Metin, M. A., Şentürk, K. (2024). Static Analysis of Main Body Parts Designed Using Carbon Fiber Material for Hexacopter Structure Drone. *The Black Sea Journal of Sciences*, 14(4), 1758-1781.

The Black Sea Journal of Sciences, 14(4), 1758-1781, 2024. DOI: 10.31466/kfbd.1474166

KFBD

Karadeniz Fen Bilimleri Dergisi
The Black Sea Journal of Sciences
ISSN (Online): 2564-7377 https://dergipark.org.tr/tr/pub/kfbd

Araştırma Makalesi / Research Article

Static Analysis of Main Body Parts Designed Using Carbon Fiber Material for Hexacopter Structure Drone

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Abstract

Drones, which entered our lives with the development of technology, are used in many areas that make our lives easier today. It is seen the effect of drones in photography, cargo transportation, mapping, defense industry, and agricultural sectors. In order for the drones used in these areas to fulfil the desired task, the mechanical and static structure of the drone is of great importance along with the software and electronic cards used. It is possible to perform the desired task in a mechanically stable and optimized air vehicle with integrated payloads. In particular, most of the electronic equipment and payloads of the drone are integrated on the parts that make up the body. For this reason, it is inevitable to examine the effect of both equipment and payloads on whether the drone can perform the desired task or not. In this study, the static analysis of the parts made of carbon fiber material forming the construction of the body of the uniquely designed drone is carried out. These analyses were performed in terms of the total deformation, the strain, and the stress with different mesh structures such as multizone, tetrahedrons, and hex dominant method mesh were performed on the body parts. The results obtained indicated that the body parts of the uniquely designed drone presented in this study can be produced by using carbon fiber materials and they will be suitable for different missions.

Keywords: Drone body, Stability, Carbon fiber material, Static analysis, Meshes.

Hexacopter Yapısındaki Drone için Karbon Fiber Malzeme Kullanılarak Tasarlanan Ana Gövde Parçalarının Statik Analizi

Öz

Teknolojinin gelişmesiyle birlikte hayatımıza giren drone'lar, günümüzde hayatımızı kolaylaştıran birçok alanda kullanılıyor. Fotoğrafçılık, kargo taşımacılığı, haritalama, savunma sanayi ve tarım sektörlerinde droneların etkisi görülmektedir. Bu alanlarda kullanılan drone'ların istenilen görevi yerine getirebilmesi için kullanılan yazılım ve elektronik kartlarla birlikte drone'un mekanik ve statik yapısı da büyük önem taşıyor. Mekanik olarak stabil ve optimize edilmiş bir hava aracında entegre faydalı yükler ile istenilen görevin gerçekleştirilmesi mümkündür. Özellikle drone'un elektronik ekipmanlarının ve faydalı yüklerinin büyük bir kısmı gövdeyi oluşturan parçaların üzerine entegre edilmektedir. Bu nedenle hem ekipmanların hem de faydalı yüklerin drone'un istenilen görevi yerine getirip getiremeyeceği üzerindeki etkisinin incelenmesi kaçınılmazdır. Bu çalışmada, özgün tasarımlı drone'un gövde konstrüksiyonunu oluşturan karbon fiber malzemeden yapılmış parçaların statik analizi yapılmıştır. Bu analizler toplam deformasyon, şekil değiştirme ve gerilme açısından çok bölgeli, tetrahedron ve altıgen baskın yöntem ağ yapısı gibi farklı ağ yapılarıyla gövde parçaları üzerinde gerçekleştirilmiştir. Elde edilen sonuçlar, bu çalışmada sunulan özgün tasarımlı drone'un gövde parçalarının karbon fiber malzemeler kullanılarak üretilebileceğini ve farklı görevlere uygun olacağını gösterdi.

Anahtar Kelimeler: Drone gövdesi, Stabilite, Karbon fiber malzeme, Statik analiz, Ağ örgüsü.

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Geliş/Received: 26.04.2024 **Kabul/Accepted:** 15.10.2024 **Yayın/Published:** 15.12.2024

1. Introduction

Unmanned aerial vehicles or drones have different and very wide application areas from military to scientific research especially in recent years. There are different categories for drones depending on their mission, structure, control system, vehicle type, and propulsion systems. The structure of the drones has a prominent place in designing the drones since it will support and lift the entire drone system in the air, and it must withstand the thrust and the total weight of a drone (Rajoo et,al., 2023). To produce a drone having higher stability and high specifications the structure of the parts of the drone must be tested effectively (Simion et, al., 2023). Drones are aerial vehicles that can be controlled through remote controllers and specialized software according to a flight route. Depending on their mission capabilities and purposes, drones can vary in size, shape, and weight. While they commonly carry cameras as part of their sensing systems, they can also include sensors capable of various measurements (Villi and Yakar, 2022). Together with all advantageous properties the drones also have some vulnerabilities which can be mainly counted as sensor accuracy, battery endurance, and harsh atmospheric conditions (Simion et,al., 2023). Moreover, drones have been equipped with specialized technical designs tailored for various purposes and have evolved into user-friendly products over time. Considering the wide range of applications for drones, it can be said that this technology has positive effects on daily life and the sectors in which it is employed. Additionally, certain high-cost operations can be carried out more economically when using drones, providing cost savings compared to other devices or methods (Arslan and Delice, 2020). Drones facilitate access to particularly hazardous areas for human being and enable the acquisition of necessary visuals, and information from locations affected by natural disasters (Kavaklı, 2018). In the agriculture sector, the rapid proliferation of digital technologies, including tools such as drones, satellites, tablets, smartphones, and field sensors, is bringing about significant transformation in agricultural activities. Particularly, remote sensing tools like drones and satellites offer the opportunity to monitor soil conditions in detail. This allows farmers to manage agricultural lands more effectively, observe plant health, and enhance productivity (Yüksel, 2020). Drones also play a significant role in detecting crop diseases and damages. This technology simultaneously takes on the function of measuring soil moisture content, making agricultural processes more efficient (Demir, Basayigit, 2020). When terrain conditions require pesticide application and ground vehicles or humans find it challenging to access these areas, the use of autonomous drones becomes an ideal option. In such rugged terrain, specially designed route planning is used for autonomous drones to conduct pesticide spraying operations. Additionally, autonomous drones play a significant role in ensuring the homogeneous distribution of pesticides in the canopy areas of trees (Ates and Senol, 2023). Drones are preferred in many industries due to their ability to reduce costs, increase efficiency, and save time. In the field of cargo and transportation, drones are a favorable choice due to their size, cost-effectiveness, and controllability. They are utilized to accomplish tasks that are time-consuming, labor-intensive, and cost-heavy, particularly for safely delivering packages, offering high efficiency and energy in their operations (Turgut and Seker, 2022). Ensuring national security involves the secure and stable transportation of materials required by the armed forces. This necessity has become more pronounced, especially with the use of advanced technology-based systems. Drones stand out as a less risky and more cost-effective alternative compared to manned aircraft (Bayram, 2022). Drones have the potential to have a significant impact in firefighting. There is an innovative design consisting of a cage attached to four propellers and a rail system specifically for firefighting activities. Additionally, in 2020, a private company in China (Ehang) manufactured a large-sized, fully autonomous firefighting drone (EHang 216F) and delivered it to the regional fire department. This drone can reach speeds of up to 130 km/h and stay airborne for 21 minutes at full load. Furthermore, it has the capacity to rapidly respond to any fires within a 5 km radius around the fire station (Toptas and Yilmaz, 2021). Drones have various applications in healthcare services, including drug delivery, carrying defibrillators, transporting blood samples, and vaccines. Autonomous drones developed by Matternet use GPS and other sensors to distribute drugs between automated stations in remote areas without road networks. Matternet has conducted operations in drug delivery, particularly in regions affected by events like the 2010 earthquake in Haiti and the Dominican Republic, as well as in New Guinea and Switzerland (Scott E., Scott H., 2017). In Germany, DHL Parcel has worked on three generations of medical drone delivery. The first generation, called "Parcelcopter," was used to deliver blood samples to Bonn, 1 km away across the Rhine River. The second generation, in 2014, tested drone deliveries of medicine and other emergency supplies to Juist, one of the remote islands in the North Sea of Germany. This "Parcelcopter" covered a distance of 12 km over open water. DHL's third-generation "Parcelcopter" tested the delivery of over 130 urgent medical and sports equipment packages from January to March 2016. Drone delivery took only 8 minutes compared to a traditional 30-minute journey during the winter months. Such rapid deliveries could make a significant difference in medical emergencies (Scott E., Scott H., 2017). Railways comprise various components of infrastructure such as rails, sleepers, ballast, and connecting elements. Faults like breakage, deficiencies, or wear in these components can now be detected without physical contact using recently developed image processing techniques and deep learning models. Automated non-contact fault detection methods, serving as an alternative to traditional fault detection systems, can yield fault detection results with high accuracy rates. In these developed methods, railway images can be obtained through cameras placed on train wheels or on the train itself, as well as using autonomous or semi-autonomous drones (Yilmazer, 2023). Information on the historical development of drones is given in Table 1.

