DESIGN OF TWIN ENGINE BUSINESS JET AIRCRAFT

AEB4433 AIRCRAFT DESIGN PROJECT-2 REPORT

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In partial fulfilment for the award of the degree

of

BACHELOR OF TECHNOLOGY

in

AERONAUTICAL ENGINEERING

DEPARTMENT OF AERONAUTICAL ENGINEERING

HINDUSTAN INSTITUTE OF TECHNOLOGY AND SCIENCE

PADUR, CHENNAI - 603 103

October 2022

HINDUSTAN INSTITUTE OF TECHNOLOGY AND SCIENCE
PADUR, CHENNAI -603103

BONAFIDE CERTIFICATE

It is Certified that this project report titled **“DESIGN OF TWIN ENGINE BUSINESS JET AIRCRAFT”** is the Bonafide work of **“AKSHAT JANI (19101103), DEBAYAN SINGHA (19101118), MAINAK MITRA (19101119)”** 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**

ACKNOWLEDGEMENT

We would like to place on record our sincere thanks to all those who contributed to the successful completion of our final year project work.

It's a matter of pride and privilege for us to express our deep gratitude to the management of Hindustan Institute of Technology and Science for providing us with the necessary facilities and support.

We express our deep sense of gratitude to our respected Chairperson **Dr. Mrs. ELIZABETH VERGHESE** and Pro-Chancellor **Dr. ANAND JACOB VERGHESE** for giving us an opportunity to do the project.

We would like to thank our Director **Dr. ASHOK VERGHESE** and Vice Chancellor

Dr. S. N. SRIDHARA for giving us moral support to complete this project.

We would like to express our grateful thanks to Dean (E&T) **Dr. ANGELINA GEETHA** and Registrar **Dr. PON. RAMALINGAM** for support and encouragement.

We extend our sincere thanks to our Dean **Dr. R. ASOKAN** and head of the department **Dr. DALBIR SINGH LOHCHAB** for inspiring and motivating us to complete this project.

We would like to thank our internal guide **Mr. S. PRAGADHESWARAN** for continually guiding and actively participating in our project, giving valuable suggestion to complete our project.

We would like to thank all the faculty members of the School of Aeronautical Sciences, who have directly or indirectly extended their support.

Last, but not least, we are deeply indebted to our parents who have been our greatest support while we worked day and night for the project to make it a success.

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ABSTRACT

This report is about the design and evaluation of a cargo turbo fan aircraft. Business Jet turbo fan aircraft have a special role in transporting small groups of people. They may be adapted for other roles, such as the evacuation of casualties or express parcel deliveries, and some are used by public bodies, government officials or the armed forces. They vary greatly in size and capacity. This report discusses the process involved in designing and optimizing a Business Jet turbo fan single engine aircraft.

The report starts with an introduction to aircraft design and Business Jet turbo fan aircrafts. Performance, specifications and other parameters of ten existing Business Jet turbo fan aircraft that are similar to the aircraft under design are compared and analysed to finalize ideal design parameters for our aircraft. Aerofoils and other essential components of aircraft design are followed. The project report is concluded with detailed performance graphs. The aircraft allows for both long- and short-range transport with better efficiency and reduced fuel consumption and noise levels owing to a state-of-the-art engine and design futures.

Keywords: Business Jet, performance, design parameters, noise level, Structural loads.

LIST OF SYMBOLS

AR	-	Aspect Ratio
b	-	Wing Span (m)
C	-	Chord of the Airfoil (m)
C_{root}	-	Chord at Root (m)
C_{tip}	-	Chord at Tip (m)
C	-	Mean Aerodynamic Chord (m)
C_d	-	Drag Co-efficient
$C_{d,0}$	-	Zero Lift Drag Co-efficient
C_p	-	Specific fuel consumption
C_L	-	Lift Co-efficient
D	-	Drag (N)
E	-	Endurance (hr)
e	-	Oswald efficiency
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)
T	-	Thrust (N)
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 aircraft (kg)
W_{fuel}	-	Weight of fuel (kg)

$W_{payload}$	-	Payload of aircraft (kg)
W_0	-	Overall weight of aircraft (kg)
W/S	-	Wing loading (kg/m^2)
$A_{stringer}$	-	Cross sectional area of stringers
A	-	Total cross-sectional area
A_{spar}	-	Cross sectional area of spar
A_t	-	Slope of the CL vs. α curve for a horizontal tail
A	-	Distance of the front spar to the nose
B_w	-	Width of the web
b_f	-	Width of the flange
I_{xx}	-	Second moment of area about X axis
I_{zz}	-	Second moment of area about Z axis
K	-	Gust alleviation factor
N_{max}	-	Maximum load factor
t_w	-	Thickness of the web
t_f	-	Thickness of the flange
T	-	Torque
U	-	Gust velocity
V_{cruise}	-	Cruise velocity
V_s	-	Stalling velocity

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1. INTRODUCTION

A business jet is a jet that is owned by a private company or individual that is used primarily for transporting the people who own the aircraft. That being said a lot of planes that were developed to be used as business jets are also used for other purposes. In addition, there are also companies that are set up exclusively to operate business jets. Therefore, the lines between a business aircraft and a commercial one has become somewhat blurred.

Over the last few years business jets have become a very popular way to travel. They offer great comfort of travel and service, with the option of having the aircraft at your beck and call whenever you require it. A private business jet trumps regular commercial transport in a number of areas. Nowadays, organizations and individuals who can afford the heavy expenses that a private jet entail are willing to invest in one. Greater ease of travel, ease of access, faster and hassle-free transit and high comfort levels are some of the advantages of business jet transport.

In most cases a business jet will be quite a bit smaller than a commercial jet. The most common ones carry fewer than twenty passengers since this allows them to operate under a different set of rules from the ones that are required for airliners. There are however now quite a few business jets that are the size of 14 airliners and in many cases, they are airliners that have been adapted for the purpose. Nevertheless, most business jets are quite small and only carry a small number of people.

Business jets have a much more luxurious interior, with a number of amenities and services that a normal airliner would not have. Airliners are designed to carry large numbers of people, most of who are looking for the lowest cost possible. Business jets on the other hand are designed to carry people in a much higher level of comfort. The people who travel by business jet are almost always quite well off and expect this level of comfort when they travel.

2.1 Classification of Business Jets

The business jet industry groups these jets into four loosely-defined classes

Mid-sized jets

Combining flight distance, speed and comfort, these mid-sized jets are ideal for intimate trips.

Number of Passengers: 8 – 10

Sample Aircraft:

Gulfstream 200, Embraer Legacy 450, Cessna Citation X, Bombardier Challenger 605

Large-cabin jets

These aircraft are fast, comfortable, and can accommodate a medium-sized group.

Number of Passengers: 8 - 15

Sample Aircraft:

Gulfstream 550, Embraer Legacy 650, Dassault Falcon 7X

Light jets

Light jets have been a staple of the business jet industry since the advent of the Learjet 23 in the early 1960s. They provide access to small airports and the speed to be an effective air travel tool.

Number of Passengers: 3 – 10

Sample Aircraft:

Learjet 40, Cessna Citation CJ1, Dassault Falcon10, Beechcraft Premier I

VIP business jets / Heavy airliners

With a variety of potential configurations, jets in this category have the capacity for dining rooms, bedrooms and offices.

Number of Passengers: 18 - 40/50 – 250

These heavy airliners are an ideal choice for larger groups, corporate meetings and special events.

Sample Aircraft:

Boeing BBJ, Airbus AGJ, Embraer Lineage 1000

What is an Airlift?

An airlift is the organized delivery of supplies or personnel primarily via aircraft. Airlifting consists of two distinct types, strategic and tactical airlifting. Typically, strategic airlifting involves moving material long distances (such as across or off the continent or theatre), whereas a tactical airlift focuses on deploying resources and material into a specific location with high precision.

Depending on the situation, airlifted supplies can be delivered by a variety of means. When the destination and surrounding airspace is considered secure, the aircraft will land at an appropriate airport or airbase to have its cargo unloaded on the ground. When landing the craft, or distributing the supplies to a certain area from a landing zone by surface transportation is not an option, the cargo aircraft can drop them in mid-flight using parachutes attached to the supply containers in question. When there is a broad area available where the intended receivers have control without fear of the enemy interfering with collection and/or stealing the goods, the planes can maintain a normal flight altitude and simply drop the supplies down and let them parachute to the ground. However, when the area is too small for this method, as with an isolated base, and/or is too dangerous to land in, a Low Altitude Parachute Extraction System drop is used.

CLASSIFICATION OF AIRLIFTS

- STRATEGIC AIRLIFT
- TACTICAL AIRLIFT

STRATEGIC AIRLIFT

Strategic airlift is the use of cargo aircraft to transport materiel, weaponry, or personnel over long distances. Typically, this involves airlifting the required items between two airbases which are not in the same vicinity. This allows commanders to bring items into a combat theater from a point on the other side of the planet, if necessary. Aircraft which perform this role are considered **strategic airlifters**. This contrasts with tactical airlifters, such as the C-130 Hercules, which can normally only move supplies within a given theater of operations.

EXAMPLE: Lockheed C-5 Galaxy, Antonov An-124.

TACTICAL AIRLIFT

Tactical airlift is a military term for the airborne transportation of supplies and equipment within a theatre of operations (in contrast to strategic airlift). Aircraft which perform this role are referred to as **tactical airlifters**. These are typically turboprop aircraft, and feature short landing and take-off distances and low-pressure tires allowing operations from small or poorly-prepared airstrips. While they lack the speed and range of strategic airlifters (which are typically jet-powered), these capabilities are invaluable within war zones. Larger helicopters such as the CH-47 Chinook and Mil Mi-26 can also be used to airlift men and equipment. Helicopters have the advantage that they do not require a landing strip and that equipment can often be suspended below the aircraft allowing it to be delivered without landing but are highly inefficient. Tactical airlift aircraft are designed to be maneuverable, allowing low-altitude flight to avoid detection by radar and for the airdropping of supplies. Most are fitted with defensive aids systems to protect them from attack by surface-to-air missiles.

EXAMPLE: Hercules C-130, Lockheed C-141 Starlifter.

DESIGN OF AN AIRPLANE

Airplane design is both an art and a science. It’s the intellectual engineering process of creating on paper (or on a computer screen) a flying machine to

- Meet certain specifications and requirements established by potential users (or as perceived by the manufacturer) and
- Pioneer innovative, new ideas and technology.

The design process is indeed an intellectual activity that is rather specified one that is tempered by good intuition developed via by attention paid to successful airplane designs that have been used in the past, and by (generally proprietary) design procedure and databases (hand books etc) that are a part of every airplane manufacturer.

PHASES OF AIRPLANE DESIGN

The complete design process has gone through three distinct phases that are carried out in sequence. They are

- Conceptual design.
- Preliminary design.
- Detailed design.

➢ **CONCEPTUAL DESIGN**

The design process starts with a set of specifications (requirements)for a new airplane, or much less frequently as the response to the desire to implement some pioneering, innovative new ideas and technology. In either case, there is a rather concrete good towards which the designers are aiming. The first steps towards achieving that goal constitute the conceptual design phase. Here, within a certain somewhat fuzzy latitude, the overall shape, size, weight and performance of the new design are determined.

The product of the conceptual design phase is a layout on a paper or on a computer screen) of the airplane configuration. But one has to visualize this drawing as one with flexible lines, capable of being slightly changed during the preliminary design phase. However, the conceptual design phase determines such fundamental aspects as the shape of the wings (swept back, swept forward or straight), the location of the wings related to the fuselage, the shape and location of the horizontal and vertical tail, the use of a engine size and placement etc, the major drivers during the conceptual design process are aerodynamics, propulsion and flight performance.

Structural and context system considerations are not dealt with in any detail. However, they are not totally absent. During the conceptual design phase, the designer is influenced by such qualitative as the increased structural loads imposed by a high horizontal tail location trough the fuselage and the difficulties associated with cutouts in the wing structure if the landing gear are to be retracted into the wing rather than the fuselage or engine nacelle. No part of the design is ever carried out in a total vacuum unrelated to the other parts.

- **PRELIMINARY DESIGN**

In the preliminary design phase, only minor changes are made to the configuration layout (indeed, if major changes were demanded during this phase, the conceptual design process have been actually flawed to begin with. It is in the preliminary design phase that serious structural and control system analysis and design take place. During this phase also, substantial wind tunnel testing will be carried out and major computational fluid dynamics (CFD) calculations of the computer flow fluid over the airplane configurations are done.

It’s possible that the wind tunnel tests the CFD calculations will in cover some undesirable aerodynamic interference or some unexpected stability problems which will promote change to the configuration layout. At the end of preliminary design phase, the airplane configuration is frozen and preciously defined. The drawing process called lofting is carried out which mathematically models the precise shape of the outside skin of the airplane making certain that all sections of the aircraft property fit together.

The end of the preliminary design phase brings a major concept to commit the manufacture of the airplane or not. The importance of this decision point for modern aircraft manufacturers cannot be understated, considering the tremendous costs involved in the design and manufacture of a new airplane.

- **DETAIL DESIGN**

The detail design phase is literally the nuts-and-bolts phase of airplane design. The aerodynamic, propulsion, structures performance and flight control analysis have all been finished with the preliminary design phase. The airplane is now simply a machine to be fabricated. The pressure design of each individual rib, spar and section of skin now take place. The size of number and location of fastness are determined. At this stage, flight simulators for the airplane are developed. And these are just a few of the many detailed requirements during the detail design phase. At the end of this phase, the aircraft is ready to be fabricated.

OUTLINE AIRCRAFT DESIGN PROJECT 2:

The structural design of the aircraft which is done in aircraft design project 2 involves:

- Determination of loads acting on aircraft
    - V-n diagram for the design study.
    - Gust and manoeuvrability envelopes.
    - Schrenk‟s Curve.
    - Critical loading performance and final V-n graph calculation.
- Determination of loads acting on individual structures
    - Structural design study – Theory approach.
    - Load estimation of wings.
    - Load estimation of fuselage.
    - Material Selection for structural members.
    - Detailed structural layouts.
    - Design of some components of wings, fuselage.

Table 1.1: Parameters Taken from ADP 1

Crew	2
Length	14.4 m
Height	4.7 m
Wing span	14.2 m
Wing Area	24 m^2
Aspect Ratio	8.4
Empty Weight	4600 kg
MAX. Take-Off Weight	7,400 kg
Service Ceiling	13500 m
Range	3400 km
Rate of Climb	19 m/s
Wing Loading	308.3 kg/m^2
Payload	500 kg
Type of Engine	Turbo fan
No. of Engine	2
Total Thrust	15.675*2 kN
Engine weight	298*2 kg
Fuel weight	2649.2 kg
Root chord	1.7 m
Tip chord	0.425 m
Mean aerodynamic chord	1.19 m
lift coefficient	0.1

2. V-n Diagram

Introduction:

Airplanes may be subjected to a variety of loading conditions in flight. The structural design of the aircraft involves the estimation of the various loads on the aircraft structure and designing the airframe to carry all these loads, providing enough safety factors, considering the fact that the aircraft under design is a commercial transport airplane. As it is obviously impossible to investigate every loading condition that the aircraft may encounter, it becomes necessary to select a few conditions such that each one of these conditions will be critical for some structural member of the airplane.

Velocity –Load Factor (V-n) diagram:

The control of weight in aircraft design is of extreme importance. Increases in weight require stronger structures to support them, which in turn lead to further increases in weight and so on. Excess of structural weight mean lesser amounts of payload, thereby affecting the economic viability of the aircraft. The aircraft designer is therefore constantly seeking to pare his aircraft's weight to the minimum compatible with safety. However, to ensure general minimum standards of strength and safety, airworthiness regulations (Av.P.970 and BCAR) lay down several factors which the primary structure of the aircraft must satisfy. These are the

Limit load: Which is the maximum load that the aircraft is expected to experience in normal operation.

Proof load: Which is the product of the limit load and the proof factor (1.0-1.25), and

Ultimate load: Which is the product of the limit load and the ultimate factor (usually 1.5). The aircraft's structure must withstand the proof load without detrimental distortion and should not fail until the ultimate load has been achieved.

