The performance curves for the selected airfoil are given as follows,

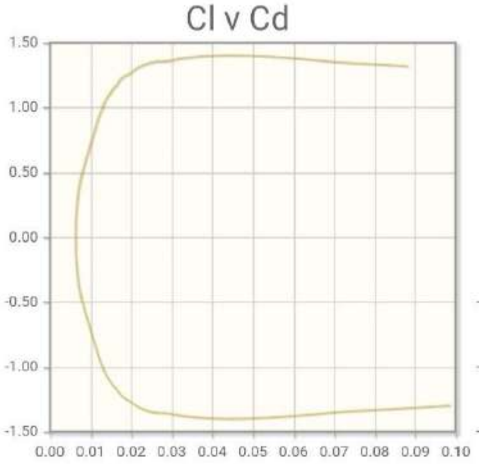


*Figure 7.35 $C_L$ Vs $C_d$*

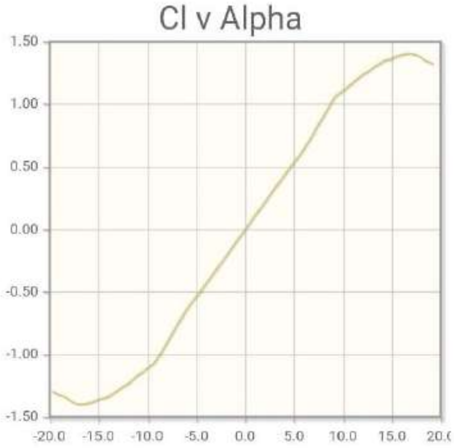


*Figure 7.36 $C_L$ Vs α*

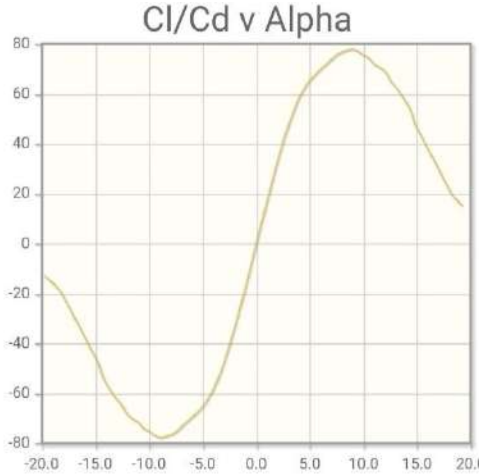


*Figure 7.37 $C_l$ Vs $C_d$*

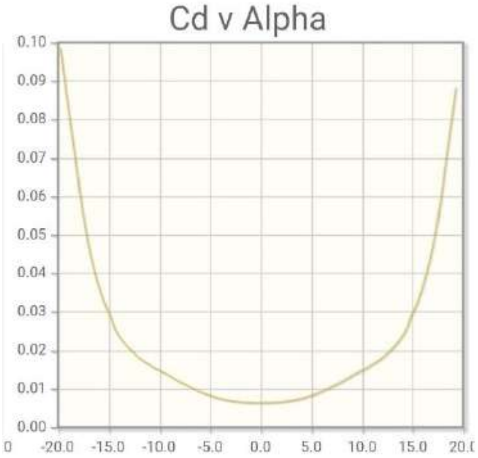


*Figure 7.38 $C_d$ Vs α*

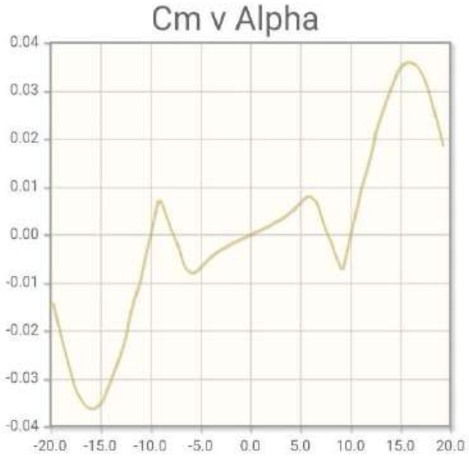


*Figure 7.39 $C_m$ Vs α*

## 7.18 WING SETTING ANGLE

The wing setting angle for business jets are generally between, $2\text{-}4^0$

The selected wing setting angle for our aircraft, $\alpha_{set} = 3^0$

## 7.19 ASPECT RATIO

The aspect ratio is selected from **Chapter 4 – 4.1.1** in the tentative parameters.

The Aspect ratio for our aircraft, A.R. = 8

## 7.20 TAPER RATIO (λ)

The taper ratio for a tapered wing varies from 0 to 1.

The taper ratio for the wing of our aircraft, $\lambda = 0.7$

### 7.20.1 ROOT CHORD $C_{Root}$

The Chord root is given by the formula,

$C_{Root} = 2*S/b*(1+\lambda)$

$C_{Root} = 2*S/b*(1+\lambda)$

Where, λ is the Taper ratio

$C_{Root} = 2*38 * (1+0.7)$

$C_{Root} = 2*38 * (1+0.7)$

$C_{Root} = 2.55$ m

**$C_{Tip}$**

The Chord tip is given by the formula,

$C_{Tip} = \lambda * C_{Root}$

Where, λ is the Taper ratio

$C_{Tip}$= 0.7∗ 2.55

$C_{Tip}$ = 1.79 m

**$C_{Mean}$ ,**

The Chord mean is given by the formula,

$C_{Mean}$=2/3∗ $C_{Root}$ $(1+\lambda+\lambda^2)/(1+\lambda)$

$C_{Mean}$= 2/3∗ 2.55$(1+0.7+0.7^2)/(1+0.7)$

$C_{Mean}$ = 2.19

**$C_{lmax}$**

The wing lift coefficient is given by the formula,

$C_{lmax}$ =2∗ W/ρ∗ $V^2_{Cruise}$∗S

$C_{lmax}$=2∗ W/ρ∗ $V^2_{Cruise}$∗S

Where, W is the Take-Off weight

ρ is the Density at cruise altitude

V is the Cruise velocity

S is the Wing area

$C_{lmax}$ = 2∗10000/1.225∗850∗38

$C_{lmax}$ = 0.51

## 7.21CONCLUSION

*Table 7.3 Selected Wing Parameters*

| Name | Parameters |
|---|---|
| Wing setting angle | $3^0$ |
| Aspect Ratio | 8 |
| Wing Area | 38 $m^2$ |
| Wing Span | 17.5 m |

| | |
|---|---|
| Taper Ratio | 0.7 |
| $C_{Root}$ | 2.55 m |
| $C_{Tip}$ | 1.79 m |
| $C_{Mean}$ | 2.19 m |
| $C_{Lmax}$ | 0.51 |

