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Original Article

Design and Development of Quadcopter Frame Through Topology Optimization

Elluru Veera Pratap[1], Srinivas Pendyala[2], Kameswara Sridhar Vepa[3], N. V. S. S. Sagar[4]

[1,2,3]*GITAM deemed to be university, Department of Mechanical Engineering, Hyderabad, Telangana, India.*
[4]*Engineering Staff College of India, Design and Prototyping Centre, Hyderabad, Telangana, India.*

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

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Abstract - *Unmanned Aerial Systems (UASs) are gradually gaining popularity in agricultural and defense sectors. Quadcopters are the most common type of UASs due to their inherent advantages, such as mobility, ease, and control. Travelling for a longer period by properly loading may be challenging. The quadcopter's battery depends on its weight in terms of its duration and efficiency. The frame is the structural part of UAS that carries the complete load of the equipment. It is recommended that the UAS frame be optimized because it contributes significantly to the total weight of the UAS, which is about 30 per cent. Current business UAS models consist of many subassemblies and additional hardware fastening points that require substantial time and effort to join. In this research, the frame is transformed into a monocoque structure, which gave good results in terms of weight optimization and time taken for assembly. Topology optimization can thus be used to construct lightweight structures without compromising the structural performance. The design for the quadcopter frame was modeled, and topological optimization was doneto arriveg at the best structure. Topology optimization provided an intricate shape for the model, which was challenging to manufacture through conventional methods; therefore, the optimized model was re-modeled and checked through the statically structural Finite Element Analysis (FEA). The optimized design is then produced through the 3D printing technique. The Powder Bed Fusion (PBF) process is used to create the redesigned quadcopter structure; the field trials indicate that the quadcopter we developed offers users a variety of benefits, including high endurance, greater maneuverability, and a significantly shorter deployment time. Consequently, it is a suitable drone for rapid response in surveillance applications.*

Keywords - *Quadcopter, Topology optimization, Unmanned Aerial Systems, Powder Bed Fusion, Additive Manufacturing.*

1. Introduction

Drone research is rapidly expanding because of its enormous potential for specific applications. Typically, the drone's mass and design both affect its aerodynamic performance. Due to their lower regulatory requirements, quadcopters with four propellors and four motors are the most commonly utilized UASs. Therefore, the goal is to combine the ideas of fused deposition modeling, topology optimization, and design optimization to create a lightweight quadcopter structure. The flow chart in Figure 1 shows the entire design process.

One significant development that has elevated the design of lightweight quadcopters is the use of Additive Manufacturing (AM) to fabricate the structure [1]. The practical applications of Fused Filament Fabrication (FFF) in the UAS industry have been described by Klippstein et al. [2], indicating the promise of AM in the field of UASs. The results showed that FFF technology may be used to successfully build complex structures and even incorporate electronics inside UASs. Components manufactured via FFF are anticipated to diminish weight and enhance the aerodynamic performance and structural efficiency of UASs.The AM method is intended to create a cohesive structure. AM is a disruptive technology [3] that makes it possible to efficiently realize functioning parts and reduce the weight of current components. AM is used to swiftly realize functional components due to its great design flexibility, simpler production process, and use of fewer tools [4].

Typically, 30% of the quadcopter's weight is made up of its structural frame. Given this, the goal of the current research project is to lighten the frame's weight. The idea of topology optimization is applied to accomplish this. Complex and irregular shapes are the product of topology optimization [5]. It is difficult to fabricate those parts using traditional manufacturing techniques. Therefore, AM technologies are favored for the fabrication of these models. According to the literature, the complicated and lightweight UAS structures are effectively manufactured by combining additive manufacturing technology with topology optimization [6, 7]. The UAS designed in this work falls under the category of

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micro drone applications in areas like surveillance and search and rescue operations. The frame of the UAS is represented by the conceptual model of a commercially available quadcopter.

In order to keep the total weight of a UAV development low while maintaining sufficient structural integrity, it is crucial to design with a high strength-to-weight ratio. Design customization is necessary for such a developmental endeavor. Based on the above literature survey, it is observed that there is still scope for reducing the weight of the quadcopter frame and assembly time by using additive manufacturing and topology optimization techniques.

The main goal of this study is to build a lightweight, monocoque quadcopter structure that requires a minimum of assembly time possible. Micro-drones' weight directly affects their flight time, with lighter models achieving up to 15 minutes of flight [8].