The basic strength and fight performance limits for a particular aircraft are selected by the airworthiness authorities and are contained in the flight envelope or **V-n diagram.**

There are two types of V – n diagram for military airplanes:

- V–n maneuver diagram.
- V–n gust diagram.

V – n MANEUVER DIAGRAM:

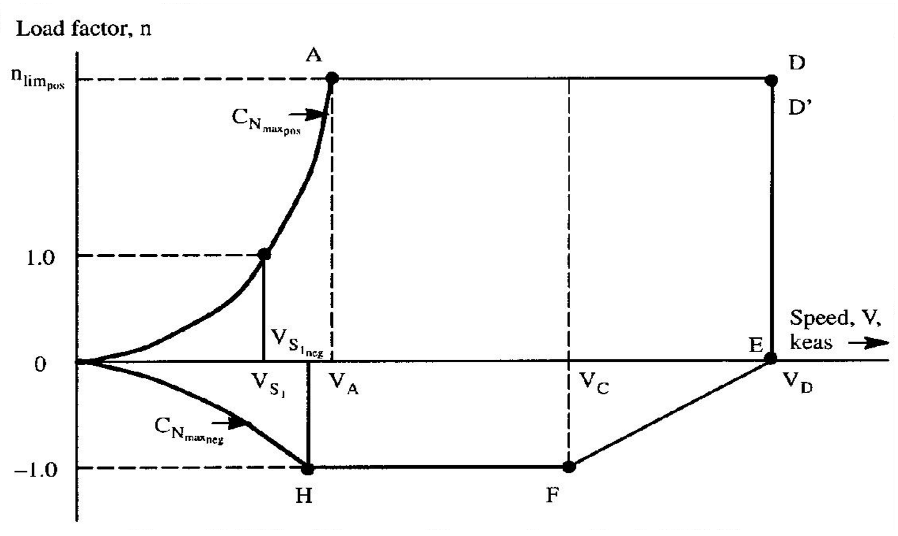


Fig 2.1 V-n Maneuver Diagram According to FAR 25.

The positive design limit load factor must be selected by the designer, but must meet the following condition:

The maximum positive limit load factor for military transport aircraft should be in the range 2 to 3. So, for our aircraft we take the maximum negative limit load factor is given by

There are four important speeds used in the V – n diagram

- 1 – g stall speed V_S
- Design maneuvering speed V_A
- Design cruise speed V_C
- Design diving speed V_D

Design Cruise speed V_C:

From Aircraft Design Project 1,

$V_C = V_{cruise}$

$V_C = 250$ m/s

Design Diving Speed V_D:

The design diving speed must satisfy the following relationship 250 m/s.

Table 2.1: V-n Values

Velocity m/s	Positive Load Factor n
0	0
55.5	1
116.53	4.4
333.3	4.4
333.3	-1.8
74.53	-1.8
55.5	-1

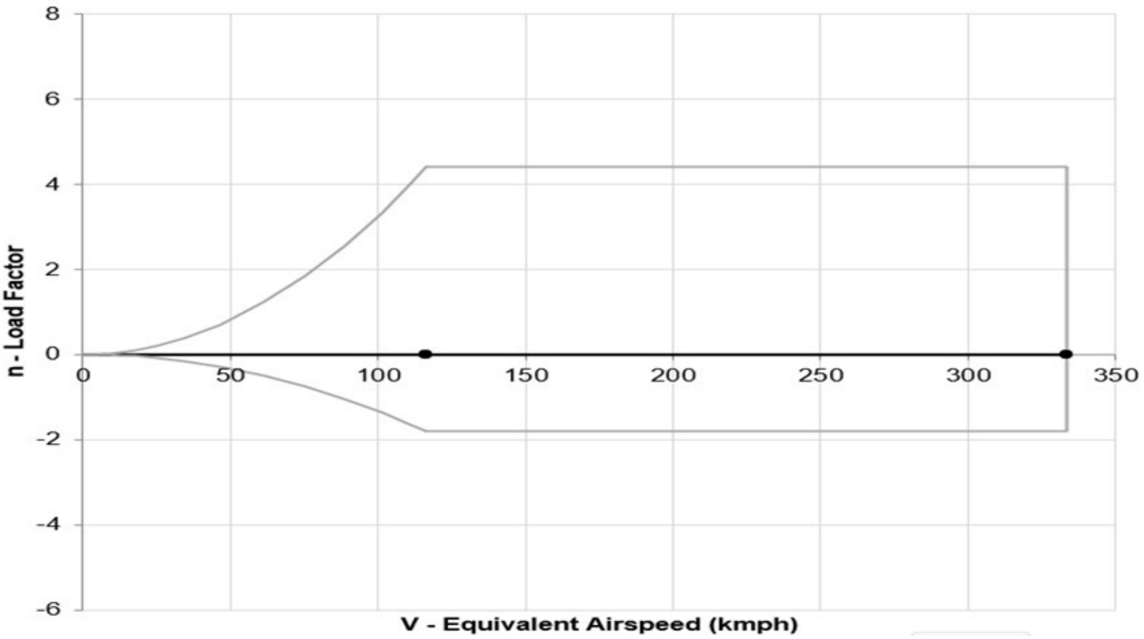


Fig 2.2 V-n Maneuver Diagram

3. GUST V-n DIAGRAM

Description:

Gust is a sudden, brief increase in the speed of the wind. Generally, winds are least gusty over large water surfaces and most gusty over rough land and near high buildings. With respect to aircraft turbulence, a sharp change in wind speed relative to the aircraft; a sudden increase in airspeed due to fluctuations in the airflow, resulting in increased structural stresses upon the aircraft. Sharp-edged gust (u) is a wind gust that results in an instantaneous change in direction or speed.

Derived gust velocity (U_g or U_{max}**)** is the maximum velocity of a sharp-edged gust that would produce a given acceleration on a particular airplane flown in level flight at the design cruising speed of the aircraft and at a given air density. As a result, a 25% increase is seen in lift for a longitudinally disturbing gust.

The effect of turbulence gust is to produce a short time change in the effective angle of attack. These changes produce a variation in lift and thereby load factor. For VB, a gust velocity of 20.1168 m/s is assumed. For VC, a gust velocity of 15.24 m/s at sea level is assumed. For VD, a gust velocity of 7.26 m/s is assumed.

Effective gust velocity: The vertical component of the velocity of a sharp-edged gust that would produce a given acceleration on a particular airplane flown in level flight at the design cruising speed of the aircraft and at a given air density.

Construction of gust load factor lines:

The gust load factor lines are defined by the following equations

where,

Gust alleviation factor

Derived gust velocity

Design speed for maximum gust intensity

Design cruise velocity

Design diving velocity

Overall lift curve slope rad-1

Construction of gust load factor line for speed ⁄ (take)

Construction of gust load factor line for speed ⁄ (take)

Construction of gust load factor line for speed ⁄ (take)

4.CRITICAL LOADING PERFORMANCE AND FINAL V-n DIAGRAM

CRITICAL LOADING PERFORANCE:

The greatest air loads on an aircraft usually comes from the generation of lift during high-g maneuvers. Even the fuselage is almost always structurally sized by the lift of the wings rather than by the pressures produced directly on the fuselage. Aircraft load factor (n) expresses the maneuvering of an aircraft as a standard acceleration due to gravity.

At lower speeds the highest load factor of an aircraft may experience is limited by the maximum lift available. At higher speeds the maximum load factor is limited to some arbitrary value based upon the expected use of the aircraft. The maximum lift load factor equals 1.0 at levels flight stall speed. This is the slowest speed at which the maximum load can be reached without stalling.

The aircraft maximum speed, or dive speed at right of the V-n diagram represents the maximum dynamic pressure and maximum load factor is clearly important for structural sizing. At this condition, the aircraft is at fairly low angle of attack because of the high dynamic pressure, so the load is approximately vertical in the body axis. The most common maneuvers that we focused are,

- Level turn.
- Pull up.
- Pull down.

5. STRUCTURAL DESIGN STUDY–THEORY APPROACH

Theory Approach:

Aircraft loads are those forces and loadings applied to the airplanes structural components to establish the strength level of the complete airplane. These loadings may be caused by air pressure, inertia forces, or ground reactions during landing. In more specialized cases, design loadings may be imposed during other operations such as catapulted take-offs, arrested landings, or landings in water.

The determination of design loads involves a study of the air pressures and inertia forces during certain prescribed maneuvers, either in the air or on the ground. Since the primary objective is an airplane with a satisfactory strength level, the means by which this result is obtained is sometimes unimportant. Some of the prescribed maneuvers are therefore arbitrary and empirical which is indicated by a careful examination of some of the criteria.

Important consideration in determining the extent of the load analysis is the amount of structural weight involved. A fairly detailed analysis may be necessary when computing operating loads on such items as movable surfaces, doors, landing gears, etc. proper operation of the system requires an accurate prediction of the loads.

Aircraft loads is the science of determining the loads that an aircraft structure must be designed to withstand. A large part of the forces that make up design loads are the forces resulting from the flow of air about the airplane's surfaces-the same forces that enable flight and control of the aircraft.

Load factors:

In normal straight and level flight the wing lift supports the weight of the airplane. During maneuvers or flight through turbulent (gusty) air, however, additional loads are imposed which will increase or decrease the net loads on the airplane structure. The number of additional loads depends on the severity of the maneuvers or the turbulence, and its magnitude is measured in terms of load factor.

The maximum maneuvering load factor to which an airplane is designed depends on its intended usage. Fighters, which are expected to execute violent maneuvers, are designed to withstand loads commensurate with the accelerations a pilot can physically withstand. Long range, heavily loaded bombers, on the other hand, are designed to low load factors and must be handled accordingly. For a typical two spar layout, the ribs are usually formed in three parts from sheet metal by the use of presses and dies. Flanges are incorporated around the edges so that they can be riveted to the skin and the spar webs Cut-outs are necessary around the edges to allow for the stringers to pass through Lightening holes are usually cut into the rib bodies to reduce the rib weight and also allow for passage of control runs fuel electrics etc

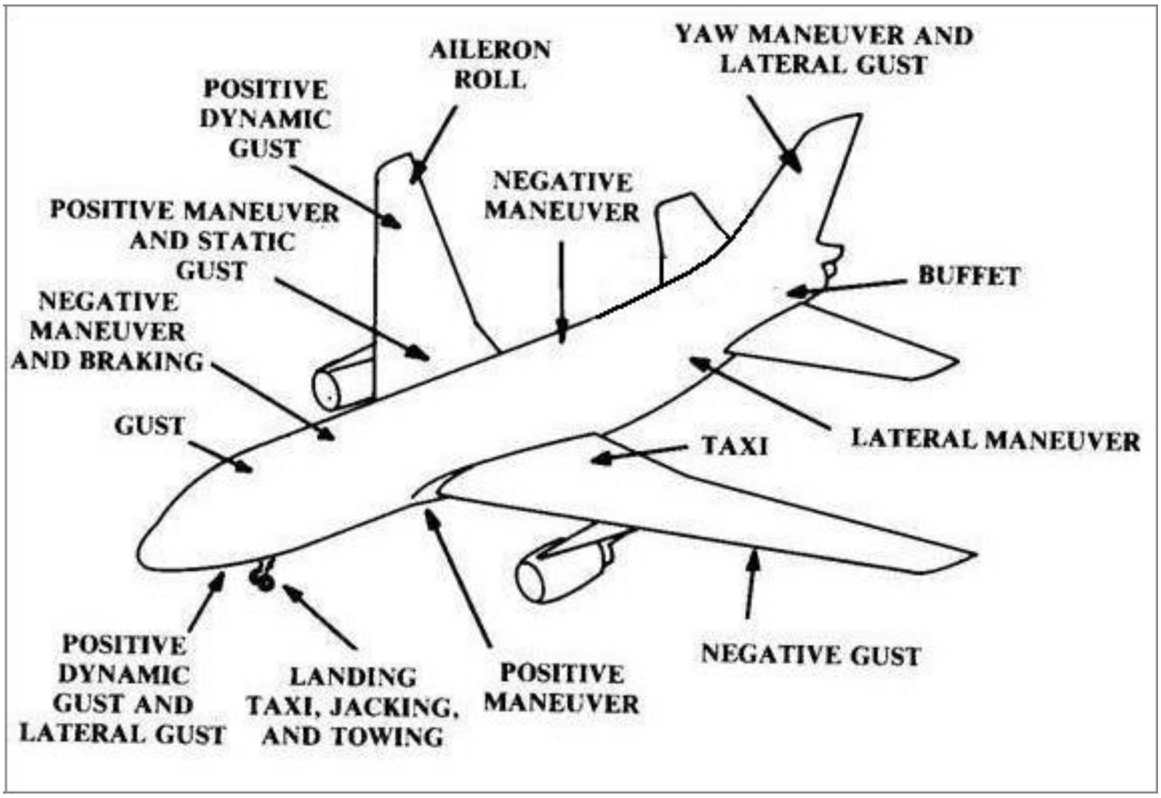


fig 5.1 Structural Details of Aircraft

STRUCTURAL DESIGN CRITERIA

The structural criteria define the types of maneuvers, speed, useful loads, and gross weights which are to be considered for structural design analysis. These are items which are under the control of the airplane operator. In addition, the structural criteria must consider such items as inadvertent maneuvers, effects of turbulent air, and severity of ground contact during landing. The basic structural design criteria, from which the loadings are determined, are based largely on the type of the airplane and its intended use.

6. LOAD ESTIMATION ON WINGS

Description:

The solution methods which follow Euler's beam bending theory (σ/y=M/I=E/R) use the bending moment values to determine the stresses developed at a particular section of the beam due to the combination of aerodynamic and structural loads in the transverse direction. Most engineering solution methods for structural mechanics problems (both exact and approximate methods) use the shear force and bending moment equations to determine the deflection and slope at a particular section of the beam. Therefore, these equations are to be obtained as analytical expressions in terms of span wise location. The bending moment produced here is about the longitudinal (x) axis.

Loads acting on wing:

As both the wings are symmetric, let us consider the starboard wing at first. There are three primary loads acting on a wing structure in transverse direction which can cause considerable shear forces and bending moments on it. They are as follows:

- Lift force (given by Schenk's curve)
- Self-weight of the wing
- Weight of the power plant
- Weight of the fuel in the wing

Shear force and bending moment diagrams due to loads along transverse direction at cruise condition

Lift varies along the wing span due to the variation in chord length, angle of attack and sweep along the span. Schrenk"s curve defines this lift distribution over the wing span of an aircraft, also called simply as Lift Distribution Curve.

Schrenk"s Curve is given by:

$$Y=Y_1 + Y_2$$

Where,

Y_1 is Linear Variation of lift along semi wing span also named as L_1.

Y_2 is Elliptic Lift Distribution along the wing span also named as L_2.

Linear lift distribution (trapezium):

Lift at root

L_{root} = 5141 N/m

Lift at tip

L_{tip} = 1285.2 N/m

By representing this lift at sections of root and tip we can get the equation for the wing.

