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Topology Optimization and Structural Analysis of an Octocopter Drone Frame Designed in SolidWorks

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ABSTRACT

Unmanned aerial vehicles (UAVs), particularly multirotor drones, face critical design challenges in balancing weight reduction and structural integrity to enhance flight performance and payload capacity. This study focuses on optimizing the frame of a flat octocopter using topology optimization (TO) techniques to achieve a lightweight yet robust design. Polylactic acid (PLA), a cost-effective and eco-friendly 3D-printing material, was selected for its suitability in prototyping. The methodology involved creating a 3D CAD model in SolidWorks, applying finite element analysis (FEA) to simulate operational stresses, and employing the solid isotropic material with penalization (SIMP) method for topology optimization. Critical components, including arms, covers, and brackets, were iteratively redesigned by removing non-critical material while preserving structural strength. The optimized design reduced the total frame mass by 31.99%, from 1595.90 g to 1086.60 g, while maintaining stress levels and deformation well within PLA's allowable limits. Post-optimization FEA validated the structural integrity under thrust, payload, and boundary conditions, confirming the design's reliability for real-world applications. The results demonstrate that topology optimization is an effective tool for UAV design development by improving flight efficiency through weight reduction.

1. Introduction

Unmanned aerial vehicles (UAVs), or drones, have rapidly expanded in use over the past decade and continue to transform various industries [1]. Their versatility, affordability, and ease of operation enable applications across surveillance [2], combat [3], search and rescue [4], remote sensing [5], delivery [6], and precision agriculture [7]. However, drone weight comprising all components and payload remains a major constraint, directly affecting flight endurance, maneuverability, payload capacity, and regulatory compliance [12].

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Drones are generally classified as fixed-wing, rotary-wing, or hybrid types. This study focuses on rotary-wing systems, specifically multirotor UAVs, including quadcopters, hexacopters, and octocopters. The number of rotors influences stability, payload capability, and flight duration. Quadcopters are lightweight, agile, and cost-effective for imaging and monitoring, while hexacopters and octocopters provide enhanced stability and lifting capacity for mapping, inspection, and heavy-lift missions [8].

Designing any structure requires balancing weight and strength, as reducing weight often compromises structural integrity. Topology optimization enables engineers to achieve minimal weight while maintaining sufficient strength to withstand applied loads [9]. This process relies heavily on finite element analysis (FEA), which provides essential input data to identify and eliminate ineffective material areas [10]. Topology optimization determines the most efficient material distribution within a design, improving performance and reducing weight. It is widely used in both new product development and optimizing existing designs, particularly in aerospace, where mass reduction is critical [11]. Unlike shape optimization, which optimizes pre-defined geometries, topology optimization produces unique, organic structures based on performance criteria.

Asif *et al*., [13] performed topology optimization SolidWorks software on the UAV frame, resulting in a 91% reduction in mass (from 1558.44 grams to 134.74 grams) by eliminating unnecessary elements, all while maintaining its structural integrity. Martinez Leon et al. [12] improved quadcopter frame design using epoxy resin thermoset polymeric matrix reinforced with pre-impregnated aramid fibres, by weight reduction 80% compared to the initial solid cube while maintaining a safety factor of 53, optimizing balance and strength through SolidWorks software. Bay and Eryıldız [14] utilized ABS (acrylonitrile butadiene styrene) to construct the quadcopter frame, optimizing structural integrity through SolidWorks simulations and successfully reducing mass by 30%. Ali *et al*., [15] developed an H-shaped quadcopter using Polylactic Acid (PLA), optimizing it for reduced weight and improved control at high altitudes after achieving a 50% mass reduction. This research aims to enhance the structural design of an octocopter using topology optimization through SolidWorks simulation. The study focuses on optimizing key parameters mechanical strength, weight, and structural integrity to develop a lightweight yet durable frame.

2. Materials and Methods

This work uses topology optimization to reduce drone structural component weight while retaining mechanical strength. A 3D CAD model of the drone frame was developed using SolidWorks software, and material properties typical of lightweight aerospace applications, such as polylactic acid (PLA) was assigned. Realistic loading conditions, including payload forces, motor thrust, and fixed support constraints, were applied to simulate operational stresses. The topology optimization was conducted using the SIMP method within SolidWorks simulation software post-processing involved refining the optimized geometry and reanalysing the design for structural performance, ensuring that the final model achieved significant weight reduction without compromising functional integrity.

