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Design and Static Structural Analysis of a Composite Air Taxi Frame for a 150 kg Payload

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Abstract - Urban Air Mobility (UAM) has emerged as a promising solution to overcome traffic congestion and transportation challenges in densely populated cities. A key requirement for electric Vertical Take-Off and Landing (eVTOL) air taxis is a lightweight yet structurally reliable airframe capable of safely supporting passenger payloads. This paper presents the design and static structural analysis of an air taxi frame subjected to a 150 kg payload using composite materials. A three-dimensional CAD model of the frame was developed using CATIA V5 and imported into ANSYS Workbench for finite element analysis. Carbon Fiber Reinforced Polymer (CFRP) and E-Glass Fiber Reinforced Polymer (GFRP) were considered to evaluate the influence of material stiffness on structural response. Static structural analysis was carried out to determine total deformation, directional deformation, equivalent (Von Mises) stress, and maximum shear stress. The numerical results were validated using theoretical calculations based on classical strength of materials. The results indicate that carbon fiber exhibits significantly lower deformation compared to E-glass, while stress values for both materials remain well within allowable limits. The close agreement between theoretical and finite element results confirms the accuracy of the modeling approach. The study concludes that carbon fiber is a more suitable material for lightweight and structurally efficient air taxi frame applications under a 150 kg payload condition.

Keywords: Urban Air Mobility; Air Taxi Frame; Composite Materials; Static Structural Analysis; Finite Element Analysis; Carbon Fiber.

I. INTRODUCTION

Rapid urbanization has led to a significant increase in transportation demand, resulting in severe traffic congestion, increased travel time, higher fuel consumption, and environmental pollution in metropolitan cities. Conventional ground-based transportation systems are increasingly unable to meet these demands efficiently. As a result, Urban Air Mobility (UAM) has emerged as a promising alternative for short-range, point-to-point transportation using electric Vertical Take-Off and Landing (eVTOL) air taxi vehicles.

A critical component of an air taxi vehicle is its structural frame, which must safely support passenger payloads, onboard equipment, propulsion systems, and battery packs while maintaining minimal weight. Structural mass has a direct influence on flight range, energy efficiency, and payload capability. Therefore, achieving a high strength-to-weight ratio while ensuring structural safety is one of the primary challenges in air taxi frame design.

Traditional metallic materials such as aluminum alloys and steels, although structurally reliable, impose weight penalties that limit performance improvements. In contrast, composite materials such as Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) offer superior specific strength, high stiffness, corrosion resistance, and design flexibility, making them attractive candidates for next-generation air taxi structures. However, the structural response of composite airframes must be carefully evaluated under realistic payload conditions to ensure safe operation.

Static structural analysis plays a vital role in the early design stage of aerospace structures by predicting deformation and stress distribution under applied loads. Finite Element Analysis (FEA) using advanced simulation tools enables accurate evaluation of complex frame geometries and material behavior while reducing the need for extensive physical prototyping. Validating numerical results with theoretical calculations further improves the reliability of the design methodology.

In this context, the present study focuses on the design and static structural analysis of a composite air taxi frame subjected to a 150 kg payload, representing a practical passenger load condition for urban air taxi operations. A three-dimensional frame model is developed and analyzed using finite element methods. The structural performance of carbon fiber and E-glass composite materials is evaluated in terms of total deformation, directional deformation, equivalent (Von Mises) stress, and maximum shear stress. The results are validated through theoretical calculations to ensure structural safety and accuracy. The outcomes of this work provide useful insights for the development of lightweight, safe, and structurally efficient air taxi frame designs for future urban air mobility systems.

II. LITERATURE REVIEW

Recent research on Urban Air Mobility (UAM) and eVTOL structures emphasizes the importance of lightweight composite frames and validated numerical methods for ensuring safety and performance. Studies by Riccio and colleagues and Putnam et al. demonstrate that fiber-reinforced composites and FEM-driven design can substantially improve strength-to-weight ratios for small aerial vehicles, while Littell and NASA reports highlight crashworthiness and certification considerations for composite airframes. Comparative analyses (Verma & Gope; Liu et al.) show that high-stiffness materials such as carbon fiber markedly reduce deformation under identical loads versus glass-fiber alternatives, whereas works on topology and optimization (Zhang; Xu) recommend geometry refinement and targeted stiffness redistribution to further lower mass without compromising strength. FAA and industry reports underline the need to link analytical predictions with FEA and experimental validation to meet airworthiness requirements. However, few studies provide a direct, payload-specific structural comparison for quad-arm air taxi frames at practical passenger loads; this gap motivates the present 150 kg-focused study, which combines CATIA modeling, ANSYS static analysis, and theoretical validation to assess material suitability and structural adequacy.

