Strength and Weight Optimization of Passenger Aircraft Fuselage Skin

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Abstract:- Since most of the crucial components, including the front, rear, and wings, are attached to the central fuselage, it plays a significant influence in the design of aircraft fuselages, leading to increased payload and improved performance. So, the load applied to the part is transferred to the central fuselage part. The primary objective of our study is to optimize the fuselage skin to withstand varying loads, with a particular focus on the central fuselage part where the load is transferred. This central fuselage plays a pivotal role in the overall weight distribution of the aircraft. To achieve weight reduction, we employ material optimization techniques, specifically comparing aluminium alloy with hybrid composite materials.

Material optimization involves a comprehensive comparison between aluminium alloy and hybrid composite materials, wherein composite laminates, comprising carbon fiber, glass fiber, and Hexply 8552, are applied over the fuselage skin. This approach allows us to analyze both the physical and structural properties of the fuselage.

Various structural analyses, including Shear Test, Bending Test, Fatigue Test, Tensile Test, and Compression Test, have been meticulously conducted using ANSYS WORKBENCH Software. Boundary conditions are established according to specific requirements. The results unequivocally demonstrate that the hybrid composite material exhibits superior properties compared to conventional aluminium alloy. This includes enhanced performance and achieved material optimization, ultimately impacting the total weight of the aircraft.

Keywords:- *Material Optimization, Aluminium Alloy, Carbon Fibre, Glass Fibre, Hexply 8552, Hybrid Composite Materials.*

I. INTRODUCTION

In the contemporary landscape of aviation, there has been substantial progress in the design and construction of aircraft, with a primary focus on achieving an optimal balance between performance, durability, and fuel efficiency. The aircraft fuselage, serving as the fundamental framework of aerial transportation, plays a critical role in influencing these key factors. In recent times, the introduction of composite materials has brought about a paradigm shift in aircraft design, offering exceptional strength-to-weight ratios and resilience to fatigue, corrosion, and high stress. Among these materials, hybrid composites, specifically the amalgamation of carbon fiber and glass fiber reinforced with advanced epoxy resins, have emerged as promising avenues for enhancing the structural integrity and performance of aircraft fuselages.

This study is geared towards exploring and optimizing the structural composition of aircraft fuselages by leveraging the interdependent properties of hybrid composites. Through the synergistic combination of the superior strength and stiffness of carbon fiber with the impact resistance and cost-effectiveness of glass fiber, this research endeavors to create a material composition that transcends the limitations of individual constituents. The incorporation of high-performance epoxy resins further bolsters the structural characteristics, imparting resilience and stability under diverse operating conditions.

The significance of this investigation lies in its potential to yield a fuselage structure that not only meets but exceeds the rigorous demands of the aviation industry. The pursuit of an optimized fuselage design using hybrid composites addresses multifaceted objectives, including weight reduction, enhanced fuel efficiency, improved mechanical properties, and elevated safety standards, all while concurrently upholding passenger comfort and operational economy.

II. LITERATURE REVIEW

Penn State Harrisburg, PA, USA, Athreya Nagesh*, Ola Rashwan, Maamoun Abu-Ayyad, Published November 2018,[1] "Composite Aeroplane Fuselage Optimisation for Optimal Structural Integrity" Rather than using AL alloys for the fuselage skin, this study used finite element analysis to find the optimal composite laminate combination..R Sreenivasa, C.S. Venkatesha, Jain Institute of Technology, Karnataka, India,[2] “Study The Effect Of Crack on Aircraft Fuselage Skin Panel Under Fatigue Loading Conditions” .This article investigates the effect of fatigue loading conditions on fuselage skin panel cracks. According to the fatigue analysis results, the uncracked model has a life under the specified parameters since it can sustain load cycles. [3] K Vamssi Venugopal, I. R. K. Raju, “Design and Optimization of Aircraft Fuselage under Dynamic Response by Finite Element Analysis” This study presents some essential components of the design and analysis of airplane structures. The selection of materials, the structure's design, the evaluation of loads, and the influence of dynamic loads are some of these essential components. It has been observed that metal weighs more than composite fiber. After

