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**Topology Optimization for Aircraft Mounting Bracket**

**Submitted in fulfillment of the requirements  
for the degree of Master of Science  
in Mechanical & Aerospace Engineering**

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## DECLARATION

I hereby declare that this manuscript, entitled “*Advanced Design Optimization: Topology Optimization for Aircraft Mounting Bracket*”, is the result of my own work except for quotations and citations, which have been duly acknowledged.

I also declare that, to the best of my knowledge and belief, it has not been previously or concurrently submitted, in whole or in part, for any other degree or diploma at Nazarbayev University or any other national or intentional institution.

\_\_\_\_\_Yerkebulan\_\_\_\_\_

Name: Yerkebulan Koishybek

Date: 13.04.2025

## **Abstract**

The need for lightweight and structurally efficient components is urgent in today's aircraft operating environment where performance, safety and fuel efficiency play a huge role. This thesis discusses the use of topology optimization in the design of mounting brackets, which constitute important components for transferring loads between structural elements as well as aircraft appendices. One effective computational technique for establishing the ideal material distribution in the design space is topology optimization. Finding the ideal material distribution to satisfy functional needs while reducing weight, preserving stability, etc., is its primary objective.

Two topology optimization techniques—density-based and the level-set based—have been illustrated in this thesis. The thesis starts with aircraft-specific design specifications and limitations, like material qualities, loading conditions, and geometry limitations. Two distinct mounting brackets were built in Ansys SpaceClaim, after which they were changed utilizing topology optimization methods to reduce weight while retaining stiffness. The original bracket and the optimized bracket are then contrasted to identify variations in structural characteristics, material efficiency, etc.

The results of this study demonstrate the potential of topology optimization in the aerospace industry, which enables manufacturers to create mounting brackets with reduced weight, low costs, and reduced material consumption. In addition, the ability to create lightweight high-performance designs is a compelling argument in favor of aviation applications, as it allows for lower fuel consumption and emissions, and the use of more sustainable processes.

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## List of Abbreviations & Symbols

TO – Topology Optimization

FEA – Finite Element Analysis

FEM – Finite Element Method

SIMP – Solid Isotropic Material with Penalization

AI – Artificial Intelligence

ML – Machine Learning

AM – Additive Manufacturing

Symbols:

$\rho(x)$  – Material density function at point  $x$  in the design space

$\Omega$  – Design domain or design space

$E$  – Young's modulus of material

$\nu$  – Poisson's ratio

$\sigma$  – Stress

$\varepsilon$  – Strain

$\mathbf{v}$  – Displacement vector

$F$  – Applied force or load

$M$  – Mass or volume of the material

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# Chapter 1 – Introduction

## 1.1. Background

Weight reduction in the aerospace industry is a critical challenge in terms of improving aircraft performance and efficiency. Every kilogram saved has an impact on important factors such as fuel efficiency, payload availability as well as manufacturing and operational cost. The aviation sector is always under pressure to reduce fuel consumption and greenhouse gas emissions, which directly affects the environmental and financial well-being of an aviation company. Reducing aircraft weight without compromising on safety, durability and efficiency are among the main design requirements in aircraft construction,

One effective way to reduce weight is to employ topology optimization for various components. These components must use the minimum possible material while maintaining their structural integrity, necessary to withstand encountered stresses from, vibrations, thermal expansion, etc. Among these are mounting brackets, which are crucial parts of aircraft. It serves as a connecting element between two parts and offers dependable fastening for parts like the fuselage, engine, and wings, among others. They must fulfill all specifications since they must be able to support enormous loads, including bending and twisting. Since brackets impact the structural integrity of the entire building, their primary attributes are strength and light weight. Geometric shapes and materials are the foundation of traditional bracket production techniques. However, this approach is more expensive and heavier. While guaranteeing that stiffness and other mechanical performance requirements are satisfied, topological optimization (TO) enables the effective distribution of material in the necessary space.

## 1.2 Motivation

The conflict between losing weight and preserving the capacity to move heavy objects is the issue. It's true that weight reduction will save materials and increase fuel efficiency. The issue is that weight reduction may result in a decrease in the bracket's strength and rigidity, endangering the aircraft's safety. Reducing weight while maintaining the operational characteristics of the initial bracket is a challenging task. Topology optimization is a modern method that can potentially address such problems in structural design. As previously mentioned, topology optimization is a computational method that allows engineers to investigate and efficiently distribute material in a

given structural space while adhering to specific performance constraints. For this specific study, we are interested in reducing the amount of material used for aircraft brackets without degrading its mechanical characteristics and potentially improve the overall mechanical performance. This type of design optimization permits the creation of lightweight and strong components, but also commonly leads to complex geometries that cannot be produced by traditional methods; hence modern manufacturing technologies need to be also employed.

- It's used to attach parts of the engine casing or internal tubes to the main structure. The bracket holds (Figure 1.1):
  - Piping
  - Sensors
  - Small mechanical subsystems

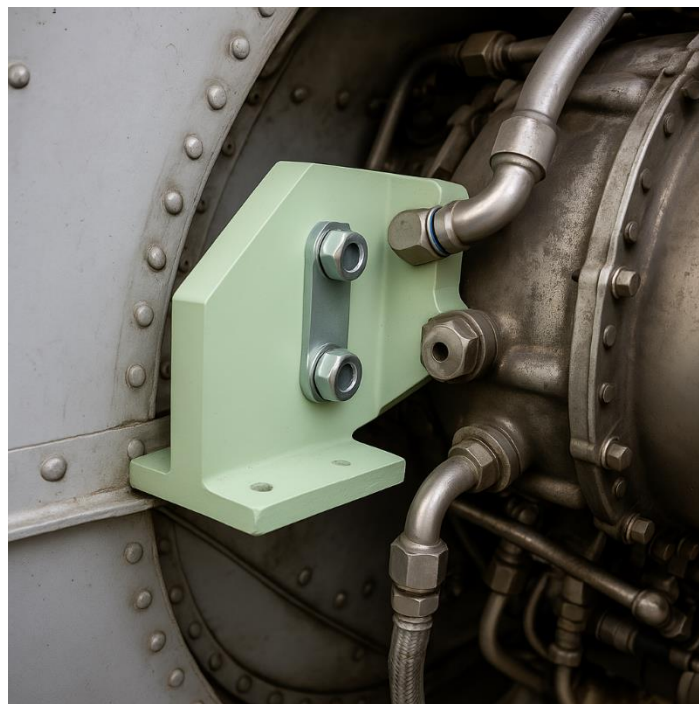


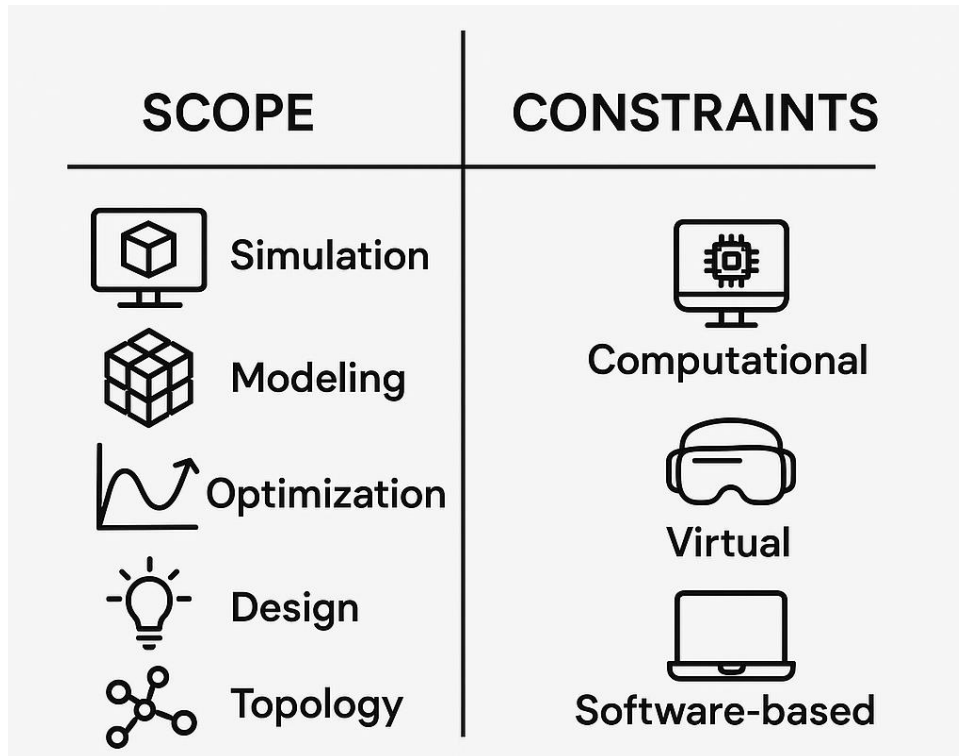
Figure. 1.1

### 1.3 Research Objectives

- Study the area of TO in the design of aircraft's mounting brackets.
- Optimize material distribution in the structural space of such brackets.
- Evaluate the effectiveness of such brackets under realistic loads.

