B.TECH EXPLORATORY PROJECT

ON

“Design Optimization of Drone Arm”

BY

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CERTIFICATE

This is to certify that the project entitled, **“Design Optimization of Drone Arm,”** submitted in the partial fulfillment for the exploratory project in Part-2, Mechanical Engineering, Indian Institute of Technology (BHU) Varanasi - 221005, is a bonafide project work carried out by the following students under my guidance and supervision:

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ABSTRACT

The **design optimization of drone arms** is an essential aspect of drone engineering, as it can significantly impact the drone's performance, stability, and efficiency. The optimization process typically involves using computer-aided design (CAD) software and simulation tools to evaluate the structural integrity of the arm and identify areas where weight can be reduced without compromising its strength and durability.

One common design approach is **topology optimization**, which involves iteratively removing material from the arm to retain the region providing more supporting stress. This can help reduce the arm's weight while maintaining its structural integrity, resulting in a lighter and more efficient drone.

While another new approach is **to use topology-optimized cellular structures** as they are already optimized and thus can give the required properties of lightweight structures. Recently research in this direction has been increased.

These are the two approaches we worked on during our exploratory project, and for analysis, we focus on attaining a high Factor Of Safety (FOS) while maintaining a low weight.

INTRODUCTION

A **drone arm** is a key component of a drone frame that provides structural support and houses various electronic and mechanical components. The arm is typically made from lightweight materials such as carbon fiber, aluminum, or plastic and is designed to be strong and aerodynamic.

The importance of the drone arm lies in its ability to support the drone's weight and distribute the forces generated during flight. The arm also serves as a mounting point for the motors, propellers, and other components that allow the drone to fly, as well as the battery and the onboard electronics that control the drone's flight.

A well-designed drone arm is crucial for achieving optimal flight performance and stability. The arm must be strong enough to withstand the stresses of flight while also being light enough to reduce the overall weight of the drone and maximize its flight time.

Overall, the drone arm plays a critical role in the design and performance of a drone, and its importance cannot be overstated. A well-designed and optimized drone arm is essential for achieving the desired flight characteristics and ensuring the safe and efficient operation of the drone.

Fig 1: A Drone Arm

The Problem

We target the **problem caused by heavy-weight drone arms**. The issues with heavy weight in drone flight are as follows: -

- The heavier the drone is, the more energy it requires to lift off and fly, which can reduce its flight time and maneuverability.

- A heavier drone can also affect the stability and control of the drone, making it more challenging to operate in windy conditions or to perform precise maneuvers.

- A heavier drone can also increase the risk of damage in a crash or collision, potentially causing more damage to the drone and any objects or people it may collide with.

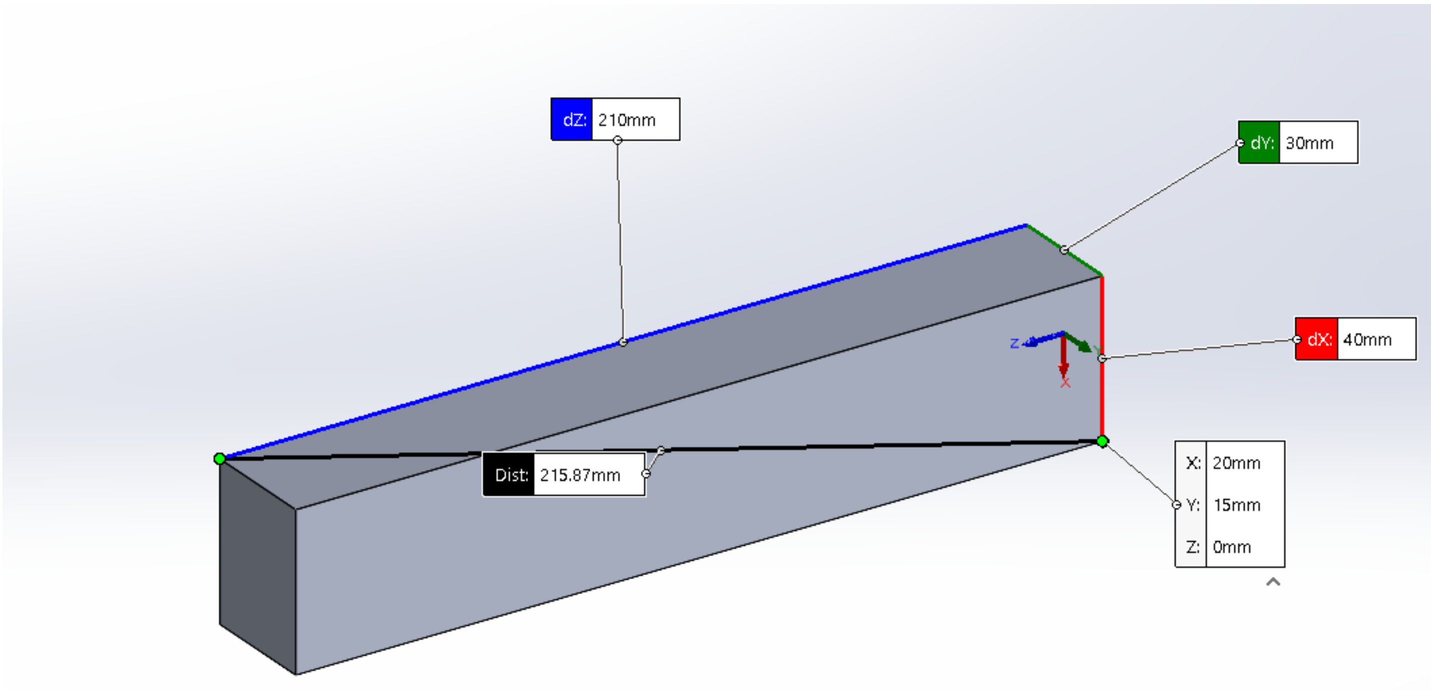

Fig 2: CAD Model of the standard drone arm

We take a **210 mm* 30 mm* 40 mm** cubical block for the **Aluminum 6061 - T6 (SS)** material drone beam. These dimensions are according to the drone arm of the F450 drone, a standard drone usually used in the market. We choose Aluminum 6061 alloy material as this is the most commonly used material We will compare our CAD models of the drone arm to this standard drone arm. Taking the dimensions of this drone arm as standard, all our CAD models will be of these exact dimensions and have the same material to keep uniformity while comparing them.

Our Idea

Our idea was to make a CAD model of a drone arm using **SOLIDWORKS** and then optimize its design using simulation software like **ANSYS using Finite Element Analysis (FEA)**. Below is the flowchart of our planning. We divide our planning into three stages: - reading research papers to get the idea of design optimization, designing CAD models, and then its analysis. Based on our analysis results, we optimize our design and then again do its analysis unless we get good results.

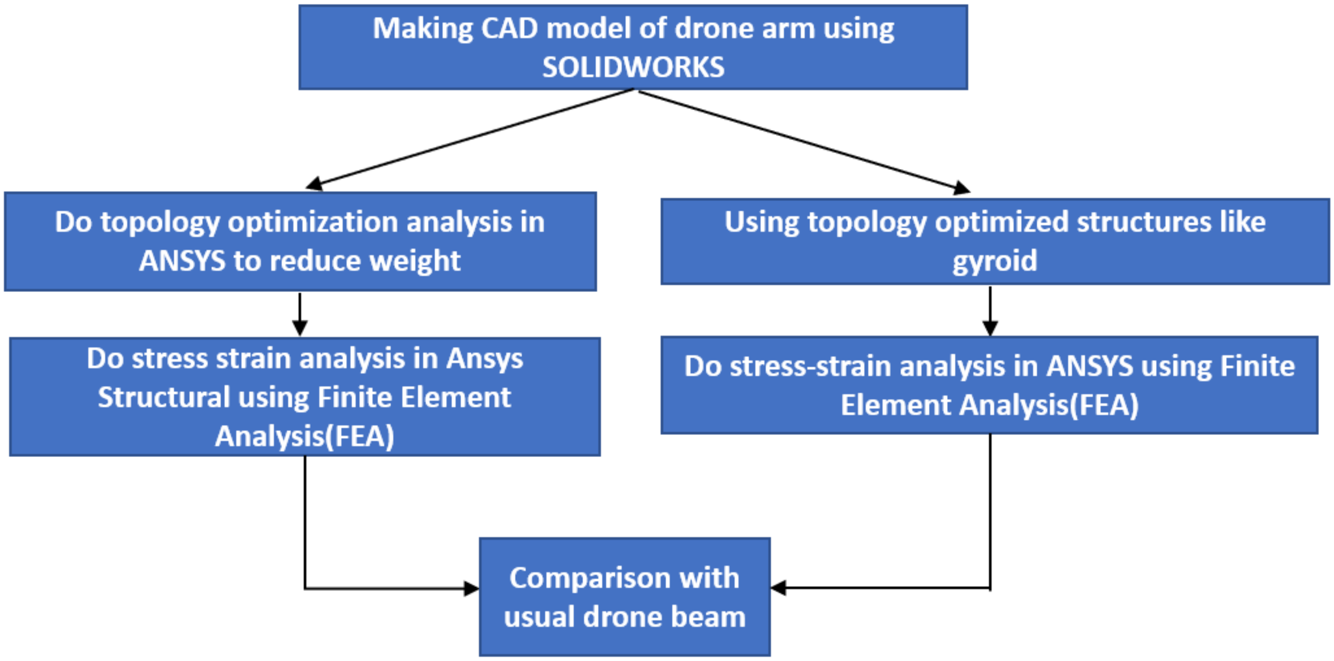

Fig 3: Flowchart of Planning

CAD Model using Topology Optimization

Topologically optimized structures are commonly used in engineering and architecture for their strength, rigidity, and ability to distribute loads evenly across a structure.

The most famous mathematical method for topology optimization is the **Solid Isotropic Material with Penalization method (SIMP)**. The SIMP method predicts an optimal material distribution within a given design space for load cases, boundary conditions, manufacturing constraints, and performance requirements.

We use SOLIDWORKS software for CAD modeling, and the dimensions and material are the same as those used for the standard drone arm.