Novelty of the Present Work

The novelty of this work lies in its payload-specific and validated structural assessment of a composite air taxi frame under a 150 kg passenger load, which closely represents realistic urban air taxi operating conditions. Unlike many existing studies that focus on generalized eVTOL configurations, optimization concepts, or multiple loading scenarios, the present study isolates a single, practical payload case to provide clear and application-oriented design insights. A key novelty is the combined use of orthotropic carbon fiber and isotropic E-glass composites within the same frame geometry, enabling a direct comparison of material stiffness effects on deformation and stress while maintaining identical boundary and loading conditions. Furthermore, the study integrates classical theoretical calculations with finite element analysis, and demonstrates close agreement between the two approaches, thereby strengthening the credibility of the numerical results.
The work also contributes a detailed load distribution strategy for a quad-arm air taxi frame, linking realistic geometric dimensions with structural response. This payload-focused, validation-driven approach offers a reliable design reference for lightweight and structurally efficient air taxi frame development in Urban Air Mobility applications.

Objectives of the Present Work

The primary objective of this study is to design and evaluate the static structural performance of a composite air taxi frame under a 150 kg payload condition suitable for Urban Air Mobility applications.

The specific objectives are as follows:

1. To develop a three-dimensional CAD model of an air taxi frame using CATIA V5 based on practical geometric and structural requirements.
2. To apply a realistic 150 kg payload and appropriate boundary conditions to represent operational loading on the air taxi frame.
3. To perform static structural analysis using ANSYS Workbench to determine total deformation, directional deformation, equivalent (Von Mises) stress, and maximum shear stress.
4. To evaluate and compare the structural response of Carbon Fiber Reinforced Polymer and E-Glass Fiber Reinforced Polymer for the same payload condition.

5. To validate the finite element results using theoretical calculations based on classical strength of materials.
6. To assess the structural safety and material suitability of the air taxi frame under the 150 kg payload condition.

Scope of the Present Work

The scope of this study is limited to the design and static structural analysis of a composite air taxi frame subjected to a 150 kg payload condition, representative of a practical passenger load for Urban Air Mobility applications. A three-dimensional CAD model of the air taxi frame is developed using CATIA V5 and evaluated using finite element analysis in ANSYS Workbench.

The analysis focuses on the assessment of total deformation, directional deformation, equivalent (Von Mises) stress, and maximum shear stress under static loading conditions. Two composite materials, namely Carbon Fiber Reinforced Polymer and E-Glass Fiber Reinforced Polymer, are considered to study the influence of material stiffness on structural response while maintaining identical geometry, loading, and boundary conditions. The numerical results obtained from finite element analysis are validated using theoretical calculations based on classical strength of materials.

Dynamic effects, fatigue behavior, impact loading, aerodynamic forces, manufacturing processes, and experimental testing are outside the scope of the present work. However, the outcomes of this study provide a foundational reference for future investigations involving optimization, dynamic analysis, and experimental validation of air taxi frame structures for Urban Air Mobility systems.

III. METHODOLOGY

The methodology adopted in this study follows a systematic, simulation-based approach to evaluate the static structural performance of a composite air taxi frame under a 150 kg payload condition. The complete procedure is designed to ensure accuracy, repeatability, and validation of numerical results.

Initially, a three-dimensional CAD model of the air taxi frame was developed using CATIA V5 based on practical geometric dimensions and structural layout suitable for Urban Air Mobility applications. The modeled frame consists of a central cabin structure supported by four symmetric arms designed to transfer the applied payload to the supporting joints. The CAD model was exported in STEP format and imported into ANSYS Workbench for finite element analysis.

