SSRG International Journal of Mechanical Engineering
ISSN: 2348-8360/ https://doi.org/10.14445/23488360/IJME-V12I1P106

Volume 12 Issue 1, 49-58, January 2025

Original Article

Numerical Simulations on Hexa-copter Drone for I-Section and Hollow Square Arm Cross-Sections for PLA-CF and CFRP Materials

Mohammad Abdul Fazal[1], A. Rajasekhar[2], R. Rajendra[3]

[1]*Department of Mechanical Engineering, Osmania University, Telangana, India.*
[2]*Department of Mechanical Engineering Department, Methodist College of Engg, & Tech., Telangana, India.*
[3] *Mechanical Engineering Department, Osmania University, Telangana, India.*

[1]*Corresponding Author : abdulfazal7@gmail.com*

Received: 10 November 2024 Revised: 19 December 2024 Accepted: 06 January 2025 Published: 25 January 2025

Abstract *- Unmanned aerial vehicles (UAVs) with rotary wings, or hexacopters, have a wide range of possible uses in strategic, industrial, medical and defense settings. The design optimization of UAVs is a crucial task that significantly affects the application possibilities due to the tradeoff between flight duration and payload capacity. The core body frame is one of the structural components that make up the majority of the weight of a standard hexacopter. The present study on selecting a hexacopter drone proposed the best cross-section and material for static deformation and stress-induced for two different materials (PLA-CF and CFRP) and two different cross-sections of the arm (I and Hollow square). Dimensions are taken initially from the literature survey. Simulations are done using ANSYS for the literature drone and proposed drone. Topological optimization was also done on the drone arm for different cross-sections and different materials. Considering structural flexibility and stiffness as objective functions for selecting the best drone decision-making through a weighted decision matrix was adopted.*

Keywords *- UAV, Hexacopters, Static analysis, Topological optimization, CFRP.*

1. Introduction

Unmanned aerial vehicles, commonly referred to as drones, have garnered extensive applications within the aerospace sector as well as both strategic and civil domains, owing to their intrinsic capability for deployment at specified locations. The proliferation of drones, particularly in civil and defense operations, is a consequence of their manifold advantages, which have led to a notable escalation in their utilization globally. The recent technological advancements in the realms of manufacturing, navigation, and control systems have rendered the development of drones viable across a broad spectrum of applications. Unmanned Aerial Vehicles (UAVs) are employed for diverse scientific and research endeavors in complex environments, including the remote monitoring of wildlife and the assessment of various environmental variables. Additional applications encompass the extraction of volumetric data from quarries, the inspection of agricultural facilities for precision farming, the deployment of communication antennas, and the examination of power lines. Furthermore, multi-rotor UAVs are primarily leveraged for short-range navigation due to their capabilities for hovering, vertical take-off and landing, and exceptional maneuverability. The principal factors that determine the efficacy of a Hexacopter are its production cost and structural robustness. It is imperative to minimize the weight of the Hexacopter frame to enhance its payload capacity. Consequently, optimization concerning reduced weight and elevated strength is of paramount significance. One of the pivotal advancements that has elevated the design of lightweight Hexacopters is the adoption of Additive Manufacturing (AM) for structural fabrication. Nvss et al. [1] discussed including design and modelling, topology optimization, and setting boundary conditions. It demonstrates how to perform modelling, apply topology optimization, and establish boundary conditions. Sagar et al. [2] show how simulations are done on the F550 drone, including the analysis of von Mises stress, displacement, and other factors under limited load conditions and thrust per motor calculation. Raghu et al. [3] discussed the physical dimensions proposed I-Cross Sectional and Hollow Square-Cross Sectional reference from it. Huang et al. [4] discussed to support the statement that the thrust must be twice the flying weight of the drone. Verbeke et al. [5] present a novel compound multicopper design, combining large lift propellers for efficiency and small control propellers for agility, optimized for narrow corridor flight and outdoor conditions. This design offers up to 60% higher endurance than a standard quadcopter with the same payload and battery capacity.

Novotnak et al. [6] present a method for developing a dynamic model of a quadcopter specifically adapted to measure UAV parameters like individual motor thrust using static laboratory measurements. This approach eliminates the need for test flights and complex models, which can aid in tuning flight control algorithms. Zhang et al. [7,8] discussed valuable insights for modeling and simulation. Grodzki et al. [9] discussed a novel approach to simulating composite materials in SolidWorks for UAV design, focusing on laminates and sandwich composites, and integrates these simulations with the UAV manufacturing process, specifically for the Air Cargo Challenge 2013 competition. Vishank et al. [10] discussed the objectives of minimizing Von Mises stress and keeping total deformation below 1 mm in the study.

Syahril et al. [11] discussed and provided the basis for considering a payload of 3000gr for medical field deliveries, such as transporting medicines and blood. Elsamanty et al. [12] describe a methodology to identify all parameters of a quadrotor system, including structure and rotor assembly parameters, and develop a CAD model in SOLIDWORKS to calculate the mass moment of inertia and other missing geometrical parameters. In comparison with existing drones in the literature, the total maximum deformation is more than 1.5mm. A new design needs to be established, considering that the total maximum deformation should be less than 1mm [13].

