All Sciences Proceedings
http://as-proceeding.com/

5th International Conference on Applied Engineering and Natural Sciences

July 10-12, 2023 : Konya, Turkey



https://www.icaens.com/

# Remodeling of the Drone Chassis Designed for Additive Manufacturing Method According to Topology Optimization

Alican YAKIN [*], Tuncay ŞİMŞEK[2] and Adnan AKKURT [3]

[1] *Department of Industrial Design Engineering, Faculty of Technology, Gazi University, Turkey*
[2]*Department of Motor Vehicles and Transportation, Kırıkkale Vocational School, Kırıkkale University, Turkey*
[3]*Department of Industrial Design Engineering, Institute of Science, Gazi University, Turkey*

[*]*alicanyakin49@gmail.com*

***Abstract –*** In the last few years, additive manufacturing methods have made remarkable advancements, and with the emergence of next-generation additive manufacturing techniques, the variety of raw materials has increased, and part design criteria have been improved. Particularly, the development of metal additive methods has made revolutionary contributions to the manufacturing field and offered a new and unique perspective on design. While traditional manufacturing methods require adherence to specific and standardized design criteria, there are no rules or standards that must be followed in additive manufacturing, except for a few criteria. This is one of the most significant features that distinguishes additive manufacturing methods from traditional methods. The freedom of design provided by additive manufacturing enables much more successful mass reduction in the parts produced using these methods. Mass reduction is expected to be minimal in aerospace, automotive, medical, and dental applications. In this study, first, a drone chassis was designed using NX software, and static analysis was performed in Ansys program by defining specific boundary conditions for the designed drone chassis. Then, based on the conducted static analysis, topology optimization was carried out in Ansys program to achieve mass reduction. As a result of the topology optimization performed, it was observed that the obtained geometry decreased from 5.8394 kg to 1.288 kg. After the topology optimization, the obtained geometry was redesigned in the NX environment, and static analysis was applied to the redesigned geometry. Considering the results of the applied static analysis, it was observed that the part can operate safely under working conditions. It was determined that the mass was reduced by approximately 78% after topology optimization, indicating that topology optimization was highly successful in the mass reduction process.

*Keywords – Topology Optimization, Layered Manufacturing, Drone Design, Advanced Manufacturing, Static Analysis*

## I. INTRODUCTION

With the rapid development of technology and industry, it is known that the manufacturing methods currently used are insufficient to meet the needs and expectations of the industry. Throughout history, scientists have worked to meet the required features and qualities, to create accessible technologies that are more comfortable, faster, more economical, and encompass multiple features in a single structure. From the past 10 years to the present, the progress made by technology has reached unimaginable levels, and it is predicted that breathtaking advancements will take place in the coming years. When it comes to manufacturing methods, it is known that the earliest humans shaped stones and objects by chiseling them with sharp stones, and later developed some hand tools with the discovery of metals. Over time, various mechanical machine-like structures were created. Then, with the onset of mechanization, manually controlled machines were developed, followed by the development of software, leading to the creation of semi-automatic and fully automatic working machines. Although the level achieved by computer-aided machines, called fully automatic, is high, it is observed that using these machines to process complex geometric structures takes a long time or is not possible [1-5]. When considering the long duration from the manufacturing of an assembly group, which involves complex and multiple parts, to its assembly, it is evident that much more advanced and high-level manufacturing methods are required. Layered manufacturing methods are seen as highly important and remarkable methods in meeting these high-level expectations. Additive manufacturing method can generally be defined as a method of material production where materials are continuously fed from a material feeding funnel and controlled melting of the fed materials using thermal sources such as laser, plasma, electron bombardment is carried out on a substrate to accumulate the material. It is observed that complex geometric structures that would take a long time or be difficult to produce using traditional methods can be produced in a single step using layered manufacturing. Additionally, while assembly structures with multiple complex geometries require multiple stages with traditional methods, assembly groups can be produced in a single step using layered manufacturing methods. This eliminates the manufacturing time for parts that would take a long time and the assembly time, resulting in time and cost savings. In layered manufacturing methods, powders or wires are commonly used as raw materials. In both cases, the fed material is melted using a power source, and the desired structure is obtained by stacking the material in layers. Various layered manufacturing methods exist, such as Vat Photo Polymerization (VP), Powder Bed Fusion, Extrusion-based systems, Material Jetting (MJ), Binder Jetting (BJ), and Directed Energy Deposition (DED) [4, 6, 7]. The selection of an appropriate method should consider parameters such as part geometry, desired characteristics, working conditions, part size, and production cost. One of the greatest advantages provided by additive manufacturing methods is the ability to offer designers a free perspective in design, allowing them to create designs as they wish. Unlike traditional methods, additive manufacturing does not require designs to adhere to standard structures and dimensions, which enables a new and innovative approach to design. It is known that the most effective way to utilize the advantages of additive manufacturing is through design. It is known that parts produced using traditional methods have higher mass compared to those produced using additive manufacturing. The capability of additive manufacturing to produce complex geometries allows for significant benefits in topology analysis. One of the main objectives of topology analysis is to minimize the mass of a part while meeting the specified boundary and load conditions, thus enabling material savings. Traditional and additive manufacturing also differ in terms of design. To effectively design parts for additive manufacturing, several parameters should be considered, including part size, post-processing operations after additive manufacturing, desired surface quality, material working conditions, and material strength. There are various CAD design and analysis software programs used in additive manufacturing, such as OptiStruct, Abaqus, Solidworks, Ansys, Netfabb, Siemens NX, Fusion, and others [8-12].