Equation of linear lift distribution for starboard wing

y_1 = -543.1x +5141

Equation of linear lift distribution for port wing we have to replace x by –x in general,

y_1 = -543.1x +5141

For the Schrenk's curve we only consider half of the linear distribution of lift and hence $y_1/2= Y_1$

Y_1= -271.55x + 2570.5

Table 6.1: Linear Lift Distribution

Span	Linear Lift
0.355	4948.2
0.71	4755.4
1.065	4562.6
1.42	4369.8
1.775	4177
2.13	3984.2
2.485	3791.4
2.84	3598.6
3.195	3405.8
3.55	3213
3.905	3020.2
4.26	2827.4
4.615	2634.6
4.97	2441.8
5.325	2249
5.68	2056.2
6.035	1863.4
6.39	1670.6
6.745	1477.8
7.1	1285

Fig 6.1: Linear Lift Distribution Graph

Elliptic Lift Distribution:

Twice the area under the curve or line will give the lift which will be required to overcome weight

Considering an elliptic lift distribution, we get

$$y_2 = (b/a)\,(\sqrt{(a_2 - x_2)})$$

Where,

"b" is actual lift at root and "a" is wing semi span

Lift at root,

$L_{root} = 5141$ N/m

Equation of Elliptical Lift,

$y_2 = 724.08(\sqrt{(50.41 - x^2)})$

For the Schrenk's curve we only consider half of the linear distribution of lift and hence $y_2/2 = Y_2$

$$Y_2 = 362.04(\sqrt{(50.41 - x^2)})$$

Table 6.2: Elliptical Lift Distribution

Span	Elliptical lift
0.355	5134.68
0.71	5115.34
1.065	5082.94
1.42	5037.24
1.775	4977.85
2.13	4904.3
2.485	4815.93
2.84	4711.9
3.195	4591.15
3.55	4452.33
3.905	4293.67
4.26	4112.88
4.615	3906.9
4.97	3671.48
5.325	3400.52
5.68	3084.66
6.035	2708.24
6.39	2240.95
6.745	1605.31
7.1	0

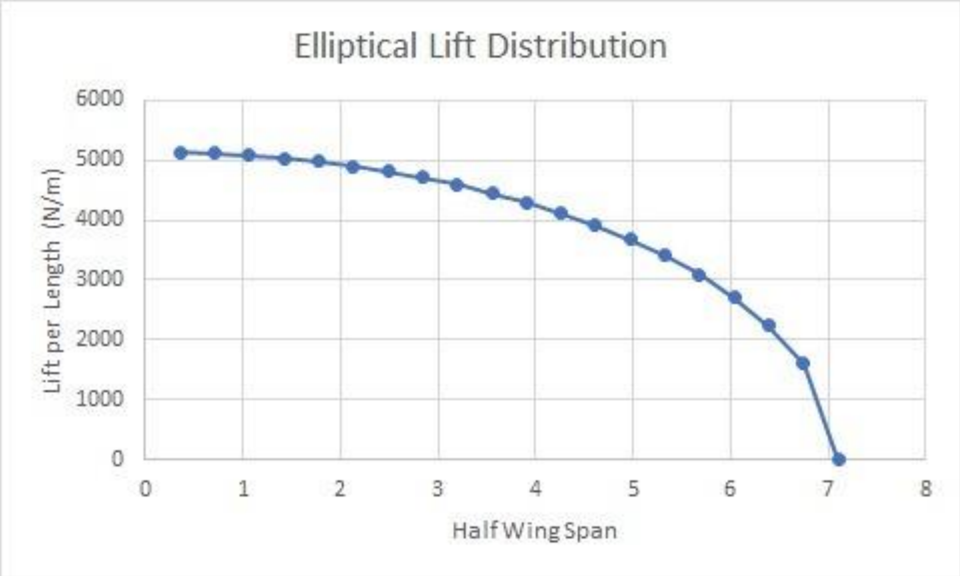


Fig 6.2: Elliptical Lift Distribution Graph

Construction of Schrenk's Curve:

Schrenk's Curve is given by,

$Y = Y_1 + Y_2$

$Y = -271.55x + 2570.5 + 362.04(\sqrt{(50.41-x^2)})$

Substituting different values for x we can get the lift distribution for the wing semi span

Table 6.3: Schrenk's Curve

Y1	Y2	(y1+y2)/2
4948.2	5134.68	5041.4
4755.4	5115.34	4935.3
4562.6	5082.94	4822.7
4369.8	5037.24	4703.4
4177	4977.85	4577.4
3984.2	4904.3	4444.2
3791.4	4815.93	4303.6
3598.6	4711.9	4155.2
3405.8	4591.15	3998.4
3213	4452.33	3832.6
3020.2	4293.67	3656.8
2827.4	4112.88	3470.1
2634.6	3906.9	3270.7
2441.8	3671.48	3056.6
2249	3400.52	2824.7
2056.2	3084.66	2570.4
1863.4	2708.24	2285.8
1670.6	2240.95	1955.7
1477.8	1605.31	1541.53
1285	0	642.495

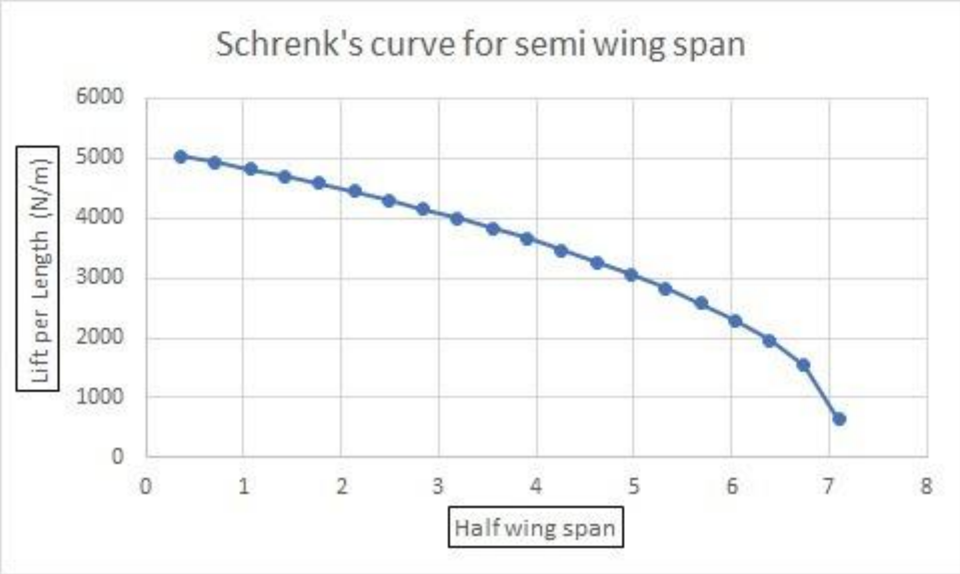


Fig 6.3: Schrenk's Curve Graph

Self-Weight of wing (y_3):

Self-weight of the wing, W_{WING}= 7.5% 0f W_{TO}

W_{WING}= 5444.55 N

$W_{portwing}$ = -2722.275 N (Acting Downwards)

$W_{starboard}$= - 2722.275N (Acting Downwards)

Assuming parabolic weight distribution, y_3= $k(x-b^2)$

where b – wing span

When we integrate from x=0 (root location) to x=b (tip location) we get the net weight of port wing.

k= -2.32

$y_3=-2.32(x-7.1)^2$

Table 6.4: Self Weight

Span	Self-Weight
0.355	-105.548
0.71	-94.7305
1.065	-84.49
1.42	-74.85
1.775	-65.8
2.13	-5703
2.485	-49.41
2.84	-42.10
3.195	-35.37
3.55	-29.237
3.905	-23.68
4.26	-18.71
4.615	-14.32
4.97	-10.52
5.325	-7.30
5.68	-4.67
6.035	-2.63
6.39	-1.16
6.745	-0.29
7.1	0

Fig. 6.4: Self-Weight Distribution Graph

Fuel weight in the wing:

This design has fuel in the wing so we have to consider the weight of the fuel in one wing.

W_{FUEL}= 2649.2 kg

$W_{SEMI\ FUEL}$= 1324.6 kg

$V_{FUEL}= C_{MEAN}*h*t_{MEAN}$

h=2.76 m

Again, by using general formula for straight line y= mx + c we get,

y_f=3411.6x-25105.51

Table 6.5: Fuel Weight

Span	Fuel weight
2.17	-17702.34
2.446	-16760.74
2.722	-15819.13
2.998	-14877.53
3.274	-13935.93
3.55	-12994.33
3.826	-12052.73
4.102	-11111.13
4.378	-10169.52
4.654	-9227.92
4.93	-8286.32

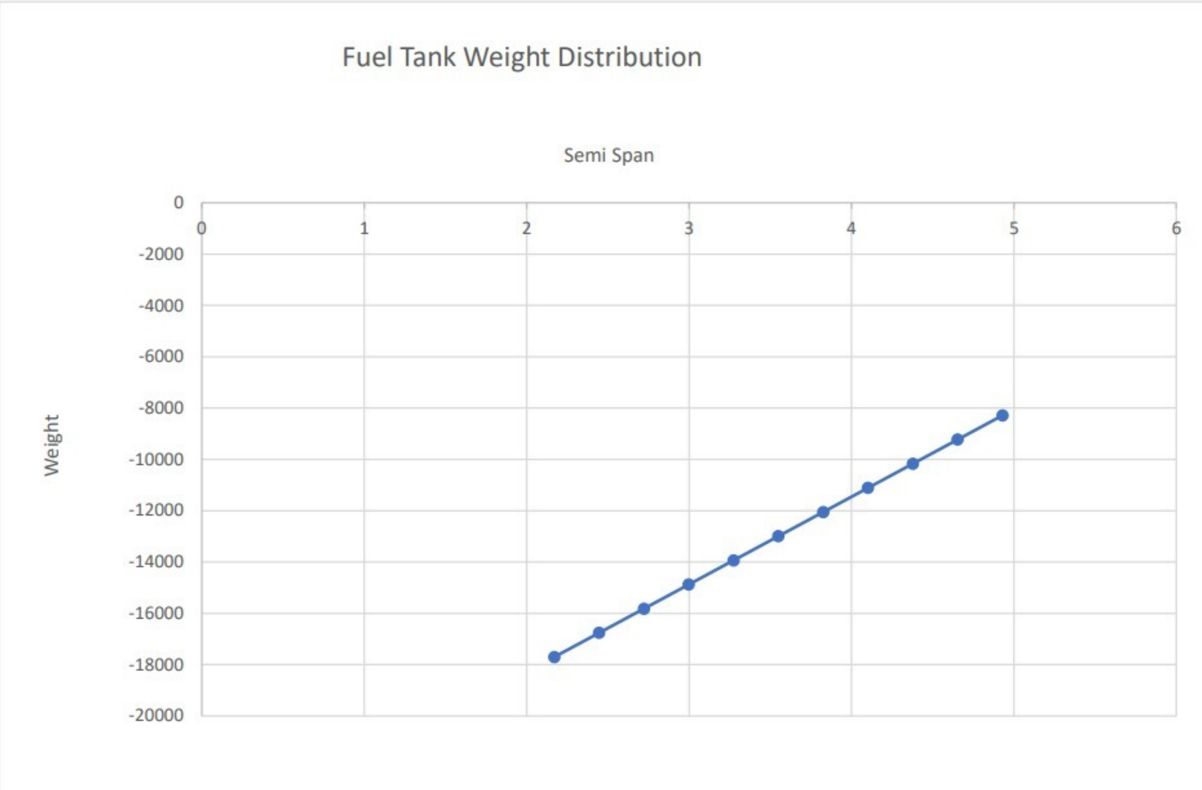


Fig. 6.5: Fuel Weight Distribution graph

Power plant weight:

Power plant is assumed to be a point load,

W_{pp}= 298 kg = 2923.38 N

Acting at x= 3.5 m from the root.

Overall Load Distribution:

Table 6.6: Overall Load Distribution

Span	Linear Lift	Elliptical lift	Self-Weight	Fuel Weight
0.355	4948.2	5134.68	-105.548	-17702.34
0.71	4755.4	5115.34	-94.7305	-16760.74
1.065	4562.6	5082.94	-84.49	-15819.13
1.42	4369.8	5037.24	-74.85	-14877.53
1.775	4177	4977.85	-65.8	-13935.93
2.13	3984.2	4904.3	-5703	-12994.33
2.485	3791.4	4815.93	-49.41	-12052.73
2.84	3598.6	4711.9	-42.10	-11111.13
3.195	3405.8	4591.15	-35.37	-10169.52
3.55	3213	4452.33	-29.237	-9227.92
3.905	3020.2	4293.67	-23.68	-8286.32
4.26	2827.4	4112.88	-18.71	-
4.615	2634.6	3906.9	-14.32	-
4.97	2441.8	3671.48	-10.52	-
5.325	2249	3400.52	-7.30	-
5.68	2056.2	3084.66	-4.67	-
6.035	1863.4	2708.24	-2.63	-
6.39	1670.6	2240.95	-1.16	-
6.745	1477.8	1605.31	-0.29	-
7.1	1285	0	0	-

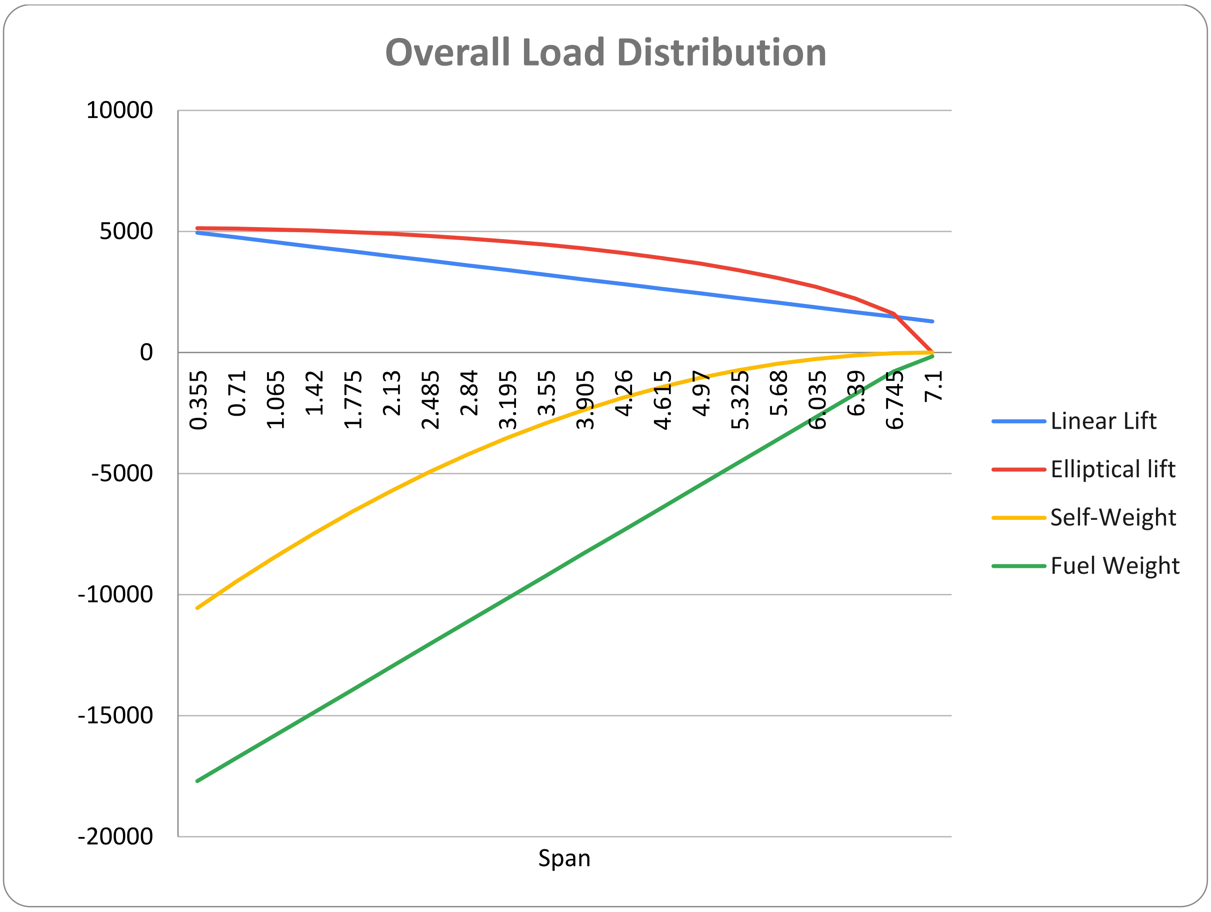


Fig. 6.6: Overall Load Distribution Graph

Table 6.7 Loads simplified as point loads:

Curve /	**Area enclosed / structural**	**Centroid**
component	**weight (N)**	**(From wing root)**
y_1	21021.467	5.35 m
y_2	27187.232	3.014 m
(y_3) Wing	2497.9	1.775m
(y_f)Fuel	35864.3	1.21 m
Power plant	2923.38	2.8 m

Reaction force and Bending moment calculations:

The wing is fixed at one end and free at the other end.