- Investigate the manufacturability of optimized designs using modern technologies.

## Scope and Constraints



**Fig.1.2** Research Scope

Modeling: The use of software tools to analyze the behavior of a structure under different conditions without creating a physical form.; Optimization: Improving design parameters such as weight, stiffness or material usage using algorithms; Modeling: Ability to create CAD models. Design: Investigation of the shape of a structure based on performance criteria.

## Chapter 2 – Literature Review

### 2.1. Overview of Topology Optimization

A sophisticated computer-aided technique called Topology Optimization (TO) is used to determine the optimal material distribution. Topology optimization (TO) seeks to determine the most effective material distribution, in contrast to conventional approaches that primarily concentrate on specified geometries and materials [1]. The objective is to optimize a bracket, wing, or frame using mathematical methods that balance variables including stiffness, weight, and cost [2].

There are various categories of structural optimization, including topological, dimensional, and form optimization [3]. While shape optimization seeks to alter the model hole's shape while preserving its topological structure, dimensional optimization seeks to maximize the element design's dimensions. Topological optimization guarantees optimal material distribution and permits topological changes [4].

#### **Common Applications of TO in Aerospace and Structural Engineering**

Many different applications that make advantage of topology optimization. TO has established itself in fields including space, thermal, and civil engineering [6]. One of the biggest difficulties in aircraft is weight reduction because every kilogram saved has a direct impact on fuel economy.

#### ***Aerospace Engineering Applications:***

Components like the wing, brackets, and gearbox are frequently optimized in aircraft using topological optimization [7]. Through material distribution optimization, engineers may minimize weight without sacrificing stiffness in these components [8]. When optimizing an airplane wing, for instance, topology can increase stiffness in high-load areas while decreasing weight in low-load places [9].

#### ***Structural Engineering Applications:***

Topology optimization has been incorporated into the building of mechanical parts, bridges, and homes in civil engineering [10]. For instance, topology optimization is utilized in bridge construction to maximize stiffness while minimizing weight [11].

The ability to optimize the topology, makes it special in aerospace and other engineering fields, where efficiency and innovation come first. Thus, the importance of topology optimization will continue to grow in the future [16].

## **Experimental studies**

### **2.2.1. Experimental research related to mounting bracket design and optimization.**

Experimental research in the field of aircraft bracket design and optimization is primarily aimed at evaluating the design characteristics of these components under real-world loads such as dynamic forces and vibration loads [12]. Brackets play an important role in ensuring the safety and integrity of an aircraft, as they are responsible for securing major components such as the engine and wings. Given that they should withstand high loads, optimal weight reduction while maintaining strength is an ongoing challenge for aviation technology [14]. Common experimental studies include testing prototypes or production versions of brackets under various operating and environmental conditions. According to members of the Yashin group, Qinglong Wang, Chong Wang, Peng Gong, Yongsheng Shi, Yi Yu, and Zhenyu Liu, the researchers focused on developing aerospace brackets that are topology-optimized and reduce weight by 37% [17]. These experiments usually include static and dynamic load tests, as well as fatigue tests. With these tests, engineers can collect data on stress distribution and material deformation, which helps modernize the structure and ensure compliance with safety and performance requirements [18].

## **2.3 Numerical Study**

### **Comparative Analysis of Different Optimization Algorithms and Their Efficacy for Complex Aerospace Components**

The effectiveness of different optimization algorithms in the engineering of complex aircraft structures can vary depending on the type and design constraints of the components being

optimized. The two most used topology optimization methods Density-based, Level-Set based have their advantages and limitations.

**Level-Set Method:** The level set-based method is effective in solving complex and topologically variable geometric problems, such as creating holes in an optimizing design [15]. This method is very important in creating smooth boundaries, which are common in aerospace components. However, this method is expensive in terms of the requirements for sophisticated numerical techniques. It is mainly used for modeling detailed structures such as engine mounts where accurate shape is important.

**Density-based method ( SIMP- Solid Isotropic Material with Penalization):** The density-based method is a general approach in which the material distribution is represented by a field density. The design space has small elements, and each element assumes a density value between 0 and 1. This method is also simple and efficient for many types of problems.

**Table 1.1:** Most notable applications

Component	Application of Topology Optimization	Weight Reduction	Performance Enhancement	Key Benefits	Author, year
Aircraft Wings	Optimized material distribution within the spars and ribs ensures lightweight construction	25-30% weight reduction	Increased aerodynamic effect and structural strength	Increased fuel efficiency.	Minghao, 2022
Fuselage Design	Optimizing the use of material for handling dynamic load	40% weight reduction	Provides structural integrity from a safety standpoint while at the	Reduced weight, high fuel efficiency, minimized operating costs	Phuong, 2019

			same time reducing weight.		
Engine Mounting Brackets	Optimizing the use of material for handling dynamic load	20-25% weight reduction	Ensures durability performance	Enhanced performance minimized material costs	Rozvany, 2001
Landing Gear Supports	Redesigning internal structure	20-30% weight reduction	Maintains necessary strength and	Improved safety, reduced weight	Suzuki, 1999
Other Components (e.g., Avionics Brackets, Winglets)	Reducing weight in auxiliary systems	Variable (up to 20% weight reduction)	Enhanced structural performance	Overall weight reduction	Zhang, 2000

Topology optimization is widely used for many components of aircraft, such as aircraft wings, fuselage design, mounting brackets, landing gear supports (See Table 1.1). According to J.S. Rao his research is aimed to get the optimal aircraft wing design concept.

## 2.4. Materials for Aerospace Applications

Material selection plays a crucial role in the success of topology optimization, especially in aerospace applications where factors such as weight reduction, stiffness, durability, and environmental performance are at the forefront. In aerospace, other requirements for materials besides the basic ones are resistance to corrosion and temperature fluctuations. The most common materials used in the aerospace industry, including the brackets we study here, are aluminum alloys, titanium, structural steel, and various composite materials [19]. Each of these materials has its own advantages and properties, making them useful in many applications, but also requiring double checking when optimizing the topology. A wide range of aerospace materials such as titanium, aluminum alloys are not machinable if the design includes thin sections. For example, for titanium alloy (Ti-6Al-4V), thicknesses less than 1.5 mm may not meet manufacturing tolerances, especially when milling [19].

**Aluminum Alloys:** Aluminum alloys are often used in the aerospace industry due to their light weight, stiffness, and good corrosion resistance. The most common alloys 2024 and 7075 have excellent properties, mostly used to create parts that require high stiffness but still need to be lightweight, such as wings and brackets [20]. Also, aluminum is easy to fabricate, making it cost effective for many aircraft designs.

Advantages: Light weight, high stiffness, good fatigue, low cost.

Limitations: Lower stiffness than titanium; may be susceptible to corrosion under special conditions.

**Titanium Alloys:** Titanium alloys are also popular due to their high strength and ability to withstand high temperatures, making them an ideal material for use in aviation applications such as engine components and brackets. Titanium has a higher specific strength than aluminum, which means it can withstand higher loads in relation to weight than aluminum, but it is a very expensive material.

Advantages: Good stiffness-to-weight ratio, good properties at high temperatures

Disadvantages: Very expensive, more difficult to process than aluminum.

**Composite Materials:** Fiber-reinforced composites, mainly polymers, are becoming increasingly popular in the aerospace industry due to their good stiffness-to-weight ratio and tailored properties. The composite material is flexible because it can change mechanical properties by changing the orientation of the fibers. For example, fiber-based composite material is mainly used to build components such as military fighter jets and commercial aircraft [17].