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material optimization, the construction is subjected to both static and dynamic load conditions.[4] Y Santosh, Prashanth Bhatti, "Structural and Modal Analysis of Fuselage" the process of conceptually designing an airplane's fuselage structure using CAD software. These findings demonstrate the superiority of the novel construction over the T-shaped cross section.[5] Sowmya R, Sreenivasa R, Kallesh SS, "Design Optimization If Airframe in Aircraft Fuselage Structure under Static Loading Conditions" The current article explains how to identify which airframe designs can withstand static loading circumstances with the least amount of deflection by optimising the design of fuselage components that include airframes. To obtain correct results, each model's boundary conditions are adjusted. 2024-T351 Aluminum Alloy is used in the fuselage structure. After comparing the optimized models, it is found that Case 6 has less produced stress (118 Mpa) while Case 7's optimised fuselage model has a 2.5mm deflection.[6] Mukhopadhyay, Vivek Sorokach, Michael R, 2015"Utilization of Advanced Composites in Fuselage Structures of Commercial Aircraft" Through a study, the knowledge and technologies needed to make it possible to employ advanced composites in the future to produce large transport aircraft fuselage structures were identified.

METHODOLOGY

The project strives to optimize fuselage skin through composite materials, utilizing Ansys software. The fuselage model, referencing the Airbus A-350, was constructed in the Discovery module of Ansys. Subsequently, the composite skin design is being developed in the ACP module of Ansys, followed by the execution of various structural tests within the Ansys platform.

A. *Fuselage model*

The 3D model of the fuselage was created using the Discovery module of Ansys. This product simulation software enables efficient model preparation and the exploration of design variations with real-time interactivity. The design process was informed by the Airbus A-350 as a reference, chosen for its remarkable fuel efficiency and exceptional comfort levels. Ansys Discovery 3D played a pivotal role in rapidly generating models for simulation and experimenting with various design concepts.

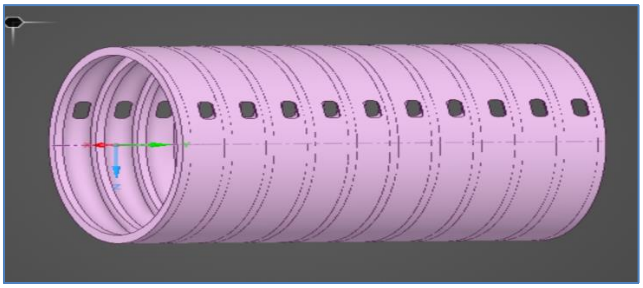

Fig. 1: 3D Model of Fuselage

The dimensions of the fuselage are as follows:

Table 1: Dimensions of fuselage model

Parameter	Value (mm)
Outer Diameter	5972
Inner Diameter	5970
Fuselage Length	7482
Window	Width – 270 Length - 518

B. *Meshing*

Following the design phase, meshing was conducted in Ansys, a critical step in Finite Element Analysis (FEA) simulation. Meshing involves transforming amorphous shapes into discrete "elements" or well-defined volumes. This step is essential for accurate simulation results. The mesh is composed of elements with nodes, the number and distribution of which depend on the type of element chosen. Nodes represent coordinates in space and define the geometry's shape, playing a pivotal role in the accuracy of the FEA simulation.

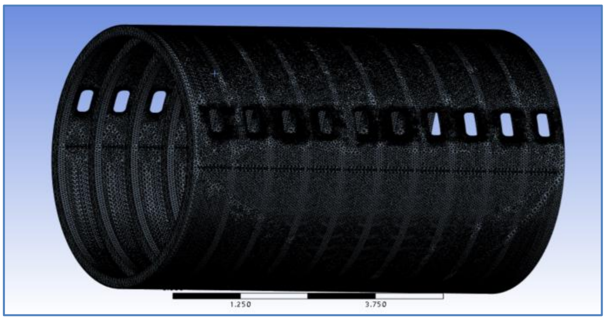

Fig. 2: Meshed model of fuselage

C. *Selection of materials*

After meshing, selecting the appropriate materials for the fuselage skin becomes a critical task, considering all parameters affecting the aircraft's performance. The chosen materials for this purpose include Carbon fiber, Glass fiber, and HexPly 8552 Epoxy matrix (resin). Carbon fiber, primarily composed of carbon atoms, is renowned for its exceptional strength, flexibility, and high tensile strength. Additionally, it offers high stiffness and chemical resistance. Glass fiber, on the other hand, is widely used in Polymeric Matrix Composites (PMCs) due to its excellent tensile strength and stiffness properties. By carefully considering these material characteristics, we aim to ensure optimal performance and durability of the fuselage skin.Glass fibers offer cost-effectiveness, chemical resistance, high tensile strength, and superior insulation. The high-performance epoxy matrix HexPly 8552 is specifically designed for critical use in major aircraft structures, ensuring durability and optimal performance. For a variety of uses, it demonstrates good damage tolerance and impact resistance. HexPly 8552 is a resilient epoxy resin system, amine-cured, and available with woven or unidirectional carbon or glass fiber options.