The current investigation examines applications in the medical and military field to carry medical equipment, medications, and general food items to reduce the weight of the drone frame to increase the flight time payload capacity, with enhanced endurance for delivering the medicines and food of weight up to 3 kgs in challenging environments. We focused on the above research gap to investigate the various materials and distinct cross-sectional configurations pertaining to the arm of a drone. Additionally, topology optimization has been conducted on a hexacopter drone. The objective is to develop a lightweight hexacopter drone frame utilizing topology optimization while preserving structural integrity by evaluating both I-cross-sectional and hollow square-cross-sectional arms accompanied by two different materials, namely PLA-CF and CFRP. The objective is to take existing drone dimensions, model them in SOLIDWORKS software, and use FEA analysis. We used PLS-CF and CFRP materials, and safety checks on deformation were considered; if it was more than 1 mm deformation, we proposed a new cross-section and checked for safety margins for the new design cross-section. We analyzed topology optimization for the new design and checked it using FEA software.

2. Materials and Methods

Material selection is the most important part of this analysis because different materials have different working parameters based on their properties. CFRP is a widely used material in UAVs for outstanding stiffness with low weight and high tensile strength. This has been used in airframe rotor blades to reduce the weight of flying vehicles [14]. PLA-CF is also another material due to its low density and ideal for applications that require a high strength-to-weight ratio, high stiffness and high tensile strength, but it is less than CFRP due to the high compressive strength used for applications such as mount support [15]. Material selection for the drone, including all the properties, is given below. The initial study took dimensions from the literature. Dimensions and drone assembly are shown in Figure 1.

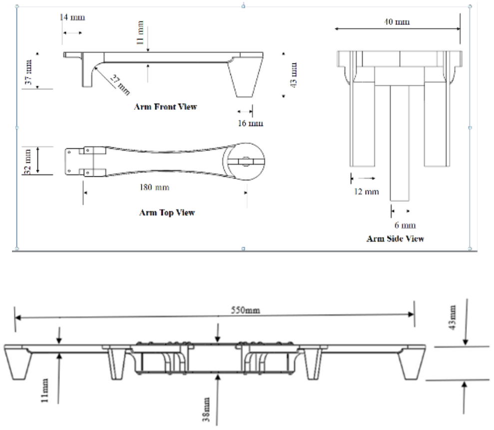

Fig. 1 Dimensions and assembly of drone

With the help of Solidworks modeling software modeled above, the drone assembled an isometric view, as shown in Figure 2.

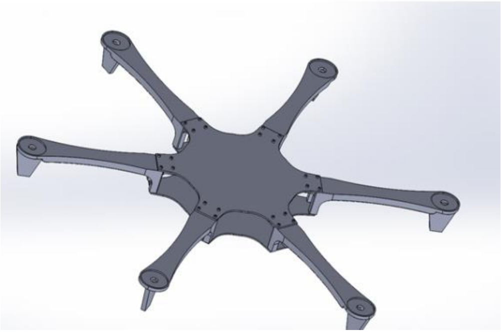

Fig. 2 Drone assemble isometric view

3. Methodology and Mechanical Properties of the Material Modeling

PLA-CF and CFRP materials are taken for study static structural analysis with different cross sections of arms. Material properties of PLA-CF and CFRP are given in Table. 1

Table 1. Material Properties of PLA-CF and CFRP

S. No.	Property	Values	
1	Material	PLA-CF	CFRP
2	Mass density (kg/m^3)	1290	1170
3	Poisons ratio	0.34	0.4
4	Young's modulus	4950	7453
5	Ultimate tensile	48	81.7
6	Compressive strength	50	500
7	Yield strength (MPa)	33.6	49.02
8	Flexural strength	89	169
9	Elongation at break	2	3

For further analysis, meshing is done in ANSYS-2023 *students used* with 1mm element size and triangle prism element and a fine type of meshing. In static structural analysis, the base plate is fixed for boundary conditions, and any load is applied at the arm tip in an upward direction. Fine meshing is done. Rational choices are taken to align with research objectives. The meshing of the Drone with PLA-CF material is shown in Figure 3. Boundary conditions of the drone, as shown in Figures 4 and 5, with a payload of 15.7 N on each arm for PLA-CF and CFRP.

Fig. 3 Meshing of drone with PLA-CF

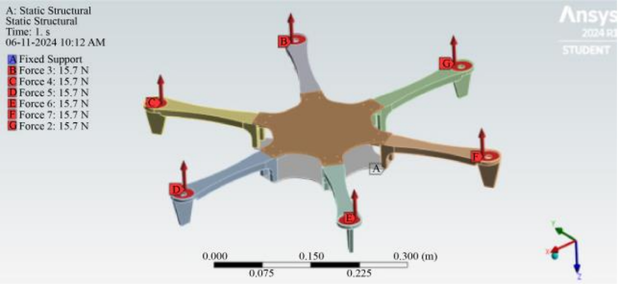

Fig. 4 Boundary condition on drone with PLA-CF

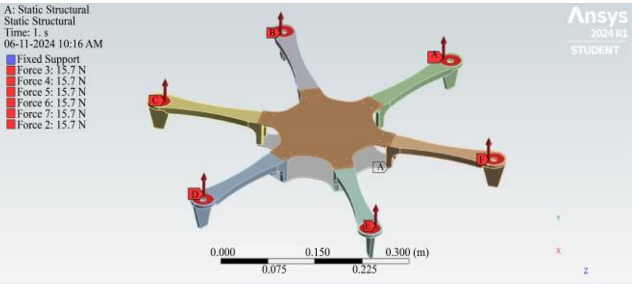

Fig. 5 Boundary condition on drone with CFRP (nylon6/6)

Proposed cross section for Drone Arm.