Advantages: Light weight, flexibility, fatigue resistance

Disadvantages: High cost, difficult to process

**Structural steel:** Structural steel has excellent properties, usually used in special applications where high performance or special properties are required.

### **Impact of Material Selection on the Optimization Process and Performance**

Material selection directly affects the outcome of topology optimization, as each material has different mechanical properties that affect the design constraints and performance of the optimized structure [16]. When using topology optimization for components such as mounting brackets, engineers must consider the strength, durability, and fatigue resistance of the material as these materials are directly related to the function requirements.

**Material Property Considerations:** Factors such as Young's modulus, Poisson's ratio, fatigue strength, and thermal expansion are considered in the optimization process.

**Strength and stiffness:** Materials with high stiffness and strength, such as titanium, can often be used in optimized models with significant weight reductions while maintaining rigidity. However, these materials are expensive and difficult to process, resulting in high costs.

**Density.** Density is a crucial factor in weight optimization, as reducing the amount of material used in a structure results in weight savings. Lighter materials such as aluminum alloy can provide an opportunity to reduce overall weight, which is especially important for components such as mounting brackets where weight savings directly affect fuel efficiency.

**Fatigue resistance.** Aerospace components, including brackets, are typically subjected to dynamic loads over long periods of time. Materials with good fatigue resistance (such as steel and other composite materials) are materials that can be subjected to such loads. The ability of a material to withstand cyclic loads without fail is an important characteristic for long term operation and safety.

**Effect on Design Geometry:** The material chosen also influences the shape and topology of the optimized structure [21]. For example, the high strength-to-weight ratio of structural steel can reduce the amount of material used in a low-use area, resulting in the creation of complex geometries that cannot be achieved with other materials.

## 2.5. Cost-Effectiveness and Scalability

### **Evaluation of the Cost Implications of Producing Topology-Optimized Components**

For mounting brackets, topology optimization (TO) may improve overall performance and minimize weight. However, despite the benefits of topology optimization, such as weight reduction, fuel efficiency, and structural strength, the financial implications of using these components must be considered [22]. The cost-effectiveness of topology optimization depends on various factors, including material selection, material quality and manufacturing methods.

**Material Costs:** The use of advanced materials such as titanium alloy and composite materials in the design for topology optimization can increase the material cost compared to aluminum alloy [20]. Although less material is required after topology optimization, these high-performance materials are expensive in most cases. Moreover, if the material requires specialized processing techniques such as additive manufacturing to produce complex geometries, the price

will increase further. However, in cases where material savings are high, the material costs can be offset by productivity gains (e.g., longer life, reduced duplication, and increased load capacity).

**Optimization Software and Computational Resources:** Topology optimization is critical to aerospace design methods that enable the creation of lightweight, high-performance components. The computational methods used in this process, including finite element analysis and topology optimization, can create optimal material distributions and structural layouts that minimize weight and maintain structural integrity [21].

## Chapter 3 – Methodology

### 3.1. Overview of Methodology

The topological optimization of brackets procedure suggests a methodical way to the creation of high-performance, lightweight structural components that satisfy mild aviation specifications..

### 3.2. Problem Definition and Boundary Conditions

Determining the boundary conditions is crucial in the topological optimization of brackets process. In order to produce components that satisfy standards, topology optimization is now done in accordance with real-world aviation requirements.

#### 3.2.1. Specification of the Design Space and Constraints

A three-dimensional volume that allows for the optimization of the design space is called a designer support. Usually, the bracket defines the support's geometric features and footprint. It comprises limitations imposed by design elements as well as interfaces with other parts (such as the engine or chassis

#### 3.2.2. Applied Boundary Conditions

Constraints placed on the model throughout the optimization process are known as boundary conditions. To guarantee the safety and effective operation of the brackets, these requirements include loading conditions, material qualities, and geometry limits. The following are a few boundary criteria that are used while mounting brackets in aircraft:

*Static load:* this relates to the static conditions that the bracket will experience, such as the weight of the motor or the mechanism on which it rests. These conditions should be distributed over the entire surface and should not cause distortion or deformation.

*Dynamic Loads:* Brackets are also subjected to dynamic loads associated with engine vibration, takeoff and landing impacts, or dynamic forces. These loads are difficult to model due to their variation over time and can also lead to fatigue problems.

**Table 2.1** Material Properties: Structural Steel

<b>Parameters</b>	<b>Value</b>
Young Modulus	200 GPa
Poisson ratio	0.3
Endurance limit	170 MPa
Yield stress	250 MPa
Ultimate tensile stress	460MPa

**Material Properties:**

Material properties play an important role in topology optimization, as stiffness, density, and fatigue strength affect the structural integrity and weight of the final design (See Table 2.1). Materials such as titanium, structural steel, aluminum, and composites are commonly used in aerospace applications due to their weight to stiffness ratio.

Geometric constraints:

Attachment points: Specific attachment points where, for example, the bracket mates with the motor must be fixed during the optimization process or only allow limited alteration during the process to obtain realistic results.

Symmetry constraints: if the bracket design is symmetric, topology optimization problems can be constrained to reflect this symmetry, reducing computational complexity and ensuring manufacturability.

Manufacturing constraints: it is important to consider constraints related to minimum material thickness, allowable overhangs, and other manufacturing process concerns.

Examples of boundary conditions:

- Fixed boundary condition
- Applied forces or moments.

- Restrictions on the distribution of the bracket material
- Symmetry or periodic boundary conditions

In this study, we analyze the components using a structural approach that includes several key steps, from static setup construction to topology optimization. The model used in this project is a mechanical component designed for static structural analysis. The part was created from the technical drawing provided and then created in Ansys SpaceClaim. The material properties were selected based on the strain curve based on the strain of the material selected for the part.

According to [7], topology optimization can be expressed as:

$$\min F = F(u(\rho), \rho) = \int_{\Omega} f(u(\rho), \rho) dV,$$

**subject to:**

$$G_0(\rho) = \int_{\Omega} \rho dV - V_0 \leq 0, G_{-0}$$

$$G_j(u(\rho), \rho) \leq 0, H_i(u(\rho), \rho) = 0, \text{ for } j=1, \dots, m, \text{ and } i=0, \dots,$$

Where:

$\rho(x) \in [0, 1]$  : Design variable (material density function).

$u(\rho)$ : State variable (e.g., displacement field) that depends on the material distribution.

$f(u, \rho)$ : Objective integrand (e.g., strain energy density).

$G_0(\rho)$ : Volume constraint ensuring material usage does not exceed  $V_0$ .

$G$ : Inequality constraints (e.g., stress or displacement limits).

$H_i$ : Equality constraints (e.g., boundary conditions, equilibrium).

According to [23], formula represents a parameterized representation of the level set function:

$$\Phi(x) \geq 0 \text{ for } x \in \Omega,$$

$$\Phi(x) < 0 \text{ for } x \in D \setminus \Omega,$$

$$\Phi(x) = 0 \text{ for } x \in \Gamma$$

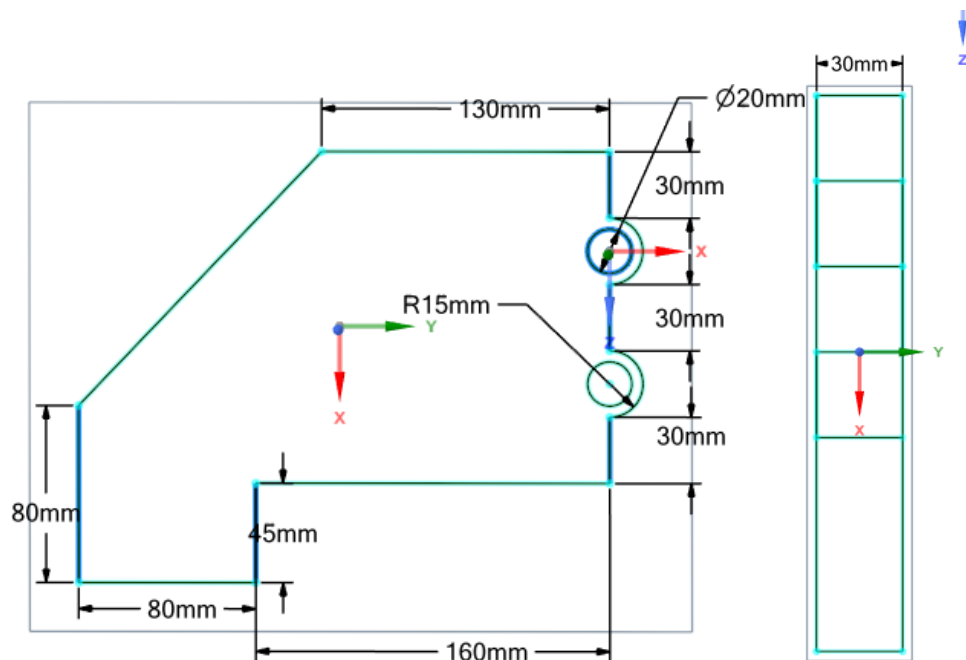
Let  $\Phi(x)$  be the level set function defined in domain  $D$ , where:

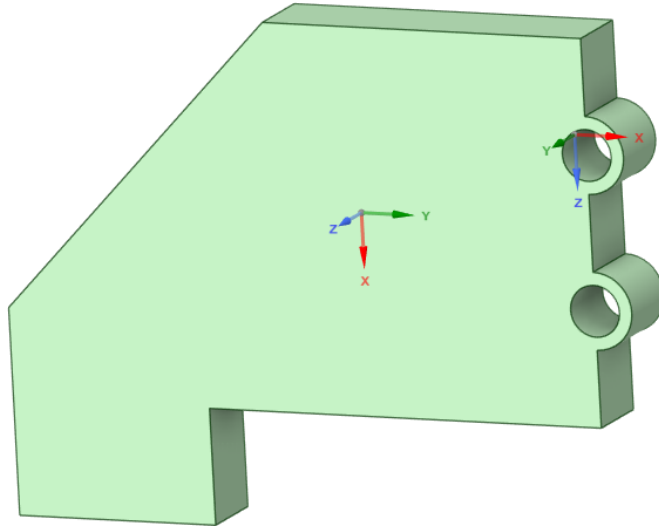
- $\Omega \subset D$  is the material/solid region,
- $D \setminus \Omega$  is the void or non-material region,
- $\Gamma = \partial\Omega$  is the interface (boundary between solid and void).

$$\Phi(x,t) = \sum_i \beta_i(t) \phi_i(x),$$

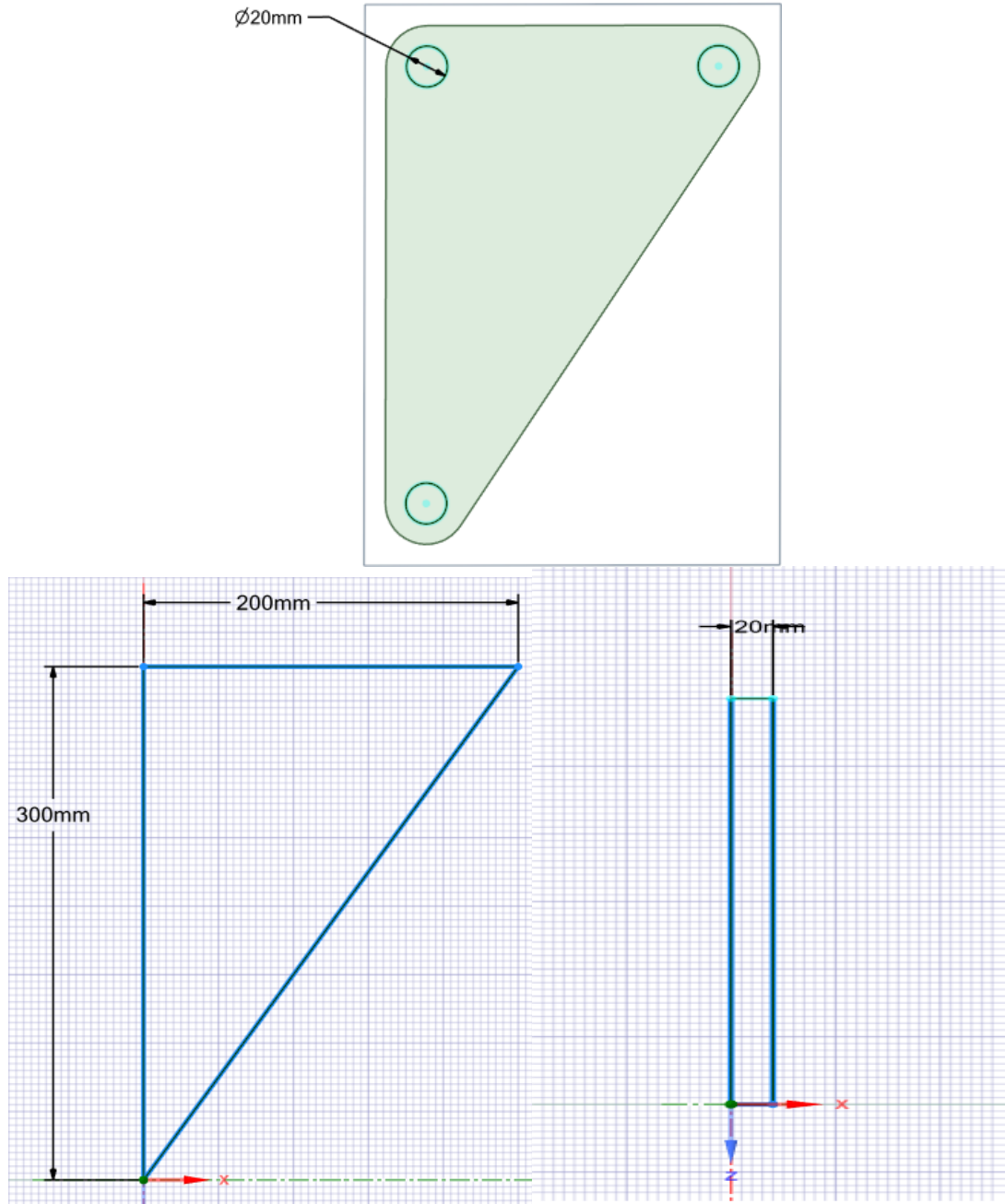
Where:

- $\Phi(x,t)$ : Level set function at position  $x \in \mathbb{R}^3$  and pseudo-time  $t$ ,
- $\phi_i(x)$ : Spatial basis functions (e.g., radial basis functions, FEM shape functions, or Fourier modes),
- $\beta_i(t)$ : Time-dependent coefficients that evolve during optimization or simulation,
- The summation runs over all basis functions indexed by  $i$ .