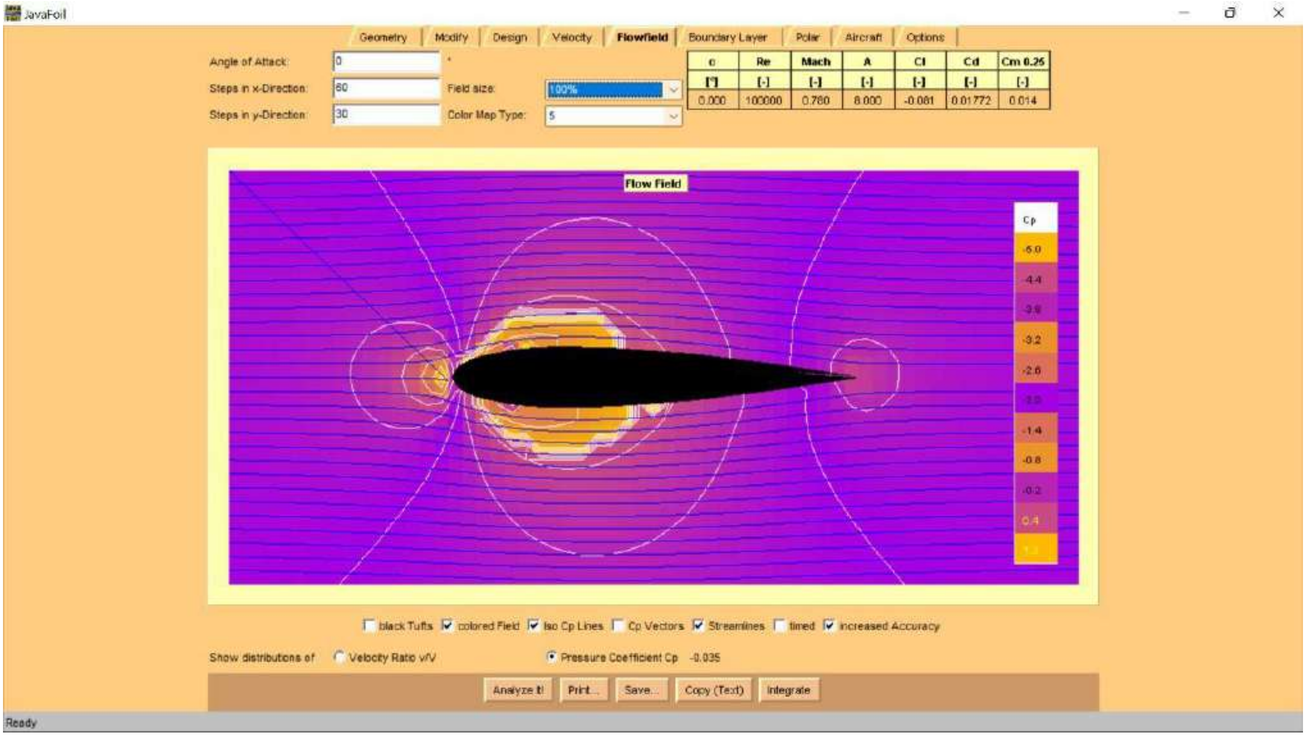
## 7.22 ACCESSORIES:

The Accessories for the wings are predominantly lift generating structures that are attached in the aircraft wings. The aircraft has the following accessories in its wings,

- Winglets
- Flaps

## 7.23 LIFT AND PRESSURE DISTRIBUTION:

The analysis is carried out for a free-stream velocity at zero angle of attack for NACA 0015 and the respective contour of static pressure is obtained.



Angle of Attack: 0 °

Steps in x-Direction: 80

Steps in y-Direction: 30

Field size: 100%

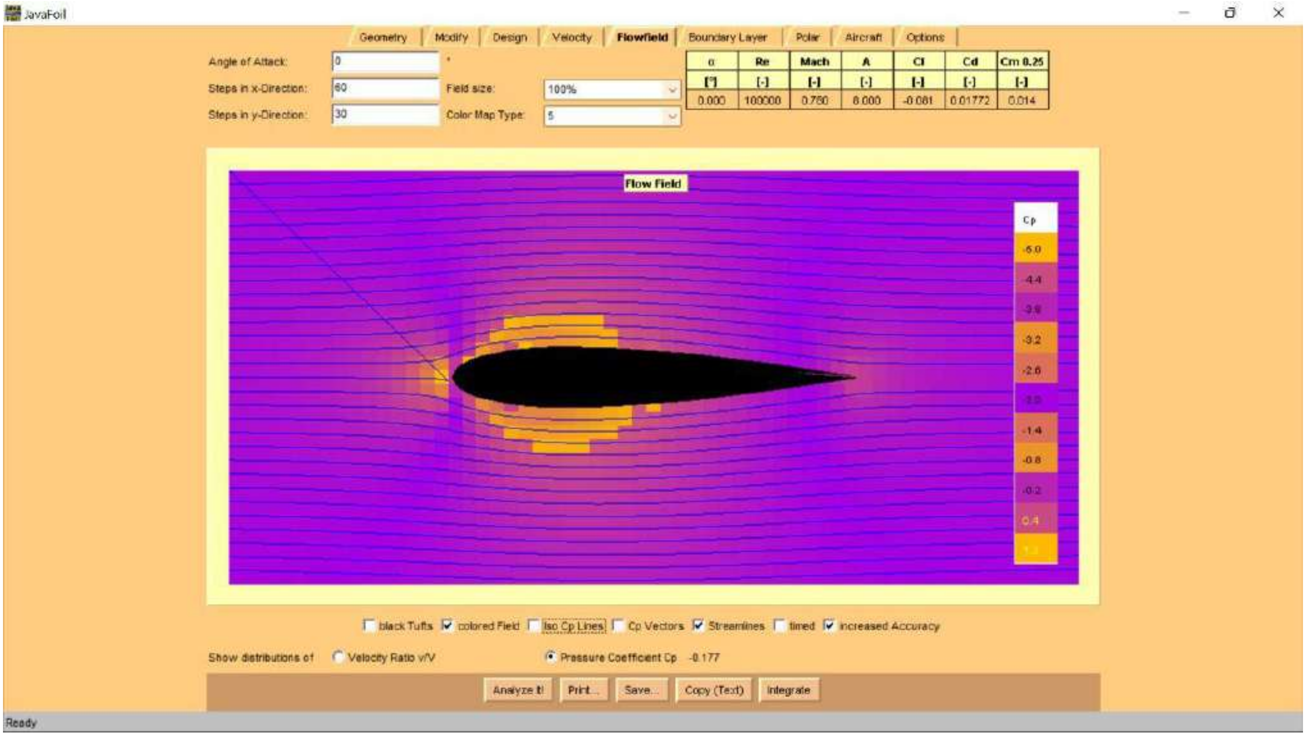
Color Map Type: 5

| α | Re | Mach | A | Cl | Cd | Cm 0.25 |
|---|---|---|---|---|---|---|
| [°] | [-] | [-] | [-] | [-] | [-] | [-] |
| 0.000 | 100000 | 0.780 | 8.000 | -0.081 | 0.01772 | 0.014 |