Table 1. Historical Development of Drones.

Date	Event
1849	The Austrian government used the first unmanned balloon, but it was unsuccessful
1917	The U.S. succeeded in flying drones during World War I.
1939	The U.S. Army began mass production of the remotely piloted drone Radioplane OQ-2.
2006	Drones were employed for humanitarian purposes after Hurricane Katrina in the U.S.
2010	The Parrot company commenced production of the PARROT AR drone, controllable via smartphones.
2014	Amazon announced plans to use drones for delivering orders.
2016	DJI began producing the Mavic Pro.
2017	Facebook started developing solar-powered drones to bring internet access to remote areas without connectivity.
2018	DJI introduced the Mavic Air with a 30 fps 4k camera to the market.
2018	Zipline commenced medical supplies delivery via drones to 1000 clinics in Tanzania.
2018	Drone technology was used for inspecting electrical power lines in the UK.

Drones are named according to the number of motors they have. If they have 4 motors, they're called quadcopters, 6 motors make them hexacopters, and 8 motors classify them as octocopters. Depending on their use in industry or civilian life, drones with 4, 6, or 8 motors can be preferred. When designing drones, there are specific features expected. Among these features, maximum speed and maximum payload capacity stand out (Oktay, Sahin, 2017). A quadcopter is a four-rotor unmanned aerial vehicle symmetrically arranged with six degrees of freedom. The term "missing actuators" means that the quadcopter's six degrees of freedom are controlled by only four inputs. Unlike conventional helicopters that use a tail rotor to correct inertia generated by the motor for balance, a quadcopter doesn't have a tail rotor. Instead, balance is maintained through the coordinated rotation of the propellers. As one pair of rotors spins clockwise, the other pair spins counterclockwise (Kuzu, 2018). Having a six-rotor configuration, this multicopter model is shaped on a hexagonal or circular frame. Hexacopters have the capability to reach higher altitudes compared to quadcopters and are considered the most effective among multicopter models in achieving stable flights. Their six rotors allow them to lift heavier weights and provide the ability to carry substantial payloads. They possess the best structure for optimizing the weight-to-power ratio (Uz, 2019).

Drones consist of various components such as brushless motors clockwise (CW) and counterclockwise (CCW), electronic speed controllers (ESCs), LiPo battery packs, power distribution boards, flight controllers, transmitters, and propellers. Connecting three phase wires from the motor to the corresponding phase wires on the ESC, linking the + and - connections on the ESC to the power distribution board, and connecting the power distribution board's battery connection to the LiPo battery establishes the electronic connections on the drone. When we connect the pins on the ESC to the corresponding pins on the flight controller, programming can be done through the flight controller. By linking the receiver pins on the transmitter to the input pins on the flight controller, control settings can be adjusted through the flight controller. Following these steps and after conducting necessary flight tests, payloads can be added for safe and secure flights. The materials used in producing the drones play an important role in their design. The structure of the drones changed from aluminum to plastic and then to carbon fiber. Aluminum alloys are lightweight but due to their low specific strength, they are vulnerable to bending deformation under external forces which can lead to balance instability during flight (Rajoo et, al., 2023). Carbon fiber composites are very useful materials used in very wide areas of application. However, they also have some limitations such as low compressive strength. This is partially due to the weak Van der Waals force between the graphene layers and their fibrillar structure. Especially after impact the notched compressive strength and compressive strengths play an important role in the design of different structures (Wu and Wisnom, 2023; Huang, 2009). Carbon fiber is a lightweight material that is intensively used in different areas such as automotive, civil engineering, disaster management, infrastructure, motorsports, surveillance, delivery of goods, military sector, agriculture sector, aerospace, renewable energy applications, and etc. One of the important properties of carbon fiber is its specific strength which can be ten times higher than aluminum and steel’s specific strength depending on the fiber used. Some of the advantages of carbon fibers are low thermal expansion, high specific strength, high stiffness, high thermal and chemical resistance, low density, excellent creep resistance, and high specific modulus (Huang, 2009; Zhang et.al., 2023; Deeraj et.al., 2020; Sundaraj et.al., 2021). The high modulus of these fibers comes from the high crystallinity, and well alignment of crystals in the fiber direction when the carbon fiber microstructure depends on the processing conditions and precursors. The microstructure of carbon fiber heavily affects its mechanical properties (Huang, 2009).

This article is organized in the following way. The first part describes the materials and the methods used in constructing the drone in detail. Later, the results related to the analyses are discussed and conclusion is given in the last part.

The study focuses on the use of carbon fiber materials in the structural design of unmanned aerial vehicles (UAVs) and the static analysis of these materials. The importance of developing drones with affordable cost and design that can be used in natural disasters that may occur constitutes one of the motivation sources of this study.The need for durable, lightweight and high-strength materials is increasing in the rapidly developing unmanned aerial vehicle technology.In particular, the fact that UAVs find a wider range of use in various sectors necessitates increasing the load-carrying capacity of these vehicles and improving their flight safety. In this context, it is aimed to contribute to the design processes of unmanned aerial vehicles by focusing on the use of these advantageous properties of carbon fiber materials in UAV design.

2. Materials and Methods

When accomplishing the desired tasks in drones, one of the most crucial mechanical parameters is static balance. Considering this parameter, durable and lightweight materials, as seen in fixed-wing aircraft, are preferred in rotary-wing unmanned aerial vehicles (drones) (Basmaci and Yoruk, 2020). Accordingly, in the design of a hexacopter structure, parts forming the body of the drone are made from carbon fiber material. Due to their superior mechanical properties such as high specific strength, specific stiffness, corrosion resistance, and increased fatigue life, carbon fibers are increasingly used in various military and civilian applications (Alarcin, 2020). Carbon fiber's atomic structure is derived from layers of carbon atoms arranged in a hexagonal pattern, namely the layers of graphite. This graphite-like structure can vary depending on precursors and production processes. Layer planes in carbon fibers can typically exhibit a turbo static, graphitic, or hybrid structure. In regions with graphite crystallinity, layer planes stack in an orderly parallel manner, indicating the presence of covalent bonds between atoms within a plane. The structural properties of carbon fiber are contributed by these orderly and strong bonds, enhancing the material's durability and mechanical characteristics (Huang, 2009). Carbon fiber materials are available in the form of plates or tubes. These materials can be shaped using machining processes. The carbon fiber plate to be processed by machining is attached to computer numerical control (CNC) milling machines using fixtures based on the plate's thickness (e.g., s: 1.5, 2.0, 2.5, 3.0 mm). The technical specifications of the carbon fiber board used in this study are shown in Table 2. These fixtures can vary depending on the shape of the product made from carbon fiber material. During the machining of the carbon fiber materials attached to the machine via fixtures, the spindle speed and cutting speed applied to the material can be adjusted using CAM software or the control panel of the machine. However, there's a high risk of tool breakage and potential damage to the part in areas with radii, drilling holes, or areas with empty space in the designed form.

