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A Finite Element Comparison of Monocoque and Semi-Monocoque Aerospace Shell Structures

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A B S T R A C T

The fuselage is one of the primary structural components of an aircraft, providing strength and support to the overall airframe. Monocoque and semi-monocoque structures are commonly used in aircraft fuselage construction, in which the outer skin carries external loads and internal pressurization loads, while the semi-monocoque structure is further reinforced using stringers, frames, and bulkheads. Nowadays, reducing structural weight has become an important consideration in aircraft design due to increasing manufacturing costs and the need for improved performance. Conventional aircraft fuselages are generally manufactured using metallic alloys, while advanced materials are being explored to reduce structural weight and improve service life. Sandwich-structured composites are a special class of composite materials consisting of two thin, stiff outer skins bonded to a lightweight and relatively thick core. Although the core material generally has lower strength, its greater thickness provides high bending stiffness while maintaining a low overall density. In the present work, sandwich composite structures are considered for monocoque and semi-monocoque aircraft fuselage configurations to evaluate their structural performance under different loading conditions. Different core materials, such as balsa wood, synthetic foam, and honeycomb, are considered for the comparative study. The three-dimensional models are developed using CATIA V5 R20. Static structural and modal analyses are carried out using ANSYS 14.5 to evaluate the strength, deformation, and vibration characteristics of the proposed structures.

Keywords: Aircraft Fuselage, Monocoque and Semi-Monocoque Structures, Sandwich Composite Materials, CATIA V5, Static Structural and Modal Analysis (ANSYS 14.5).

1. Introduction

The aircraft fuselage is one of the major structural components of an aircraft, providing accommodation for passengers, crew, cargo, and essential equipment while connecting the wings, tail assembly, landing gear, and other important structural components. It plays a significant role in maintaining the overall strength, stiffness, stability, and aerodynamic efficiency of an aircraft. During flight and ground operations, the fuselage is subjected to various structural loads, including bending, shear, torsion, compression, and internal cabin pressure. Therefore, the selection of a suitable structural configuration and material is essential to ensure adequate strength, structural reliability, and minimum weight.

Aircraft fuselage structures are generally classified into two major types: monocoque and semi-monocoque structures. In a monocoque construction, the outer skin acts as the primary load-carrying member and resists the applied structural loads. This construction provides a relatively simple structural arrangement; however, thin unsupported skins may experience excessive deformation and buckling under compressive and shear loading. In contrast, semi-monocoque construction consists of an outer skin supported by internal structural members such as frames, stringers, bulkheads, and longerons. These components work together to distribute the applied loads and improve the overall strength, stiffness, and stability of the fuselage. Weight reduction is one of the major objectives in modern aircraft structural design. A reduction in structural weight can contribute to improved aircraft performance, reduced fuel consumption, and increased payload capacity. Conventional metallic materials, particularly aluminium alloys, have been widely used in aircraft fuselage manufacturing because of their favourable mechanical properties and manufacturing characteristics. However, the increasing demand for lightweight and high-performance structures has encouraged the development and application of advanced composite materials. Sandwich composite structures are particularly attractive for aerospace applications because they provide high bending stiffness and strength while maintaining relatively low structural weight. A sandwich composite structure generally consists of two thin, stiff outer face sheets bonded to a lightweight and relatively thick core material. The outer skins primarily resist tensile and compressive stresses, while the core maintains the separation between the face sheets, provides support, and improves bending stiffness. The selection of a suitable core material plays an important role in determining the mechanical performance, weight, and stability of the structure. Different core materials, such as balsa wood, synthetic foam, and honeycomb, offer different structural characteristics. Balsa wood is known for its low density and lightweight nature, synthetic foam provides low weight and energy absorption characteristics, while honeycomb structures offer a favourable strength-to-weight ratio and high stiffness. These materials are widely considered for lightweight sandwich structural applications, particularly in aerospace engineering.