☐ black Tufts ☑ colored Field ☑ Iso Cp Lines ☐ Cp Vectors ☑ Streamlines ☐ timed ☑ increased Accuracy

Show distributions of ○ Velocity Ratio v/V ● Pressure Coefficient Cp -0.035

*Figure 7.40 Pressure Distribution in Airfoil*



Angle of Attack: 0 °

Steps in x-Direction: 60

Steps in y-Direction: 30

Field size: 100%

Color Map Type: 5

| α | Re | Mach | A | Cl | Cd | Cm 0.25 |
|---|---|---|---|---|---|---|
| [°] | [-] | [-] | [-] | [-] | [-] | [-] |
| 0.000 | 100000 | 0.780 | 8.000 | -0.081 | 0.01772 | 0.014 |

☐ black Tufts ☑ colored Field ☐ Iso Cp Lines ☐ Cp Vectors ☑ Streamlines ☐ timed ☑ increased Accuracy

Show distributions of ○ Velocity Ratio v/V ● Pressure Coefficient Cp -0.177

*Figure 7.41 Pressure Distribution in Airfoil with Vectors*

# CHAPTER 08

# TAIL PLANE SELECTION

## 8.1 TAIL PLANE SELECTION

A tail plane, 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 tail plane of an aircraft are classified as follows,

a. Conventional Tail
b. T – Tail
c. V – Tail
d. Inverted V – Tail
e. Cruciform Tail
f. Tailless

### 8.1.1 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.

*Figure 8.1 Conventional Tail*

### 8.1.2 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.

*Figure 8.2 T - Tail*

### 8.1.3 V - TAIL

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

*Figure 8.3 V - Tail*

### 8.1.4 INVERTED TAIL

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

*Figure 8.4 Inverted V-Tail*

### 8.1.5 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.

*Figure 8.5 Cruciform Tail*

### 8.1.6 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.

*Figure 8.6 Tailless*

## 8.2 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 effective glider ratio.

# CHAPTER 09

# ENGINE SELECTION

## 9.1 ENGINE SELECTION

An aircraft's engine is necessary because it creates thrust that allows the plane to take off and fly forward. The engines are divided into four categories based on how they work.,

a. Reciprocating Engine
b. Turbojet Engine
c. Turbofan Engine
d. Turboprop Engine
e. Ramjet Engine
f. Scramjet Engine
g. Pulsejet Engine

### 9.1.1 RECIPROCATING ENGINE

A reciprocating engine, also often known as a Piston engine, is typically a heat engine. Uses one or more reciprocating pistons to convert pressure into a rotating motion. There may be one or more pistons. Each piston is inside a cylinder, into which a gas is introduced, either already under pressure or heated inside the cylinder either by ignition of a fuel air mixture or by contact with a hot heat exchanger in the cylinder. The linear movement of the piston is converted to a rotating movement via a connecting rod and a crankshaft or by a swashplate or other suitable mechanism.

*Figure 9.1 Reciprocating Engine*

### 9.1.2 TURBOJET ENGINE

A turbojet engine is a jet engine that generates all of its thrust by ejecting a high-energy gas stream from the exhaust nozzle of the engine. Unlike a turbofan or bypass engine, all of the air entering the turbojet engine's intake passes through the engine core. The compressor compresses and heats the air that is pulled into the engine through the inlet. The fuel is subsequently ignited in the combustion chamber. By heating and expanding the air, the burning fuel adds energy to the exhaust stream. The turbine extracts enough energy from the exhaust stream to power the compressor.

*Figure 9.2 Turbojet Engine*

### 9.1.3 TURBOFAN ENGINE

A Turbofan engine is the most modern variation of the basic gas turbine engine. As with other gas turbines, there is a core engine. In the turbofan engine, the core engine is surrounded by a fan in the front and an additional turbine at the rear. The fan and fan turbine are composed of many blades, like the core compressor and core turbine, and are connected to an additional shaft.

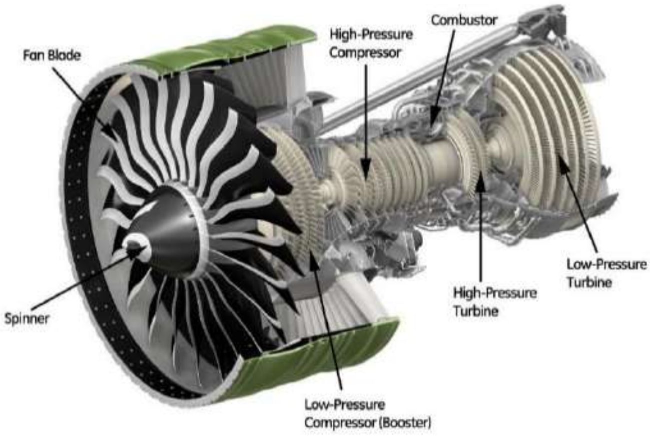


*Figure 9.3 Turbofan engine*

### 9.1.4 TURBOPROP ENGINE

A turboprop engine is a turbine engine that powers the propeller of an aeroplane. A turboprop consists of an intake, compressor, combustor, turbine, and propelling nozzle in its most basic form.

*Figure 9.4 Turboprop Engine*

### 9.1.5 RAMJET ENGINE

A ramjet, sometimes referred to as a flying stovepipe or an athodyd, is a form of air breathing jet engine that uses the engine's forward motion to compress incoming air without an axial compressor or a centrifugal compressor.

*Figure 9.5 Ramjet Engine*

### 9.1.6 SCRAMJET ENGINE

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 (thus the name ramjet), however unlike ramjets, which reduce the air to subsonic velocities before combustion, scramjets have supersonic airflow throughout the engine.

*Figure 9.6 Scramjet Engine*

### 9.1.7 PULSEJET ENGINE

A pulsejet engine, sometimes known as a pulse jet, is a type of jet engine that burns in pulses. A pulsejet engine can be built with few or no moving parts and can run statically, meaning it does not require air to be driven into its inlet, which is generally done by forward motion.

