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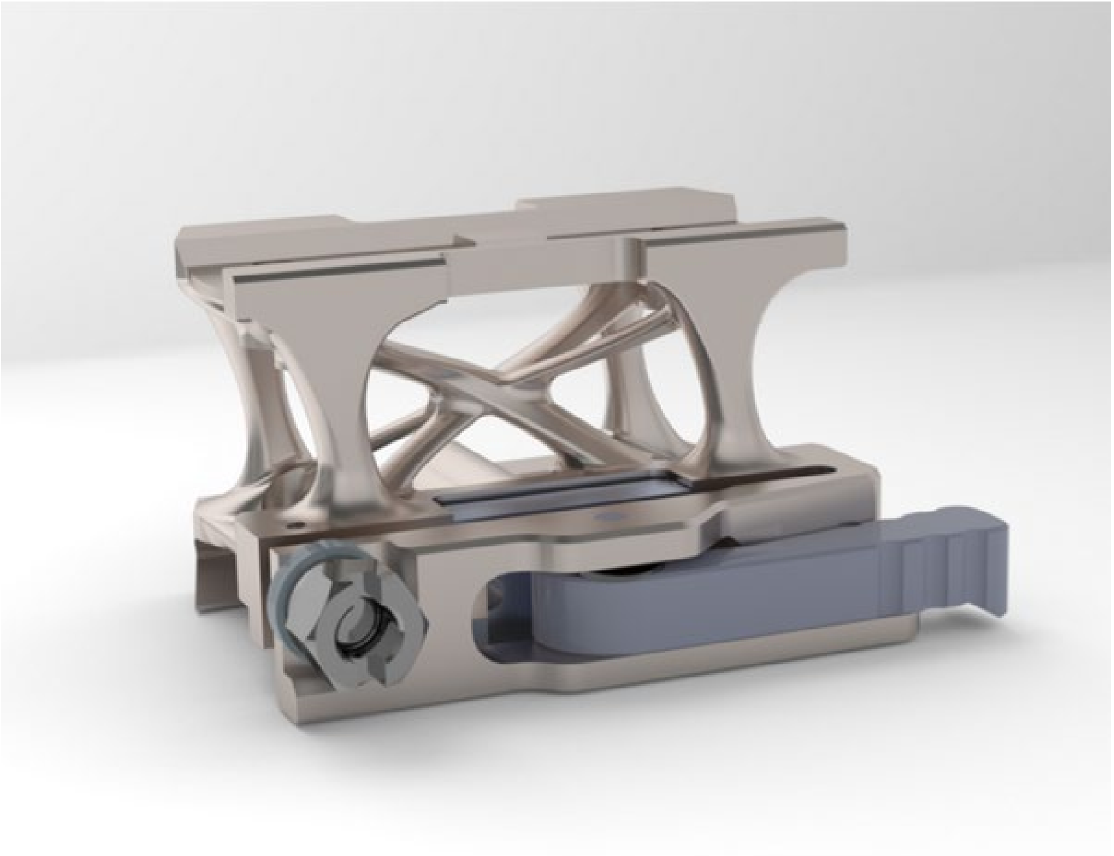

Weight reduction of a mount for a red dot sight through topology optimization and additive manufacturing

A study of red dot sight mount weight optimization

Bachelor's Thesis in Mechanical Engineering

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BACHELOR’S THESIS IN MECHANICAL ENGINEERING

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Cover:
Render of optimized design of red dot sight mount

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Abstract

This thesis investigates weight reduction of a mount for a red dot sight through simulation driven design optimization and laser powder bed fusion (LPBF). The aim was to reduce mass while maintaining the required mechanical performance, functional interfaces, and sight alignment.

The original and redesigned geometries were evaluated using CAD modelling and finite element analysis (FEA) in Abaqus. The simulations were used to study stress distribution, displacement, and load paths under recoil loading. Based on these results, the design was modified in SolidWorks through repeated iterations and then evaluated with respect to structural performance and manufacturability.

Physical validation was performed using mechanical shock and mounted drop tests. Titanium and aluminium prototypes were tested with the same procedure, where visual inspection and reticle position movement were used to evaluate functional performance.

The results showed that the redesigned mount could reduce weight while maintaining acceptable mechanical behaviour in the simulations. The manufacturability evaluation also showed that build orientation, support placement, post processing, and tolerance sensitive features such as holes and threads were important when adapting the design for LPBF.

Key words: Laser Powder Bed Fusion, Computer Aided Design, Topology Optimization, Weight reduction, Finite Element Analysis, Additive Manufacturing, Structural Simulation, Design Optimization,

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Malmö, June 2026

Måns Severinson & John Joheman

Disclosure for the use of AI-tools for thesis report writing

This thesis has been written with support from AI tools during parts of the writing process. The tools were used to improve grammar, sentence structure, clarity, and the overall flow of the text. They were also used as support when formulating explanations, restructuring sections, and improving the readability of the report.

AI tools were not used to generate technical results, simulation data, test results, or conclusions of the thesis. The CAD modelling, simulations, design decision, manufacturing evaluation, physical validation, analysis, and final conclusion were carried out and evaluated by the authors.

AI tools used:
ChatGPT and Gemini: Used to support language improvement, sentence structure, grammar, and the organization of report sections. It was also used to help formulate clearer explanations based on information and results provided by the author.

ChatSBDev: Used as an internal support tool at Aimpoint for general troubleshooting, software related questions, and guidance during parts of the workflow, mainly connected to simulation and modelling issues.

The authors have reviewed, edited, and approved all text included in the final thesis report.

1 Introduction

1.1 Background to Project

In many engineering applications, there is a continuous demand for lighter and more material efficient components. Reducing the weight of a component can lead to improved handling, reduced material usage, and more efficient production, as long as the performance is not compromised. Lightweight design is therefore often connected to structural optimization, where the objective is to remove unnecessary material while maintaining sufficient stiffness and strength [1].

Topology optimization has become an increasingly useful tool in the development of lightweight mechanical components. The method is based on distributing material within a given design space according to defined loads, boundary conditions, and constraints. This allows engineers to identify areas where material can potentially be removed without significantly affecting the structural performance of the component [2]. For this reason, topology optimization is especially relevant in applications where weight reduction is desired, but where the component must still withstand functional and mechanical requirements.

Additive manufacturing (AM) has further increased the possibilities of using topology-optimized designs in practice. Since AM allows components to be built with fewer geometric restrictions than many conventional manufacturing methods, it can make it possible to produce complex and material efficient structures that would otherwise be difficult to manufacture [2], [3]. This makes the combination of topology optimization and AM relevant when developing lightweight components.

This thesis project is conducted in collaboration with Aimpoint AB, a company that develops and manufactures red dot sights. In this type of product, the mount has an important function since it connects the sight to a weapon and helps maintain the correct position of the sight. Because of this, the mount must be stiff and strong enough to withstand operational loads, such as recoil, vibrations, and handling forces, without affecting the stability or alignment of the sight.

The component investigated in this project is an existing mount for the CompM5 sight. In this report, the investigated mount will be referred to as LRP 39mm spacer.

LRP 39mm spacer may contain more material than what is necessary from a structural point of view. This creates an opportunity to investigate whether a more material-efficient design can be developed while still maintaining the required mechanical performance. Therefore, this thesis focuses on reducing the weight of LRP 39mm spacer through topology optimization and simulation-based design evaluation. The original and redesigned geometries are compared with respect to weight, strength, stiffness, and manufacturability. In addition, the project investigates whether metal AM could be a suitable production method for the optimized design.

The thesis, therefore, focuses on the redesign of LRP 39mm spacer with the aim of reducing its weight through topology optimization and simulation-based design evaluation. The original and redesigned geometries will be compared with respect to weight, strength, stiffness, and manufacturability. In addition, the project will investigate whether metal AM could be a suitable production method for the optimized design.

1.2 Problem Statement

A sight mount is a critical component that allows for a red dot sight to be connected to a weapon while ensuring that the sight remains stable and correctly aligned during use. Although the component is relatively small, its mechanical performance is important, since excessive deformation or loss of stiffness may affect the position of the sight and thereby its functional reliability.

LRP 39mm spacer is designed to withstand operational loads such as recoil, vibrations, and external handling forces. However, conventionally designed components may contain more material than necessary, partly because their geometry is often influenced by machining constraints, standard design principles, and safety margins. This creates a potential for weight reduction through topology optimization, a method commonly used to improve material distribution in structural components.

When combined with AM, topology optimization can be especially useful, since AM enables more complex geometries than many conventional manufacturing methods [2].

The main challenge of this project is to reduce the weight of LRP 39mm spacer while maintaining the required mechanical performance and functional interfaces. The redesigned component must therefore remain sufficiently strong and stiff to preserve sight alignment under relevant load cases.

In addition to the mechanical requirements, manufacturability must also be considered. Topology optimized designs can result in complex shapes that may be difficult or inefficient to produce using conventional machining. Metal AM may therefore provide new possibilities for producing a more material efficient design. However, AM also introduces limitations related to support structures, build orientation, surface quality, dimensional accuracy, and post processing, which can affect both the final performance and the practical feasibility of the component [4].

This thesis investigates whether topology optimization, supported by CAD modelling and FEA, can be used to develop a lighter sight mount while maintaining the required structural performance. The problem is therefore not only to reduce the mass of the component, but also to evaluate whether the resulting design is mechanically reliable and practically manufacturable.

1.3 Research Questions & Objectives

The objective of this thesis is to investigate how topology optimization can be used to reduce the weight of a sight mount while maintaining its required mechanical performance. The project focuses on redesigning an existing mount used for a red dot sight, with the aim of improving material efficiency without compromising strength, stiffness, or functional reliability.

To achieve this, the original design will be evaluated and compared with an optimized design using CAD modeling and FEA. The simulations will be used to identify areas where material can be removed while still preserving the structural integrity of the

component. The optimized geometry will then be assessed with respect to both mechanical performance and manufacturability.
Since designs created through topology optimization often result in complex geometries, the project also aims to investigate whether AM in metal is a suitable production method for this type of component. The resulting design will be evaluated not only in terms of weight, strength, and stiffness, but also with respect to manufacturing constraints, post-processing requirements, cost and supplier feasibility.