Carbon fiber plates can be shaped more simply and cost-effectively using water jet cutting compared to machining. In water jet cutting, a jet is created by compressing the fluid used at high pressures through a nozzle. This method is suitable for processing both soft and brittle materials. In water jet cutting:

- No mechanical cutting tool is used.
- Cutting performance is higher compared to laser and traditional cutting methods.
- It does not produce harmful smoke and dust that can affect the environment.
- Suitable for cutting various materials such as carbon fiber, foam, wood, aluminum, and Kevlar.
- It does not create slag on the material.
- Low force is applied to the material during cutting (Akkurt, 2004).

Table 2. Technical specifications of the carbon fiber board used.

Properties	Values
Thickness	3 mm
Color	Black
Front Finish	Gloss/Satin/Matte
Back Finish	Texture
Pattern	2x2 Twill Weave
Fabric	Carbon Fiber
Resin	Epoxy
Glass Transition – Tg	96.7
Linear Weight – g/m^2	4237
Tensile Strength – MPa	4200
Tensile Modulus – GPa	240
Strain	%1.8

2.1. Design of Components Forming the Drone Body

The unique design given in Figure 1 and Figure 2 belongs to an uniquely designed hexacopter structure drone. Not only the parts forming the body but also the wing profiles connected to the motors and the profiles in the landing system have been made of carbon fiber material. The design process was carried out using the Solidworks program. Figure 1 shows the upper part forming the body, while Figure 2 shows the lower part forming the body of the drone.

In this design, the body parts consist of six pieces made of 304-grade stainless steel, each measuring 40 mm in length, combined with six parts 3D printed using PLA material. Additionally, the integration of carbon fiber tubes through the 3D printed parts has been ensured to form the body and create the wing profiles.

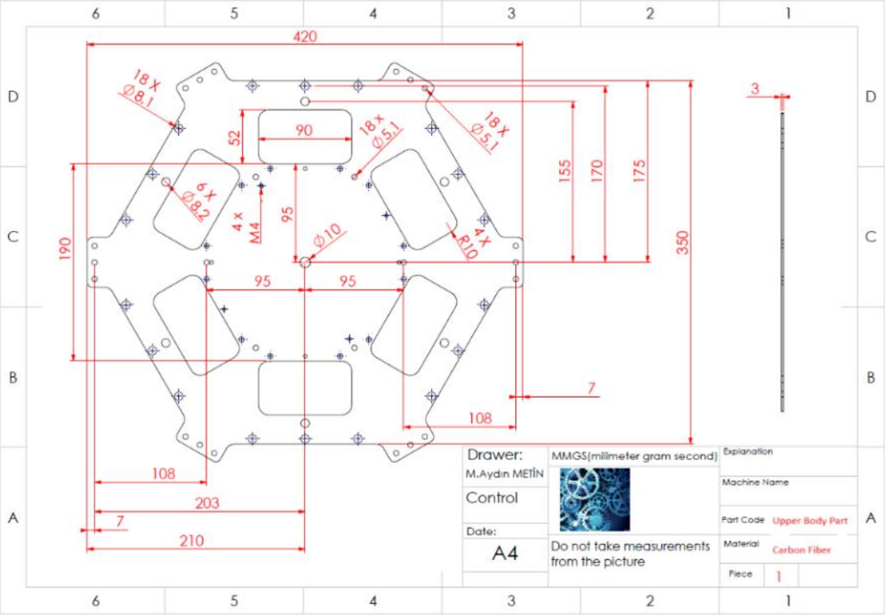

Figure 1. Upper body part of the drone.

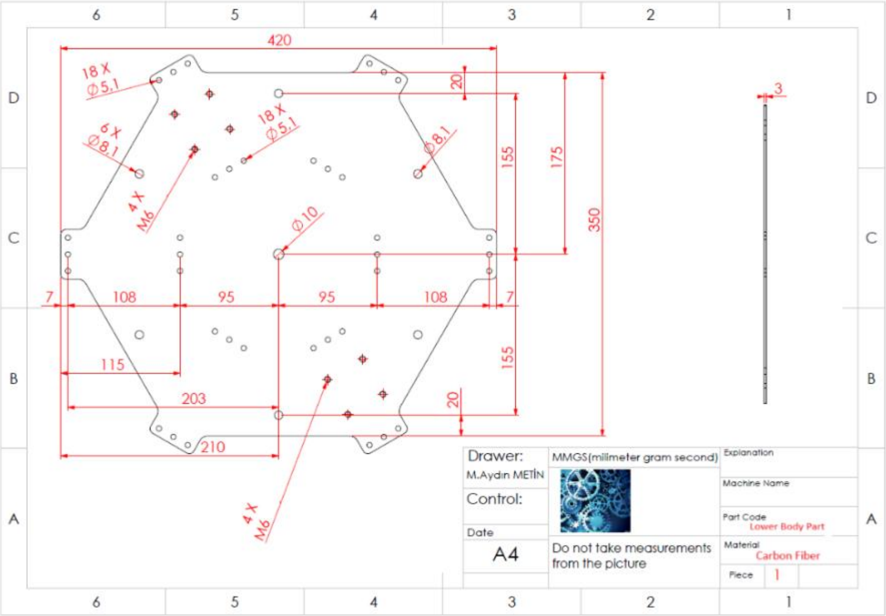

Figure 2. Lower body part of the drone.

2.2. Calculation of the Force Value to Be Used in Static Analysis

In this study, an aircraft with a hexacopter structure was designed and 6 brushless DC motors were used in this aircraft. An important parameter that increases the thrust power of the brushless DC motors used is the size of the propeller used. In the Hexacopter, a 15*5.5 propeller and a 22 V battery were used. The total force acting on the drone's body was used 147.15 N which is the total gravitational force for the system. This force is acting at the center of gravity of the drone and the directioan is downward.

3. Findings and Discussion

The lower and upper body parts that make up the body of the hexacopter rotary wing unmanned aerial vehicle were designed in the Solidworks CAD program. After the design of these parts was completed, static analyses were made with the finite element method in the Ansys analysis program, mesh was made according to the multizone, tetrahedrons and hex dominant method mesh structure, and the suitability and strength of the part geometries were tested by performing total deformation analysis, strain and stress analysis of the parts. In this direction, according to the results obtained in the analysis of carbon fiber parts, the parts were manufactured and production started. Figure 3 shows the multizone mesh structure of the lower part forming the body of the drone, Figure 4 shows the tetrahedrons mesh structure, and Figure 5 shows the hex dominant method mesh structure for the same part. After these mesh structures were created, the number of nodes and elements of the meshes are shown in Table 3.

Multizone, tetrahedrons ve hex dominant gibi farklı mesh türleri, analiz edilen geometrinin karmaşıklığına ve analiz yapılacak geometrinin özelliklerine göre seçilmiştir. Her bir mesh türünün belirli avantajları ve kullanım alanları vardır, bu da analizlerin doğruluğunu ve hesaplama verimliliğini doğrudan etkiler:

Multizone mesh accurately simulates the nonlinear load distribution in the structure and also enables high calculation speeds.

Tetrahedrons mesh is used in more complex and irregular geometries and has been preferred to increase the mesh quality and analysis accuracy in such regions.

It provides a more flexible mesh structure on complex surfaces, allowing the stresses on the structure to be analyzed more precisely.

Hex dominant mesh provides high accuracy results using fewer elements and speeds up the analysis process.

Each mesh type in the study has been selected to be most suitable for the analysis of the structure, considering the balance of sensitivity and calculation time. These selections both increase the accuracy of the structural analysis results and optimize the calculation efficiency.