*Figure 9.7 Pulsejet Engine*

## 9.2 SELECTION:

Our airplane will be equipped with a turbofan engine. When compared to other engines, it has the following advantages:

- Our aeroplane will be equipped with a turbofan engine. When compared to other engines, it has the following advantages:
- At lesser airspeeds, it can attain higher speeds.

- It necessitates a shorter take-off runway.
- It is mostly used to minimise noise in commercial aircraft.

## 9.3 ENGINE THRUST

The thrust produced by the engine is selected from the table. The selected Thrust for the engine is 31.29kN

*Table :9.1 Engine Thrust Data*

| **Aircraft\Data** | **Type of engine/Power plant** | **Thrust (kN)** |
|---|---|---|
| **Cessna Citation X** | 2 × Rolls-Royce AE 3007C2 turbofan | 31.29 |
| **Learjet 45** | 2 × Honeywell TFE731-20 turbofan | 15.57 |
| Bombardier's Global 5000 | 2 × Rolls-Royce BR710A2-20 turbofan | 66.1kN |

*Table:9.2 Engine Performance Data*

| **Data** | **Parameters** |
|---|---|
| **Thrust** | 31.29kN |
| **Fan Diameter** | 0.98 m |
| **Dry Weight** | 744.4 kg |
| **Bypass ratio** | 5:1 |

*Figure 9.8 Rolls-Royce AE 3007C2 turbofan*

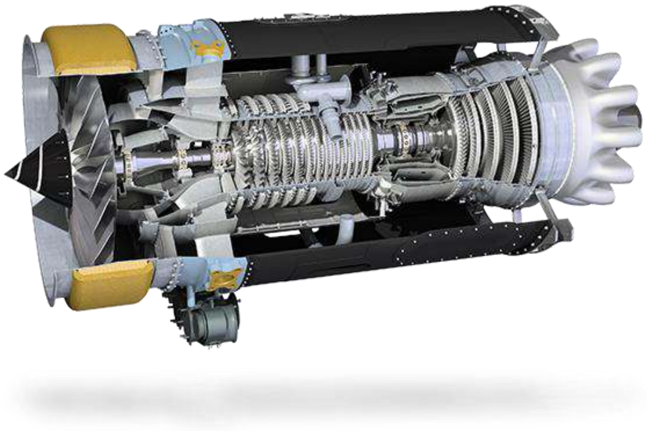


*Figure 9.9 Rolls-Royce AE 3007C2 turbofan*

## 9.4 ENGINE LOCATION

The engine is mounted in the rear fuselage pods.

It has the following advantages:

- It decreases drag and rudder usage
- It allows us to construct complex wing designs.

## 9.5 NUMBER OF ENGINES

The aircraft has 2 engines at the aft of the fuselage within the pods. It is a twin engine aircraft.

# CHAPTER 10

# LANDING GEAR SELECTION

The landing gears are classified as follows,

a. Fixed
b. Retractable

## 10.1 FIXED LANDING GEAR

*Figure 10.1 Fixed Landing Gear*

Fixed landing gear always remains extended and has the advantage of simplicity combined with low maintenance. Fixed gear is designed to simplify design and operation. Fixed landing gear is common with slow (e.g. general aviation) aircraft.

## 10.2 RETRACTABLE LANDING GEAR

*Figure 10.2 Retractable Landing Gear*

Retractable landing gear is designed to streamline the airplane (reduce the drag) by allowing the landing gear to be stowed inside the structure during cruising flight.

Most commercial aircraft use retractable landing gear. Retractable landing gear systems may be operated either hydraulically or electrically, or may employ a combination of the two systems.

## 10.3 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.

## 10.4 LANDING GEAR CONFIGURRATIONS

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

a. Single wheel
b. Bicycle
c. Tricycle
d. Quadricycle
e. Multi-bogey

## 10.5 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.

*Figure 10.3 Single Wheel Landing Gear*

### 10.6 BICYCLE

Bicycle landing gear, as the name implies, has two main gears, one aft and one forward of aircraft cg; and both wheels have a similar size. To prevent the aircraft from tipping sideways, two auxiliary small wheels are employed on the wings. The distance between two gears to the aircraft cg is almost the same, thus, both gears are carrying a similar load. This arrangement is not popular among aircraft designers due to its ground instability. The main advantages of this configuration are the design simplicity and the low weight.

*Figure 10.4 Bomber aircraft Boeing B-47 Stratojet with bicycle landing gear*

### 10.7 TRICYCLE

The most commonly used landing gear arrangement is the tricycle-type landing gear. Tail-gear landing gear has two main wheels forward of the aircraft cg and a small wheel under the tail. 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.

*Figure 10.5 Tricycle*

### 10.8 QUADRICYCLE

As the name implies a quadricycle landing gear (see Fig. 9.3-3) utilizes four gears; similar to a car conventional wheel system. Two wheels at each side where two wheels are in front of aircraft cg and other two aft of cg. The load on each gear depends on its distance to cg. 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 quadricycle landing gear configuration is usually used in a very heavy cargo or bomber aircraft.

Figu*re* 10.6 Bomber aircraft B-52 Stratofortress with quadricycle landing gear

## 10.9 MULTI-BOGEY

As the aircraft gets heavier, number of gears needs to be increased. A landing gear configuration with multiple gears of more than four wheels also improves take-off and landing safety. When multiple wheels are employed in tandem, they are attached to a structural component referred to as “bogey” that is connected to the end of the strut. It is very stable on the ground and also during taxiing. This landing gear is the most expensive, and most complex for manufacturing. Large transport aircraft such as Boeing B-747 and Airbus A-380 utilize multi-bogey landing gear. A final variation that is worth mentioning is the use of multiple wheels per landing gear strut. Multiple wheels are also often used on main gear units for added safety, especially on commercial airliners.

*Figure 10.7 Boeing 747 with multi-bogey landing gear*

## 10.10 SELECTION:

The **Tricycle landing gear** configuration is implemented 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.

# CHAPTER 11

# FUSELAGE SELECTION

The fuselage, or body of the airplane, is a long hollow tube which holds all the pieces of an airplane together. The fuselage is hollow to reduce weight. As with most other parts of the airplane, the shape of the fuselage is normally determined by the mission of the aircraft. The fuselage construction of an aircraft are classified as follows,

a. Monocoque
b. Semi-Monocoque
c. Geodesic
d. Truss

## 11.1MONOCOQUE

The monocoque design uses stressed skin to support almost all imposed loads. This structure can be very strong but cannot tolerate dents or deformation of the surface. This characteristic is easily demonstrated by a thin aluminum beverage can. You can exert considerable force to the ends of the can without causing any damage. However, if the side of the can is dented only slightly, the can will collapse easily. The true monocoque construction mainly consists of the skin, formers, and bulkheads. The formers and bulkheads provide shape for the fuselage.

