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PARAMETRIC OPTIMIZATION OF STRUCTURAL FRAME DESIGN FOR HIGH PAYLOAD HEXACOPTER

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Abstract: For drones, the use of which has been increasing recently for load carrying, lightweight drone frame design is significant for increased flight time and payload capacity. Drones are produced in different configurations with three, four, or six rotors, and in different sizes depending on the purpose of use. While agility is more important in three and four rotor drone applications, six-rotor and relatively large-bodied drones are preferred in cases such as load carrying. When the body structure has to be large, lightening the design becomes very critical. Lightweight designs can be achieved by two commonly used methods for structural optimization: topology optimization and parametric optimization. Topology optimization is an advanced method that can significantly reduce weight but is expensive and time-consuming. Parametric optimization is a more practical approach to conventional manufacturing methods and was used in this study. This study aims to first simplify the hexacopter frame model and define key geometric parameters for mass-decreasing optimization. Finite element analysis simulations were used to evaluate the strength and deformation of the frame under various design scenarios. The results showed that parametric optimization successfully reduced the weight of the hexacopter frame while maintaining structural integrity. The maximum Von Mises stress was found as approximately one quarter of the yield strength of the frame material. The maximum total deformation was achieved below 0.3 mm, and deformation under 1 mm is considered safe in the literature. As a result, the optimized design offers a lighter drone structure in line with conventional manufacturing methods, providing better flight time and payload capacity while maintaining cost effectiveness. In future studies, comparisons can be made based on this study by performing weight optimizations suitable for current methods such as topology optimization or generative design. The cost factor and the availability of existing production lines should be taken into consideration when comparing the mentioned methods with parametric optimization.

Keywords: Parametric optimization, Hexacopter, Drone design, Finite element analysis

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1. Introduction

Unmanned Aerial Vehicles (UAVs), also commonly known as drones, are a type of aircraft that does not require a human pilot onboard to operate. They are controlled remotely or autonomously using pre-programmed flight plans and onboard sensors. UAVs encompass a wide range of vehicles with varying sizes, capabilities, and applications. The two main categories of UAVs are fixed-wing UAVs and rotary-wing UAVs. The fixed-wing UAVs generate lift similar to traditional planes and are suitable for long-range missions (Fahlstrom et al., 2022). On the other hand, rotary wing UAVs utilize multiple rotors to generate lift and achieve vertical takeoff and landing capabilities. Two of the most common rotary-wing UAV types are hexacopters and quadcopters.

Hexacopters, also known as hexadrones, are a type of multirotor drone with six rotors. Compared to quadcopters (four rotors), hexacopters offer several advantages that make them increasingly popular across various sectors. First of all, with six rotors, even if one of the six rotors fails, the remaining five can provide enough thrust to maintain stability and allow for a controlled landing. Therefore, hexacopters are ideal for critical missions where reliability is crucial. The additional rotors translate to more lifting power, enabling hexacopters to carry heavier payloads than quadcopters. Increased payload enables the user to lift larger cameras, sensors, or delivery packages. The maximum takeoff weight is significantly higher for hexacopters compared to all other types of UAVs (Ramesh and Jeyan, 2022). The efficient lift distribution across six rotors translates to better energy efficiency, resulting in longer flight times than quadcopters with similar battery capacities. In conclusion, hexacopters are revolutionizing the drone industry with their decent stability, high payload capacity, and longer flight times. Because of these advantages, hexacopters are used in many sectors such as aerial photography and videography, search and rescue operations, agriculture, and delivery services (Elouarouar and Medromi, 2022).

The lightweight design of the hexacopter body is very significant for maximizing the flight performance of the drone (Wu et al., 2022). Because the weight of the hexacopter frame impacts three concepts: flight time, payload capacity, and maneuverability. The relationship between lightweight design and these three concepts will be explained respectively because lowering the weight impacts these concepts positively or negatively. It is a known fact that there is a direct correlation between flight time and lightweight design. Every gram shaved off translates to less energy required to hover or fly. This allows the drone to stay in the air for longer on a single battery charge. Lighter weight translates to less strain on the motors, allowing them to operate more efficiently. This translates to increased battery life as less energy is wasted, overcoming the drone's weight. Although lightweight design offers a benefit, it also has less capacity to carry additional weight. Therefore, an optimization is required to achieve the best balance between weight and payload capacity for the intended application. For instance, the designer of a photography drone might prioritize stability and flight time for capturing smooth aerial footage, while a delivery drone might prioritize payload capacity to carry heavier packages. Also, maneuverability can be affected by the lightness. A lighter drone has less inertia, requiring less effort to change direction or perform maneuvers. This translates to increased agility and responsiveness, allowing for sharper turns, faster acceleration, and smoother overall flight control. This is crucial for drone races or aerial video capturing for high-speed motorsports.

Up to this point, the importance of lightweight design for vehicles such as drones has been emphasized. For this very reason, optimizing the structural parts of drones in terms of weight and strength is significant. Topology optimization, an advanced method, is currently used to reduce weight and material in the structural design of a drone. However, the costs of structural parts obtained through topology optimization are high, mainly when metallic materials are used. In some cases, it is not even possible to access metal additive manufacturing devices. Considering both these disadvantages and the existing traditional production methods in the industry, the parametric optimization method is lower in terms of material and labor costs. Parametric optimization is based on converting certain dimensions of easily machined geometries, such as holes or slots, into parameters on the structure whose weight is desired to be reduced. Optimizing these parametric dimensions to provide appropriate strength is possible with Computer Aided Engineering (CAE) software. In studies comparing topology optimization and parametric optimization, low labor cost and rapid production are shown as the advantages of parametric optimization. Removing the support parts of the parts produced with topology optimization by secondary operations is a more costly and time-consuming process than parametric optimization (Hassani et al., 2021).

