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# Structural comparison of vertical and horizontal layout of carrying arms of rotary-wing UAV with finite element analysis

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**Abstract**: In this study, numerical analysis of the fuselage of a rotary-wing unmanned aerial vehicle (UAV) was conducted. A fuselage that is resistant to the loads on the fuselage and has maximum lightness has been designed. In this context, the fuselage design was conducted based on the loads that the UAV's fuselage would be exposed to during landing and take-off, and three-dimensional models with vertically and horizontally positioned carrier arms were created for comparison. Numerical analysis was carried out using the designed solid models via the finite element method. In conclusion, it has been observed that in both configurations it can meet the loads on the fuselage without any breakage, and it has been concluded that the vertical configuration is more suitable in terms of control capability and flight performance due to its lower displacement.

**Keywords**: Numerical analysis, structure, rotary-wing UAV

## 1. Introduction

Unmanned aerial vehicles (UAVs) are generally divided into 3 groups according to the wing type: fixed-wing, rotary-wing, and hybrid wings (VTOL-vertical take-off and landing) [1,2]. Fixed-wing UAVs have a relatively greater range than rotary-wing UAVs. However, rotary-wing UAVs have vertical take-off and landing capabilities [3,4]. Those with a hybrid wing structure have features between these two UAV types [5]. In this study, the structural analysis of a rotary-wing type unmanned aerial vehicle fuselage was conducted with computer-aided engineering (CAE). The motivation of this study is to investigate whether it is appropriate to place the carrier arms horizontally or vertically on the fuselage of the rotary-wing UAV in terms of flight performance.

The mechanical part of rotary-wing unmanned aerial vehicles generally consists of the fuselage, carrier arms, and propellers. It can be expected from this fuselage and carrier arms to be as light as possible and strong enough not to undergo deformation [6]. In this context, computer-aided design and structural analysis carried out before the production of a UAV are of great importance. When considered from this point of view, many studies in which structural analyses for rotary-wing UAVs were conducted before production can be found in the literature. For example, Muralidharan et al. [7] performed stress and strain analysis before the additive manufacturing of an X-shaped drone fuselage. Shelare et al. [8] designed a rotary-wing UAV fuselage and conducted finite element analysis before manufacturing this fuselage by additive manufacturing. Sundararaj et al. [9] conducted a structural and modal analysis of a drone airframe for carbon fiber and ABS material. Javir et al. [10] studied a quadcopter in detail from design to production. Kim et al. [11] analyzed the fatigue of the fuselage of a rotary-wing unmanned aerial vehicle and calculated its lifespan. Additionally, it also carries out topology optimization studies to reduce the fuselage weight of unmanned aerial vehicles (examples of [12] and [13]). In addition, strain and von mises stress analysis of the UAV was investigated in this study.

In light of the above-mentioned literature research, structural analysis studies of a quadcopter fuselage and its carrier arms were carried out in this study. The first step of this study consists of the design of the solid model of the quadcopter. The fuselage and the arms of the quadcopter designed here are designed as a single piece. In addition, according to the position of the carrier arms to the fuselage, two different designs, horizontal and vertical, have been put forward for comparison with each other in terms of stress and strain. As a novelty of

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this study, after the solid model design phase, structural analysis of these two different designs was conducted and compared in terms of stress and strain. High-impact ABS (acrylonitrile butadiene styrene) material was defined in both designs in the structural analysis module. As a result of this study, it has been observed that there is more displacement and stress in the design that is horizontal compared to the body. For this reason, it has been concluded that the vertical configuration is more suitable for the flight performance of the UAV. The headings of this study have organized the design of rotary-wing UAV, meshing, structural analysis of rotary-wing UAV, results and discussion, and conclusion.

## 2. Material and Method

### 2.1. Design of Rotary-Wing UAV

The rotary-wing unmanned aerial vehicle was modeled using a solid model program as shown in Figure 1. Fuselage carrier arms consisted of 2 different configurations that were positioned vertically and horizontally. These configurations were compared in terms of stress and strain.

