Optimization and Finite Element Analysis of Composite Fuselage Floor Beam of an Aircraft

Srikanth[1], Dr. Prashanth. A. S[2]

[1]P.G. Scholar, Dept. Of Mechanical Engineering, Dr. Ambedkar Institute of Technology, Bengaluru, Karnataka, India
[2]Assistant Professor, Dept. Of Mechanical Engineering, Dr. Ambedkar Institute of Technology, Bengaluru, Karnataka, India

---***---

Abstract - *Floor Beam is a structural element of fuselage; it is mainly used for providing horizontal space to Passengers, Cargo, Aircraft crew and is fixed with fuselage skin. The fuselage is continuously subjected to various load while flight take-off and while landing. In this Optimization, Analysis and Design of 0I-shaped fuselage floor/cross beam of an aircraft is selected which is better than other cross-section using Finite Element Analysis. Here design of fuselage floor/cross beam is conceptual for strength enhancement, durability, weight reduction and cost. The major problems occurred in aluminium floor beam is less stiffness and increased weight. Hence, for designing of floor beam in the fuselage, CFRP (Carbon Fiber Reinforced Plastic) is selected. After selecting the cross-section and material of fuselage beam, UG NX8 software is used to study and design the whole parameters of cross-section of floor with standard dimensions of the floor beam. Then the Design model is imported to ANSYS for analysis and optimization. The expected outcome is to reduce cost, design, and weight to strength ratio and style outlook with weight reduction of aircraft*

Key words: Fuselage, Floor Beam, Structural Analysis, Equivalent Stress, ANSYS, CFRP

1. INTRODUCTION

An aircraft consists of complex structure hence it is very efficient man-made flying machine. Aircraft structure is the most distinct example hence functional requirements demands light in weight and stronger structures. The improvements of aircraft structures are mainly achieved by improving the material and configuration properties under the skin. Hence, aircraft manufacturers are increasing gradually its reliance on Fiber Metal Laminates and materials of composite. Example, all-composite empennage and composite of fuselage floor beam are present in Boeing 777. The five main sections built by composite materials in Boeing 787 fuselage aircraft account about 50% of the total structural weight of aircraft.

1.1 THE AIRCRAFT

An airplane designates a fixed-wing driven through the Earth atmosphere by power plant units mounted with airplane attained for producing required dynamic lift. It can be anticipated here airplane is directed using aircraft crew except it is identified as Unmanned Aerial Vehicle. A light civil aircraft is an example that is shown in Fig.1

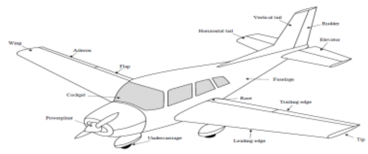


Fig - 1: The Airplane

The aircraft comprises mainly three sections:

a. wing
b. Empennage
c. Fuselage with floor/cross beam.

1.2 FUSELAGE CONSTRUCTION

The fuselage is major body or structure of the aircraft. They provide space for cargo, personnel, controls, and for most attachments. The landing gear, power plant, wing and stabilizers are connected to it. In fuselage cross-sections the shape of sequence of frames are rigid fixture by holding in position.

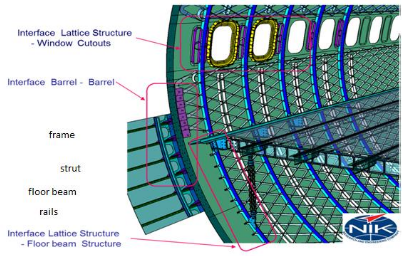


Fig - 2: The Fuselage floor beams is done by Alasca Development

The mounting of floor structure will be the next step. This process begins at fabrication of structure where vertical struts and cross-beams are fabricated and integrated in CFRP using process of RTM. The Fig. 2 demonstrates typical structures of lifting surface and fuselage floor/cross beam containing the following