This study focuses on one of the additive manufacturing methods, namely the Powder Bed Fusion (PBF) method, discussing its advantages, disadvantages, and detailed process parameters. A drone chassis was designed to be synthesized using the PBF method, and topology optimization was performed for the designed chassis. Based on the optimization results, the chassis was redesigned. The redesigned chassis underwent static analysis, and the results of the analysis were discussed.

### *A. Additive Manufacturing Method*

The additive manufacturing method, considered as a superior and next-generation manufacturing method compared to traditional manufacturing methods, is widely used and researched in various industrial sectors, academia, biomaterials, medicine, aerospace industry, automotive industry, toy industry, electronics, and many other engineering fields [10, 13-19]. Despite having superior and intriguing features, it is necessary to mention that there are certain aspects of additive manufacturing technologies that need to be improved. Some of these aspects include limited material size that restricts the production of larger components, material strength issues due to rapid cooling process, high cost of raw materials, machine setup, and initial investment. Its superior properties, promising future, and areas for improvement have attracted researchers to focus on this field and conduct studies. As a result of these studies, various additive manufacturing technologies have been developed, expanding the range of materials used in the additive manufacturing process. Examples of these technologies include Vat Photo Polymerization Process (VP), Powder Bed Fusion Process, Extrusion-based systems, Material Jetting (MJ), Binder Jetting (BJ), Directed Energy Deposition (DED), and others [20]. There are various process steps involved in additive manufacturing. The production process of a part using additive manufacturing consists of eight steps: conceptualization and CAD design, STL/AMF conversion, transferring the conversion file to the machine, machine setup, building/material deposition, part removal, post-processing operations, and application [9], [21].

### *B. Powder Bed Fusion (PBF)*

The Powder Bed Fusion (PBF) method is one of the first commercially available additive manufacturing methods. The Selective Laser Sintering (SLS) method, developed at the University of Texas in the United States, is known as the first commercialized PBF method. All other PBF methods have been developed based on this system with modifications. Through these developments and improvements, the variety of materials used in the method and productivity have increased. In all PBF methods, one or more thermal heat sources are used to melt the powders and create layers. The most commonly used heat sources in the PBF system are lasers. Machines that utilize lasers in the PBF process are referred to as LS machines. Polymer Laser Sintering (pLS) and Metal Laser Sintering (mLS) are two different systems within the PBF methods and have significant differences from each other [5].

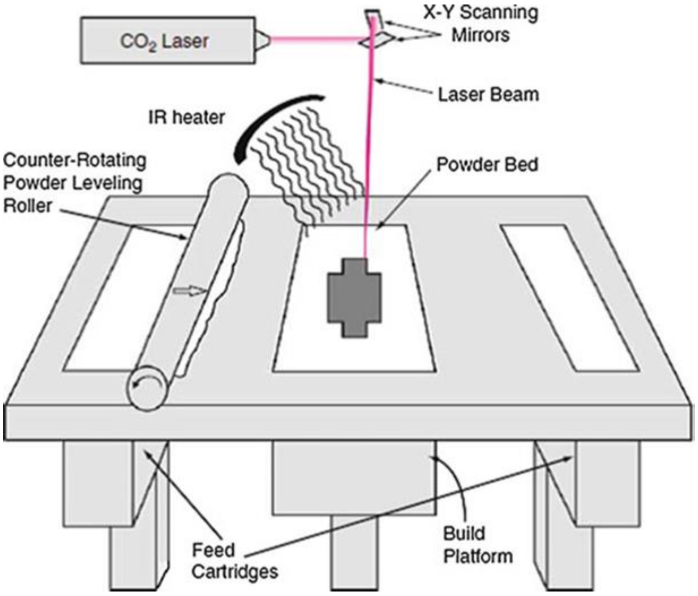



Fig.1. Schematic representation of the PBF process [5]

The LS process was initially used for producing three-dimensional geometric structures by melting plastic materials. However, with advancements in technology and scientific research, the LS process started to be utilized for processing metals and even ceramics. Figure 1 illustrates the schematic representation of the PBF process. As shown in the figure, PBF consists of an adjustable build platform, powder feeding units, a powder spreading roller, a powder bed, and a $CO_2$ laser. The particle size, shape, and uniform spreading of the powders are crucial in this process. The spread powders are selectively melted either completely or partially by laser beams that scan the desired geometry. After the melting process, a new layer of powder is spread and melted to continue the process until the final geometry is completed. One of the significant advantages of the PBF process is that it does not require any support structures, eliminating the need for post-processing support removal. Even if a part requires support, these support structures are incorporated into the part design itself, serving as structures that enhance the part's strength and necessary mechanical properties [5], [22], [23].

In the PBF process, several parameters need to be considered, which can be categorized into four categories: (1) laser-related parameters (laser power, spot size, pulse duration, pulse frequency), (2) scanning-related parameters (scanning speed, scanning environment, scanning pattern), (3) powder-related parameters (particle size, shape, distribution, layer thickness), and (4) temperaturerelated parameters (powder bed temperature, temperature distribution, powder feeder temperature).

Most of these parameters are interrelated, and selecting the appropriate parameters allows for easy synthesis of three-dimensional materials with the desired properties. The advantages and disadvantages of the PBF process are listed below
:

Advantages:

- Wide variety of materials can be used in the process
- Ability to produce high-strength parts
- No need for support structures
- High accuracy and good surface quality in part production
- PBF is one of the most popular additive manufacturing methods and is expected to continue its popularity in the future.

Disadvantages:

- Longer processing time compared to other methods
- Residual powder particles may remain in the material.

## II. Materials and Method

Design of the drone chassis was designed using Siemens NX software with dimensions of 300x300x25 mm. Similar to the aerospace industry, lightweight and durable materials are preferred for drone components. This not only enables energy efficiency but also allows the drone to achieve higher speeds and perform agile maneuvers easily and smoothly. Considering these factors, Aluminum (Al) was selected as the material for the drone. The geometry of the design created in NX is shown in Figure 2. The designed geometry was saved as a STEP file and prepared for topology optimization in the Ansys program.