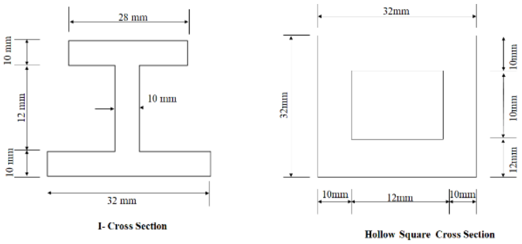

Fig. 6 Proposed cross-section for drone arm

The proposed cross section for arms of dimensions is shown in Figure 6. Confirming Safety of Proposed Cross-Sectional Arms Quantitative analysis of thrust load, CG, maximum bending moment, maximum bending stress and deformation are calculated for both cross sections.

Considering each arm of the drone as a Cantilever Beam of length 180mm with an I-Cross Sectional Arm and applying point load (i.e. THRUST LOAD) up-word direction at the free end.

The thrust force acting, i.e. thrust per motor = (total body weight + payload) ∗2 /6, Where 2 is the safety factor.

Total body weight = 1822.4gr, Payload = 3000gr
Thrust per motor = (1822.4+3000) ∗2 /6
= 1607.4gr
= 15.7 N i.e. W =15.7N.
Max Bending Moment M_{max} = W*L
= 15.7 *180 N-mm
= 2826 N-mm

Center of gravity (CG) = $\frac{A1Y1+A2Y2+A3Y3}{A1+A2+A3}$
A1, A2, and A3 are shown in Table 2 below.

Table 2. Dimensions

A1	320 mm^2	Y1	5 mm
A2	120 mm^2	Y2	16 mm
A3	280 mm^2	Y3	27 mm

CG =15.38 mm

Max Bending Stress = $\frac{Mmax*16.62}{78771.161}$
= 0.60 MPa

But bending strength is 89 MPa for PLA-CF and 169 MPa for CFRP

Deformation = $\frac{W*L^3}{3EI}$ As it is a cantilever beam

= 0.07 mm for PLA-CF
=0.051 mm for CFRP

The bending strength and deformation (less than 1 mm) of the proposed I-section arm are within safe limits, so it can safely support the applied payload.

Consider each arm of the drone as a Cantilever Beam of length 180mm with a Hollow Square-Cross Sectional Arm and apply point load (i.e. THRUST LOAD) up-word direction at the free end. Followed the same procedure as section 3 in the initial stage.

Total body weight = 1822.4gr
Payload = 3000gr
Thrust per motor = 1607.4gr
= 15.7 N i.e. W =15.7N

Deformation 0.07 for PLA-CF and 0.041 for CFRP, so the bending strength and deformation (less than 1 mm) of the proposed Hollow Square-sectional arm are within safe limits, so it can safely support the applied payload.

3.1. Hexa-Copter Drone frame with I- Cross Section and Hollow square Arms

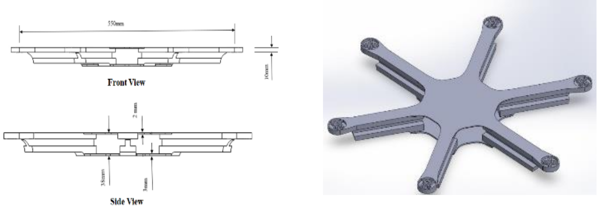

Fig. 7 Front, side, and isometric view of I cross-section arms drone

Fig. 8 Isometric view of Hollow square cross-section arms drone

Cross sections of arms were changed to I sections, and hollow square sections are shown in Figures 7 and 8. Analysis needs to be performed for different types of materials.

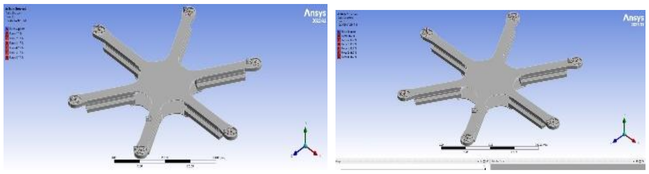

Fig. 9 Boundary Condition on I – Cross Section and hollow square Armed Drone with PLA-CF

Boundary conditions for the I-section and hollow square are shown in Figure 9.

3.2. Topological Optimization of Drone Arm I-section and Hollow Square with PLA-CF and CFRP Material

Topology optimization has emerged as one of the important techniques for developing hexacaptors. It helps engineers to propose structures that offer maximum performance with the minimum amount of material usage. This technique systematically redistributes the material within the given design to achieve specified functional requirements of stiffness, weight reduction and structural stability. Considering operational constraints as well.

Topological optimization was performed on a drone with two different cross-sections and two different materials.