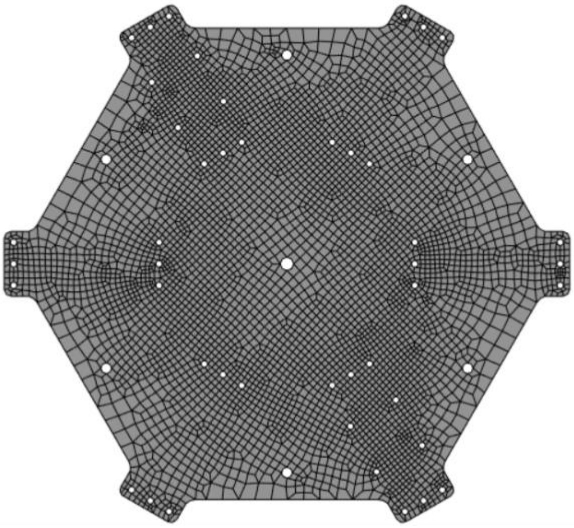

Figure 3. Multizone mesh structure for lower body part of the drone.

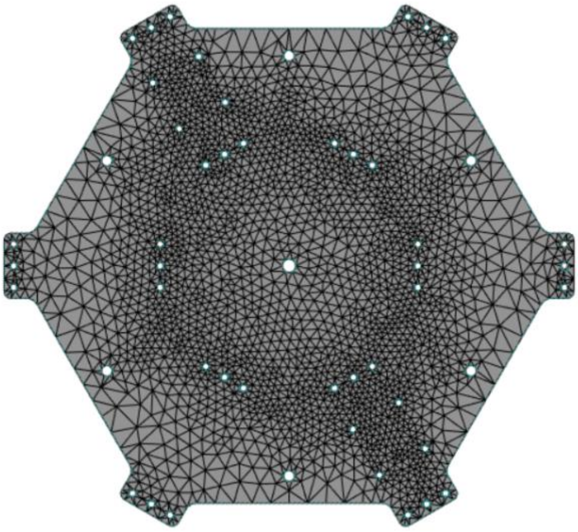

Figure 4. Tetrahedrons mesh structure for lower body part of the drone.

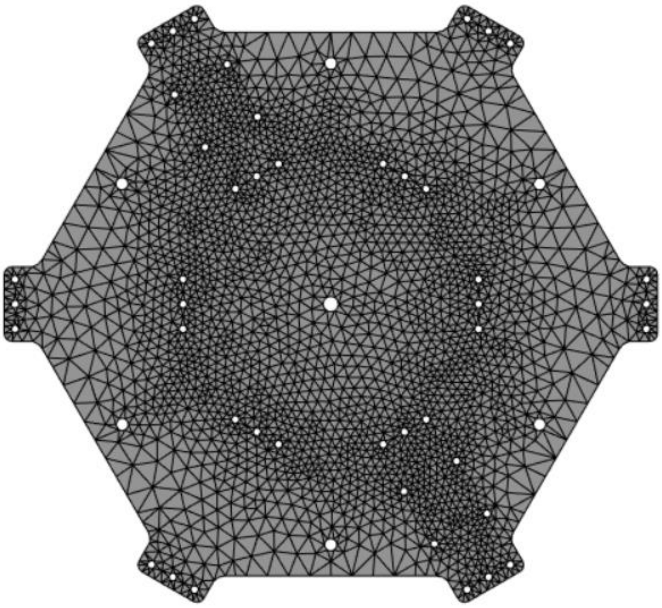

Figure 5. Hex dominant method mesh structure for lower body part of the drone.

Table 3. Number of elements and nodes according to the mesh structures for the lower part forming the body of the drone.

Mesh Type	Nodes	Elements
Multizone	35144	4902
Tetrahedrons	33371	16159
Hex Dominant Method	29253	11859

After the mesh operations are concluded, total deformation, strain, and stress analyses were performed by entering the force value that will act on the lower part forming the body. Figure 6 shows the direction of the force acting on the lower part of the body, Figure 7, Figure 8, and Figure 9 show the total deformation analysis of the multizone mesh structure, tetrahedrons mesh structure, and hex dominant method mesh structure respectively. The maximum and minimum values for the total deformation analysis for different mesh structures are shown in Table 4.

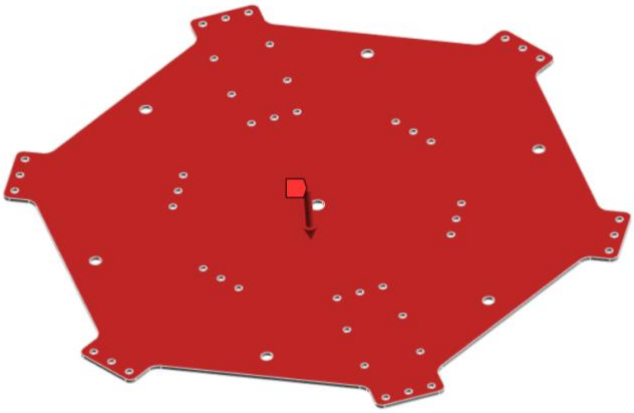

Figure 6. Direction of the force acting on the lower body part.

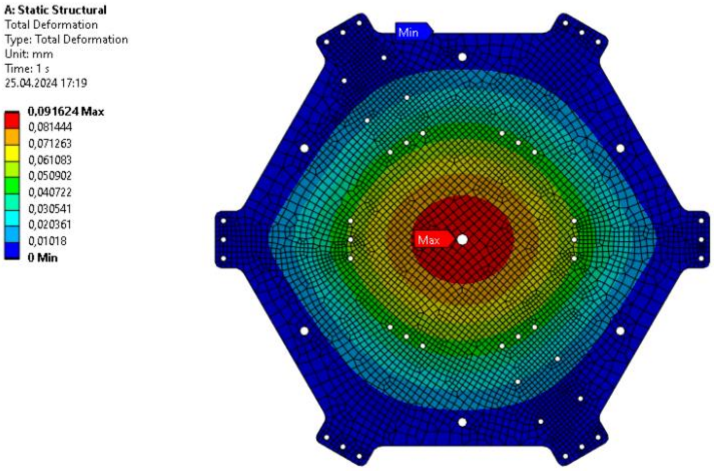

Figure 7. Total deformation analysis for the multizone mesh structure.

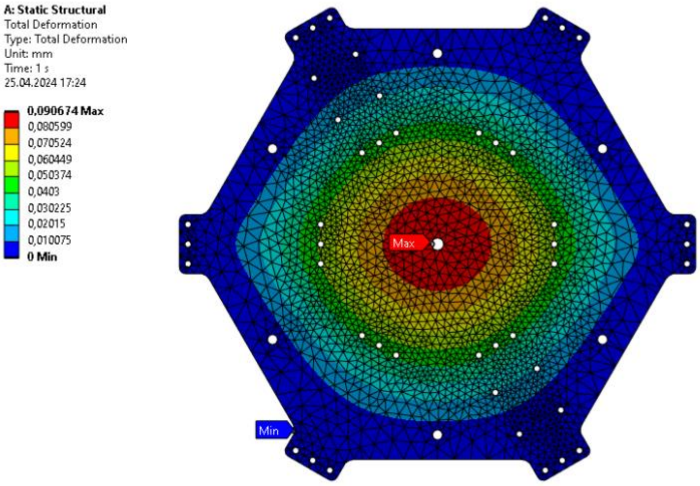

Figure 8. Total deformation analysis for the tetrahedrons mesh structure.

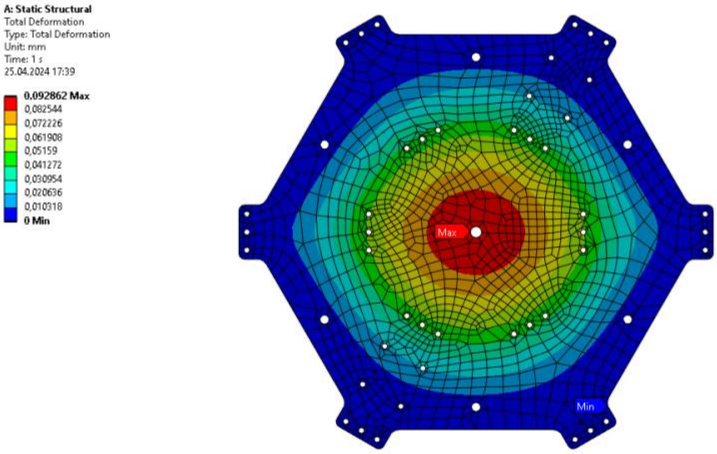

Figure 9. Total deformation analysis for the hex dominant method mesh structure.