**Figure 3.1.** Sketch of the model 1

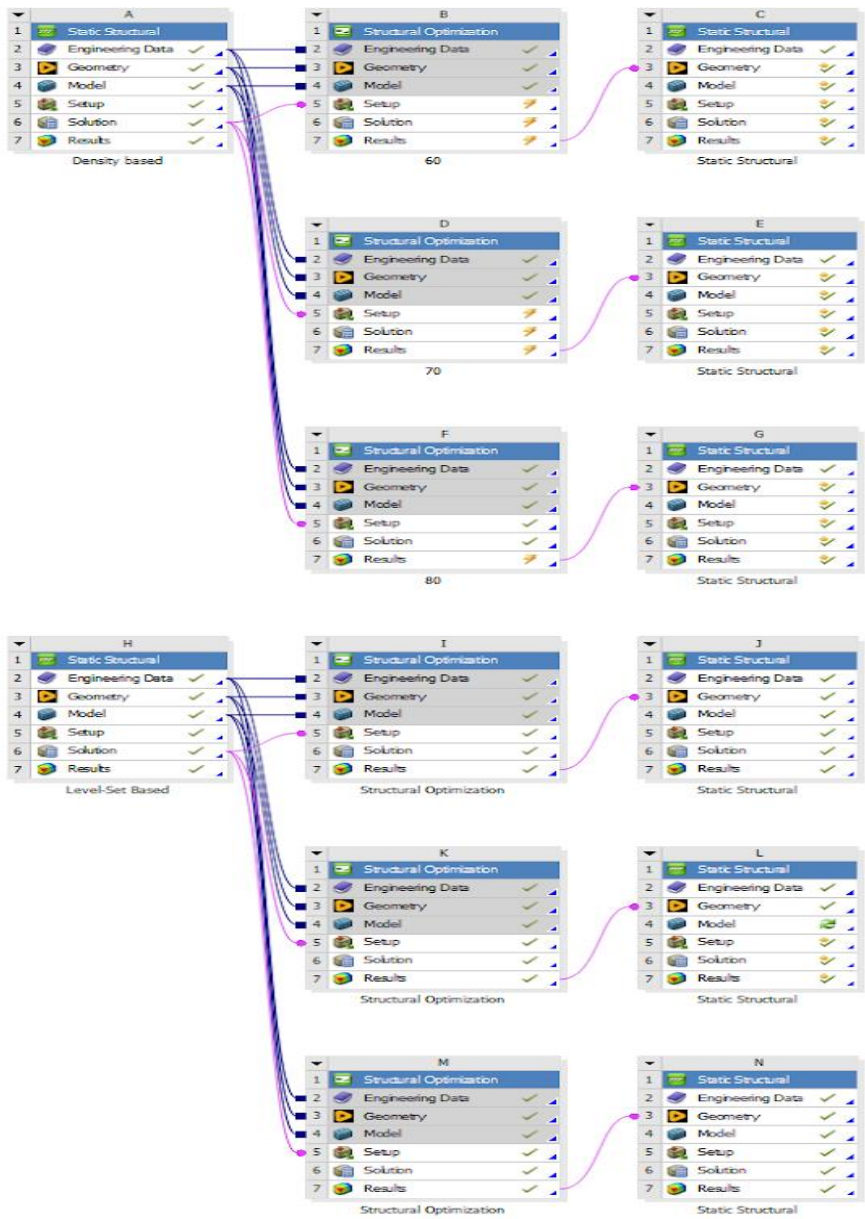


**Figure 3.2** Sketch of model 2

Topology Optimization and Static Structural are the two main optimization modules in Ansys Workbench. (Figure 3.1, Figure 3.2) The first step is to draw and import the geometry into Static Structural, where the initial setup and mesh creation takes place. Ansys Workbench should be used to solve problems to determine the maximum stresses in a static structure. One boundary

condition is selected for the fixed support in the X direction and a pressure (4 MPa) is introduced for the holes (Figure 5.1). After the structural analysis is completed, all the necessary analysis including engineering information, geometric model specification and solution goes into the topology optimization module. In this model, we perform optimization by specifying functions, optimization constraints, maximum number of iterations and other key parameters.

For the second model, there are two cylindrical support holes, and a bearing load is applied to one hole (X 500N direction and Z 1000N direction) (Figure 7.1).

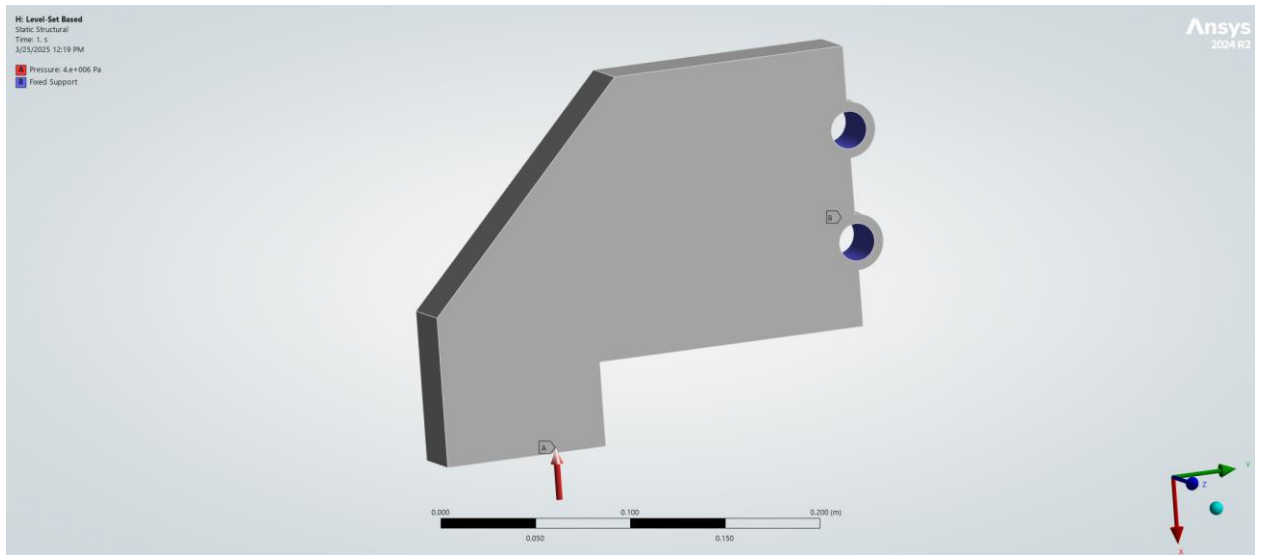


**Figure 4.1.** The Ansys modules connection

Designmodeler-Static Structural-Topology Optimization (TO)- SpaceClaim (again) (Figure 4.1).

## 2.2. Mesh refinement and convergence

To obtain highly accurate results, it is necessary to optimize the geometry mesh. Determining the optimal element size will save processing time and ensure correct results. Initially, the default Ansys setting was used, then it was necessary to correct it by analyzing the sensitivity and convergence of the mesh.



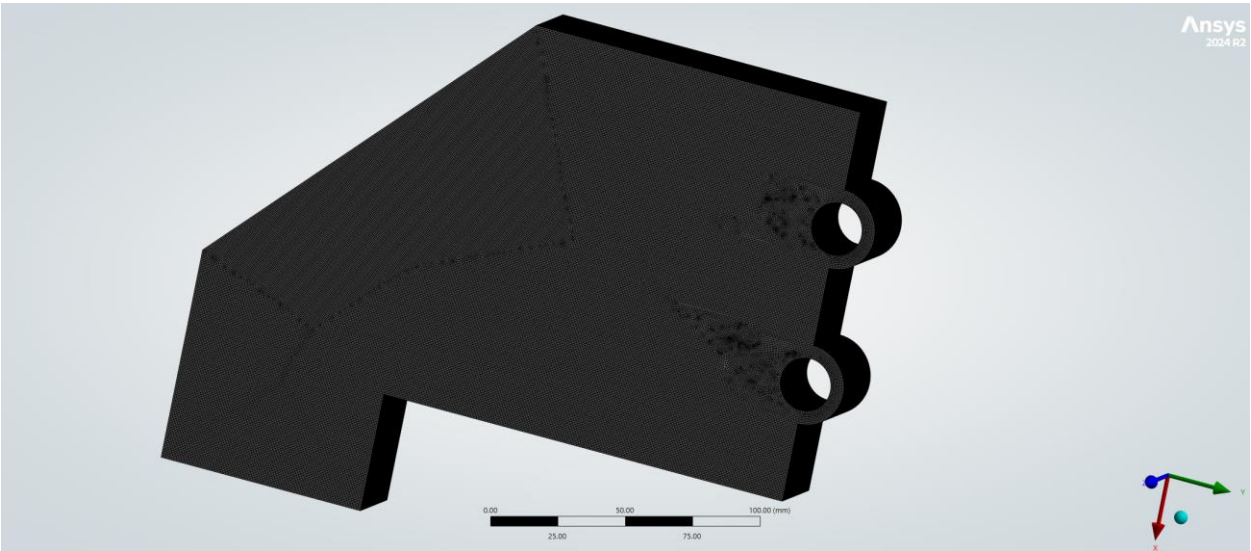
**Figure 5.1** Model 1 in Ansys

The maximum equivalent stress (Figure 8.1 and Figure 8.2) was chosen to test the appropriateness of the mesh. In each element size, a mesh of higher quality than the previous one was created. A mesh is considered to be of appropriate size if the relative error does not exceed 4%. The initial mesh had 2789 nodes and 480 elements, for model one. It was increased to 25103681 and 6156920 elements for the final mesh (Figure 6.1), with a relative error of 3.9% and an element size of 0.6 mm; see Table 3.1. For the second model, the initial mesh had 2506074 nodes and 597765 elements, while the final mesh (Figure 6.2) had 6970593 nodes and 1684842 elements with a relative error of 1.57%; see Table 4.1. The resulting element size was around 0.7 mm this time.