There are various studies in the literature regarding the structural frame design of multicopters. Ismail et al. (2020) studied the design and development of the structural frame and propeller parts for a hexacopter intended to carry heavy loads. HEX-6X, one of the multicopter configurations, was used, and the frame material was Al 6061-T6 Grade, which is a lightweight option for UAV applications (Anweiler and Piwowarski, 2017). Using finite element simulations, a multicopter that is safe regarding equivalent stress and total deformation was designed to carry a 20 kg payload where each rotor has been designed to provide 3.4 kg thrust force. Aswath and Raj (2021) studied the design process of a payload hexacopter. Simulation of the multicopter arm is made by the researchers to obtain the safety of the structure in the design process. Maximum deformation is found as 8 mm where the material of the arm is plastic. Kumar et al. (2021) investigated different types of multicopter frame designs for four different materials. As a result, it has been seen that “X” or “+” type body frames using fiber-reinforced composite materials are suitable for quadcopter design. Wu et al. (2021) performed finite element simulations to obtain a sound multicopter design where the propeller and foldable arm are optimized for best performance. Certain airfoil design is proposed for better thrust force. Carbon fiber reinforced composite material for the foldable multicopter frame is also found as an alternative to the mostly used aluminum alloy. Shelare et al. (2023) performed both theoretical and numerical studies to design a hexacopter with a bottle hanger to carry a maximum 7500 g load. The results of the simulations indicate maximum 1 mm displacement for a safe multicopter design. Azhagan et al. (2023) used a generative design approach to find the best alternative body frame and structural arm for a hexacopter. In generative design, Artificial Intelligence (AI) algorithms are used to generate a great number of design alternatives. This design approach is only useful for applications where additive manufacturing is available because the final designs are organically shaped (Radakovic, 2021). Using nonlinear analysis, Sharma and Selvakumar (2018) examined a drone's structure. They increased the drone's weight until it reached the failure point. Sundararaj et al. (2021) conducted modal and structural analyses on various drone frames. The simulation yielded the maximum allowable stress, strain displacement, and frequency values. They discovered that although producing short armed rectangular frames is difficult, they indicate higher strength. MohamedZain et al. (2022) conducted a series of simulations to determine the weight of the drone components, considering allowable stress and displacement. Sreeramoju and Rao (2023) Using Autodesk Fusion 360 software, the frame is modeled in this work with regard to its durability and stress analysis. Its materials, ranging from metal to plastic, are compared, and the design is shape-optimized to achieve the goal. There are many studies in the literature that deal with the weightreducing optimization of the drone frame (Yemle et al., 2019; Urdea, 2021; Tura and Zaharia, 2023). All of the researchers above performed their studies mostly in the last five years. Therefore, the optimization of the drone frame has recently become a very popular topic because the use of drones is increasing very rapidly today. In addition, the geometry of the frame is particularly important because it needs to be high strength enough but also have a lower mass. The motivation of this study is to propose an approach to the optimization problem of the high payload hexacopter frame design. With the proposed approach, hollow-like geometries that can be parametrized in the hexacopter frame can be designed and these cavities can be brought to their optimum dimensions with the help of numerical simulations. In addition, the motivation for using parametric optimization instead of topology optimization is to achieve a design optimization suitable for drone frame structures that can be machined on existing CNC machines due to the cost advantage.

In this study, the frame and arm of a payload hexacopter are simplified and redesigned for parametric optimization. SolidWorks Simulation and Design Study modules are used for parametric optimization. The design process is divided into two phases to prevent excessive design scenarios. Two types of hollow geometries are defined for each phase. The optimal result has been achieved by user selection to ensure both low weight and high strength.

2. Materials and Methods

2.1. Material

The aerospace, defense, and automotive industries frequently utilize aluminum 6061-T6, owing to its excellent mechanical qualities, strong corrosion resistance, and exceptional weldability (Namlu et al., 2019). In this paper, Al 6061-T6 was preferred in this study due to its lightness and the exceptional properties described above. Additionally, this material has very good machinability, allowing for a clean surface finish (Najiha et al., 2015). The material properties of aluminum alloy is given in Table 1. These values were obtained from the material database of SolidWorks.

Table 1. The mechanical and physical properties of Al 6061 T6

Property	Value	Unit
Elastic Modulus	69	GPa
Poisson’s Ratio	0.33	-
Tensile Strength	310	MPa
Yield Strength	275	MPa
Mass Density	2700	kg/m³
Hardening Factor	0.85	-

2.2. CAD Modeling and Simplification of Hexacopter

The structural components of a hexacopter with a high-payload were redesigned and optimized in the present study. There are various types of configurations for multicopters and the most used ones are called; Quad+, Quad X, Tri, Y4, Hex 6, Hex 6 X, and Hex 6 Y shaped (Anweiler and Piwowarski, 2017). These configurations, as well as the one presented in this study, are given in Figure 1. Two main differences exist in these configurations; the shape of the frame and propeller rotation. Propeller rotations are designed to ensure the stability of the drone. In this study, a Hex 6 Y-shaped hexacopter design was preferred. The hexacopter model called “Multirotor Drone with Payload Carrying” was obtained from GrabCAD Library with permission from the designer. Since the structural body of the hexacopter was to be optimized, the two frames and propeller arm had been isolated from the main assembly, as in Figure 2. To proceed with the parametric optimization, the frames and arm were simplified to determine the design parameters. The simplified and isolated components are given in Figure 3. The simplification process is essential because the original design is suitable for additive manufacturing, while this study depends highly on the design for conventional manufacturing methods.

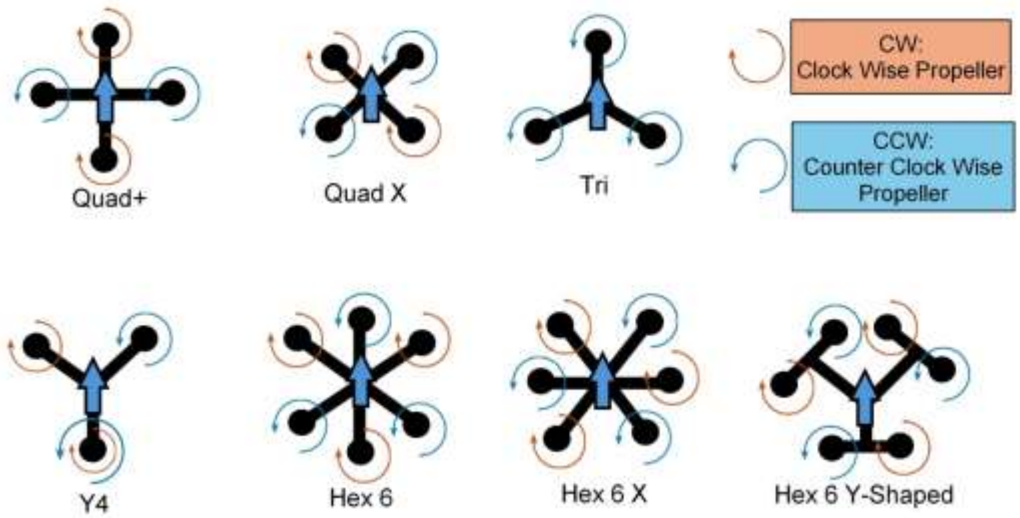

Figure 1. Configurations of multicopter body (Anweiler and Piwowarski, 2017).