1. **Lifting surface:**

- Ribs
- Spars

- Stringers

2. **Fuselage:**

- Frames
- Floor beams
- Stringers

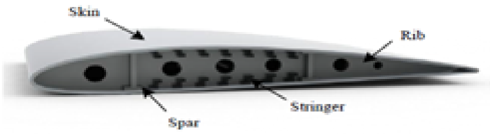


Fig - 3: The typical Airframe structure Lifting

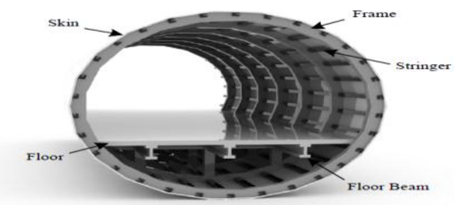


Fig - 4: The typical Airframe structure Fuselage

1.3 MAJOR MONOLITHIC SOLID CFRP AND THERMOPLASTIC APPLICATIONS

CFRP materials are utilized to make up of higher cross/floor beams and the reader bulkhead pressure decks in the flying machine. The various technologies like RFI are used to test these materials. This knowledge is established for A340-600 Aircraft; exhibiting weight saving, enhancing the damage tolerance, and enhancing inspection ability and enhancing reparability compared to previous A340 metallic D-nose.

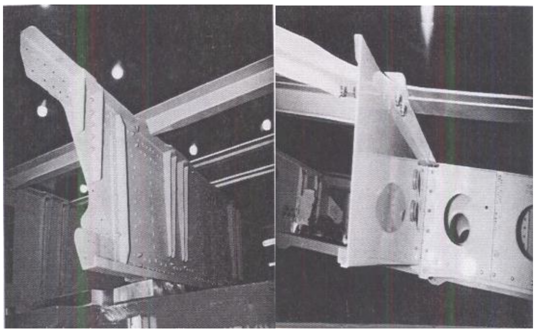
1.4 ROLE OF AIRFRAME

The design of airplane structure principally considers the following:

1. Design of external profile for obtaining suitable airflow for flight maneuvers.
2. Design of airplane engine by adequate thrust maneuverability in-flight and on ground;
3. Design of control, route, hydraulic, electrical and pneumatic aircraft systems;
4. Design of airplane structure to give structural strength under load.

1.5 FLOOR BEAM IN TRAVELER OR PASSENGER AIRCRAFT:

To start with aircraft fuselage floor beam, this is main structure of aircraft. They are closed from both sides and having structure of tunnel type and accommodates passengers, control unit, cargo, accessories and other equipment's.



(a) (b)

Fig - 5: Manufactured finished floor beam

The Fig. 5 (a) shows the manufactured finished floor beam for the 747 Aircraft and Fig. 5 (b) shows the manufactured finished floor beam for the 767 Aircraft.

It is structural member; the floor beam is used for cargo, control unit, passengers and other equipment. With help of this bracket attachment floor beam and fuselage skin can be fixed. The floor beam selected is of I-section and connections are provided for fuselage floor beam with bracket attachment and other system of joining. Manufacturability, weight reduction, improvement of strength and cost reduction for conceptual design of aircraft floor beam in this project. The floor structure is comprised of several structural elements.

A. Floor panels
B. Crease beams
C. Seat tracks
D. Galley and lavatory intercostal
E. Floor beams
F. Floor beam stabilization

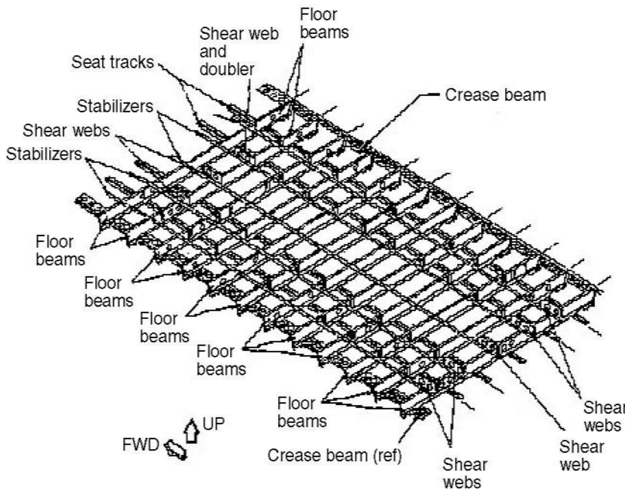


Fig - 6: Typical Floor Structure

The redundant floor structure consists of floor beams part that supports galleys, passenger seats, lavatories, etc. The ends by frames where fuselage floor beams are encouraged. Seat tracks are joined to floor beam webs or upper beam chords and run over the floor/cross beams. To transferring of loads from seats to seat track is joined to the floor beam, they work combined to withstand applied load.