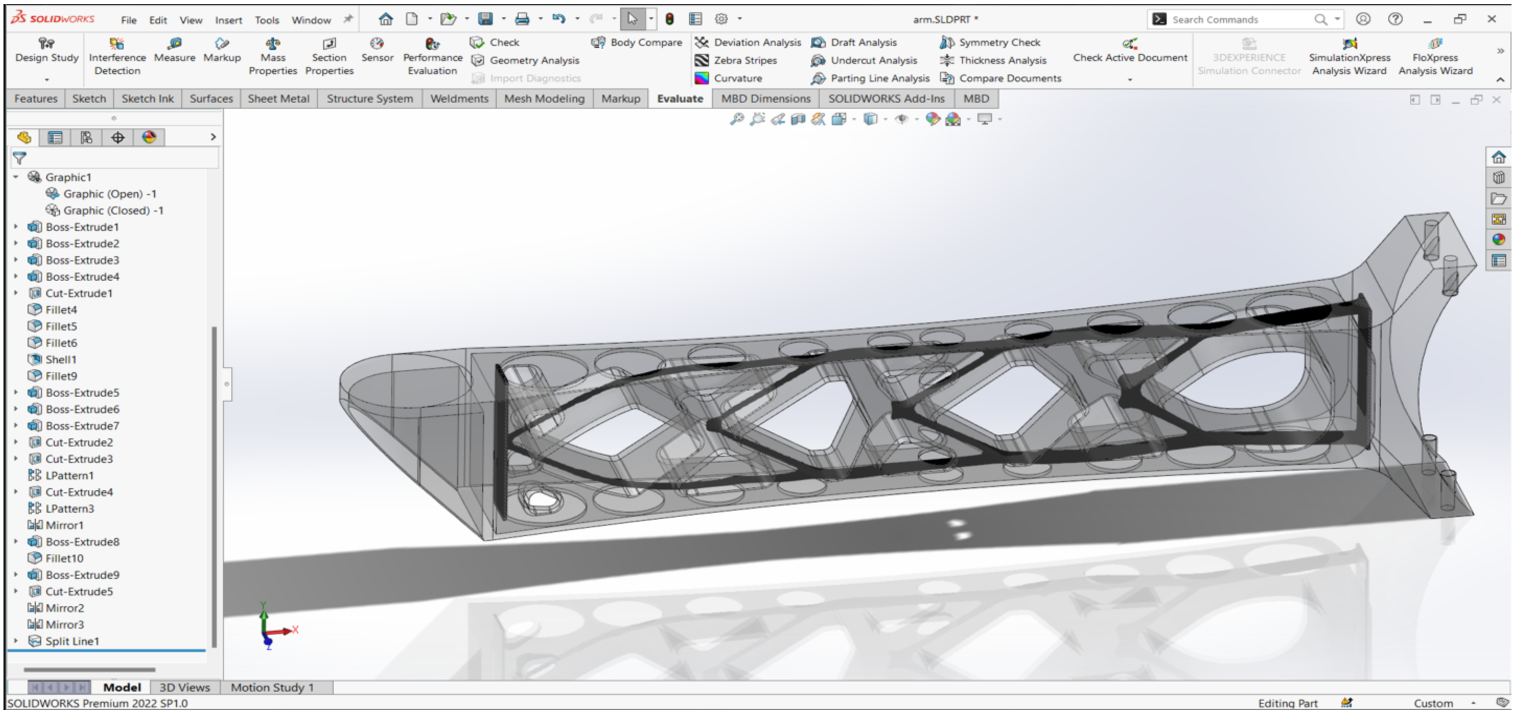

Fig 4: - CAD model of topologically optimized drone arm in SOLIDWORKS

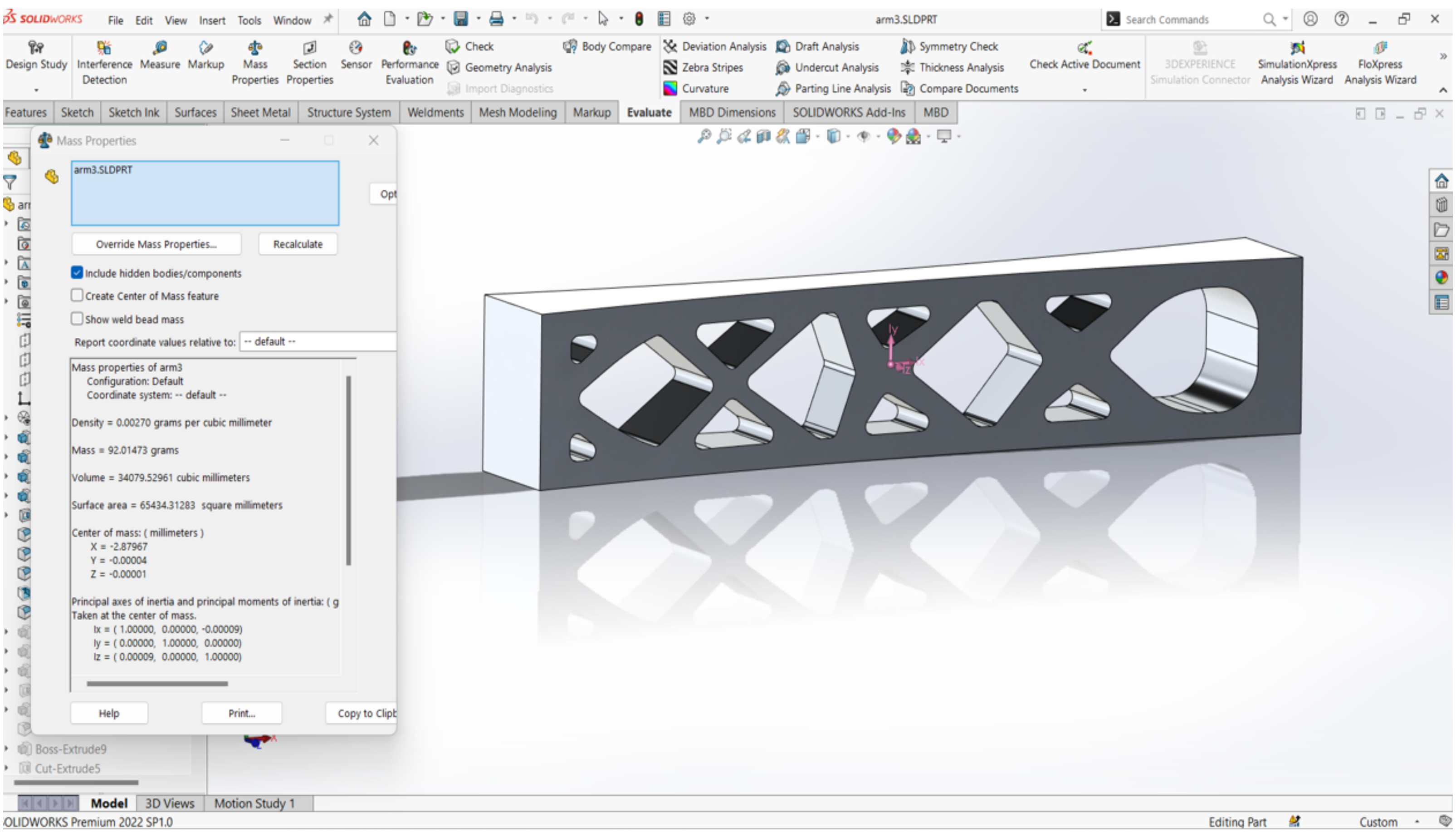

Fig 5: CAD model of topologically optimized drone arm having standard dimensions and its mass properties