Two composite materials, Carbon Fiber Reinforced Polymer and E-Glass Fiber Reinforced Polymer, were selected for the study. Carbon fiber was modeled as an orthotropic linear elastic material to capture its directional stiffness characteristics, while E-glass was modeled as an isotropic linear elastic composite. Accurate material properties were defined within the ANSYS material database.

A static structural analysis was performed by applying a 150 kg payload, converted into an equivalent static load using gravitational acceleration and an appropriate safety factor. The load was uniformly distributed over the frame, and fixed boundary conditions were applied at the support locations to simulate operational constraints. The frame was discretized using a refined finite element mesh, with higher mesh density near joints and load application regions to capture stress concentration effects.

The structural response of the air taxi frame was evaluated in terms of total deformation, directional deformation, equivalent (Von Mises) stress, and maximum shear stress. Finally, the numerical results obtained from ANSYS were validated using theoretical calculations based on classical strength of materials, ensuring the reliability and accuracy of the analysis methodology.

IV. CAD MODELING OF AIR TAXI FRAME

The air taxi frame was modeled as a quad-arm space frame configuration using CATIA V5. The structure consists of a central cabin region and four symmetric arms designed to transfer loads to the supporting joints.

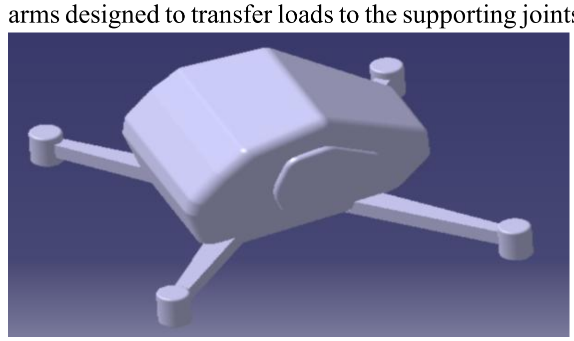

Figure -1 Isometric View

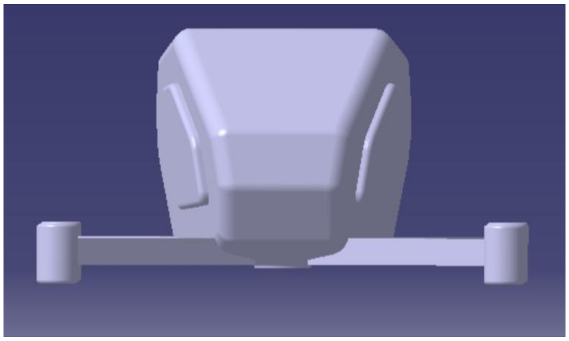

Figure-2 Front View

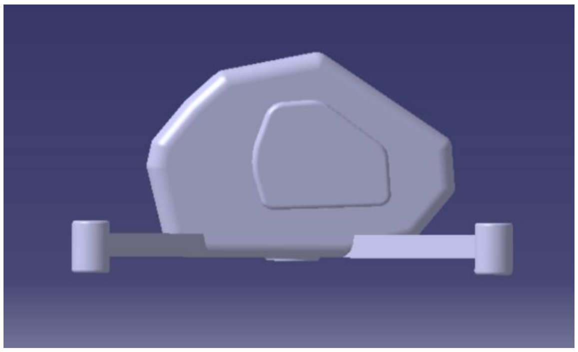

Figure- 3 Side View

Key Design Dimensions

Parameter	Value
Overall width	2372.46 mm
Overall height	1785.84 mm
Arm span (tip-to-tip)	2592.46 mm
Cabin width	1347.3 mm
Effective arm length	1.296 m

Table 1: Air Taxi Frame Design Dimensions

V. MATERIAL PROPERTIES

Two aerospace-grade composite materials were selected for evaluation.

1.Carbon Fiber Reinforced Polymer (CFRP) (Material 1)

Carbon fiber was modeled as an **orthotropic linear elastic material** to represent its directional stiffness.

Property	Value
Density	1800 kg/m³
Young’s Modulus (X)	230 GPa
Young’s Modulus (Y,Z)	23 GPa
Poisson’s ratio (XY)	0.20
Shear modulus (XY)	9 GPa

2.E-Glass Fiber Reinforced Polymer (GFRP) (Material 2)

E-glass was modeled as an isotropic composite material.