2.1 Frame Design

This study employs a flat octocopter frame, chosen over quadcopters and hexacopters for its superior safety, payload capacity, and stability, making it ideal for professional and industrial missions. The flat configuration, featuring eight rotors symmetrically spaced 45° apart around the center of gravity, ensures balanced thrust distribution and enhanced aerodynamic performance [16]. The drone frame is composed of several key components, as shown in Fig. 1, including the drone arm, bottom cover, middle and top cover, and leg bracket. These parts serve as the mounting points for the drone's electronic components.

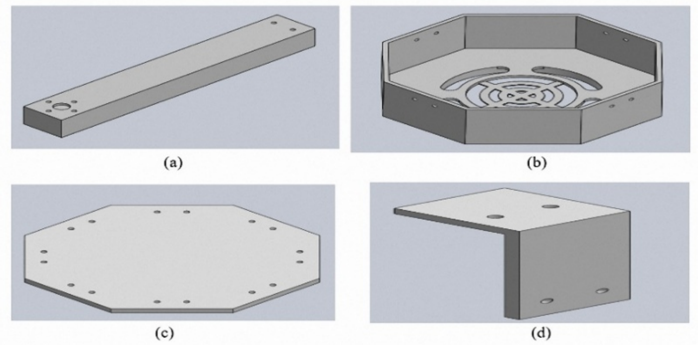


Fig. 1. Drone parts before optimization: (a) drone arm, (b) bottom cover, (c) middle and top cover, (d) leg bracket

This study designs a lightweight octocopter frame using polylactic acid (PLA), chosen for its low cost, ease of 3D printing, and biodegradability. PLA offers sufficient rigidity for small to medium drones and supports sustainable, eco-friendly manufacturing from renewable resources [17].

2.2 Finite Elements Analysis

Finite element analysis (FEA) is essential in UAV design, enabling engineers to simulate and evaluate structural behavior under various loading conditions. It helps identify stress concentrations, deformations, and potential weak points, ensuring compliance with safety and performance standards [18]. Performing FEA prior to topology optimization validates the prototype and identifies optimization targets [19]. In this study, FEA was performed using SolidWorks simulation to accurately assess the structural integrity of an eight-blade helicopter. This process provides reliable data for material redistribution and design optimization, enabling a lightweight and robust structure that enhances performance, reduces material usage, and improves overall flight efficiency.

Table 1 Drone's parts

Part name	Number of the parts	Initial weight of the part (g)
Drone arm	8	154.35
Bottom cover	1	163.64
Middle cover	1	67.25
Top cover	1	67.25
Leg bracket	4	14.23
Total weight		1595.90

Table 2 The properties of PLA [20].

Property	Value
Yield strength (MPa)	49.5
Mass density (g/cm^3)	1.3
Ultimate strength (MPa)	50
Poisson ratio	0.39
Youngs modulus (GPa)	3.5

2.3 Thrust Force

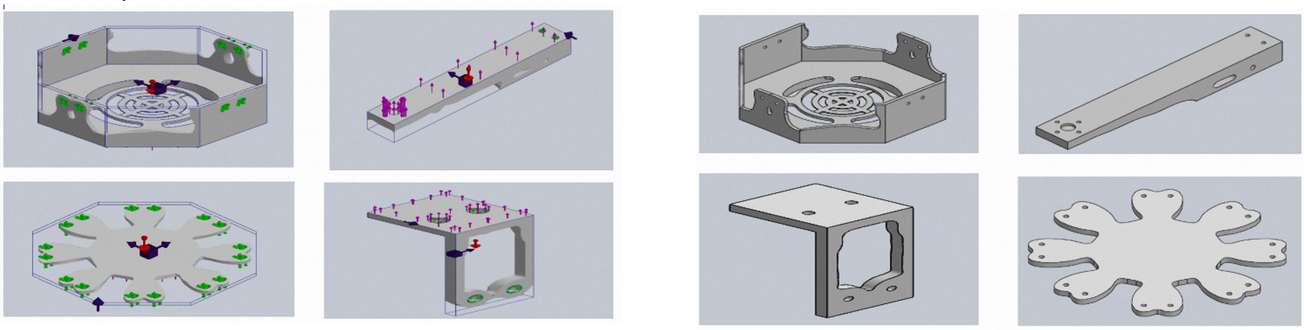
In an octocopter, motors generate thrust the upward force enabling lift and maneuverability. Each motor produces a specific amount of thrust depending on load distribution [20]. The thrust generated is expressed as Eq. (1).