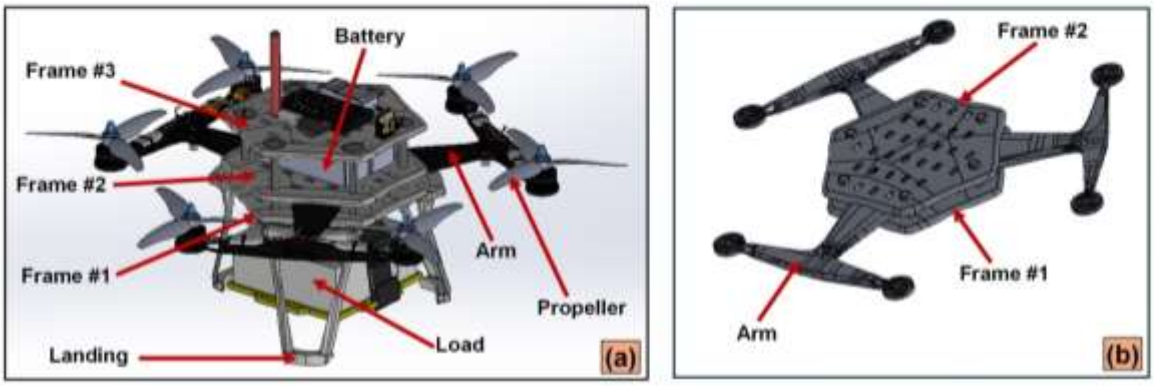

Figure 2. (a) Design of the high-payload carrying hexacopter, (b) isolated frames and propeller arm.

Figure 3. (a) Original design of the frame and propeller arm of the hexacopter, (b) Simplified design of the frame and propeller arm of the hexacopter.

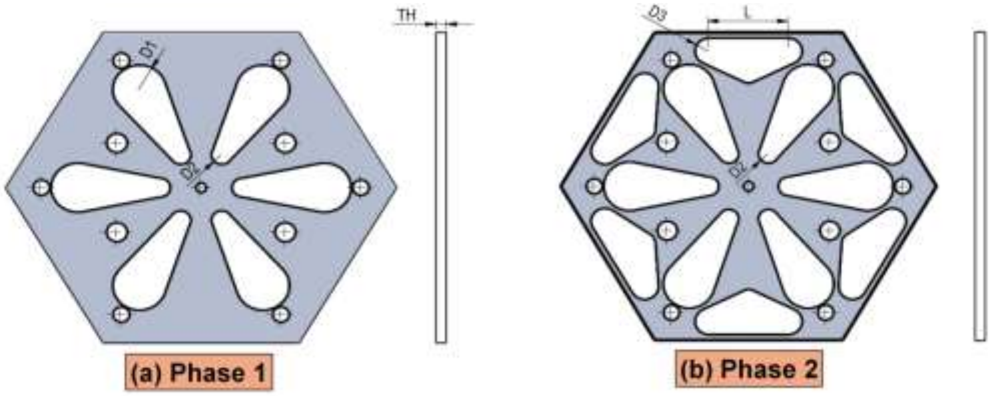

Figure 4. (a) 1st phase of the optimization and corresponding parameters (D1, D2 and TH), (b) 2nd phase of the optimization and corresponding parameters (D3 and L).

For the parametric optimization of the hexacopter drone, five different dimensions were defined as variable parameters of the design space. Since the design study depends on the number of parameters and levels, the optimization process was divided into two phases. The first phase consists of three parameters such as; D1 (first radius of slot), D2 (second radius of the slot), and TH (thickness of the frame). After optimizing parameters of the first phase, the second phase was performed. The parameters of the second phase are D3 (twin radii of the slot) and L (distance between slot origins). The phases and corresponding parameters of the frame are given in Figure 4. The parameter levels and design table are given in Table 1. There are 27 and 9 design scenarios in 1st phase and 2nd phase of the parametric optimization, respectively.

2.3. Finite Element Simulation

After the optimization parameters were determined, the finite element model was established. The frames are fixed at the bolt connection surfaces. The external forces are defined as the following constraints of the hexacopter:

- the thrust force of each propeller (3.5 kgf),
- the payload at the bottom (20 kgf),
- and weight of the Frame #3 and other electronic components.

In Figure 5, defined forces are demonstrated. The thrust force for each propeller was determined as 34.3 N (3.5 kgf) which is in agreement with the literature considering the high payload. The payload was defined as 219 N. The actual load was 196 N (20 kgf) and the remaining was the landing component, Frame #3 and other electronic components are given in Figure 2 previously in this study.

The materials were also defined as Al 6061-T6 Grade for Frame #1, Frame #2 and the propeller arm. Al 6061-T6 Grade is a commonly used multicopter structure material due to its high strength/weight ratio. The connection components were defined as 1045 steel. Thus, the software could calculate the overall weight of the isolated parts. When forces and materials were defined, the curvature type mesh was generated in SolidWorks Simulation.

A mesh sensitivity analysis was conducted to examine how simulation results change with mesh element size. In a mesh sensitivity analysis, convergence occurs when the numerical solution obtained with one grid size or configuration is not significantly different from another (Abdulsalam, 2021). This means that an acceptable level of accuracy has been attained, and further refinement is not required. The sensitivity analysis was made according to the gradual change of the maximum element size between 32 mm and 8 mm. Figure 6 shows the variation in mesh distribution between the extreme points of this gradualness, which ranges from coarse to fine.

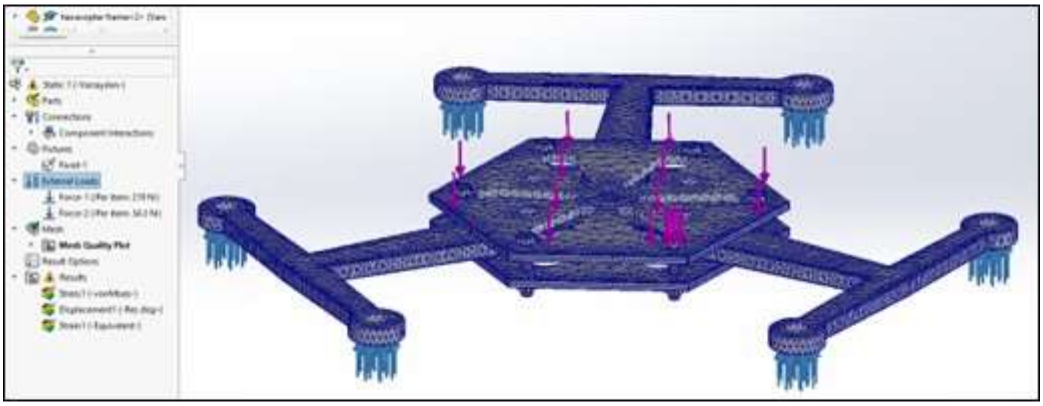

Figure 5. Defining external loads and generating mesh in SolidWorks simulation.