Based on this objective, the following research questions have been formulated:

RQ1: "To what extent can the weight of a traditionally manufactured sight mount be reduced through topology optimization while maintaining sufficient strength, stiffness, and structural integrity?"

RQ2: "How does the optimized design compare to the original design in terms of weight, stress distribution, displacement, and overall mechanical performance?"

RQ3: "What geometric and manufacturing constraints must be considered when adapting the optimized design for metal AM?"

RQ4: "Is AM in metal a technically and practically viable alternative to conventional manufacturing methods for producing this type of sight mount?"

1.4 Scope & Limitations

The conducted work is limited to an analysis of only one specific sight mount (LRP 39mm spacer) for a red dot sight in collaboration with Aimpoint. The result of the study is therefore only applicable to this specific mount, and it would be wrong to assume that the results will carry over to other mounts and products.
The work mainly focuses on structural performance, like weight, stress, deformation and strength. Other factors like fatigue, wear and corrosion over a long period of time will not be considered in detail within the project frame.

CAD-modelling, FEA and physical testing are what the report is based on. The simulations were used to compare the original model to the optimized one, while the physical tests is used to get a practical indication of how the optimized version gets affected under load.

The number of design iterations will be limited due to the time constraint of the project, as well as the simulation and production capabilities. The goal is therefore not to develop a complete production-ready construction, but instead to analyze the potential of weight reduction and to examine if the optimized version would be mechanically and commercially viable.

The project also includes an overall assessment of metal AM as a possible production method. This includes manufacturability, cost, and supplier availability, but does not include a complete economic analysis or material optimization

1.5 Confidentiality

Certain parts of this project are limited by confidentiality, since the work is based on an industrial product and company specific information. Therefore, some technical details that are not publicly available, such as exact dimensions, internal specifications, material data, load cases, and detailed design requirements, may be generalized or excluded from the report.

The report will only include information that can be presented without revealing sensitive data. When necessary, specific values or design details will be described in a more general way, while still allowing the method and reasoning behind the work to be understood.

Although some information may be limited, the aim is to present the project as clearly and transparently as possible. The overall methodology, the comparison between the original design and the redesigned geometry, and the main conclusions regarding weight reduction, mechanical performance, and manufacturability will still be included in the report.

Due to confidentiality and proprietary agreements with Aimpoint, certain technical specifications and quantitative performance thresholds are withheld from this report. Specifically, the exact numerical limit for the maximum allowable reticle deviation under recoil testing is classified information. Consequently, all experimental and simulation results regarding structural deformation and alignment stability are evaluated and discussed in relation to a generalized "set acceptance limit" or "specified tolerance threshold" rather than the absolute performance metrics defined by the manufacturer.

2 Technical Background

This chapter presents the technical background needed to understand the methods and evaluations used in the project. It introduces the main concepts related to AM, weight optimization, topology optimization, structural simulation, and measurement of sight alignment.

2.1 Additive Manufacturing

AM is a process that allows for a high freedom in geometry design and production of complex and customized parts [5]. This is because of the low amounts of constraints during the manufacturing process, due to the process not being done in similar ways to other manufacturing methods, such as subtractive manufacturing. In subtractive manufacturing, the part is cut from an existing solid block of material, which results in waste material. AM only produces waste material from the building supports and surface finishing. The parts designed for AM have no need to incorporate tool space and a thought out design that allows for manufacturing such as subtractive manufacturing where the tools need to reach [5]. The biggest restriction to parts designed for AM is to make sure no enclosed cavities exist, as this would result in metal powder being enclosed and unable to be removed [6]. The speed at which CAD designs can come into reality can be much faster than traditional manufacturing due to AM being a single process rather than several steps to produce parts as in subtractive manufacturing [5].

There are multiple variants of AM processes that utilize different technologies and materials for both industrial and private use. In industries where a high strength to weight ratio is critical, such as aerospace, defense, and the energy sector, AM allows for complex designs, such as lightweight mechanical metamaterials, to be produced efficiently in one process [7], [8]. AM is also used in healthcare for unique personalized prostheses of bone structures made with high durability alloys that are accepted by the body's immune system [7].

2.1.1 Metal Additive Manufacturing

As AM has evolved and its application has become more widespread across various industries, the desire to manufacture using a broader range of materials has grown. Metallic components possess highly favorable material properties and mechanical performance compared to polymers [7]. As a result, metals are the most commonly utilized materials within structural engineering applications. Combining the expansive production capabilities of AM with the robust structural properties of metals results in a production method capable of rapidly creating complex and unique components [7]. This, combined with the minimal material usage of AM, allows for unprecedented geometric freedom while maintaining a high level of material efficiency compared to traditional subtractive manufacturing [5].

2.1.2 Laser Powder Bed Fusion (LPBF)

Within metallic AM, LPBF is one of the most widely adopted and commercially established processes. The process utilizes a high intensity laser source, a controlled build platform and a powder delivery system, to melt metal powder layer by layer. During operation, a thin layer of metal powder (specialized for this process) is spread uniformly across a flat build plate by a leveling scraper or roller. Then the laser beam is directed via mirrors onto predetermined regions of the powder bed, melting and fusing the particles according to the CAD model cross section [5]. Once the layer is completed, the build plate lowers by one layer thickness and a new layer of metal powder is applied. This repeats until the full object is created [5].

This fabrication done layer by layer with metal powder offers significant advantages, particularly regarding design flexibility discussed before. This fabrication does however introduce specific limitations. During printing the component remains submerged within the surrounding unused metal powder bed. While this powder offers limited thermal insulation, it offers little to none structural support. Therefore additional support structures must be anchored to the build plate. These structural supports are needed to counteract thermally induced stresses caused by the rapid heating and cooling cycles [7]. These forces can cause the part to warp and lift during the print [7].

The resulting finish of the prints surface also needs to be disclosed. While the part is solid and homogeneous, the surface finish is inherently rough due to phenomena such as the adhesion of partially melted powder particles and beading along the weld tracks [9]. This in combination with the support material, means that to receive a smooth finish, post processing is required [5], [9].

2.1.3 Post Processing

Post processing consists of several steps, depending on the required end result. The first step involves clearing any unmelted metal powder trapped within the geometry or internal cavities [5]. After this is completed, the structural supports need to be separated from the build plate using methods such as handheld tools, a fixed bandsaw, or wire electrical discharge machining (EDM) [5]. Once detached, surface finishing techniques, including manual filing and polishing, can be applied to ensure that the surface quality meets specific design tolerances [9]. If the part requires enhanced material characteristics, such as increased corrosion resistance or surface hardness, coatings can be applied. A commonly utilized process is the electrochemical treatment, electroplating. This process submerges the component in an electrolyte bath where an electric current is applied to deposit a very thin layer (typically 1 to 50 μm) of another metal onto the surface [5]. This allows for the enhancement of corrosion resistance, wear protection, or aesthetic appearance, without significantly altering the component's core geometry [5].

2.2 Weight Optimization

The purpose of weight optimization is to reduce the weight of a part by removing unutilized material in the model, while still keeping the overall structural integrity of the part. By utilizing computational tools such as FEA, the mechanical loads and stress distribution within a component at a given scenario can be accurately evaluated [10]. This allows for identification of load paths through the part. Material in areas subjected to low stress can be systematically eliminated [10].
Historically, components designed for traditional manufacturing were often over dimensioned to ensure large safety margins and to accommodate the geometric limitations of conventional subtractive manufacturing tools [6]. In the context of AM, weight optimization offers significant advantages. Since AM builds parts layer by layer, reducing the total volume of material in any printed part will translate to

shortened build times [5]. This allows weight optimization to be fully utilized, whereas previously, such complex and material efficient geometries would have been impossible or extremely expensive to produce due to the tooling constraints of manufacturing [11].

2.2.1 Topology Optimization

Topology optimization is a mathematical method that optimizes the material layout within a given design space for a specified set of loads, boundary conditions and constraints [10]. Unlike shape or sizing optimization which modifies predefined geometric boundaries or parameters, topology optimization can create entirely new boundaries and internal voids within the defined domain [10]. The optimization algorithm iteratively evaluates the material density of individual elements to eliminate material that does not significantly contribute to the overall structural performance of the part [10]. This process results in complex organic geometries that maximize the stiffness to weight ratio, making the method highly synergistic with the geometric freedom offered by AM [11]. An example of this material distribution process can be seen in **Figure 1**, where an initial design space is optimized in SolidWorks Simulation based on defined boundary conditions and loads.

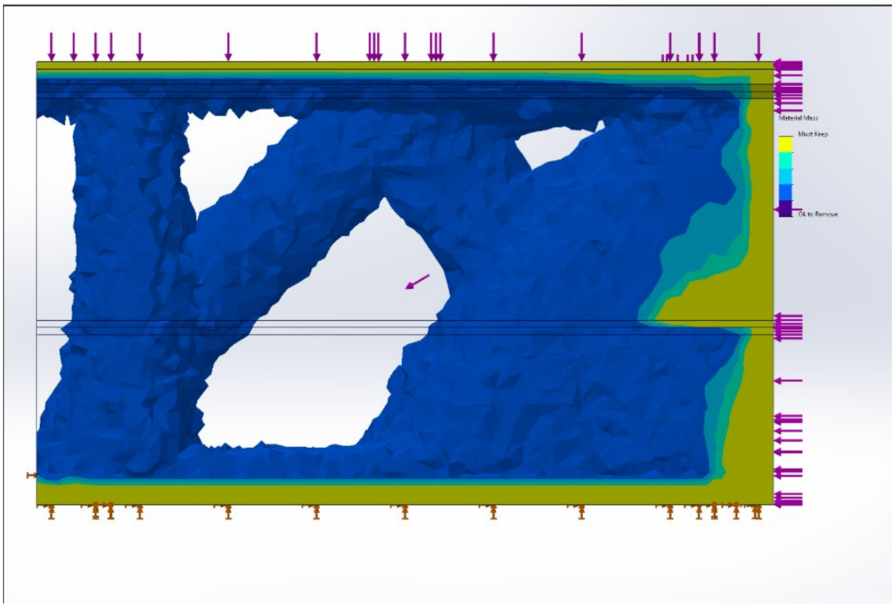


Figure 1: *A conceptual example of the topology optimization process applied to a generic solid block under a defined load, illustrating how the algorithm removes unutilized material to create an organic, load bearing structure.*

2.2.2 Design Optimization

Design optimization involves refining an existing geometry to improve specific performance metrics, such as minimizing mass or reducing stress concentrations [10]. It is typically used as a critical final step to process the raw organic output from topology optimization [11]. By adjusting boundaries and smoothing surfaces, design optimization translates the conceptual results into a functional and manufacturable CAD model [11]. This process often involves manually reconstructing and refining the optimized organic shapes within CAD software [11].