$$Thrust\ per\ motor = \frac{Total\ weight}{Number\ of\ motors} \times 2 \qquad (1)$$

In this study, a thrust-to-weight ratio of 2:1 is applied, meaning the total thrust is twice the drone's weight. This ratio ensures stable hovering while using only half of the available battery power [21]. The additional power reserve enhances maneuverability and payload capacity. Based on this ratio, with a total drone weight of 2518 g (including all components), the required thrust per motor is 629.5 g, equivalent to approximately 6 N, ensuring balanced lift and efficient performance during operation.

2.4 Topology Optimization

This process removes excess material while maintaining sufficient strength to withstand operational loads, thereby enhancing structural efficiency and improving the thrust-to-weight ratio. In this study, SolidWorks topology optimization was used to refine the octocopter frame by preserving critical structural regions and removing material from low-stress areas. The resulting design maintains structural integrity while significantly reducing weight, improving flight stability and efficiency.



(a) (b)

Fig. 2. Drone parts (a) after topology optimization, (b) after optimized geometry

3. Results and Discussion

The topology optimization results for the drone frame were thoroughly analyzed through iterative structural evaluation and design refinement. For PLA material, the maximum allowable stress is 49.5 MPa [20], and the acceptable deformation limit is 4.7 mm [22]. As shown in Table 3, the optimized frame achieved a 31.99% mass reduction compared to the original design, minimizing material usage while maintaining structural integrity and overall functionality.

Table 3
Comparison between the mass of the original frame and the final optimized frame

Property	Original frame	Optimized frame
Mass (g)	1595.90 g	1086.60 g
Percentage of reduction (%)	31.99 %	

FEA was performed to validate the optimized frame reliability and safety under realistic loading conditions. Static structural analysis, conducted using the same loads and constraints as the initial design, confirmed that stress levels remained within allowable limits, ensuring the optimized frame can safely withstand operational forces.

3.1 Validation through Static Structural Finite Element Analysis

Table 4 presents the simulation results for key drone frame components, including the bottom cover, leg bracket, top and middle covers, and arms. These parts were analyzed to evaluate structural performance under operational conditions, ensuring rigidity and stability. The results confirm that the frame remains structurally sound, capable of withstanding maximum lift forces and payload stresses. Setup validation verified that stress and displacement values for all components were within acceptable engineering limits. Since no excessive deformation or material yielding occurred, the optimized frame is deemed robust and reliable for all flight phases, including take-off, hovering, and landing.