Computer-Aided Design (CAD) and Finite Element Analysis (FEA) have become important tools in the design and evaluation of aircraft structural components. CAD software enables the development of accurate three-dimensional models, while FEA helps predict the structural response under different loading conditions without requiring extensive physical testing. CATIA V5 R20 is used for developing the three-dimensional models of the proposed monocoque and semi-monocoque fuselage configurations. ANSYS 14.5 is employed to perform numerical simulations and evaluate their structural behaviour. Static structural analysis is used to determine the deformation and stress distribution under applied loading conditions, whereas modal analysis is performed to identify the natural frequencies and corresponding mode shapes of the structures. The structural performance of a fuselage depends not only on the material properties but also on the configuration and arrangement of its structural components. Therefore, comparing different core materials in monocoque and semi-monocoque configurations is important for identifying a suitable combination that provides improved structural performance with reduced weight. The evaluation of deformation, stress distribution, natural frequencies, and mode shapes provides useful information about the strength, stiffness, and vibration characteristics of the proposed structures.

In the present investigation, monocoque and semi-monocoque aircraft fuselage configurations incorporating sandwich composite structures are modelled and analysed using CATIA V5 R20 and ANSYS 14.5, respectively. Three different core materials, namely balsa wood, synthetic foam, and honeycomb, are considered for comparative evaluation. Static structural and modal analyses are performed to investigate the influence of core material selection and structural configuration on the overall performance of the fuselage. The results are compared to identify the material and structural configuration offering favourable deformation, stress, and vibration characteristics for lightweight aircraft fuselage applications.



Figure 1.1: Aircraft structure

2. Literature Review

The structural design of an aircraft fuselage has received considerable attention because of the need to achieve high strength, stiffness, durability and reduced structural weight. Earlier studies have investigated different fuselage configurations, including monocoque and semi-monocoque structures, along with the application of composite materials and numerical techniques for evaluating their structural behaviour. The following literature review discusses research related to fuselage structural design, sandwich composite materials, static structural analysis and modal analysis.

Boni and Fanteria (2004) investigated the development of analytical methods for aircraft fuselage design and validated the proposed methods using finite element analysis. Their study focused on the structural behaviour of fuselage sections under realistic loading conditions. The finite element results were used to understand the limitations of simplified analytical approaches and to improve the design of complex fuselage structures. The study highlighted the importance of numerical analysis in evaluating aircraft structural components.

Boni and Fanteria (2006) presented a finite-element-based assessment of analytical methods for the design of aircraft fuselage frames. Their research examined the influence of realistic loading conditions and the effect of frames on the surrounding structural components. The study demonstrated the usefulness of finite element simulations in understanding stress distribution and the structural contribution of fuselage frames.

Dababneh and Kayran (2014) studied the design, analysis and optimization of thin-walled semi-monocoque wing structures using different structural idealizations. Their work explained the importance of selecting suitable structural models for analysing semi-monocoque aerospace components. The authors highlighted that finite element methods are useful for analysing complex geometries and combined loading conditions, particularly when simplified structural models may not fully represent actual behaviour.

Schwinn (2016) presented a methodology for coupling static and dynamic design considerations in semi-monocoque aircraft fuselage structures. A fuselage barrel was evaluated using finite element methods under static and dynamic conditions. The study demonstrated the application of a global-local analysis approach for evaluating structural performance during the preliminary design stage. It also emphasized the importance of considering both static strength and dynamic behaviour during fuselage design.

Castanié, Bouvet and Ginot (2020) reviewed the applications of composite sandwich structures in aeronautical engineering. Their study discussed the development, design considerations and applications of sandwich structures in civil and military aircraft. The authors explained that sandwich construction generally consists of high-strength outer face sheets separated by a lightweight core. The review also discussed different core and face-sheet material combinations, including honeycomb cores and fibre-reinforced composite skins. The study highlighted the importance of sandwich structures in achieving lightweight aircraft components with suitable structural performance.