2.3 Structural Simulation

Structural simulation is a comprehensive approach used to evaluate the mechanical performance and behavior of a component under specific operational conditions. A simulation can be conducted both computationally and physically, either in a virtual environment or in real world testing. Both methods aim to analyze how a design responds to external factors such as loads, impacts and vibrations. These factors are derived from real world examples of what the part is expected to experience during actual use.

Computational simulations allow for rapid changes in these factors to simulate different situations, yielding fast and detailed results compared to physical simulations [5]. However, a limitation is the need to accurately set up the simulation to imitate real world scenarios. Physical tests allow complicated scenarios to be recreated more naturally, where several unpredictable forces are applied to a part, such as in a free fall simulation, where dynamic forces are applied to the part in different directions.

Together these forms of simulation complement each other. Computational methods provide detailed data and allow for quick adjustments, while physical simulations provide indisputable evidence to validate the theoretical models and to ensure real world reliability [12].

2.3.1 Finite Element Analysis (FEA)

FEA is a numerical method used to predict how a part or assembly behaves under given physical conditions [13]. The fundamental principle of the method is to break

down a complex, continuous structure into a finite number of smaller, simpler geometric shapes called elements. This process is known as meshing.
Elements are connected at specific points called nodes; these nodes form a comprehensive grid over the entire model. Mathematical equations can be applied to each individual element to calculate responses, simulating stress, strain, and displacement based on defined loads and boundary conditions. The collective response of all elements is then calculated to approximate the behavior of the entire structure. FEA is an essential tool for identifying stress concentrations and evaluating structural integrity prior to physical manufacturing [13].

2.3.2 Abaqus CAE

Abaqus CAE (Complete Abaqus Environment) is a comprehensive software suite used for finite element modeling and visualization. It provides a complete interface that allows for the creation, editing, monitoring, and evaluation of FEA models. The software is used to accurately simulate actual operational conditions using geometries, material properties, contact interactions, and boundary conditions. Abaqus is recognized for its computational solvers, which are capable of handling both linear and complex nonlinear structural behaviors. This makes it an effective tool for analyzing stress distributions and for validating the structural integrity of components [14].

2.3.3 Physical Simulation

Physical simulations are often referred to as experimental testing, which involves subjecting a manufactured prototype to controlled conditions as close to real life as possible, to evaluate its mechanical performance. Compared to computational FEA, experimental testing offers true physical forces instead of theoretical predictions, making it suitable for unpredictable forces and complex behaviors such as dynamic impacts. These conditions can be hard to accurately model mathematically even with FEA software. Physical simulation also takes manufacturing variations into account, such as surface irregularities and precise material responses. Ultimately, physical simulation serves as the validation method for the accuracy of computational models [15].

Determining whether a physical prototype meets the given specifications after physical simulations requires precise measurement and validation techniques. In comparison to FEA software, where the result data is instantly accessible and easily extracted from every node in the model, physical testing requires significantly more time and effort to accurately record results [15].
To ensure the quality of physical tests, it is essential to utilize established international standards, such as those provided by ISO and ASTM [16]. These standards provide strict guidelines on how tests should be executed, including details on test specimen geometry, loading rates, and environmental conditions. Adhering to these protocols ensures that the experimental data is objective and repeatable. This enables comparability, ensuring that identical conditions are experienced across different prototypes.

2.4 LRP 39mm spacer Geometry and Functional Features

LRP 39mm spacer is the sight mount investigated in this project. The component connects the red dot sight to the weapon and must maintain the position and alignment of the sight during use. The mount includes several functional features that are important for sight attachment, recoil load transfer, and clamping to the rail. **Figure 2** shows an annotated CAD model of LRP 39mm spacer, and **Table 1** describes the numbered features and their functions.

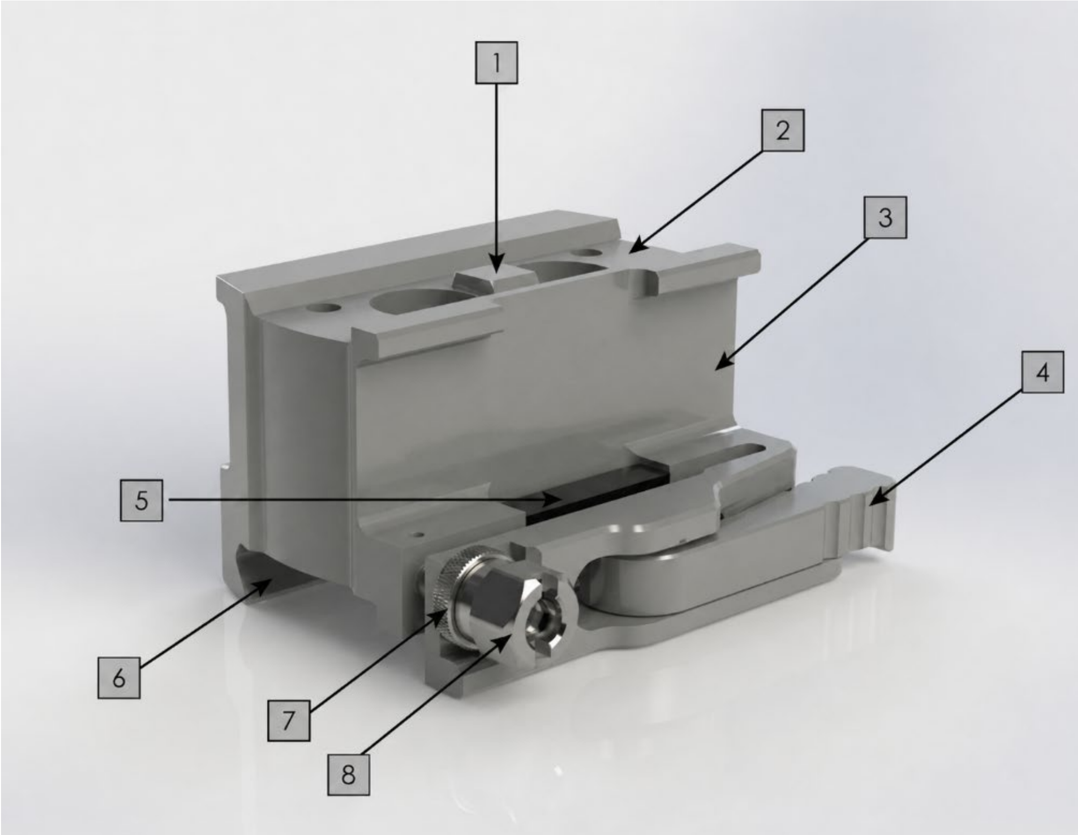


Figure 2: *Isometric view of original mount and arrows that point to the responding future*

Table 1: *Overview of the numbered LRP 39mm spacer features and their functions.*

MountM5		
Number	**Component name**	**Explanation**
1	Recoil lug	Feature that fits into a corresponding slot in the sight and helps transfer recoil loads
2	Sight mounting holes	Four screw holes used to fasten the sight to the mount
3	Mount body	Main structural body of the Mount
4	LRP-arm	Lever arm used in the locking mechanism
5	Barlock	Locking bar used to clamp the mount to the rail
6	Rail contact interface	Lower interface that aligns with the Picatinny rail and transfers clamping forces when the barlock is tightened
7	Nord-Lock washer	Washer used to secure the screw joint and reduce the risk of loosening
8	Preload adjustment screw	Screw used to set the preload in the LRP-arm before it is closed

A Picatinny rail is a standardized mounting rail used to attach accessories, such as optical sights, to a weapon. In this project, the lower interface of LRP 39mm spacer is designed to fit and clamp onto this rail. This interface is important for positioning and securing the mount and was therefore kept unchanged during the redesign to maintain compatibility with the existing mounting system.

2.5 Minute of Angle (MOA)

MOA stands for Minute of Angle and is an angular measurement commonly used when evaluating sight adjustment and changes in point of aim, as well as to determine sighting error and the bullet spread of firearms. One MOA corresponds to 1/60 of one degree. Since MOA is an angular unit, the linear distance it represents increases with distance. At 100 meters, 1 MOA corresponds to approximately 2.91 cm. This means that a change of 1 MOA in red dot position would correspond to a shift of about 2.91 cm at 100 meters, while 2 MOA would correspond to approximately 5.82 cm.

3 Methodology

3.1 Literature Review and Software Familiarization

A literature review was carried out to build an understanding of the main technical areas used in the project. The review focused mainly on topology optimization, AM, LPBF, FEA, and physical validation of mechanical components. Scientific articles were mainly found through databases such as ScienceDirect and Google Scholar. These sources were used to support the theoretical background and to better understand the methods used later in the project.

In addition to academic sources, software-related information was gathered to understand how the simulation tools could be used in practice. Since Abaqus was an important part of the project, an introduction to the software was given by one of the supervisors at Aimpoint. The introduction covered the general workflow in Abaqus and how a model could be prepared for simulation. An internal handbook provided by Aimpoint was also used as support when setting up the recoil simulation. This handbook gave guidance on how the model should be built and how the simulation process should be structured. The specific boundary conditions and load cases used in the simulations are described later in this chapter.

An instruction guide for Tosca Structure was also provided during the software familiarization. This guide showed an example of how Tosca Structure could be used together with Abaqus for topology optimization. However, the example was based on an Abaqus/Standard implicit setup and did not directly match the recoil simulation used in this project. Since the recoil load case was dynamic, the workflow could not be applied directly in the same way. Tosca Structure was therefore briefly investigated as a possible tool for the optimization process. However, the available workflow did not match the dynamic recoil simulation used in this project. For that reason, the final optimization method was instead developed as a manual simulation-driven process which is described in section 3.4

Additional learning material, such as online tutorials and videos, was also used to understand the basic functions of Abaqus and to solve practical modeling or simulation issues. When problems occurred, support was first sought from supervisors or other employees at the office. In cases where direct help was not available, Aimpoint's internal AI tool, ChatSBDEV, was used as an additional support tool for general questions and troubleshooting related to the workflow.