Objective function: Minimize C(x) = $F^T U$, where C(x) is the compliance (a measure of structural flexibility, with lower values indicating higher stiffness), F is the applied force vector, U is the displacement vector Subject to Constraints:

Mass Constraint: $m(x) \geq 0.35m_0$
Stiffness Constraint (Maximum Displacement): $U_{max} \leq 1$ mm, Strength Constraint (von Mises Stress): $\sigma_{vM} \leq \sigma_{yield}$ (24MPa with safety factor 2) for PLA-CA (40MPa with safety factor 2) for CFRP.

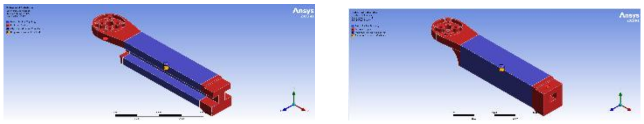

Fig. 10 Boundary Condition on I section and hollow square – Cross Section

Boundary conditions of sections are shown in Figure 10.

4. Results and Discussion

4.1. Results and Discussions on Static Structural Analysis for Drones in Literature

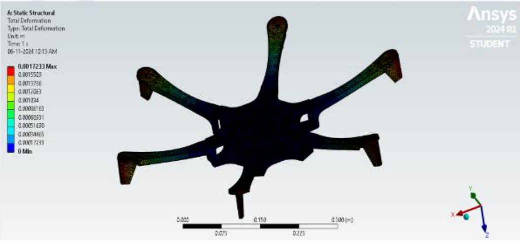

Fig. 11 Deformation of Drone with PLA-CF

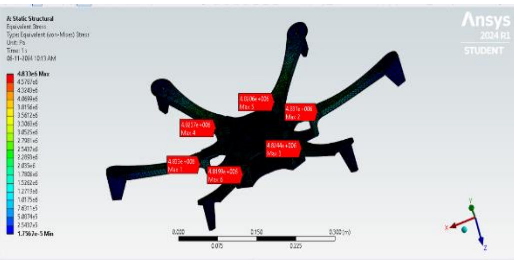

Fig. 12 Stress of Drone with PLA-CF

Static structural analysis is performed with PLA-CF material; the load is applied at the arm with pay load applied on each arm, total deformation observed is 1.723mm, and von misses stress is 4.8Mpa, as shown in Figures 11 and 12.

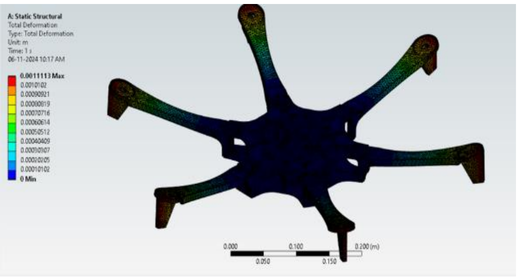

Fig. 13 Deformation of Drone with CFRP

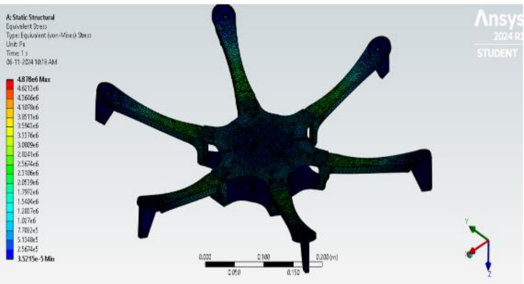

Fig. 14 Stress of Drone with CFRP

Static structural analysis is performed with CFRP material; the load is applied at the arm with pay load applied on each arm, total deformation is observed at 1.11mm, and von misses stress is at 4.8Mpa, as shown in Figures 13 and 14. The force applied on each arm is 15.7 N.

4.2. Results and Discussions on Static Structural Analysis for I Section and Hollow Square Cross Sections

Now, to study different cross sections for the same materials analyzed by ANSYS.