Deshmukh and Shrigandhi (2015) investigated the modal behaviour of composite sandwich panels. Their study considered aluminium honeycomb as the core material and evaluated the influence of sandwich panel parameters, such as face-sheet thickness, core thickness and cell pitch, on natural frequencies and mode shapes. The research used finite element modelling to study the free-vibration characteristics of sandwich panels under different boundary conditions. The findings emphasize the importance of geometric and material parameters in determining the vibration response of sandwich structures.

Kumar, Kar and Chandravanshi (2022) investigated the free-vibration behaviour of honeycomb-core sandwich composite plates using the finite element method. The researchers developed a numerical model in ANSYS APDL and studied the natural frequencies and corresponding mode shapes using the Block Lanczos method. Their work demonstrated the application of finite element modelling for predicting the vibration characteristics of honeycomb sandwich structures.

Sulthan et al. (2024) presented a study on the static and modal finite element analysis of a composite aircraft fuselage. Their research focused on developing a three-dimensional composite fuselage model and evaluating its structural response under different loading conditions. The reported numerical results indicated reductions in stress and deformation compared with an equivalent aluminium fuselage model. The study highlighted the potential of composite materials for improving aircraft structural performance while reducing weight.

2.1 Research Gap

From the reviewed literature, it is observed that several researchers have investigated aircraft fuselage structures, semi-monocoque configurations, composite sandwich panels and their structural behaviour using finite element methods. Previous studies have addressed static strength, stress distribution, deformation and vibration characteristics. Research has also established the importance of selecting suitable core materials and structural configurations for lightweight aerospace applications.

However, a comparative numerical investigation considering both monocoque and semi-monocoque fuselage configurations with different sandwich core materials, namely balsa wood, synthetic foam and honeycomb, remains an important area for further study. The combined evaluation of static structural behaviour and modal characteristics can provide a better understanding of the influence of structural configuration and core material selection.

Therefore, the present investigation focuses on the modelling of monocoque and semi-monocoque aircraft fuselage structures using CATIA V5 R20. Static structural and modal analyses are carried out using ANSYS 14.5 to evaluate and compare the structural response of the selected core materials. The results are considered in terms of deformation, stress, strain and vibration characteristics to identify a comparatively suitable material and structural configuration.

3. Software tools and Methodology

The present study investigates the structural behaviour of monocoque and semi-monocoque aircraft fuselage structures using three sandwich core materials: Balsa Wood, Synthetic Foam and Honeycomb. The three-dimensional models are developed using CATIA V5 R20, and finite element analyses are performed using ANSYS 14.5.

The monocoque configuration consists of an outer fuselage skin that carries the applied structural loads, whereas the semi-monocoque configuration incorporates additional internal supporting members, such as frames and stringers, to improve structural rigidity. The selected core materials are considered to evaluate their influence on the structural and vibration characteristics of both configurations.

The developed three-dimensional models are imported into ANSYS 14.5, where material properties are assigned and finite element meshing is performed. Static structural analysis is carried out to determine total deformation, equivalent von Mises stress, equivalent elastic strain, hoop stress and longitudinal stress under the specified loading and boundary conditions. Modal analysis is also performed to determine the natural frequencies and corresponding mode shapes of the structures.

Finally, the results obtained for the three core materials and two fuselage configurations are compared to evaluate their structural performance and vibration characteristics. The comparative study helps identify a suitable combination of core material and fuselage configuration for lightweight aircraft structural applications.

This consolidated version is more appropriate for a journal paper. Detailed material descriptions, separate software explanations and lengthy analysis procedures are unnecessary unless the journal specifically requires them.

4. Modeling and static analysis of the monocoque fuselage

The monocoque fuselage structure is modelled using CATIA V5 R20. In this configuration, the outer skin acts as the primary load-carrying element, providing structural strength and rigidity. The model is developed using a sandwich construction with three different core materials: Balsa Wood, Synthetic Foam and Honeycomb. The same basic geometry is maintained for all three models to ensure a consistent comparison of their structural performance.

The developed models are imported into ANSYS 14.5 for static structural analysis. The corresponding material properties are assigned, and the finite element mesh is generated. Appropriate boundary conditions and structural loads are applied to evaluate the response of the monocoque fuselage under the specified loading conditions.