Then,

V_A+21021.467+27187-2497.9-35864-2923.38=0

V_A= -6923.187 N

Then,

M_A = (21021.467*5.35) + (27187*3.014) – (2497.9*1.775) – (35864.3*1.21) – (2923.38*2.8)

M_A =138000 N/m

Now we know V_A and M_A, using this we can find out shear force and Bending moment.

SHEAR FORCE

Table 6.8: Shear Force points

POINT	X	Shear Force(N)
A	0	51479.96
E	2.17	109319.9
D	2.8	113763.7
C	4.93	67015.76
C	4.93	20764.33
B	7.1	276.66

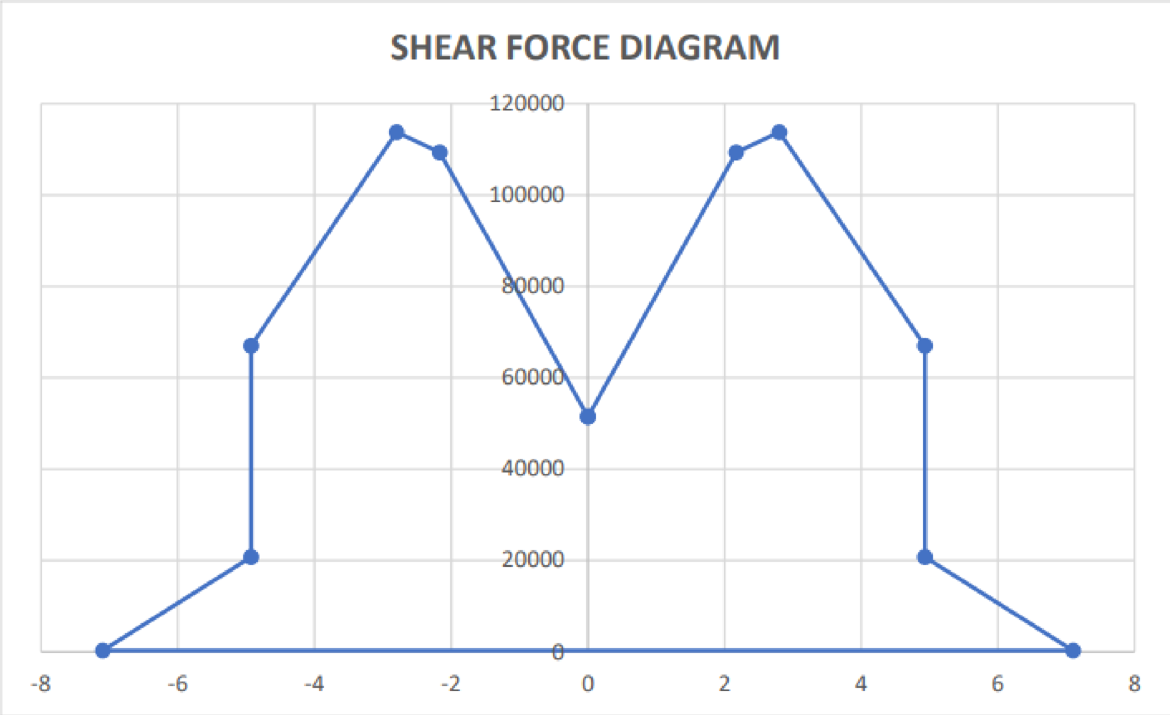


Fig. 6.7: Shear Force Diagram

BENDING MOMENT:

Table 6.9: Bending Moment points

Span	Bending Moment Diagram
7.1	0
4.93	73797.81
2.17	95742.4
0	138644.7

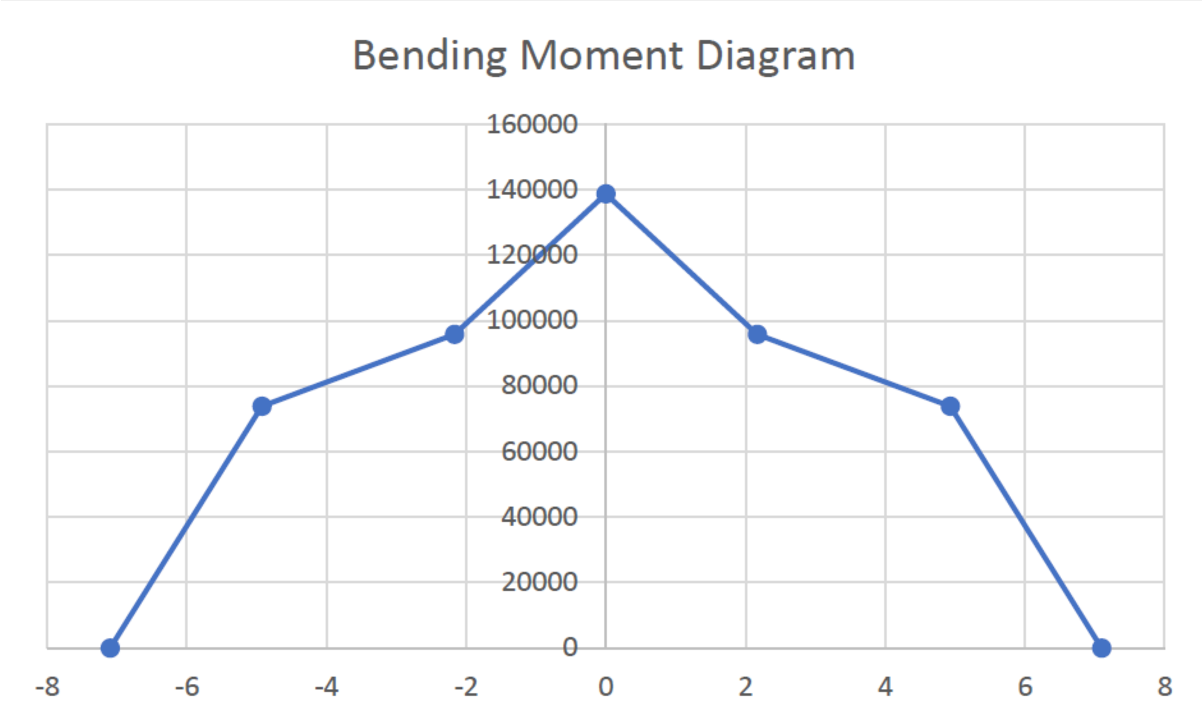


Fig. 6.8: Bending Moment Diagram

7. LOAD ESTIMATION ON FUSELAGE

Load Estimation on Fuselage:

Fuselage contributes very little to lift and produces more drag but it is an important structural member/component. It is the connecting member to all load producing components such as wing, horizontal tail, vertical tail, landing gear etc. and thus redistributes the load. It also serves the purpose of housing or accommodating practically all the equipment, accessories and systems in addition to carrying the payload. Because of large amount of equipment inside the fuselage, it is necessary to provide sufficient number of cutouts in the fuselage for access and inspection purposes. These cutouts and discontinuities result in fuselage design being more complicated, less precise and often less efficient in design. As a common member to which other components are attached, thereby transmitting the loads, fuselage can be considered as a long hollow beam. The reactions produced by the wing, tail or landing gear may be considered as concentrated loads at the respective attachment points. The balancing reactions are provided by the inertia forces contributed by the weight of the fuselage structure and the various components inside the fuselage. These reaction forces are distributed all along the length of the fuselage, though need not be uniformly. Unlike the wing, which is subjected to mainly unsymmetrical load, the fuselage is much simpler for structural analysis due to its symmetrical cross-section and symmetrical loading. The main load in the case of fuselage is the shear load because the load acting on the wing is transferred to the fuselage skin in the form of shear only. The structural design of both wing and fuselage begins with shear force and bending moment diagrams for the respective members.

To find out the loads and their distribution, consider the different cases. The main components of the fuselage loading diagram are:

- Weight of the fuselage.
- Engine weight.
- Weight of the horizontal and vertical stabilizers.
- Tail lift
- Weight of crew, payload and landing gear
- Systems, equipment, accessories

Symmetric flight condition, steady and level flight: (Downward forces negative) Values for the different component weights are obtained from aerodynamic design calculations.

8. BALANCING AND MANEUVERING LOADS ON TAIL PLANE, RUDDER ANDAILERON LOADS

Maneuvering loads:

Each horizontal surface and its supporting structure, and the main wing of a canard or tandem wing configuration, if that surface has pitch control, must be designed for the maneuvering loads imposed by the following conditions:

- A sudden movement of the pitching control, at the speed VA, to the maximum aft movement, and the maximum forward movement, as limited by the control stops, or pilot effort, whichever is critical.
- A sudden aft movement of the pitching control at speeds above VA, followed by a forward movement of the pitching control resulting in the following combinations of normal and angular acceleration. At speeds up to VA, the vertical surfaces must be designed to withstand the following conditions. In computing the loads, the yawing velocity may be assumed to be zero.
- With the airplane in unaccelerated flight at zero yaw, it is assumed that the rudder control is suddenly displaced to the maximum deflection, as limited by the control stops or by limit pilot forces.
- With the rudder deflected, it is assumed that the airplane yaws to the over swing sideslip angle. In lieu of a rational analysis, an over swing angle equal to 1.5 times the static sideslip angle may be assumed.
- A yaw angle of 15 degrees with the rudder control maintained in the neutral position (except as limited by pilot strength).
- The airplane must be yawed to the largest attainable steady state sideslip angle, with the rudder at maximum deflection caused by any one of the following:
    - Control surface stops.
    - Maximum available booster effort.
    - Maximum pilot rudder force.
    - The rudder must be suddenly displaced from the maximum deflection to the neutral position.
    - The yaw angles may be reduced if the yaw angle chosen for a particular speed cannot be exceeded in:
    - Steady slip conditions
    - Uncoordinated rolls from steep banks or
    - Sudden failure of the critical engine with delayed corrective action.

The ailerons must be designed for the loads to which they are subjected:

- In the neutral position during symmetrical flight conditions; and
- By the following deflections (except as limited by pilot effort), during unsymmetrical flight conditions
- Sudden maximum displacement of the aileron control at VA. Suitable allowance may be made for control system deflections.
- Sufficient deflection at VC, where VC is more than VA, to produce a rate of roll not less than obtained

- ❖ Sufficient deflection at VC to produce a rate of roll not less than one-third of that obtained

(a). Symmetric maneuvering conditions:

Where sudden displacement of a control is specified, the assumed rate of control surface displacement may not be less than the rate that could be applied by the pilot through the control system. In determining elevator angles and chord wise load distribution in the maneuvering conditions, the effect of corresponding pitching velocities must be taken into account. The in-trim and out-of-trim flight conditions must be considered.

(b). Maneuvering balanced conditions:

Assuming the airplane to be in equilibrium with zero pitching acceleration, the maneuvering conditions on the maneuvering envelope must be investigated. (c)Pitch maneuver conditions:

(c). Pitch Maneuver Conditions:

The movement of the pitch control surfaces may be adjusted to take into account limitations imposed by the maximum pilot effort, control system stops and any indirect effect imposed by limitations in the output side of the control system (for example, stalling torque or maximum rate obtainable by a power control system.

Maximum pitch control displacement at V_A:

The airplane is assumed to be flying in steady level flight and the cockpit pitch control is suddenly moved to obtain extreme nose up pitching acceleration. In defining the tail load, the response of the airplane must be taken into account. Airplane loads that occur subsequent to the time when normal acceleration at the c.g. exceeds the positive limit maneuvering load or the resulting tail plane normal load reaches its maximum, whichever occurs first, need not be considered.

Specified control displacement:

A checked maneuver, based on a rational pitching control motion vs. time profile, must be established in which the design limit load factor will not be exceeded. Unless lesser values cannot be exceeded, the airplane response must result in pitching accelerations not less than the following:

- ➢ A positive pitching acceleration (nose up) is assumed to be reached concurrently with the airplane load factor of 1.0. The positive acceleration must be equal to at least 39n(n-1)/v, (rad/sec)

Where “n” is the positive load factor at the speed under consideration; and V is the airplane equivalent speed in knots.

- ➢ A negative pitching acceleration (nose down) is assumed to be reached on currently with the positive maneuvering load factor. This negative pitching acceleration must be equal to at least -26n(n-1)/v, (rad/sec)

Where “n” is the positive load factor at the speed under consideration; and V is the airplane equivalent speed in knots.

Balancing loads:

- A horizontal surface balancing load is a load necessary to maintain equilibrium in any specified flight condition with no pitching acceleration.
- Horizontal balancing surfaces must be designed for the balancing loads occurring at any point on the limit maneuvering envelope and in the flap conditions
- It is not required to balance the rudder because it will not deflect due to gravity.
- Aileron will defect in vice versa direction so it is doesn’t require balancing load.

9. DETAILED STRUCTURAL LAYOUTS

Function of the structure

The primary functions of an aircraft's structure can be basically broken down into the following:

- ❖ To transmit and resist applied loads.
- ❖ To provide and maintain aerodynamic shape.
- ❖ To protect its crew, passenger, payload, systems, etc.

For the vast majority of aircraft, this leads to use of a semi-monocoque design (i.e., a thin, stressed outer shell with additional stiffening members) for the wing, fuselage & empennage. These notes will discuss the structural layout possibilities for each of these main areas, i.e., wing, fuselage & empennage.

Wing structural layout:

Specific Roles of Wing (Main wing) Structure:

The specified structural roles of the wing (or main plane) are:

- ❖ To transmit:
  - ➢ wing lift to the root via the main span wise beam
  - ➢ Inertia loads from the power plants, undercarriage, etc., to the main beam.
  - ➢ Aerodynamic loads generated on the aerofoil, control surfaces & flaps to the main beam.

- ❖ To react against:
  - ➢ Landing loads at attachment points
  - ➢ Loads from pylons/stores
  - ➢ Wing drag and thrust loads

- ❖ To provide:
- ➢ Fuel tank age space
- ➢ Torsional rigidity to satisfy stiffness and aero-elastic requirements.

- ❖ To fulfil these specific roles, a wing layout will conventionally compromise:
- ➢ Span wise members (known as spars or booms).
- ➢ Chord wise members(ribs).
- ➢ A covering skins.
- ➢ Stringers

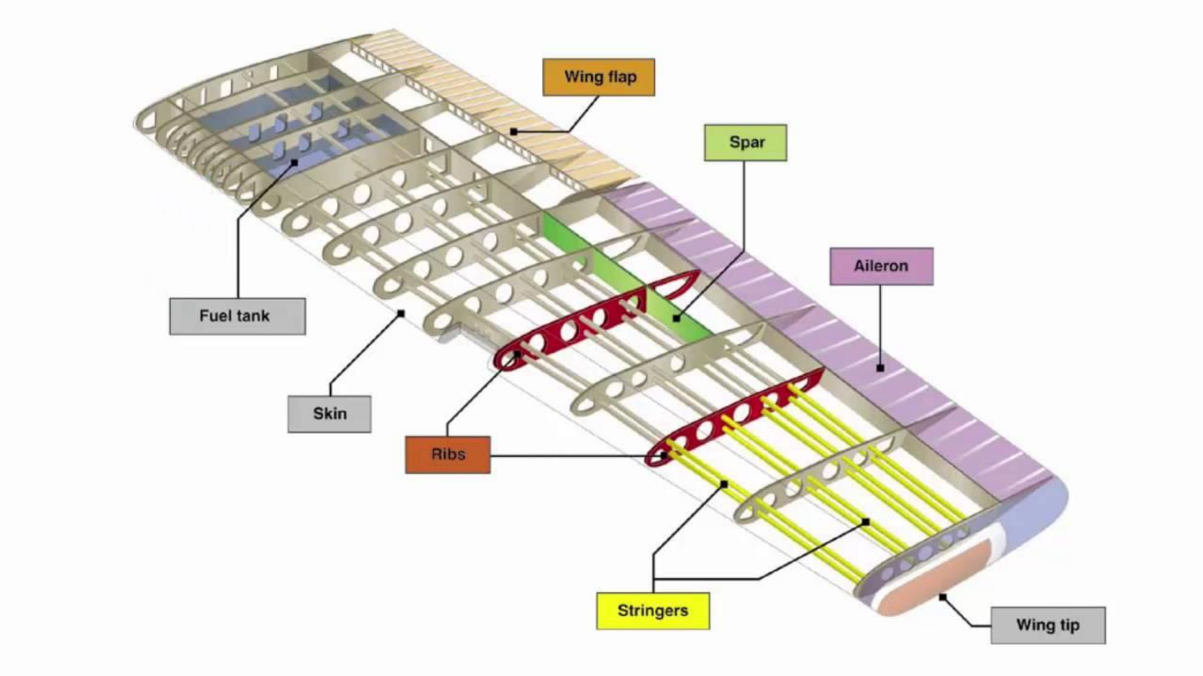


fig 9.1 structure of Aircraft wing.