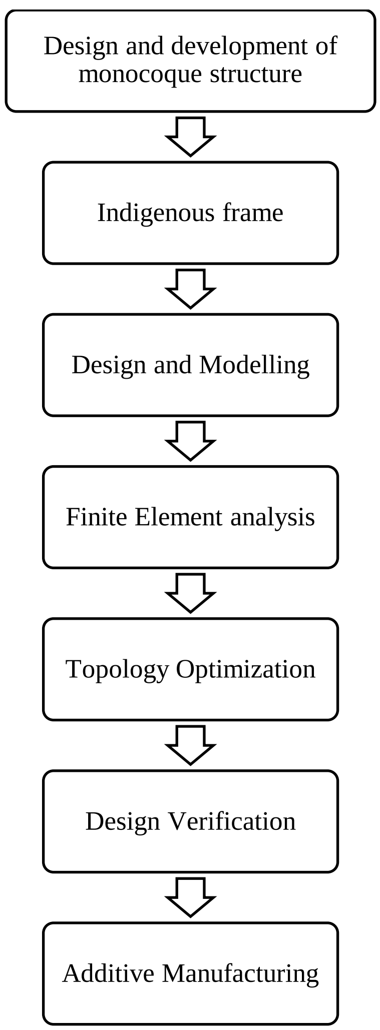


Fig. 1 An outline of the research methodology

2. Design of Quadcopter Frame

2.1. Design Optimization

A frame measuring 143 mm diagonally and made of Acrylonitrile Butadiene Styrene (ABS) is used to begin the design process. Below is a summary of the ABS material's characteristics: Table 1 lists the pertinent characteristics of the used material.

Table 1. ABS material properties

Properties	**Values**
Modulus of Elasticity	2.9 GPa
Density	1080 kg/m^3
Poisson Ratio	0.422

The basic geometry is depicted in Figure 2, with a diagonal length of 143 mm and a frame height of 110 mm. The cost of production and manufacturing feasibility are taken into account when selecting ABS as a material.

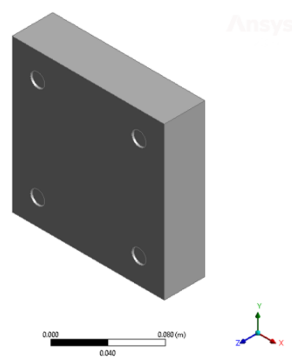


Fig. 2 Primitive geometry

2.2. Topology Optimization

The model needs to be divided into two parts for the first step of topology optimization: the design space, which needs to be optimized, and the non-design space, which shouldn't be altered. The component is then analyzed using finite element techniques to determine the stress distribution and resulting deformation, taking into account the designated loading and boundary conditions.

Subsequently, the topology optimization process aims to remove material from regions where the applied load has minimal impact. Topology optimization provides engineers with a methodology to ascertain the optimal mass while ensuring adequate strength to endure the specified loading conditions [9]. The flow chart for the topology optimization process is shown in Figure 3.

Usually, the objective of topology optimization is to minimize weight while increasing rigidity. Any construction can be optimized to reduce weight, which raises the thrust-to-weight ratio. The Solid Isotropic Microstructure with Penalization (SIMP) method in ANSYS software is used to optimize the stress-based topology.

This will partition the design space volume into N elements, which are solid isotropic microstructures. A function known as density will be linked to each of the elements. It may be a solid or a void, and all of the related numbers will fall between 0 and 1.