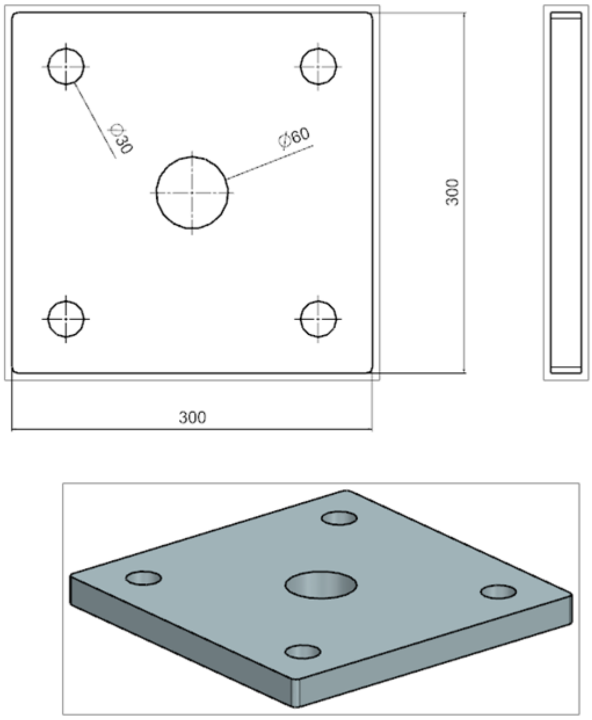



Fig.2 Drone chassis with dimensions of 300x300x25 mm designed in the NX program

### A. *Static Analysis and Topology Optimization*

The 3D geometry modelled in NX was transferred to the Ansys program in STEP format for topology optimization. The transferred geometry was first subjected to static analysis under specified boundary conditions. Subsequently, based on the results of the static analysis, a topology analysis was performed. In the Ansys environment, Al alloy (5052 Hx9) was selected as the material for the chassis, and static and topology analyses were conducted under specific boundary conditions. Figure 3 shows the steps of the solved static and topology analyses in the Ansys project environment.

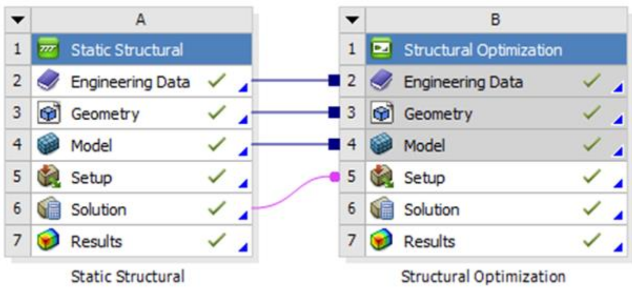



Fig.3 Static analysis and topology analysis steps

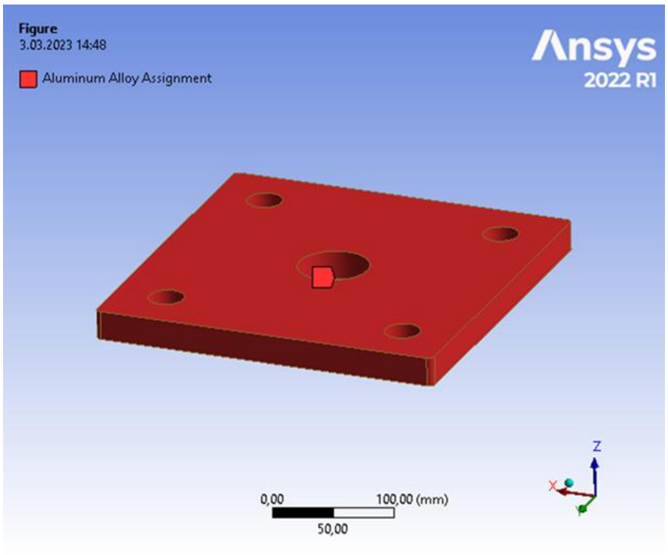



Fig. 4 The process of assigning Al alloy (5052 Hx9 ) in Ansys program

Figure 4 shows the assignment of Al alloy (5052 Hx9) to the drone chassis. Figure 5 illustrates the meshing process applied to the chassis. In the meshing process, an element size of 5 mm was selected and applied. As a result of the meshing process, it was observed that the chassis had a total of 82,312 nodes and 17,292 elements. Considering the mesh density, it can be said that the 5 mm element size is sufficient for static and topology analysis. Although increasing the number of mesh elements up to a certain value can lead to more accurate and realistic analysis results, further increasing this number does not make a significant difference in terms of analysis outcomes. Selecting an excessive number of mesh elements can increase the analysis time and burden the computer. Therefore, it is important to choose the appropriate number and shape of mesh elements that are suitable for the geometry under investigation.

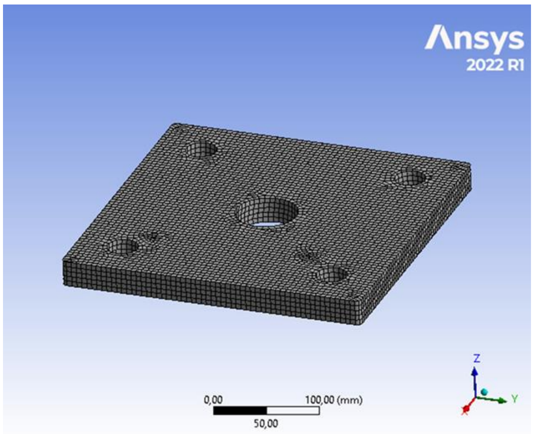



Fig. 5. Illustration of the meshing process made in the Ansys program

*B. Boundary Conditions Applied*

In order to achieve the desired outcome in topology optimization, static analysis needs to be conducted under certain boundary conditions. The results of the static analysis are utilized by the topology analysis to perform mass reduction. For the static analysis, forces applied by the drone propellers and the weight of the object itself are taken into account. As shown in Figure 6, forces up to 100 N are applied from four different surfaces in the +Z direction.

