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Static and Dynamic Analysis of Floor Beam (Cross beam) of Aircraft

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Abstract - *The primary goals of this project are to design, analyze, and optimize I-cross sectional floors. Ansys is utilized for analysis and CATIA v5 is used for design of the passenger airplane beam. The majority of researchers have looked into the choice of flooring materials. The cross-section of the cross beam member and the beam in the aircraft construction have a bigger impact on the cross-beam and floor performance of the aircraft. Very little study has been published on the cross/floor beam optimization procedure in airplanes; much of the research has been done on the portion of the cross/floor beam member that runs across an aircraft's fuselage. The primary focus of this project was on composite components, specifically the CFRP (carbon fiber reinforced plastic) floor/cross beam and the I-cross sectional floor beam with cuts for optimization to lower the aircraft's structural weight. In order to determine whether or not the design is safe under the specified load circumstances, linear analysis is performed for the floor beam in order to study the bending and shearing stresses for the specific applied load. In light of this, we also examine how to properly connect the ends of the floor beam to the frame junction and the floor beam to the seat track junction in order to ensure that the floor beam can sustain the load applied to it.*

***Key Words*: FEA, Floor beam, CATIA V5, Static analysis, Modal analysis, etc…**

1. INTRODUCTION

An aircraft is a complicated machine that is also a very efficient man-made flying machine. The aircraft structure is the most severe example of a functional desire for lighter and stronger constructions. Three key features of a successful structural element are its ability to perform its intended function, an acceptable service life, and the ability to be produced at a reasonable cost. Due to customer and market demands, the aviation industry is currently seeing a shift toward low-emission and environmentally friendly aircraft. Airline operators want to request a decrease in operating costs because they are concerned on the growing expense of gasoline. To conserve fuel and lower CO2 emissions, manufacturers are seeking to construct lighter aircraft. Aircraft more and more constructions are making use of innovative and advanced materials achieve this.

The main ways to improve aircraft structures are through the properties of the configuration and Material that are located beneath surface. The order of reference in the running text should match with the list of references at the end of the paper.

In the aerospace industry the aircraft design optimization is becoming more and more important as rival airlines try to cut costs and military forces require vehicles that perform better in struggle. Because of this efficient tools are needed to help engineers create nearly ideal aircraft designs so that the finished products are carry out their assigned tasks as effectively as possible. The floor beam is one quite structural component that provides room on the ground for objects, persons, things, accessories, equipment, and control units. In order to improve strength, manufacturing feasibility, weight reduction, and cost effectiveness, the airplane floor beam design in this project is conceptual in nature.

An aircraft with the less amount of structural mass is a common goal of structural optimization. Therefore, in order to optimize an aircraft's structural performance, the airframe's design is typically varied to achieve the lowest possible mass while still offering the resistance required to loads that are likely to be encountered during operation.

1.1 Literature Review

Ruhani Thakur, et.al. [1], A floor beam with an I-shaped cross section that is employed in fuselage construction is the subject of this paper's stress study. Today's planes are made to carry larger loads and can hold more passengers thanks to the growth of the aviation sector. Fuselage floors must be strong and able to support weight as well as cyclic loads because they bear the weight of the aircraft directly. For the I-beam with longerons added to the fuselage floor, this is the main rationale. We study and establish the viability of this beam.

Patent Russia 244/2440278 [2], examined in relation to the support beam and bearing carcass of the fuselage floor. Particularly, airplane engineering is involved in this innovation. A T-shaped slot and a rectangular ledge running the length of the beam on the top flange give the support beams cross sectional profile an I-beam-like appearance. Transverse beam top flange ends are linked to the top flange ends of support beams. A one-sided flange is positioned at the bottom of T-shaped sections that make up transverse beams. Transverse beams are routed through openings in support beams. The brackets that attach the support carcass to the base are installed through the wall, and attachment components pass through the top flanges of the transverse and support beams to be placed in the support beam slot.

Guy Nolla [3], Patent US 8317133 B2 was built in 2012 using an aircraft floor and accompanying fuselage: A floor of an airplane having two longitudinal external beams and at least one pair of the cross beams between them, the external ends of each cross beam being interlocked with a lengthwise beam. The inside ends of the pair of the cross beams are united when the cross beams are tilted so that they are attached to one another.

Krog Lars. et.al. [4], 2015 European Patent EP2593360 was unveiled on Beam for the fuselage floor of an aircraft: A beam with first and second flanges with a first region and a second region extending between the flanges. An applied concentrated shear stress is intended to be supported by the first region, whereas a primarily bending load is intended to be supported by the second region.