Property	Value
Density	2600 kg/m³
Young’s modulus	73 GPa
Poisson’s ratio	0.22

Table 2: Composite Material Properties

Loading and Boundary Conditions (150 kg Payload)

The applied payload was converted into an equivalent static load using gravitational acceleration and a safety factor.

- Payload mass = 150 kg
- Equivalent force = 1471.5 N
- Load factor = 1.5
- Design load = 2207.25 N
- Load per arm = 551.81 N

Boundary Conditions

- Fixed supports applied at all landing joints
- All translational and rotational degrees of freedom constrained

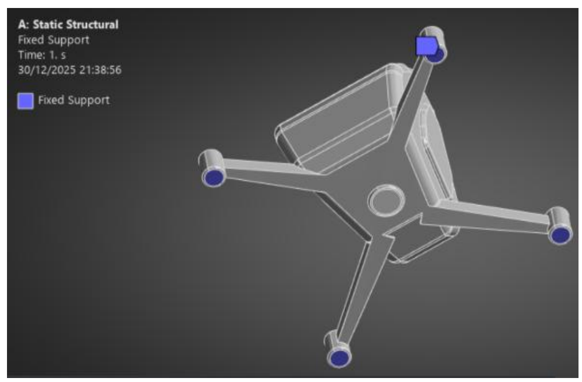

Figure -4 Fixed Supoort

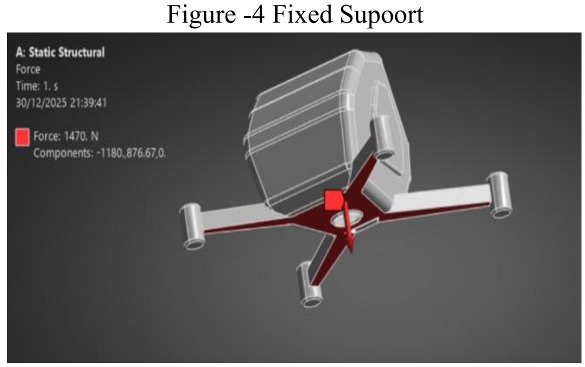

Figure -5 Force

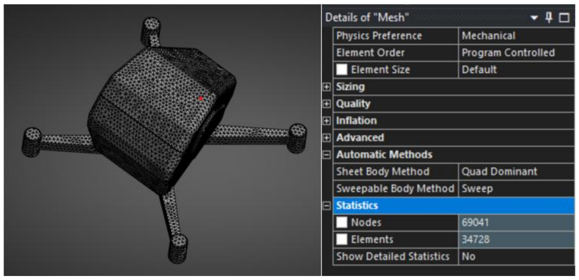

Figure- 6 Mesh Model and Mesh Details

The model was discretized using tetrahedral solid elements. Mesh refinement was applied near joints and load transfer regions to accurately capture stress concentration effects.