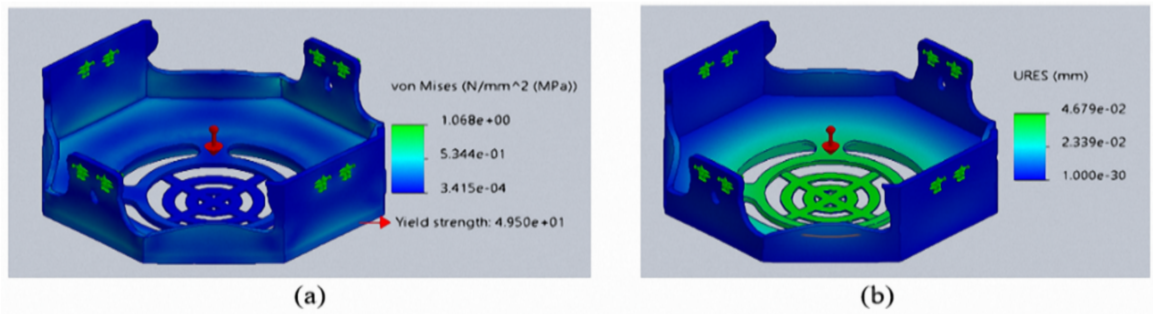


Fig. 3. FEA results of the bottom cove, (a) Von Mises stress and (b) deformation

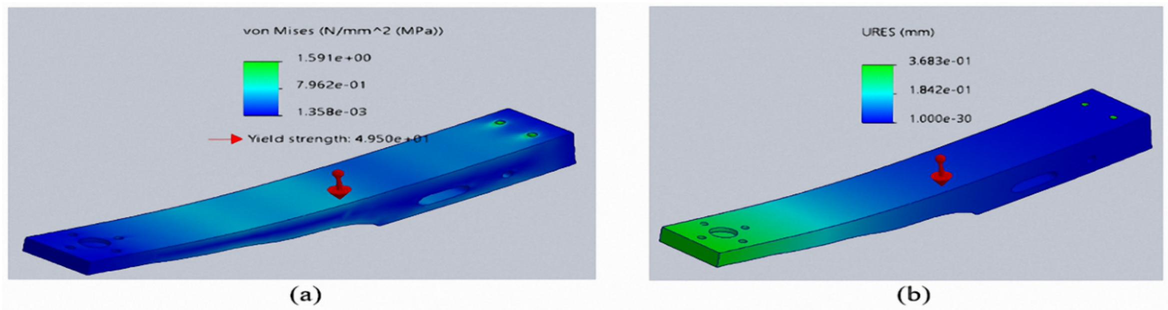


Fig. 4. FEA results of the drone arm, (a) Von Mises stress and (b) deformation

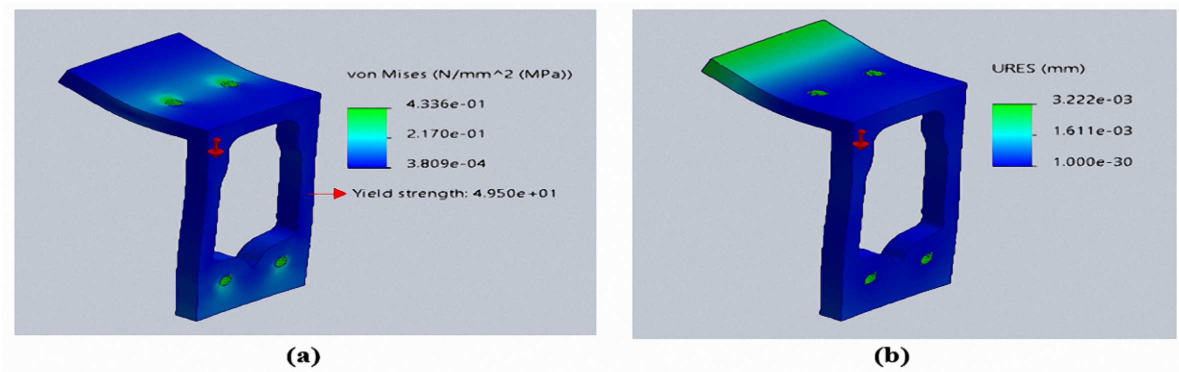


Fig. 5. FEA results of the leg bracket, (a) Von Mises stress and (b) deformation

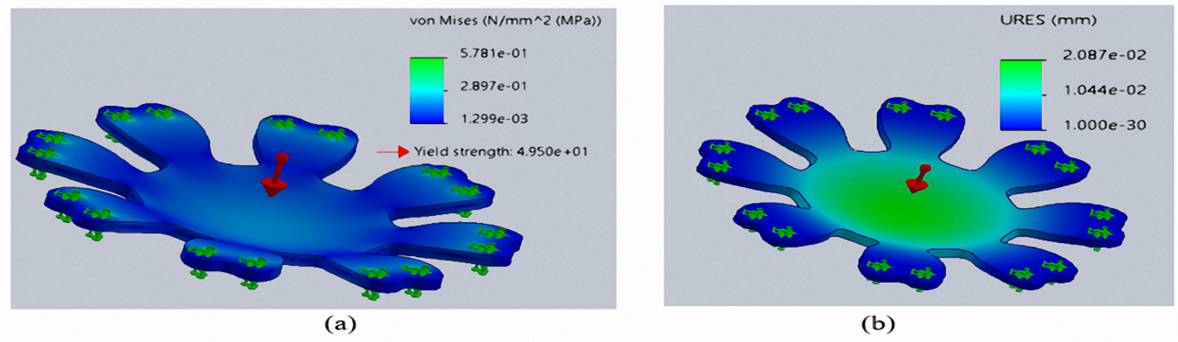


Fig. 6. FEA results of the middle and top cover, (a) Von Mises stress and (b) deformation