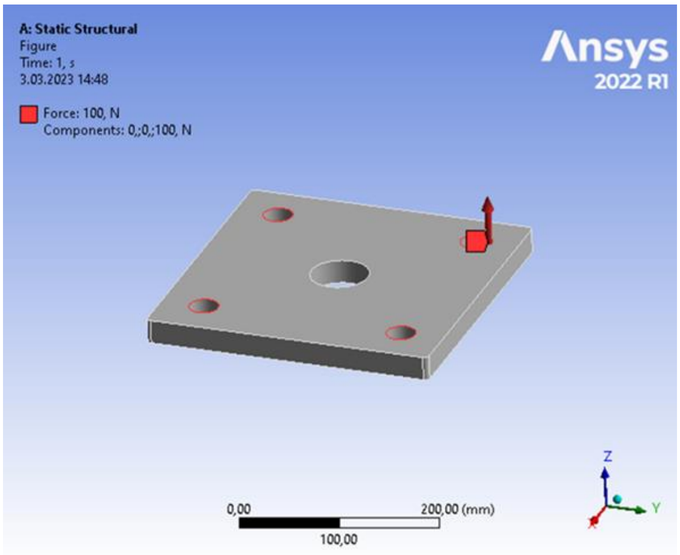



Fig. 6 Aplied forces

In Figure 7, it is seen that the chassis is fixed from the circular surface in the middle. In order to calculate the amount of deformation and stress created by the applied force, the object must be fixed.

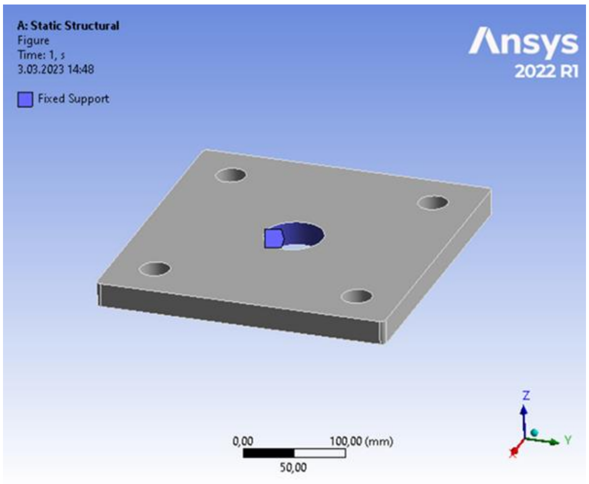



Fig. 7 Fixing the chassis

## III. Results

### A. *Static Analysis Results*

The drone chassis without topology optimization was subjected to static analysis and the results are given in figure 8 and figure 9. When Figure 8 is examined, it is seen that the maximum value of the total deformation amount is as small as 0.0013314 mm.

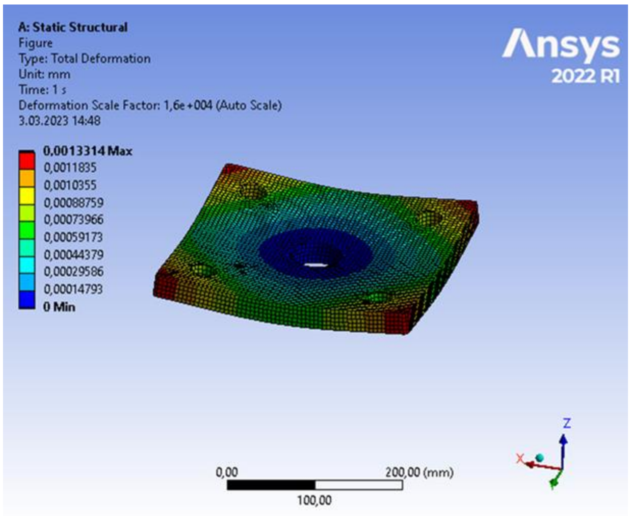



Fig.8 Total amount of deformation in the chassis

When examining Figure 9, it can be seen that the maximum stress value (Von Mises) obtained is 0.39 MPa. Evaluating the total maximum deformation and maximum stress values obtained, it is evident that the current drone chassis can operate safely.

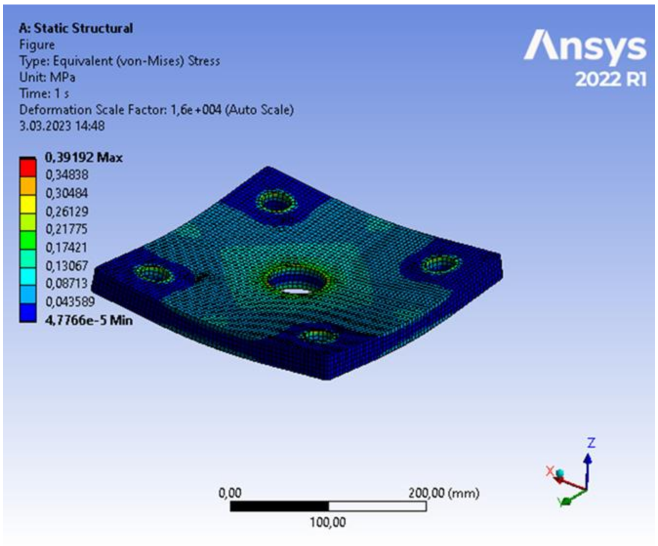



Fig. 9 The total amount of stress in the chassis

### B. *Boundary conditions applied for Topology Optimization*

To achieve the desired results in topology analysis, certain boundary conditions need to be applied. When the objective of topology optimization is to minimize mass, it raises the question of where the mass should be reduced. Answering this question involves expressing which areas should not have mass reduction through boundary conditions. In Figure 10, five cylindrical surfaces where mass needs to be preserved are selected. It is stated that these cylindrical surfaces will be preserved during the mass reduction. In addition to the mentioned boundary conditions, providing the required amount of mass to be conserved as a condition also helps to save time by reducing the analysis duration and the number of iterations. Figure 11 illustrates the magnitude of the mass to be preserved.