Table 2: Properties of composites

Sr. No.	Properties	Carbon fiber (395 GPa)	Glass fiber (S Glass)	HexPly 8552 Epoxy matrix
1	Density (kg/m3)	1750	1857	1301
2	Thermal Conductivity(W/m.k)	6	0.04	low
3	Tensile Strength (MPa)	3000-7000	2000-4000	60-120
4	Young's Modulus (GPa)	230	70-80	2.5-5
5	Comp. Strength (MPa)	3000	3000-4000	80-150
6	Flexural Strength (MPa)	3000-7000	1000-2000	80-150

D. Design of composite fuselage skin

The fuselage skin design was accomplished using the ACP module of Ansys. Ansys Composite PrepPost (ACP) is an integrated tool within the Workbench platform specifically designed for modeling composite laminates. ACP facilitates the precise definition and selection of material data, allowing for accurate specification of stacking sequences throughout the entire structure during the pre-processing phase.

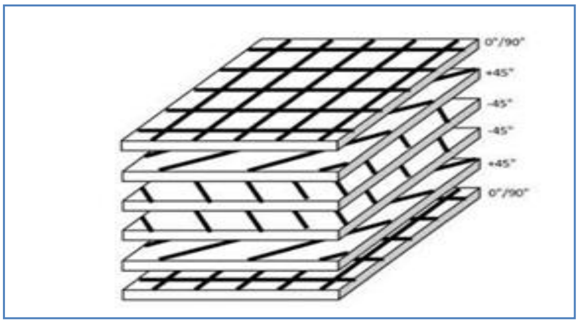

Fig. 3: Composition and fibre orientation

III. STRUCTURAL TESTS AND BOUNDARY CONDITIONS

Various static structural tests were conducted in Ansys software to analyze stress, strain, and deformation under different loading scenarios. This process aids in identifying weak points with low strength and durability during the design stage. Initial tests were performed on conventional materials, followed by evaluations on our designed composite material.

The tests which have been performed are:

A. Fatigue Test

Fatigue tests were conducted to determine the number of load cycles until failure and assess the material's stiffness and strength degradation under repeated loading. The tests involved applying pressure at the top and bottom of the fuselage in an outward orientation, with fixed supports at the right and left ends. The magnitude of the applied pressure was 20000 Pa.

B. Tensile Test

Tensile testing is a destructive method employed to measure the ductility, yield strength, and tensile strength of metallic materials. This technique involves applying force to break a composite or plastic specimen and observing the elongation before failure. In this study, tensile testing was performed by applying forces of equal magnitude at the ends of the fuselage in opposite directions to the center. The applied force had a magnitude of 10000 N.

C. Compression Test

In a compression test, a mechanical device is utilized to assess how a product or material responds to applied forces. In this context, the fuselage skin serves as the test specimen. The test is conducted by applying forces of equal magnitude at the ends of the fuselage in the same direction towards the center. The applied force has a magnitude of 10000 N.

D. Bending Test

This rapid and cost-effective qualitative test assesses the ductility, bend strength, fracture strength, and resistance to fracture of a material. The test involves fixing both ends of the fuselage and applying loads to the top surface. The magnitude of the applied load is 10000 N.

E. Shear Test

Shear testing involves subjecting a test sample to stress to induce sliding failure along a plane parallel to the applied forces. Understanding how a material responds to forces acting parallel to its surface is crucial for assessing structural integrity. In the case of fuselage testing, one end is fixed, and a tangential load is applied to the skin in the opposite direction. The magnitude of the applied load is 10000 N.

IV. RESULTS AND DISCUSSIONS

Following the design of the composite fuselage skin, a comprehensive set of static structural analyses, including Fatigue, Compressive, Tensile, Shear, and Bending tests, were conducted. For each test, two key parameters, namely Stress and Strain, were considered. This approach facilitates a meaningful comparison between the performance of the composite fuselage and the conventional Aluminium alloy fuselage. The analysis aims to provide insights into the structural behavior and performance differences between the two materials under various loading conditions.