Jeffrey H. Wood. et al., [5], 2010 Patent US7775478B2, the floor beam assembly, the associated technology, and the system have been shown. Floor beams can be installed in a building using a specific assembly, system, and technology. Installing a floor beam within a structure is made possible in one embodiment by the floor beam assembly.

US8240606 B2 by Willard N. Westre [6] was investigated in 2012 on the integrated airplane floor with longitudinal beams: A composite panel serving as the floor surface and composite beams adhered to the floor panel make up an integrated floor for an airplane fuselage. The floor is supported by beams that run the length of fuselage.

Ilhan Sen [7] an aircraft fuselage design study thesis was reviewed. An industry trend in the aircraft sector is the intense search for lightweight materials. New aerospace materials are being introduced by aircraft manufacturers in response to this trend in order to construct lighter airplanes. The calculation of running loads and the behavior of materials in fuselage structures, however, remain unknown to material makers like as Tata Steel. Thus, to ascertain the running loads and assess the efficacy of novel materials, an assessment instrument is required. Better understanding of the precise qualities and capabilities required for materials in airplane constructions will result from this for material producers. Developing an analytical design, analysis, and evaluation tool in Visual Basic Application for both metal and composite fuselage configurations is the goal of this project in order to gain an understanding of the structural performance of these material classes and to estimate the weight and required structural dimensions for aluminum and composite fuselages.

Rahul Sharma, et.al. [8], released a paper titled "Design Modification and Analysis for a Fuselage Floor Beam Attachment Bracket." Floor beam I is its cross section. Total weight transferred to a single bracket by the floor beam is 180 kg. Within the work's scope, the current setup will be redesigned with an emphasis on strengths. It is best to give priority to things like weight reduction, cost effectiveness, and manufactured goods. Check that the optimal design that was selected through manual calculation methods is correct.

David DELSART. et.al. [9] to design a crashworthy fuselage for a composite commercial airplane, the finite element modeling approaches were examined. AIRBUS France created a two-frame section as part of the European Program "Commercial Aircraft Design for Crash Survivability" [CRASURV] (BRPR-CT96-0207, 1996-2000), which aims to develop methodologies to design crashworthy composite commercial aircraft fuselages. The section was based on the A321 AIRBUS standard dimensions. A crash test of the part is scheduled at the Toulouse Aeronautical Test Centre [CEAT]. Using Finite Elements [F.E.] simulations with the RADIOSS commercial crash code (MECALOG business), the design of the full-scale structure under consideration was verified prior to this test. The reason for this was specifically related to the sinewave beams, which are parts of the structure's underfloor system and are designed to gradually crush in order to release the energy released during impact

Jonathan, George and Allen [10], In publication, his thesis was titled A Framework for Hyper-Heuristic Optimization of Conceptual Aircraft Structural Designs. In conceptual aircraft structural design, the goal is to create an airframe that will provide sufficient strength under the loads encountered during aircraft operation. An aircraft's performance and cost can be adversely affected by an excessively heavy design, as the airframe's immense strength results in a substantial increase in mass. Weight reduction of the airframe without sacrificing adequate load resistance is the aim of structural mass optimization

1.2 Objectives

- Cross beam to frame connection analysis and design.
- The aircraft's floor beam's design and linear analysis.
- The study and design of the cross beam to seat track junction.
- Increasing the lifespan and effectiveness of aircraft floor beams by optimizing the material.

2. Methodology

The floor beam, sometimes called the existing cross beam, is modeled using Catia V5 and the standard dimensions of a floor beam in an airplane structure. To assess and optimize the cross beam of the aircraft construction, import the model into Ansys 14.5.

To ascertain the lowered weight and the strength, efficacy, and performance of the cross beam, the cross-section and different cut-out forms in the floor/cross beam's web are utilized. We perform load route analysis and topology optimization in the floor beam.

The CFRTP floor beam with comparable exterior dimensions should be used to replace the existing aluminum C56 component.

Table -1: Dimensions table

Sl no	Parameters	Dimensions in mm
1	Overall Length	5550
2	Height	201
3	Flange width	25
4	Structure attachment	2125

2.1 Modelling

PASSENGER AIRCRAFT: DESIGN OF THE FUELAGE FLOOR/CROSS BEAM

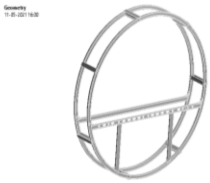


Fig 3- The passenger aircraft's geometric 3D CAD model of the floor/cross beam with the necessary cutouts across the fuselage.

Meshed Model

Fig 2- The meshed model of the Floor beam.

The hex dominating elements and number of nodes in the current model were meshed using ANSYS, as previously mentioned. Static structural analysis is done after meshing is complete. Boundary conditions, such as loads, have been applied to both ends of the floor beam in this.