Basic Functions of Wing Structural Members

The structural functions of each of these types of members may be considered independently as:

Spars:

- Form the main span wise beam
- Transmit bending and torsional loads
- Produce a closed-cell structure to provide resistance to torsion, shear and tension loads.

In particular:

- Webs – resist shear and torsional loads and help to stabilize the skin.
- Flanges - resist the compressive loads caused by wing bending.

Skin:

- To form impermeable aerodynamics surface
- Transmit aerodynamic forces to ribs & stringers
- Resist shear torsion loads (with spar webs).
- React axial bending loads (with stringers).

Stringers:

- Increase skin panel buckling strength by dividing into smaller length sections.
- React axial bending loads

Ribs:

- Maintain the aerodynamic shape.
- Act along with the skin to resist the distributed aerodynamic pressure loads.
- Distribute concentrated loads into the structure & redistribute stress around any discontinuities.
- Increase the column buckling strength of the stringers through end restraint.
- Increase the skin panel buckling strength.

Spars:

These usually comprise thin aluminium alloy webs and flanges, sometimes with separate vertical stiffeners riveted on to the webs.

Types of spars:

In the case of a two or three spar box beam layout, the front spar should be located as far forward as possible to maximize the wing box size, though this is subject to there being:

- Adequate wing depth for reacting vertical shear loads.
- Adequate nose space for LE devices, de-icing equipment, etc.

This generally results in the front spar being located at 12% to 18% of the chord length. For a single spar D-nose layout, the spar will usually located at the maximum thickness position of the aerofoil section (typically between 30% & 40% along the chord length). For the standard box beam layout, the rear spar will be located as for aft as possible, once again to maximize the wing box size, but positioning will be limited by various space requirements for flaps, control surfaces, spoilers etc. This usually results in a location somewhere between about 55%and 70% of the chord length. If any intermediate spars are used, they would tend to be spaced uniformly unless there are specific pick-up point requirements.

Ribs:

For a typical two spar layout, the ribs are usually formed in three parts from sheet metal by the use of presses &dies. Flanges are incorporated around the edges so that they can be riveted to the skin and the spar webs. Cut-out are necessary around the edges to allow for the stringers to pass through. Lightening holes are usually cut into the rib bodies to reduce the rib weight and also to allow for the passage of control runs, fuel, electrics, etc.

Rib bulkheads do not include any lightening holes and are used at fuel tank ends, wing crank locations and attachment support areas. The rib should be ideally spaced to ensure adequate overall buckling support to spar flanges. In reality, however, their positioning is also influenced by:

- Facilitating attachment points for control surfaces, flaps, slats, spoiler hinges, power plants, stores, undercarriage attachment etc.
- Positioning of fuel tank ends, requiring closing ribs.
- A structural need to avoid local shear or compression buckling; there are several different possibilities regarding the alignment of the ribs on swept-wing aircraft is a

hybrid design in which one or more inner ribs are aligned with the main axis while the remainders are aligned perpendicularly to the rear spar and usually the preferred option but presents several structural problems in the root region also Gives good torsional stiffness characteristics but results in heavy ribs and complex connections.

Skin:

The skin tends to be riveted to the rib flanges and stringers, using countersunk rivets to reduce drag. It is usually pre-formed at the leading edges, where the curvature is large due to aerodynamic considerations.

Fuselage structure:

The fundamental purpose of the fuselage structure is to provide an envelope to support the payload, crew, equipment, systems and (possibly) the power-plant. Furthermore, it must react against the in-flight manoeuvre, pressurisation and gust loads; also, the landing gear and possibly any power-plant loads. It must be also be able to transmit control and trimming loads from the stability and control surfaces throughout the rest of the structure

Fuselage contributes very little to lift and produces more drag but it is an important structural member/component. It is the connecting member to all load producing components such as wing, horizontal tail, vertical tail, landing gear etc. and thus redistributes the load. It also serves the purpose of housing or accommodating practically all equipment, accessories and systems in addition to carrying the payload. Because of large amount of equipment inside the fuselage, it is necessary to provide sufficient number of cutouts in the fuselage for access and inspection purposes. These cutouts and discontinuities result in fuselage design being more complicated, less precise and often less efficient in design.

As a common member to which other components are attached, thereby transmitting the loads, fuselage can be considered as a long hollow beam. The reactions produced by the wing, tail or landing gear may be considered as concentrated loads at the respective attachment points. The balancing reactions are provided by the inertia forces contributed by the weight of the fuselage structure and the various components inside the fuselage. These reaction forces are distributed all along the length of the fuselage, though need not be uniformly. Unlike the wing, which is subjected to mainly unsymmetrical load, the fuselage is much simpler for structural analysis due to its symmetrical cross-section and symmetrical loading. The main load in the case of fuselage is the shear load because the load acting on the wing is transferred to the fuselage skin in the form of shear only. The structural design of both wing and fuselage begin with shear force and bending moment diagrams for the respective members. The maximum bending stress produced in each of them is checked to be less than the yield stress of the material chosen for the respective member.

Fuselage Layout Concepts:

There are two main categories of layout concept in common use;

- Mass boom and longeron layout.
- Semi-monocoque layout.

Mass Boom & Longeron layout

This is fundamentally very similar to the mass-boom wing-box concept discussed in previous section. It is used when the overall structural loading is relatively low or when there are extensive cut-outs in the shell. The concept comprises four or more continuous heavy booms (longeron), reacting against any direct stresses caused by applied vertical and lateral bending loads. Frames or solid section.

Semi-Monocoque layout

The semi-monocoque is the most often used construction for modern, high-performance aircraft. **Semi-monocoque** literally means half a single shell. Here, internal braces as well as the skin itself carry the stress. The vertical structural members are referred to as bulkheads, frames, and formers. The heavier vertical members are located at intervals to allow for concentrated loads. These members are also found at points where fittings are used to attach other units, such as the wings and stabilizers.

Primary bending loads are taken by the longerons, which usually extend across several points of support. The longerons are supplemented by other longitudinal members known as stringers. Stringers are more numerous and lightweight than longerons. The stringers are smaller and lighter than longerons and serve as fill-ins. They have some rigidity but are chiefly used for giving shape and for attachment of skin.

The strong, heavy longerons hold the bulkheads and formers. The bulkheads and formers hold the stringers. All of these joins together to form a rigid fuselage framework. Stringers and longerons prevent tension and compression stresses from bending the fuselage. The skin is attached to the longerons, bulkheads, and other structural members and carries part of the load. The fuselage skin thickness varies with the load carried and the stresses sustained at particular location.

10.DESIGN OF SOME COMPONENTS OF WING AND FUSELAGE

Design of wing component spar:

Wing is the major lift producing surface. Therefore, the analysis has to be very accurate. The structural analysis of the wing by defining the primary load carrying member Spars is done below.

Spars are members which are basically used to carry the bending and shear loads acting on the wing during flight. There are two spars, one located at 15-20% of the chord known as the front spar, the other located at 60-70% of the chord known as the rear spar. Some of the functions of the spar include: They form the boundary to the fuel tank located in the wing.

- The spar flange takes up the bending loads whereas the web carries the shear loads.
- The rear spar provides a means of attaching the control surfaces on the wing.

Considering these functions, the locations of the front and rear spar are fixed at 0.17c and 0.65c respectively. The spar design for the wing root has been taken because the maximum bending moment and shear force are at the root. It is assumed that the flanges take up all the bending and the web takes all the shear effect. The maximum bending moment for high angle of attack condition is Nm. The ratio in which the spars take up the bending moment is

Design Of Fuselage Component Stringer

The circumference of the fuselage is 43.102 m. To find the area of one stringer, number of stringers per quadrant is assumed to be 4. i.e. the total number of stringers in the fuselage is 16. The stringers are equally spaced around the circumference of the fuselage.

Stringer Spacing:

The stringers are symmetrically spaced on the fuselage with the spacing.

Stringer area calculation:

The stress induced in each stringer is calculated with the area keeping constant in the stress term. Then the maximum stress (i.e., one which has larger numerator) is equated with the yield strength of the material. From this area of one stringer is calculated.

11. MATERIAL SELECTION

Description:

Aircraft structures are basically unidirectional. This means that one dimension, the length, is much larger than the others - width or height. For example, the span of the wing and tail spars is much longer than their width and depth; the ribs have a much larger chord length than height and/or width; a whole wing has a span that is larger than its chords or thickness; and the fuselage is much longer than it is wide or high. Even a propeller has a diameter much larger than its blade width and thickness, etc.... For this simple reason, a designer chooses to use unidirectional material when designing for an efficient strength to weight structure.

Unidirectional materials are basically composed of thin, relatively flexible, long fibers which are very strong in tension (like a thread, a rope, a stranded steel wire cable, etc.). An aircraft structure is also very close to a symmetrical structure. Those mean the up and down loads are almost equal to each other. The tail loads may be down or up depending on the pilot raising or dipping the nose of the aircraft by pulling or pushing the pitch control; the rudder may be deflected to the right as well as to the left (side loads on the fuselage). The gusts hitting the wing may be positive or negative, giving the up or down loads which the occupant experiences by being pushed down in the seat or hanging in the belt.

Because of these factors, the designer has to use a structural material that can withstand both tension and compression. Unidirectional fibers may be excellent in tension, but due to their small cross section, they have very little inertia (we will explain inertia another time) and cannot take much compression. They will escape the load by bucking away. As in the illustration, you cannot load a string, or wire, or chain in compression.

In order to make thin fibres strong in compression, they are "glued together" with some kind of an "embedding". In this way we can take advantage of their tension strength and are no longer penalized by their individual compression weakness because, as a whole, they become compression resistant as they help each other to not buckle away. The embedding is usually a lighter, softer "resin" holding the fibres together and enabling them to take the required compression loads. This is a very good structural material.

Wood:

Historically, wood has been used as the first unidirectional structural raw material. They have to be tall and straight and their wood must be strong and light. The dark bands (late wood) contain many fibers, whereas the light bands (early wood) contain much more "resin". Thus the wider the dark bands, the stronger and heavier the wood. If the dark bands are very narrow and the light bands quite wide, the wood is light but not very strong. To get the most efficient strength to weight ratio for wood we need a definite numbers of bands per inch. Some of our aircraft structures are two-dimensional (length and width are large with respect to thickness). Plywood is often used for such structures. Several thin boards (foils) are glued together so that the fibers of the various layers cross over at different angles (usually 90 degrees today years back you could get them at 30 and 45 degrees as well). Plywood makes excellent "shear webs" if the designer knows how to use plywood efficiently. (We will learn the basis of stress analysis sometime later).

Today good aircraft wood is very hard to come by. Instead of using one good board for our spars, we have to use laminations because large pieces of wood are practically unavailable, and we no longer can trust the wood quality. From an availability point of view, we simply need a substitute for what nature has supplied us with until now.

Aluminium alloys:

So, since wood may not be as available as it was before, we look at another material which is strong, light and easily available at a reasonable price (there's no point in discussing Titanium - it's simply too expensive). Aluminium alloys are certainly one answer. We will discuss the properties of those alloys which are used in light plane construction in more detail later. For the time being we will look at aluminium as a construction material.

Extruded Aluminium Alloys:

Due to the manufacturing process for aluminium, we get a unidirectional material quite a bit stronger in the lengthwise direction than across. And even better, it is not only strong in tension but also in compression. Comparing extrusions to wood, the tension and compression characteristics are practically the same for aluminium alloys so that the linear stress analysis applies. Wood, on the other hand, has a tensile strength about twice as great as its compression strength; accordingly, special stress analysis methods must be used and a good understanding of wood under stress is essential if stress concentrations are to be avoided!

Aluminium alloys, in thin sheets (.016 to .125 of an inch) provide an excellent two-dimensional material used extensively as shear webs - with or without stiffeners - and also as tension/compression members when suitably formed (bent). It is worthwhile to remember that aluminium is an artificial metal. There is no aluminium ore in nature. Aluminium is manufactured by applying electric power to bauxite (aluminium oxide) to obtain the metal, which is then mixed with various strength-giving additives. (In a later article, we will see which additives are used, and why and how we can increase aluminium's strength by cold work hardening or by tempering.) All the commonly used aluminium alloys are available from the shelf of dealers. When requested with the purchase, you can obtain a "mill test report" that guarantees the chemical and physical properties as tested to accepted specifications.

As a rule of thumb, aluminium is three times heavier, but also three times stronger than wood. Steel is again three times heavier and stronger than aluminium.

Steel:

The next material to be considered for aircraft structure will thus be steel, which has the same weight-to-strength ratio of wood or aluminium.

Apart from mild steel which is used for brackets needing little strength, we are mainly using a chrome-molybdenum alloy called AISI 413ON or 4140. The common raw materials available are tubes and sheet metal. Steel, due to its high density, is not used as shear webs like aluminium sheets or plywood. Where we would need, say.100" plywood, a .032inch aluminium sheet would be required, but only a .010 steel sheet would be required, which is just too thin to handle with any hope of a nice finish. That is why a steel fuselage uses tubes also as diagonals to carry the shear in compression or tension and the whole structure is then covered with fabric (light weight) to give it the required aerodynamic shape or desired look. It must be noted that this method involves two techniques: steel work and fabric covering.

Composite Materials:

The designer of composite aircraft simply uses fibers in the desired direction exactly where and in the amount required. The fibers are embedded in resin to hold them in place and provide the required support against buckling. Instead of plywood or sheet metal which allows single curvature only, the composite designer uses cloth where the fibers are laid in two directions. (The woven thread and weft) also embedded in resin. This has the advantage of freedom of shape in double curvature as required by optimum aerodynamic shapes and for very appealing look (importance of aesthetics).

Today's fibers (glass, nylon, Kevlar, carbon, whiskers or single crystal fibers of various chemical compositions) are very strong, thus the structure becomes very light. The drawback is very little stiffness. The structure needs stiffening which is achieved either by the usual discreet stiffeners, -or more elegantly with a sandwich structure: two layers of thin uni- or bi-directional fibers are held apart by a lightweight core (foam or "honeycomb"). This allows the designer to achieve the required inertia or stiffness.

From an engineering standpoint, this method is very attractive and supported by many authorities because it allows new developments which are required in case of war. But this method also has its drawbacks for homebuilding: A mold is needed, and very strict quality control is a must for the right amount of fibers and resin and for good adhesion between both to prevent too "dry" or "wet" a structure. Also, the curing of the resin is quite sensitive to temperature, humidity and pressure. Finally, the resins are active chemicals which will not only produce the well-known allergies but also the chemicals that attack our body (especially the eyes and lungs) and they have the unfortunate property of being cumulatively damaging and the result (in particular deterioration of the eye) shows up only years after initial contact.

Another disadvantage of the resins is their limited shelf life, i.e., if the resin is not used within the specified time lapse after manufacturing, the results may be unsatisfactory and unsafe.

Heavy Aircraft Raw Materials:

1. **Magnesium:** An expensive material. Castings are the only readily available forms. Special precaution must be taken when machining magnesium because this metal burns when hot.
2. **Titanium:** A very expensive material. Very tough material and difficult to machine.
3. **Carbon Fibers:** Still very expensive materials.
4. **Kevlar Fibers:** Very expensive and also critical to work with because it is hard to "soak" in the resin.

A number of properties are important to the selection of materials for an aircraft structure. The selection of the best material depends upon the application. Factors to be considered include yield and ultimate strength, stiffness, density, fracture toughness, fatigue, crack resistance, temperature limits, producibility, repairability, cost and availability. The gust loads, landing impact and vibrations of the engine and propeller cause fatigue failure which is the single most common cause of aircraft material failure.