2. LITERATURE SURVEY

A detailed review on the relevant literature has been carried out for the better understanding of various sections for the floor and cross beam in passenger aircraft and the previous research for the appropriate material selections are showed below.

Ruhani Thakur, et.al. [1], in this paper, they designate stress analysis of Fuselage floor beam which is used as I-beam.

Patent Russia 244/2440278 [2], was surveyed on Fuselage floor/cross bearing carcass and its backing beam.

Guy Nolla [3], Patent US 8317133 B2 was conceived in 2012 on the Airplane floor and airplane fuselage floor beam.

Krog Lars. et.al. [4], 2015 European Patent EP2593360 was presented on Beam for an airplane fuselage floor:

Jeffrey H. Wood. et.al. [5], 2010 Patent US7775478B2, have presented floor/cross beam assembly, system and related method.

US8240606 B2 by Willard N. Westre [6] was surveyed on the integrated aircraft cross/floor with longitudinal beams**.**

Ilhan Sen[7] was studied a thesis on Aircraft Fuselage Design Study.

Rahul Sharma,0**et.al. [8],** was published their paper on Design Modification and Analysis for an Attachment Bracket of Fuselage Floor Beam.

David DELSART. et.al. [9] was examined their proposal on Evaluation of Finite Element Modelling

Jonathan, George and Allen [10], was published his proposal on Framework for Hyper-Heuristic ptimization of Conceptual Aircraft Structural Designs.

Michel van Tooren. et.al. [11] was presented their proposal on Multi-Disciplinary Design of Aircraft Fuselage Structures.

Mahesh B L . et.al. [12], Design Optimization of Display Unit Supporting Structure under Static and Spectrum Loads using FEA.

3. PROBLEM DEFINITION

After the comprehensive study of literature, a number of gaps are detected in cross-section as of the floor beam. Most of the researchers have investigated that the selection of material for the floor beam in the aircraft structure and cross-section of the cross beam member have a greater influence on the performance of the floor/cross beam in the Aircraft. Literature review reveals that the researchers have carried out most of the work on the section of the Cross/floor beam member across the fuselage of an aircraft and a very limited work has been reported on the optimization process of the floor beam in aircraft. Finite element simulation is performed using Ansys software and the output characteristics are plotted.

4. OBJECTIVES

A. In aircraft finding Linear analysis of Floor Beam
B. To find Cross beam to frame junction using FEA
C. To find Cross beam to seat track junction using FEA
D. Material Optimization of fuselage Floor Beam of an aircraft to increase the life and efficiency.

5. SCOPE OF THE PRESENT WORK

A. Composite materials which have more advantages compare to the metallic materials due its higher stiffness and higher ratios strength to density, less progressive damage under in-service fatigue and lower sensitivity to corrosion.
B. To improve the bending performance of fuselage Floor beam used for better cross-section of the floor/cross beam.
C. Based on the findings the finite element simulation and optimization is done to find the best section for the cross beam member in the aircraft.
D. Due to the analysis of floor beam to frame junction and floor beam to seat track junction, we can find the sustainability at junctions whether design is unsafe or safe.
E. We can reduce weight of fuselage floor beam due to optimization of it as cut-outs in the web of the floor.

6. METHODOLOGY

6.1 Methodology

It is carried out to identify the problem, existing in the Cross beam/Floor beam of the aircraft. Based on the literature survey the problem is identified in the floor beam and cross-section selection is also made for fuselage floor beam in Aircraft structure. Research methodology is formulated in two respective ways, such as design and analysis of the selected cross-section.

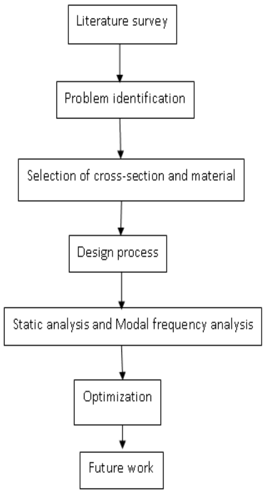


Fig - 7: Methodology

6.2 MATERIAL AND CROSS-SECTION SELECTION

The selection of appropriate material plays most important role in design of aircraft because of incredible weight reduction and gives greater stiffness for the aircraft The I-cross-sectional shape is chosen for the designing fuselage floor/cross beam of an aircraft.