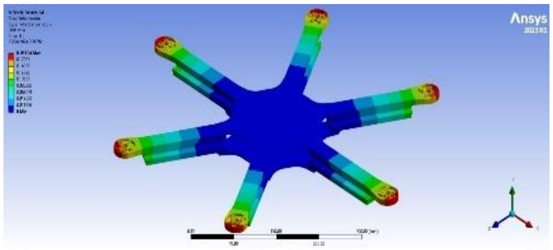

Fig. 15 Deformation of Drone with I section PLA-CF

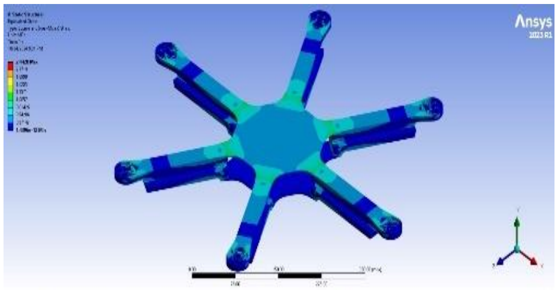

Fig. 16 Stress of Drone with I section PLA-CF

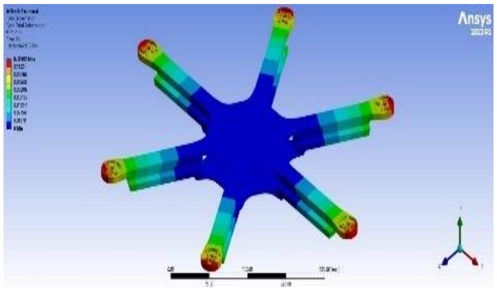

Fig. 17 Deformation of Drone with I section CFRP

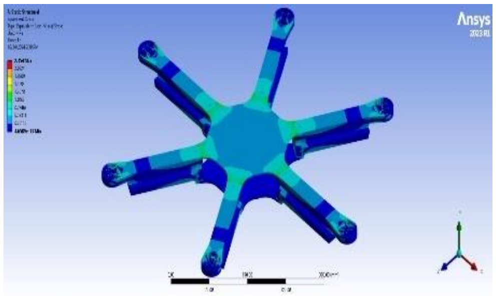

Fig. 18 Stress of Drone with I section CFRP

For PLA-CF material 17N applied on each arm, a total deformation of 0.19mm and 2.44 Mpa was generated; for CFRP material, 16.7 N, 0.12 mm deformation, 2.35 Mpa generated as shown in Figures 15,16,17 and 18. In the same way, simulations were done for hollow square sections with PLA-CF and CFRP material. 17.8N, 17.4 N applied, 0.16mm and 0.10mm deformation, stress generated 2.47Mpa and 2.38 Mpa for PLA-CF and CFRP material.

4.3. Results and Discussions on Topology Optimization for I Section and Hollow Square Cross-Sections

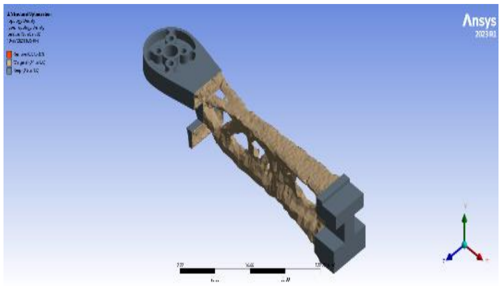

Fig. 19 Topology Optimization Result Isometric View for PLA-CF

Fig. 20 Topology Optimization Result Isometric View for CFRP

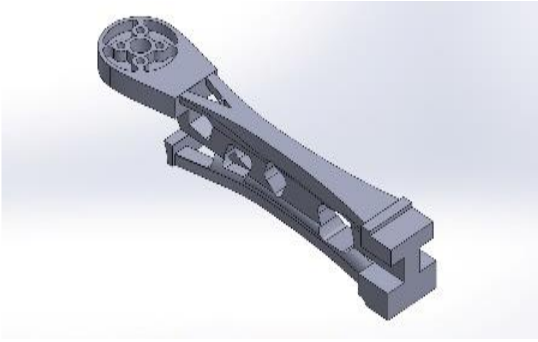

Fig. 21 Topology Optimization Result Isometric View for PLA-CF after smoothing in Space Clalim Tool

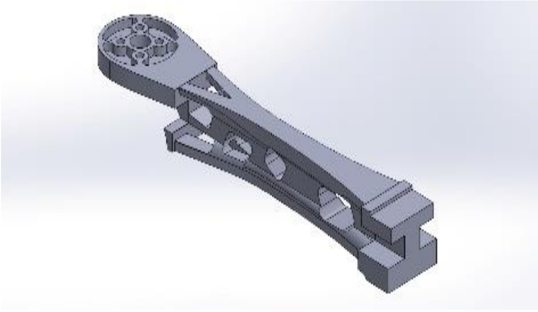

Fig. 22 Topology Optimization Result Isometric View for CFRP after smoothing in Space Clalim Tool

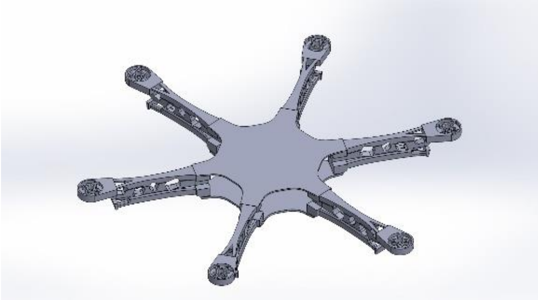

Fig. 23 Optimized I-Sectional Armed Drone

The optimized procedure was discussed in previous section 2. For the I section, PLA-CF and CFRP materials are used to optimize topologically. Simulation is done with only one arm, and after 34 iterations, topological optimization results are shown in Figures 19, 20,21, and 22. Figure 24 shows a hollow square section armed drone.

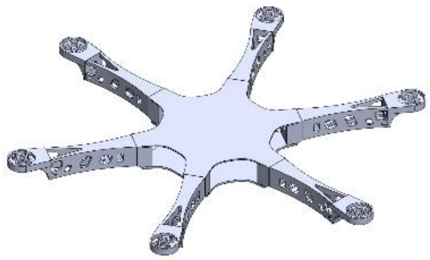

Fig. 24 Optimized Hollow Square Sectional Armed Drone

4.4. Validation of redesigned model through FE analysis

The model has been updated in modelling, and static structural analysis results are shown in Table 3 and Figures 25,26 and 27. Figures indicate that total deformation, stress maximum and mass are reduced due to optimization**.**