Static structural analysis is performed to determine total deformation, equivalent von Mises stress, equivalent elastic strain, hoop stress and longitudinal stress. These parameters are used to assess the deformation and stress distribution in the fuselage structure and to understand the influence of the selected core materials on its structural behaviour.

The analysis results for Balsa Wood, Synthetic Foam and Honeycomb core materials are compared to identify their effect on the structural performance of the monocoque fuselage.

The design and structural analysis of drone landing gear are important stages in the development of an unmanned aerial vehicle (UAV) for forest fire sensing applications. The landing gear supports the drone during ground operations and transfers the load between the main body and the ground. Its structural performance depends on the geometry, material properties, applied forces, mounting arrangement, and support conditions.

In the present study, a U-shaped, two-frame landing gear is modelled using Autodesk Fusion. The design is investigated using three candidate materials: Aluminium 6061, carbon fibre-reinforced polymer (CFRP), and Titanium (TI-6AL-4V). The material configurations are evaluated under three prescribed static load conditions of 50 N, 100 N, and 150 N.The final design should also be checked for mounting compatibility, propeller clearance, ground clearance, and potential interference with the UAV body. These checks are part of the design assessment and are not replaced by the static structural simulation.

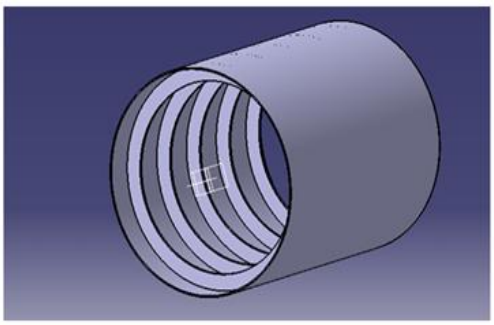


Figure 4.1: 3D Modeling of Monocoque Structure

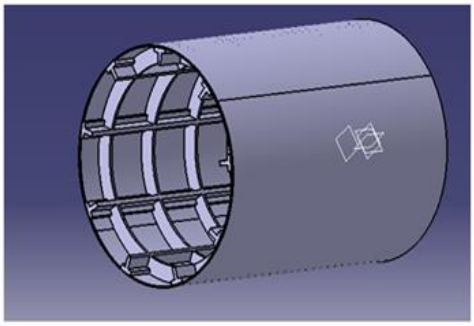


Figure 4.2: 3D Modeling of Semi-Monocoque Structure

5. Results and Discussions

The structural performance of monocoque and semi-monocoque fuselage configurations is evaluated using Balsa Wood, Synthetic Foam and Honeycomb as sandwich core materials. Static structural analysis is carried out to investigate total deformation, equivalent stress, equivalent strain, hoop stress and longitudinal stress. The numerical results are compared to understand the influence of core material and structural configuration on the overall structural response.

5.1 Static Structural Analysis

The static structural analysis results for both fuselage configurations are presented in Table 1. The comparison includes the deformation and stress-related parameters obtained for the three selected core materials.

Table 6.1: Static analysis results

Condition	Materials	Total deformation (mm)	Stress (Mpa)	Strain	Hoop stress (Mpa)	Longitudinal stress (Mpa)
Monocoque	**Balsa wood**	0.2426	29.23	0.077	14..419	14.432
	Synthetic foam	0.25062	30.95	0.0823	15.268	15.281

Condition	Materials	Total deformation (mm)	Stress (Mpa)	Strain	Hoop stress (Mpa)	Longitudinal stress (Mpa)
Semi - monocoque	**Honey comb**	0.22989	27.51	0.0732	13.571	13.583
	Balsa wood	1.9966	26.828	0.0625	12.131	12.232
	Synthetic foam	1.8968	25.487	0.0612	13.092	13.256
	Honey comb	1.6971	22.804	0.059	11.981	11.991

5.1.1 Total Deformation

Total deformation represents the displacement developed in the fuselage structure under the applied loading conditions. For the monocoque configuration, Honeycomb exhibits the lowest deformation of 0.22989 mm, followed by Balsa Wood at 0.24260 mm and Synthetic Foam at 0.25062 mm. Similarly, for the semi-monocoque configuration, Honeycomb records the lowest deformation of 1.6971 mm, followed by Synthetic Foam at 1.8968 mm and Balsa Wood at 1.9966 mm.