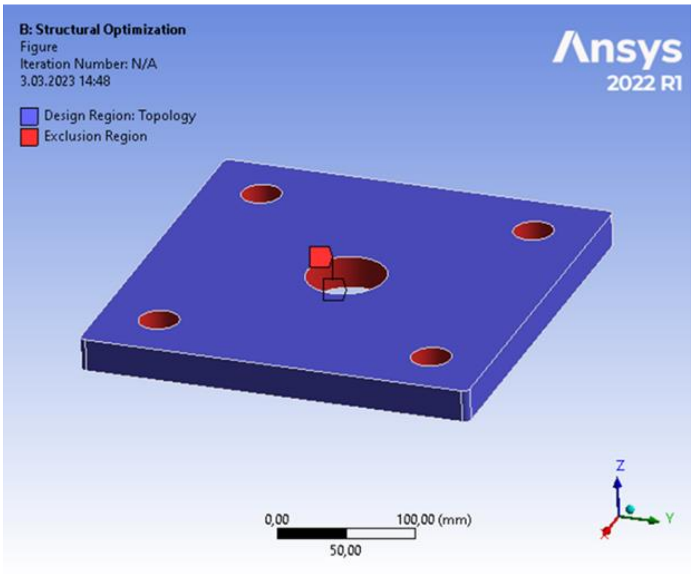



Fig. 10 Regions where topology optimization is excluded

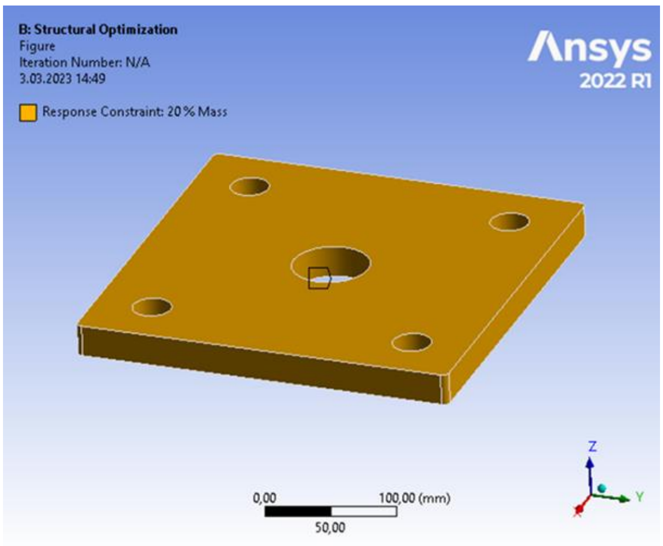


Figure 11. Percentage of mass to be protected (20%)

If production is to be carried out using additive manufacturing, designing the part to require minimal support is crucial as it reduces post-processing operations. In order to achieve additive manufacturing without the need for support structures, the part should be designed with a minimum angle restriction of 45 degrees. Therefore, it is important to set the minimum angle constraint when determining the boundary conditions. This way, during topology optimization, mass reduction can be achieved by creating minimum 45-degree angles. Figure 12 show overhang angle condition (minimum 45 degrees) during the additive manufacturing process.

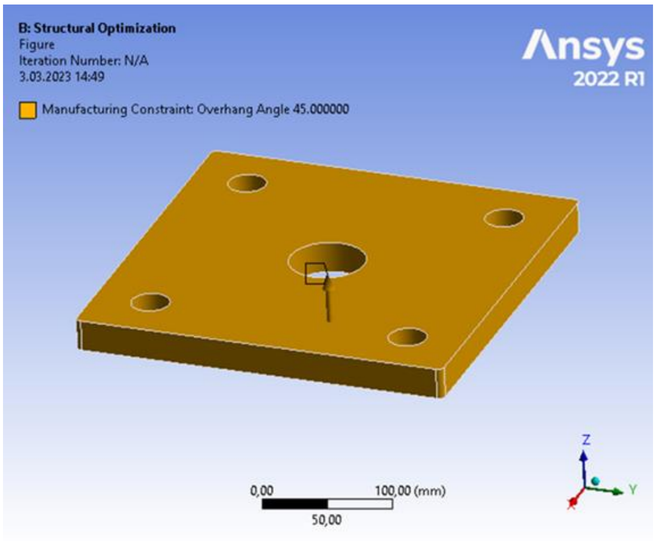



Fig. 12 Representation of the overhang angle condition (minimum 45 degrees) during the mass accumulation process in the +Z direction.

C. *Topology Optimization Results*

The topology optimization, conducted with the applied boundary conditions mentioned above, was successfully completed in 35 iterations, reaching the target mass. When examining Table 1, it can be seen that the mass reduced from 5.8394 kg to 1.288 kg, resulting in an approximate decrease of 22.057% compared to the initial mass. The obtained results demonstrate that significant mass reduction can be achieved through topology optimization, resulting in approximately 80% material savings.