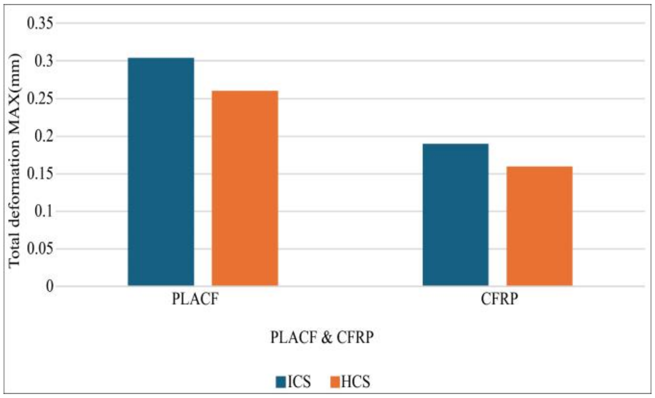

Fig. 25 Total deformation (ICS means I-Cross section& HCS means Hollow Square Cross section)

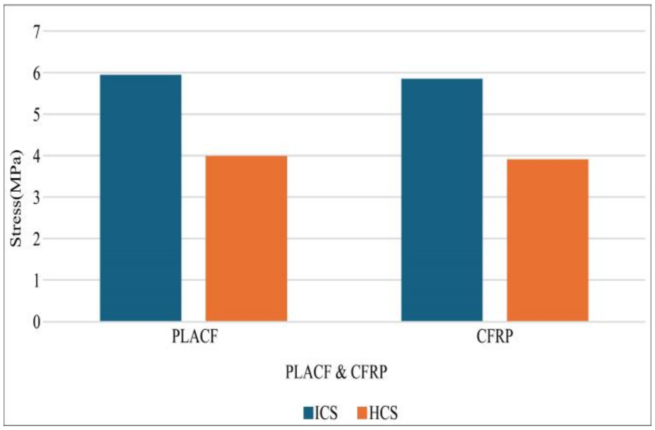

Fig. 26 Max stress (ICS means I-Cross section& HCS means Hollow Square Cross section)

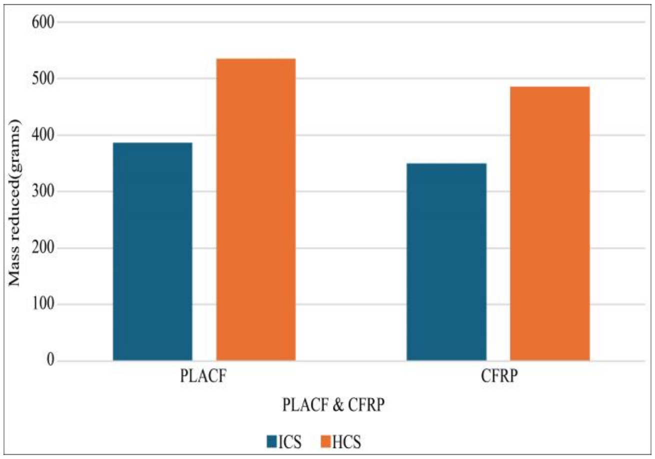

Fig. 27 Mass reduced due to optimization (ICS means I-Cross section& HCS means Hollow Square Cross section)

Table 3. Static structural analysis results after optimization.

Parameter	**Values**
Setup-1	Static Structural(I-C/S PLA-CF)
Boundary Condition (BC)	Fix@ A, load applied @ B,C,D,E F,G
Force Applied	15.8N (i.e. thrust per motor)
Total Deformation (Max)	0.304 mm
Total Deformation (Min)	~ 0 - 0.033 mm
Equivalent Stress (Max)	5.95MPa
Equivalent Stress (Min)	6.20e-12 MPa
Mass of the Frame before optimization	1108.44grm
Mass of the Frame after optimization	721.91grm
Mass reduced due to Optimization	386.53grm
Parameter	Values
Setup-2	Static Structural(I-C/S CFRP)
Boundary Condition (BC)	Fix@ A, load applied @ B,C,D,E F,G
Force Applied	15.6N(i.e. Thrust per motor)
Total Deformation (Max)	0.19 mm
Total Deformation (Min)	~ 0 - 0.022 mm
Equivalent Stress (Max)	5.87MPa
Equivalent Stress (Min)	5.79e-12 MPa
Mass of the Frame before optimization	1005.33grm
Mass of the Frame after optimization	654.75grm
Mass reduced due to Optimization	350.58grm
Parameter	Values
Setup-3	Static Structural(HS-C/S PLA-CF)
Boundary Condition (BC)	Fix@ A, load applied @ B,C,D,E F,G
Force Applied	16N(i.e. Thrust per motor)
Total Deformation (Max)	0.26 mm
Total Deformation (Min)	~ 0 - 0.028 mm
Equivalent Stress (Max)	3.99MPa
Equivalent Stress (Min)	1.48e-12 MPa
Mass of the Frame before optimization	1329.74grm/1323.98
Mass of the Frame after optimization	794.2grm
Mass reduced due to Optimization	535.54grm
Parameter	Values
Setup-4	Static Structural(HS-C/S CFRP)
Boundary Condition (BC)	Fix@ A, load applied @ B,C,D,E F,G
Force Applied	15.8N(i.e. Thrust per motor)
Total Deformation (Max)	0.16 mm
Total Deformation (Min)	~ 0 – 0.01 mm
Equivalent Stress (Max)	3.91MPa
Equivalent Stress (Min)	6.79e-13 MPa
Mass of the Frame before optimization	1206.5grm
Mass of the Frame after optimization	720.32grm
Mass reduced due to Optimization	486.18grm

