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Design and fabrication of an optimized drone chassis through generative design and additive manufacturing

Bandari Harshavardhan Yadav [a], ***P. Seema Rani*** [b]

a M. Tech Scholar, Department of Mechanical Engineering, J.B. Institute of Engineering and Technology, Moinabad, Hyderabad-75, Telangana, India.
b Assistant Professor, Department of Mechanical Engineering, J.B. Institute of Engineering and Technology, Moinabad, Hyderabad-75, Telangana, India.

A B S T R A C T :

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, are increasingly being used across various fields such as defence, agriculture, surveillance, and logistics due to their versatility and efficiency. The structural design of the drone chassis plays a crucial role in determining the drone's performance, flight time, and payload capacity. A well-optimized chassis must ensure adequate mechanical strength while minimizing weight. The aim of this project is to design, simulate, and fabricate a drone chassis frame using generative design techniques and to compare its performance against a conventionally designed frame, with a focus on weight reduction, structural efficiency, and manufacturability using Fused Deposition Modeling (FDM). In this study, two drone frame models—conventional and generative—were designed using Autodesk Fusion 360 and analyzed under identical loading and boundary conditions. EPX 150, a carbon-reinforced thermoplastic, was selected for its high strength-to-weight ratio and compatibility with 3D printing. Finite Element Analysis (FEA) was performed to evaluate key mechanical parameters including stress distribution, factor of safety, displacement, and reaction forces. The generative design achieved a significant 77% reduction in weight (446.104 g vs. 1951.265 g) while maintaining a high factor of safety (FoS = 15). Although it showed slightly higher displacement and stress, these remained within safe limits. Both models were successfully manufactured using FDM, confirming the practicality of complex generative geometries in real-world applications. This study demonstrates that integrating generative design with additive manufacturing can lead to lightweight, efficient, and structurally reliable drone components, making it a suitable approach for advanced UAV systems.

Keywords: Drone Frame, Generative Design, UAV, Fused Deposition Modeling (FDM), Additive Manufacturing, EPX 150, Finite Element Analysis (FEA), Structural Optimization, Lightweight Design, 3D Printing.

1. Introduction

The development of unmanned aerial vehicles (UAVs), also known as drones, has been one of the most important technological advances in recent times. Drones were first designed for military purposes, especially for surveillance and tactical missions without the need for a human pilot. Over time, they have become highly useful machines in many other fields such as agriculture, industry, medicine, research, and even entertainment. Improvements in electronic parts, batteries, and wireless communication have helped drones grow from specialized military tools into everyday devices for various civil and commercial uses. As the number of drone applications increases, so does the demand for better performance, longer flying time, higher payload capacity, and stronger yet lighter structures. These needs have put pressure on the way drones are built, making structural optimization an essential part of modern drone design.

In the beginning, drone structures were quite simple. Makers used easily available materials like wood, aluminum, and plastic. These early drones mainly focused on getting the job done rather than flying efficiently. But as drone applications expanded into areas like precision farming, disaster management, and aerial filming, they had to fly longer, carry more weight, and remain stable under different conditions. This led engineers to carefully study the structure of drones and look for better ways to design them. They realized that any extra weight made the drone consume more power, reduced its flight time, and made it harder to control. Therefore, designers began looking for ways to make drones lighter while keeping them strong.

At the same time, advances in material science helped improve drone construction. Common metals like steel and traditional aluminum were strong, but they were too heavy for drones that needed to stay in the air for longer periods. This encouraged the use of lightweight and strong materials like carbon fiber-reinforced polymers (CFRP), fiberglass, advanced plastics, and light aluminum alloys. These materials had excellent strength-to-weight ratios and could handle mechanical stress while keeping the drone lightweight. With the help of these materials, engineers could now design stronger frames without adding too much weight. However, using good materials alone was not enough. They needed to be used wisely and in the right amount. This led to the idea of structural optimization.