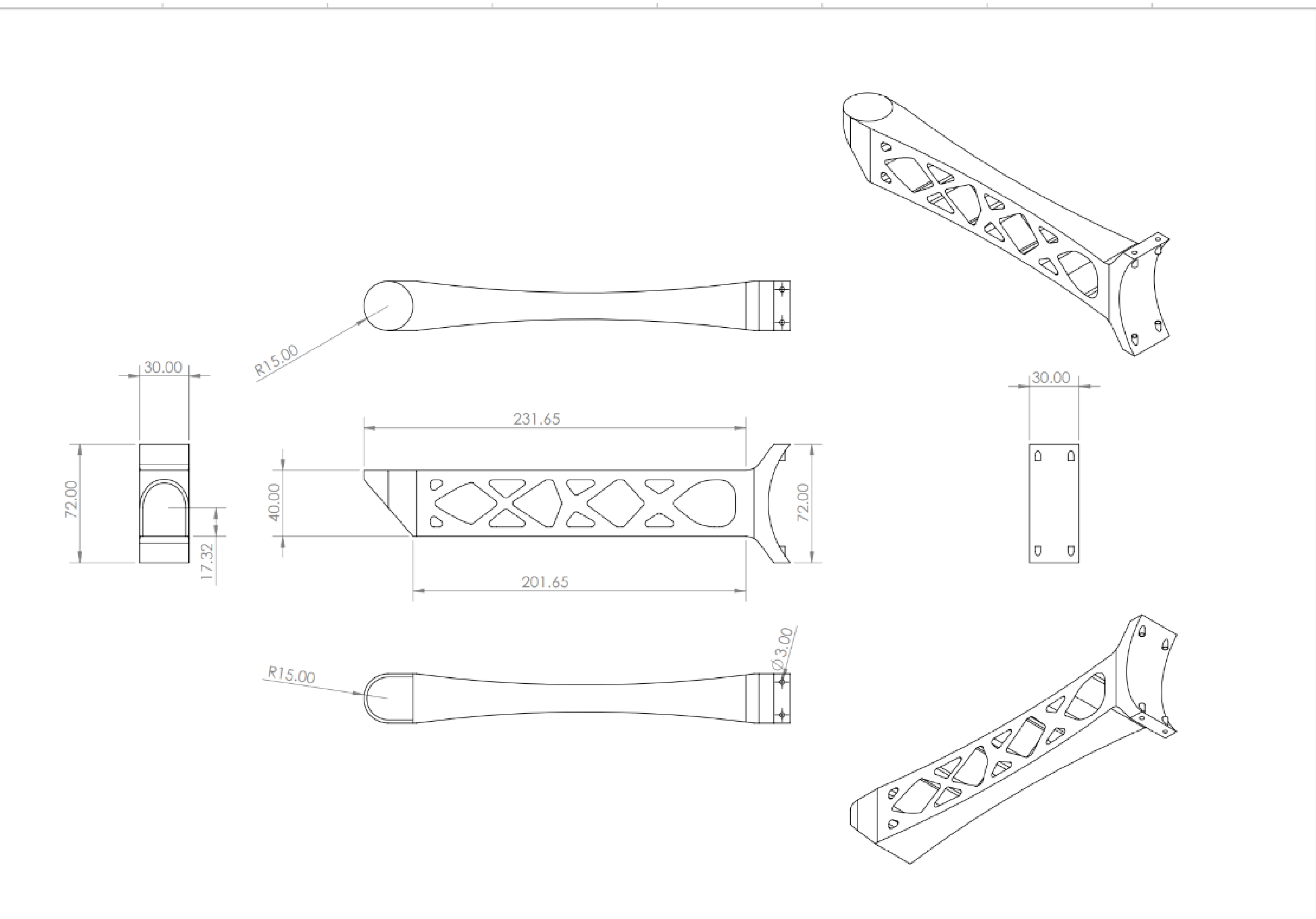

Fig 6: Different views and dimensions of topologically optimized drone arm

Fig 7: Section View of topologically optimized drone arm

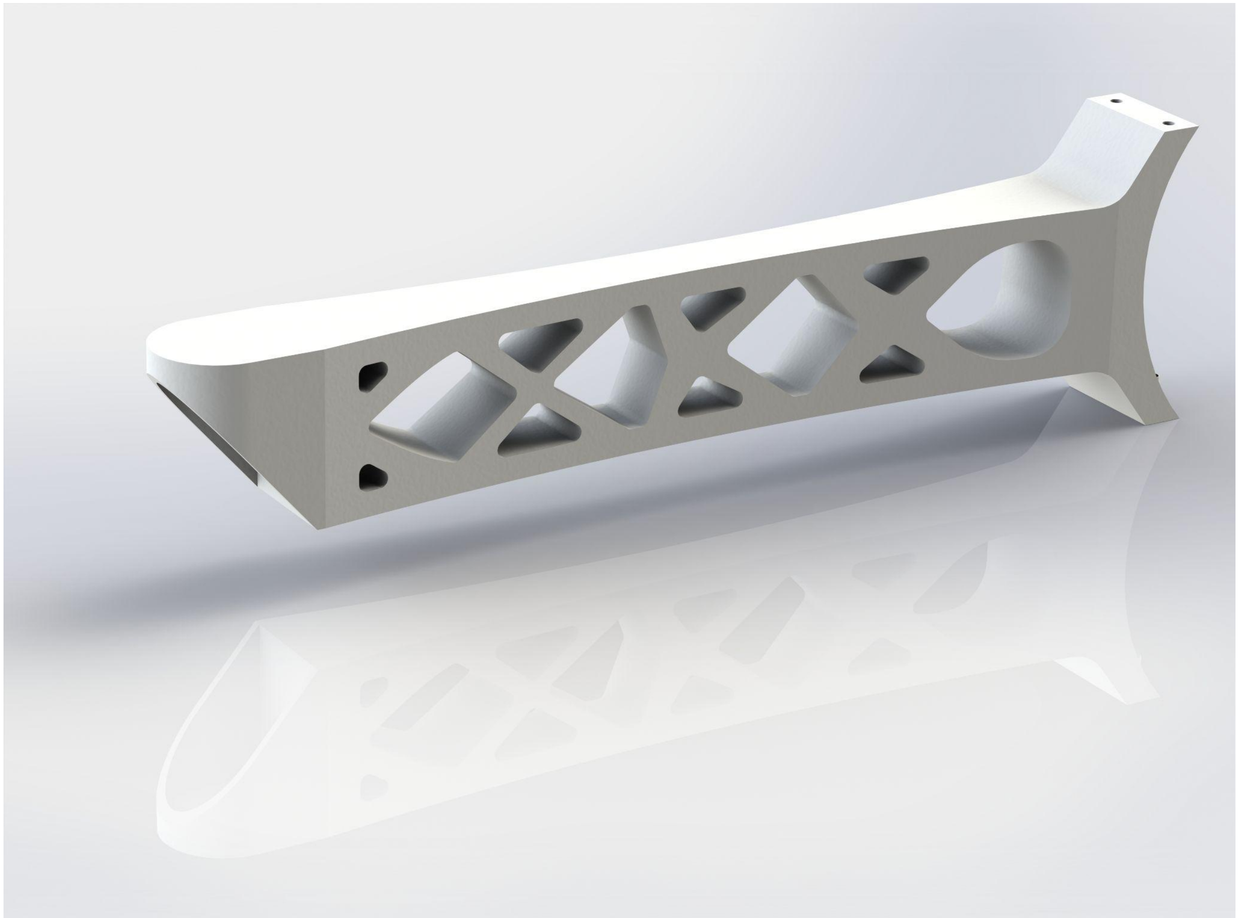

Fig 8: Rendered Image of topologically optimized drone arm

Structural Analysis of topologically optimized drone arm

Structural analysis of a topologically optimized drone arm involves using engineering principles and computer simulation tools to evaluate the arm's strength, stiffness, and stability under various loads and conditions. This analysis is crucial to ensure that the drone arm can withstand the forces and stresses of flight and maintain its structural integrity over time.

The CAD model of the drone arm is imported into ANSYS - a simulation software that uses mathematical algorithms of Finite Element Analysis (FEA) to simulate the behavior of the arm under different loads and conditions. First, we use topology optimization analysis of ANSYS, which involves iteratively removing material from the arm while maintaining its load-bearing capacity. Then, during the FEA simulation, the software analyzes the stress and strain distributions, as well as the displacements and deformations of the structure. This information can identify areas of the arm under excessive stress or strain and determine whether the arm will deform or buckle under specific loads or conditions.

Overall, the structural analysis of the topologically optimized drone arm is an essential step in the design process. It ensures that the arm is strong, stable, and capable of withstanding the forces of flight.

Boundary Conditions Used

We used the boundary condition of fixed support at one end (Fig 9) and 50 N of the drone arm's thrust force generated by motors and propellers at the other end (Fig 10).

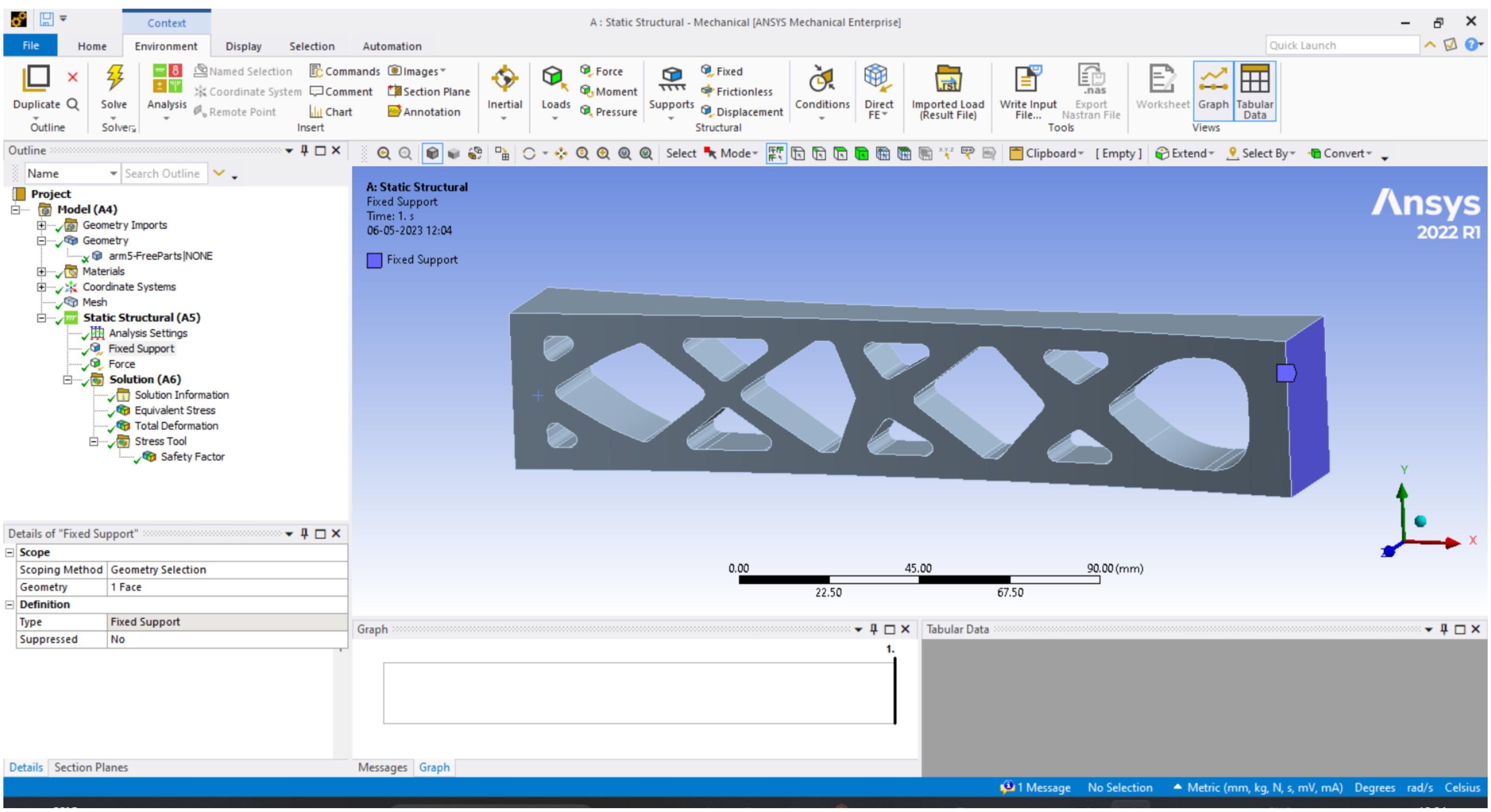

Fig 9: Boundary Condition of Fixed Support

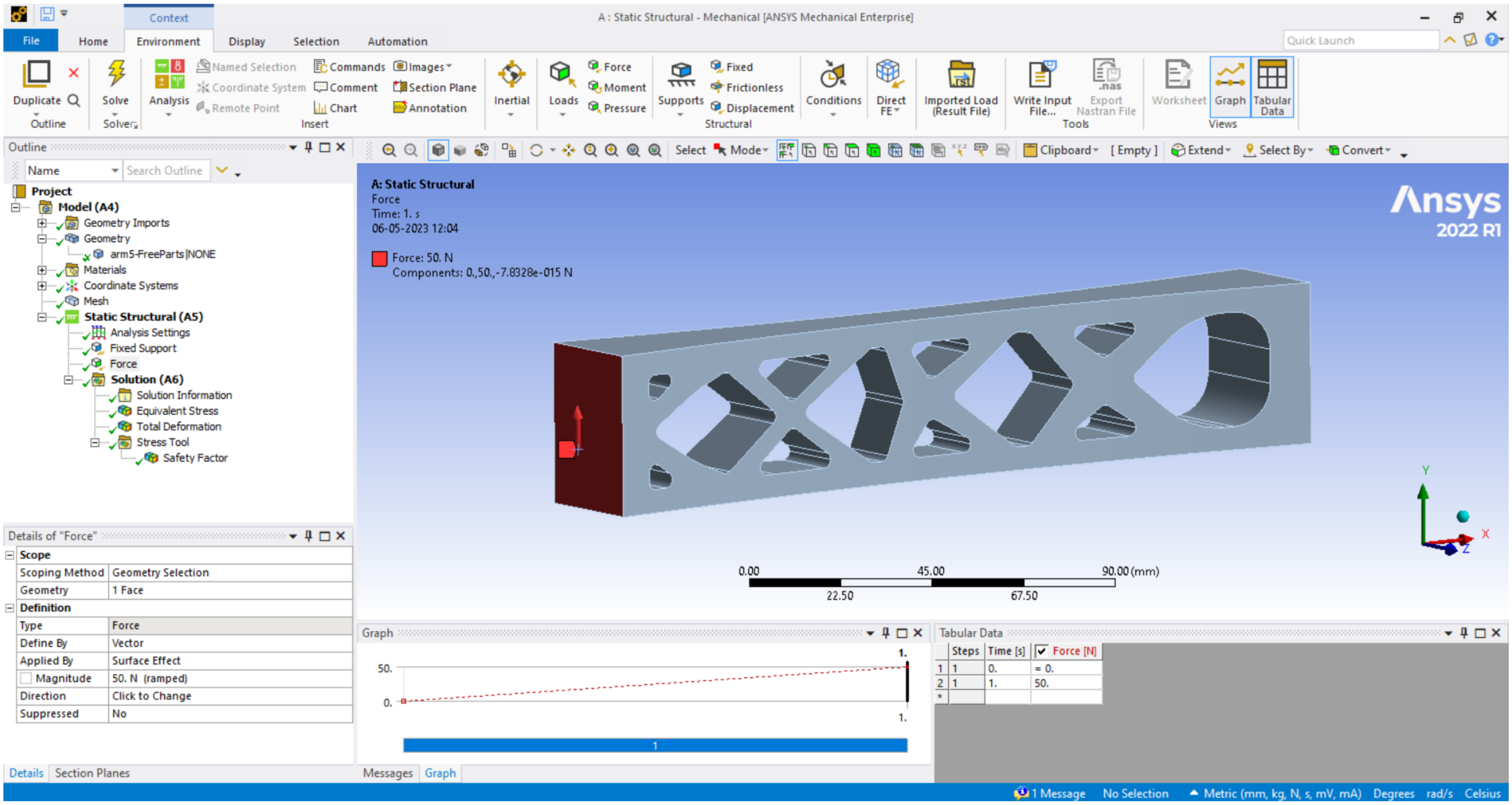

Fig 10: Boundary Condition of 50 N at another end of drone arm

Analysis results

Maximum deformation (mm)	0.1 mm
Average stress (MPa)	6.574 MPa
Average Factor Of Safety	15