Table 1. Comparison of the mass value obtained through topology optimization with the initial mass.

| | |
|---|---|
| **Original mass** | 5,8394 kg |
| **Final mass** | 1,288 kg |
| **Percent mass of original** | 22,057 |
| **Information** | |
| **Iteration number** | 35 |

The geometry obtained from the topology optimization is shown in Figure 13 and Figure 14.

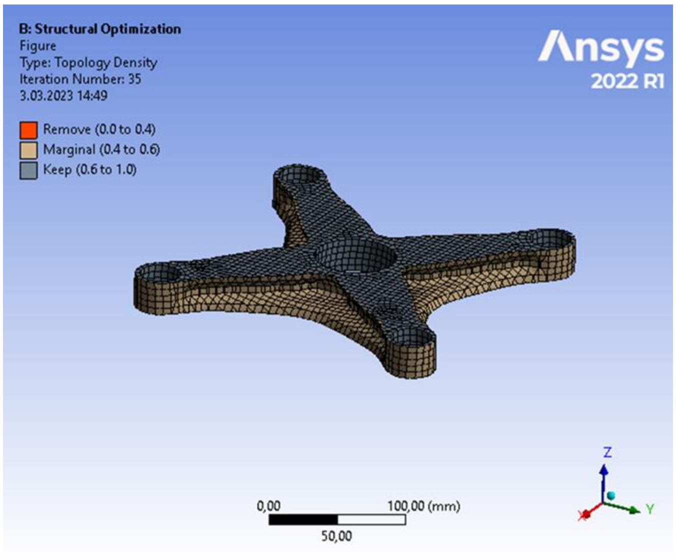



Fig. 13 Isometric view of the geometry obtained as a result of topology optimization

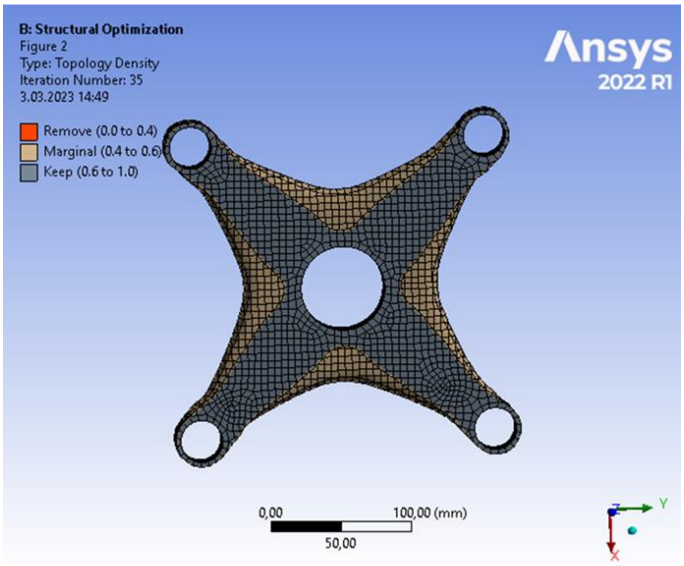



Fig.14. Top view of the geometry obtained as a result of topology optimization

D. *Redesigning the geometry according to the topology result*

The drone chassis illustrated at figure 15 was redesigned in the NX environment, taking into account the proposed geometry after the topology. It is necessary to test whether the designed new chassis will perform its duty safely under operating conditions. For this purpose, the static analysis of the newly designed geometry should be done by adopting all the static analysis boundary conditions applied to the initial geometry.

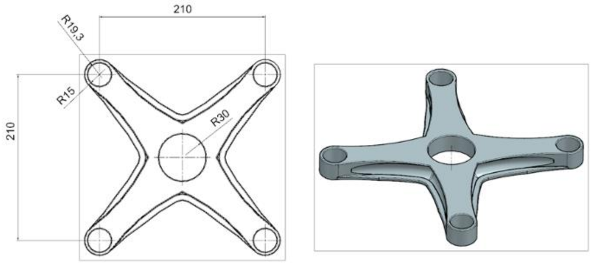



Fig. 15 Top and trimetric view of the redesigned chassis considering the topology result.

E. *Static analysis of the newly designed chassis*

The newly designed chassis was imported into the Ansys environment in STEP format, and a new static analysis was conducted by adopting all the selected boundary conditions for the initial chassis. The distribution of deformation values obtained from the static analysis is shown in Figure 16, and the distribution of stress values is shown in Figure 17. When examining Figure 16, it can be observed that the maximum displacement value is very small, measuring 0.0045422 mm. In Figure 17, the maximum stress value obtained from the static analysis is observed to be 1.2827 MPa.

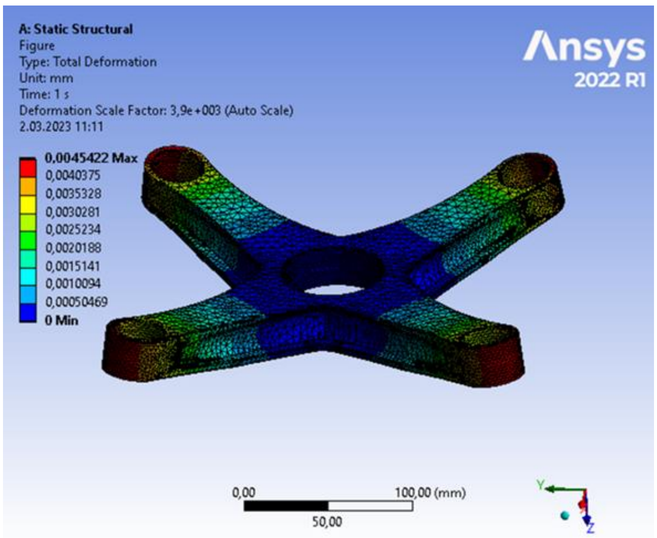



Fig.16 Total deformation graph of the designed new chassis (mm)