A. Fatigue test

➢ *Life cycle*

- The life cycle of the Al alloy fuselage is 10^8.
- The fuselage of the hybrid composite has 10^10 life cycles.

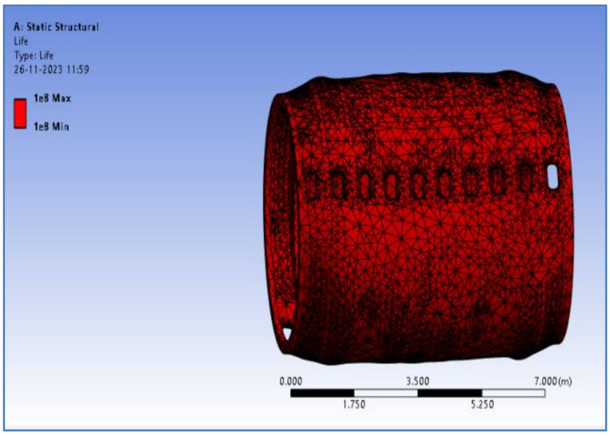

Fig. 4: Life cycle of the fuselage in Fatigue test

- *Stress*
  - In an alloy fuselage, the highest equivalent stress created during a fatigue test is 2.8*10^6 Pa.
  - In a fatigue test, the hybrid composite fuselage's maximum equivalent stress was 4.1*10^6 Pa.

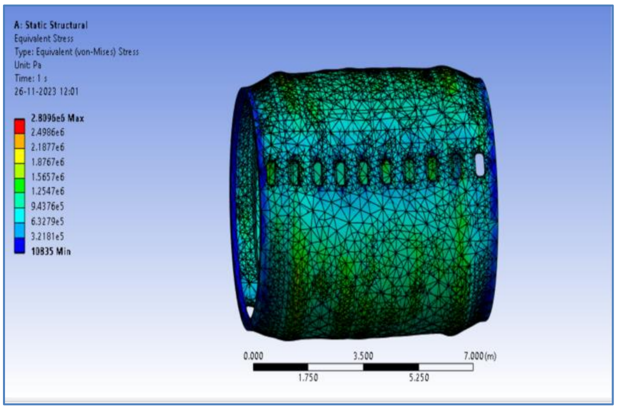

Fig. 5: Al alloy fuselage

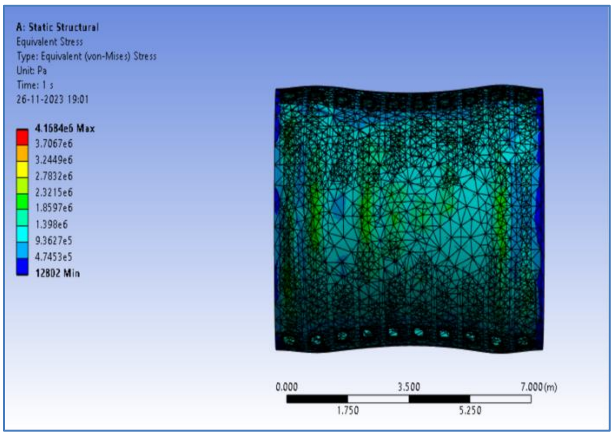

Fig. 6: Composite fuselage

- *Strain*
  - The highest strain that the fatigue test can create in an aluminium alloy fuselage is 0.00048.
  - 5.5*10^-5 is the strain that the fatigue test of the hybrid composite fuselage causes.