6.3 DESIGN PROCESS

After material selection and cross-section of fuselage floor beam, the entire parameters of cross-section of fuselage floor is studied and designed in UG NX8 software.

6.4 EXPERIMENTAL ANALYSIS

The existing cross beam or Floor beam is modeled using UG NX 8 with dimension of standard of aircraft fuselage Floor beam structure. In ANSYS 14.5 model is imported for optimization and analysis of floor/cross beam in the airplane structure.

6.5 OPTIMIZATION

The cross-section and the cut-outs of dissimilar shapes in web of floor/cross beam are used for identifying decreased weight and its strength, efficiency and performance of the cross beam. Topology optimization is performed and study of load path is carried in fuselage floor beam.

A. DESIGN REQUIREMENTS:

The requirements that both the current and future CFRP floor beam have to meet have been listed below

B. DIMENSIONS

The CFRP fuselage floor beam should restore the aluminium C56 parts having similar proportions:

Height:	201 mm
Flange width:	25 mm
Overall length:	5550 mm
Strut attachment:	2125 mm from midpoint.

C. MECHANICAL REQUIREMENTS:

The mechanical loads on the floor beam shall be assigned to several, sometimes interfacing causes:

-Gust	-	cabin pressure
-Crashes	-	frame bending
-Landing	-	fatigue loading
-Rapid decompression-		impact damage

D. THERMAL REQUIREMENTS:

Thermal loads are the forces related to the dimensional changes caused by temperature differences. The lower/upper maximum service temperatures have been defined as -40/+56^{0}C on the ground (without operational loads) and -20/+56^{0}C in flight (with maximum static load possible). The moisture absorption effect should be included.

E. ELECTRIC CONDUCTIVITY:

The applications of carbon fibre implies that the material is highly conductive if direct contact with the fibres is established. The use of titanium rivets and a glass cloth interlayer for example are highly recommended.

F. CHEMICAL RESISTANCE:

The floor beam should be resistant to solvents, interior cleaning agents, fuel and skydrol. The resistance either has to be provided by an protective coating.

6.6 CFRP DESIGN CONSIDERATION:

The cost-effectiveness of fuselage floor/cross beam project is determined by five important parameters:

1. The structure efficiency, denominating the "performance" per unit mass
2. The number of different part geometries that should be produced.
3. Definition of the maximum deviation of the beam properties & dimensions due to the manufacturing process.
4. The required amount of additional machining/forming and thus the scrap percentage.
5. The type of material (e.g. preconsolidated sheet, prepregs or FIT material)
6. The need for design changes of the surrounding structure.

Material	CFRP
Density ρ (Mg/m^3)	1.5
Youngs moduls (E, GPa)	1.5
Shear moduls (E,GPa)	53
Poisson's Ratio(ϑ)	0.28
Yield stress (σ_y, MPa)	250
UTS (σ_{ult}, MPa)	550
Breaking strain (ϵ_f ,%)	2.0
Fracture toughness K_c, ($MNm^{-3/2}$)	38

Table -1: CFRP Material Properties

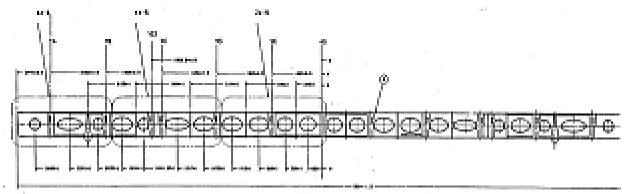


Fig - 8: Dimension of optimized I-section beam

The structure of fuselage floor/cross beam of an aircraft is taken from aluminum Aircraft. The representation of structure fuselage floor/cross beam is examined for determination of maximum Von-Mises stress is given within load of 16000N and finished to get maximum equivalent Von-Mises stress 207.7MPa is low than Yield stress 250MPa of CFRP and therefore Designed CFRP Fuselage cross/Floor beam is safe within given conditions of applied load and shear stresses and bending stresses, they are theoretically confirmed using appropriate methods.