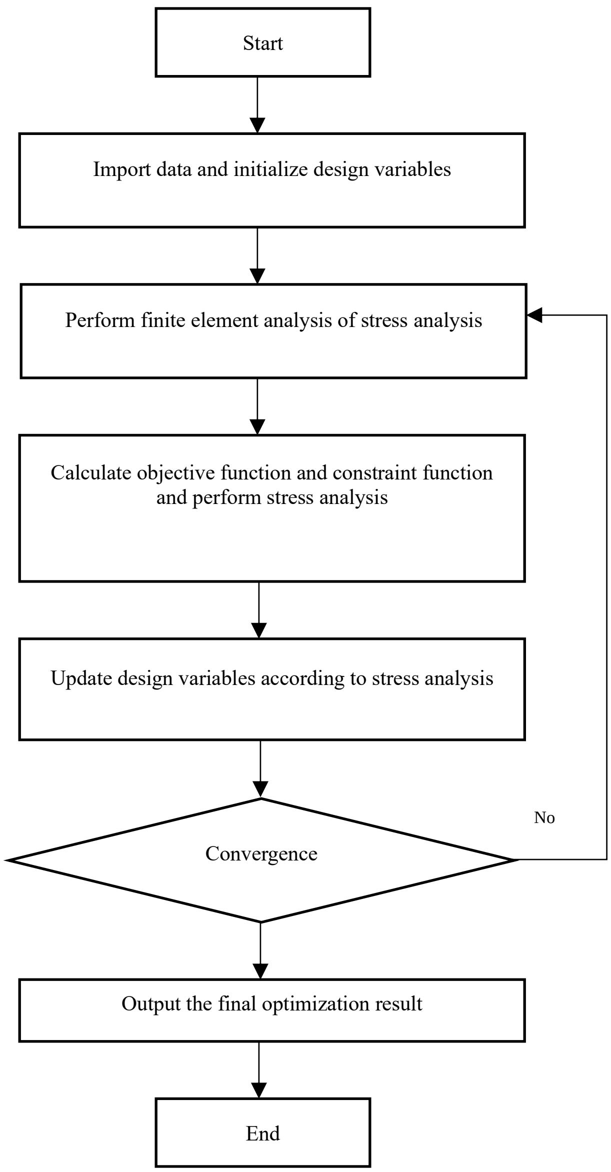


Fig. 3 Topology optimization process

Using a topology optimization tool, the model is further improved by taking into account permissible maximum stress as a response constraint and mass minimization as the objective function, as seen in Figure 4. A geometry with the lowest weight and the ability to lift a total weight of 900 grams was produced by topology optimization, as seen in Figure 5. Lastly, the topology-optimized model is validated and confirmed using static structural FEA.

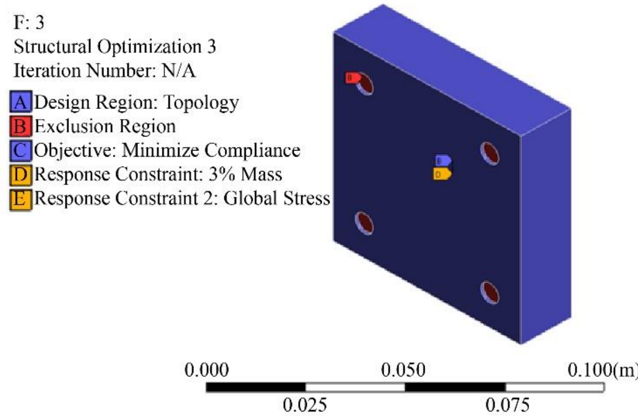


Fig. 4 Design and Non-design spaces; Response constraints

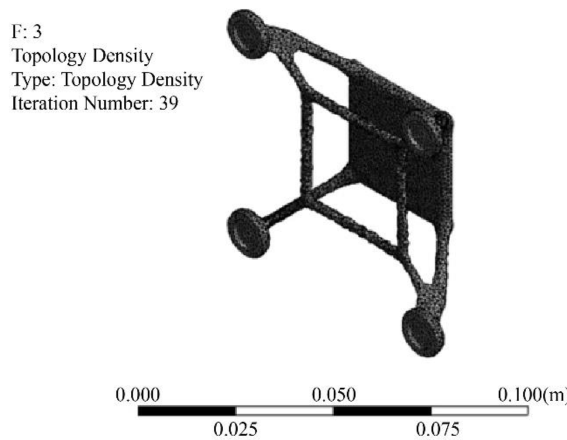


Fig. 5 Geometry after topology optimization

The topology optimization result is depicted in Figure 5. As can be seen, the shape is irregular, and the surface has a very jagged line, so its production is very challenging. Thus, the design has been changed to control the complexity, as indicated in Figure 6.