Table 1: Analysis results of topologically optimized drone arm

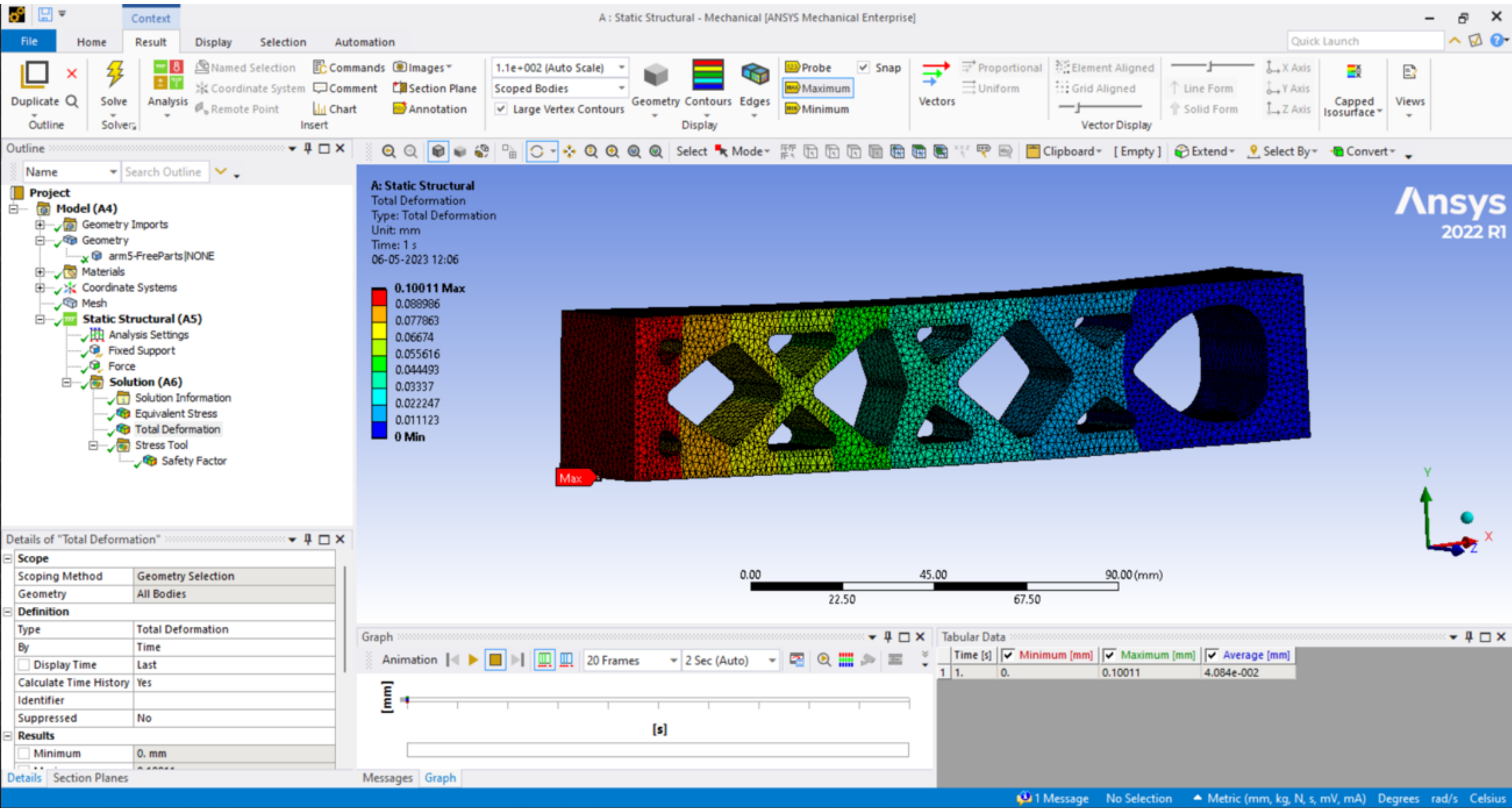

Fig 11: Total Deformation of topologically optimized drone arm

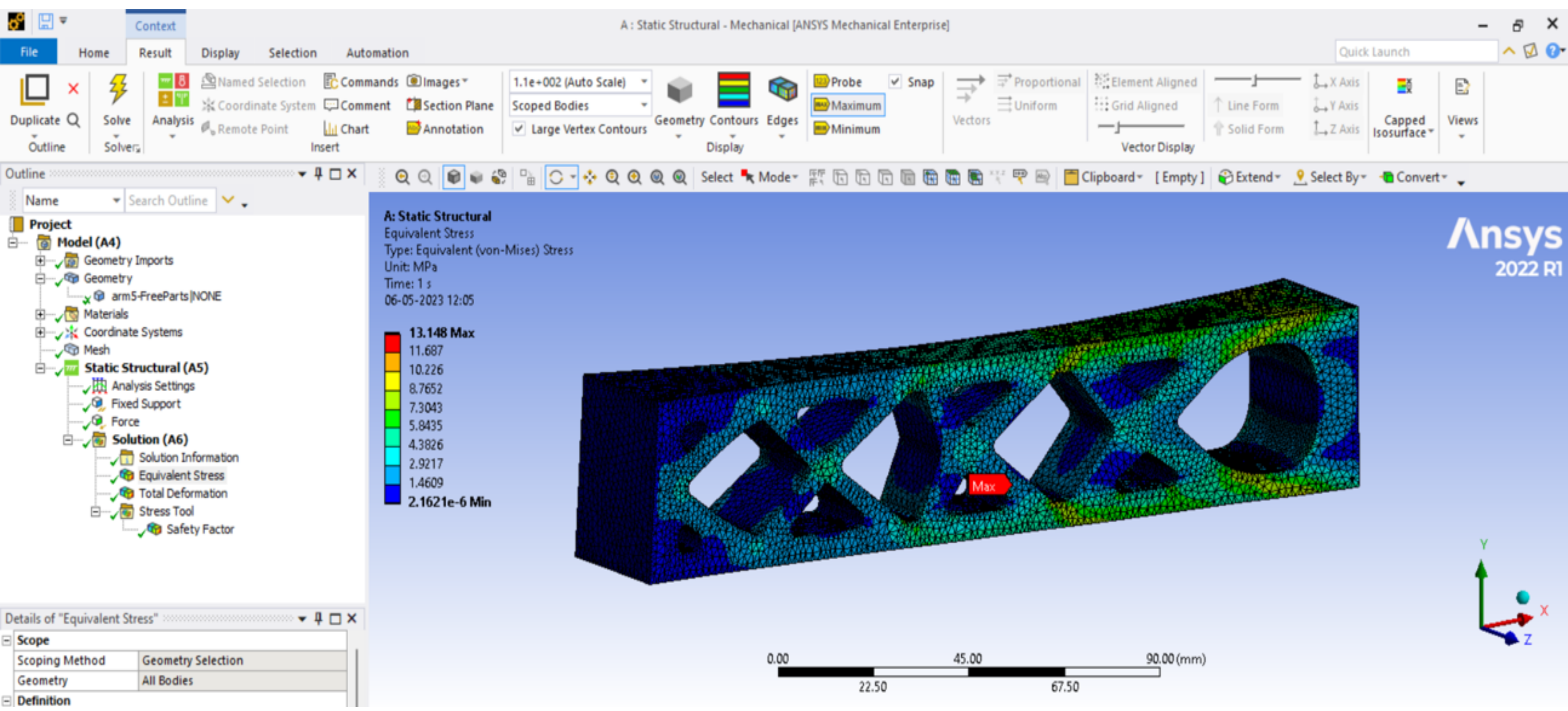

Fig 12: Equivalent (Von-Mises) stress of topologically optimized drone arm

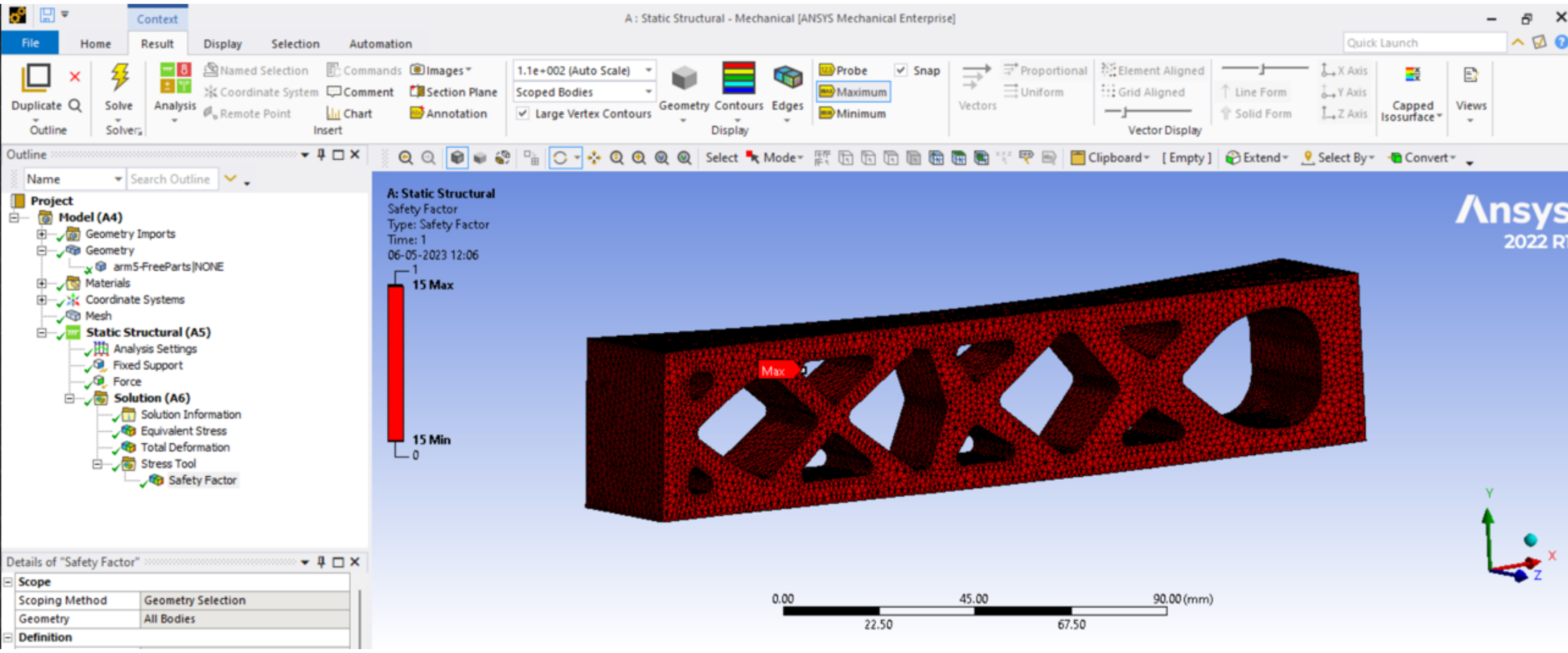

Fig 13: Factor Of Safety of topologically optimized drone arm

CAD Model using Gyroids

What are gyroids?

Gyroid structures are complex, three-dimensional structures characterized by repeating patterns of interconnected, curved surfaces. They are often found in nature [1], such as in certain corals and butterfly wings [3], but can be created synthetically using 3D printing or other fabrication methods.

The gyroid structure is unique because it is a triply periodic minimal surface. It has the smallest possible surface area for a given volume and can be repeated infinitely in three dimensions without intersecting itself. This makes it an ideal structure for various applications, from materials science and engineering to architecture and design. One major example of their application is in the shock absorber of Lockheed Martin [4] .