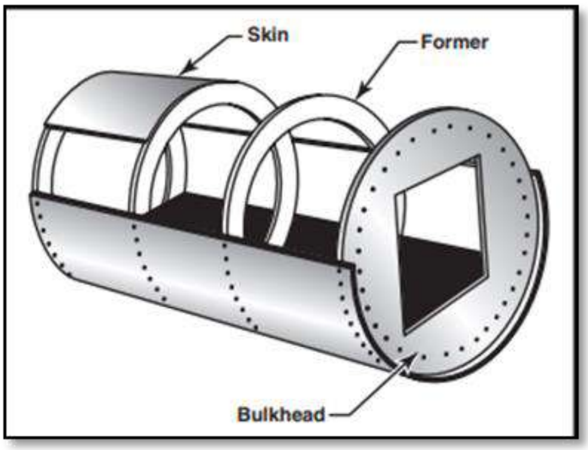


*Figure 11.1 Monocoque fuselage design*

### 11.2 SEMI - MONOCOQUE

The semi-monocoque system uses a substructure to which the airplane's skin is attached. The substructure, which consists of bulkheads and/or formers of various sizes and stringers, reinforces the stressed skin by taking some of the bending stress from the fuselage. The main section of the fuselage also includes wing attachment points and a firewall.

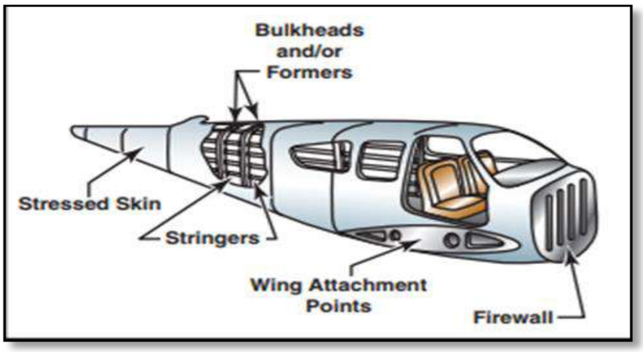


*Figure 11.2 Semi - Monocoque fuselage design*

### 11.3 TRUSS TYPE

A truss is a rigid framework made up of members, such as beams, struts, and bars to resist deformation by applied loads. The truss-framed fuselage is generally covered with fabric. The truss-type fuselage frame is usually constructed of steel tubing welded together in such a manner that all members of the truss can carry both tension and compression loads. It has diagonally web members and longitudinally longerons.

They are sub classified in to

a. Pratt truss type
b. Warren truss type
c. Pratt Truss

#### 11.3.1 PRATT TRUSS:

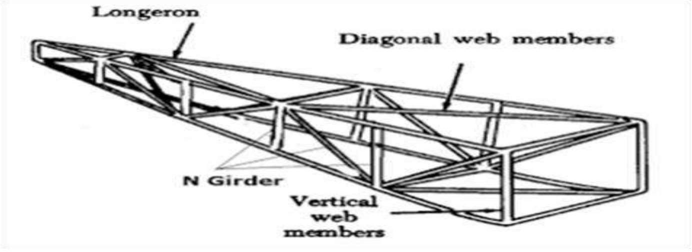


*Figure 11.3 Pratt Truss*

The primary strength members are the four longerons the longerons were connected with rigid vertical and lateral members called struts but the diagonal members were made of strong steel wire and were designed to carry tension only.

### 11.2.2WARREN TRUSS:

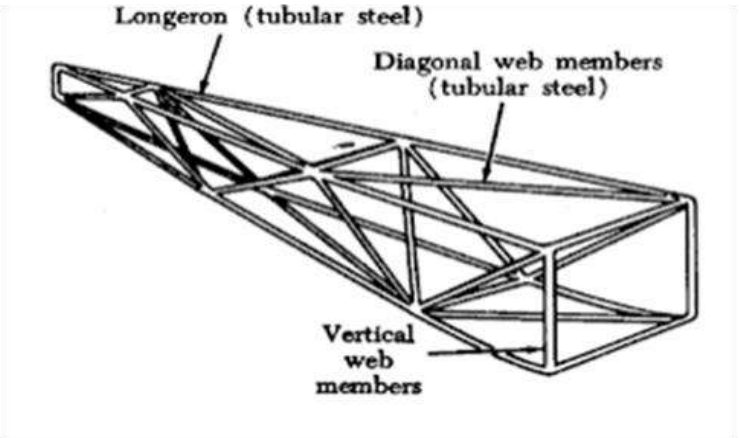


*Figure 11.4 Warren Truss*

In this construction the longerons are connected with only diagonal members normally all members in the truss are capable of carrying both tension and compression.

When the load in one direction compression loads are carried every other member and the alternate member carry the tension loads.

### 11.3 SELECTION:

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

**The bulkheads, frames, stringers, and longerons facilitate the design and construction of a streamlined fuselage that is both rigid and strong**.

The Semi-Monocoque structure is less in weight compared to Truss structures.

Spreading loads among these structures and the skin means no single piece is failure critical.

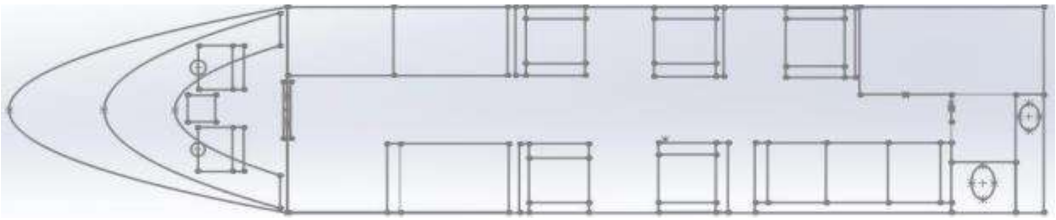


*Figure 11.5 Complete top view of plane's cockpit and fuselage*

The total length of the plane's cockpit and fuselage will amount to 8.9 meters and a width of 1.83 meters at any point of the fuselage. The height within the cabin will be 1.8 meters.