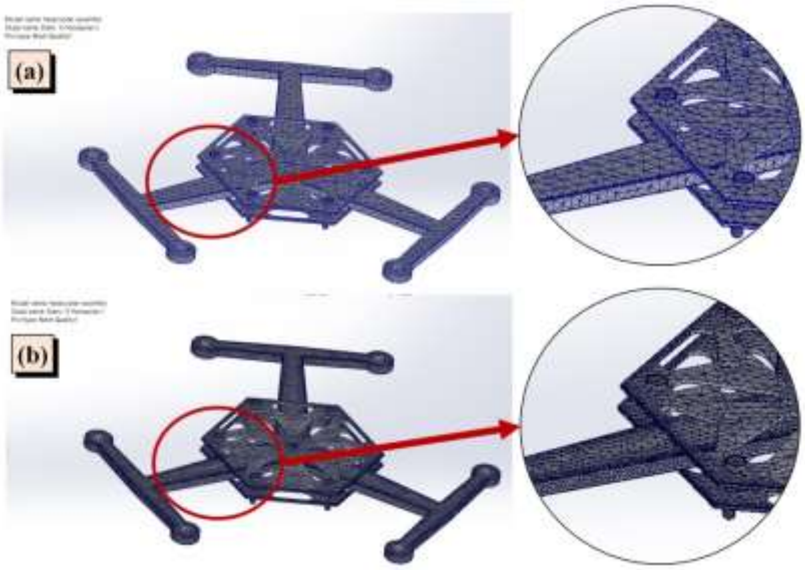

Figure 6. (a) Coarse and (b) fine meshing of hexacopter sub-assembly.

3. Results and Discussion

3.1. Mesh Sensitivity Analysis

The results of the mesh sensitivity analysis are given in Table 2. As can be seen from the Table, the maximum stress of the resultant did not significantly change after 14 mm of element size. Therefore, in this study, fine meshing, which is between 9 mm and 14 mm, was preferred. The visualization of the Table 2 is given in Figure 7. In this figure, the convergence was clear, and a 9 mm element size was chosen for the simulations. Further decreasing the mesh size was not allowed in the educational version of SolidWorks Simulation.

Table 2. The results of the mesh sensitivity analysis

Mesh Density	Max. Element Size (mm)	Max. Von Mises Stress (MPa)	Maximum Deformation (mm)	Max. Equivalent Strain
Coarse	32	49.84	0.3045	$3.625 \cdot 10^{-4}$
↑	29	53.57	0.3059	$3.349 \cdot 10^{-4}$
↑	26	54.62	0.3053	$3.484 \cdot 10^{-4}$
↑	23	56.22	0.3028	$2.731 \cdot 10^{-4}$
↑	20	58.86	0.2997	$2.916 \cdot 10^{-4}$
↓	17	61.94	0.3046	$3.179 \cdot 10^{-4}$
↓	11	61.98	0.3041	$3.301 \cdot 10^{-4}$
↓	14	62.22	0.3044	$2.558 \cdot 10^{-4}$
Fine	9	63.10	0.3158	$3.875 \cdot 10^{-4}$

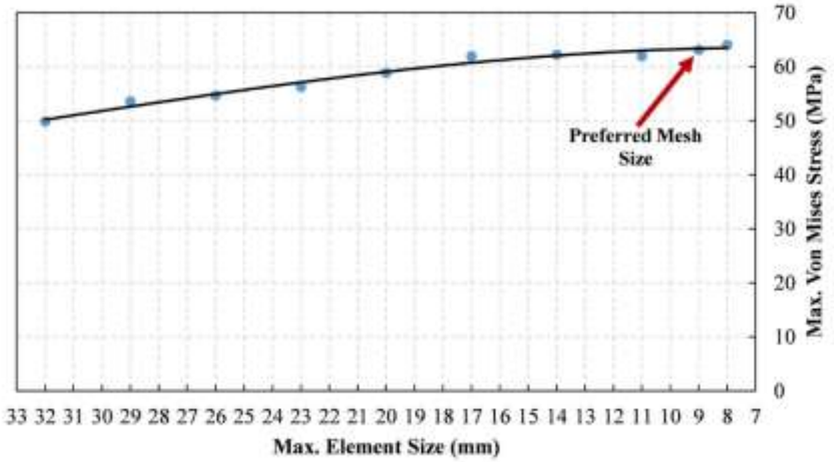

Figure 7. Result of the mesh sensitivity analysis.

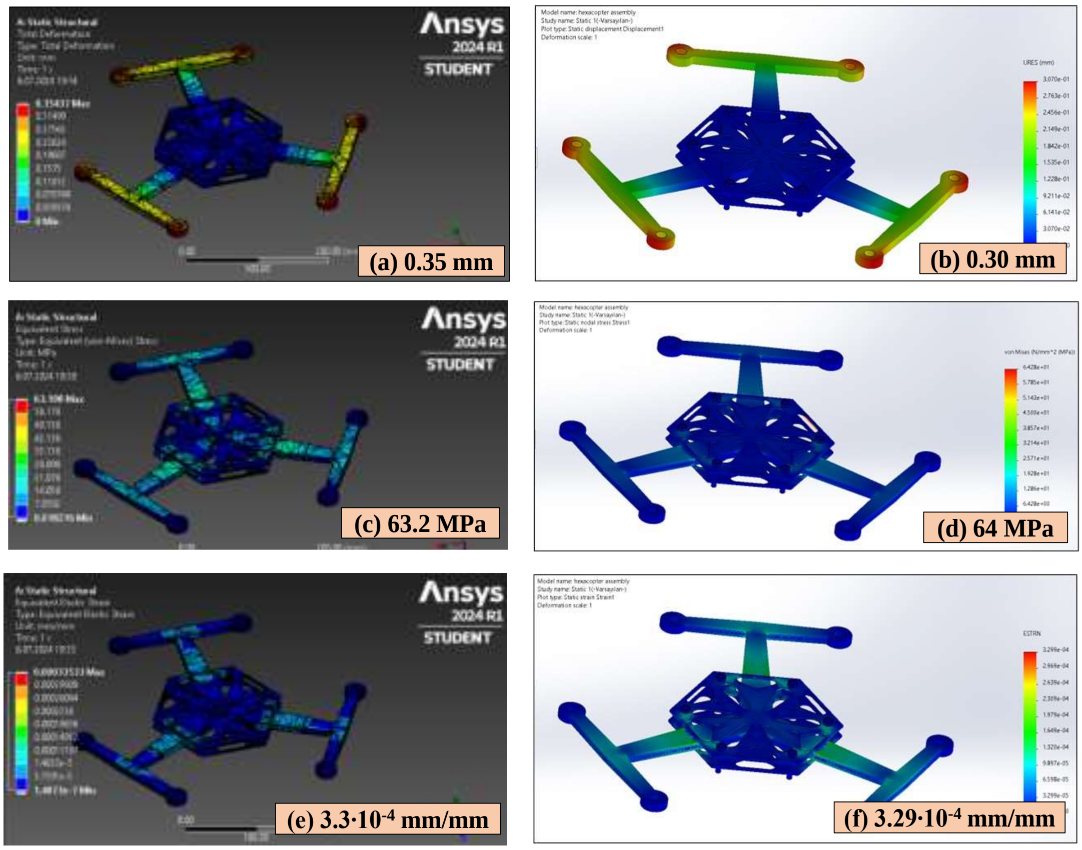

Figure 8. The comparison between total deformation for (a) ANSYS Mechanical and (b) SolidWorks Simulation; between Von Mises stress for (c) ANSYS Mechanical and (d) SolidWorks Simulation; between equivalent strain for (e) ANSYS Mechanical and (f) SolidWorks Simulation.