2.2 Static Analysis of Floor beam

Equivalent (von mises) stress

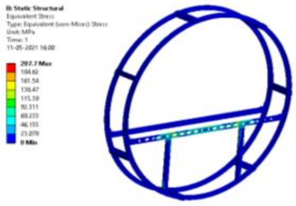


Fig 3- Equivalent stress in a floor beam

2.3 Static Analysis of Floor beam of CFRP

Equivalent (von mises) stress

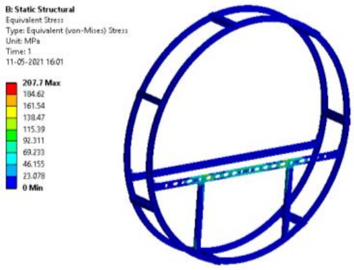


Fig 4- Equivalent stress in a floor beam of CFRP

Maximum Principal Stress

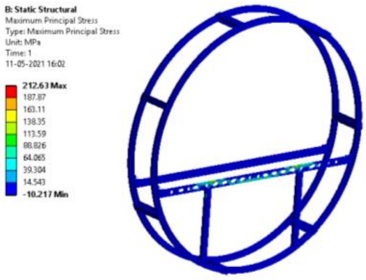


Fig 5- Maximum principal stress in a floor beam of CFRP

2.4 Vibrational Analysis

Six distinct modal frequencies

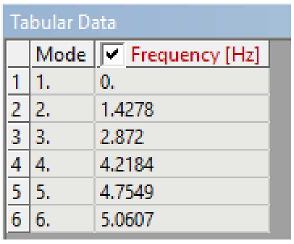
Sl. No.	Number of modes	Frequency, Hz
1	1	6.53×10^{-2}
2	2	7.333
3	3	9.0976
4	4	11.507
5	5	11.695
6	6	13.598

Table 2- Modal frequency

Under conditions of free vibration, the table presents the six distinct natural frequencies for each of the six modes. As one mode evolves into the next, these natural frequencies grow.

The vibration properties, inherent frequencies and mode shapes of a structure are ascertained using modal analysis. It is the most fundamental kind of dynamic analysis and usually serves as the foundation for other forms. When a thing vibrates naturally, it does so at a pace unaffected by external forces or spontaneous vibration. An object's inherent frequency varies with each degree of freedom.

Primarily, the purpose of modal analysis is to identify the various modal frequencies under vibrating settings so that the safety of the planned model may be assessed. Floor beam that was constructed in this case is safe to vibrate freely because none of obtained modal frequencies should surpass the maximum vibrating conditions. In addition, floor beam has a longer lifespan in these circumstances.



Tabular Data

	Mode	☑ Frequency [Hz]
1	1.	0.
2	2.	1.4278
3	3.	2.872
4	4.	4.2184
5	5.	4.7549
6	6.	5.0607

Table 3- Frequency

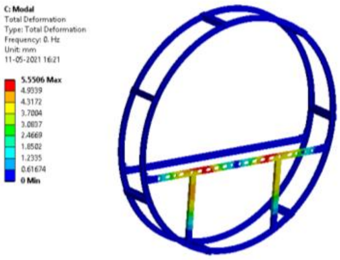


Fig 6- first mode and corresponding natural frequency.

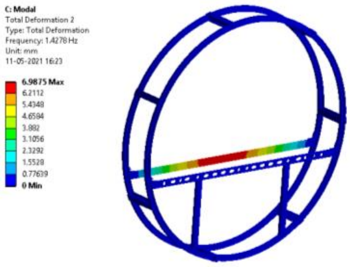


Fig 7- Second mode and corresponding natural frequency.

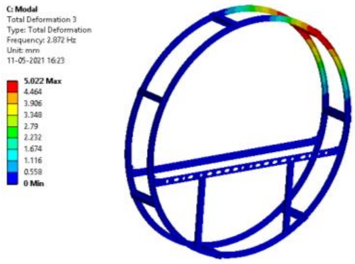


Fig 8- Third mode and corresponding natural frequency.

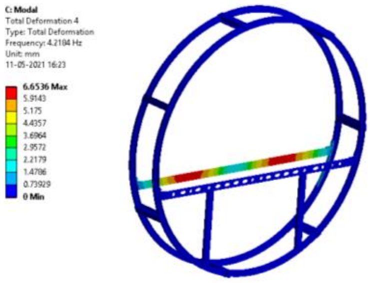


Fig 9- Fourth mode and corresponding natural frequency.