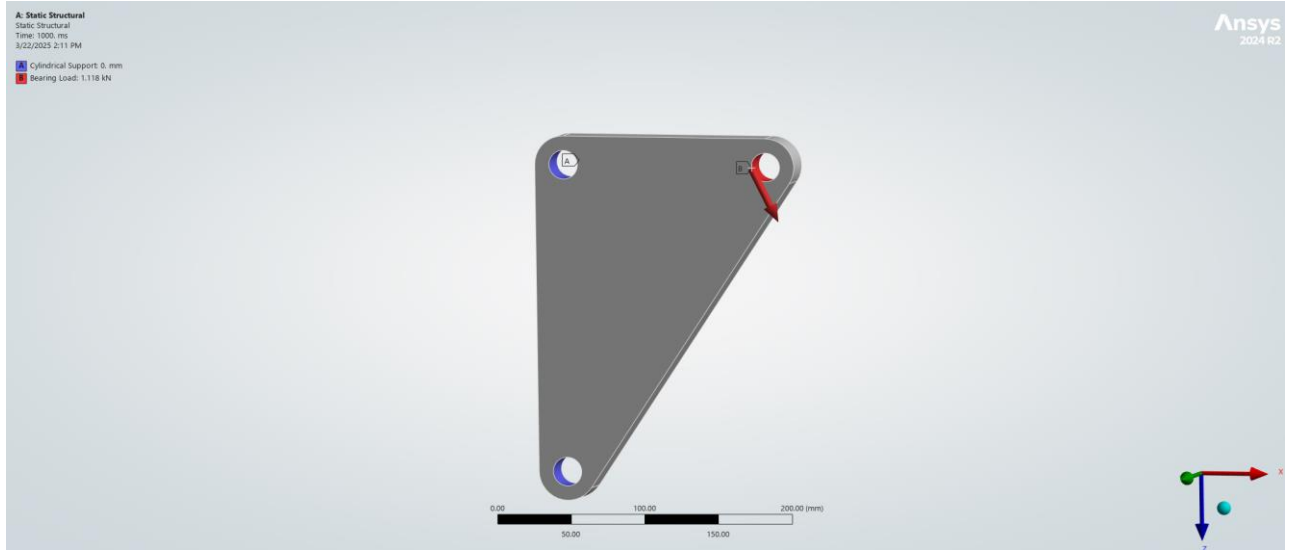
**Table 3.1** Mesh convergence results for model 1

	Equivalent stress (MPa)	Change, % RMS error	Nodes	Elements
1	60.629		2789	480

2	90.722	49.63	4348554	1050621
3	98.497	8.57	8289024	2015786
4	103.93	5.52	12509519	3053248
5	110.83	6.64	19614608	4802823
6	115.15	3.9	25103681	6156920



**Figure 6.1** The final mesh of the model with a 0.5mm element size



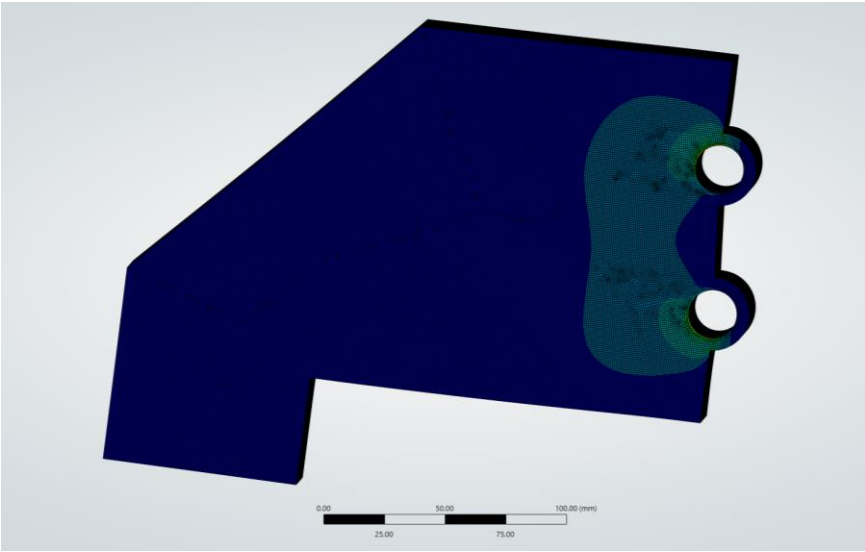
**Figure 7.1** Model 2 in Ansys

**Table 4.1** Mesh refinement results

	Equivalent stress (MPa)	Change, %	Nodes	Elements
1	8.53		2506074	597765
2	8.89	4.22	4810128	1158092
3	9.03	1.57	6970593	1684842



**Figure 6.2** The final mesh of the model with a 0.7mm element size



**Fig 8.1** Distribution of equivalent stresses (model 1)



**Fig 8.2** Distribution of equivalent stresses (model 2)

Details of "Analysis Settings"	
<b>Definition</b>	
<input type="checkbox"/> Maximum Number Of Iterations	500.
<input type="checkbox"/> Minimum Normalized Density	1.e-003
<input type="checkbox"/> Convergence Accuracy	0.1 %
<input type="checkbox"/> Initial Volume Fraction	Program Controlled
<input type="checkbox"/> Penalty Factor (Stiffness)	3.
Region of Manufacturing Constraint	Include Exclusions
Region of Min Member Size	Exclude Exclusions
Region of AM Overhang Constraint	Exclude Exclusions
Filter	Program Controlled
<b>Output Controls</b>	
<b>Solver Controls</b>	
Solver Type	Program Controlled
<b>Analysis Data Management</b>	

Details of "Response Constraint"	
<b>Scope</b>	
Scoping Method	Optimization Region
Optimization Region Selection	Optimization Region
<b>Definition</b>	
Type	Response Constraint
Response	Mass
Define By	Constant
<input checked="" type="checkbox"/> Percent to Retain	60 %
Suppressed	No

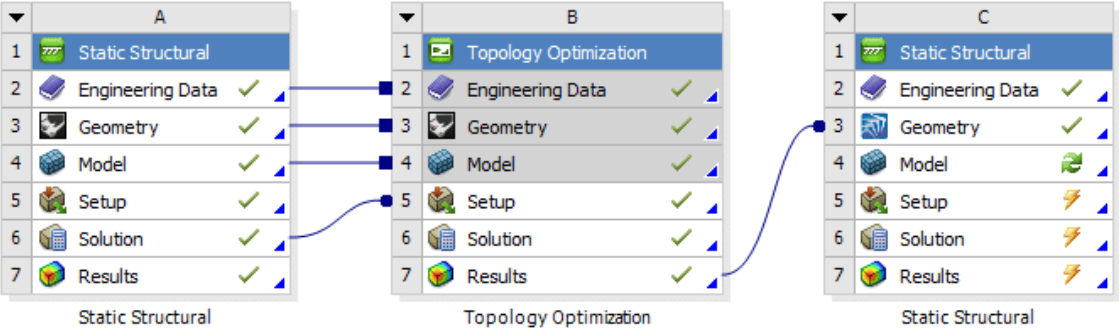
**Figure 9.1** Region optimization and setup

### 3.3. Topology Optimization Process

Through a well-established and iterative computational process, a topology optimization process has been carried out in this study. The main objective is to minimize the amount of material used (Figure 9.1), while the final design must meet important parameters including strength,

stiffness, durability. A certain algorithm is used for optimization, usually combining finite element analysis and optimization algorithm. The iterative process allows the bracket design to be refined step by step, ensuring that the material is used where it is most needed (See Figure 10.1).

**Figure 10.1** Command line of Topology process



## Chapter 4 – Results and Discussion

**SIMP (Solid Isotropic Material with Penalization)** density method: A popular method used in topology optimization. Its goal is to find the best material distribution in the design space. In this approach, the material properties are represented using a density function. The density ranges from 0 (no material) to 1 (material on). The goal is to find the optimal material distribution to satisfy the performance criteria.

How it works:

A grid of elements divides the design area. A density value between 0 and 1 is assigned to each element. To provide a precise answer for the on (material) and off (no material) states, the approach considers the density value.

- Pros: Easy to implement and works well for simple problems.
- Cons: Can create gray areas that are difficult to fabricate and can result in less smooth shapes

**Level-Set based:** One approach to optimizing topology is level-set based. The boundary of the material is defined by a level set function rather than by densities, which are utilized to describe the material distribution. The level set function is a mathematical surface that varies over time during optimization and is often represented as a scalar field.

How it works: The surface between the material and the void represents the design domain. This boundary is changed iteratively by updating the level set function. The emptiness is outside the barrier, while the substance is inside.