4.4.1. Decision making through Weighted Decision Matrix

A Weighted Decision Matrix is a tool used to help make decisions when there are multiple options and various criteria to consider. The process involves as follows:

- Identify Criteria: The first step involves determining the factors that are important for making the decision, such as mass reduction, total deformation, and other relevant metrics.
- Assign Weights: Next, each criterion is assigned a weight based on its importance. For example, if mass reduction is considered more critical, it may receive a higher weight than other factors, as shown in Table 4.
- Score Options: Each option is then rated against each criterion, typically on a defined scale (such as 1 to 5 or 1 to 10).
- Calculate Weighted Scores: The scores are multiplied by the respective weights for each criterion, and the results are summed up for each option to determine their total weighted scores, as shown in Table 5.
- Compare Results: Finally, the total scores are compared to identify which option has the highest score, thus enabling a more informed decision-making process.

Criteria and Weights

- Mass Reduction - Important for adding other extra load or for longer flight time.
- Total Deformation - Indicates structural rigidity.
- Equivalent Stress - Ensures the frame can handle loads without risk of failure.

Weights are based on the goal of balancing flight time with structural integrity:(The total weight is up to 100% (or 1 for decimal form).

Mass Reduction: 0.4 (40%)
Total Deformation: 0.4 (40%)
Equivalent Stress: 0.2 (20%)
i.e. Total weight 0.4+0.4+0.2 = 1 (or 100%)
Rating Each Setup for Each Criterion
Rating 1-10 scale, where 10 is the best

Table 4. Assign Weights on topological optimization

Criterion	Setup-1	Setup-2	Setup-3	Setup-4
Mass Reduction	8	7	10	9
Total Deformation	7	9	8	10
Equivalent Stress	7	8	9	10

Based on this Weighted Decision Matrix, Setup-4 is the best choice, as it provides the best balance between flight time (mass reduction) and structural rigidity (low deformation and stress). Now checking for Load-Bearing Capacity for the Hollow Square – Cross-Sectional armed Drone with CFRP.

Table 5. Calculated Weighted Scores for topological optimization

Setup	Mass Reduction	Total Deformation	Equivalent Stress	Total Score
Setup-1	8*0.4=3.2	7*0.4=2.8	7*0.2=1.4	7.4
Setup-2	7*0.4=2.8	9*0.4=3.6	8*0.2=1.6	8
Setup-3	10*0.4=4	8*0.4=3.2	9*0.2=1.8	9
Setup-4	9*0.4=3.6	10*0.4=4	10*0.2=2	9.6

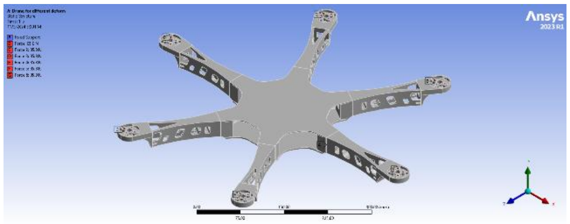

Fig. 28 Boundary Condition on Hollow Square –Cross-Sectional Armed Drone with CFRP(nylon6/6)

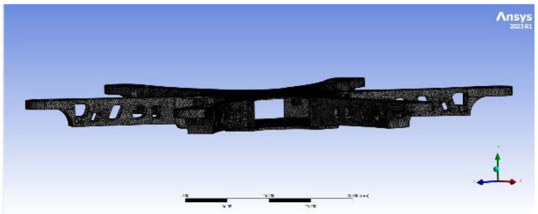

Fig. 29 Meshing of Hollow Square – Cross-Sectional Armed Drone with CFRP

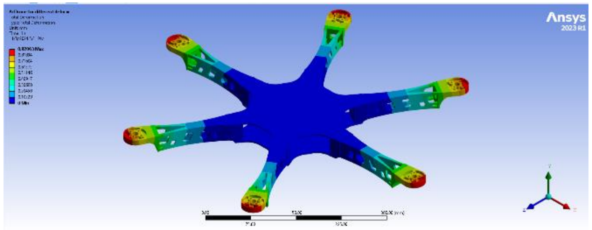

Fig. 30 Deformation For Hollow Square – Cross Sectional Armed Drone with CFRP(nylon6/6)

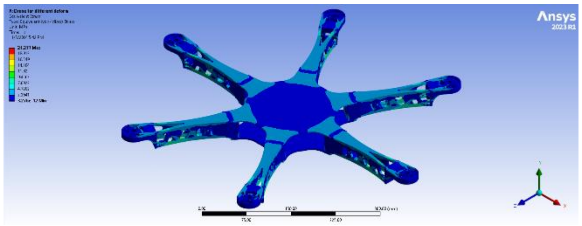

Fig. 31 Stress For Hollow Square - Cross Sectional Armed Drone with CFRP(nylon6/6)

Table 6. Static structural analysis results for load bearing capacity

Parameter	Values
Setup-4	Static Structural(HS-C/S CFRP)
Boundary Condition (BC)	Fix@ A, load applied @ B,C,D,E F,G
Force Applied	85.8N
Total Deformation (Max)	0.92 mm
Total Deformation (Min)	~ 0 – 0.01 mm
Equivalent Stress (Max)	21.27MPa
Equivalent Stress (Min)	3.27e-12 MPa