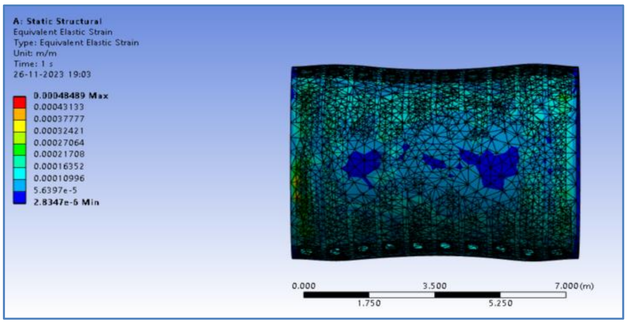

Fig. 7: Al alloy fuselage

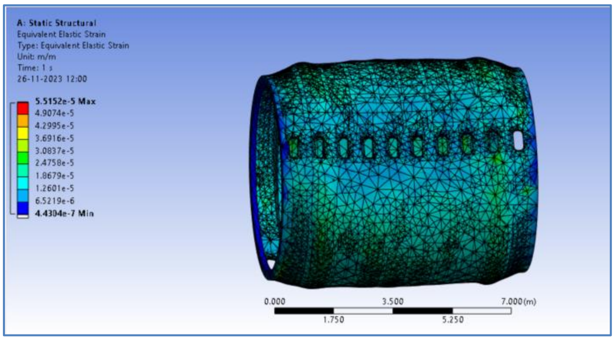

Fig. 8: Composite fuselage

B. Bending Test

- *Stress*
  - In a bending test, the highest equivalent stress generated in an aluminum alloy fuselage is 2.9*10^5 Pa.
  - In a bending test, the hybrid composite fuselage's maximum equivalent stress is 3.5*10^5 Pa.

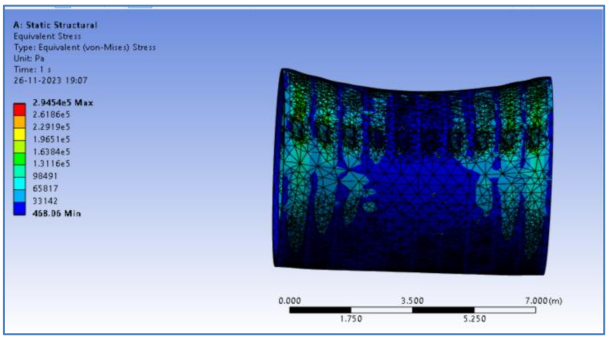

Fig. 9: Al alloy Fuselage

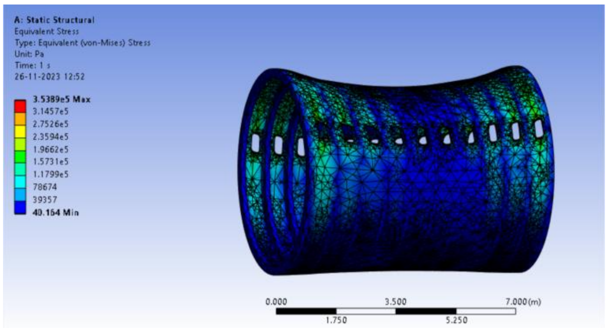

Fig. 10: Composite Fuselage

➢ *Strain*

- In a bending test, the Al alloy fuselage experiences a maximum strain of 3.4*10^-5.
- The hybrid composite fuselage experiences a maximum strain of 4.9*10^-6 during the bending test.

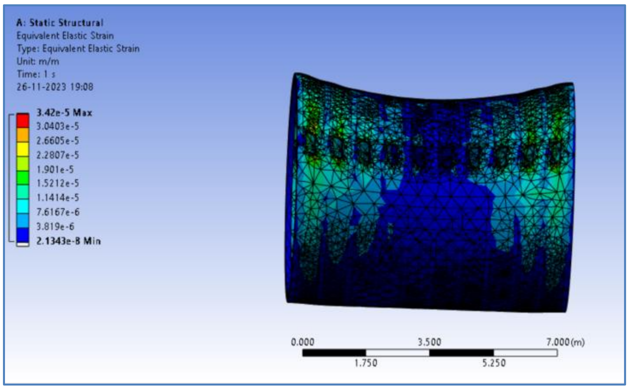

Fig. 11: Al Alloy Fuselage

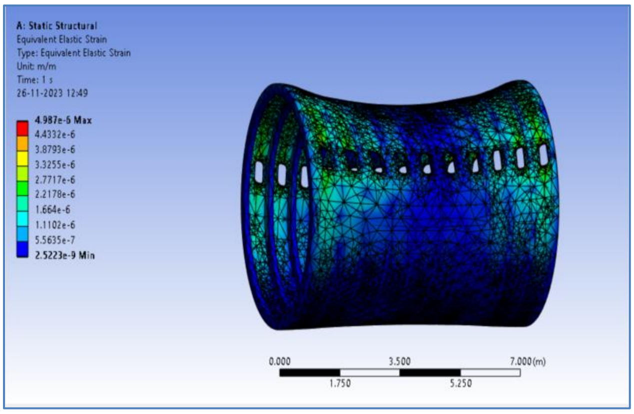

Fig. 12: Composite Fuselage

C. Compression Test

➢ *Stress*

- In a compression test, the maximum equivalent stress generated in the Al alloy fuselage is 15413 Pa.
- In a compression test, the hybrid composite fuselage had a maximum equivalent stress of 20897 Pa.