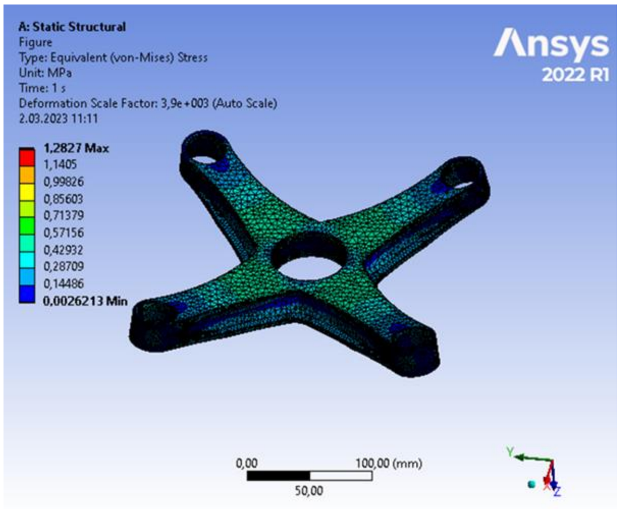
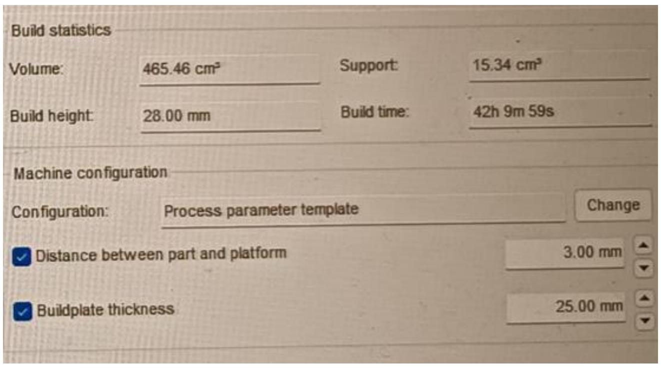



Figure 17. Tension graph (MPa) of the designed new chassis

F. *Calculation of the Production Time for the Final Geometry Using the PBF Method in the Netfabb Program*

The producibility and production time of the obtained final geometry using the PBF method were calculated using the Netfabb program. MetalFAB's PBF device was selected for manufacturing the part, and the part was positioned in the device to require minimal support. When examining Figure 18, it can be seen that the total geometry volume is 465.46 cm3, and the total support volume is 15.34 cm3. It is evident that the volume requiring support is relatively small within the total volume. The distance between the build plate and the part is 3 mm, and the thickness of the build plate is 28 mm. The gap left between the part and the build plate is to facilitate easy removal of the part after manufacturing and to prevent damage to the part and the build plate. The production time calculated by the Netfabb program for the final part is approximately 42 hours.



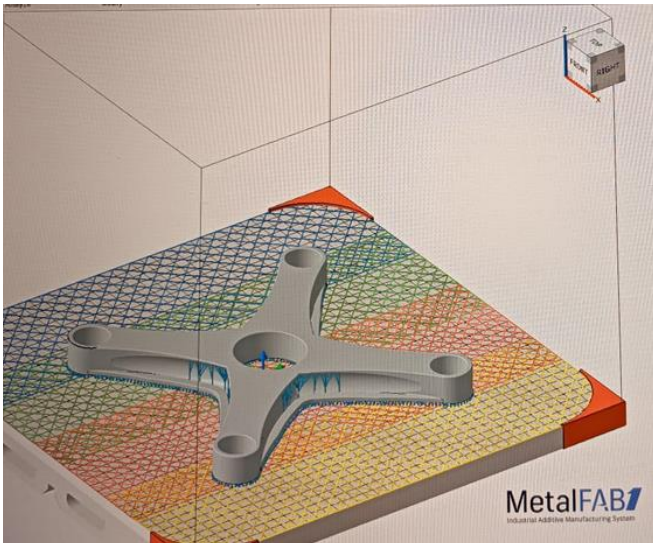



Fig.18 Demonstration of the production time of the final geometry with the PBF method and the placement of the geometry on the device.

## IV. DISCUSSION

### A. *Static Analysis Results*

When examining Figure 9, it can be seen that the maximum stress value (Von Mises) obtained is 0.39 MPa. Evaluating the total maximum deformation and maximum stress values obtained, it is evident that the current drone chassis can operate safely.

### B. *Topology Optimization*

The geometry obtained from the topology optimization is shown in Figure 13 and Figure 14. When examining the figures, it can be observed that the mass has significantly and symmetrically reduced. In addition to the defined boundary conditions, the program takes into account the distribution of deformation and stress values obtained from the static analysis while reducing the mass. It focuses on reducing the mass from regions where these values are low. As a result, it is evident that the program has reduced the mass in a way that allows the part to operate safely under working conditions.

### C. *Static analysis of the newly designed chassis*

The distribution of deformation values obtained from the static analysis is shown in Figure 16, and the distribution of stress values is shown in Figure 17. When examining Figure 16, it can be observed that the maximum displacement value is very small, measuring 0.0045422 mm. In Figure 17, the maximum stress value obtained from the static analysis is observed to be 1.2827 MPa. Considering that the yield strength of the Al alloy (5052 Hx9) is 280 MPa, it can be seen that the stress experienced by the part is significantly low. Evaluating the yield strength of Al alloy (5052 Hx9), deformation values, and stress values, it can be concluded that the part can operate safely.

### D. *Production Time for the Final Geometry Using Netfabb Program*

The production time calculated by the Netfabb program for the final part is approximately 42 hours. Although this time may seem long, it should be noted that traditional manufacturing methods for this part would involve material waste and multiple assembly and disassembly operations. In the PBF method, material waste is minimal, and there are no assembly or tool change operations, which are among the advantages of this method.