5. Conclusion

Simulations were done on the hexacopter drone for static structure analysis using ANSYS. In the initial stage, we took taken drone from the literature and analyzed it for deformation and stress analysis. Based on the results, we proposed I- a cross-section and hollow square cross-section. Simulations are done for two different materials PLA-CF and CFRP material. Deformation 0.07 mm for PLA-CF and 0.041 mm for CFRP, so the bending strength and deformation (less than 1 mm) of the proposed Hollow Square-sectional arm are within safe limits, so it can safely support the applied payload. For PLA-CF material 17N applied on each arm, a total deformation of 0.19mm and 2.44 Mpa was generated; for CFRP material 16.7 N, 0.12 mm deformation, 2.35 Mpa was generated as shown in Figures 15,16,17 and 18. In the same way, simulations were done for the hollow square section with PLA-CF and CFRP material. 17.8N, 17.4 N applied, 0.16mm and 0.10mm deformation, stress generated 2.47Mpa and 2.38 Mpa for PLA-CF and CFRP material. A Weighted Decision Matrix is a tool used to help make decisions. Based on this Weighted Decision Matrix, Setup-4 is the best choice, as it provides the best balance between flight time (mass reduction) and structural rigidity (low deformation and stress). Finally checked for Load-Bearing Capacity for the Hollow Square – Cross Sectional armed Drone with CFRP. The results show that it can withstand a maximum load of 85.8N, with Equivalent Stress (Max) and deformation of 0.92 mm, which is within the safe limits. This paper analyzed the assumption of linear analysis. The behaviour of drones in the presence of air conditions needs to be investigated. This investigation results will help in real world scenarios.

References

[1] Sagar Nvss et al., "Design and Development of Unibody Quadcopter Structure Using Optimization and Additive Manufacturing Techniques," *Designs*, vol. 6, no. 1, pp. 1-25, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[2] Sagar Shelare et al., "A Payload Based Detail Study on Design and Simulation of Hexa-Copter Drone," *International Journal on Interactive Design and Manufacturing*, vol. 18, pp. 2675-2692, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[3] Remote Controlled Air Vehicle Based Sanitizing System with Payload Carrier, Wipo, 2021. [Online]. Available: https://patentscope.wipo.int/search/en/detail.jsf?docId=IN335044887&_cid=P21-LCSPDH-44778-1

[4] C. Huang Shen et al., "Theoretical Development and Study of Takeoff Constraint Thrust Equation for A Drone," *2017 IEEE 15th Student Conference on Research and Development (SCOReD)*, Wilayah Persekutuan, Putrajaya, Malaysia, pp. 18-22, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[5] J. Verbeke et al., "The Design and Construction of a High Endurance Hexa-Copter Suited for Narrow Corridors," *2014 International Conference on Unmanned Aircraft Systems (ICUAS)*, Orlando, FL, USA, pp. 543-551, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[6] Jozef Novotňák et al., "Quadcopter Modeling Using a System for UAV Parameters Measurement," *Drones*, vol. 8, no. 7, pp. 1-18, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[7] Yongjie Zhang et al., "A Simplified FE Modelling Strategy for the Drop Process Simulation Analysis of Light and Small Drone," *Aerospace*, vol. 8, no. 12, pp. 1-33, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[8] Endrowednes Kuantama, Dan Craciun, and Radu Tarca, "Quadcopter Body Frame Model and Analysis," *Annals Of The University of Oradea Fascicle of Management and Technological Engineering*, vol. 25, no. 1, pp. 71-74, 2016. [Google Scholar] [Publisher Link]

[9] W. Grodzki, and A. Łukaszewicz, "Design and Manufacture of Unmanned Aerial Vehicles (UAV) Wing Structure Using Composite Materials," *Meterials Science and Engineering Technology*, vol. 46, no. 3, pp. 269-278, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[10] Vishank Bhatia et al., "Design Optimisation and Analysis of a Quadrotor Arm Using Finite Element Method," *Applied Mechanics and Materials*, vol. 664, pp. 371-375, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[11] Syahril Amir Mohd, Kok Beng Gan, and Ahmad Kamal Ariffin Mohd Ihsan, "Development of Medical Drone for Blood Product Delivery: A Technical Assessment," *International Journal of Online & Biomedical Engineering*, vol. 17, no. 9, pp. 1-14, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[12] M. Elsamanty et al., "Methodology for Identifying Quadrotor Parameters, Attitude Estimation and Control," *2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, Wollongong, NSW, Australia, pp. 1343-1348, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[13] Osman Öztürk, “Parametric Optimization of Structural Frame Design for High Payload Hexacopter,” *Black Sea Journal of Engineering and Science*, vol. 7, no. 5, pp. 854-865, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[14] M. Hassanalian, and A. Abdelkef, “Classifications, Applications, and Design Challenges of Drones: A Review,” *Progress in Aerospace Sciences*, vol. 91, pp. 99-131, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[15] Anouar El Magri et al., “Mechanical Properties of CF-Reinforced PLA Parts Manufactured by Fused Deposition Modeling,” *Journal of Thermoplastic Composite Materials*, vol. 34, no. 5, pp. 581-595, 2021. [CrossRef] [Google Scholar] [Publisher Link]