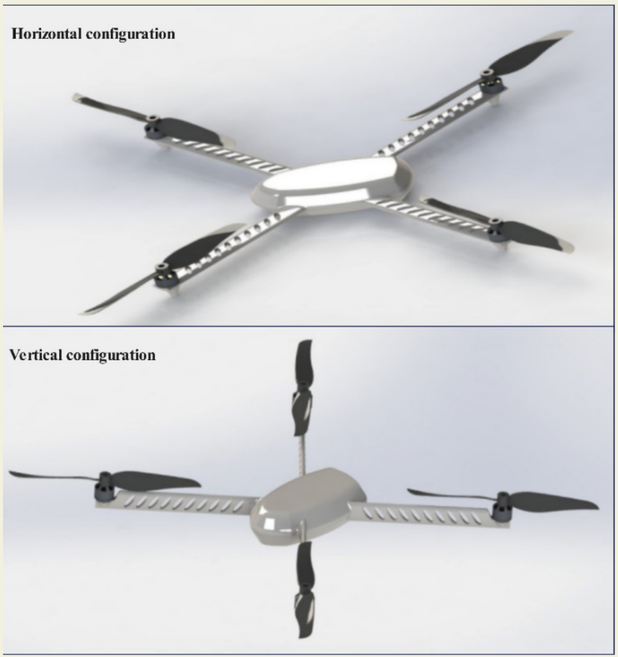


**Figure 1.** Solid models of rotary-wing UAV configurations

### 2.2. Finite Analysis

Ansys software frequently used for computer-aided engineering (CAE) allows us to solve the complexity of structural engineering problems and make faster design decisions. The finite element analysis method helps in solving mechanical problems of structural analysis for aircraft such as quadcopters [14]the central body frame constitutes major portion of the total weight. The present study aims at reduction of the frame weight while conforming with structural integrity requirements, through an integrated approach involving topology optimization, part consolidation and design for additive manufacturing (DFAM. Additionally, it helps to optimize the accuracy of structural analysis, design parameters of products, and reduce costs. Improving the flight performance of a quadcopter is related to the resistance of the fuselage structure to the loads that may occur during flight and its structural weight to be as low as possible. Integration of the structural equipment of the quadcopters and absorbing the loads it encounters significantly affects the payload and lifetime [15-18]. The quadcopter frame, which undertakes the task of carrying the main loads, is exposed to high compressive and tensile loads [19]. In this study, finite element analysis is carried out by examining the Von-mises stress and total deformation of a rotary-wing UAV fuselage that has different configurations according to the position of carrying arms.

### 2.3. Meshing

In the structural analysis, after applying a separate load to each of the quadcopter arms and stabilizing the body, the meshing process was started. Tetrahedonal 3D mesh element type was preferred in order to better analyze the stresses, compression and tensile forces, and deformations on the arms in the regions where the quadcopter arms are attached to the body. The fact that the mesh elements are more intense, especially in the regions where fracture, fatigue, torsion, and shear forces can occur, will give more accurate results in the analysis of the results [20]. Therefore, in order to obtain mesh density in the regions we mentioned above, face sizing and edge sizing methods have been applied repeatedly to obtain opti-