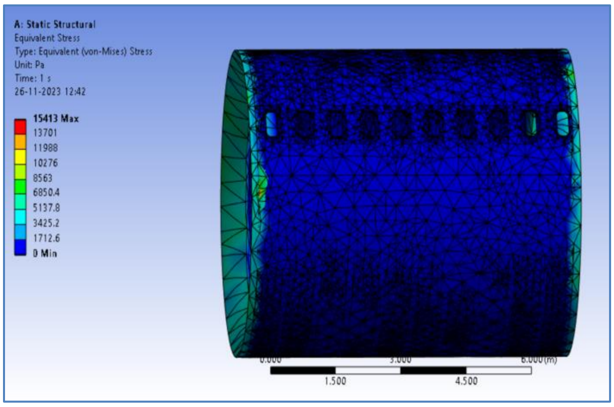

Fig. 13: AL Alloy Fuselage

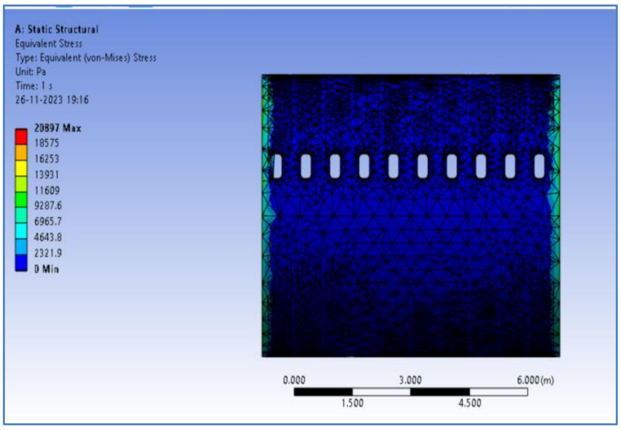

Fig. 14: Composite Fuselage

➢ *Strain*

- The Al alloy fuselage experiences a maximum strain of 1.3*10^-6 during the compression test.
- 2.2*10^-7 is the maximum strain that a compression test on a hybrid composite fuselage may create.

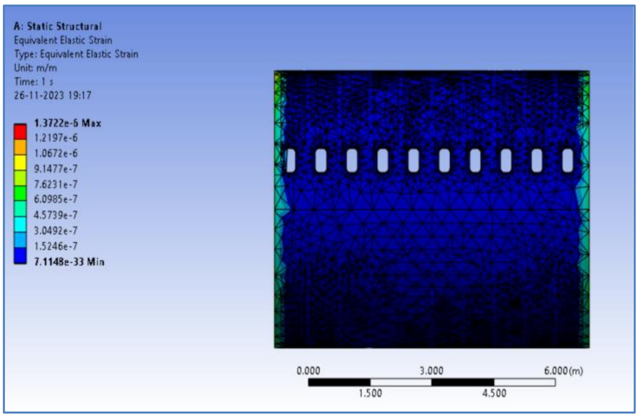

Fig. 15: Al alloy Fuselage

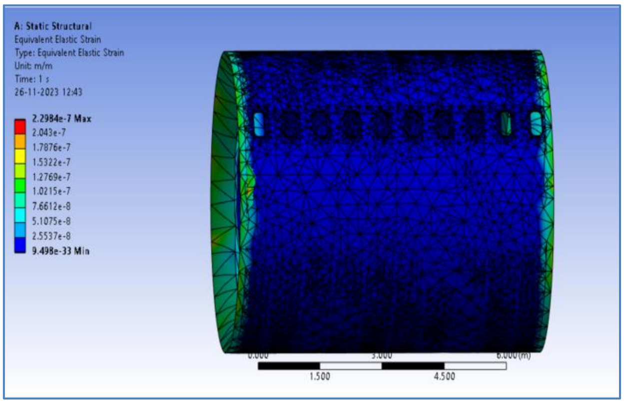

Fig. 16: Composite Fuselage

D. Shear Test

➢ *Stress*

- The highest comparable stress generated in the Al alloy fuselage during the shear test is 1.26*10^5 Pa.
- In a shear test, the hybrid composite fuselage's maximum equivalent stress is 1.28*10^5 Pa.