One notable feature of gyroid structures is their high surface area-to-volume ratio, making them useful for energy storage, filtration, and catalysis applications. In addition, their interconnected pore network provides a high degree of structural stability and mechanical strength, making them ideal for lightweight and strong materials.

The cellular structure of the gyroid

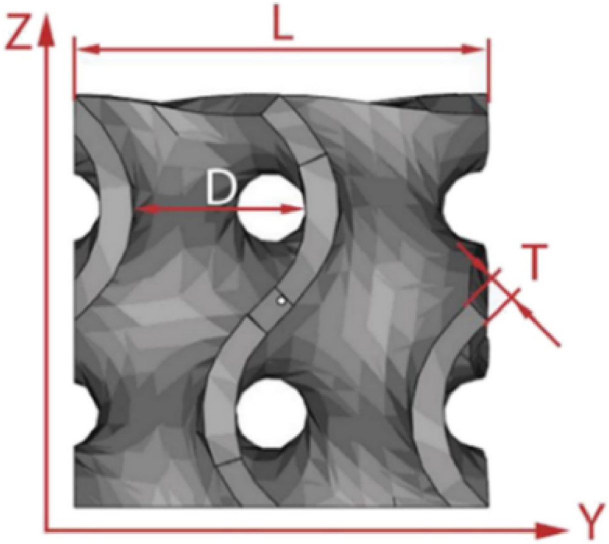

Fig 14: Design parameters of the gyroid cell[2]

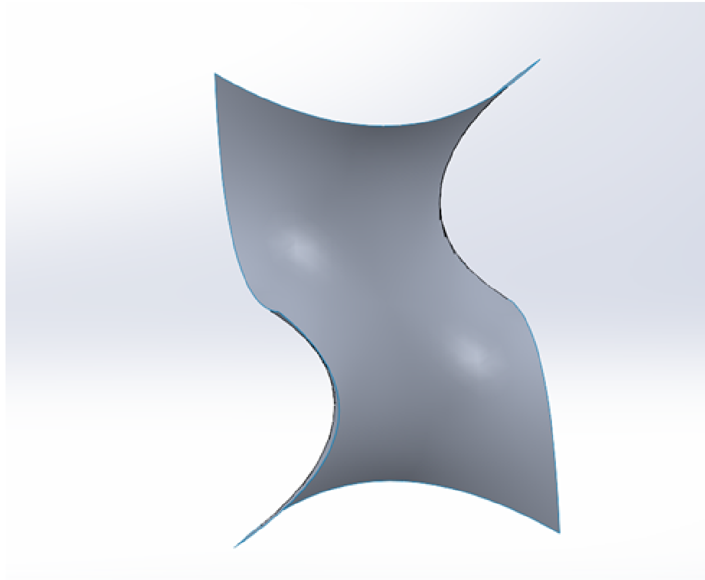

Fig 15: The CAD model of the gyroid

The principal design parameters in the gyroid cell are **unit cell size (L)** and **thickness (T)[2]**. The thickness of the gyroid cell is the main parameter that provides strength to the gyroid cell. In other words, **the strength of the gyroid cell is directly proportional to the thickness of the gyroid cell.** In our design, we choose a **thickness of 1 mm**.

Fig 15 shows the surface of the gyroid cell we design in SOLIDWORKS. After this, we vary its thickness according to the analysis results, which we will discuss further.

CAD model of gyroid drone arm

A CAD model of a drone arm using gyroids is a computer-generated 3D representation of a drone arm structure that utilizes a complex geometrical shape called a gyroid to provide structural support.

In the CAD model of a drone arm using gyroids, the arm is typically represented as a complex network of interconnected gyroid shapes arranged to form a continuous and highly efficient structure.

One of the advantages of using gyroids in the CAD model of a drone arm is that they can be easily adjusted and customized to meet specific design requirements. The gyroids' shape, size, and orientation can be modified to optimize the arm's strength, weight, and aerodynamic performance.

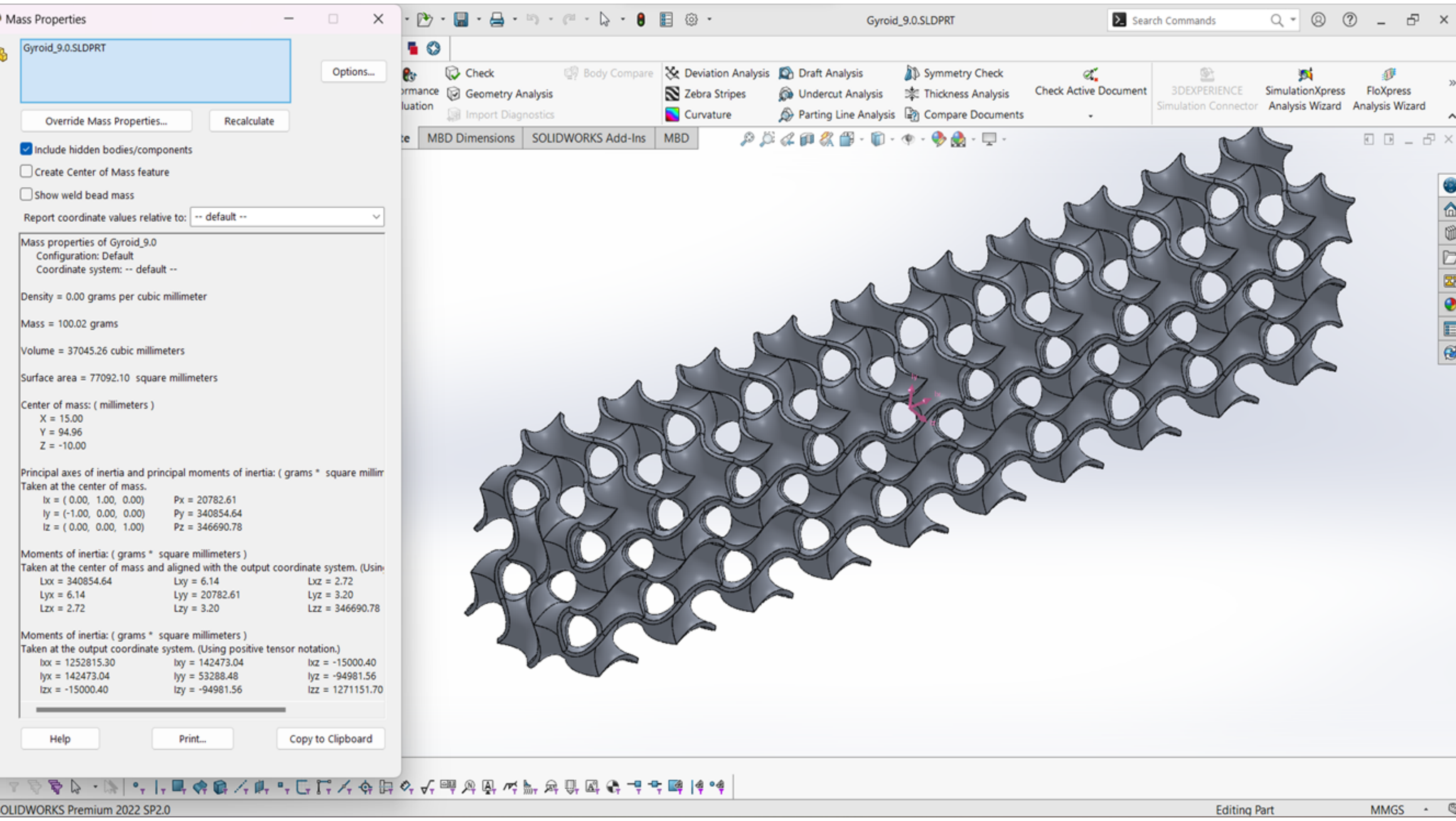

Fig 16: CAD model of drone arm with gyroids having standard dimensions and its mass properties