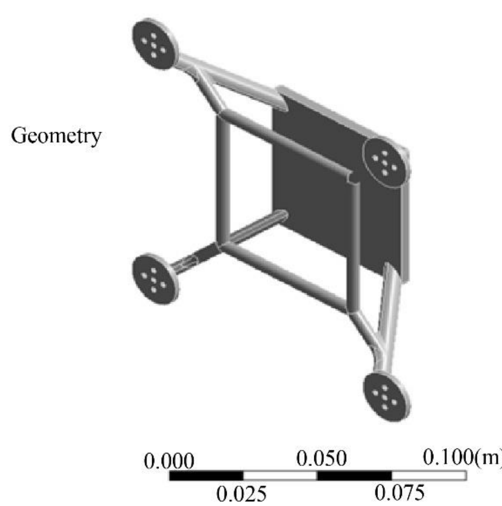


Fig. 6 Re-modeled Geometry

3. Fabrication of Quadcopter Frame

This work aims to construct a monocoque quadcopter structure. The advantages of the suggested structure are as follows: It cuts down on assembling time, the assembled models show no signs of joint breakdown, and it improved structural integrity. The AM method is intended to create a cohesive structure. AM is a disruptive technology [10] that makes it possible to efficiently realize functioning parts and reduce the weight of current components. AM is used to swiftly realize functional components due to its great design flexibility, simpler production process, and use of fewer tools [11]. In order to achieve a high strength-to-weight ratio, AM technologies can be used to construct the quadcopter structure.

The final designed optimization model is intricate, and manufacturing the model employing a conventional approach is always a tasking endeavor. As a result, it is impossible to build using a normal method, and the resulting optimization model appears more sophisticated. Fused Deposition Modeling (FDM) is recommended as the manufacturing approach to develop a design and manufacturing process that can accommodate any ideal geometry. As shown in the parameters in Table 2, the finished model applied FDM technology. For parameter selection, the information used here was derived from the author's previous work in the same area. This concurs with the fabricated actual model, as shown in Figure 7.

Table 2. 3D Printing parameters

Parameter	Value
Infill density (%)	100
Layer Thickness (mm)	0.1
Orientation	XY

The following are the design principles used for developing the quadcopter frame.

1. The overhang angle is limited to 45^0 in accordance with the Design for Additive Manufacturing concept.
2. Maximum allowable principle stress is limited to 20 MPa.

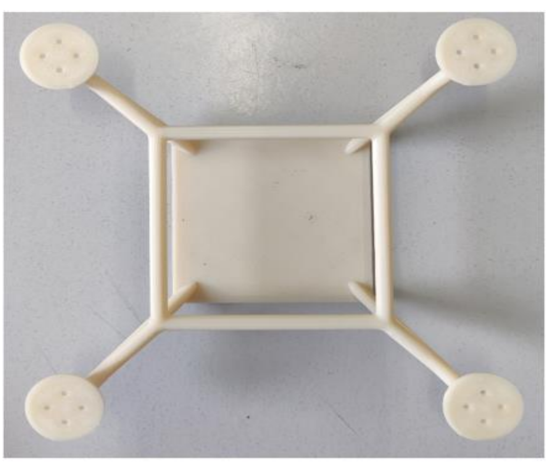


Fig. 7 Fabricated model

4. Results and Discussions

4.1. Statistical Structure Analysis

This work proposes a method for designing, optimizing, and fabricating a quadcopter's structural frame for a particular payload. Structural optimization combined with 3D printing technology is realized to develop a quadcopter construction that can support an overall weight of 900 grams.

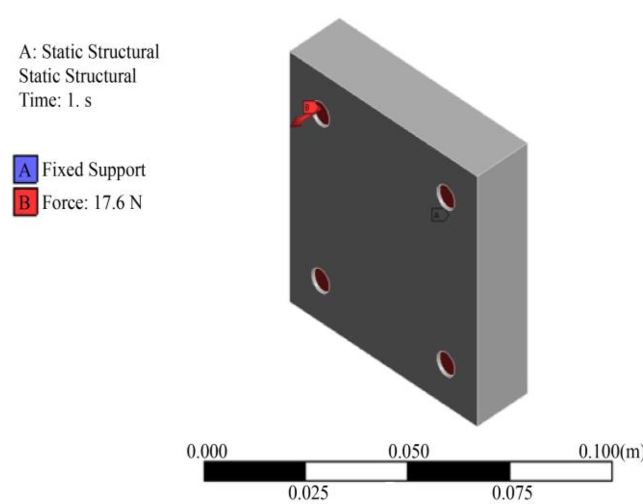
The overall thrust needed by the motors is taken as 17.6N at 50% operational efficiency of the motors. Since the total thrust is divided among the four motors, it is 4.4N per motor.