7. GEOMETRICAL MODEL OF 2D & 3D CAD FOR FUSELAGE FLOOR/CROSS BEAM

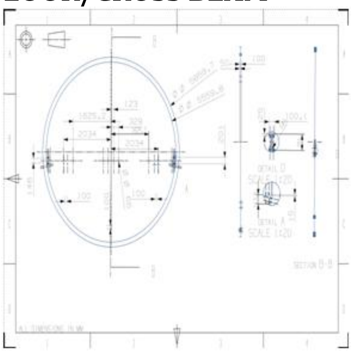


Fig - 9: The geometrical 2D CAD model of Floor/Cross beam in Aircraft

8. FEM ANALYSIS

Step 1: The geometrical CAD of aircraft floor/Cross beam, they are imported to ANSYS software in '.igs' format file. Figure show the procedure for importing the .igs file of the model for designing and analysing the FE model of CAD model.

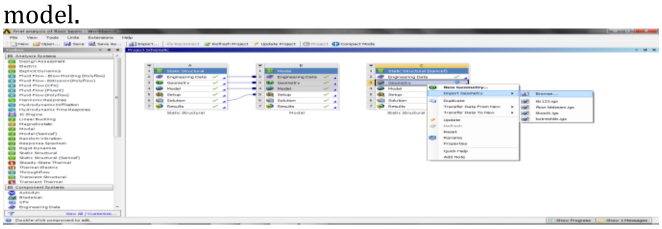


Fig - 10: Importing CAD geometry

Step 2: The geometry imported is ready to get meshed. Figure gives the meshed CAD model of cross/floor beam geometry.

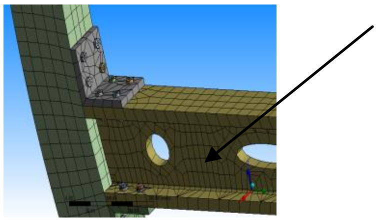


Fig - 11: The meshed model of Fuselage cross/Floor beam

The present model is meshed by Tetrahedron dominant elements having number of nodes using ANSYS as shown up above.

Step 3: The static analysis is done after meshing, the boundary conditions having Loads, that are fixed in both ends of Fuselage cross/Floor beam.

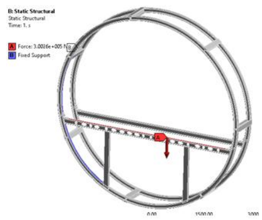


Fig - 12: Boundary conditions

Step 4: After boundary conditions has done, and then solve it to the required stresses of static analysis of linear aircraft fuselage floor beam. Finally, the result has done, then the result as obtained for the required analysis.

9. RESULTS AND DISCUSSIONS

9.1 STATIC ANALYSIS- Equivalent (Von-Mises) stresses:

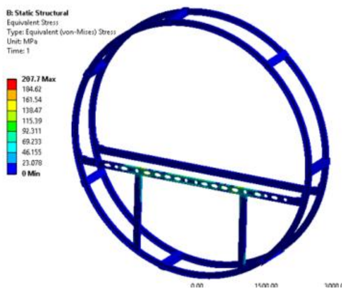


Fig - 13: Equivalent (Von-Mises) stresses

The optimized model of fuselage cross/floor beam are analyzed statically for determining maximum Von-Mises stress within specified conditions of load and determined maximum Von-Mises stress obtained (207.7 Mpa)is lower than yield stress (250MPa) and therefore the optimized design of CFRP Fuselage Floor/cross beam is safe with in conditions of applied load and total deformation is formed.

9.2 MINIMUM PRINCIPAL STRESSES AT FLOOR BEAM:

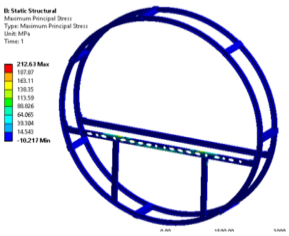


Fig - 14: Minimum Principal stresses at floor beam

The above figure shows the result of minimum principal stress for floor/cross beam of an aircraft. Hence, the minimum principal stresses not exceeding maximum stress.