The results indicate that Honeycomb provides the lowest deformation among the three core materials in both configurations. However, the semi-monocoque models exhibit higher deformation values than the monocoque models under the reported conditions.

5.1.2 Equivalent Stress

Equivalent stress is used to evaluate the combined stress developed in the structure under the applied loading. In the monocoque configuration, Synthetic Foam exhibits the highest equivalent stress of 30.95 MPa, whereas Honeycomb records the lowest value of 27.51 MPa. For the semi-monocoque configuration, Balsa Wood exhibits the highest stress of 26.828 MPa, followed by Synthetic Foam at 25.487 MPa. Honeycomb again shows the lowest stress of 22.804 MPa.

The comparison indicates that Honeycomb exhibits the lowest equivalent stress in both structural configurations, suggesting a comparatively favourable stress response under the specified loading conditions.

5.1.3 Equivalent Strain

The equivalent strain values are compared to evaluate the deformation behaviour of the selected core materials. For the monocoque structure, Synthetic Foam records the highest strain of 0.0823, while Honeycomb exhibits the lowest value of 0.0732. In the semi-monocoque structure, Balsa Wood shows the highest strain of 0.0625, whereas Honeycomb records the lowest value of 0.0590.

The results indicate that Honeycomb exhibits the lowest equivalent strain in both configurations among the materials considered.

5.1.4 Hoop and Longitudinal Stresses

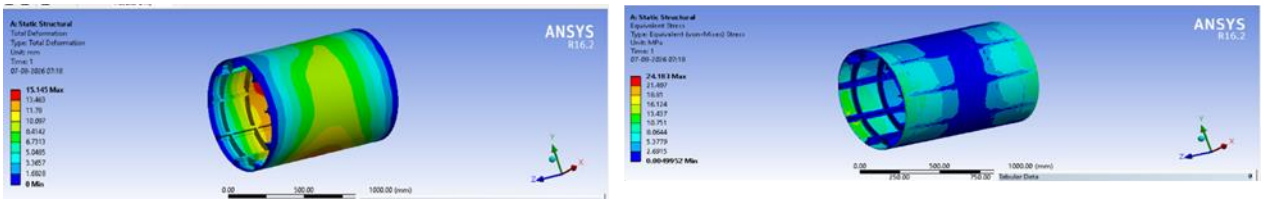
Hoop stress and longitudinal stress represent the circumferential and lengthwise stress responses of the fuselage, respectively. In the monocoque configuration, Synthetic Foam exhibits the highest hoop and longitudinal stresses of 15.268 MPa and 15.281 MPa, respectively. Honeycomb records the lowest values of 13.571 MPa and 13.583 MPa.

For the semi-monocoque configuration, Synthetic Foam shows the highest hoop stress of 13.092 MPa and longitudinal stress of 13.256 MPa. Honeycomb exhibits the lowest values of 11.981 MPa and 11.991 MPa, respectively.

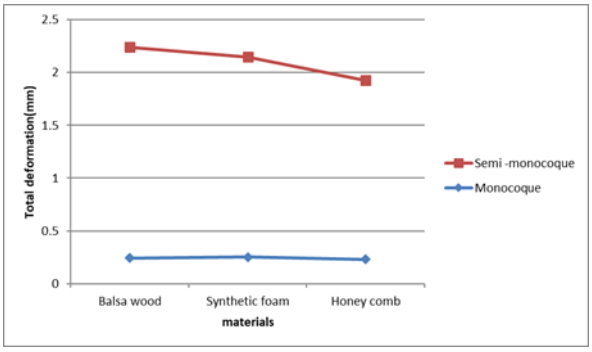
These results demonstrate that Honeycomb provides the lowest circumferential and longitudinal stress values in both configurations.