3.2. Sofware Reliability Assessment

In this study, SolidWorks Simulation software was chosen for linear static analyses. When performing linear static analyzes in which Hooke's law of elasticity is valid, SolidWorks Simulation is used because the analysis time is faster than other software (Tyflopoulos and Steinert, 2022). However, software such as ANSYS Mechanical, where simulation parameters are more flexible and tunable, can be perceived as more reliable. Therefore, to test the reliability of SolidWorks Simulation software, linear static analyses were performed with both software with the same parameters. According to the results, the maximum Von Mises stresses were obtained as 63.2 MPa and 64 MPa for ANSYS and SolidWorks Simulation, respectively. The equivalent elastic strain was obtained as $3.3 \cdot 10^{-4}$ and $3.29 \cdot 10^{-4}$ in the same order. Finally, the total deformation was obtained as 0.35 mm and 0.30 mm in the same order. When the results were examined, it was seen that there was a maximum of 2% difference between the stress and strain values. The total deformation was also consistent with each other with a maximum error of 15%. As a result, SolidWorks Simulation was used in the continuation of the study due to its advantages such as shorter analysis time. The results of the two software are given in Figure 8 to clearly observe the differences.

3.3. 1st Phase of Parametric Optimization

The results of the 1st phase of parametric optimization are given in Table 3. The maximum deformation was below 0.3 mm which was acceptable when compared to 1 mm deformation of the hexacopter arm in the literature (Shelare et al., 2023). The maximum Von Mises stress was found to be approximately 52 MPa, indicating a safe drone design, considering the yield strength of the Al 6061-T6 is 275 MPa. The Von Mises stress, equivalent strain, and total deformation results are given in Figure 9, Figure 10, and Figure 11, respectively.

To determine the optimal design scenario, the mass of the sub-assembly (mass of the frame-arm assembly) was sorted in ascending order. Sorted data is visualized in Figure 12. It is clear from Figure 12 that the optimal design scenario can be chosen as simulation no. 3. Because simulation no. 3 is below the average mass and indicates the minimum equivalent strain in that region. The optimal simulation was chosen by the user-driven optimization approach because the minimizing weight approach does not consider changes in equivalent strain.

Table 3. Result table for 1st phase parametric optimization. The optimal design scenario is highlighted

No.	D1 (mm)	D2 (mm)	TH (mm)	Max. Deformation (mm)	Mass (g)	Eq. Strain
1	R10	R5	5	0.26	1215	$2.57 \cdot 10^{-4}$
2	R10	R5	4	0.27	1117	$2.71 \cdot 10^{-4}$
3	R10	R5	3	0.28	1020	$2.58 \cdot 10^{-4}$
4	R10	R7	5	0.26	1175	$2.70 \cdot 10^{-4}$
5	R10	R7	4	0.27	1102	$2.67 \cdot 10^{-4}$
6	R10	R7	3	0.28	1009	$2.62 \cdot 10^{-4}$
7	R10	R9	5	0.26	1175	$2.60 \cdot 10^{-4}$
8	R10	R9	4	0.27	1086	$2.61 \cdot 10^{-4}$
9	R10	R9	3	0.28	997	$2.62 \cdot 10^{-4}$
10	R12.5	R5	5	0.26	1183	$2.60 \cdot 10^{-4}$
11	R12.5	R5	4	0.27	1092	$2.72 \cdot 10^{-4}$
12	R12.5	R5	3	0.29	1002	$2.69 \cdot 10^{-4}$
13	R12.5	R7	5	0.26	1165	$2.62 \cdot 10^{-4}$
14	R12.5	R7	4	0.28	1078	$2.53 \cdot 10^{-4}$
15	R12.5	R7	3	0.29	990	$2.73 \cdot 10^{-4}$
16	R12.5	R9	5	0.26	1144	$2.50 \cdot 10^{-4}$
17	R12.5	R9	4	0.27	1061	$2.68 \cdot 10^{-4}$
18	R12.5	R9	3	0.29	978	$2.62 \cdot 10^{-4}$
19	R15	R5	5	0.27	1149	$2.70 \cdot 10^{-4}$
20	R15	R5	4	0.28	1065	$3.08 \cdot 10^{-4}$
21	R15	R5	3	0.29	981	$2.61 \cdot 10^{-4}$
22	R15	R7	5	0.27	1131	$2.59 \cdot 10^{-4}$
23	R15	R7	4	0.28	1051	$2.76 \cdot 10^{-4}$
24	R15	R7	3	0.29	970	$2.62 \cdot 10^{-4}$
25	R15	R9	5	0.27	1110	$3.41 \cdot 10^{-4}$
26	R15	R9	4	0.28	1034	$2.78 \cdot 10^{-4}$
27	R15	R9	3	0.29	958	$2.64 \cdot 10^{-4}$

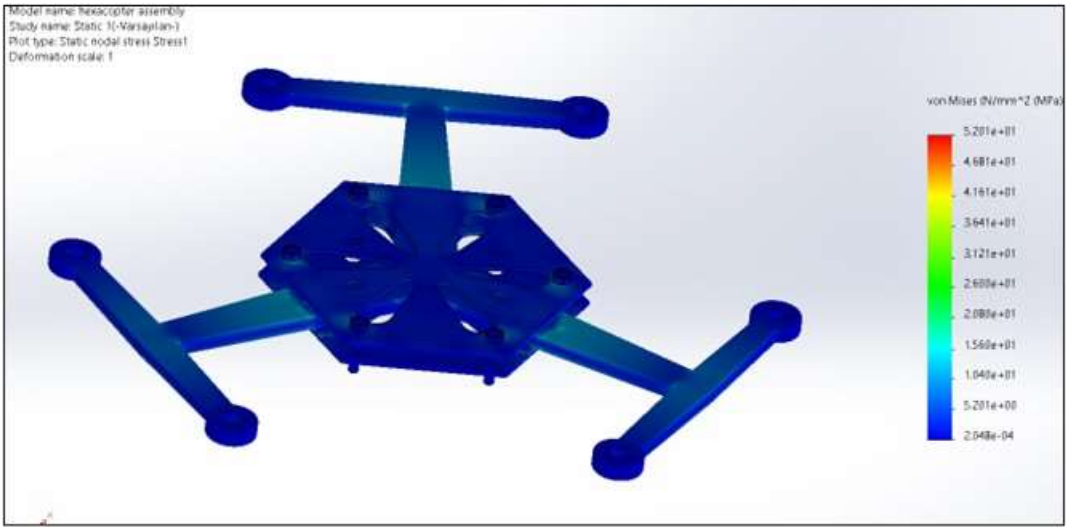

Figure 9. Von Mises stress results for the optimal solution in 1st phase.