Table 4. Maximum and minimum values for the total deformation analysis.

Mesh Type	Min. Value (mm)	Max. Value (mm)
Multizone	0	0.091624
Tetrahedrons	0	0.090674
Hex Dominant Method	0	0.092862

The maximum value in the total deformation analysis with a multizone mesh structure is 0.091624 mm (see Figure 7) , the maximum value in tetrahedrons mesh structure is 0.090674 mm (see Figuer 8) , and the maximum value in hex dominant method mesh is found to be 0.092862 mm (see Figure 9). The greatest deformation is seen in the hex dominant mesh structure, then in the multizone mesh structure, and the least deformation is seen in the tetrahedrons mesh structure. In all three mesh structures, the place where the deformation is the greatest is the center of the lower part forming the body of the drone. After the total deformation analysis, strain analysis was also performed. Strain analysis of multizone mesh structure, tetrahedrons mesh structure, and hex dominant method mesh structure are shown in Figure 10, Figure 11, and Figure 12 respectively. The maximum and minimum values for the strain analysis for the mesh structures are shown in Table 5.

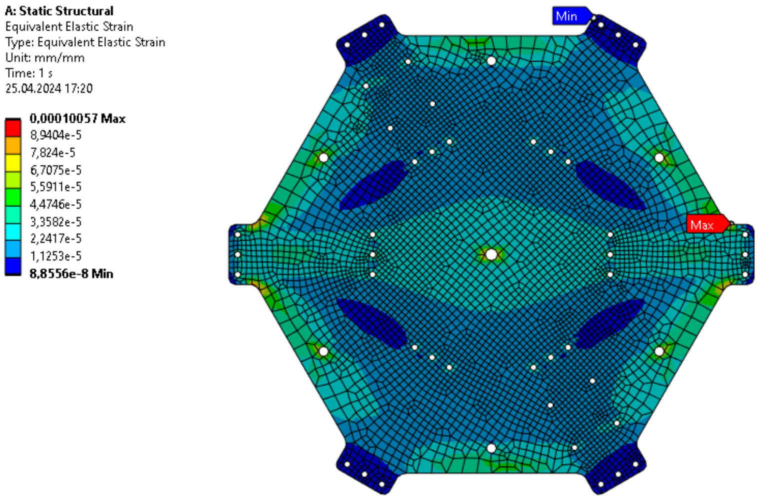

Figure 10. The strain analysis for the multizone mesh structure.

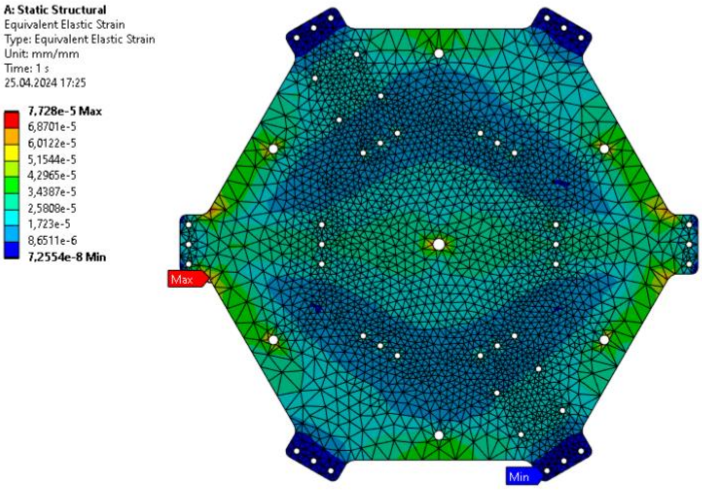

Figure 11. The strain analysis for the tetrahedrons mesh structure.

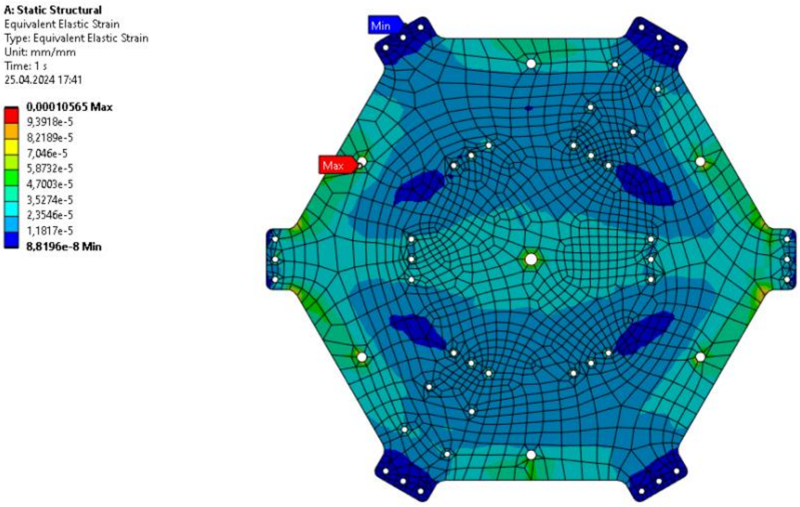

Figure 12. The strain analysis for the hex dominant method mesh structure.

Table 5. Maximum and minimum values for the strain analysis.

Mesh Type	Min. Value (mm/mm)	Max. Value (mm/mm)
Multizone	8.8556 e- 8	0.00010057
Tetrahedrons	7.2554 e-8	7.728 e-5
Hex Dominant Method	8.8196 e-8	0.00010565

The result for the strain analysis with multizone mesh structure is given in Figure 10 and the maximum value of the strain is found to be 0.00010057 mm. In Figure 11 the maximum value for the strain analysis with tetrahedrons mesh structure is found to be 7.728 e-5 mm, and finally, in Figure 12 the strain analysis with hex dominant mesh structure is given and the maximum value of the strain is found to be 0.00010565 mm. The smallest values for both minimum and maximum values in deformations found from the strain analysis belong to the tetrahedrons mesh structure. It is seen that the total force acting on the lower body part of the drone does not cause deformation in terms of the strain analysis. The stress analysis was also performed for the same body part of the drone. Figure 13, Figure 14, and Figure 15 show the stress analysis for multizone mesh structure, the tetrahedrons mesh structure, and for hex dominant method mesh structures respectively. The maximum and minimum values for the mesh structures of the stress analysis are shown in Table 6.

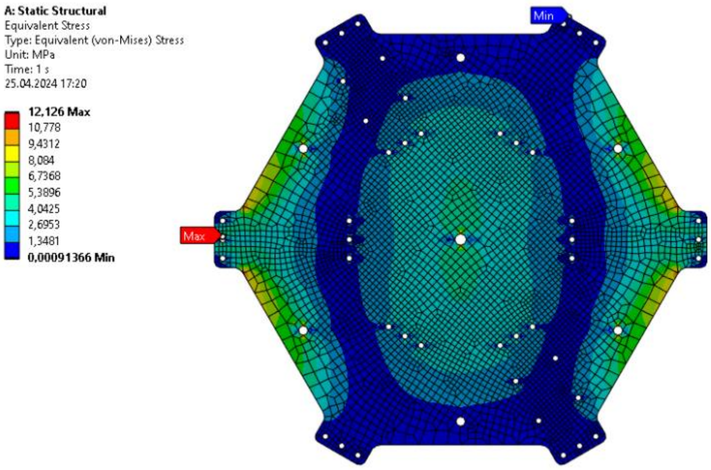

Figure 13. Stress analysis of multizone mesh structure.