5.2 Modal Analysis

Modal analysis is performed to determine the natural frequencies and corresponding mode shapes of the monocoque and semi-monocoque fuselage structures. The modal characteristics are evaluated for Balsa Wood, Synthetic Foam and Honeycomb core materials to understand the influence of material selection and structural configuration on the vibration behaviour.



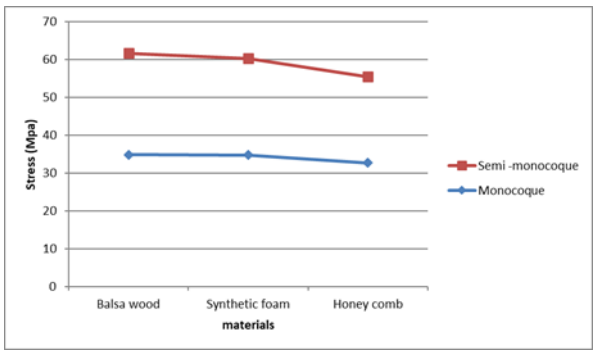
Conditions and Materials versus Total Deformation



The graph compares the total deformation values obtained for the monocoque and semi-monocoque structures using the three selected materials. In the monocoque configuration, Honeycomb exhibits the lowest deformation of 0.22989 mm, whereas Synthetic Foam shows the highest deformation of 0.25062 mm. In the semi-monocoque configuration, Honeycomb again shows the lowest deformation of 1.6971 mm, while Balsa Wood shows the highest deformation of 1.9966 mm. The graph clearly indicates that Honeycomb provides the lowest deformation in both structural configurations.

Conditions and Materials versus Equivalent Stress

The graph represents the equivalent stress values obtained for the monocoque and semi-monocoque structures. For the monocoque configuration, Honeycomb shows the lowest stress of 27.51 MPa, while Synthetic Foam shows the highest stress of 30.95 MPa. For the semi-monocoque configuration, Honeycomb again exhibits the lowest stress of 22.804 MPa, whereas Balsa Wood shows the highest stress of 26.828 MPa. The comparison indicates that Honeycomb experiences the lowest equivalent stress among the three materials in both configurations.



6. Conclusions

The present work focuses on the modelling and structural analysis of monocoque and semi-monocoque aircraft fuselage structures using different sandwich core materials. Balsa Wood, Synthetic Foam and Honeycomb were considered for evaluating the structural performance under different loading conditions. The three-dimensional models were developed using CATIA V5 R20, and numerical analyses were carried out using ANSYS 16.2. Based on the results obtained from static structural, dynamic, fatigue, thermal and random vibration analyses, the following conclusions are drawn:

- The monocoque and semi-monocoque fuselage models were developed using CATIA V5 R20 and analysed using ANSYS 16.2.
- Static analysis shows that Honeycomb provides the lowest deformation, stress and strain compared with Balsa Wood and Synthetic Foam.
- The semi-monocoque Honeycomb structure shows a minimum deformation of 1.6971 mm and equivalent stress of 22.804 MPa.
- Honeycomb also exhibits comparatively lower hoop and longitudinal stresses in both configurations.
- Dynamic analysis of the semi-monocoque structure shows maximum deformation, stress and strain of 1.6485 mm, 25.471 MPa and 0.007242 mm/mm, respectively.
- Fatigue analysis indicates that the semi-monocoque structure performs better than the monocoque structure for all three materials.

- Honeycomb shows the best comparative fatigue performance, with a damage value of 103.78 and a safety factor of 0.325 in the semi-monocoque configuration.
- Since all fatigue safety factors are below 1, further design modifications are required.
- Thermal analysis shows that the semi-monocoque Honeycomb structure has a maximum temperature of 500.49 K and heat flux of 0.582 W/mm².
- Random vibration analysis was performed on both configurations to evaluate their responses under random excitation.

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