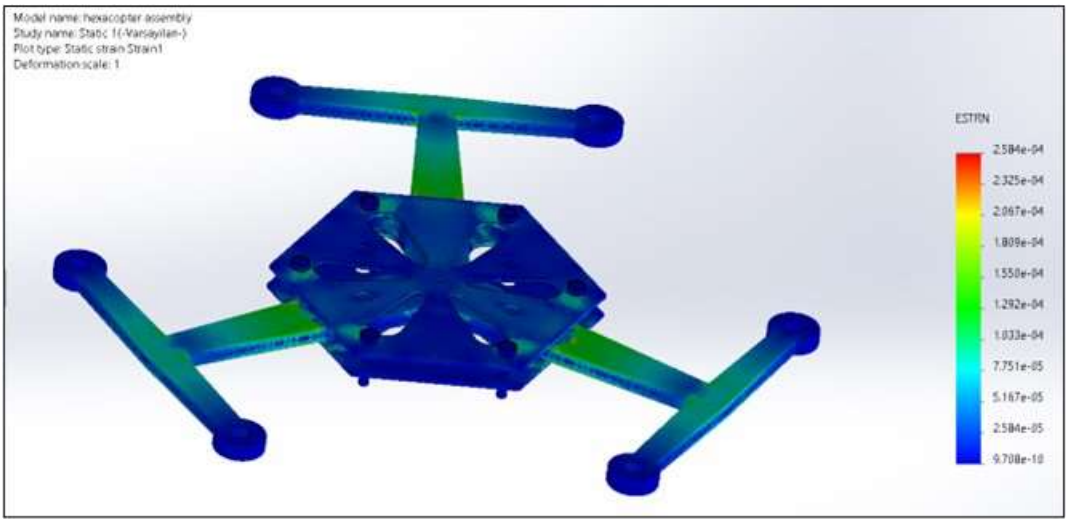

Figure 10. Equivalent strain results for the optimal solution in 1st phase.

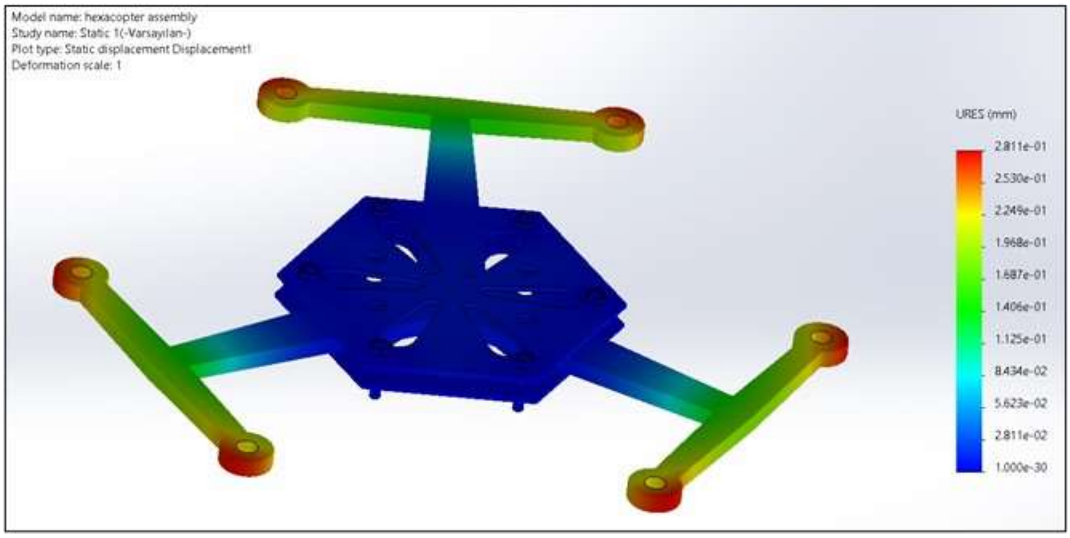

Figure 11. Total deformation results for the optimal solution in 1st phase.

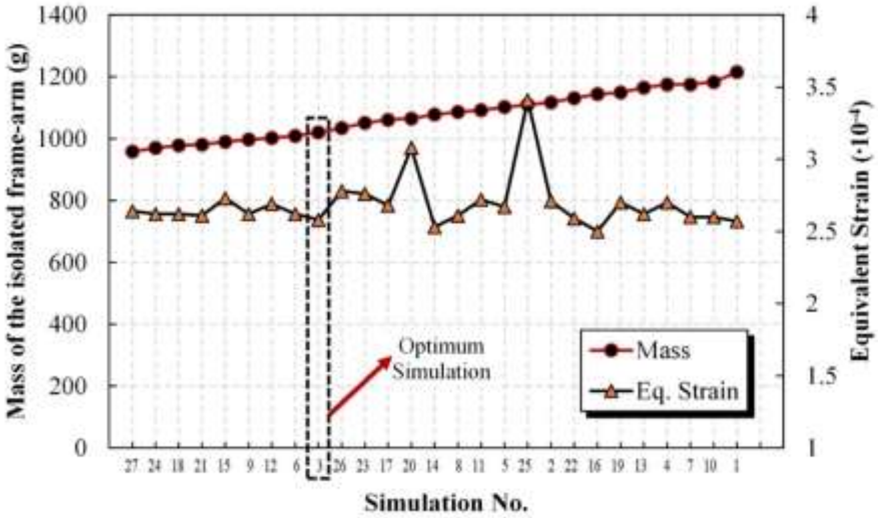

Figure 12. 1st phase graph of mass-equivalent strain where the mass of the frame-arm assembly was sorted in ascending order.