# CHAPTER 12

# LIFT AND DRAG ESTIMATION

## 12.1 LIFT CALCULATION

### 12.1.1 LIFT AT CRUISE

The lift at cruise is given by the formula,

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

Where, ρ is the density at cruising altitude

V is the cruising velocity

$C_L$ is the Coefficient of lift

$$L = 0.5 * 0.31 * 236.11 * 38 * 1.4$$

L= 459697.44 N

### 12.1.2 LIFT AT TAKE-OFF

The lift at take-off is given by the formula,

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

Where, ρ is the density at sea level

$V = 0.7 * 1.2 * V_{Stall}$

$C_L$ is the Maximum Coefficient of lift

V = 0.7 * 1.2 * 54.8

V = 46.07 m/s

$$L = 0.5 * 1.225 * 46.07^2 * 38 * 1.4$$

L= 69159.87 N

### 12.1.3 LIFT AT LANDING

The lift at landing is given by the formula,

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

Where, ρ is the density at sea level

$V = 0.7 * 1.3 * V_{Stall}$

$C_L$ is the Minimum Coefficient of lift

$V = 0.7 * 1.3 * 54.84$

V = 49.9 m/s

$L = 0.5 * 1.225 * 49.9^2 * 38 * 0.8$

L= 46363.98 N

## 12.2 DRAG CALCULATION

$$D = \frac{1}{2} * \rho * V^2 * S * C_D$$

$$C_D = C_{D,0} + \frac{\emptyset * C_L^2}{\pi * A * E} + Wave\ drag$$

$$\emptyset = \frac{(16 * \frac{h}{b})^2}{1 + (16 * \frac{h}{b})^2}$$

### 12.2.1 DRAG AT CRUISE

The Drag at cruise is given by the formula,

Where, b is the wing span

h is the wing from ground

$C_{D,0}$= 0.0030

$$\emptyset = \frac{(16 * \frac{2.5}{17.5})^2}{1+2}$$

$$\emptyset = 0.84$$

$$C_D = 0.0030 + \frac{0.84 * 0.14^2}{\pi * 8 * 0.85}$$

$$D = 0.5 * 0.31 * 236.11^2 * 38 * 0.183$$

D= 60089.024 N

### 12.2.2 DRAG AT TAKE-OFF

The drag at take-off is given by the formula,

$$D = \frac{1}{2} * \rho * V^2 * S * C_D$$

$$C_D = C_{D,0} + \frac{\emptyset * C_L^2}{\pi * A * E} + Wave\ drag$$

$$\emptyset = \frac{(16 * \frac{h}{b})^2}{1 + (16 * \frac{h}{b})^2}$$

Where, ρ is the density at sea level

$V = 0.7 * 1.2 * V_{Stall}$

$C_L$ is the Maximum Coefficient of lift

$$\emptyset = \frac{(16 * \frac{2.5}{17.50})^2}{1+2}$$

$$\emptyset = 0.84$$

$$C_D = 0.0030 + \frac{0.84 * 1.4^2}{\pi * 8 * 0.85}$$

$$D = 0.5 * 1.225 * 76.34 * 76.34 * 38 * 0.183$$

D= 24822.475 N

### 12.2.3 DRAG AT LANDING

The drag at landing is given by the formula,

$$D = \frac{1}{2} * \rho * V^2 * S * C_D$$

$$C_D = C_{D,0} + \frac{\emptyset * C_L^2}{\pi * A * E} + Wave\ drag$$

$$\emptyset = \frac{(16 * \frac{h}{b})^2}{1 + (16 * \frac{h}{b})^2}$$

Where, ρ is the density at sea level

$V = 0.7 * 1.3 * V_{Stall}$

$C_L$ is the Minimum Coefficient of lift

$C_D = 0.0030$

$$\emptyset = \frac{(16 * \frac{2.5}{17.50})^2}{1+2}$$

$$\emptyset = 0.84$$

$$C_D = 0.0030 + \frac{0.84 * 0.8^2}{\pi * 8 * 0.85}$$

$$D = 0.5 * 1.225 * 82.7^2 * 38 * 0.062$$

D= 9869.44 N

### 12.3 CONCLUSION

*Table 12.1 Calculated Lift and Drag Data*

| **Conditions** | **Lift**<br>N | **Drag**<br>N |
|---|---|---|
| **Cruise** | 459697.44 | 60089.024 |
| **Take-off** | 69159.87 | 24822.475 |
| **Landing** | 46363.98 | 9869.44 |

# CHAPTER 13

# PERFORMANCE CALCULATION

## 13.1 RATE OF CLIMB

The Rate of Climb is given by the formula,

$$\left(\frac{R}{C}\right)_{Max} = \frac{(T * V_{Stall}) - (D * V_{Stall})}{W_{To} * 9.80}$$

Where, $V_{Stall}$ = 54.84 m/s

$W_{To}$ = 10000 kg

D = 24822.475 N

T = 62580 N

⇨ $\left(\frac{R}{C}\right)_{Max} = \frac{2070622.671}{98000}$

⇨ $\boxed{\left(\frac{R}{C}\right)_{Max} = 21.128 \text{ m/s}}$

## 13.2 GLIDING ANGLE

The Gliding Angle is given by the formula,

$$\alpha = \tan^{-1}\left(\frac{1}{\left(\frac{L}{D}\right)_{Max}}\right)$$

Where, $(L/D)_{Max}$ = 33.575

⇨ $\alpha = \tan^{-1}\left(\frac{1}{33.575}\right)$

⇨ $\alpha = \tan^{-1}(0.02978)$

⇨ $\boxed{\propto = 1.71^{0}}$

## 13.3 TAKE-OFF DISTANCE CALCULATION

The Take-Off distance is given by the formula,

$$S_{LO} = \frac{1.44 * W^2}{g * \rho * S * C_{l_{Max}} * \left[T - \left(D + \mu_r (W - L)\right)\right] * 0.7 * V_{LO}}$$

Where, $V_{LO} = 1.2 * V_{Stall}$

$_T$ = Mean Design Parameter

$W = W_{TO}$

$D = D_{TO}$

$L = L_{TO}$

$\rho$ = Density at sea level

$\mu_r$ = Coefficient of friction between tyres and ground

$$\Rightarrow S_{LO} = \frac{1.44*(10000*9.81)^2}{9.81*1.225*38*1.4*\left[62580-\left(24822.475+0.02(10000*9.81-69159.87)\right)\right]65.808}$$

$S_{LO}$=1020 m

### 13.4 LANDING PERFORMANCE

The Landing performance is given by the formula,

$$S_{LO} = \frac{1.69 * W^2}{g * \rho * S * C_{l_{Max}} * \left[T - \left(D + \mu_r (W - L)\right)\right] * 0.7 * V_{LO}}$$