3.2 CAD Model Preparation

The CAD model preparation was done to create a model that could be used for both simulations and later design work. The original mount was used as a starting point, and the model was prepared in SolidWorks before being imported into Abaqus. The goal was to keep the important functional parts of the mount while removing or simplifying details that were not needed for the simulations.

The model needed to be detailed enough to represent the real component, but not so detailed that the simulation became unnecessarily difficult to run. Because of this, the CAD preparation included remodeling of the existing design, simplification of the geometry, and some design changes connected to AM.

3.2.1 Remodelling of Existing Design

The existing mount geometry was first reviewed and prepared in SolidWorks. The purpose was not to create a completely new model at this stage, but to make a usable reference model that could be analyzed and compared with later design iterations. The original design was therefore kept as close as possible to the real component.

Important functional areas were preserved during this step. This included the surfaces where the sight is mounted, the interface towards the Picatinny rail, mounting holes, and other features needed for assembly. These areas were kept because they affect how the mount connects to the sight and to the weapon, and changing them could affect the function of the component.

Some dimensions and details are not described in full. However, the main geometry and the functional interfaces were kept in the CAD model. This made it possible to use the original design as a baseline when evaluating weight, stress distribution, displacement, and stiffness later in the project.

3.2.2 Geometry Simplification

Before the simulations were performed, the CAD model was simplified. The purpose of this was to make the model easier to mesh and to reduce simulation time. Small features that were not expected to have a large influence on the overall structural behavior were removed or simplified. This included minor fillets, very small details, and geometry that could create unnecessarily small mesh elements.

A detailed CAD model is not always the best option for FEA. If the geometry contains many small features, the mesh can become more complex and the simulation can take longer to solve. It can also increase the risk of poor element quality or numerical problems. By simplifying the geometry, the model became more stable to work with in Abaqus.

The simplification was still done carefully. Features that were important for load transfer, stiffness, mounting or alignment were kept. The locking mechanism was simplified in the simulation. In the real mount, a screw preload and lever mechanism press the barlock against the Picatinny rail. To reduce the complexity of the model, the lever was decided to not be included. There was instead an equivalent clamping force applied to the barlock to represent the force created by the screw and lever system. This allowed the rail connection to be represented without modelling the full locking mechanism in detail.

The goal was to remove details that made the simulation more complicated without affecting the main result. In this way, the simplified model could still represent the behavior of the real mount well enough for the purpose of the project.

3.2.3 Design Adjustments for Additive Manufacturing

Some adjustments were also made to prepare the design for AM. Since the optimized mount was intended to be manufactured using LPBF, the CAD model had to be considered from a manufacturing and structural perspective. The geometry could not only be designed to reduce weight, but also had to be possible to print, remove the build plate, post processing, and assemble.

One important example was the holes in the mount. Some hole diameters were reduced to 1 mm in CAD and later drilled to their final diameter after printing. This was done to improve the final dimensional accuracy of the holes, since LPBF can introduce deviations in small geometric features such as holes. Previous studies have shown that hole accuracy in LPBF depends on feature size, machine configuration, and process parameters, and that smaller holes can be more difficult to reproduce accurately [6].

Threaded holes were also not treated as finished directly after printing. Instead, threading was planned as a post processing step. This was necessary because threads need to be accurate and have enough surface quality to function in the intended way. Creating the threads in the print would not have given the same control over the final result.

These adjustments showed that the CAD model had to be prepared for the whole manufacturing chain, not only for the printing process itself. Even if the main shape of the mount can be produced with AM, some functional features still need drilling, threading, or surface finishing afterwards. This was considered before manufacturing so that the printed parts could later be assembled and tested properly.

3.3 Simulation Setup

The simulation setup was created to evaluate how the mount behaves under the main loading conditions considered in the project. The model was prepared in Abaqus using defined material properties, boundary conditions, contact interactions, and load cases. The purpose of the simulations was to study stress distribution, displacement, and load transfer in both the original and redesigned geometries.

3.3.1 Material Data

Table 2: *Material properties used in the simulations*

LRP Mount to CompM5 sight					
Component	**Material**	**Elastic modulus [N/m^2]**	**Mass Density [kg/m^3]**	**Yield Strength [N/m^2]**	**Poisson's Ratio [N/A]**
Base	Al. EN7075-T6	7,17e+10	2810	4,6e+08	0,33
Barlock	Al. Alloy 7075-T6 (SN)	7,2e+10	2810	5,05e+08	0,33
Picatinny rail	Al. Alloy 6063-T6	6,9e+10	2700	2,15e+08	0,33
Screw	Stainless Steel A2	2,0e+11	7850	1,72e+08	0,28
Base (Printed)	AlSi10Mg	7,0e+10	2670	2,4e+08	0,33
Base (Printed)	Ti6Al4V	1,1e+11	4430	8,8e+08	0,33

The material data used in the simulations was entered into Abaqus for each part of the assembly. Since the model consisted of several components, different materials had to be defined for the mount, barlock, picatinny rail, and screw. The original mount and barlock were modelled with aluminum materials, while the screw was modelled as stainless steel.

The material properties used were elastic modulus, mass density, yield strength, and Poisson's ratio. These values were needed to describe the stiffness, weight, and mechanical response of the parts during the simulations. The yield strength was mainly used as a reference when evaluating if the stresses in the mount were within an acceptable range.

For the printed aluminum version, AlSi10Mg was used, and for the printed titanium version, Ti6Al4V was used. The properties of additively manufactured materials can vary depending on process parameters, build orientation, heat treatment, and supplier. Because of this, the values used in the simulations should be seen as representative values instead of exact values for every printed part.

The same material setup was used when comparing the original and optimized designs, except for the material change in the printed aluminum and titanium versions. This made it possible to compare how the different materials affected stress distribution, displacement, and overall mechanical performance.

3.3.2 Boundary Conditions and Load Cases

The boundary conditions and load cases used in Abaqus were defined with support from an internal recoil simulation guideline provided by Aimpoint. This guideline was used as practical support for how the model should be constrained and how the recoil load case should be applied.

The boundary conditions were defined to represent how LRP 39mm spacer is connected to both the Picatinny rail and the red dot sight in use. Since the complete physical assembly contains several small component and mechanical interfaces, some simplifications were made in order to create a stable and computationally efficient model. The main goal was to represent the important load transfer paths without modelling every detail of the real locking and screw mechanisms.

The simulation was divided into two main steps. In the first step, the screw tightening and clamping of the mount around the Picatinny rail were simulated to represent how the mount is assembled and fixed to the rail before recoil. The simulated sequence consisted of three time intervals: an initial tightening step of 0.5 ms, followed by the recoil load during 0.5 ms, and finally an additional 0.5 ms interval where the model was allowed to stabilize after the recoil event. This sequence was also used when extracting and interpreting the stress-time graphs.

In the second step, the recoil load case was applied. The boundary condition that fixed the rail in space during the tightening step was deactivated before the recoil event. This was done so that the recoil response could be simulated without keeping the rail artificially fixed by the same constraint used during assembly. The recoil load was applied in one direction only, representing the main direction of loading expected during recoil. This simplification made it possible to focus on the dominant recoil response of the mount.

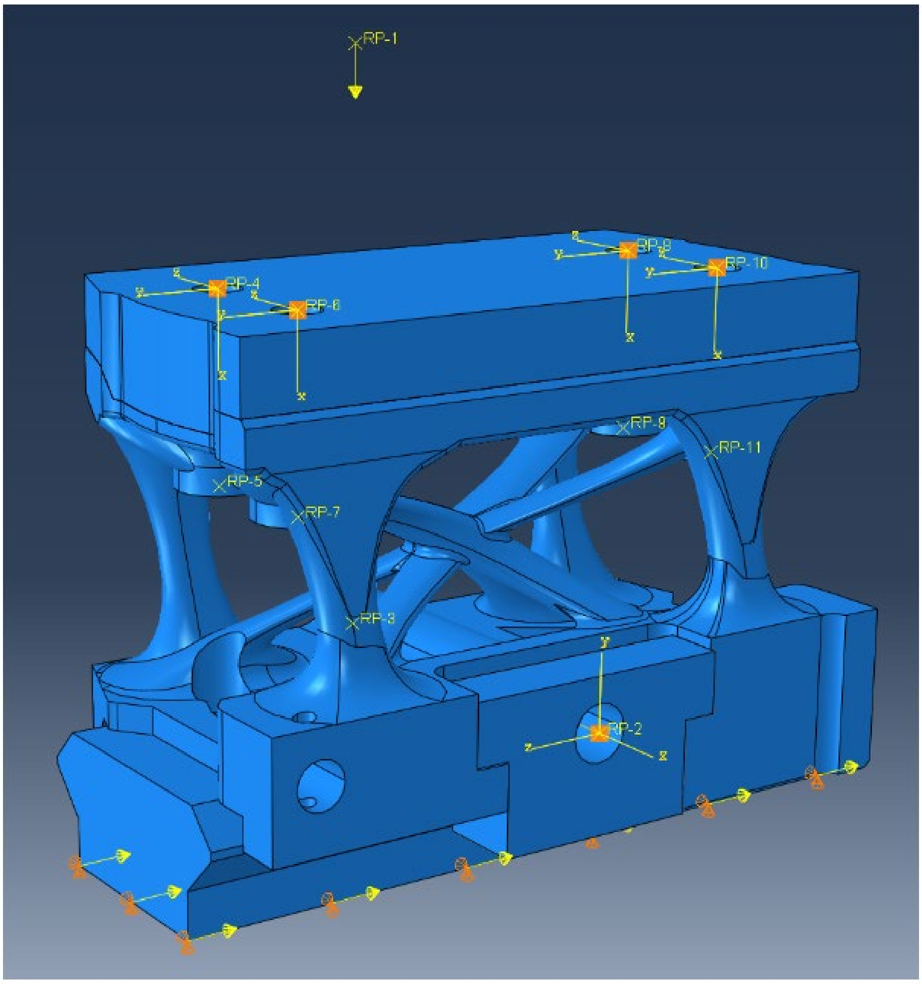


Figure 3: *Simplified sight representation on top of the mount, used to transfer the inertial effect of the sight to the LRP 39mm spacer through coupling constraints.*

The red dot sight was represented by a simplified geometry instead of being modelled in full detail. This simplified part represented the lower interface of the sight and the screw attachment regions. A reference point was placed at the approximate center of gravity of the sight and assigned to represent the inertial effect of the sight during recoil. The reference point was coupled to the simplified sight geometry, which was then connected to the corresponding mounting holes in the mount through coupling constraints.