Benefits: It enables the creation of smooth, unambiguous structures with distinct boundaries. Drawbacks: It is computationally costly.

In order to determine a trade-off between reduction and structural performance, topology optimization was carried out in this study at a certain material retention.

Specifically, the optimization was performed at material retention rates of 70%, 80%, and 90%, meaning that only this percentage of the original material volume was retained in the final optimized design.

The level set method uses an implicit function to represent the boundary of the structure. Instead of density values across the domain, the material-void boundary is defined as the zero level of a signed distance function. This method typically yields clearer and more defined structural boundaries with smoother geometry, making it more suitable for direct manufacturing.

**Key Settings in ANSYS:**

- Volume Constraint: Also set to 0.7, 0.8, or 0.9 to match the density-based method for comparison.
- Level Set Initialization: Usually starts from a uniform geometry or previous density-based result.

**Table 5.1** Density-based method model 1.

Density Based	Original Bracket Equivalent stress	Original bracket Total deformation	70%	70%	80%	80%	90%	90%
			Equivalent stress	Total deformation	Equivalent stress	Total deformation	Equivalent stress	Total deformation
Min	36300 Pa	0. m	8.6798e+005 Pa	0 m	1.5369e+006 Pa	0 m	1.2275e+006 Pa	0. m
Max	9.2155e+007 Pa	3.9365e-005 m	8.5603e+007 Pa	4.6172e-005 m	9.3495e+007 Pa	4.3969e-005 m	8.7304e+007 Pa	4.2201e-005 m

Mean	1.1515e+007 Pa	1.4659e-005 m	1.3666e+007 Pa	1.4636e-005 m	1.5176e+007 Pa	1.1175e-005 m	1.2411e+007 Pa	1.3881e-005 m

**Table 5.2** Level-Set-based method model 1

Level-Set Based	Original Bracket Equivalent stress	Original bracket Total deformation	70%	70%	80%	80%	90%	90%
			Equivalent stress	Total deformation	Equivalent stress	Total deformation	Equivalent stress	Total deformation
Min	36300 Pa	0. m	2.3216e+005 Pa	0 m	7.4513e+005 Pa	0 m	2.8318e+005 Pa	0. m
Max	9.2155e+007 Pa	3.9365e-005 m	1.0357e+008	5.4098e-005 m	9.4396e+007 Pa	5.86e-005 m	1.4878e+008 Pa	1.5814e-004 m
Mean	1.1515e+007 Pa	1.4659e-005 m	1.6861e+007 Pa	1.7111e-005 m	1.6844e+007 Pa	1.9047e-005 m	1.9956e+007 Pa	7.978e-005 m

**Table 6.1** Density based method of model 2.

Density Based	Original Bracket Equivalent stress	Original bracket Total deformation	70%	70%	80%	80%	90%	90%
			Equivalent stress	Total deformation	Equivalent stress	Total deformation	Equivalent stress	Total deformation

Min	12069 Pa	1.5972e-008 m	6963. Pa	0. m	13263 Pa	1.5286e-008 m	20922 Pa	1.9453e-008 m
Max	8.6053e+006 Pa	3.6357e-006 m	8.7785e+006 Pa	3.991e-006 m	9.1398e+006 Pa	3.804e-006 m	9.0892e+006 Pa	3.8367e-006 m
Mean	9.4292e+005 Pa	8.2283e-007 m	1.3689e+006 Pa	9.6586e-007 m	1.0989e+006 Pa	9.0357e-007 m	1.0307e+006 Pa	8.8035e-007 m

**Table 6.2** Level-Set based method of model 2.

Level-Set Based	Original	Original	70%	70%	80%	80%	90%	90%
	Bracket Equivalent stress	bracket Total deformation	Equivalent stress	Total deformation	Equivalent stress	Total deformation	Equivalent stress	Total deformation
Min	36300 Pa	1.5972e-008 m	13263 Pa	1.5286e-008 m	20922 Pa	1.9453e-008 m	29274 Pa	1.9761e-008 m
Max	9.2155e+007 Pa	3.6357e-006 m	9.1398e+006 Pa	3.804e-006 m	9.0892e+006 Pa	3.8367e-006 m	8.6783e+006 Pa	3.6211e-006 m
Mean	1.1515e+007 Pa	8.2283e-007 m	1.0989e+006 Pa	9.0357e-007 m	1.0307e+006 Pa	8.8035e-007 m	9.6331e+005 Pa	8.1329e-007 m

The total deformation and maximum equivalent stress were chosen for different threshold levels (70%, 80%, 90%) using the density-based and level-set methods. The data includes min,

max , mean values for each case. The comparison between them you can see (Table 5.1, Table 5.2, Table 6.1, Table 6.2)

- The first two columns present the original bracket equivalent stress (in Pa) and total deformation (in m).
- The next columns show the results of equivalent stress and total strain at three different threshold levels: 70%, 80% and 90%.

**Table 6.3 Bracket 1**

Initial mass	70% Density based	80% Density based	90% Density based	70% Level set based	80% Level set based	90% Level set based
7.85	5.42	6.34	7.02	5.32	6.15	6.95

**Table 6.4 Bracket 2**

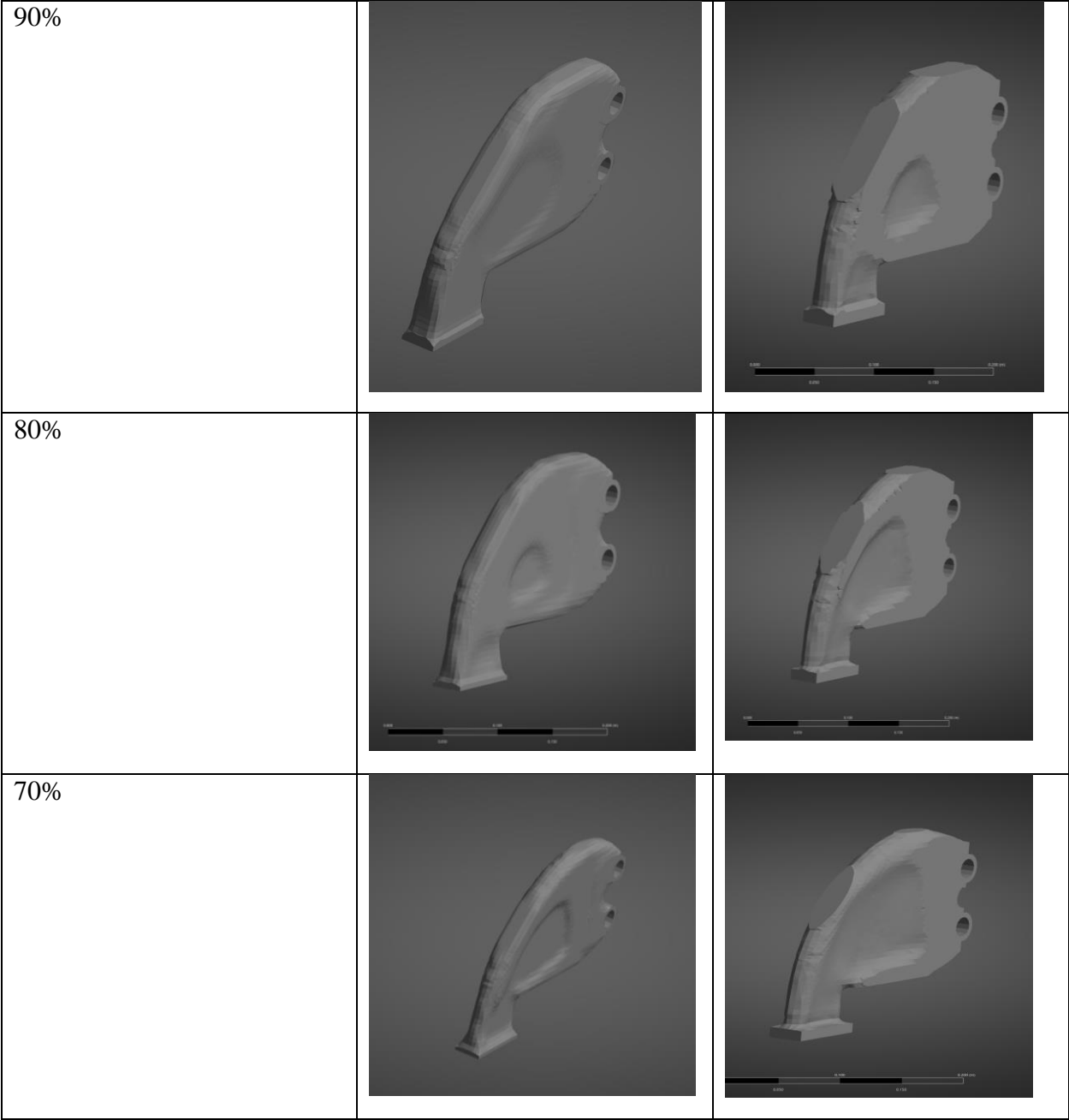
Initial mass	70% Density based	80% Density based	90% Density based	70% Level set based	80% Level set based	90% Level set based
4.37	2.89	3.38	3.9	2.8	3.29	3.81

In this study, topology optimization was performed at a given material retention rate in order to compromise between reduction and structural performance.