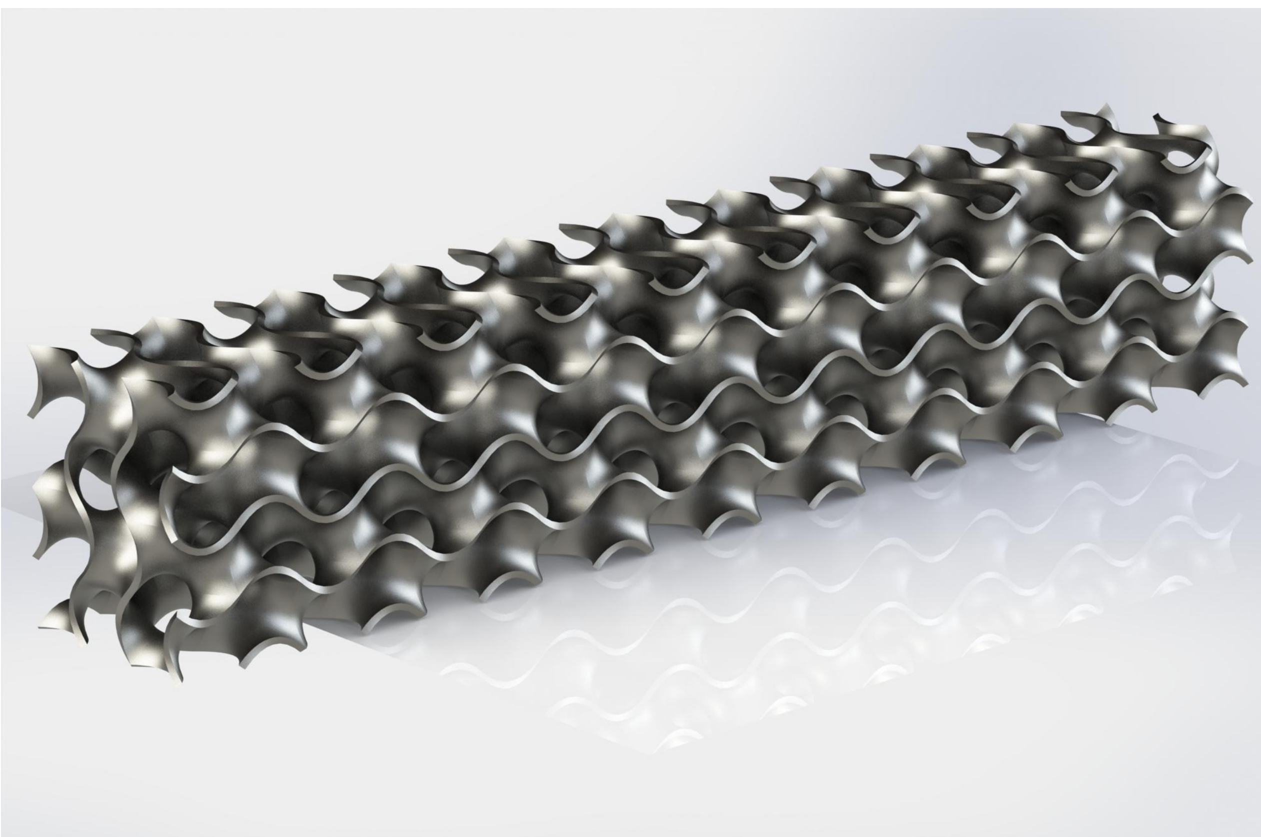

Fig 17: Rendered Image of Drone arm with gyroids

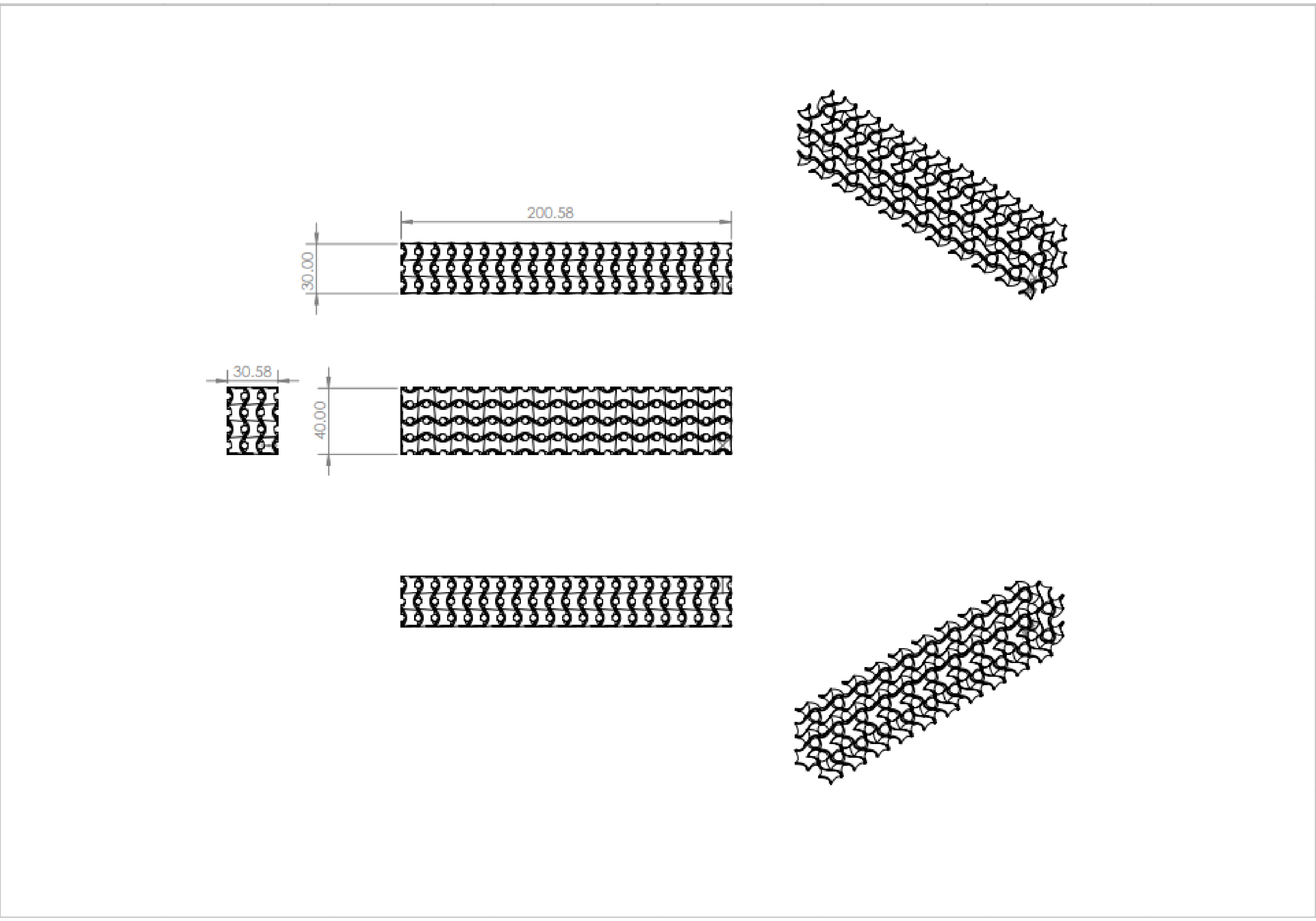

Fig 18: Different views and dimensions of drone arm with gyroids

Structural Analysis of gyroid drone arm

Structural analysis of a drone arm with gyroids involves using engineering principles and computer simulation tools to evaluate the arm's strength, stiffness, and stability under various loads and conditions. This analysis is crucial to ensure that the drone arm can withstand the forces and stresses of flight and maintain its structural integrity over time.

The CAD model of the drone arm with gyroids is imported into ANSYS - a simulation software that uses mathematical algorithms of Finite Element Analysis (FEA) to simulate the behavior of the arm under different loads and conditions. During the FEA simulation, the software analyzes the stress and strain distributions as well as the displacements and deformations of the structure. This information can identify areas of the arm under excessive stress or strain and determine whether the arm will deform or buckle under certain loads or conditions.

Overall, the structural analysis of a drone arm with gyroids is an essential step in the design process, as it ensures that the arm is strong, stable, and capable of withstanding the forces of flight.

Boundary Conditions Used

We used the boundary condition of fixed support at one end (Fig 19) and 50 N of the drone arm's thrust force generated by motors and propellers at the other end (Fig 19).

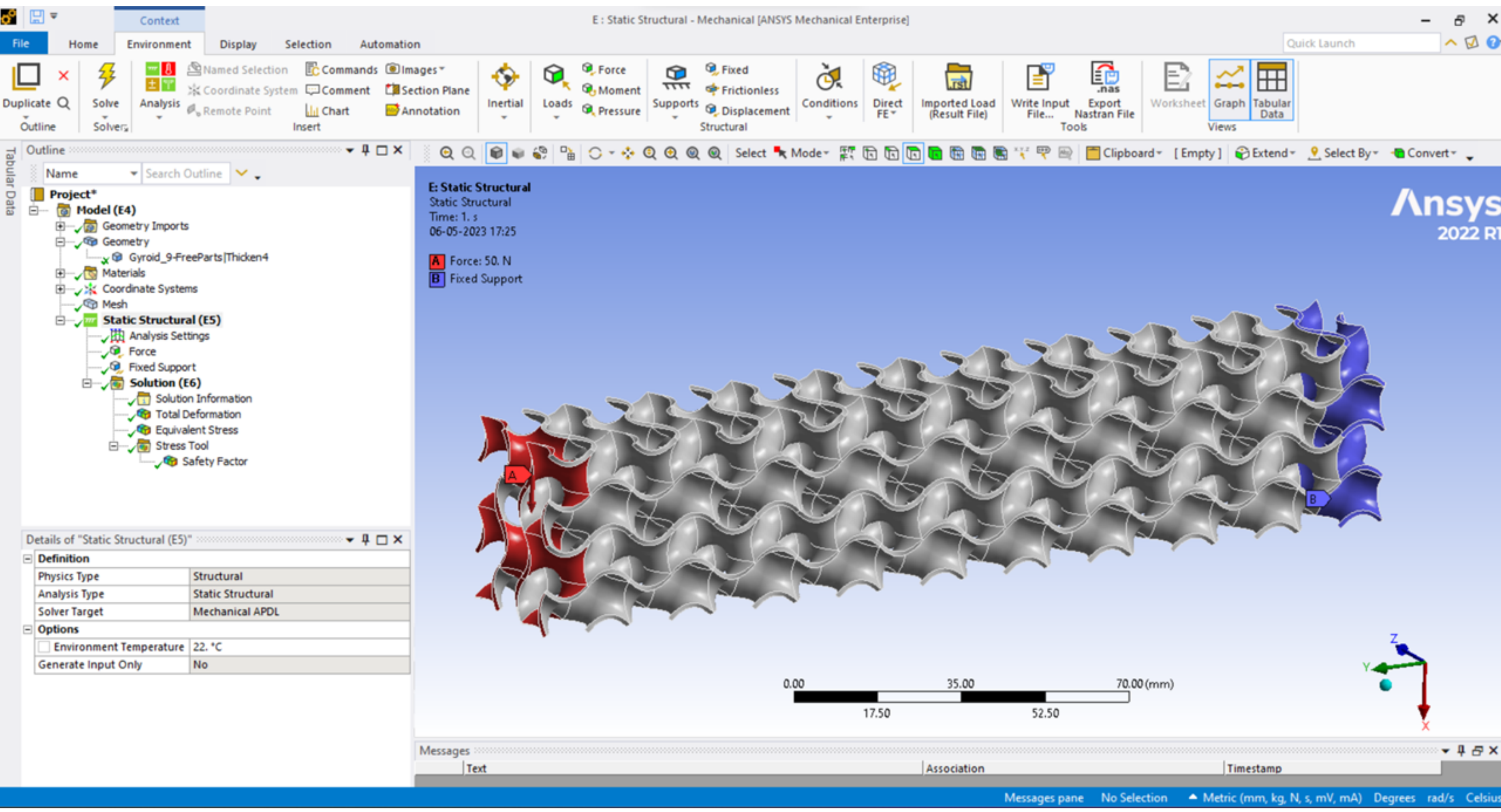

Fig 19: Boundary condition of fixed support and thrust force

Analysis results

Maximum deformation (mm)	0.319 mm
Average stress (MPa)	28.599 MPa
Average Factor Of Safety	9.9