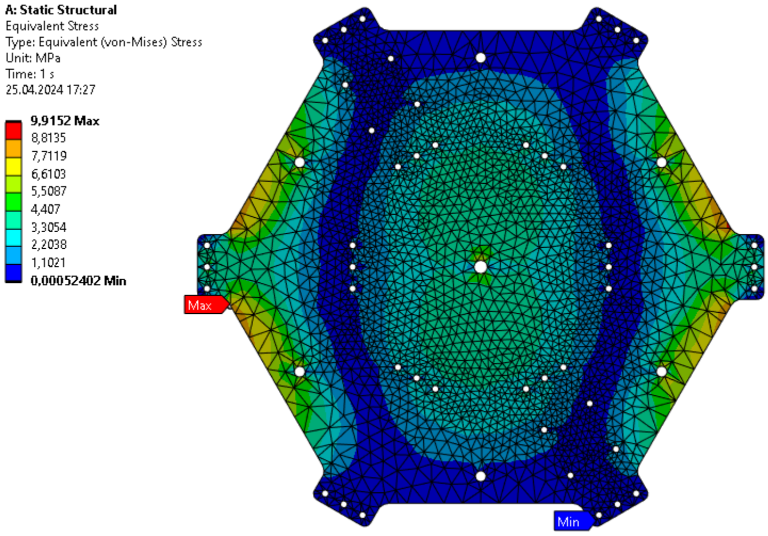

Figure 14. Stress analysis of tetrahedrons mesh structure.

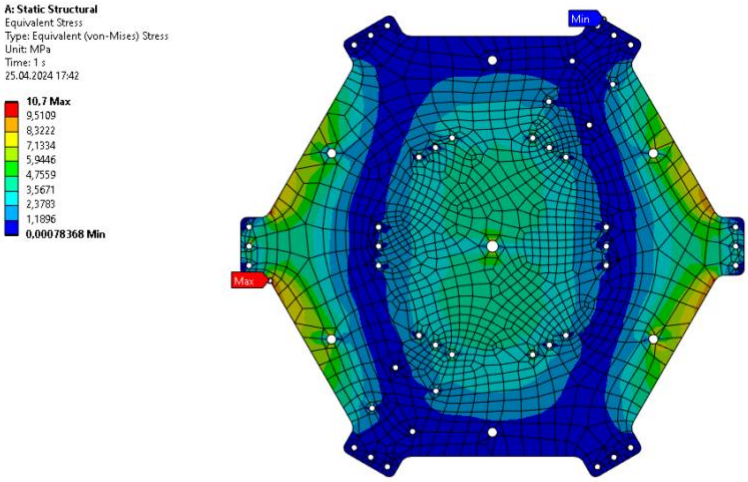

Figure 15. Stress analysis of hex dominant method mesh structure.

Table 6. Maximum and minimum values for the stress analysis.

Mesh Type	Min. Value (MPa)	Max. Value (MPa)
Multizone	0.00091366	12.126
Tetrahedrons	0.00052402	9.9152
Hex Dominant Method	0.00078368	10.7

In the stress analysis with multizone mesh structure the maximum value is found to be 12.126 MPa (see Figure 13). The maximum value in the stress analysis with tetrahedrons mesh structure is found to be 9.9152 MPa (see Figure 14), and in the stress analysis with hex dominant method mesh structure the maximum value is found to be 10.7 MPa (see Figure 15). The minimum deformation in terms of the stress analysis is seen in the tetrahedrons mesh structure, then in the hex dominant method mesh structure, and then in the multizone mesh structure. The results indicate that the total force acting on the lower body part of the drone does not cause deformation in terms of the stress analysis.

For the upper part forming the body of the drone, Figure 16, Figure 17, and Figure 18 show the multizone mesh structure, the tetrahedrons mesh structure, and the hex dominant method mesh structures respectively. Table 7 shows the number of elements and nodes according to the mesh structures mentioned.

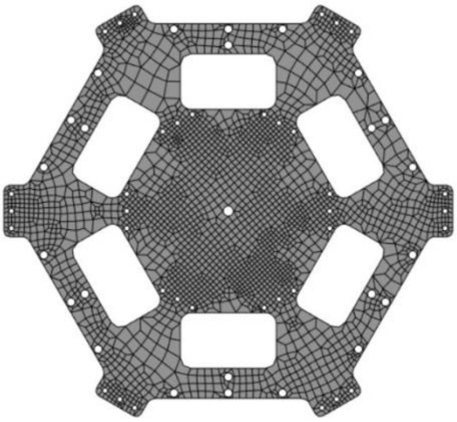

Figure 16. Multizone mesh structure for the upper body part.

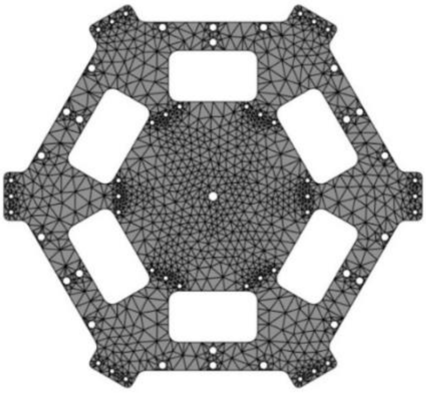

Figure 17. Tetrahedrons mesh structure for the upper body part.

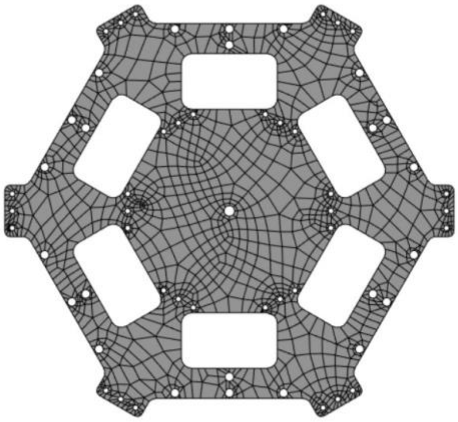

Figure 18. Hex dominant method mesh structure for the upper body part.

Table 7. Number of elements and nodes according to the mesh structures of the upper part forming the body.

Mesh Type	Nodes	Elements
Multizone	20263	2703
Tetrahedrons	19510	8618
Hex Dominant Method	18872	5501

After the meshing process is concluded, the total deformation, the strain and the stress analyses were performed by defining the direction and the magnitude of the force acting on the upper part of the drone. Figure 19 shows the direction of the force acting on the upper part of the body. Figure 20, Figure 21, and Figure 22 show the total deformation analysis for the multizone mesh structure, for the tetrahedrons mesh structure, and for the hex dominant method mesh structures respectively. The maximum and minimum values with respect to the mesh structures of the total deformation analysis are shown in Table 8.

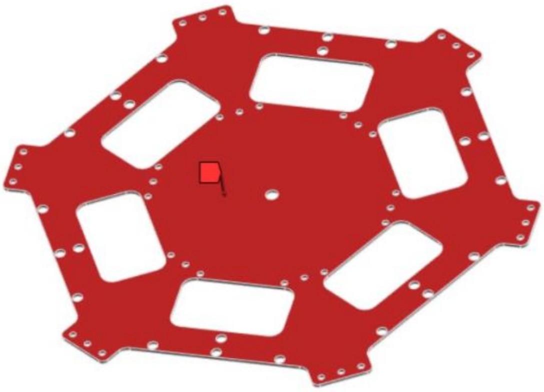

Figure 19. Direction of the force acting on the upper body part.

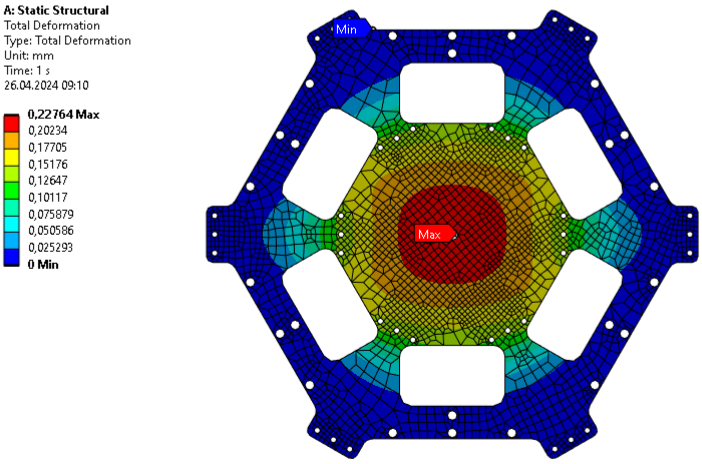

Figure 20. Total deformation analysis for the multizone mesh structure.