This approach allowed the sight mass and its load transfer into the mount to be included in the simulation, while avoiding the need to model the complete sight geometry, screw threads, and detailed contact interactions. The simplified representation is shown in **Figure 3**.

The main computational load case used in the simulations was recoil. The recoil load case was based on internal Aimpoint information and was treated as the most important simulated loading condition, since it represents one of the most relevant operational loads for a sight mount. To represent the recoil event, an 800G half-sine acceleration pulse was applied dynamically in Abaqus. This was done to approximate the short-duration response of the mount during recoil as realistically as possible.

Mechanical shock and mounted drop tests were handled separately. These tests were used later as physical validation methods, while the Abaqus model was mainly used to compare different design iterations and evaluate the structural behavior under the simulated recoil load case.

3.3.3 Mesh and Analysis Settings

After the CAD model had been prepared, the geometry was meshed in Abaqus before running the simulations. The mesh was created to give a reasonable balance between accuracy and simulation time. A very fine mesh can give more detailed results, but it also increases the computational time. Because of this, the mesh had to be detailed enough to capture the important structural behavior, while still being possible to run within a reasonable time.

The mesh quality was checked before the simulations were started. This was important since poor mesh quality can lead to numerical problems and unreliable results. During the first simulation attempts, some errors occurred where certain elements suddenly received a negative density, which caused the simulation to crash, or aborted as Abaqus calls it. This was connected to the mesh quality and not to the applied recoil load itself. The mesh was therefore adjusted until the simulation could run without this type of error.

Critical areas of the model were given extra attention during meshing. These were mainly areas where higher stresses were expected, such as contact surfaces, load paths, and regions close to mounting components. The goal was to make sure that the mesh was fine enough without making the full model unnecessarily heavy to solve.

Similar mesh and analysis settings were used when comparing the original design with the optimized design. This was done to make the comparison as fair as possible. The models mesh had to be changed slightly though, when switching the material and its data between titanium and aluminum. The reason for that is because titanium can withstand greater force compared to aluminum, which made the model's behavior change due to different strengths and limits. Tosca Structure was investigated as a possible tool, since it can be used together with Abaqus for structural optimization. The idea was to define the design space, apply the relevant load cases, and let the software suggest where material could be removed.

During the setup of the recoil simulation, it became clear that this approach was not suitable for the load case used in the project. The recoil load was treated as a dynamic load in Abaqus/Explicit, while the available Tosca Structure workflow was based on an Abaqus/Standard implicit setup. This meant that the topology optimization could not be used directly to the recoil simulation in the intended way.

One possible solution would have been to simplify the recoil load into a static load case. This could have made it possible to use an automatic topology optimization workflow, but it would also have changed the force situation in the model. Since recoil acts over a short time and creates a dynamic response in the mount, a static simplification was considered less representative of the real loading condition.

Instead, the project continued as a manual simulation-driven optimization process. The original design was first simulated in Abaqus to identify stress distributions, displacement, and load paths. Based on these results, material was removed manually in SolidWorks from areas considered less critical for the structural performance. The modified geometry was then simulated again in Abaqus, and the results were used as feedback for further design changes. This iterative process was repeated until a lighter design with acceptable mechanical behavior was achieved.

3.4 Manual design optimization process

This section describes how the mount was manually optimized through repeated CAD modifications and Abaqus simulations, after the initial topology optimization approach was found unsuitable for the dynamic recoil load case.

3.4.1 Initial topology optimization approach

The original idea for the project was to use topology optimization to reduce the weight of the mount. Tosca Structure was investigated as a possible tool, since it can be used together with Abaqus for structural optimization. The idea was to define the design space, apply the relevant load cases, and let the software suggest where material could be removed.

During the setup of the recoil simulation, it became clear that this approach was not suitable for the load case used in the project. The recoil load was treated as a dynamic load in Abaqus/Explicit, while the available Tosca Structure workflow was based on an Abaqus/Standard implicit setup. This meant that the topology optimization could not be used directly to the recoil simulation in the intended way.
One possible solution would have been to simplify the recoil load into a static load case. This could have made it possible to use an automatic topology optimization workflow, but it would also have changed the force situation in the model. Since recoil acts over a short time and creates a dynamic response in the mount, a static simplification was considered less representative of the real loading condition.

Because of this, automatic topology optimization was not used for the final design development. Instead, the project continued with a manual simulation-driven optimization process. The original design was first simulated in Abaqus. This process was repeated until a lighter design with acceptable mechanical behavior was achieved.

3.4.2 Evaluation of the Original Design

The original mount was first simulated in Abaqus to understand how it behaved under the recoil load case. This was done before any material was removed from the model, since the original design was used as the reference for the rest of the optimization process. The purpose of this simulation was to study the stress distribution, displacement, and how the forces travelled through the geometry.

The simulation was divided into two different steps. The first step simulated the tightening of the screws and barlock, while the second step simulated the recoil event. After the simulation was completed, it was possible to analyze each frame of the recoil sequence.

The stress display was adjusted to make the results easier to interpret. The upper value in the color scale was lowered to 50 MPa, not to change the actual simulation result, but to make the lower stress regions more visible. By doing this, it became easier to see how the stresses were distributed in the component and where the main load paths were located. The result can be seen below in **Figure 4, 5**.

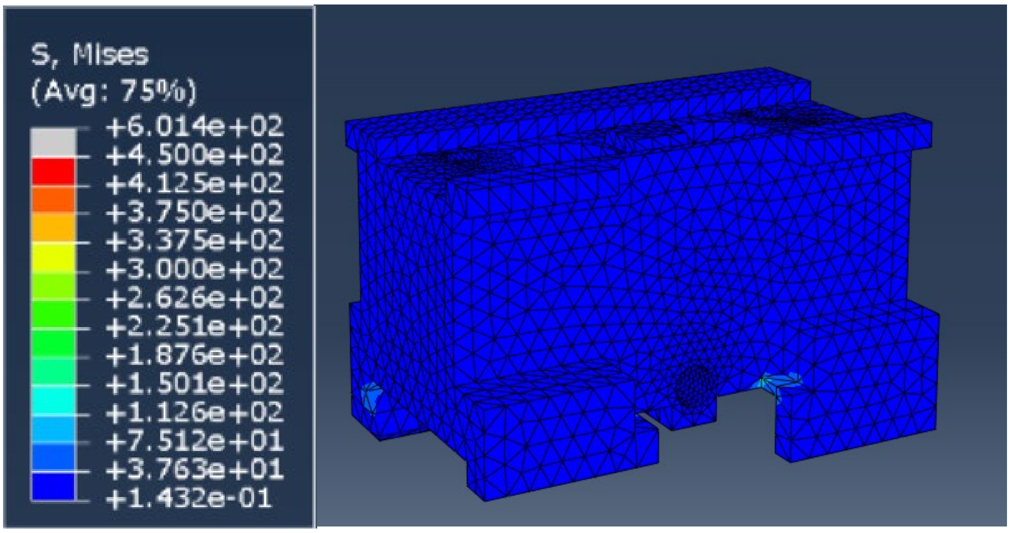


Figure 4: *460MPa yield strength*

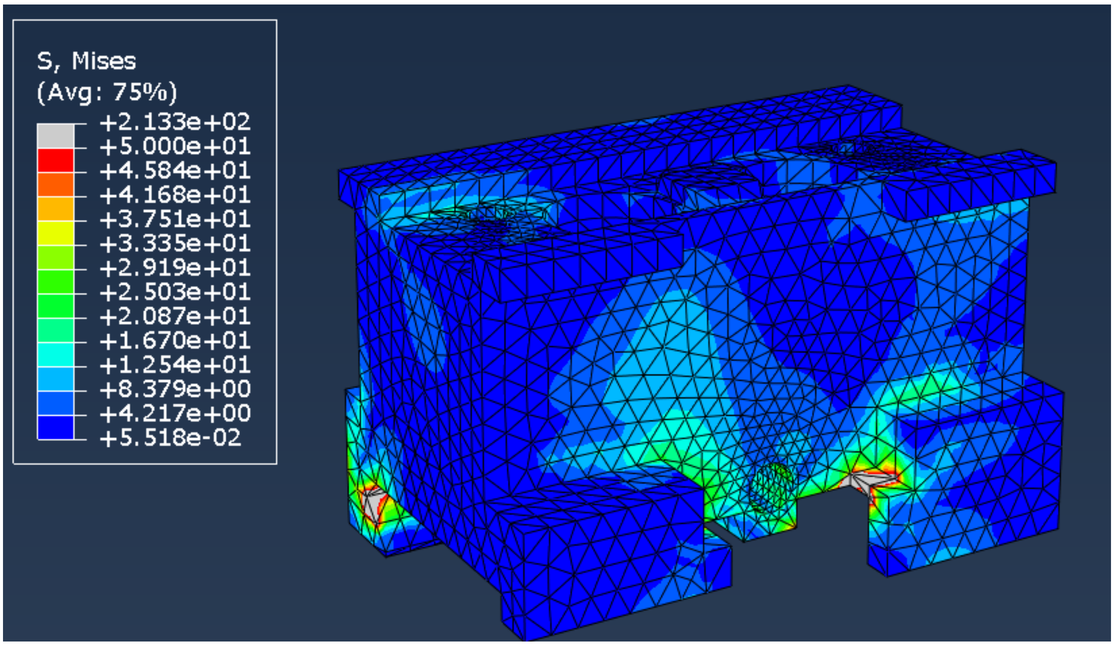


Figure 5: *50 MPa yield strength*

The color spectrum in Abaqus was used to show how much stress different areas of the mount were exposed to. Areas with higher stress were shown more clearly, while areas with less stress could be identified as less structurally active. This gave a visual understanding of which parts of the mount were most loaded and which areas could potentially be modified or reduced.