Table 4. Result table for 2nd phase parametric optimization. The optimal design scenario is highlighted

No.	D3 (mm)	L (mm)	Max. Deformation (mm)	Mass (gr)	Eq. Strain
1	R5	20	0.29	976	$2.93{\cdot}10^{-4}$
2	R5	30	0.30	962	$3.29{\cdot}10^{-4}$
3	R5	40	0.32	947	$4.13{\cdot}10^{-4}$
4	R6	20	0.29	970	$3.22{\cdot}10^{-4}$
5	R6	30	0.30	954	$3.53{\cdot}10^{-4}$
6	R6	40	0.33	938	$3.36{\cdot}10^{-4}$
7	R7	20	0.30	963	$3.39{\cdot}10^{-4}$
8	R7	30	0.30	946	$3.29{\cdot}10^{-4}$
9	R7	40	0.35	929	$4.81{\cdot}10^{-4}$

3.4. 2nd Phase of Parametric Optimization

The results of the 2nd phase of parametric optimization are given in Table 4. Similarly, the maximum deformation was nearly 0.3 mm. The maximum Von Mises stress was found approximately 64 MPa, indicating a safe drone design considering the yield strength of the Al 6061-T6 is 275 MPa. The Von Mises stress, equivalent strain, and total deformation results are given in Figure 13, Figure 14, and Figure 15 respectively. A similar user-driven optimization approach leads the designer to choose the optimal simulation as simulation no. 8 as shown in Figure 16. The parameters corresponding to these optimum simulations will lead to the parameter set that will give the optimum result.

As a result, the first and second optimization processes are summarized in Figure 17 where the highest, lowest, and optimal parameters are given. Using parametric optimization, basic hollow geometries on the hexacopter frame are optimized for low weight and high strength. The most important result of this study was the weight reduction of the hexacopter, where the weights of the battery, motors, propellers, and payload are assumed to be constant. Considering the design in Figure 3b, a weight reduction was achieved with the optimized design compared to the fully filled frame. According to the numerical analysis results, the mass information of the sub-assembly in Figure 3b was taken from the SolidWorks mass properties option. Accordingly, based on alternative situations where the frame thickness is 3 mm, 4 mm, and 5 mm; the total mass of the sub-assembly was reduced by 15 %, 18 %, and 20 % respectively. If the change in mass is examined, the mass of the sub-assembly using the 3 mm thick frame design decreased from 1108 g to 946 g; the 4 mm thick one decreased from 1235 g to 1019 g; and the 5 mm thick one decreased from 1361 g to 1092 g. Since the flight time increases as the thrust to mass ratio increases as stated in the previous studies, mass reduction will increase the flight time of the hexacopter in this study (Pollet et al., 2022). In literature, the studies mostly focus on the optimal configuration of multicopters, instead of focusing on the mass reduction of the frame. For instance, in a study conducted by Shelare et al. (2023), the mass optimization of the payload in a hexacopter design by numerical simulations has been investigated. They carried out analyzes at six different payload values while keeping the hexacopter frame weight constant. Based on the maximum stress values obtained in the analysis, they found that the maximum weight that could be used would be 7.5 kg. In this study, unlike the previously mentioned study, the load was assumed to be constant, and the drone frame design was optimized, resulting in a mass reduction of up to 20 % in the frame design of the drone.

In future studies, it is possible to improve the optimization process, the same hexacopter body can be improved by both parametric and topology optimization for comparison. There are studies in the literature comparing both optimization methods. In one of these studies, three methods which are topology optimization, parametric optimization and simultaneous parametric topology optimizations were compared (Tyflopoulos and Steinert, 2020).

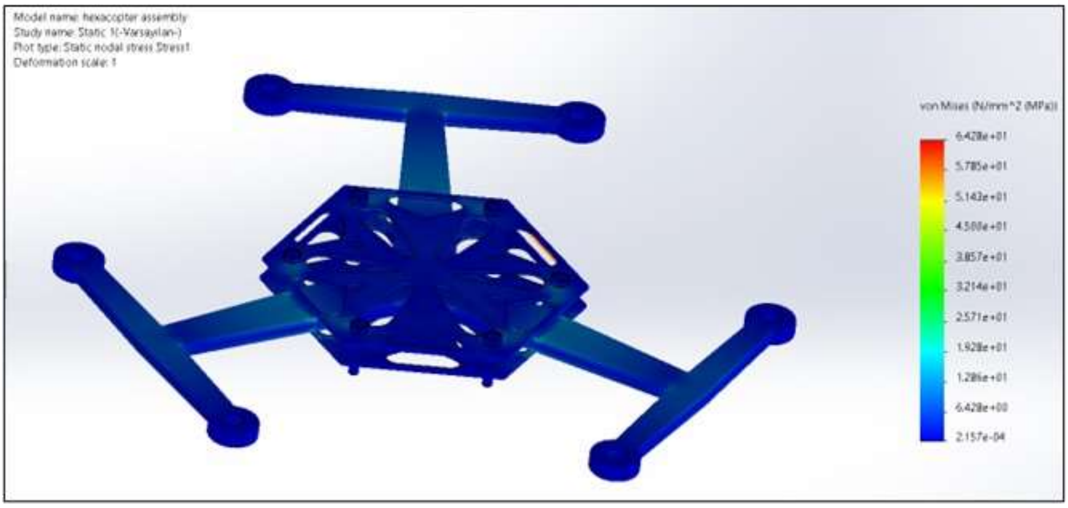

Figure 13. Von Mises stress results for the optimal solution in 2nd phase.

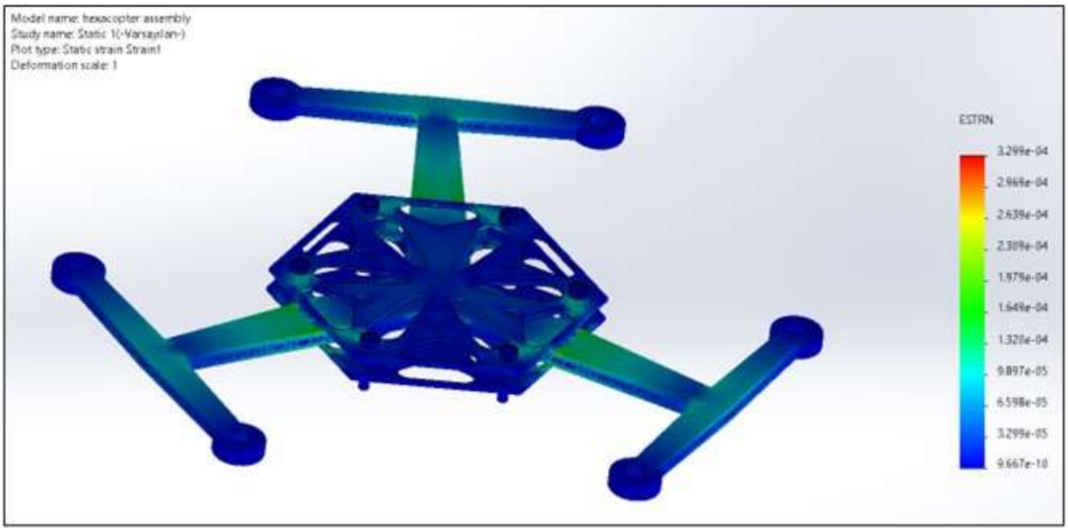

Figure 14. Equivalent strain results for the optimal solution in 2nd phase.