Where, $V_{LO} = 1.2 * V_{Stall}$

$_T$ = Mean Design Parameter

W = Landing Weight

D = Landing Drag

L = $L_{TO}$

ρ = Density at sea level

$\mu_r$ = Coefficient of friction between tyres and ground

$$\Rightarrow S_L = \frac{1.69*(116727.71)^2}{9.81*1.225*50*1.435*\left[68670-\left(1909.23+0.46(70650)\right)\right]*0.7*70.82}$$

$S_L$=1215.8m

## 13.5 RESULT

*Table 13.1 Performance Parameters*

| Data | Parameters |
|---|---|
| **Rate of Climb** | 21.128 m/s |
| **Gliding Angle** | $1.71^0$ |
| **Take-Off Distance** | 1020 m |
| **Landing Performance** | 1215.8 m |

# CHAPTER 14

# FINAL DESIGN PARAMETERS

## 14.1 BASIC PARAMETERS

*Table 14.1 Basic Parameters*

| Main Parameters | Optimum value |
|---|---|
| Crew | 2 |
| Passengers | 4 |
| Length | 20m |
| Height | 5.5m |
| Wing Span(b) | 17.5m |
| Wing area(s) | 38m$^2$ |
| Aspect ratio | 8 |
| Cruising Speed | 850 kmph |

## 14.2 WEIGHT

- Take-off weight, $W_{TO}$ = 10,000 kg
- Fuel weight, $W_F$ = 9094.063 lbs
- Actual weight, $W_E$ = 12,136.9892 lbs

## 14.3 WING TYPE

Our wing is swept back planform with straight monoplane configuration mounted as a low-wing.

## 14.4 AIRFOIL

The chosen airfoil is NACA 0015.

### 14.5 FUSELAGE TYPE

A Semi-Monocoque fuselage has been constructed.

### 14.6 EMPENNAGE

A T-Tail configuration tail is mounted.

### 14.7 ENGINE

A pair of Rolls-Royce AE3007C2 turbofan Engine mounted in pod is fixed in the rear fuselage.

### 14.8 LANDING GEAR

A retractable Tri-cyclic landing gears is constructed.