This evaluation was used as the starting point for the manual optimization process. Areas with low stress and limited contribution to the load transfer were considered possible regions for material removal. At the same time, areas with higher stress, contact surfaces, and functional interfaces were kept more carefully, since changing these areas could affect the strength, stiffness, or function of the mount.

3.4.3 Iterative Redesign Between Solidworks and Abaqus

After the original design had been evaluated, the redesign work was carried out through an iterative process between SolidWorks and Abaqus. The results from Abaqus were used to identify how the recoil load travelled through the mount and where the stress levels were lower. The lower stressed areas were then considered as possible regions where material could be removed.

The geometry was modified manually in SolidWorks and then imported back into Abaqus for new simulation. Each version was checked with respect to stress distribution, displacement, and stiffness. If the simulation showed high stresses in a critical area, or if the deformation became too large, the geometry was adjusted again. In this way, the design was changed step by step instead of being redesigned all at once.

Several different structural shapes were tested during this process. Some changes gave a lower weight but also created stress concentrations or weaker load paths, which meant that they had to be changed or removed. The final geometry was therefore selected based on both the simulation results and engineering judgement.

The design also had to be considered for the later physical validation. Even though the recoil simulation was the main computational load case, the mount also had to withstand the mechanical shock test and the mounted drop test. Because of this, the design was not only optimized for the simulation result, but also for practical strength and function.

3.4.4 Final Optimized Design Selection

The final design was selected after several iterations between SolidWorks and Abaqus. The earlier versions still contained more material and were mainly used to understand how different shapes affected the stress distribution and displacement. These versions helped guide the redesign, but they were not considered complete enough to be manufactured and tested. The final model can be viewed in **Figure 6**.

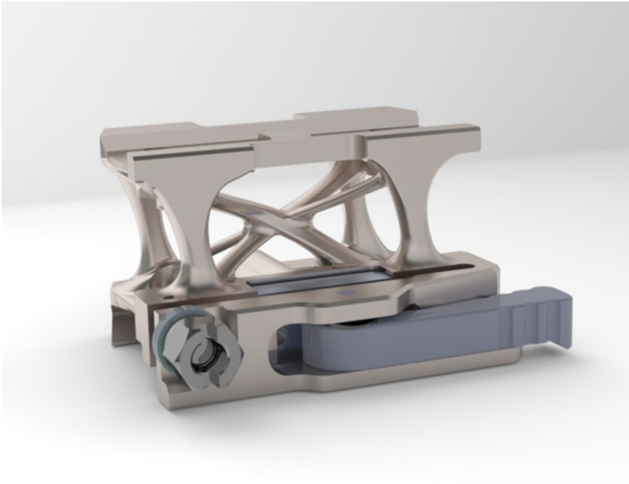


Figure 6: showing the final model assembled in SolidWorks and rendered.

As the design developed, more focus was placed on the practical requirements of the mount. One important change was that the final design considered the screw holes and assembly features more clearly. These details were not the main focus in the earlier models, but they had to be included properly in the final geometry since they are necessary for mounting, tightening, and later post processing.

The final design also had to be suitable for the planned physical validation. Earlier concepts were mostly evaluated with respect to the recoil simulation, but the final version also had to be robust enough for the mechanical shock test and mounted drop test. Because of this, the final geometry was not only selected based on weight reduction, but also on how realistic it was for testing and practical use.

The selected design kept the important functional interfaces from the original mount, such as the sight mounting surface, the Picatinny rail interface, and the locking mechanism. It also showed acceptable behavior in the recoil simulation and was considered suitable to continue with manufacturing and physical validation.

3.5 Physical Validation Method

Physical validation was included to compare the design work that was simulation based, with real testing. The reason behind the physical tests was to evaluate whether the optimized mount could maintain its function when exposed to loading conditions that are difficult to fully represent in a simulation. The tests were carried out according to Aimpoint's internal test procedures for this type of product, where the inspection points and evaluation method were defined before testing.

The same overall validation approach was intended to be used for both titanium and aluminum. This made it possible to compare the two materials under similar test conditions. The physical validation was based on visual inspection and comparison of the red dot position before, during, and after testing. The detailed test results are presented in Chapter 6.

3.5.1 Evaluation of Reticle Position

The main functional measurement during the physical validation was the change in reticle position. In this project, MOA was used to quantify how much the red dot position changed after the shock and drop tests. The reticle position was compared before, during, and after testing according to the test plan, and the measured movement was then evaluated against the acceptance criteria from the test specification. Together with visual inspection, this made it possible to assess whether the mount had been damaged, deformed, loosened, or moved in a way that could affect its function.

3.5.2 Mechanical Shock Test

The shock test was performed in a test machine. In this test, the mount was exposed to a repeated impact load of 800 G, where G refers to the acceleration due to gravity. This corresponds to approximately 7848 m/s^2 . The shocks were repeated 10 000 times to evaluate how the mounts responded to repeated high-acceleration loading as well as end of life testing.

After the shock test, the mount was first inspected visually to identify any visible damage, deformation, or loosening of components. The red dot position was then measured and compared with the position recorded before testing. This comparison was used to evaluate whether the repeated shock impacts had caused any shift in sight alignment or loss of stability in the mount.

3.5.3 Mounted Drop Test

The mounted drop test was used to evaluate how the mount behaved when exposed to impacts from different directions. For this test, a sight was mounted on the redesigned mount, and the mount was attached to a dummy rifle with the correct dimensions and an approximate total weight of 4 kg.
The test setup was manually dropped from a height of 122 cm onto concrete covered by a plywood surface. A total of 26 drops were performed from different directions. All corners, sides, and edges were covered. The red dot position was inspected after a defined amount in the test plan in order to evaluate whether the mount maintained its functional alignment.

3.6 Evaluation and Comparison

The final evaluation of the optimized mount was based on a comprehensive comparison between the original design and the redesigned AM geometries. The primary quantitative metric was the calculated weight reduction, which was evaluated alongside the structural performance parameters extracted from the FEA, specifically focusing on stress distribution and displacement under simulated recoil loads.
In addition to the computational data, the physical validation results from the mechanical shock and mounted drop tests were integrated into the evaluation. Due to different delivery schedules from the manufacturers, the physical testing of the titanium (Ti6Al4V) and aluminum (AlSi10Mg) prototypes had to be conducted in separate phases. However, the final test data for the two materials was ultimately compared to distinguish their respective mechanical behaviors and suitability for the required load cases. Finally, the overall manufacturability was assessed by reviewing the necessary post-processing steps and build parameters, leading to a conclusive evaluation based on the balance between structural performance, weight reduction, and practical production feasibility.

4 Results

4.1 Optimized Geometry and Mass Reduction

The iterative optimization process resulted in a new geometry where the mass was significantly reduced compared to the original design.

The most substantial geometric modifications were made in the middle section of the component, between the sight interface and the Picatinny rail connection. Material that did not contribute significantly to the structural load path was removed, creating a narrower, neck-like support structure. However, to ensure functional reliability, the critical interfaces connecting the mount to the sight and to the Picatinny rail remained unchanged. Furthermore, the arm constituting the locking mechanism was also fully retained in its original design. A comparison between the original and the resulting optimized geometry can be seen in **Figure 7**.

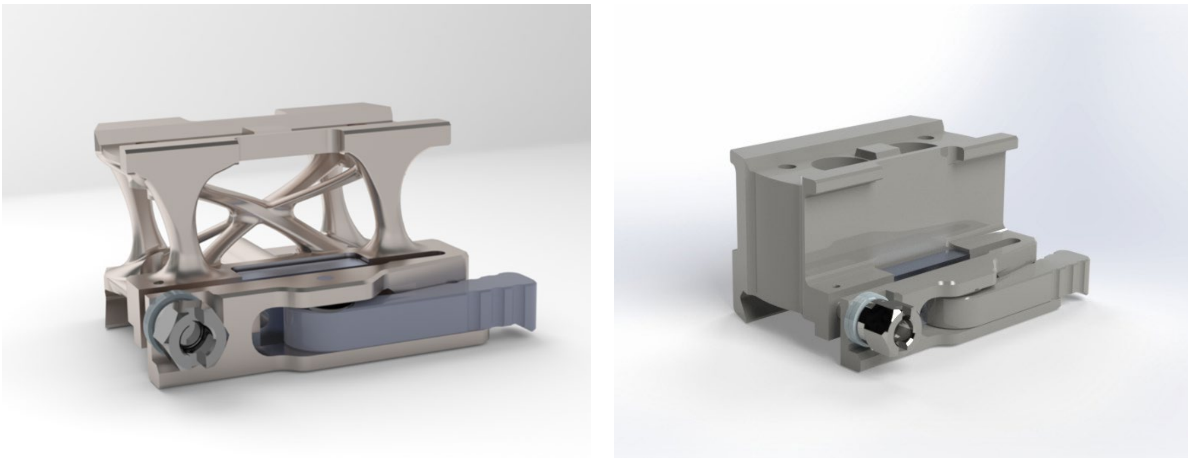


Figure 7: *CAD rendering in SolidWorks comparing the original mount geometry (left) to the optimized design (right). The optimized version illustrates the material removal in the middle section to create a neck-like support structure while preserving the functional mounting interfaces.*

The LPBF manufactured mounts can be seen in **Figure 8** below, for both titanium and aluminum.