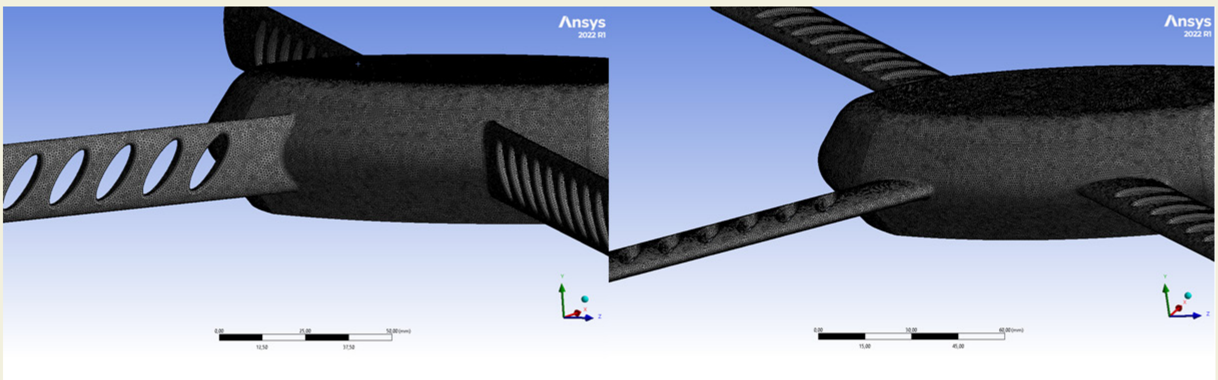


**Figure 2.** Images of mesh for both configurations.

mum mesh quality and number. The analyzes were carried out selected at the beginning to eliminate by reducing the face sizing values, and the skewness, which is the mesh metric value, was obtained as 0.85. The mesh structure created for both configurations is given in Figure 2.

## 3. Results and Discussion

Two different configurations with horizontal and vertical carrier arms according to the fuselage of the rotary-wing UAV were considered and their structural analyzes were examined separately. Accordingly, each arm was subjected to a load of 10 N. 30% Carbon-Fiber ABS is set as the body material data in the analysis setup. Minimum Principal Stress, Normal Stress, Normal Elastic Strain, Shear Stress, Equivalent Stress, Total Deformation, Maximum Principal Elastic Strain, and Maximum Shear Elastic Strain values are given in Table 1. Accordingly, it was seen that the total deformation is more in the horizontal configuration. The finite element analyses obtained as a result of the horizontal and vertical layout of the carrier arms of our quadcopter design were given in Figure 3 and Figure 4.

## 4. Conclusion

In this study, a force was applied to the carrier arms according to the total lift force of the quadcopter. As a result of this applied force, for the quadcopter was determined about the total deformations, tensile, compressive, and shear stresses in the carrier arms via finite element simulations. When the quadcopter carrier arms were placed vertically, a maximum deformation of 0.19572 mm was observed as a result of the same applied force, and a maximum deformation of 5.7663 mm when placed horizontally. When the shear stress was examined, it was observed that the stress of 2.4083 MPa in the vertical carrier arms and 14,337 MPa in the horizontal carrier arms. When the Equivalent (von Mises) Stress values were examined, 78.102 MPa maximum stresses were observed in the horizontal carrier arms and 9.3173 MPa in the vertical carrier arms. The finite element analyses given in Figure 3 and Figure 4 have also shown that the traditionally designed horizontal support arms exhibit higher deformations and stresses than the vertical arrangement. As a result of this study, it is clear that the vertical arrangement of the carrier arms for the quadcopter will improve the control capability of the aircraft, as well as the flight performance parameters.

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**Table 1.** Minimum and maximum values of the structural analysis result for both configurations.

| | Vertical | | Horizontal | |
|---|---|---|---|---|
| | Max | Min | Max | Min |
| Total Deformation (mm) | 0,19572 | 0 | 5,7663 | 0 |
| Equivalent Elastic Strain (mm) | 0,00048369 | 1,1425e-8 | 0,0040531 | 1,1773e-8 |
| Minimum Principal Elastic Strain (mm) | 8,4253e-9 | -0,00036779 | 5,3003e-10 | -0,0040666 |
| Equivalent (von-Mises) Stress (MPa) | 9,3173 | 9,526e-5 | 78,102 | -0,00014629 |
| Strain Energy (mJ) | 0,00022846 | 6,0365e-14 | 0,0064819 | 1,5943E-13 |
| Normal Stress (MPa) | 5,9077 | -4,3184 | 67,445 | -61,666 |
| Shear Stress (MPa) | 2,4083 | -2,4094 | 14,337 | -14,698 |
| Shear Elastic Strain (mm) | 0,00033319 | -0,0003335 | 0,0019836 | -0,0020334 |
| Maximum Principal Stress (MPa) | 9,9573 | -0,66189 | 80,829 | -6,4411 |
| Maximum Shear Stress (MPa) | 4,9377 | 5,2079e-5 | 39,703 | 7,9936e-5 |