For most aerospace materials, creep is a problem only at the elevated temperature. However, some titanium plastics and composites will exhibit creep at room temperatures.

Taking all the above factors into considerations, the following aluminium alloys which have excellent strength to weight ratio and are abundant in nature are considered.

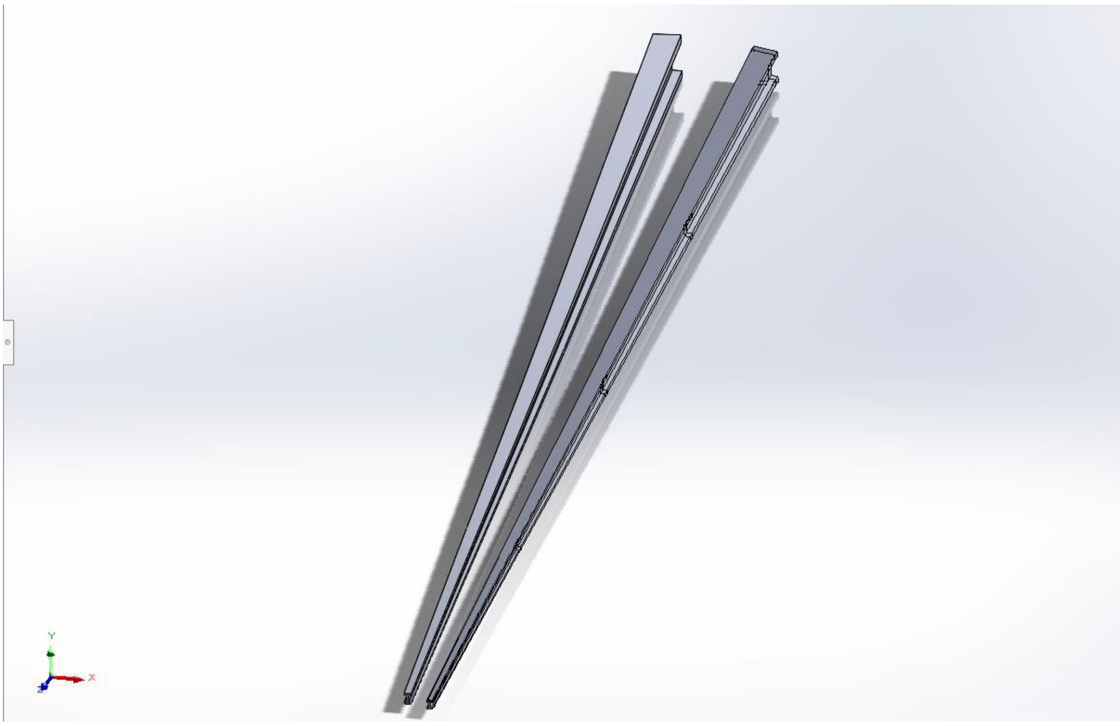
Table 11.1: Yield Strength & Ultimate Strength of Different Aluminium Alloys

S.No	Aluminium Alloy	Yield Strength (MPa)	Ultimate Strength (MPa)
1	Al 2021-T35	280	470
2	Al 2024-T3	276	427
3	Al 7075-T6	476	538
4	Al 7075-T651	462	538
5	Al 6061-0	55	112
6	Al 6064-T4	110	207
7	Al 6061-T6	241	290
8	Al 6082-T6	210	340

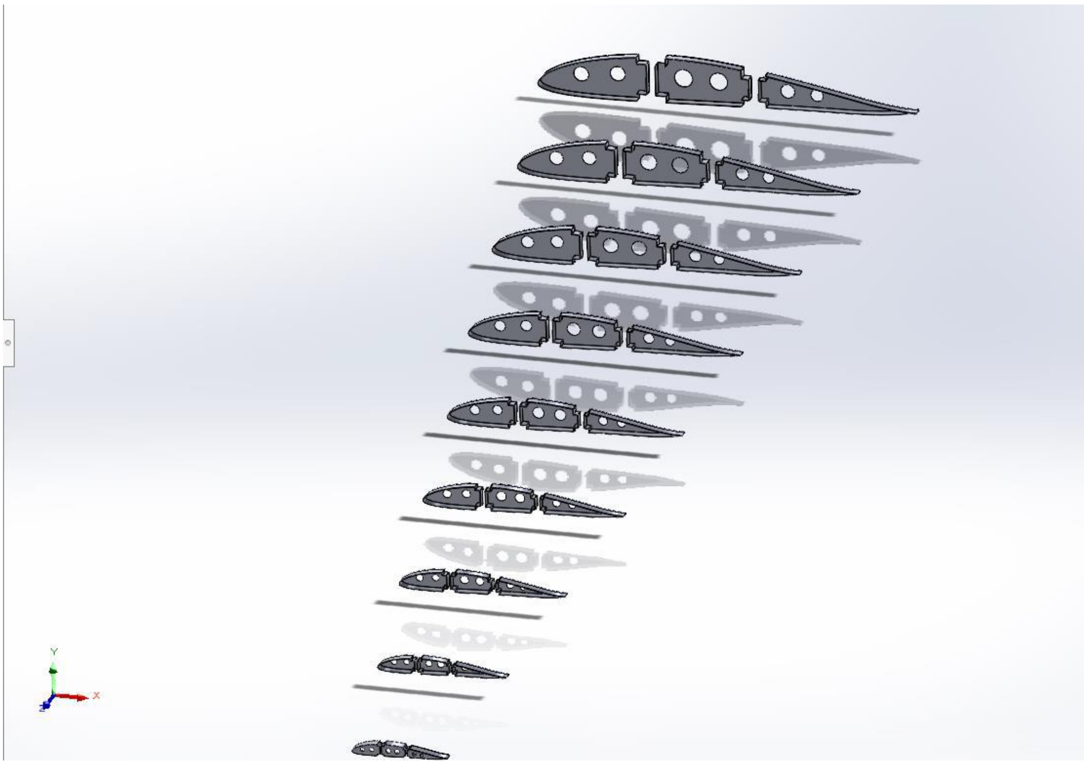
Table 11.2: Final Parameters

Parameters	Values
Span	14.2 m
Wing Area	24 m^2
Aspect Ratio	8.4
Empty Weight	4600 kg
Maximum Take-off Weight	7400 kg
Root Chord	1.7 m
Tip Chord	0.425 m
Wing Loading	308.3 kg/m^2
Cruise Speed	222.22 m/s
Max Speed	285 m/s
Oswald's Efficiency	0.8
Power Delivered by Motor	15.675 kN
Rate Of Climb	19 m/s
Range	3400 km
Landing Distance	848.3 m
Take-off Distance	1020 m
Lift Coefficient	0.1
Maximum Bending Moment	138644.7 N/m

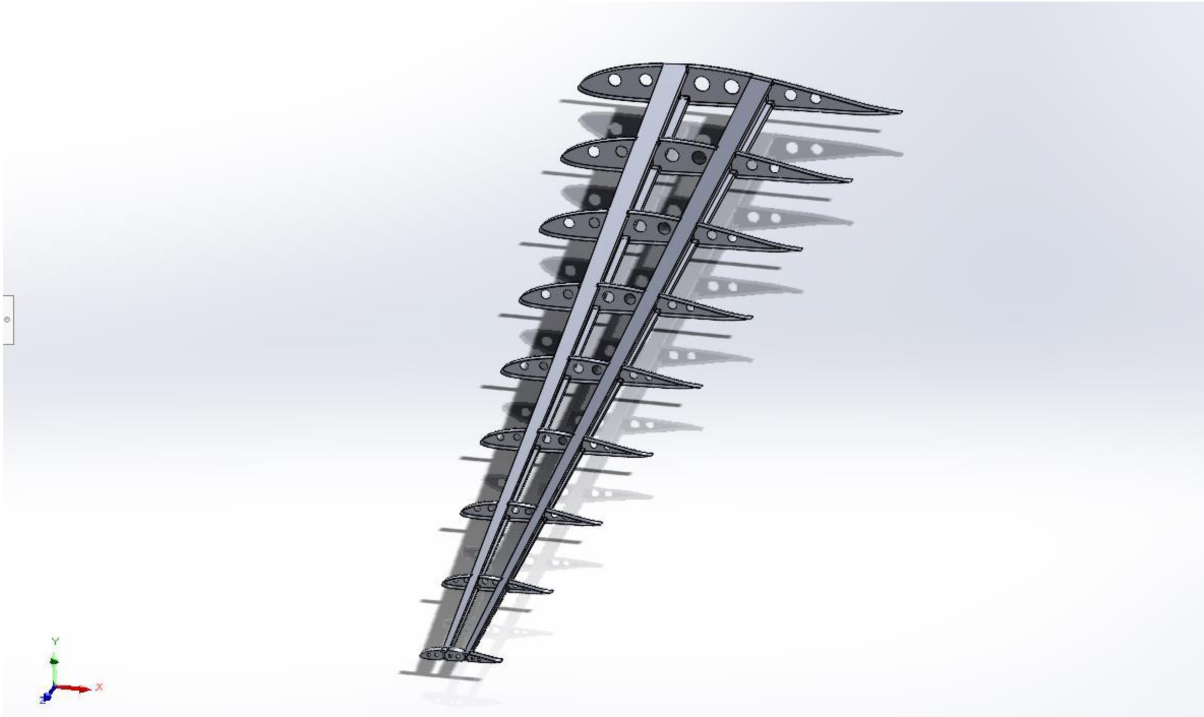
CAD MODEL:



1. **STRINGER**

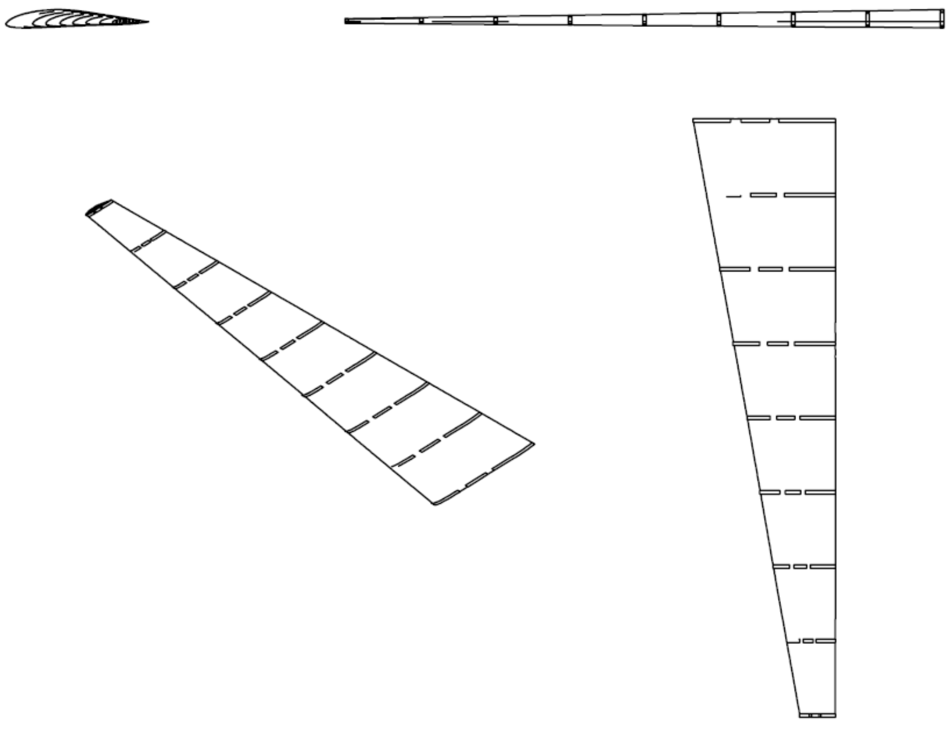


2. **RIBS**

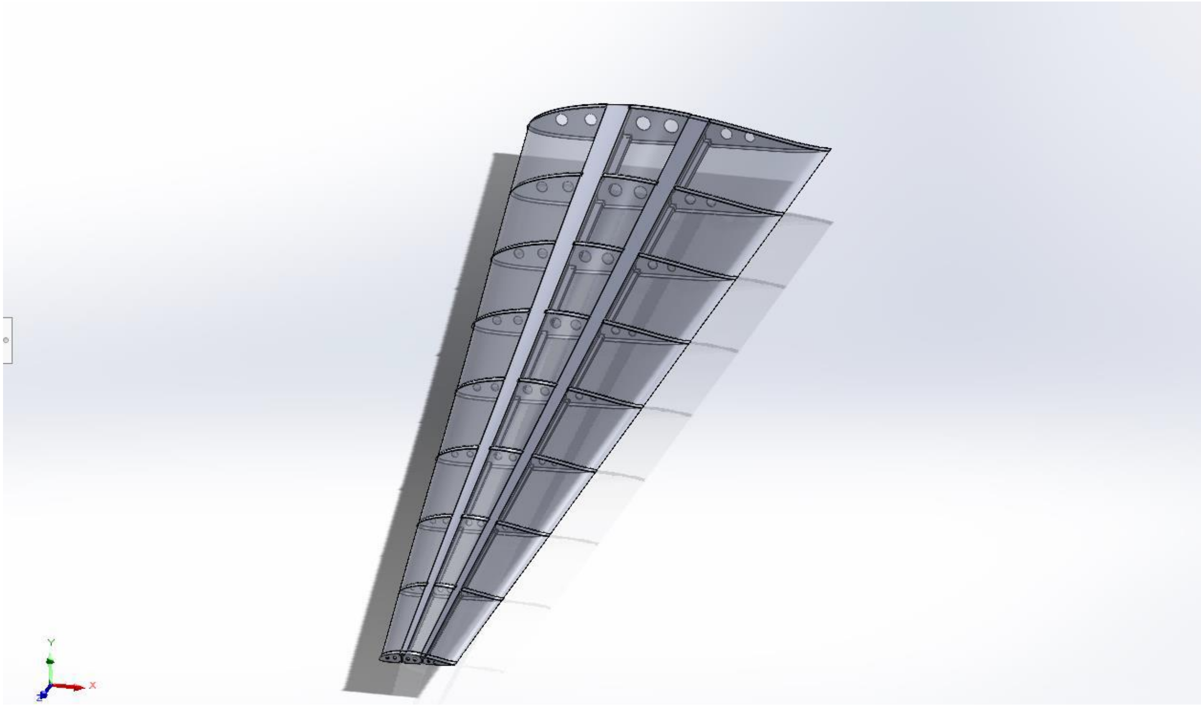


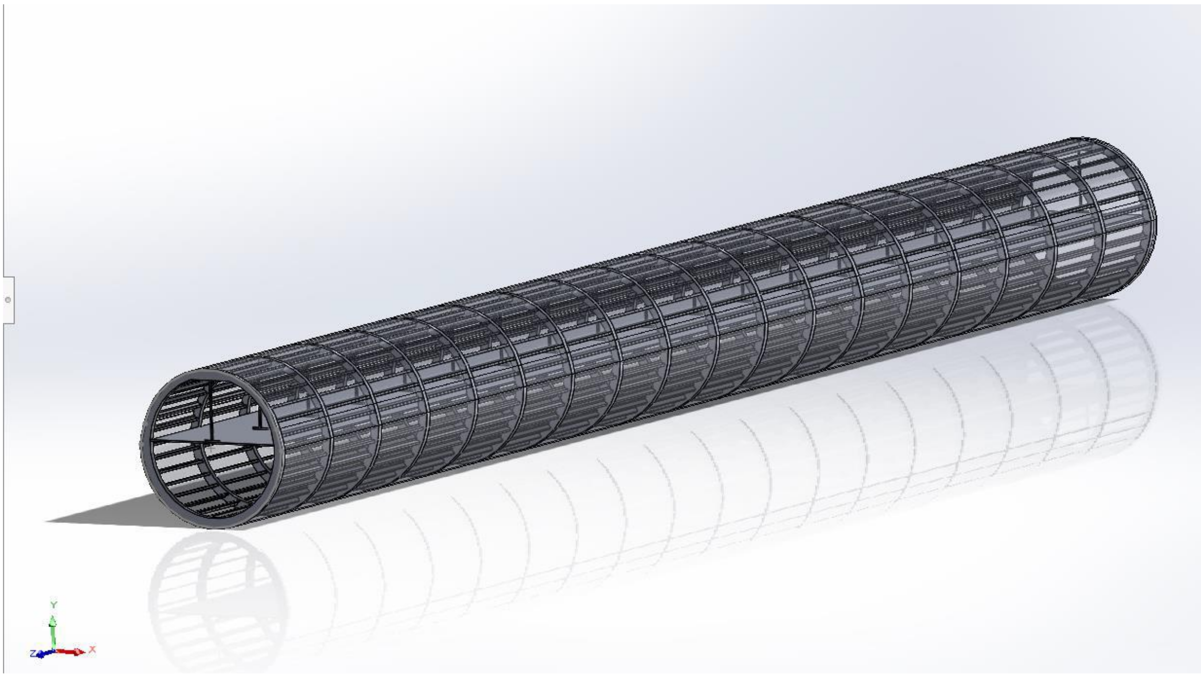
3. WING INTERNAL STRUCTURE

2D View:

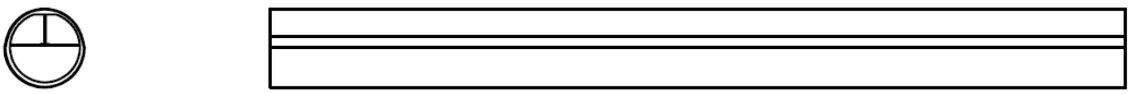


2D View

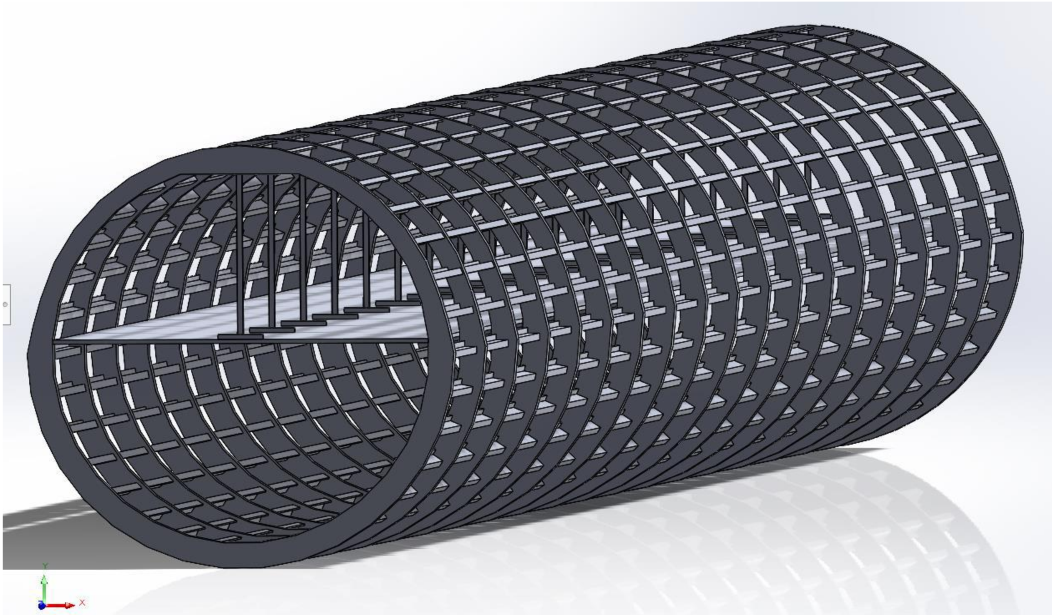




4.FUSELAGE STRUCTURE

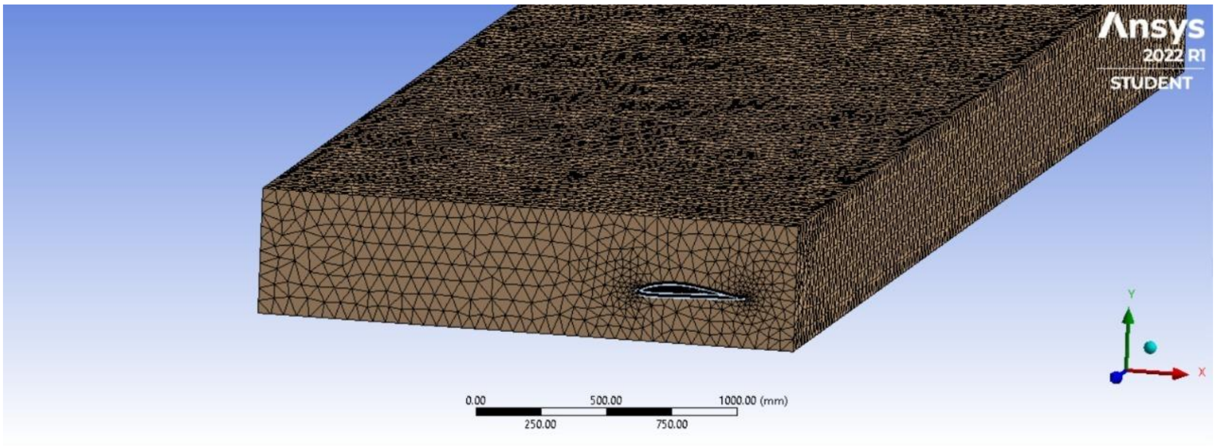


2D View

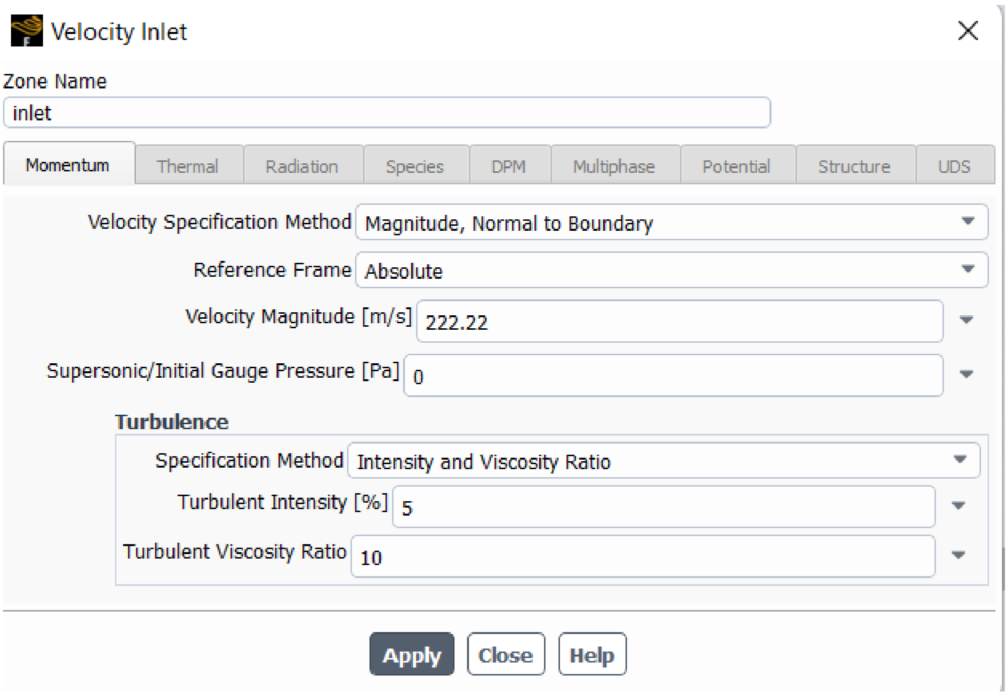


ISOMETRIC VIEW

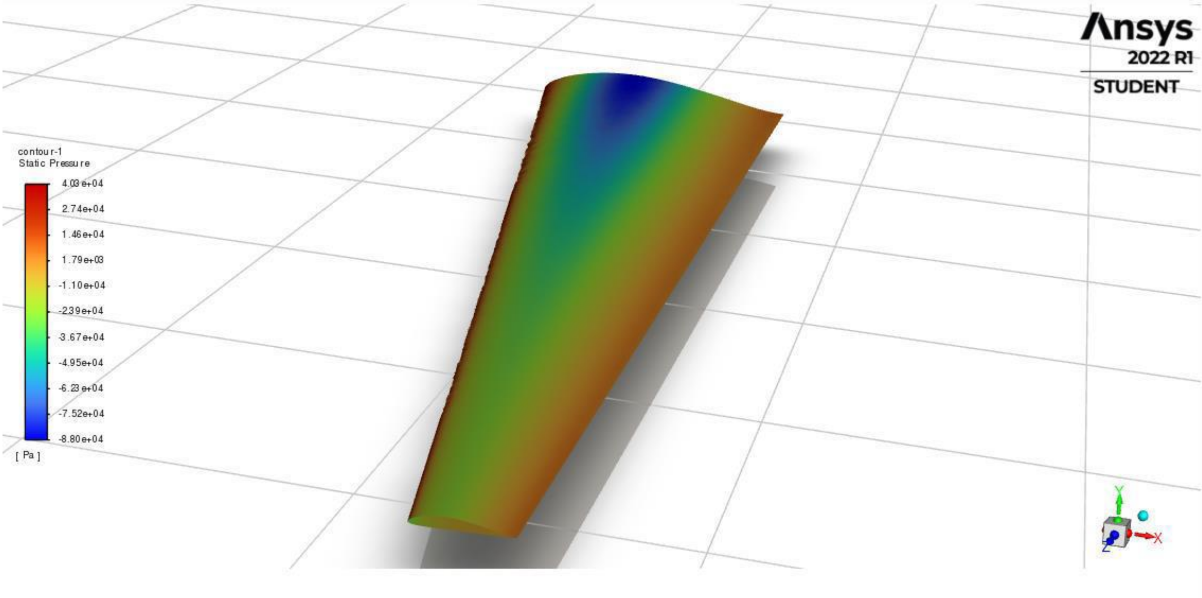
CFD ANALYSIS:



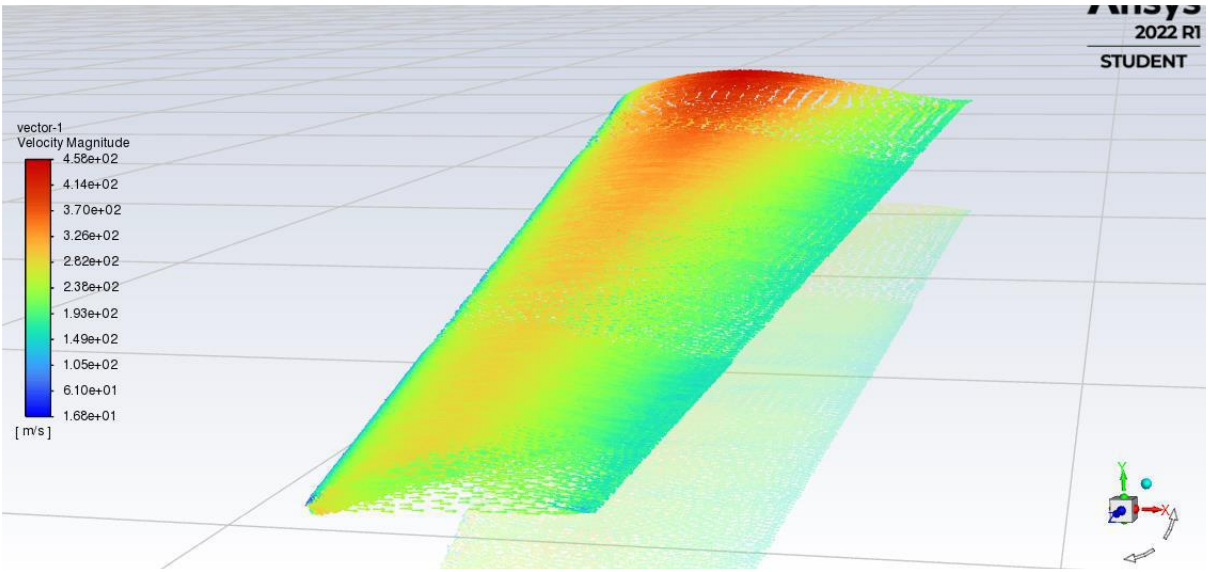
MESHING



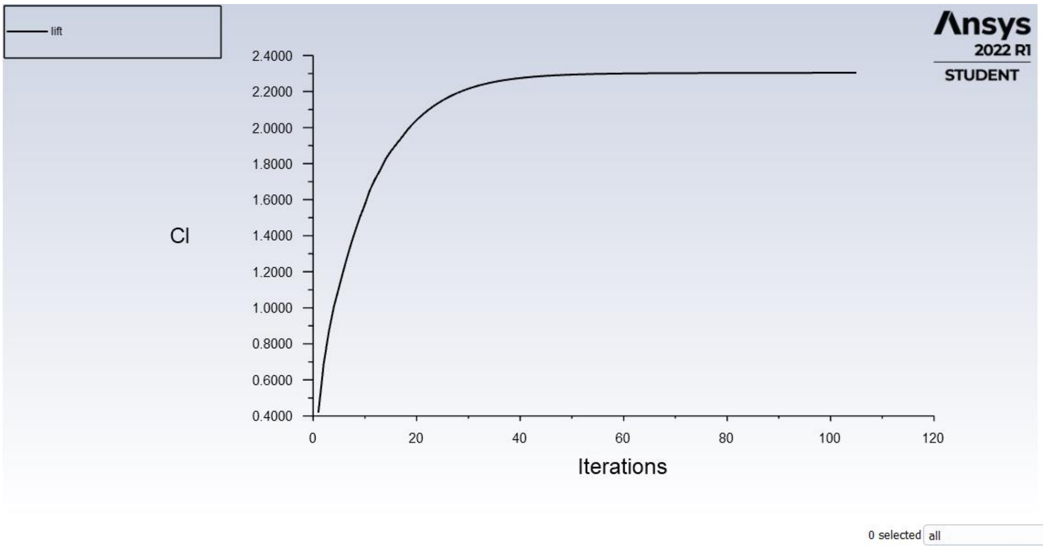
BOUNDARY CONDITIONS



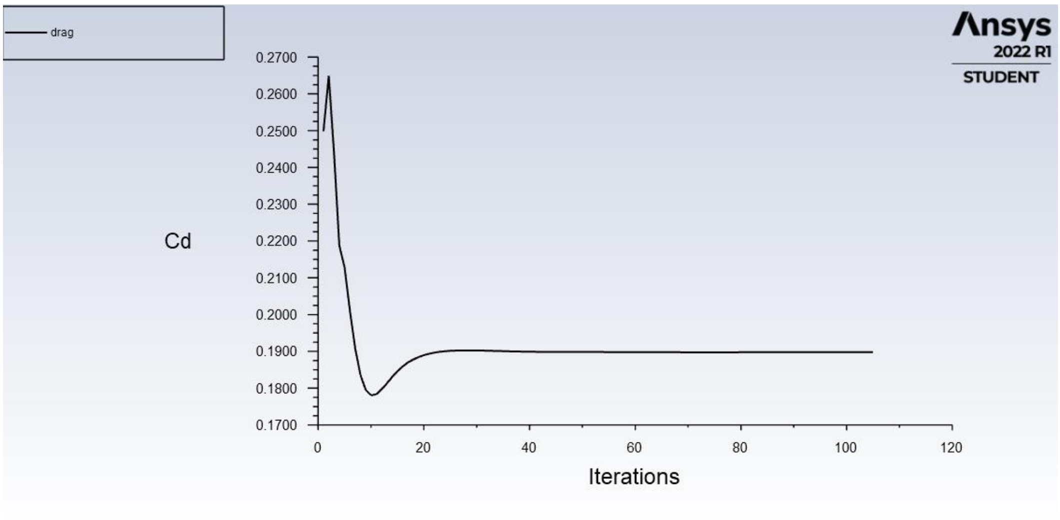
PRESSURE CONTOUR



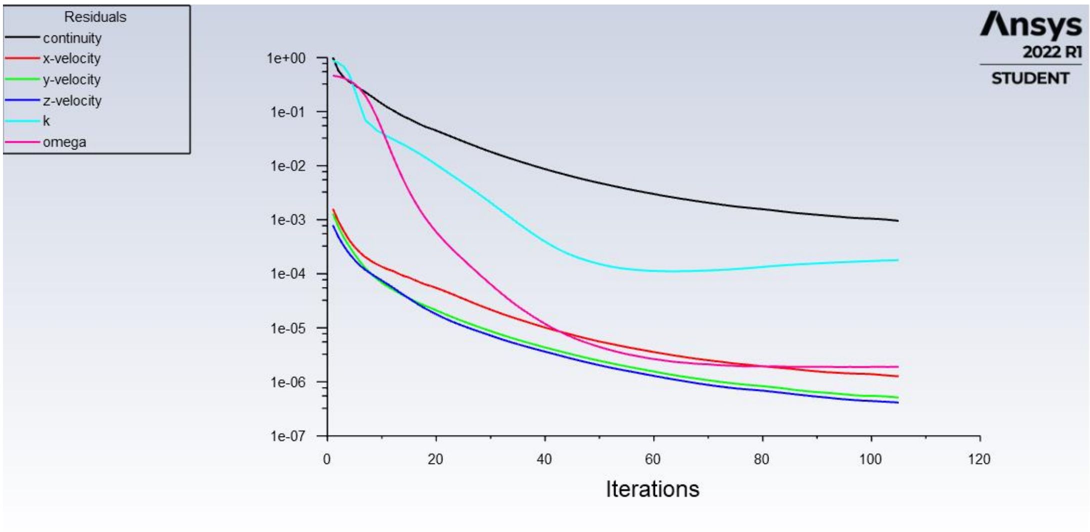
VELOCITY CONTOUR



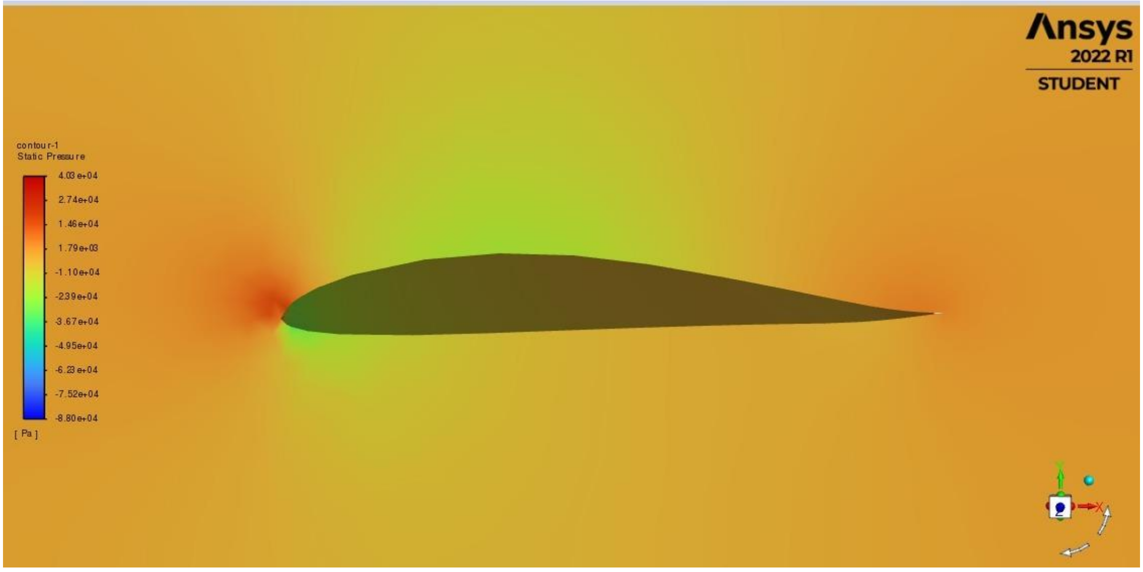
LIFT CO-EFFICIENT



DRAG CO-EFFICIENT



SCALED RESIDUES



PRESSURE

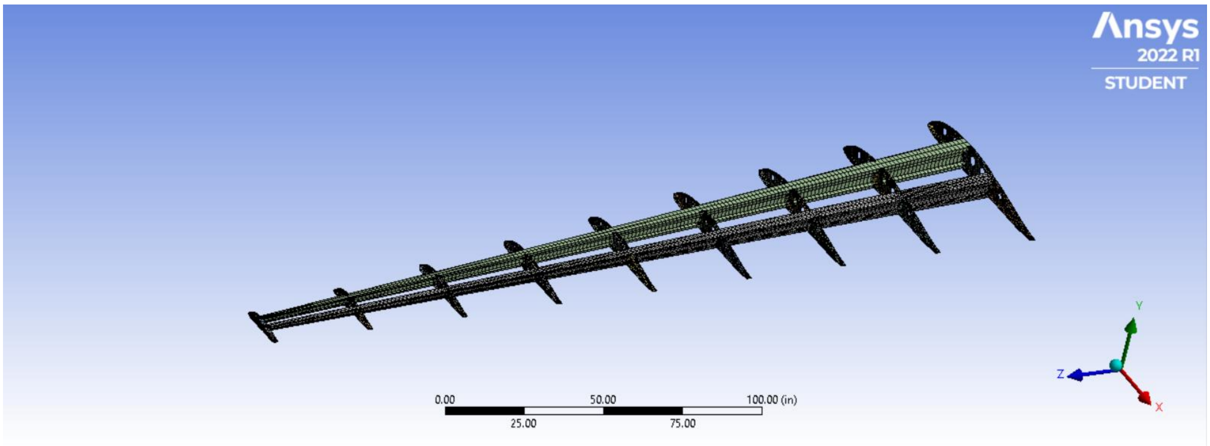
PRE-PROCESSING DETAILS:

No of Nodes	**55806**
No of Elements	**22227**

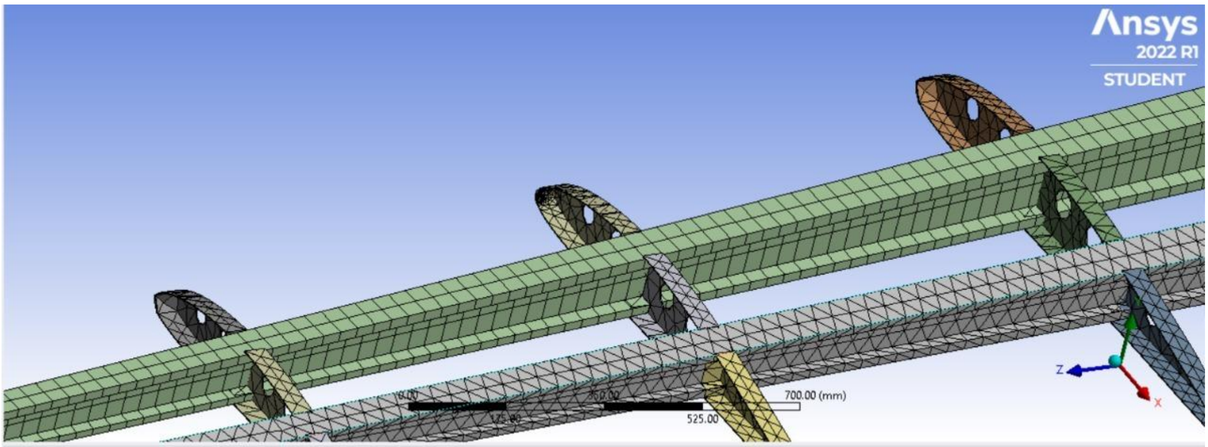
RESULT

Component	**Velocity**		**Pressure**	
	Max	**Min**	**Max**	**Min**
Wing	**458 m/s**	**16.8 m/s**	**4.03 * 10^4 Pa**	**-8.8 * 10^4 Pa**

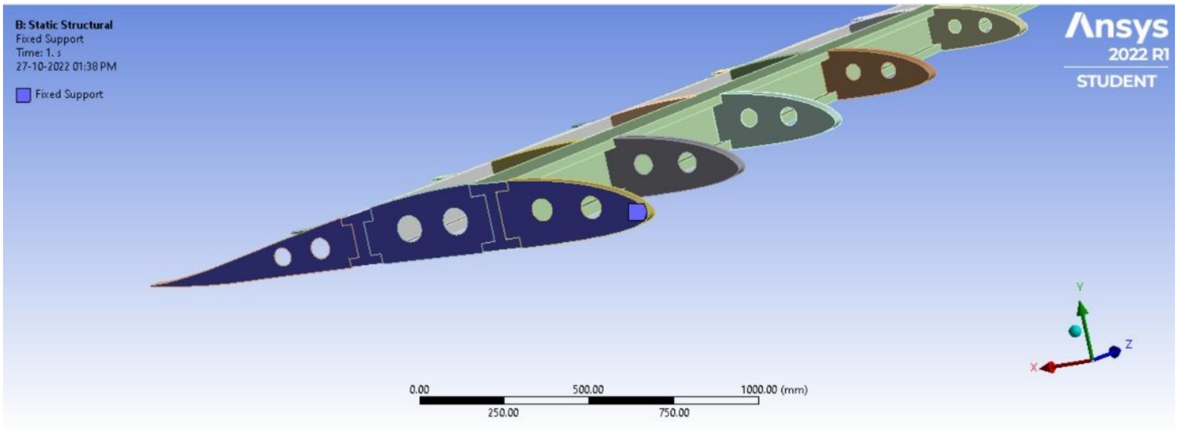
STRUCTURAL ANALYSIS:



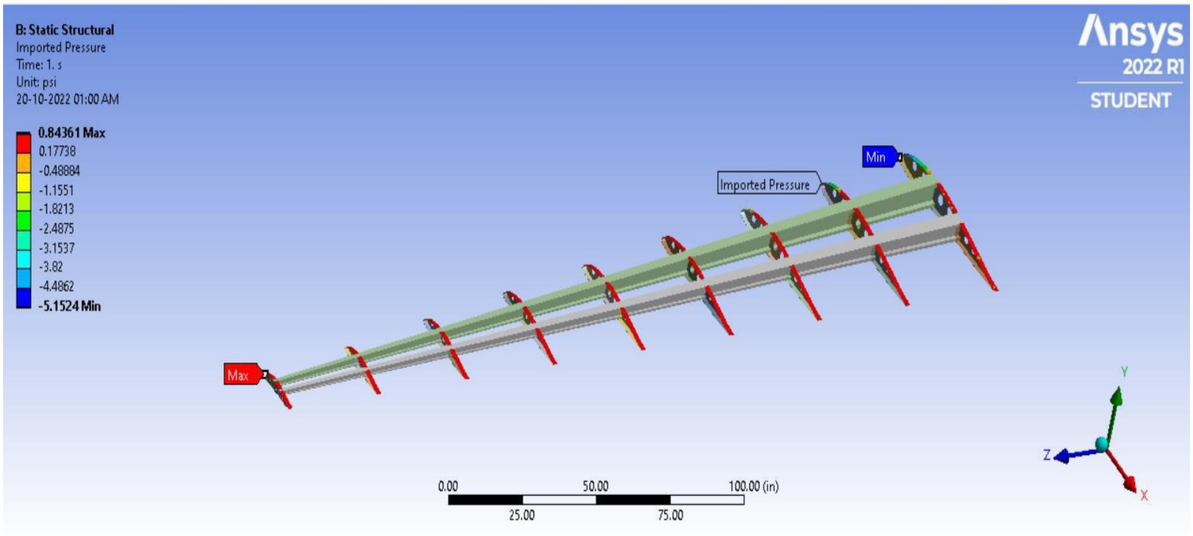
MESHING

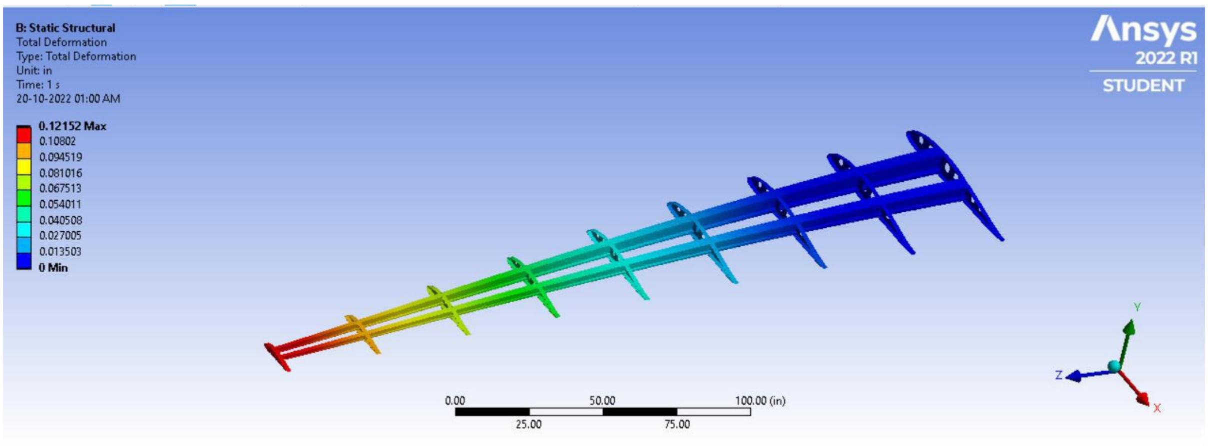


ZOOMED IN MESHING VIEW

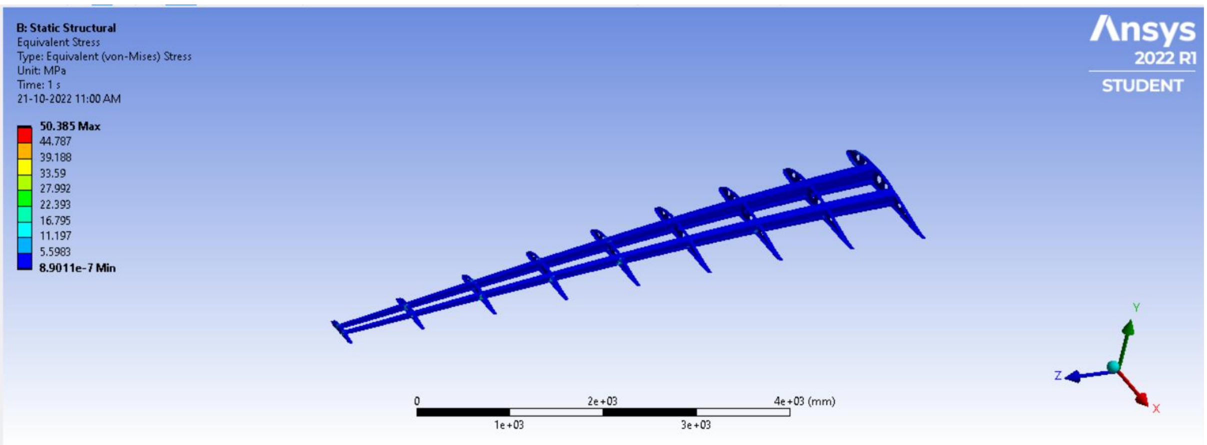


FIXED SUPPORT





TOTAL DEFORMATION



EQUIVALENT STRESS

PRE-PROCESSING DETAILS:

No of Nodes	**55806**
No of Elements	**22227**
Type of Support	**Fixed Support**

RESULT

Component	**Total Deformation**		**Von-Mises Stress**	
	Max	**Min**	**Max**	**Min**
Stringer	**42.11 mm**	**0 mm**	**27.66 MPa**	**0.00063 MPa**
Wing	**3.087 mm**	**0 mm**	**50.385 MPa**	**0.8 Pa**

CONCLUSION:

The structural design of the Heavy- Weight cargo aircraft which is a continuation of the aerodynamic design part carried out last semester is completed satisfactorily. The aeroplane has gone through many design modifications since its early conceptual designs expected, among these was a growth in weight.

To ensure continued growth in payload and the reduced cost of cargo operations, improvements in methods, equipment and terminal facilities will be required in order to reduce cargo handling costs and aircraft ground time and to provide improved service for the shippers.

We have enough hard work for this design project. A design never gets completed in a flutter sense but it is one step further towards ideal system. But during the design of this aircraft, we learnt a lot about aeronautics and its implications when applied to an aircraft design.

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