Table 2: Analysis results of drone arm with gyroids

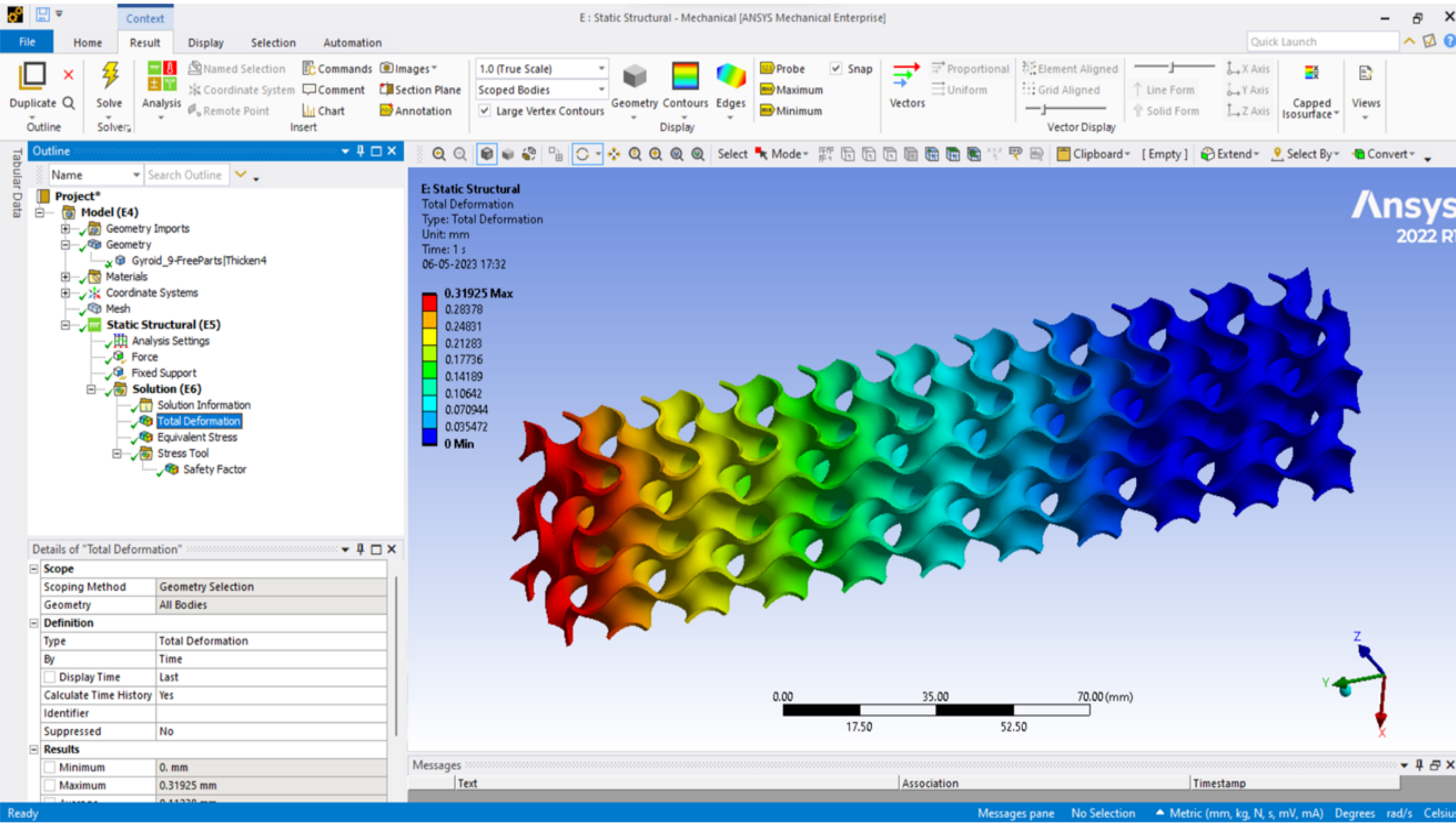

Fig 20: Total Deformation of drone arm with gyroids

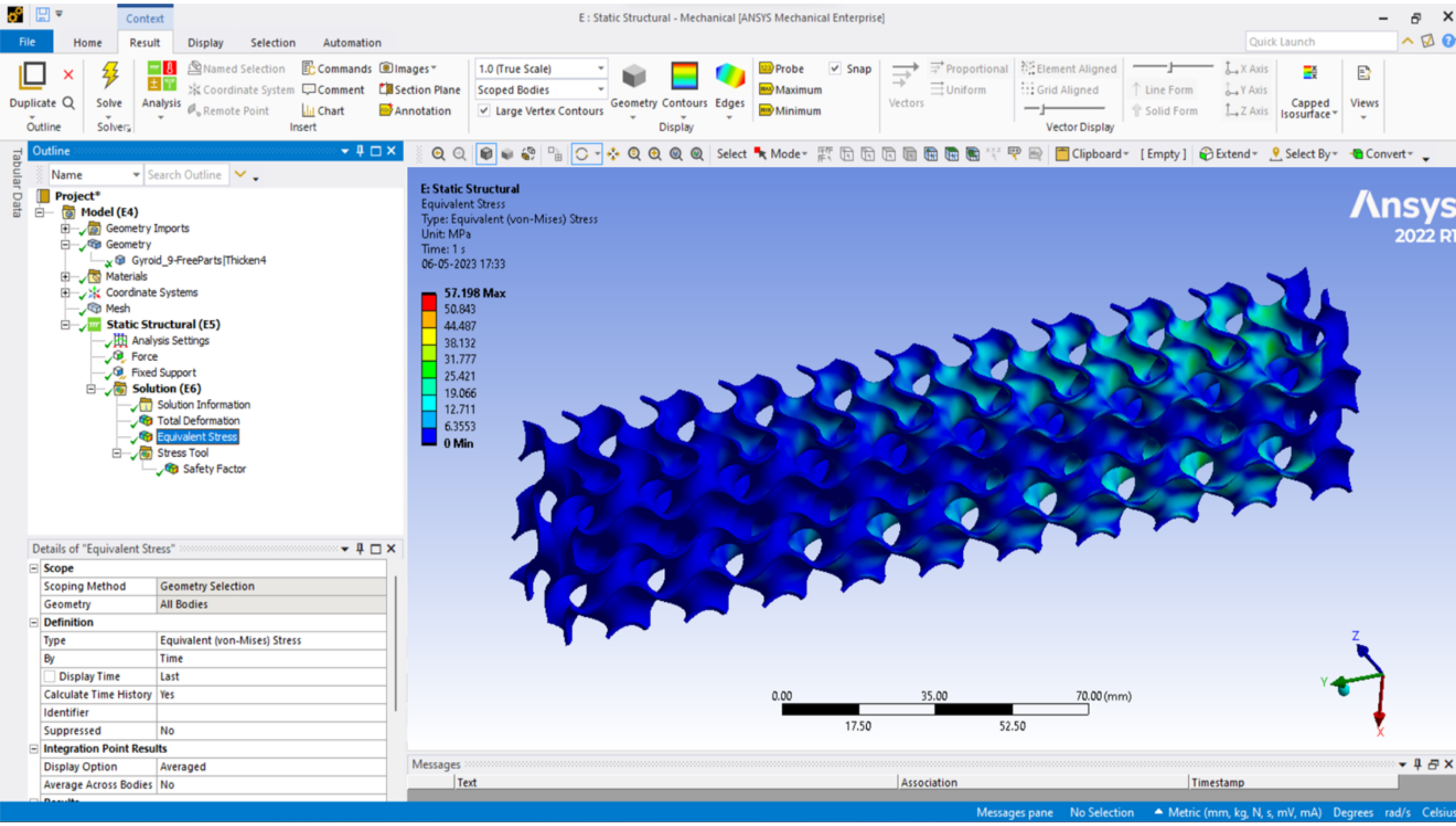

Fig 21: Equivalent (Von-Misses) Stress of drone arm with gyroids

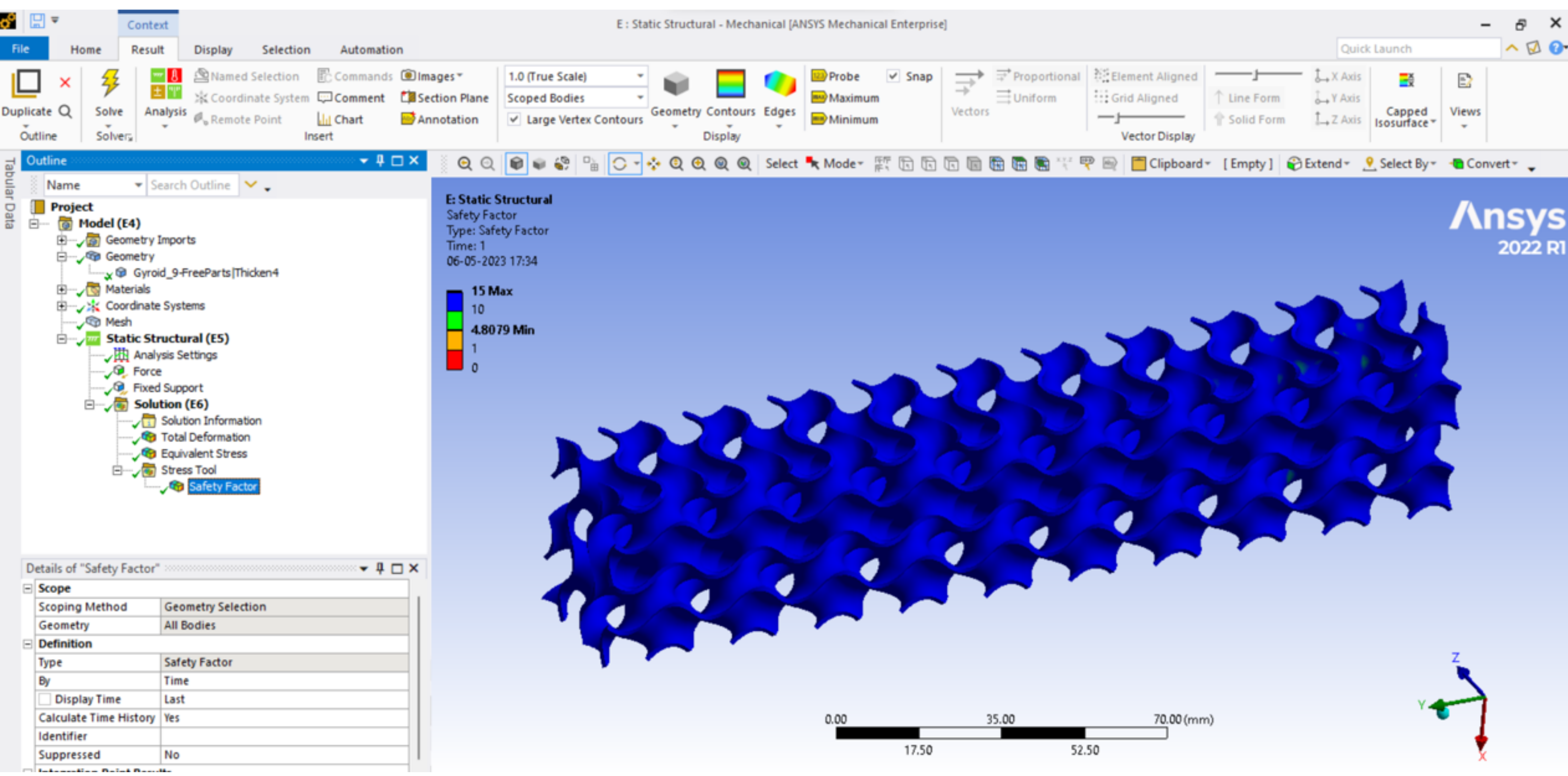

Fig 22: Factor of Safety of drone arm with gyroids

Conclusion and Comparison of analysis results

In this section, we will compare the results of the analysis of topologically optimized drone arm and drone arm with gyroids to that of standard drone arm. We used ANSYS and applied the same boundary conditions on the standard drone arm as the other two.

Analysis results of standard drone arm

Maximum deformation (mm)	0.01 mm
Average stress (MPa)	1.585 MPa
Average Factor Of Safety	15

Table 3: Analysis results of standard drone arm

We choose the Factor Of Safety per gram as the main parameter to compare all three drone arms. The strength of the drone arm is directly proportional to the Factor Of Safety, and minimizing weight is our main aim. Hence this ratio gives us a reasonable estimate efficiency of all three drone arms.

	Weight (grams)	**Maximum deformation (mm)**	**Average stress (MPa)**	**Average Factor Of Safety(FOS)**	**FOS/Weight (grams)$^{-1}$**
Standard Drone Arm	680.4	0.010	1.585	15	0.022
Drone arm with gyroids	100.2	0.319	28.599	9.9	0.098
Topologically optimized Drone arm	113	0.100	6.574	15	0.133

Table 4: Comparison of all analysis results

As we can see from Table 4 that **topologically optimized drone arm is the most efficient**. In contrast, **the standard drone arm is the least efficient.** As previously mentioned in the drone arm with gyroids, we have chosen a thickness of 1 mm; varying its thickness will give us different results. Increasing thickness will increase weight, but at the same time, it will also increase the average safety factor.

Challenges We Faced

Design optimization is a new and vast field for us. We try to explore this field and apply it in the design of drone arms. We faced these problems: -

- Designing the gyroid and its analysis proved problematic due to software limitations (Fig 21).