In drone design, optimization means improving the shape, layout, and material use of the structure to get the best performance. Traditional methods often depended on fixed shapes and experience, but optimization uses mathematics and computer models to test and find better designs. The goal is to make the structure lighter or stiffer while still meeting the required strength, safety, and manufacturing conditions. As drones are increasingly used in challenging situations like high winds, tight spaces, and rough landings, their structural design becomes even more critical. The basic science of flight also supports this idea. A drone's motors must lift the entire weight of the vehicle. The heavier it is, the more power it needs, which reduces flight time. In missions like delivering packages or monitoring large areas, even a small amount of extra weight can make a big difference. So, optimization helps reduce unnecessary weight and ensures the frame handles only the necessary loads.

The use of modern computer tools has made optimization easier and more accurate. Finite Element Analysis (FEA) is one such tool. It lets engineers test how a drone frame behaves under forces like motor thrust, vibration, or heat. Topology optimization goes a step further by suggesting where material can be removed without affecting strength. Another modern method, called generative design, uses artificial intelligence to create thousands of design options based on the designer's input like material type, loading conditions, and size limits. These tools help engineers quickly test many designs and pick the best one. They also make it possible to create new, complex structures that were hard or impossible to make using traditional methods.

A drone frame is not just an empty shell—it must support parts like motors, batteries, cameras, and sensors. The location of these parts affects how the drone flies and how balanced it is. An optimized design carefully considers where each component is placed to keep the drone stable and easy to control. It also allows room for easy maintenance and wiring. Moreover, the design should match the manufacturing process. Thanks to 3D printing (additive manufacturing), even the most complex designs created through optimization can now be built easily and accurately. 3D printing also helps reduce waste, making the process more sustainable and cost-effective. Many studies and real-world examples show that optimization really works. Research has shown that drone frames can be made 30–40% lighter through topology optimization without losing strength. Today, many drone companies are using generative design to make strong, lightweight, and even beautiful frames. Engineering colleges and research institutions also use optimization to teach and study how structure, material, and performance interact in UAVs. All these examples prove that structural optimization is not just an academic concept but a practical tool for better drone design.

Figure 1.1: Drone

Optimization also plays an important role in sustainability. By using fewer materials and reducing power needs, optimized drone designs help save resources and energy. This fits well with the global trend of environmentally friendly and sustainable engineering practices. As drone usage continues to grow around the world, building them in a sustainable and responsible way becomes more important. Optimization helps achieve this by reducing material waste during manufacturing and cutting down energy use during operation. Looking ahead, the future of drones includes greater autonomy, longer flying range, and more complex tasks. As they become part of systems like smart cities, fast delivery services, and remote monitoring networks, they will need to meet higher structural and performance standards. In such a future, there will be no place for bulky, outdated, or inefficient structures. Optimization will play a key role in ensuring that drones are ready for new roles and challenges. Engineers must continue to develop skills in aerodynamics, mechanical design, and advanced optimization tools to stay ahead.

2. Literature Review

1. Bright et al. (2021) – Optimization of Quadcopter Frame Using Generative Design. This study uses Autodesk Fusion 360's generative design engine to create a DJI F450-compatible frame and validate it through FEA and modal analysis. The PLA FDM-printed prototype demonstrated reduced displacement and improved fracture resistance compared to the stock model. Their results highlight the practical advantages of AI-designed geometries in UAV frames. The study confirms generative design's effectiveness in enhancing structural stiffness and vibration resistance. It serves as a practical roadmap for integrating AI-driven design with additive manufacturing in drone development. The paper showcases how even minor geometric refinements yield significant mechanical improvements.
2. Le Van Thao & Mai Dinh Si (2024) – Topology and Lattice Optimization for Drone Arms. This work applies topology and lattice optimization in HyperWorks to DJI F450 arms, reducing weight by 21.9% and improving rigidity. The parts are designed specifically for PLA FDM printing, considering overhangs and layer alignment. FEA confirms enhanced stiffness and structural safety. Post-print prototypes show real-world manufacturability and strength. This study proves that combining DfAM and optimization delivers lightweight yet durable UAV components. It enables weight-efficient design without compromising integrity.
3. Asif, Hasan & Dhar (2024) – Topology Optimization and 3D Printing of a Unibody Quadcopter Airframe. Using SolidWorks, the authors reduced frame weight from 1558 g to 135 g—a 91% decrease—while ensuring structural safety through FEA. A fatigue analysis predicts 160,000 load cycles, and CFD indicates reduced aerodynamic drag. Components were printed in PLA on an FDM system with optimized orientation. The workflow combines structural, fatigue, and aerodynamic optimization in a single design. The study validates those advanced shapes can be practically realized in low-cost prints.
4. Qu et al. (2022) – Topology Optimization of Quadcopter Chassis with AM Constraints. Topology optimization directly incorporated FDM build constraints such as overhang and layer orientation. The design achieved weight reduction while maintaining structural and vibrational performance, verified by FEA. Modal analysis showed favorable dynamic behavior. Optimized parts were successfully printed with no build errors. Their methodology underscores the importance of integrating manufacturing considerations into optimization. It bridges algorithmic design with practical FDM fabrication.