# CHAPTER 15

# 3 VIEW DIAGRAMS

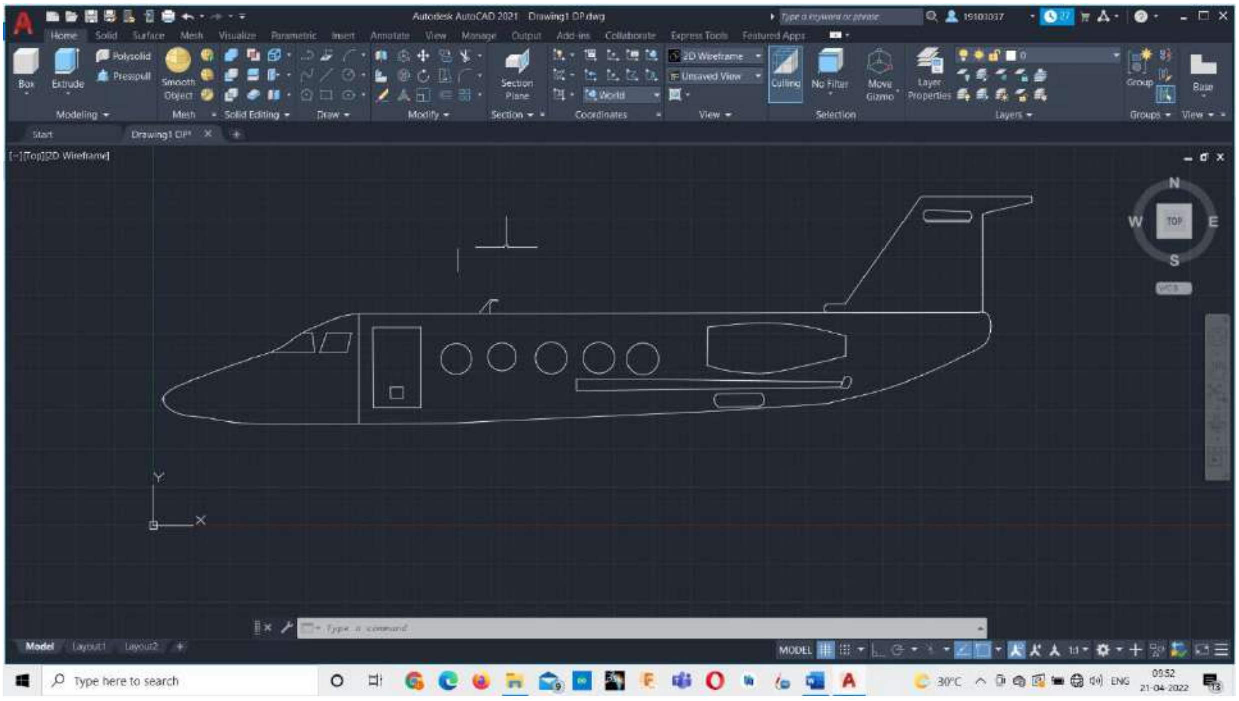


*Figure 15.1 Aircraft Side View*

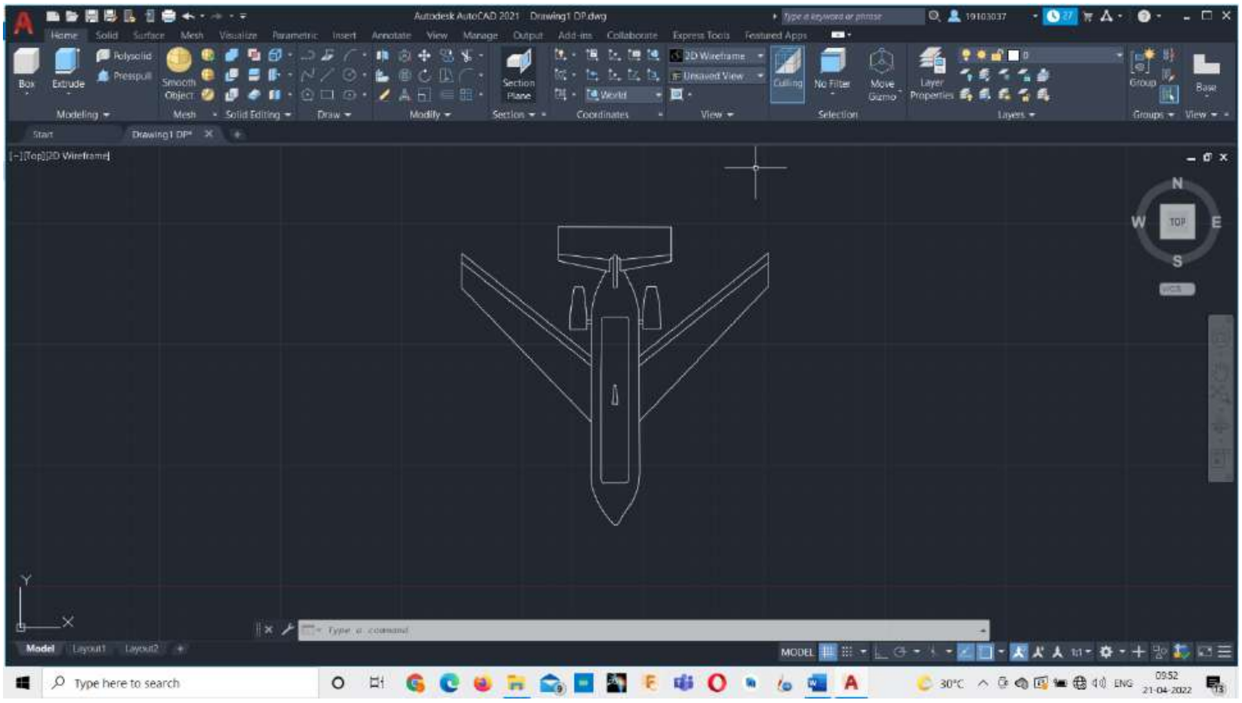


*Figure 15.2 Aircraft Top View*

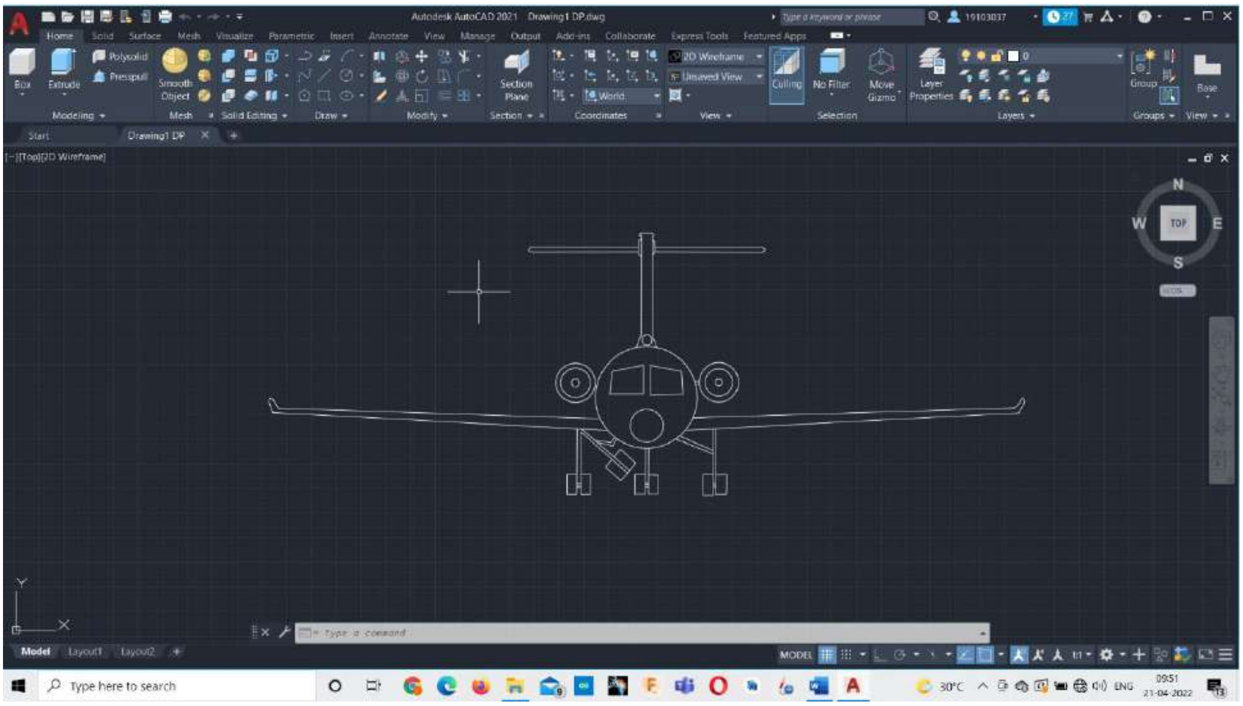


*Figure 15.3 Aircraft Front View*

# CONCLUSION

The preliminary design of a twin engine business jet with morphing wing has been developed based on systematic calculations and appropriate references. The design may not fulfil the requirements of an actual aircraft, it is completely a conceptual design. The design is always subjected to changes and implementation. This design depends on the works of Jan Roskam. All the parameters for the design of aircraft are completely obtained out of calculations.

This design consists of three major advantage factors; it has a supercritical aerofoil which accounts for high lift characteristics and very good take-off and landing performances. This enables us to reduce the effort taken during take-off; thus being more effective. The other advantage is that it is a long range business jet which can give both luxury and privacy for all the businessmen or rich people in the society. The next advantage is that it has morphing wings which have the greatest potential to dramatically improve aircraft aerodynamic performance. They are designed to accomplish with a single device what conventional mechanisms can do with major aerodynamic penalties

# FUTURE WORKS

The following are the future works of the same project,

- Preliminary design of the aircraft wing – Shrenck's Curve, Structural Load Distribution, Shear force, Bending Moment and Torque Diagrams
- Detailed design of an aircraft wing – Design of Spars and Stringers, Bending Stress and Shear flow Calculations, Buckling analysis of fuselage panels.
- Preliminary Design of an aircraft fuselage – Load Distribution on an aircraft fuselage
- Detailed design of an aircraft fuselage – Design of bulkheads and longerons, bending stress and shear flow calculations, buckling analysis of fuselage panels.
- Design of control surfaces – Balancing and manoeuvring loads on the tail plane and aileron, rudder loads.
- Design of Wing-root attachment
- Landing gear design
- Preparation of a detailed design report with CAD drawings.
- Fabrication- 3D printing with flexible PLA material of the morphing wing.

# AUTHOR NOTES

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A dedicated engineer with specialization in B. tech Aerospace engineering with academic CGPA of 8.4 pursuing at Hindustan institute of technology and science. She uses her technical skills for achieving the target and developing best performance. She always implements her innovative ideas, skills and creativity for accomplishing the goal.

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