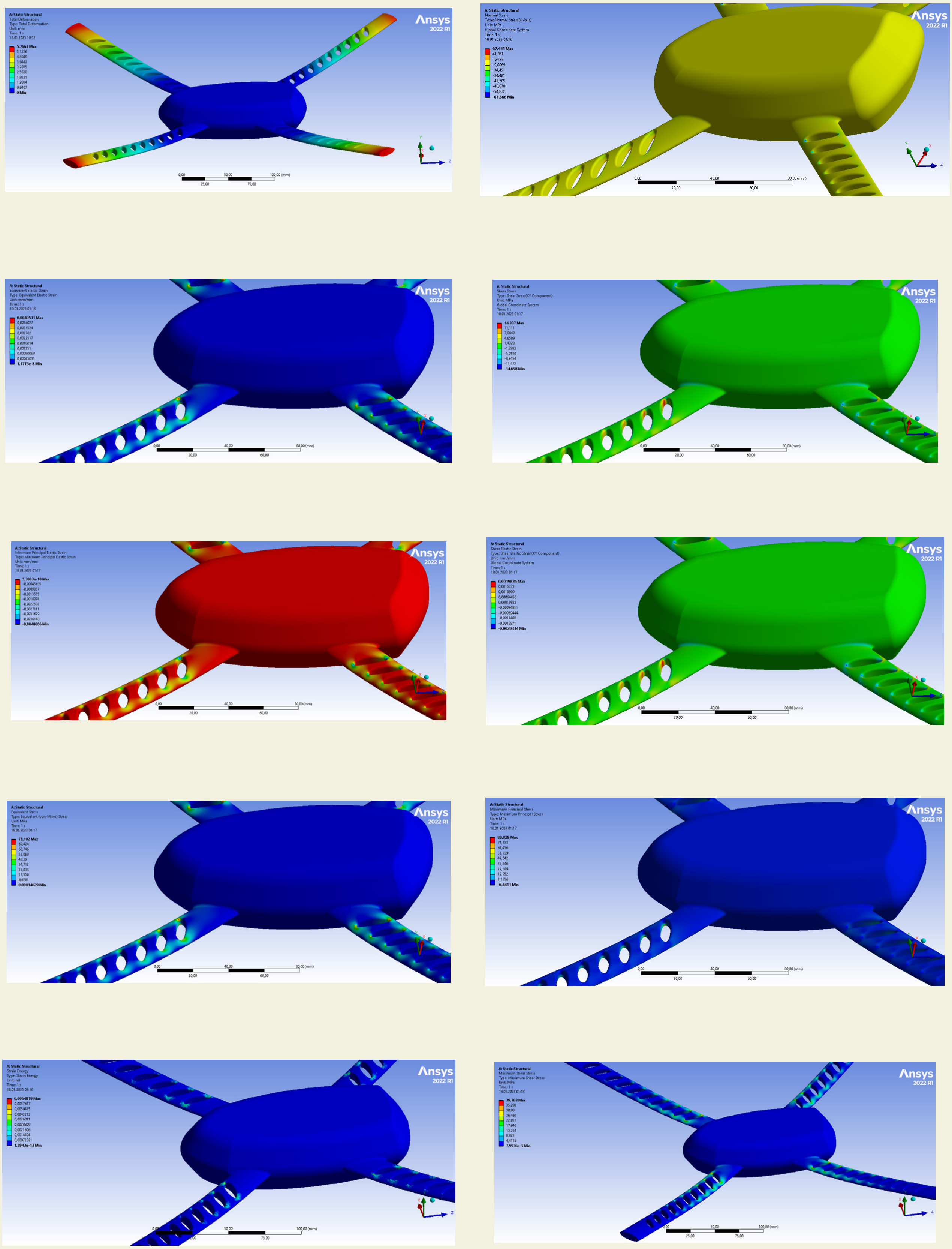


**Figure 3.** Structural analysis results of horizontal configuration.

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