5. Çaska et al. (2020) – Structural Analysis of FDM-Printed Quadcopter Chassis Using FEA. This paper compares ABS and PLA FDM-printed UAV frames under static loading via FEA. ABS shows 0.053 MPa stress with 0.014 mm deflection; PLA has 0.065 MPa and 0.010 mm. The results verify that both plastics are mechanically viable for UAV structures. The study provides baseline data for material selection in drone design. It highlights the benefit of simulation-based validation. This work supports the use of consumer-grade polymers in engineering applications.
6. Barua & Singha (2024) – Simulation-Driven Structural Optimization of a 3D-Printable Quadcopter. A design workflow combining topology optimization and FEA was applied to both PLA and ABS under 20 N per motor load. PLA variant saw a 14% weight reduction with ~12.84 MPa von Mises stress; ABS required local reinforcement. The study systematically removed material in low-stress zones. It demonstrates structurally robust, printable UAV frame outcomes. Multi-material evaluation enhances design confidence.
7. Bay (2024) – Topology Optimized Quadcopter Drone Frame for Enhanced Performance. Using HyperWorks, the authors achieved ~30% mass reduction while verifying structural integrity through FEA. CFD was also conducted to assess aerodynamic drag improvements. The optimized frame is FDM-printable with manageable support requirements. The work demonstrates a true integration of structural and aerodynamic design. Printed prototypes validate simulation predictions. This study sets a precedent for performance-driven frame development.
8. Öztürk (2024) – Parametric Optimization of Hexacopter Frame Considering Manufacturability. A parametric model was optimized for arm thickness and length, reducing weight while maintaining deformation under 0.3 mm. Von Mises stress stayed within material limits. FEA verified structural performance. The method avoids complex topology, favoring manufacturable geometry. This approach is fast and practically accessible. It shows the value of simple parametric tuning in UAV design.
9. Zhang, Zhou & Das (2021) – Integrated Battery Layout and Structural Topology Optimization. This study optimizes wing structures for solar UAVs by combining battery placement with topology design, maintaining structural mass while improving integrity. Load distribution is enhanced without mass increase. The approach offers insights for fuselage design with internal payloads. It highlights multi-component structural synergy. The paper establishes design methodologies for integrated optimization.
10. Wiranto et al. (2024) – Topology Optimization of Carbon-Fiber Composite MAV Frames. Composite-aware topology optimization achieved ~34% mass reduction with ply-orientation and failure analysis. Fiber directions follow principal stress, ensuring load capacity. Fatigue performance was included, ensuring durability. The study confirms feasibility and strength of composite-optimized designs. It bridges material science with generative structure.
11. Regenwetter, Heyrani Nobari & Ahmed (2021) – Deep Generative Models in Structural Design: A Review. This review discusses GANs, VAEs, and deep learning techniques for structural topology. It highlights their ability to generate creative, constraint-satisfying designs. UAV applications, however, are still rare. The survey anticipates Generative AI's impact in engineering design. It sets a theoretical foundation for AI-driven structure engineering.
12. Jang, Yoo & Kang (2020) – Generative Design by Reinforcement Learning. Jang et al. propose an RL-based topology optimization method using PPO, enabling rapid and diverse structural generation. An AI agent selects material layouts as a sequential decision process. Trained networks mimic traditional solvers for efficient inference. Tested on automotive parts, it yields abundant high-quality, varied topologies. The results show RL enables creative and efficient structural exploration. This technology could revolutionize UAV frame design.