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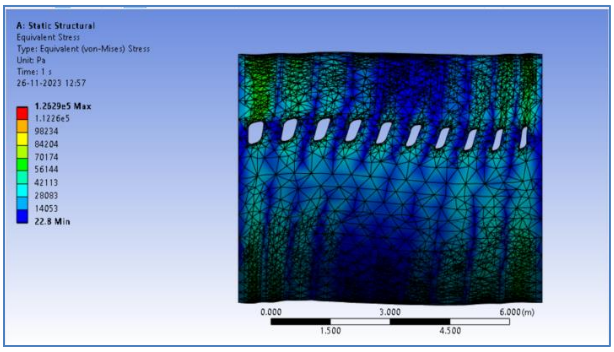

Fig. 17: AL Alloy Fuselage

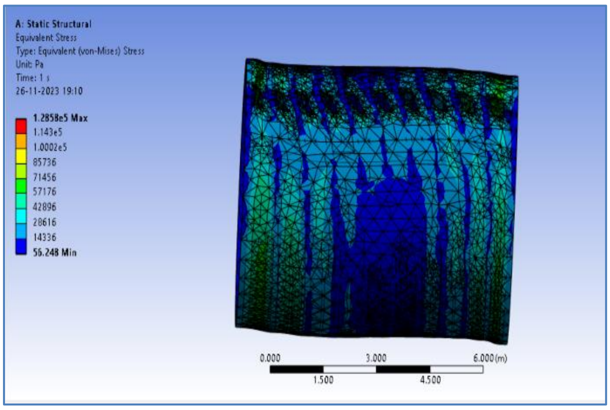

Fig. 18: Composite Fuselage

➢ *Strain*

- In a shear test, the highest strain caused in the Al alloy fuselage is 1.6*10^-5.
- The hybrid composite fuselage experiences a maximum strain of 1.7*10^-6 during the shear test.

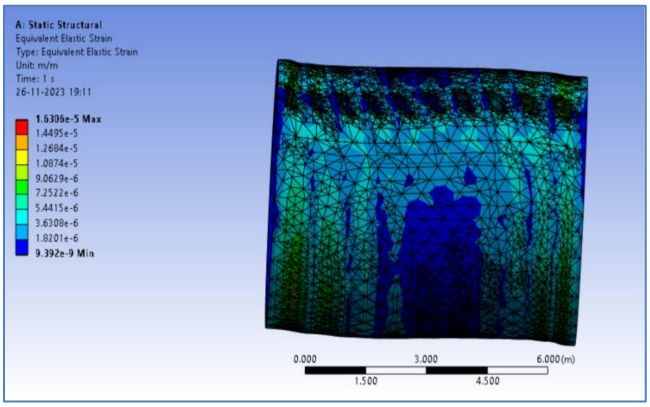

Fig. 19: Al alloy Fuselage

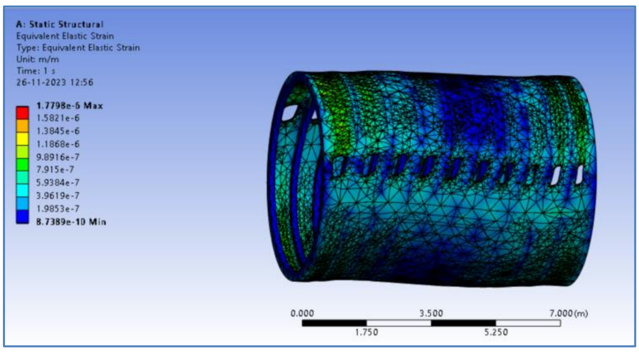

Fig. 20: Composite Fuselage

E. Tensile Test

➢ *Stress*

- In an Al alloy fuselage, the maximum equivalent stress produced during a tensile test is 15413 Pa.
- The hybrid composite fuselage's highest equivalent stress during the tensile test was 20897 Pa.