For generating this thrust, propellors of 2.5-inch diameter are used. It produced a geometry with the lowest weight that could help the payload and still meet all loading and boundary requirements. While maintaining the frame's strength and potential, design optimization was used to lower its weight by 98%.

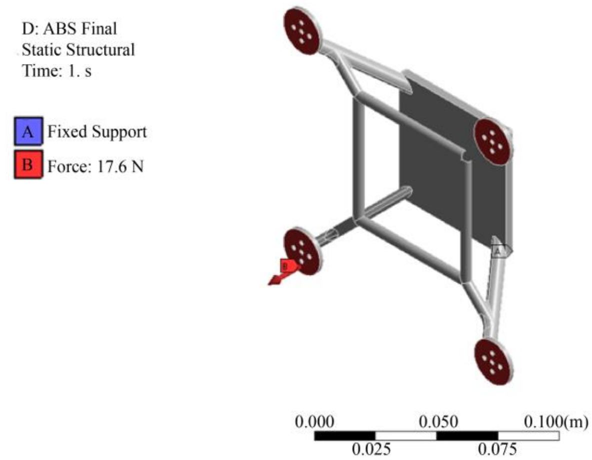
Compared to the original design's mass of 2339 grams, the final modified geometry produced a mass of 47 grams. The findings demonstrate that stresses and deformations are within tolerable bounds across the component. Therefore, combining additive manufacturing and structural optimization is a viable strategy for lowering the weight of quadcopter structures.

The loading and displacement conditions for the initial and optimized geometry are displayed in Figure 8. According to Figure 9, the highest equivalent stress that may be achieved is 4.5 MPa. As illustrated in Figure 10, the highest total deformation achieved for both initial and optimized geometries is 0.03nm and 0.1 mm.

The results show that the deformations and stresses in the frame are within permissible bounds. Thus, combining topology optimization with 3D printing is a viable method for reducing the weight of the quadcopter construction.

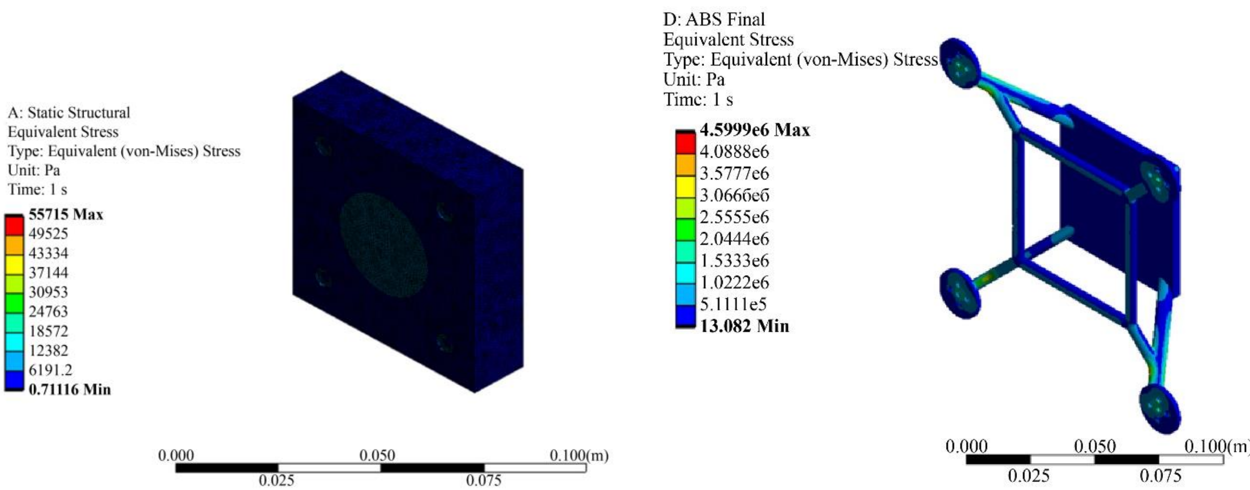


(a)