3. Softwares Used

The present study aims to perform a complete software-based structural optimization of a drone frame using generative design and finite element analysis tools. The methodology adopted here relies entirely on digital tools and simulation platforms, without involving physical prototyping or experimental validation. This chapter outlines the software environments used throughout the research, the step-by-step procedures followed in modeling, optimization, and analysis, and the approach for evaluating performance criteria. Emphasis has been placed on establishing a systematic, repeatable, and simulation-driven design flow using advanced software applications. This methodology ensures both precision in evaluation and agility in iterative improvements.

3.1: Overview of Software Workflow

The methodology employed in this study is based on three main stages: CAD modeling, generative design optimization, and structural analysis through finite element simulation. Autodesk Fusion 360 has been chosen as the primary software platform for all stages of this project. This choice is based on its integrated capabilities of 3D modeling, cloud-based generative design, and built-in simulation tools. The software allows for seamless transition between conceptualization, design iteration, and final evaluation.

Fusion 360 serves as an ideal platform for engineers and researchers due to its user-friendly interface and the ability to handle both parametric and free-form modeling. Furthermore, the generative design environment in Fusion 360 offers artificial intelligence-based tools that explore multiple solutions while meeting defined structural and material constraints. The built-in simulation module, using Finite Element Analysis (FEA), enables stress, displacement, and safety factor evaluations. The combination of these features ensures that the drone frame can be optimized for minimum weight and maximum strength.

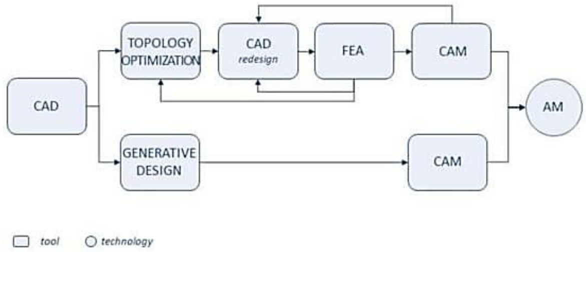


Figure 3.1: Generative design workflow

The software workflow begins with a conceptual CAD model of the drone frame, which includes defining geometry, constraints, and essential features such as motor mounts and payload holders. Afterward, the model is transferred to the generative design environment, where multiple optimized geometries are generated based on predefined criteria. Each output is analyzed using FEA tools to evaluate structural performance under realistic loading conditions. Finally, the best-performing design is selected based on stress distribution, displacement, safety factor, and manufacturability.

This software-centric workflow not only accelerates the design cycle but also provides insights into structural behaviour, material utilization, and design feasibility. With cloud integration, multiple design outcomes can be processed in parallel, significantly reducing development time. Additionally, by integrating all stages within a single platform, data consistency and design integrity are preserved throughout the process.

3.2: CAD Modeling in Fusion 360

The first step in the software-based workflow is the creation of the base model of the drone frame. The drone frame is modeled using parametric tools in Fusion 360, taking into account the dimensions required for a quadcopter setup. The design consists of four arms extending symmetrically from a central body, with mounting positions for motors, electronic components, and payload. Each arm is modeled considering the expected thrust generated by the motors and the overall balance of the system. Features such as mounting holes, chamfers, and fillets are added based on mechanical needs and to reduce stress concentrations. The dimensions are carefully selected to represent a typical small-to-medium size UAV used in surveillance and package delivery applications. While modeling, special attention is given to ensuring uniformity, symmetry, and compatibility with optimization requirements. The final CAD model serves as the baseline geometry to initiate the generative design process.