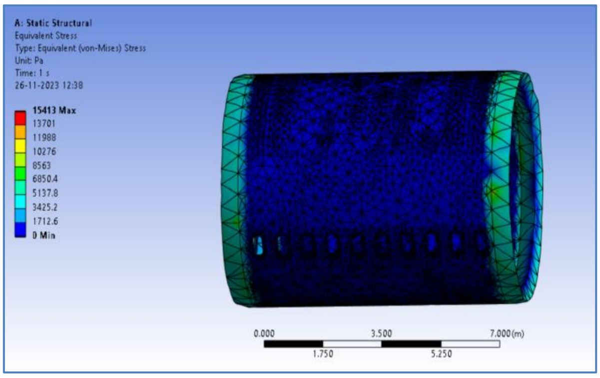

Fig. 21: Al Alloy Fuselage

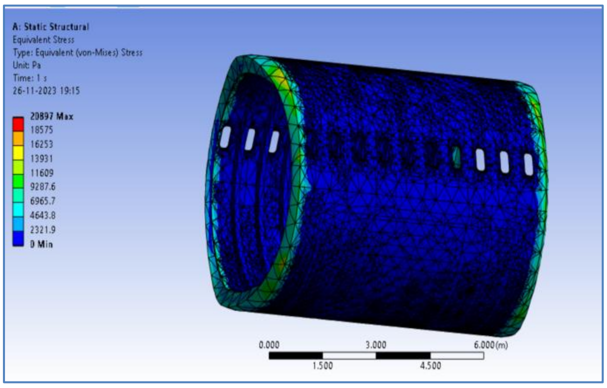

Fig. 22: Composite Fuselage

➢ *Strain*

- The Al alloy fuselage experiences a maximum strain of 1.3*10^-6 during the Tensile Test.
- 2.2*10^-7 is the maximum strain that can be created in the hybrid composite fuselage during a tensile test.

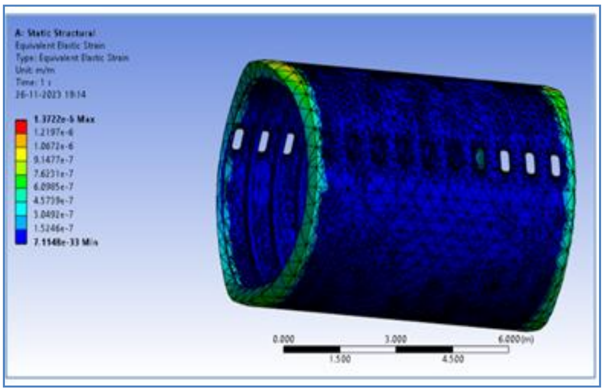

Fig. 23: Al Alloy Fuselage

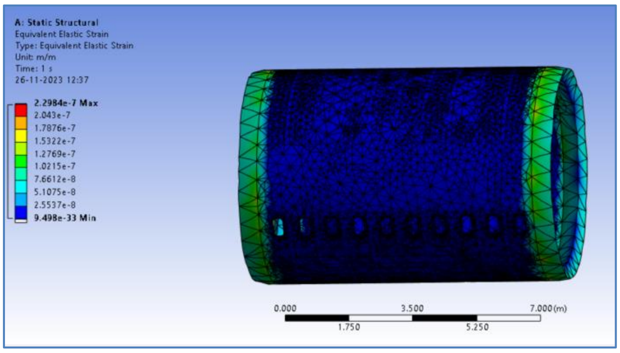

Fig. 24: Composite Fuselage

F. Weight analysis

- Masses of the Al and hybrid composite skin fuselages are 22356.94 kg and 12438.73 kg, respectively.
- Weight reduction in the fuselage skin is 44.36%.

V. CONCLUSION ANDFUTURE SCOPE

- After conducting structural tests, including Fatigue, Tensile, Bending, Compressive, and Shear tests on the fuselage skin models made from conventional material (Aluminium alloy) and modern material (Hybrid Composite with Carbon fiber, Hexply, and Glass fiber), it was observed that the performance of the fuselage skin made from the composite materials surpassed that of the Aluminium alloy. The combination of Carbon fiber, Hexply, and Glass fiber demonstrated superior performance across these tests compared to the traditional Aluminium alloy.
- The fatigue test revealed that the Aluminum alloy fuselage exhibited premature failure compared to the composite fuselage. Consequently, the composite fuselage demonstrated superior resistance to cyclic loads, highlighting its enhanced durability.
- In Tensile, Compressive, Bending, and Shear tests, the Hybrid Composite fuselage exhibited higher stress than the Al alloy fuselage, indicating superior strength and structural properties.
- In all tests, the Hybrid Composite skin fuselage demonstrated lower strain compared to the Al alloy fuselage skin. This signifies greater resistance to deformation in Tensile, Compressive, Bending, and Shear tests for the Hybrid Composite material.
- Beside the Structural advantages, the use of composite skin fuselage reduces the weight of the skin by 44.36 % which in return is a significant advantage when it comes to the fuel consumption.

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