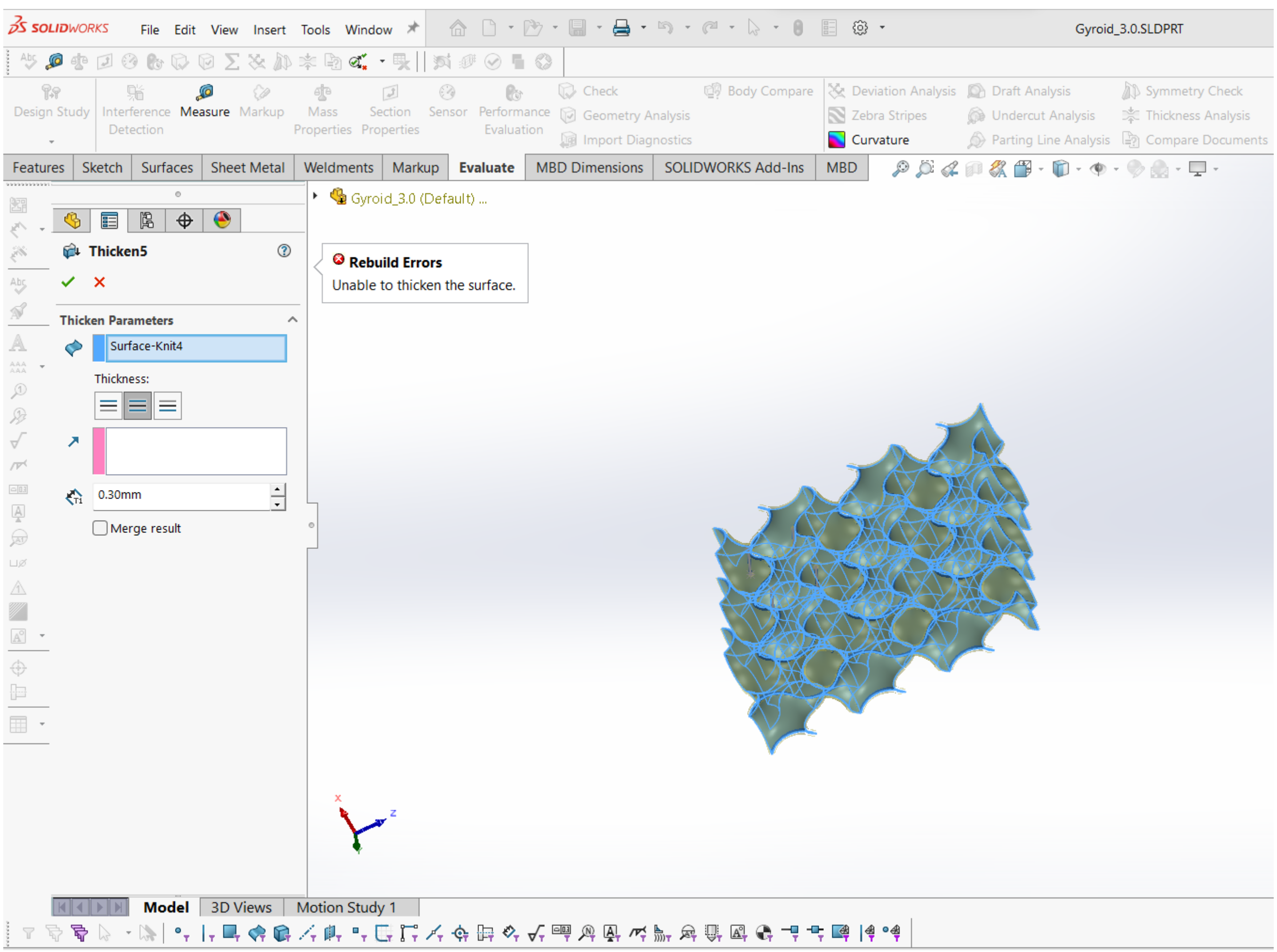

Fig 23: Errors while designing

- Topology optimization analysis in ANSYS doesn't work on non-linear materials; due to this limitation, we cannot test the drone arm by using materials like carbon fiber which are non-linear.

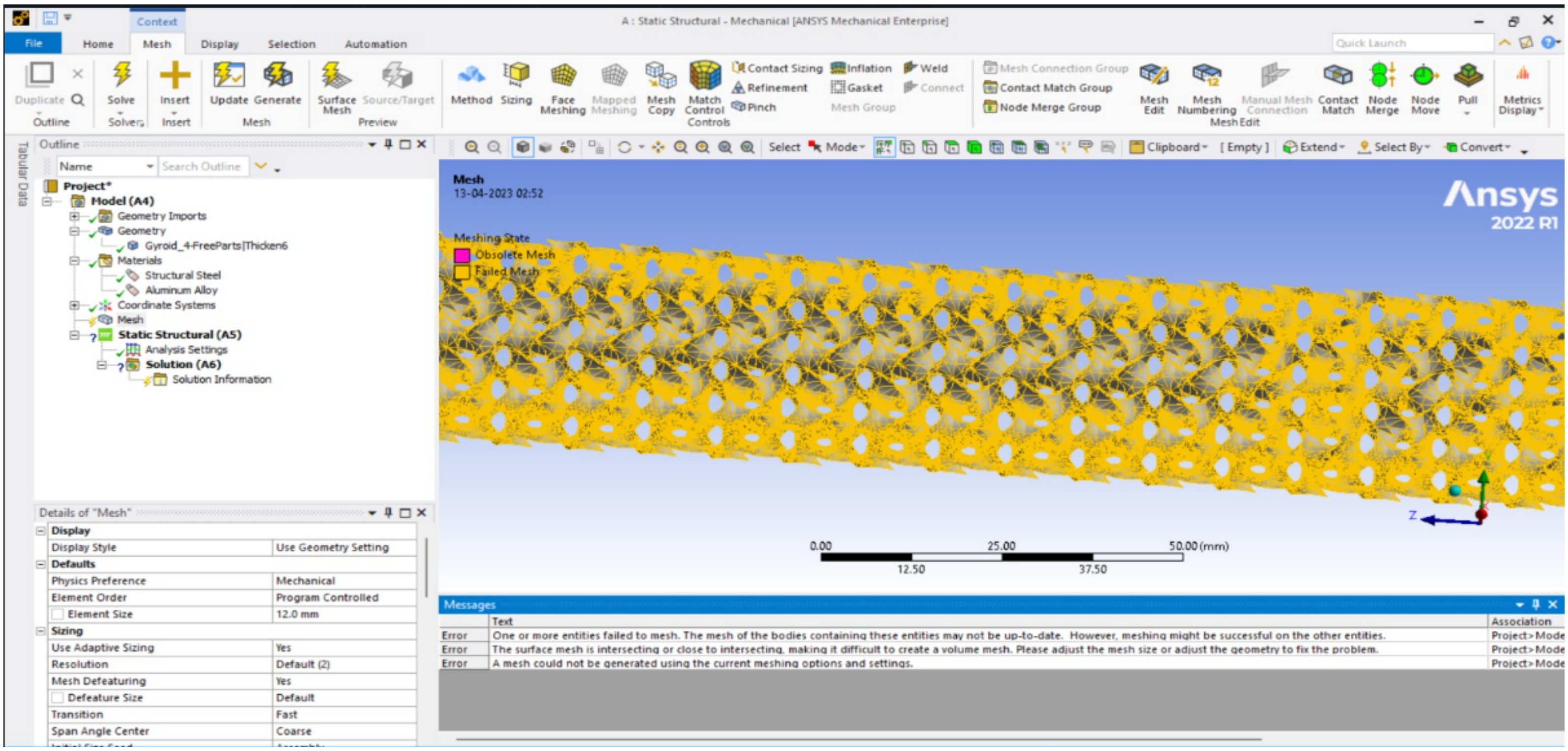

Fig 24: Errors while doing analysis

- There are also errors while meshing in ANSYS; FEA cannot be applied without meshing. Thus, these errors are quite a steeping block while doing simulation and analysis (Fig 22).

Future Works

We have discussed with our supervisor how to continue this project. These ideas have come up in our mind:-

- We are thinking of learning more about other simulation softwares to have better analysis results. This will allow us to present our design optimization results in competitions.

- We are looking to 3D print all three CAD models and do their analysis to compare experimental and simulation results (Fig 23).

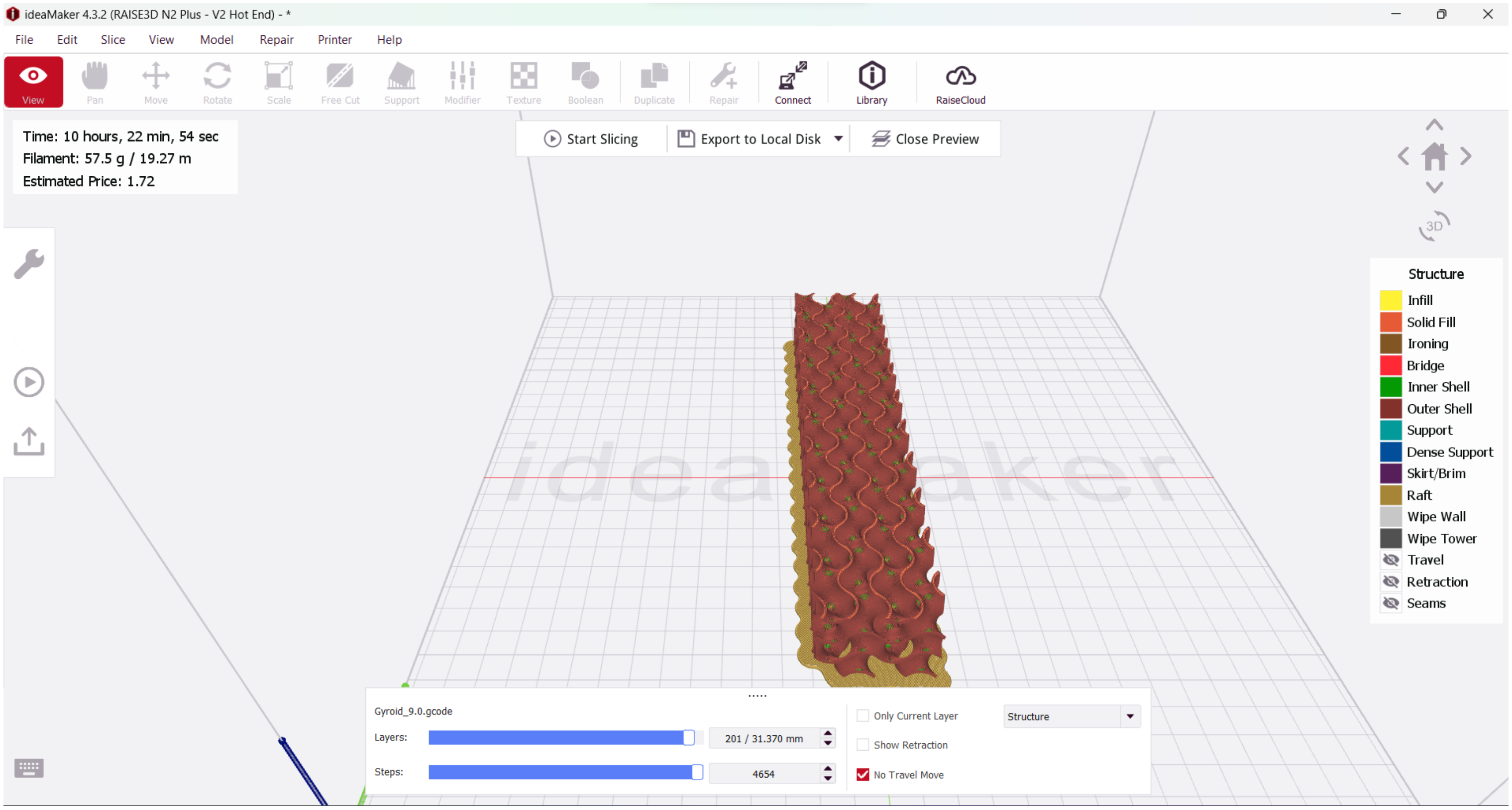

Fig 25: Slicing of CAD model of gyroid drone arm for 3D printing

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