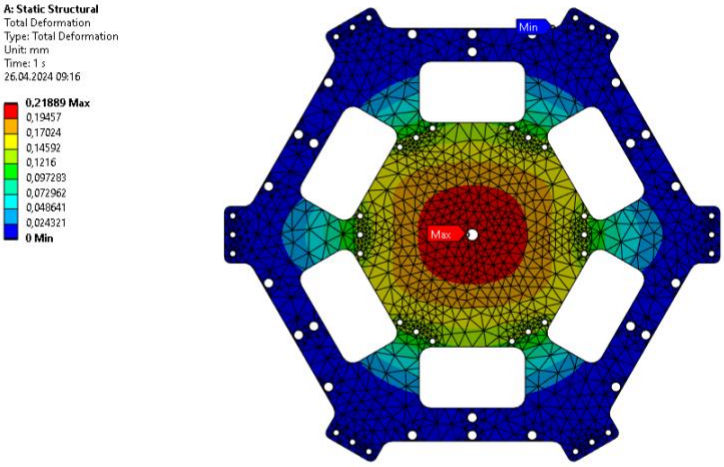

Figure 21. Total deformation analysis for the tetrahedrons mesh structure.

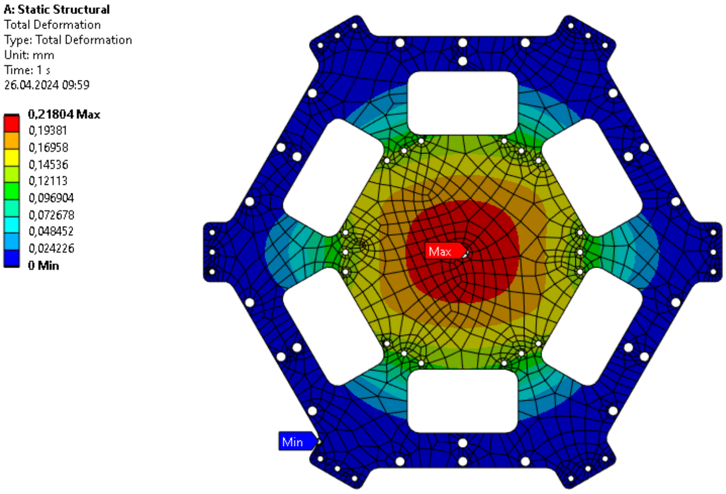

Figure 22. Total deformation analysis for the hex dominant method mesh structure.

Table 8. Maximum and minimum values for the total deformation analysis.

Mesh Type	Min. Value (mm)	Max. Value (mm)
Multizone	0	0.22764
Tetrahedrons	0	0.21889
Hex Dominant Method	0	0.21804

In the total deformation analysis with the multizone mesh structure (see Figure 20), the maximum value is found to be 0.22764 mm. The maximum value for the same analysis with the tetrahedrons mesh structure (see Figure 21) is found to be 0.21889 mm, and in Figure 22 the total deformation analysis with the hex dominant method mesh structure is presented, where the maximum value is found to be 0.21804 mm. The maximum deformation is seen in the multizone mesh structure, then in the tetrahedrons mesh structure, and then in the hex dominant mesh structure. In all three mesh structures, the place where the deformation is the most is the center of the upper part forming the body of the drone. After the total deformation analysis, strain analysis was performed. Figure 23 shows the strain analysis of the multizone meh structure, Figure 24 shows the tetrahedral meh structure, and Figure 25 shows the strain analysis for the hex dominant method mesh structure. The maximum and minimum values of the mesh structures for the strain analysis are shown in Table 9.

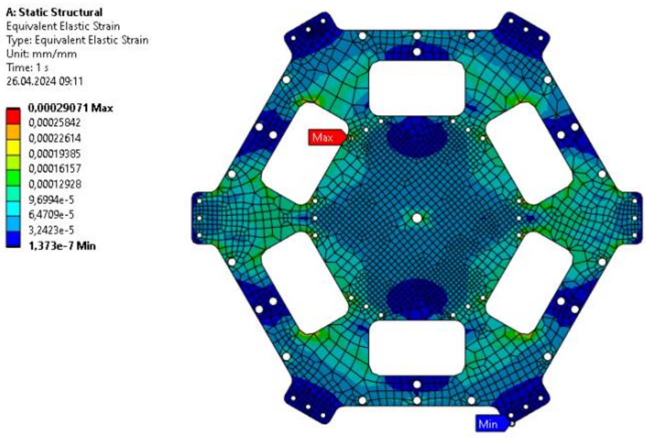

Figure 23. Strain analysis for the multizone mesh structure.

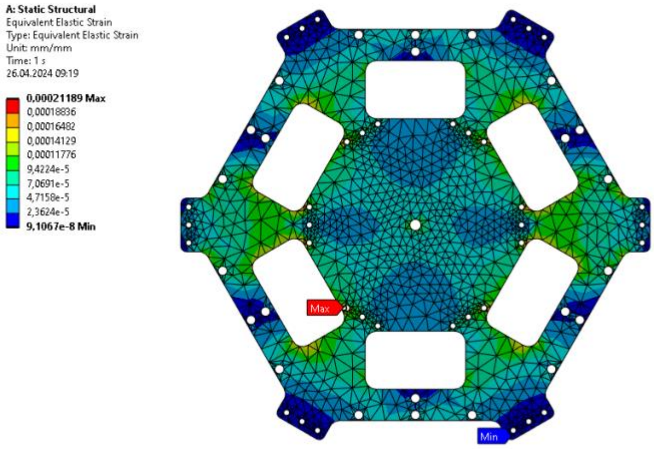

Figure 24. Strain analysis for the tetrahedrons mesh structure.

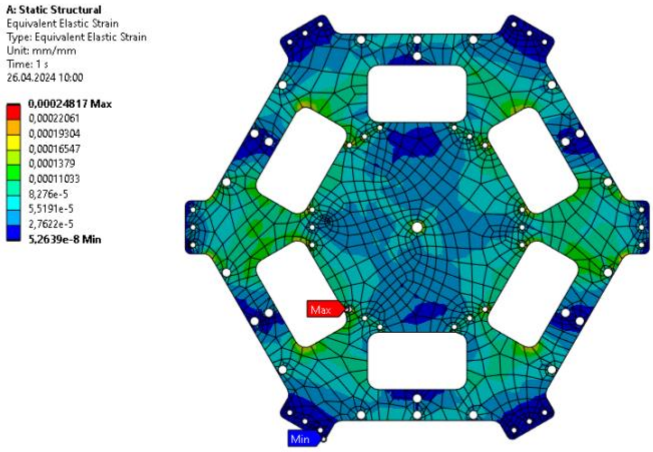

Figure 25. Strain analysis for the hex dominant method mesh structure.

Table 9. Maximum and minimum values for the strain analysis.

Mesh Type	Min. Value (mm/mm)	Max. Value (mm/mm)
Multizone	1.373 e-7	0.00029071
Tetrahedrons	9.1067 e-8	0.00021189
Hex Dominant Method	5.2639 e-8	0.00024817

The maximum value in the strain analysis with the multizone mesh structure (see Figure 23) is calculated to be 0.00029071 mm. The maximum value for the same analysis with the tetrahedrons mesh structure (see Figure 24) is found to be 0.00021189 mm, and finally the maximum value for the strain analysis with the hex dominant method mesh structure (see Figure 25) is calculated to be 0.00024817 mm. The deformation values in terms of the strain analysis are found to be maximum in the multizone mesh structure, then in the hex dominant method mesh structure, and then in the tetrahedrons mesh structure. However, it is seen that the total force acting on the upper body part of the drone does not cause a crucial deformation in terms of the strain analysis. Finally, stress analysis were performed to the same body part of the drone. Figure 26 shows the stress analysis of multizone mesh structure, Figure 27 shows the stress analysis of tetrahedrons mesh structure, and Figure 28 shows the same analysis of hex dominant method mesh structure. The maximum and minimum values for the mesh structures for the stress analysis are shown in Table 10.