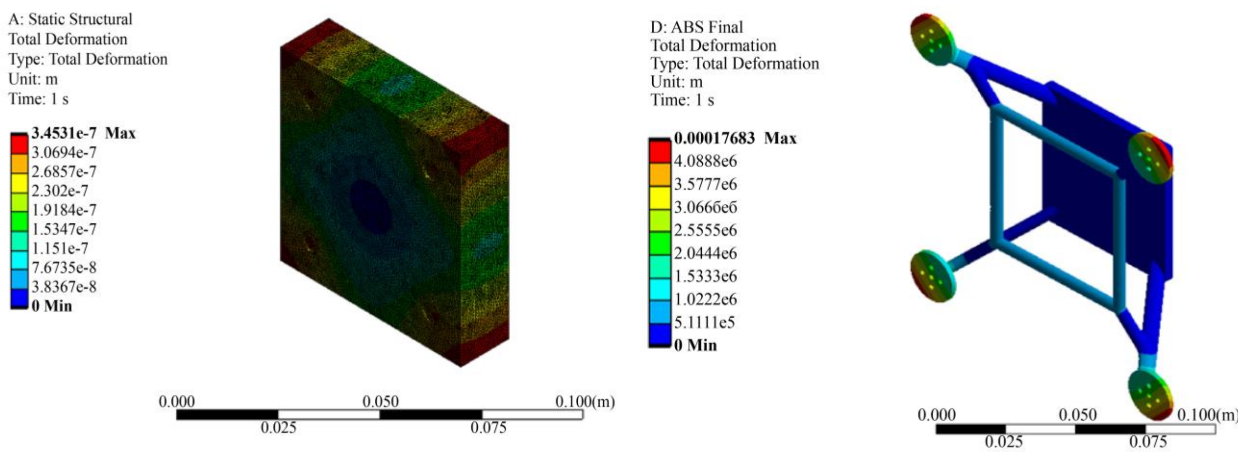
(b)

Fig. 8 Loading and displacement conditions for a) Primitive Geometry, and b) Optimized Geometry.



(a) **(b)**

Fig. 9 von-Mises stress for a) Primitive Geometry, and b) Optimized Geometry.



(a) **(b)**

Fig. 10 Total deformation for a) Primitive Geometry, and b) Optimized Geometry.

All the results of initial geometry and optimized geometry are summarized in Table 3.

Table 3. Stress and Strain Analysis for quadcopter frame

Parameter	Initial Geometry	Re-modeled Geometry
Weight (grams)	2339	47
von-mises stress (MPa)	0.06	4.5
Maximum deformation	0.03nm	0.1mm

4.2. Aerodynamic Behavior

The quadcopter will move against the wind if it is moving forward. This type of scenario is replicated by leaving the quadcopter to hover at a fixed point, with the wind velocity changing from 0 to 15m/s. In order to quantify this behavior, the drag force is taken from the simulation results, and the coefficient of drag (c_d) is calculated. The resulting c_d of 0.092 is very close to that of a streamlined half-body from the literature. This is ensuring higher aerodynamic stability and endurance for the quadcopter. Table 4 shows drag forces at different velocities.

Table 4. Velocities and drag forces during the forward phase

Velocity (m/s)	Drag Force (N)
0.1	8.127e-05
2	0.0385
5	0.0357
8	0.0601
10	0.0929
12	0.1326
15	0.2054

4.3. Assembly Integration

The building of motors and integrating electronic components were made possible by the 3D-printed unibody quadcopter structure. Four motors with 2.5-inch propellers and 900 grams of thrust are selected based on the frame size and expected thrust. The power source is a single-cell, 450 mAh lithium polymer battery with a 75 C rating. Thrust force is produced by M1104 motors, which have a 7500 KV rating and a 13 amp Electronic Speed Controller. GPS-enabled electronic speed controllers from the EMAX BLHELI SERIES are utilized. A 2.4 GHz radio communication system transmits and receives the signals, and a 500 KHz telemetry system allows real-time data transmission to the ground control center. The entire quadcopter assembly is shown in Figure 11. In order to ascertain the flight time and validate the structural integrity for an overall weight of 900 grams, field testing was carried out both indoors and outdoors following a successful assembly. Analyzing relevant flight data allows one to observe the vehicle’s attitude and behavior. As a result, the construction is strong and can sustain 900 grams of weight while still having an 8-minute endurance. The unique aspect of this study is the development of a unibody quadcopter with a high thrust-to-weight ratio that improves maneuverability and is complimented by other features while needing a much-reduced amount of time to assemble.