## V. CONCLUSION

Additive manufacturing methods have revolutionized the production of complex and lightweight parts using metal materials, making them widely used in industries such as aerospace, automotive, medical, and dentistry. The ability of these methods to process metal materials and produce intricate and lightweight geometries has introduced a new approach to design. Designers are now granted more freedom in their designs, as they are no longer bound by the constraints and criteria of traditional manufacturing methods. This has opened up possibilities for the creation of more complex and lightweight structures. In this study, a drone chassis was designed for production using layered manufacturing. Topology optimization was applied to the designed chassis, resulting in a redesigned geometry. The redesigned part underwent static analysis to test its performance under operating conditions. The following are the results obtained:

- The initial designed drone chassis was subjected to a 100 N force applied to the hole surfaces at its four corners, while being fixed at the center hole. Static analysis results showed that the maximum stress (Von Mises) was 0.39 MPa, and the maximum displacement was 0.0013 mm. Considering that the yield strength of the Al alloy (5052 Hx9 ) is 280 MPa, it can be concluded that the part can operate safely.

- Through topology optimization driven by static analysis, the mass was reduced by approximately 78%, reaching a final value of 1.288 kg. The significance of topology optimization becomes evident when considering the achieved mass reduction.
- The geometry obtained from topology optimization was further redesigned, and a new static analysis was performed while maintaining the same boundary conditions as the previous analysis. The results of the static analysis showed a maximum stress (Von Mises) value of 1.28 MPa and a maximum displacement of 0.0045 mm. Considering these results together with the yield strength of the Al material (280 MPa), it can be concluded that the drone chassis can operate safely under the applied boundary conditions.
- The production time for the final geometry using the PBF method was calculated using the Netfabb program and found to be approximately 42 hours. Considering the part thickness of 25 mm, this calculated time is not excessive. Furthermore, it is evident that if the part with dimensions of 300x300x25 mm were to be produced using traditional methods, there would be significantly more material waste.

## ACKNOWLEDGMENT

The heading of the Acknowledgment section and the References section must not be numbered.

## REFERENCES

[1] P. Bajaj, A. Hariharan, A. Kini, P. Kürnsteiner, D. Raabe, E.A. Jägle, Materials Science and Engineering: A, 772 138633(year).

[2] M. Burns, Automated fabrication: improving productivity in manufacturing, Prentice-Hall, Inc., 1993.

[3] A. Du Plessis, I. Yadroitsava, I. Yadroitsev, Materials & Design, 187 108385(year).

[4] N. Guo, M.C. Leu, Frontiers of mechanical engineering, 8 215-243(year).

[5] I. Ian Gibson, springer publication, 2015.

[6] J. Jiang, Y. Ma, Micromachines, 11 633(year).

[7] C. Sun, Y. Wang, M.D. McMurtrey, N.D. Jerred, F. Liou, J. Li, Applied Energy, 282 116041(year).

[8] M. Abdi, I. Ashcroft, R.D. Wildman, International Journal of Powertrains, 7 142-161(year).

[9] J. Plocher, A. Panesar, Materials & Design, 183 108164(year).

[10] M. Seabra, J. Azevedo, A. Araújo, L. Reis, E. Pinto, N. Alves, R. Santos, J.P. Mortágua, Procedia Structural Integrity, 1 289-296(year).

[11] D. Walton, H. Moztarzadeh, Procedia Cirp, 60 205-210(year).

[12] J.-H. Zhu, W.-H. Zhang, L. Xia, Archives of computational methods in engineering, 23 595-622(year).

[13] C.H. Chuang, S. Chen, R.J. Yang, P. Vogiatzis, International Journal for Numerical Methods in Engineering, 113 1434-1445(year).

[14] W. Gao, Y. Zhang, D. Ramanujan, K. Ramani, Y. Chen, C.B. Williams, C.C. Wang, Y.C. Shin, S. Zhang, P.D. Zavattieri, Computer-Aided Design, 69 65-89(year).

[15] A.L. Jardini, M.A. Larosa, R. Maciel Filho, C.A. de Carvalho Zavaglia, L.F. Bernardes, C.S. Lambert, D.R. Calderoni, P. Kharmandayan, Journal of Cranio-Maxillofacial Surgery, 42 1877-1884(year).

[16] S.N. Reddy K, V. Maranan, T.W. Simpson, T. Palmer, C.J. Dickman, International design engineering technical conferences and computers and information in engineering conference, American Society of Mechanical Engineers, 2016, pp. V02AT03A030.

[17] S. Stübinger, I. Mosch, P. Robotti, M. Sidler, K. Klein, S.J. Ferguson, B. von Rechenberg, Journal of Biomedical Materials Research Part B: Applied Biomaterials, 101 1154-1163(year).

[18] D.-A. Türk, R. Kussmaul, M. Zogg, C. Klahn, B. Leutenecker-Twelsiek, M. Meboldt, Procedia CIRP, 66 306-311(year).

[19] P. Zhang, J. Liu, A.C. To, Scripta Materialia, 135 148-152(year).

[20] M. Padmakumar, Lasers Manuf. Mater. Process, 7 338-371(year).

[21] Z. Jihong, Z. Han, W. Chuang, Z. Lu, Y. Shangqin, W. Zhang, Chinese Journal of Aeronautics, 34 91-110(year).

[22] J.D. Williams, C.R. Deckard, Rapid Prototyping Journal, 4 90-100(year).

[23] H. Zarringhalam, N. Hopkinson, N. Kamperman, J. De Vlieger, Materials Science and Engineering: A, 435 172-180(year).