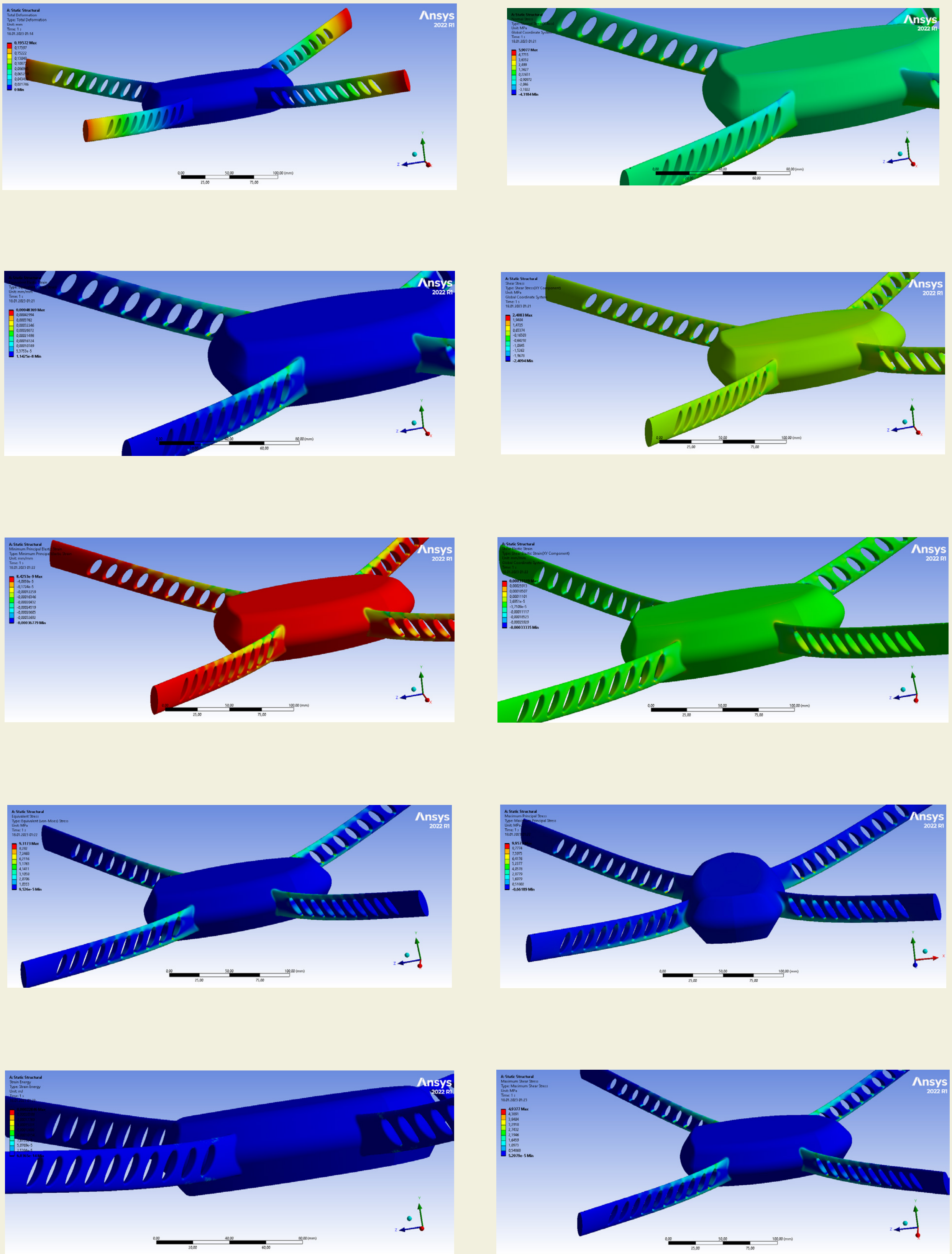

**Figure 4.** Structural analysis results of vertical configuration.

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