Figures 3 to 6 present the finite element analysis (FEA) results for the optimized components of the drone frame, including the bottom cover, arm, leg bracket, and the middle and top covers. As shown in Fig. 3(a), the optimized bottom cover exhibits a maximum stress of 1.068 MPa and a minimum of 3.415×10^{-4} MPa, both well below the allowable tensile stress limit for PLA (49.5 MPa), confirming safe operation under applied loads. The corresponding deformation, illustrated in Fig. 3(b), reaches only 0.04679 mm, far under the permissible limit of 4.7 mm, indicating excellent dimensional stability and effective load distribution. The optimized arm (Fig. 4) records a maximum stress of 1.591 MPa and a minimum of 1.358×10^{-3} MPa, with deformation limited to 0.3683 mm well within safety margins demonstrating high structural stiffness and minimal distortion. The leg bracket (Fig. 5) also performs effectively, showing a peak stress of 0.4336 MPa and a displacement of 0.003222 mm, both significantly below PLA limits, which ensures durability and resistance to mechanical fatigue. Lastly, the middle and top covers (Fig. 6) reveal a maximum stress of 0.578 MPa, a minimum of 1.299×10^{-3} MPa, and a maximum deformation of just 0.02087 mm, confirming uniform stress distribution and robust mechanical stability. The FEA results demonstrate that all optimized components remain well within allowable stress and deformation limits, ensuring safety, structural integrity, and long-term reliability. The low stress concentrations and minimal displacements across all parts indicate efficient load transfer and material utilization, validating the effectiveness of the topology optimization process in achieving a lightweight yet structurally sound drone frame suitable for demanding operational conditions.

Table 4
Validation results for the drone parts

Property	Allowable range	Bottom cover	Drone arm	Leg bracket	Middle and top cover
Maximum stress (MPa)	49.5	1.07	1.59	4.34×10^{-1}	5.78×10^{-1}
Maximum deformation (mm)	4.7	4.68×10^{-2}	3.68×10^{-1}	3.22×10^{-3}	2.09×10^{-2}

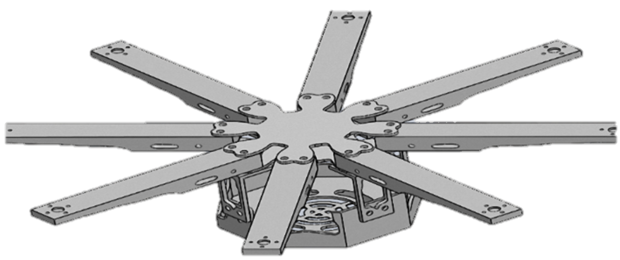


Fig. 7. Final optimized octocopter airframe model

4. Conclusion

This study successfully demonstrated the application of topology optimization (TO) using the SIMP method in SolidWorks to achieve a lightweight yet structurally robust octocopter drone frame. The optimized design reduced the total frame mass by 31.99% (from 1595.90 g to 1086.60 g) while preserving critical structural performance. Key outcomes include:

(a) Weight Reduction: Non-critical material was systematically removed from arms, covers, and brackets, significantly enhancing the thrust-to-weight ratio without compromising functionality.
(b) Structural Integrity: Post-optimization FEA validation confirmed that stress and deformation across all components remained well below PLA's allowable limits (49.5 MPa stress, 4.7 mm deformation).
(c) Material Efficiency: PLA proved highly suitable for prototyping, balancing cost-effectiveness, eco-friendliness, and adequate mechanical properties for drone applications.
(d) Methodology Validation: The integrated workflow combining CAD modelling, FEA simulation, and TO effectively optimized material distribution, yielding an organic yet functional geometry ready for 3D printing.

These results underscore topology optimization as a vital tool for advancing UAV design, enabling extended flight endurance, higher payload capacity, and improved energy efficiency. Future work should explore experimental validation of the optimized frame, multi material TO for hybrid composites, and dynamic load analysis under real-world flight conditions.

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