9.3 ANALYSIS OF CROSS BEAM TO SEAT TRACK JUNCTION

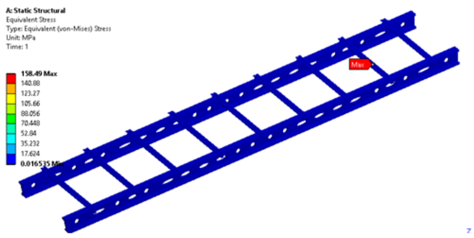


Fig - 15: Minimum Principal stresses at floor beam

The above figure shows the analysis of seat track junction for I-cross sectional floor/cross beam of an aircraft.

9.4 DYNAMIC ANALYSIS –

Modal analysis results under free vibration for I-cross sectional floor beam with cut-outs

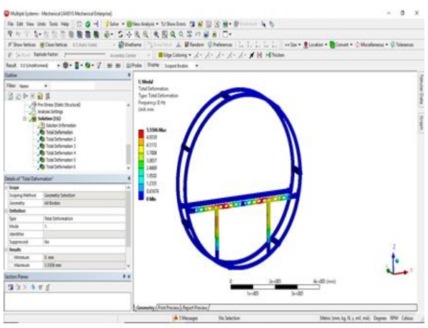


Fig - 16: First mode of modal analysis in free vibration

The above figure shows the result of first mode of modal analysis in free vibration for I-cross section cross/floor beam of an aircraft with cut-outs. In this mode the frequency obtained from result is 0Hz

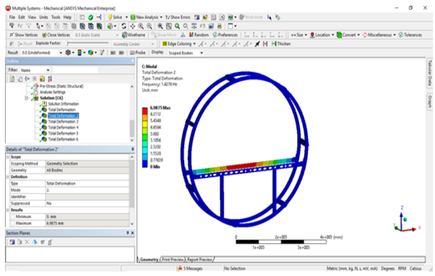


Fig - 17: Second mode

In this mode the frequency obtained from result is 1.4278Hz

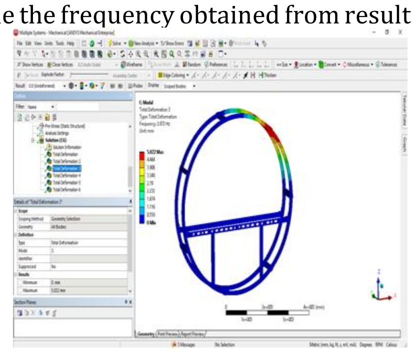


Fig - 18: Third mode

In this mode the frequency obtained from result is 2.872Hz.

The below table shows the results of modes of modal analysis in free vibration for I-cross section of an aircraft with cut-outs and Six modal frequencies are noted as shown in table.

Sl. No.	Number of modes	Frequency, Hz
1	1	0
2	2	1.4278
3	3	2.8720
4	4	4.2184
5	5	4.7549
6	6	5.0607

Table - 2: Modal Analysis Results

10. VALIDATION OF LIFE ESTIMATION WITH ANALYTICAL METHOD AND FEM RESULT.

10.1 FATIGUE ANALYSIS:

In material science, fatigue is the wearying of a material caused by recurrently applied loads. It is the broad-minded and restricted structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material classically quoted as the ultimate tensile stress limit, or the yield stress limit.

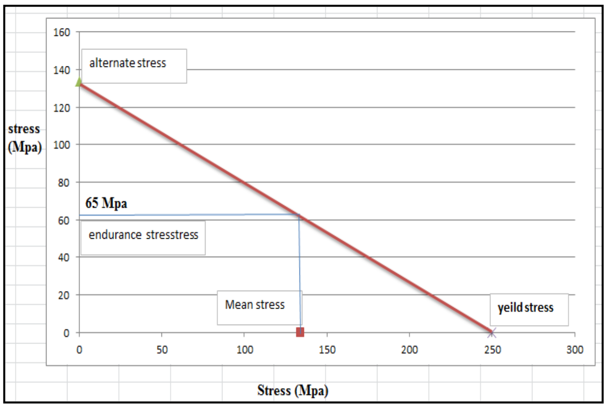


Fig - 19: Alternative stress v/s Yield stress

10.2 GOODMAN DIAGRAM

Mean Stress can be calculated from,

$$\sigma_{mean} = \frac{\sigma\, von}{2} = \frac{207.7}{2} = 103.85 \text{ Mpa}$$