Fig. 11 Quadcopter assembly

The created quadcopter is designed for surveillance and thermal applications. To evaluate stability and measure endurance, roughly 20 field treks are undertaken. Tests were conducted in a range of wind and environmental conditions. Under normal wind conditions, the quadcopter system demonstrated high stability; when wind speed increases, instability occurs. The wind speed during the field test is measured using a portable anemometer and ranges from 3 to 8 m/s. Based on field trials, the quadcopter we built provides users with many benefits, such as enhanced maneuverability, high endurance, and noticeably quicker deployment times. Because of this, the drone is perfect for surveillance applications requiring prompt replies. The frame of the UAS is represented by the conceptual model of a commercially available quadcopter. Table 5 compares the specifications of the commercially available UAS and the conceptual model used in this work.

Table 5. Compare the quadcopter frame for the commercial model and conceptual model

Feature	Commercial Model (ARRIS X110)	Conceptual Model
Weight	127 grams	118 grams
Frame shape	X Frame	X Frame
Material usage	Carbon Fiber	ABS
Endurance	3 to 8 minutes	8 to 10 minutes
Application	Racing / Surveillance	Surveillance, Search, and rescue operations
Assembly time for quadcopter frame	15 Minutes	No need to assemble

5. Conclusion

This study integrates optimization and AM techniques for a quadcopter structure. Both compliance and mass are considered together to achieve optimum product design layout. ANSYS topology optimizer resulted in geometry with the lowest possible weight capable of withstanding the all-up weight of 900 grams and satisfying the constraints. The model resulting from topology optimization is a monocoque structure fabricated using FDM without the need for assembly. Therefore, it is thought that combining topology optimization and AM is a useful strategy that can be applied to lighten the quadcopter structure and improve the monocoque quadcopter's performance. Therefore, it is thought that combining topology optimization and AM is a useful strategy that can be applied to lighten the quadcopter structure and improve the monocoque quadcopter's performance. Other AM approaches will be used in the future, along with dynamic analysis and impact strength characteristics.

References

[1] G.D. Goh et al., "Additive Manufacturing in Unmanned Aerial Vehicles (UAVs): Challenges and Potential," *Aerospace Science and Technology*, vol. 63, pp. 140-151, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[2] Helge Klippstein et al., "Fused Deposition Modeling for Unmanned Aerial Vehicles (UAVs): A Review," *Advanced Engineering Materials*, vol. 20, no. 2, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[3] Thomas A. Campbell, and Olga S. Ivanova, "Additive Manufacturing as a Disruptive Technology: Implications of Three-Dimensional Printing," *Technology & Innovation*, vol. 15, no. 1, pp. 67-79, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[4] Tuan D. Ngo et al., "Additive Manufacturing (3D Printing): A Review of Materials, Methods, Applications and Challenges," *Composites Part B: Engineering*, vol. 143, pp. 172-196, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[5] Robin Larsson, "*Methodology for Topology and Shape Optimization: Application to a Rear Lower Control Arm,*" Master's Thesis, Chalmers University of Technology, Goteborg, Sweden, pp. 1-53, 2016. [Google Scholar] [Publisher Link]

[6] Carlo Giovanni Ferro et al., "A Comparison between 3D Printing and Milling Process for a Spar Cap Fitting (Wing-Fuselage) of UAV Aircraft," *Procedia CIRP*, vol. 62, pp. 487-493, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[7] Ionut Stelian, and Sebastian Marian Zaharia, "Design and Testing of an Unmanned Aerial Vehicle Manufactured by Fused Deposition Modeling," *Journal of Aerospace Engineering*, vol. 33, no. 4, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[8] Tomoya Watamura et al., "Flying a Micro-Drone by Dynamic Charging for Vertical Direction Using Optical Wireless Power Transmission," *Energies*, vol. 18, no. 2, pp. 1-19, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[9] Jana Dvorakova, and Karel Dvorak, "Topological Optimization of a Component Made by the FDM Method," *International Journal of Mechanical Engineering and Robotics Research*, vol. 10, no. 2, pp. 67-71, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[10] Silvia Vock et al., "Powders for Powder Bed Fusion: A Review," *Progress in Additive Manufacturing*, vol. 4, pp. 383-397, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[11] Austin T. Sutton et al., "Powder Characterisation Techniques and Effects of Powder Characteristics on Part Properties in Powder-Bed Fusion Processes," *Virtual and Physical Prototyping*, vol. 12, no. 1, pp. 3-29, 2017. [CrossRef] [Google Scholar] [Publisher Link]