4. Design and analysis of drone chassis frame

The process of designing a drone chassis frame involves several crucial steps, beginning with concept sketching, progressing through detailed modeling, and culminating in optimization and structural analysis. The design is intended for quadcopter applications, focusing on minimal weight, adequate strength, and ease of fabrication using Fused Deposition Modeling printing.

4.1: Design of Drone frame

The initial 2D sketch, as developed in Autodesk Fusion 360, lays the foundation for the entire drone structure. The top view of the drone chassis reveals a symmetrical cross configuration, typical of quadcopters, with four arms radiating at 90-degree intervals from a central circular hub. Each arm is uniformly spaced and dimensioned, maintaining an arm-to-arm distance of 200 mm.

Figure 4.1: Drone frame in different stages

4.2: Output parameters of Drone

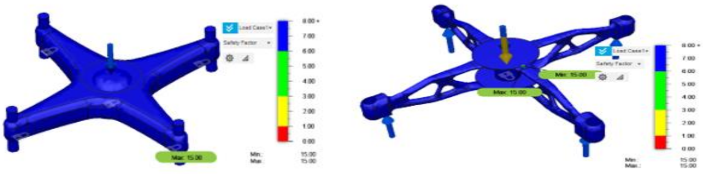
4.4.1: Weight

(a) (b)

Figure 4.6: Weight of the Drone frame. (a) Conventional method, (b) Generative method

The comparison between conventional and generative design methods in drone frame development clearly highlights the efficiency benefits offered by generative design, especially in terms of weight reduction. The conventional frame, shown in Figure 4.6(a), has a mass of approximately 1951.265 grams, with a volume of 1.790E+06 mm³, indicating a relatively heavy and material-intensive structure. In contrast, the generative design approach, as illustrated in Figure 4.6(b), results in a significantly lighter frame with a mass of only 446.104 grams and a volume of 409.269 cm³. The generative design is nearly 77% lighter, which directly improves flight time, reduces energy consumption, and allows for better payload capacity. Despite the generative design having a more intricate and open structure, it maintains structural integrity while reducing the overall material usage and weight. This reduction in mass is critical for drone applications, as it directly influences flight efficiency, battery life, and payload capacity. The optimization in material distribution offered by the generative process ensures a better strength-to-weight ratio compared to traditional design, making it a preferable method for lightweight and performance-critical components.

4.4.2: Factor of safety

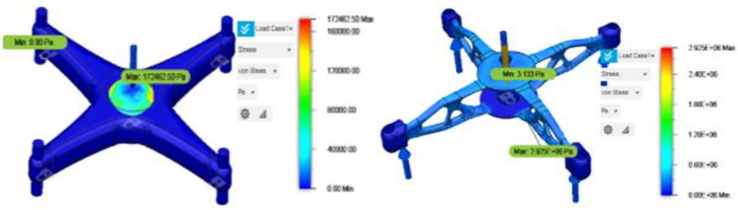


(a) (b)

Figure 4.7: Factor of safety of the Drone frame. (a) Conventional method, (b) Generative method

The images in Figure 4.7 show the factor of safety (FoS) distribution for the drone frame designed using both conventional (a) and generative (b) methods. A central vertical load of 10 N was applied during simulation using the Fusion 360 static stress module, with fixed boundary conditions at the motor mount ends to simulate realistic constraints during flight. Both frames are made from EPX 150 – Air Baked with Carbon, a material with a yield strength of 79 MPa. The simulation results reveal that both designs have a minimum and maximum FoS of 15, as indicated by the uniform blue regions in the analysis. This blue coloration across both structures means all areas are well within safe stress limits.