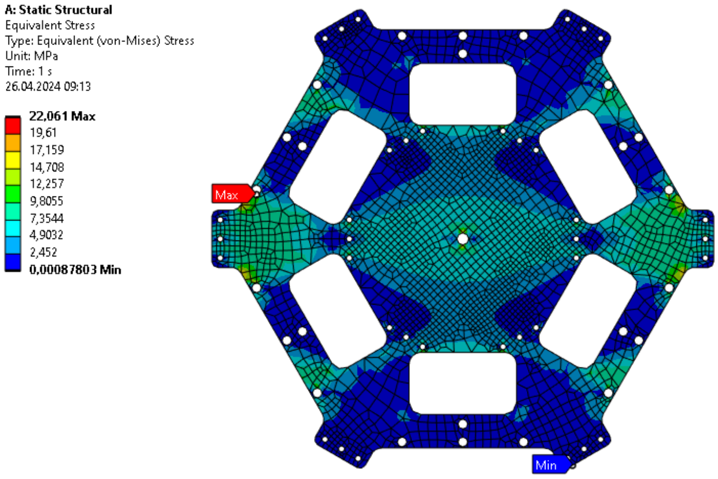

Figure 26. Stress analysis for the multizone mesh structure.

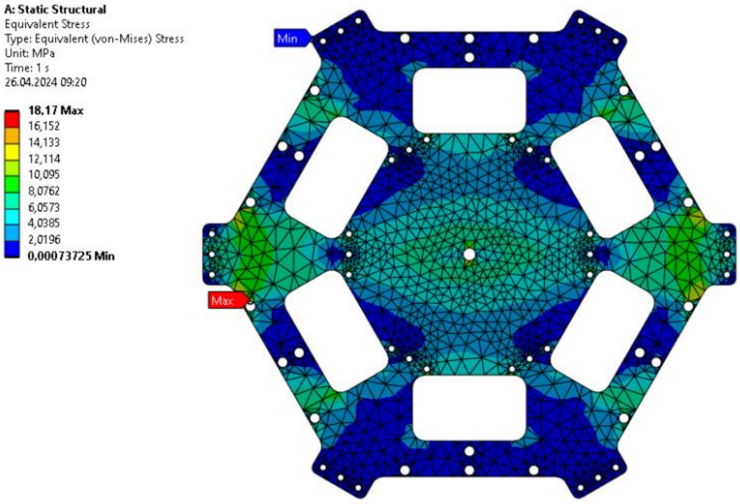

Figure 27. Stress analysis for the tetrahedrons mesh structure.

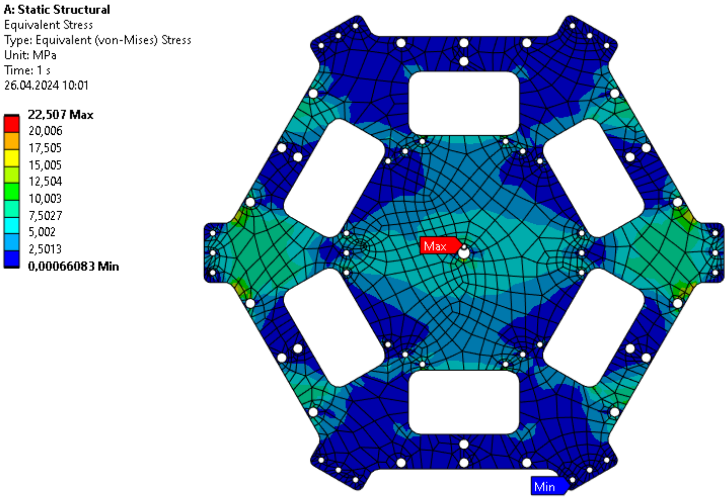

Figure 28. Stress analysis for the hex dominant method mesh structure.

Table 10. Maximum and minimum values for the stress analysis.

Mesh Type	Min. Value (MPa)	Max. Value (MPa)
Multizone	0.00087803	22.061
Tetrahedrons	0.00073725	18.17
Hex Dominant Method	0.00066083	22.507

For the stress analysis with the multizone mesh structure (see Figure 26), the maximum value is found to be 22.061 MPa, for the stress analysis with the tetrahedrons mesh structure (see Figure 27), the maximum value is calculated to be 18.17 MPa, and for the stress analysis with the hex dominant method mesh structure (see Figure 28), the maximum value is found to be 22.507 MPa. The greatest deformations in terms of the stress analysis is seen in the hex dominant method mesh structure, then in the multizone mesh structure, and then in the tetrahedrons mesh structure. It is also seen that the total force acting on the upper body part of the drone does not cause a vital deformation in terms of the stress analysis.

4. Conclusions and Recommendations

The mechanical and static structure of the drones apart from their electronic and software equipment is very important especially for the drones used for industrial purposes to perform the desired tasks. Drone design is prominently affected by the systems used so that the payload added to the drone does not cause a negative impact on the drone structure in line with the effects it will be exposed to in the air. In order for uniquely designed industrial drones to be optimized and perform their duties by providing safe flight and high endurance in a stable manner, the mechanical components or parts of the drone must be structurally examined. The hexacopter structure drone can reach high altitudes with higher performance compared to industrial quadcopters. One of the most important factors in reaching high altitudes is the materials used in the structures that make up the drone. Lightweight, high-strength, low thermal expansion coefficient, high hardness, and high thermal and chemical resistance carbon fiber materials are very suitable for drones' structures. In this study, the upper and lower parts that will form the body structure of the hexacopter drone designed by using the Solidworks CAD program are planned to be produced by carbon fiber. The suitability and strength of the part geometries were tested by analyzing the total deformation, strain and stress of the lower and upper body parts of the hexacopter structure drone by using multizone, tetrahedrons and hex dominant mesh structures with the finite element method in the Ansys analysis program. The total deformation analysis, the maximum value for the lower part forming the body is seen in the hex dominant method mesh structure, while the maximum value for the upper part forming the body is seen in the multizone mesh structure. The maximum value for the lower part is 0.092862 mm and for the upper part is 0.22764 mm. In the strain analysis, the maximum value for the lower part forming the body is seen in the hex dominant method mesh structure, while the maximum value for the upper part forming the body is seen in the multizone mesh structure. The maximum value for the lower part is 0.00010565 mm/mm and for the upper part is 0.00029071 mm/mm. In the stress analysis, the maximum value for the lower part forming the body is seen in the multizone mesh structure, while the maximum value for the upper part forming the body is seen in the hex dominant method mesh structure. The maximum value for the lower part is 12.126 MPa and for the upper part is 22.507 MPa. There are design differences for the upper and lower parts that make up the designed body of the drone. The values in all mesh structures used in this study are significant even if they are different but near to each other and remain within acceptable limits for optimum analysis. It is normal not to have exactly the same results when different geometries are analyzed with different mesh structures since they do not respond exactly in the same way to these geometries. The difference in part geometry resulting from the design was also reflected in the results of total deformation, stress, and strain analysis for different mesh structures. However, as a result, it was seen that this unique design and material analyzed in this work can be used to produce drones that can quickly transport useful materials, equipment, etc. to people in difficult situations, especially in countries where natural disasters occur frequently.

The SOLID187 finite element was used to create the finite element mesh while setting up the model. This element has 10 nodes and each node has 3 degrees of freedom. These degrees of freedom can be listed as translational movements in the X, Y, Z directions. The most important constraints of the element used are as follows: An edge with a removed mid-side node implies that the temperature changes linearly along this edge. Specific heat capacity and enthalpy are calculated at each integration point to allow sudden changes within a coarse element mesh. The free surface of the element is assumed to be adiabatic. None of these constraints affect the accuracy of the results of the analyzed problem. In addition, this finite element is based on 3D elasticity theory and is widely used for three-dimensional finite element analyses.

Authors' Contributions

All authors contributed equally to the study.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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