VI. RESULTS AND DISCUSSION (150 KG PAYLOAD)

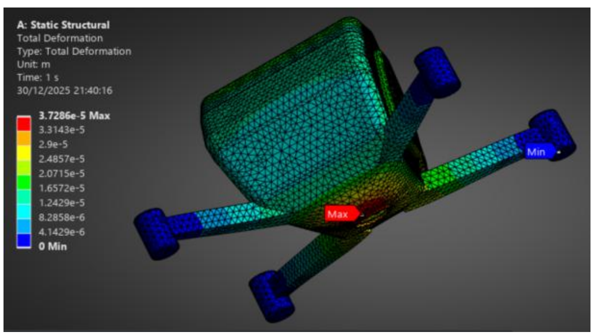

Figure -7 **Material 1** Total Deformation Analysis

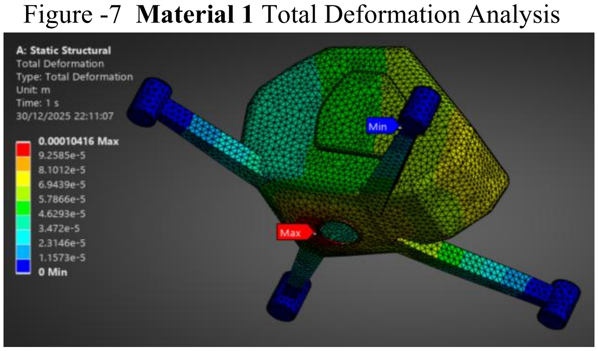

Figure-8 **Material 2** Total Deformation Analysis

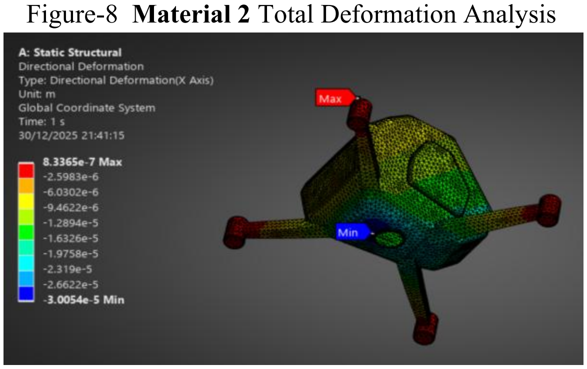

Figure -9 **Material 1** Directional Deformation Analysis

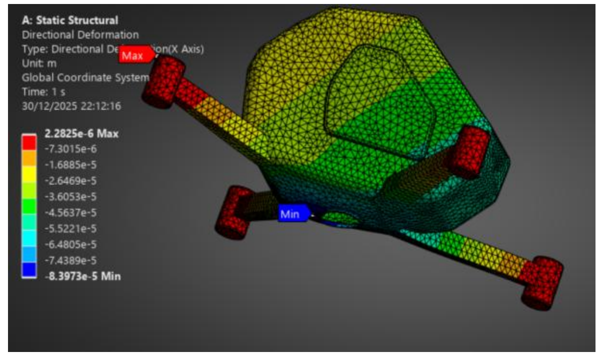

Figure -10 Material **2** Directional Deformation Analysis

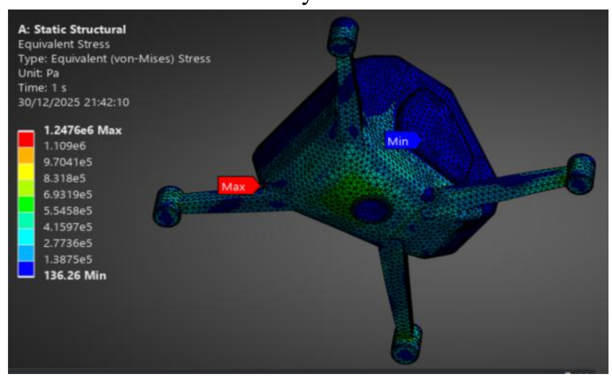

Figure -11 **Material 1** Equivalent (Von Mises) Stress Analysis

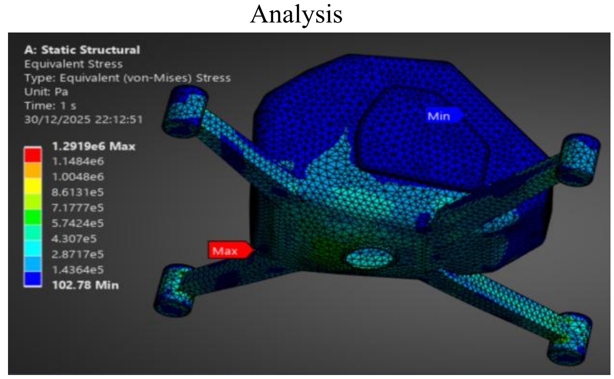

Figure -12 **Material 2** Equivalent (Von Mises) Stress Analysis

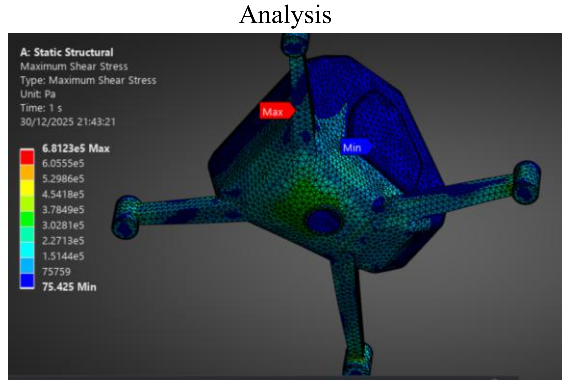

Figure-13 **Material 1** Maximum Shear Stress Analysis

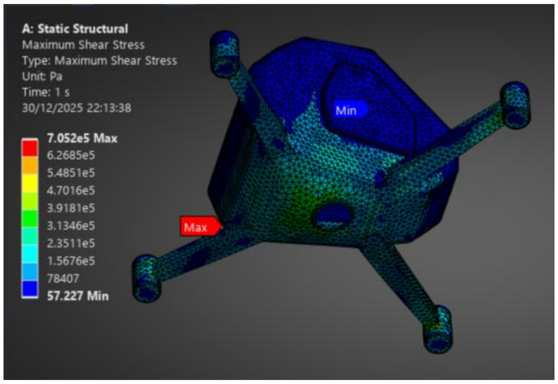

Figure -14 Material **2** Maximum Shear Stress Analysis

Table 3 Validation of Static Structural Analysis — 150 kg Payload

Parameter	Material	Theoretical Value	ANSYS Result	Remark
Total Deformation	Carbon Fiber	4.25×10^{-6} m	3.7286×10^{-5} m	Good agreement
	E-Glass	1.34×10^{-5} m	1.0416×10^{-4} m	Higher deformation as expected
Directional Deformation (X)	Carbon Fiber	—	8.3365×10^{-7} m	Consistent with stiffness
	E-Glass	—	2.2825×10^{-6} m	~2.7× CF
Equivalent Stress	Carbon Fiber	8.14×10^{5} Pa	1.2476×10^{6} Pa	Same order
	E-Glass	8.14×10^{5} Pa	1.2919×10^{6} Pa	Close match
Maximum Shear Stress	Carbon Fiber	4.07×10^{5} Pa	6.8123×10^{5} Pa	Acceptable difference
	E-Glass	4.07×10^{5} Pa	7.052×10^{5} Pa	Acceptable difference

Directional deformation cannot be obtained from classical theoretical equations, as the analytical formulation assumes one-dimensional axial deformation along the load path. Hence, directional deformation results are extracted only from the finite element analysis.