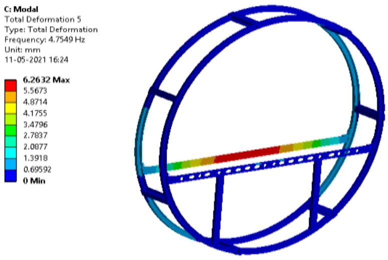


Fig 10- Fifth mode and corresponding natural frequency.

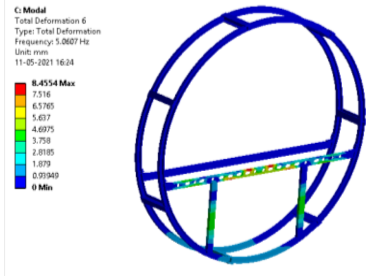


Fig 11- Sixth mode and corresponding natural frequency

2.5 validation of the life estimate using an analytical technique and the fem result

Fatigue Life

Fatigue in materials science refers to a material's deterioration from repeated application of loads. It is the limited and wide-ranging structural damage that results from cyclic loading of a material. The material strength, which is traditionally cited as the ultimate tensile stress limit or yield stress limit, may be substantially less than the nominal maximum stress values that result in such damage.

When a material is in danger of repetitive loading and unloading, fatigue results. Microscopic fractures can occur at stress concentrators, such as the surface and persistent slip bands (PSBs), constituent interfaces in composite materials, grain interfaces in metal materials, if the loads exceed a specific threshold. When a crack eventually reaches a critical size, it will spread quickly and cause the structure to shatter. The fatigue life will be greatly impacted by the design of the structure. Square holes or corners will increase the local pressures where fatigue cracks can start. The structure's fatigue strength will be increased by round holes and seamless transitions or fillets.

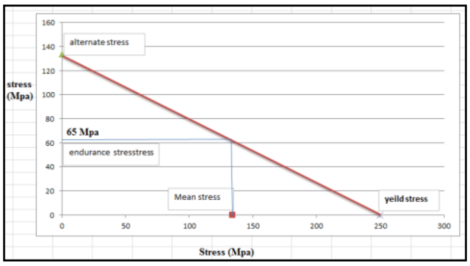


Fig 12- Goodman diagram

Number of stress cycles of a given character that a specimen endures before failure of a particular nature occurs is known as fatigue life, or N_f, according to the American Society for Testing and Materials. There exists a fatigue limit, endurance limit, or fatigue strength for certain materials, which is the theoretical value of the stress amplitude below which the material will not fail after a certain number of cycles.

The stress-life approach, the strain-life method, and the linear-elastic fracture mechanics method are the three techniques that engineers have utilized to ascertain a material's fatigue life. The Uniform Material Law is one technique to forecast a material's fatigue life (UML) by the end of the 20th century, UML was developed for high-strength alloy fatigue life prediction for aluminum and titanium alloys.

Mean Stress can be calculated from,

$$\sigma_{mean} = \frac{49.345}{2}$$

Where

σ_{von} = Equivalent von-Mises Stress

Or $\sigma_{mean} = \frac{\sigma_1+\sigma_2}{2}$ = (54.31+0.0028) / 2 = 134 Mpa

Alternate stress

$\sigma_{alt} = \frac{\sigma_1-\sigma_2}{2}$ = (268 .31- 0.0028) / 2 = 134 Mpa

Life calculation

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

= after substituting the values we get = N_f =3*e6

Life estimation of CFRP martial avt frame is 3000000 cycles.

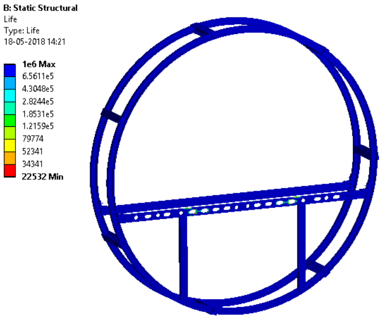


Fig 13 – Life evaluation of CFRP material is 3000000 cycles

3. CONCLUSIONS

CFRP floor beam is less weight compare to the aluminum material. Static structural analysis is carried out for the CFRP Floor beam in the passenger Aircraft to find the von-mises stresses and deformations. The maximum von-mises stress obtained under given load conditions from the analysis is less than yield strength of the chosen material. Therefore the designed fuselage CFRP floor beam is safe under given load. Dynamic analysis is carried out for the CFRP floor beam to find different initial critical modes and corresponding natural bending frequencies under vibrational conditions and it gives long life under these free vibrational loads. Optimization is done by making cut-outs like ellipse, holes in the web of the floor beam to reduce the weight of floor beam which in turn leads to reduce the weight of the aircraft structure and also replace the current aluminum C56 floor beam by future CFRP floor beam in order to obtain better performance due to its higher stiffness and higher weight to strength ratios and also reduces the weight of the aircraft structure.

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