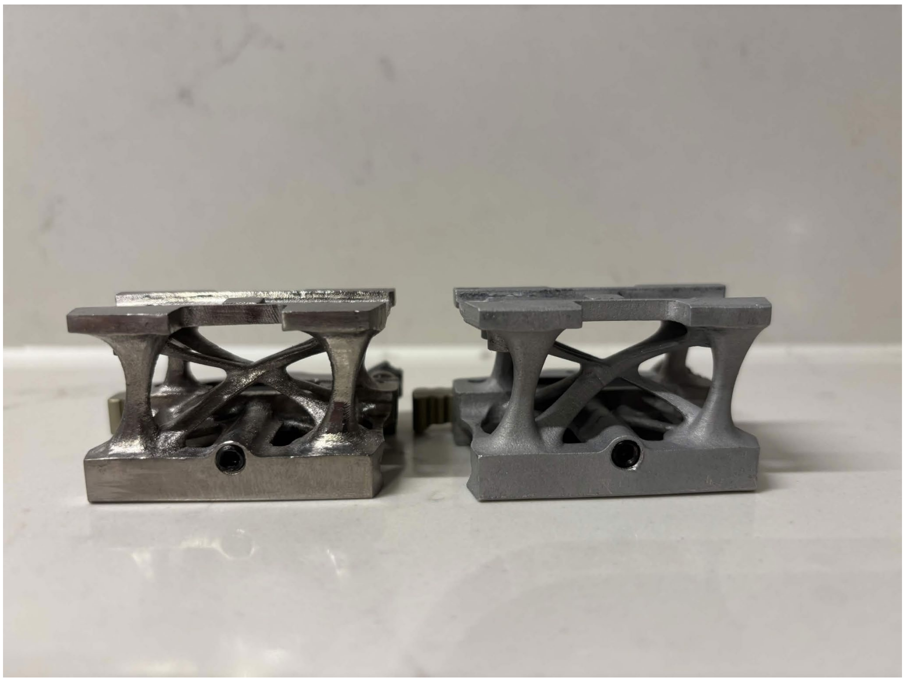


Figure 8: *Real world assembled mounts, left is titanium and right is aluminum.*

By applying the optimized geometry, the mass was reduced for both of the intended manufacturing materials. The final evaluated weights from SolidWorks can be found in **Table 2.**

Table 2*: Final weight of the different mounts with comparison to the original.*

Weight of the different mounts		
Versions:	**Weight:**	**Reduction amount**
Original Design	70,43g	-
Optimized Design in Aluminium	34,21g	51,40%
Optimized Design in Titan	56,8g	19,40%

4.2 Computational Simulation Results

To evaluate the structural integrity of the optimized designs, FEA was performed in Abaqus. The recoil load case was simulated to observe the stress distribution and displacement for the original design as well as the aluminum and titanium versions of the optimized mount.

4.2.1 Computational Simulation Results

Across all simulations, the absolute highest stress concentrations consistently occurred around the screw holes. This was an expected result caused by the simulated clamping forces from the screws. The results can be shown in **Figure 9,10,11.**

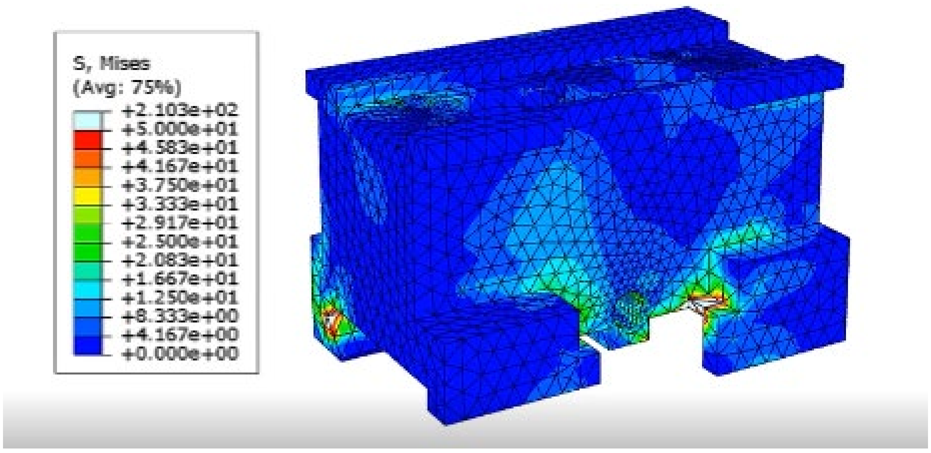


Figure 9: *Von mises stress distribution for the original mount with Al. EN7075-T6*

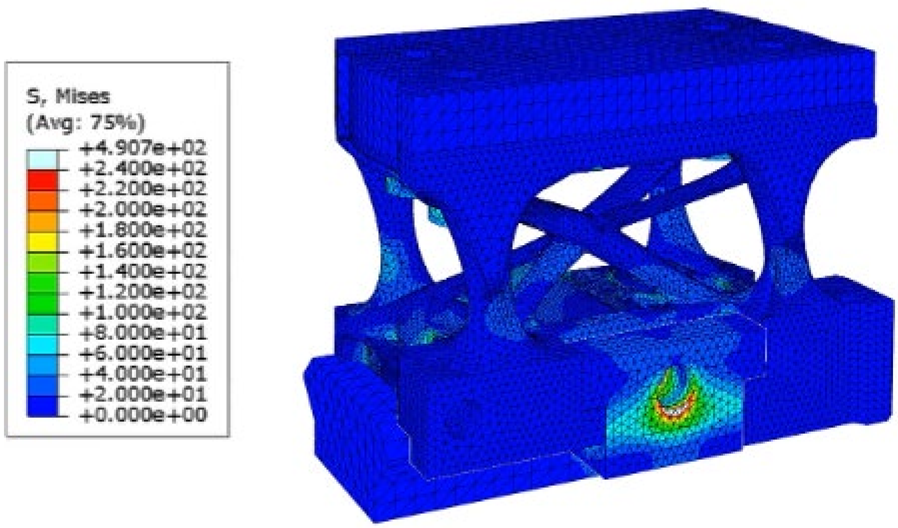


Figure 10: *Von mises stress distribution for the optimized version with AlSi10Mg*

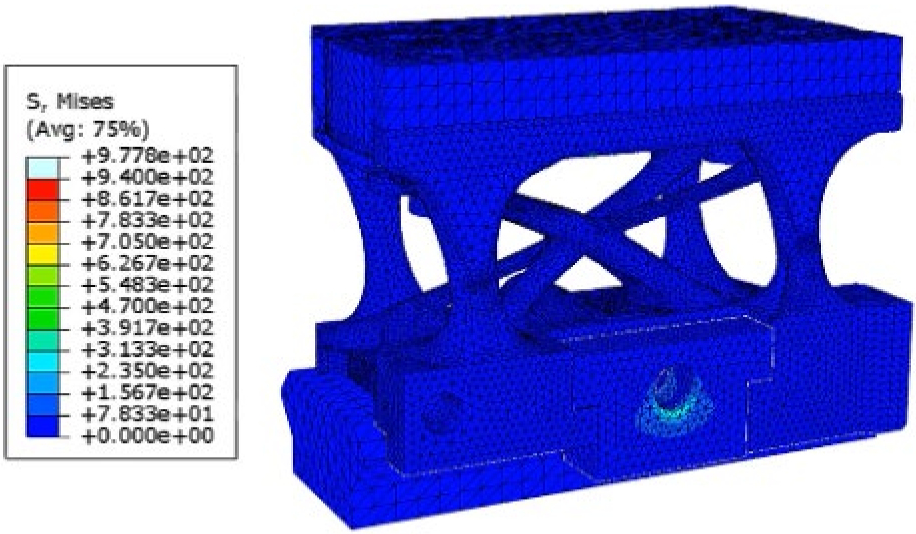


Figure 11: *Von mises stress distribution for the optimized version with Ti6Al4V*

To specifically evaluate the structural impact of the weight reduction in the middle section, measurement nodes were placed in the "legs" (the newly formed neck-like support structure). These nodes can be seen as the red dots in **Figure 12** below. The graphs below illustrate the stress measured at these points to allow for a direct comparison between the materials.

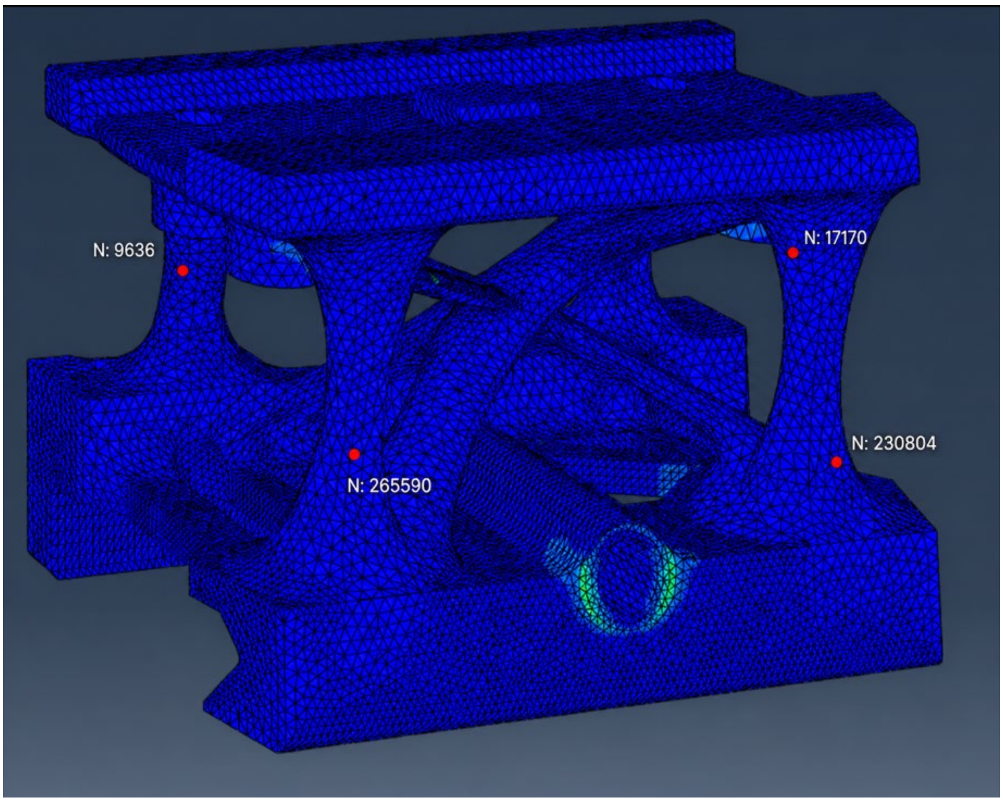
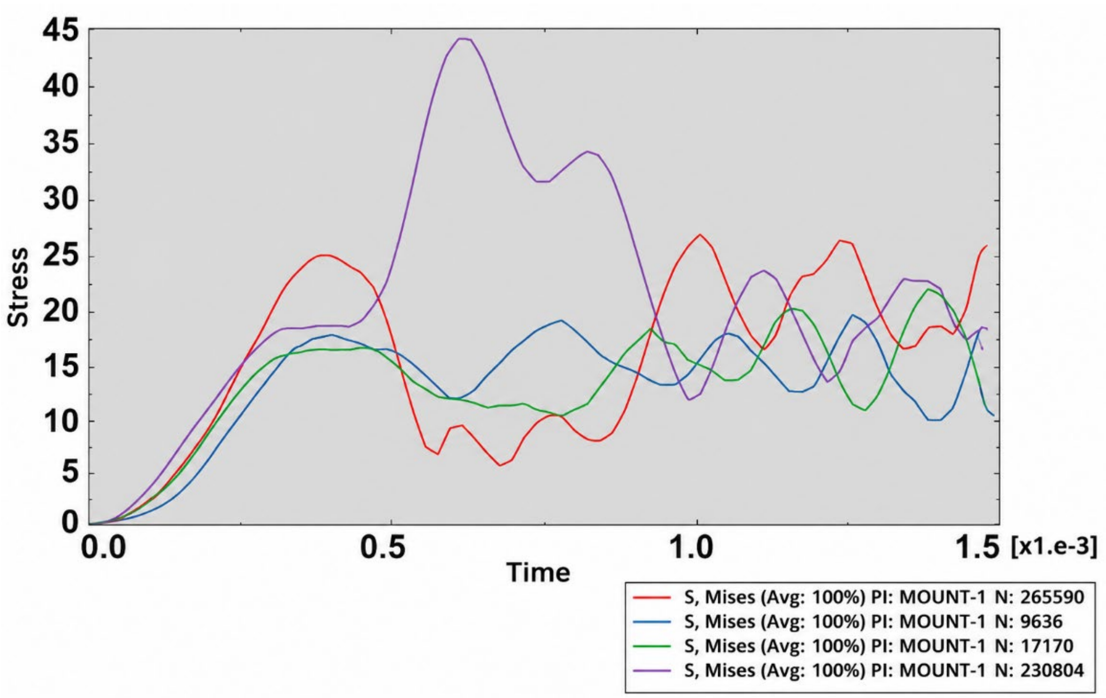