Specifically, the optimization was performed at material retention rates of 70%, 80%, and 90%, meaning that only that percentage of the original amount of material was retained in the final optimized design. See Table 7.1 and Table 8.1.

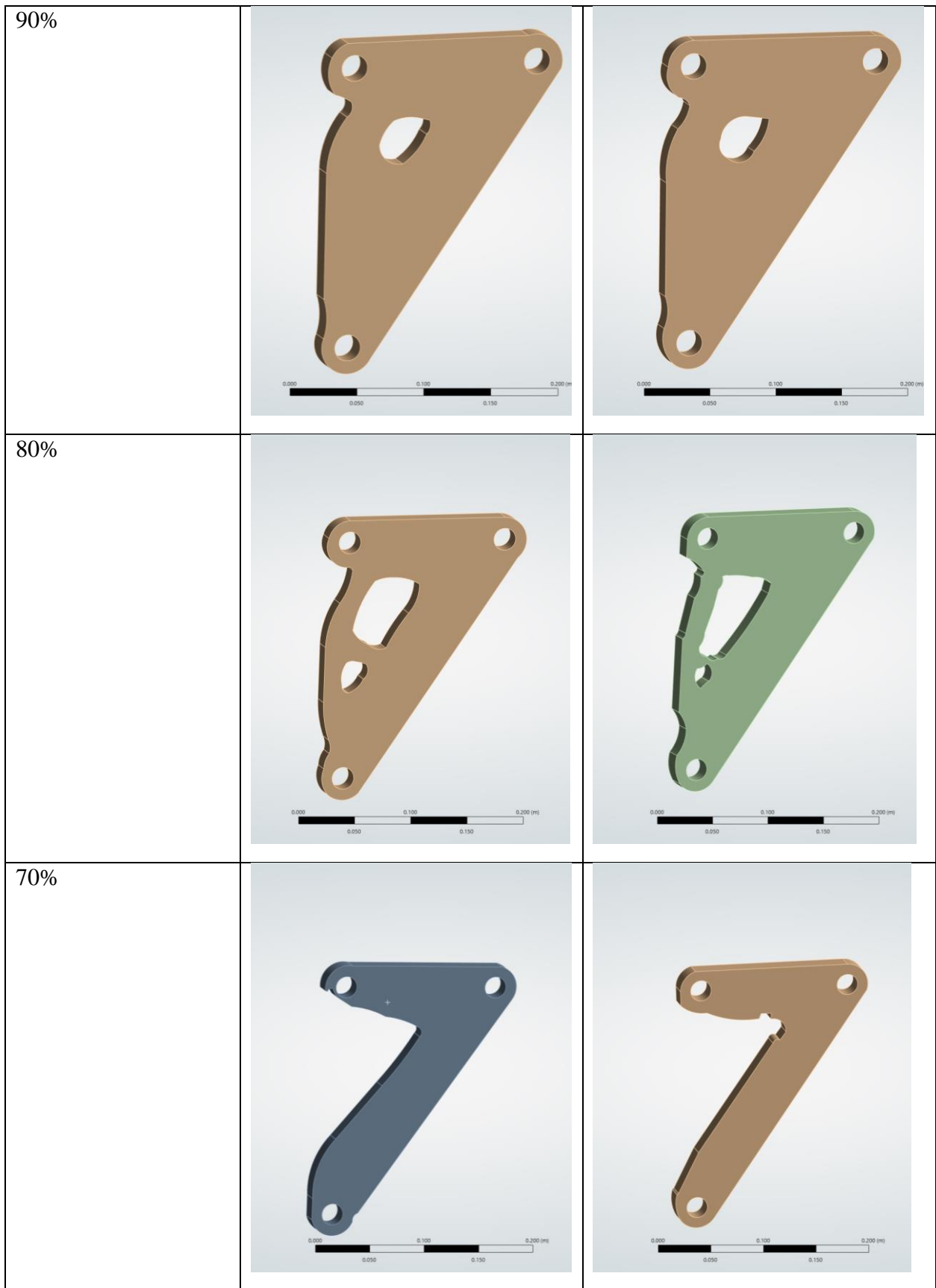
**Table 7.1** Structurally evolved design of the specimen (model 1)

Optimization method	Density based method	Level-Set based method
Percent of retain		



**Table 7.2** Structurally evolved design of the specimen (model 2)

Optimization method	Density based method	Level-Set based method
Percent of retain		



The outcomes of topology optimization utilizing two distinct approaches—a density-based approach and a level set-based approach—are displayed in this table. Three material retention levels—70%, 80%, and 90%—were used to test each process. These values indicate how much of the original material was kept in the finished design.

The density-based method (25 min, 85.60 MPa) provided a design with lower stress than the level-set method (25 min, 103.57 MPa) for 70% material. See Table 8.1.

The level-set approach had the highest stress (148.78 MPa) at 90% material, but the density-based approach remained below 91 MPa. This suggests that level-set designs may concentrate stress greater at high material retention.

**Table 8.1** Overall results

<b>Specimen #</b>	<b>Percent retained</b>	<b>Optimization time, min</b>	<b>Max stress, MPa</b>
1 / density based	70%	<b>25min</b>	<b>85.60</b>
2 / density based	80%	<b>28min</b>	<b>93.49</b>
3 / density based	90%	<b>40min</b>	<b>87.30</b>
4 / level-set based	70%	<b>25min</b>	<b>103.57</b>
5 / level-set based	80%	<b>28min</b>	<b>94.39</b>
6 / level-set based	90%	<b>40min</b>	<b>148.78</b>
7 / density based (2 model)	70%	<b>30 min</b>	<b>87.78</b>

8 / density based	80%	<b>35min</b>	<b>91.39</b>
9 / density based	90%	<b>40min</b>	<b>90.89</b>
10 / level-set based	70%	<b>30min</b>	<b>91.39</b>
11 / level-set based	80%	<b>35min</b>	<b>90.89</b>
12 / level-set based	90%	<b>40min</b>	<b>86.78</b>

## **Chapter 5- Conclusion and Further Research**

In this study, we created a comprehensive component focused on optimizing the topology of a mounting bracket used in the aerospace industry. The primary goal was to reduce weight while maintaining stiffness and strength.

The process involved the use of FEA techniques combined with topology optimization. We used Ansys SpaceClaim as our main software, allowing parametric modeling and iterative refinement of the design. Optimization was carried out under different loads and boundary conditions with the mass retained 70%,80%, 90%. Also used two different methods of topology optimization, which are Density-based and level-set based methods. The density-based method showed flexibility in topology exploration and allowed the formation of complex geometries. The Level-set based provides natural smoothness and manufacturability of boundaries.

Limitations of the study:

- Lack of experimental validation: Due to time constraints
- Simplified loading conditions: Loading conditions were idealized, real-world scenarios may include fatigue and thermal stresses that were not fully modeled

Reason for not performing experiments

One of the main drawbacks of this work is the lack of experimental verification. Due to time constraints, it was not possible to fabricate prototypes and conduct physical tests. As a result, results based on computational models, while valuable, may not fully reflect the complexities of the real world.

### **Future work and studies**

Based on the results of this study, future work will focus on improving the realism and practical use of the optimised design. A key area of interest is the use of improved material models to better understand the behaviour of modern engineering materials under complex loading conditions.

However, in the future, I would like to address these limitations:

- Conducting experimental tests on physical prototypes
- 3D printing optimised designs to assess their structural performance
- Comparing experimental data with numerical results

However, the results still offer meaningful insights and serve as a robust

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