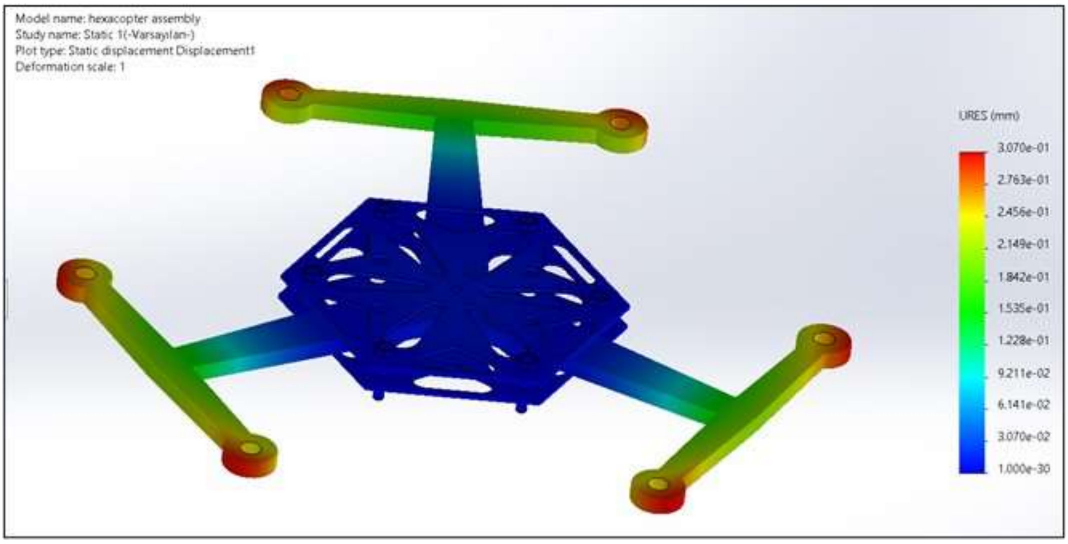

Figure 15. Total deformation results for the optimal solution in 2nd phase.

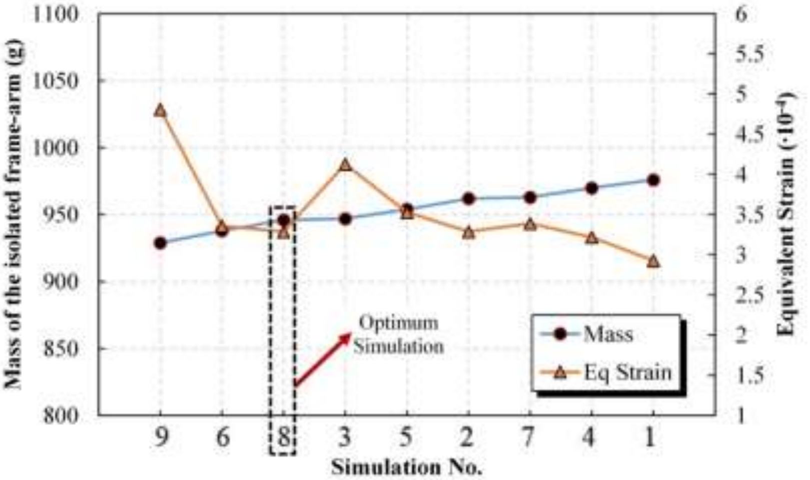

Figure 16. 2nd phase graph of mass-equivalent strain where the mass of the frame-arm assembly was sorted in ascending order.

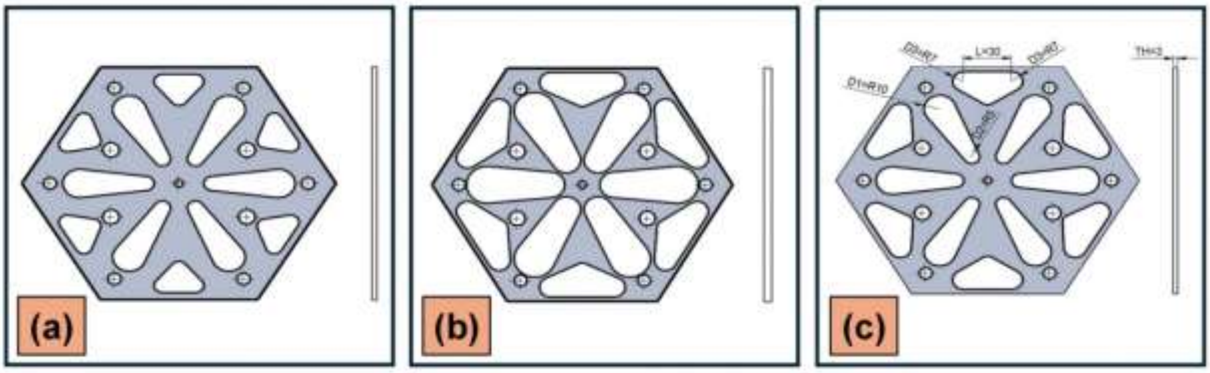

Figure 17. (a) Minimum parameter levels for both 1st phase and 2nd phase, (b) Maximum parameter levels for both 1st phase and 2nd phase, (c) Optimal parameter levels for both 1st phase and 2nd phase with optimal dimensions.

According to the results of the study, the third alternative method, which is simultaneous, was found to be the most efficient optimization method. Therefore, although they are quite different in terms of cost and optimization time, topology optimization and parametric optimization can be seen as methods that positively affect each other in calculations such as mass reduction.

4. Conclusion

A parametric optimization via design study for the essential structural parts of a high payload hexacopter drone was presented. The main load-carrying parts of the hexacopter were isolated and simplified. The payload was 20 kgf, and each propeller had 3.5 kgf lifting capability. The material of the components was Al 6061-T6, primarily used for drone structures. The parametric optimization was performed in two stages. In the first stage, both frames are updated with a slot geometry to decrease the total mass of the drone body. In the second stage, mass was reduced even further. The maximum Von Mises stress was found to be 64 MPa, and the design is safe since the stress was nearly one-quarter of the yield strength. The maximum deformation was also below 0.3 mm with optimal parameters. As a result, a lighter hexacopter structure is achieved by using a design approach suitable for conventional machining methods. Further studies can be conducted by generating the G-codes using computer-aided manufacturing (CAM) software. This allows a cost comparison between the drone frame made by additive manufacturing and the one designed to be machined using conventional methods for a similar size.

Author Contributions

The percentage of the author(s) contributions is presented below. The author reviewed and approved the final version of the manuscript.

	O.Ö.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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