4.4.3: Stress

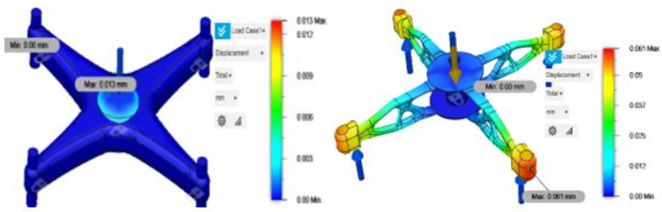


(a) (b)

Figure 4.8: Stresses in the Drone frame. (a) Conventional method, (b) Generative method

Stress analysis plays a vital role in evaluating how a component responds under applied loads, particularly in aerospace structures like drone frames where weight and strength must be balanced. Figure 4.8 illustrates the von Mises stress distribution in drone frames designed using both the conventional method (a) and the generative method (b), under the same load conditions. The simulation was conducted using Fusion 360, applying a central vertical load with fixed supports at the ends of the frame arms, which accurately replicates in-flight conditions. In the conventional design (Figure 4.8a), the maximum stress recorded is approximately 174,262.50 Pa, concentrated around the central region of the frame where the load is applied. In contrast, the generative design (Figure 4.8b) shows a dramatically reduced maximum stress of only 2.9754e+06 Pa (or 2.97 MPa), with stress more evenly distributed along the optimized structure. Despite its lightweight geometry, the generative frame handles the applied load more efficiently, spreading stress through its skeletal structure. The minimum stress values in both designs are close to zero, as seen at areas far from the load path.

4.4.4: Displacement



(a) (b)

Figure 4.9: Displacement in the Drone frame. (a) Conventional method, (b) Generative method

Displacement analysis is essential to determine how much a structure deforms when subjected to an external load. In drone design, even small displacements can affect stability, flight accuracy, and long-term durability. Figure 4.9 presents the total displacement results for the drone frame under a central vertical load, comparing both the conventional (a) and generative (b) design methods.

•In the conventional design (Figure 4.9a), the maximum displacement is 0.013 mm, concentrated near the central region where the load is applied. The displacement is minimal and spread mostly around the loaded zone, while the rest of the structure remains relatively rigid.

•In the generative design (Figure 4.9b), the maximum displacement is higher, around 0.061 mm, occurring at the outer ends of the frame arms. This increase in displacement is due to the reduced material and open geometry in the generative design, which, while maintaining strength, allows for slightly more flexibility.

5. Conclusions

This study focused on evaluating and comparing the mechanical performance of conventional and generative drone chassis designs using simulation analysis and additive manufacturing through Fused Deposition Modeling (FDM). Based on the results the following conclusions can be drawn:

1.Significant Weight Reduction: The generative design achieved an impressive 77% reduction in mass compared to the conventional frame (446.104 g vs 1951.265 g). This weight reduction enhances drone performance in terms of flight time, payload capacity, and energy efficiency.

2.Material Efficiency Without Compromising Safety: Despite using substantially less material, the generative design maintained a factor of safety (FoS) of 15, identical to the conventional design. This proves that the generative structure is equally safe and reliable under the given loading conditions.

3.Improved Stress Management: While the generative model showed higher peak stress (2.975 MPa) compared to the conventional frame (174,262.5 Pa), it remained well within the material's elastic limits. Moreover, the generative design exhibited better stress distribution along optimized paths, minimizing the presence of critical stress zones.

4.Acceptable Flexibility: The generative design experienced higher displacement (0.061 mm) than the conventional design (0.013 mm). However, this flexibility is within safe limits for drone operation and is a reasonable trade-off considering the weight savings.

5.Efficient Load Transfer: Although the reaction force at the supports was significantly higher in the generative model (2.658 N vs 0.291 N), the forces were effectively absorbed and managed due to the reinforced geometries. This highlights the optimized structural behaviour of the generative design.

6.Suitability for Additive Manufacturing: The generative design was successfully realized using FDM technology, proving its manufacturability and practicality in real-world applications. It supports complex geometries while minimizing material waste.

7.Overall Design Superiority: The generative drone chassis clearly outperforms the conventional design in terms of weight, material efficiency, and structural optimization, without compromising on safety. This makes it an ideal solution for applications where weight and performance are critical, such as aerospace, robotics, and UAV systems.

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