Where, σ_{von} = Equivalent von-Mises Stress

Or

$$\sigma_{mean} = \frac{\sigma_1+\sigma_2}{2} = (207.7+0) / 2 = 103.85\text{Mpa}$$

10.3 ALTERNATE STRESS

$$\sigma_{alt} = \frac{\sigma_1-\sigma_2}{2} = (207.7- 0) / 2 = 103.85\text{Mpa}$$

10.4 LIFE CALCULATION

$$N_f = \left\{\frac{[\sigma_{ult} - \sigma_{ult}(\frac{1}{fos} - \frac{\sigma_e}{\sigma_a})]}{\sigma_a}\right\}^{\frac{1}{0.08}}$$

$$N_f = \left\{\frac{[550-550(\frac{1}{1}-\frac{65}{103.85})]}{103.85}\right\}^{\frac{1}{0.08}}$$

$= 3.204704*10^6$

N_f =3204704 cycles. Life estimation of CFRP material average frame is 3204704 cycles

11. CONCLUSIONS

- The CFRP floor beam has more stiffness and reduction in weight compared to Aluminium material
- The static analysis of CFRP is done by using ANSYS Workbench to calculate Equivalent stress within given boundary condition
- Therefore, we conclude that CFRP with floor beam is better due to its high durability, strength compared to aluminium
- The analysis of static structural is done for CFRP fuselage floor beam for cargo or passenger aircraft to determine deformation and von-mises stress
- The maximum von-mises stress gained within specified load conditions by analysis is less than yield stress of selected material. Thus, design of CFRP for fuselage cross/floor beam is safe within specified load condition
- The dynamic analysis is done for CFRP floor beam to obtain different preliminary critical modes and corresponding bending frequencies below vibrational condition. Hence, it provides long life span underneath free vibration load conditions
- The optimization is carried by creating cut-outs like ellipse, holes in web of fuselage cross/floor beam to decrease weight of floor beam which results in weight reduction of airplane structure

REFERENCES

[1] Ruhani Thakur, et.al. [1], in this paper, they designate stress analysis of Fuselage floor beam which is used as I-beam i.e. the cross section of beam is of I-shape.

[2] Patent Russia 244/2440278 [2], was surveyed on Fuselage floor/cross bearing carcass and its backing beam, Development narrates to aircraft manufacturing, particularly, fuselage floor carcass and its backing beam.

[3] Guy Nolla [3], Patent US 8317133 B2 was conceived in 2012 on the Airplane floor and airplane fuselage floor beam.

[4] Krog Lars. et.al. [4], 2015 European Patent EP2593360 was presented on Beam for an airplane fuselage floor: A beam containing first and second flanges, the beam having a first region covering among flanges and a second region covering among flanges.

[5] Jeffrey H. Wood. et.al. [5], 2010 Patent US7775478B2, have presented floor/cross beam assembly, system and related method. A floor/cross beam assembly, system, and technique for mounting floor beams within a structure are provided.

[6] US8240606 B2 by Willard N. Westre [6] was surveyed on the integrated aircraft cross/floor with longitudinal beams. An integrated cross/floor of an aircraft fuselage consist of composite panel developing a floor/cross surface and composite beams joined to cross/floor panel.

[7] Ilhan Sen[7] was studied a thesis on Aircraft Fuselage Design Study. The resilient search for lightweight materials has become a trend in the aerospace engineering.

[8] Rahul Sharma,et.al. [8], was published their paper on Design Modification and Analysis for anAttachment Bracket of Fuselage Floor Beam.

[9] David DELSART. et.al. [9] was examined their proposal on Evaluation of Finite Element Modelling Methodologies for Design of Crashworthy Composite Commercial Aircraft Fuselage.

[10] Jonathan, George and Allen [10], was published his proposal on Framework for Hyper-Heuristic Optimization of Conceptual Aircraft Structural Designs.

[11] Michel van Tooren. et.al. [11] was presented their proposal on Multi-Disciplinary Design of Aircraft Fuselage Structures. Maintaining the Integrity of the Specifications

[12] Mahesh B L, H S Manjunath, Vijay Kumar V, Surekha A, “Design Optimization of Display Unit Supporting Structure under Static and Spectrum Loads using FEA”, Vol. 04, Issure 10, IRJET, Oct- 2017.