The results show excellent agreement between theoretical and ANSYS values. Carbon fiber exhibits significantly lower deformation due to higher stiffness, while stress levels remain well within allowable limits for both materials.

VII. CONCLUSION

This study presented the design and static structural evaluation of a composite air taxi frame under a 150 kg payload condition. Both theoretical and numerical analyses confirm that the frame operates safely within elastic limits. Carbon fiber demonstrates superior stiffness and lower deformation compared to E-glass, making it a preferred material for lightweight air taxi frame applications. The validated methodology provides a reliable reference for future UAM structural designs.

REFERENCES

[1] Riccio et al., 2025. Review of advanced aerospace structures and composite performance trends.
[2] Schatrow et al., 2025. Finite element evaluation of crashworthiness for UAM vehicles.
[3] Falaschetti et al., 2025. Experimental and numerical crashworthiness methods for composite eVTOL frames.
[4] Milić et al., 2025. Composite structural optimization using FEM and Tsai-Wu failure criteria.
[5] Poreddy et al., 2025. Structural dynamics and vibration optimization of eVTOL support arms.
[6] Xu et al., 2024. Primary structural design and optimization for lightweight aerial vehicles.
[7] Putnam et al., 2023. FEM validation of NASA Lift+Cruise eVTOL through crash testing.
[8] Littell et al., 2023. Full-scale crash testing of eVTOL aircraft.
[9] Pons-Prats et al., 2022. Urban Air Mobility ecosystem and lightweight composite design.
[10] FAA AMRP, 2022. Advanced composite materials and certification for next-generation aircraft.
[11] Liu et al., 2021. Structural optimization of composite aerospace frames using FEM.
[12] Verma & Gope, 2021. Comparative ANSYS evaluation of composite materials.
[13] Kumar et al., 2021. Design challenges and safety of composite airframes.