Figure 12: *The red dots are showing the selected analyzed nodes from the legs.*



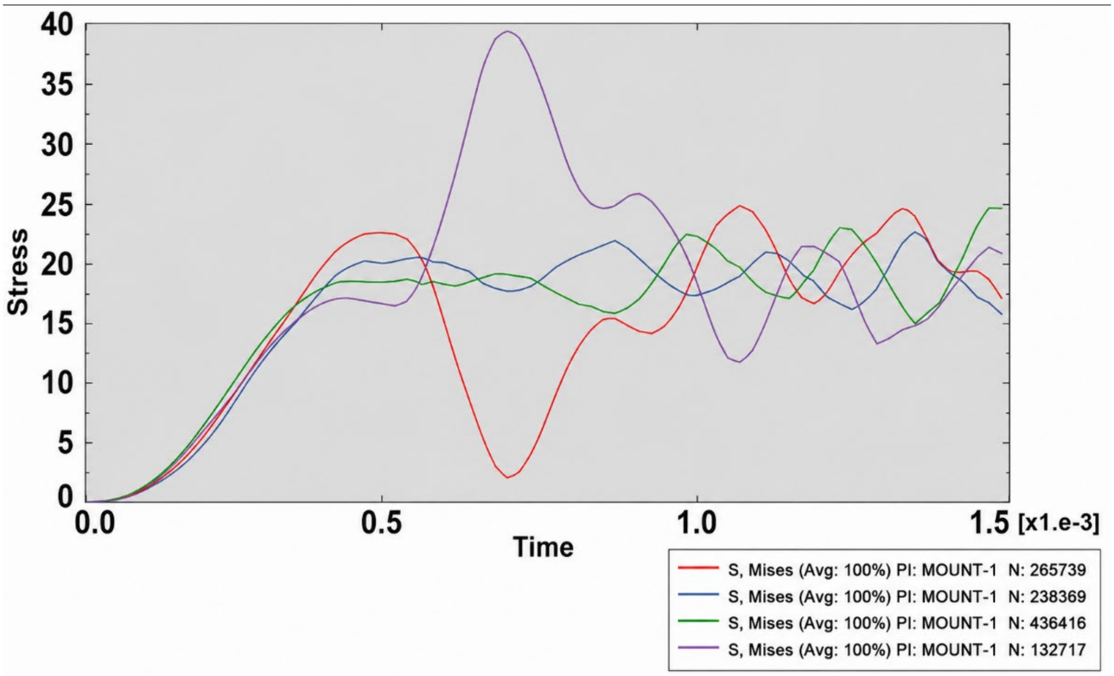


Figure 13: *Simulated Von Mises stress over time measured in the support legs of the optimized aluminum mount (top) and titanium mount (bottom).*

For the optimized aluminum mount, the Von Mises stress in the measured support legs reached approximately 45 MPa. This is safely below the yield limit of 240 MPa for the chosen aluminum alloy (AlSi10Mg), meaning the material handles the recoil elastically.

For the optimized titanium mount (Ti6Al4V), the stress in the exact same measurement points as for aluminum peaked at approximately 40 MPa. This lower stress value is a result of titanium's greater stiffness, which alters how forces are distributed through the geometry. However, since the yield limit for the titanium alloy is approximately 1000 MPa, the mount operates with a substantial safety margin.

4.2.2 Displacement

In addition to stress, the displacement at the top and bottom plates of the mount was evaluated to ensure the functional stability of the sight.

For the optimized aluminum version, the maximum displacement at the top plate was recorded at approximately 0.055 mm. The bottom plate showed minimal displacement, confirming that the base of the mount remained securely attached. The relative movement of 0.055 mm at the top plate was deemed acceptable and not expected to severely impact the sight's alignment.

For the optimized titanium version, the simulated displacement was negligible, with values approaching zero. The higher elastic modulus of titanium provided superior stiffness, resulting in a practically rigid response under the simulated load case. Graph is shown in **Figure 14**.

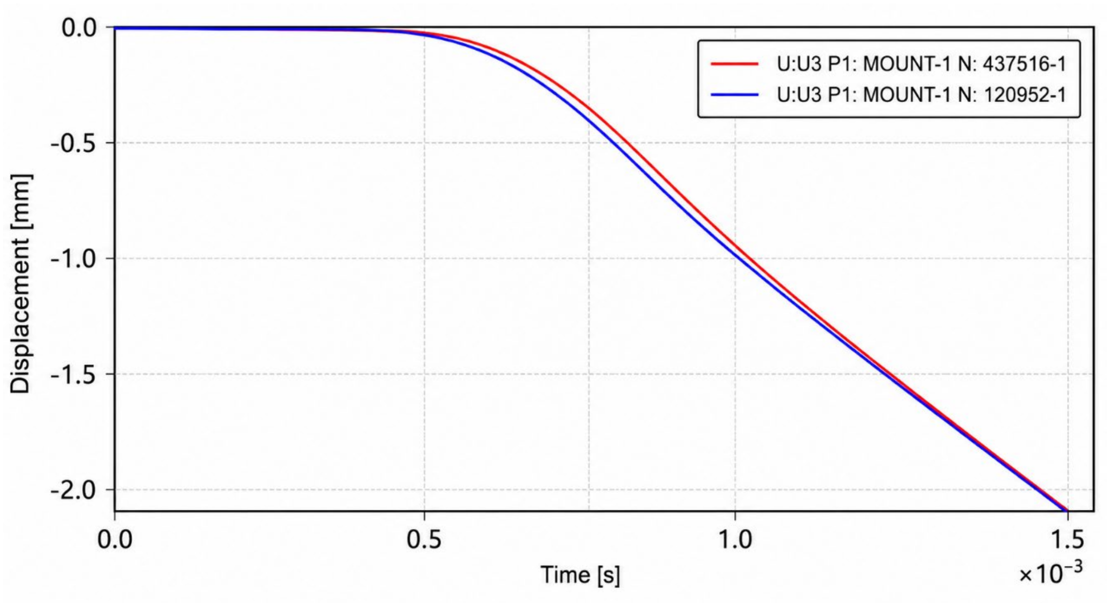


Figure 14: *Simulated displacement over time for the optimized aluminum mount. The red curve represents the displacement at the top plate, while the blue curve represents the bottom plate.*

4.3 Physical Testing Results

Physical testing of both titanium and aluminium mount were conducted and the result is presented in this chapter.

4.3.1 Titanium Mount

The titanium mounts were the first prototypes to be tested according to the validation plan. Two samples were tested and evaluated using both the mechanical shock test and the mounted drop test. The results from the tests are shown in **Table 3** and **Table 4.**

Before the mechanical tests, both samples passed the visual inspection. After the shock test, some chipping of the LRP arm was observed, but no critical failure was found. After the drop test, the samples were inspected again and were classified as passed.

During the mechanical shock test, sample 1 showed a total red dot movement of 1.56 MOA after 10 000 shocks. Sample 2 showed a larger total of movement of 5.02 MOA, which is slightly above the set acceptance limit. However, this value should be interpreted with some caution. Sample 2 did not have a Nordlock lock washer under the locking nut, and during the test the locking nut unscrewed itself. This caused the mount to become loose on the rail, which most likely affected the measured red dot movement.

For the mounted drop test, both titanium samples stayed within the required limit. Sample 1 showed a total movement of 1.35 MOA after the full drop sequence, while sample 2 showed a total movement of 1.48 MOA. This indicates that the titanium mounts kept their functional alignment after being dropped from different directions.

Overall, the titanium mount were considered to have passed the validation tests. Even though sample 2 showed a slightly higher movement during the mechanical shock test, this was linked to the missing lock washer rather than a clear failure of the optimized mount geometry. The results therefore indicate that the titanium version of the optimized mount can handle both repeated shock loading and mounted drop loading without losing its main function.

The total MOA shown in the tables below is calculated as the vector sum of the measured horizontal and vertical reticle displacement, which gives an overall value for the change in red dot position after testing.

Table 3: *Drop test results in MOA after predetermined amount of iterations.*

Sample	Comparison of red dot position [MOA]		
	5 drops	26 drops	Total
1	0,41	1,48	1,35
2	2,08	2,01	1,48

Table 4: *Mechanical shock test results in MOA after predetermined amount of iterations.*

Sample	Comparison of red dot position [MOA]					
	1	5	100	5 000	10 000	Total
1	0,1	0,62	1,09	2,21	1,18	1,56
2	0,72	0,83	1,18	2,73	3,17	5,02

4.3.2 Aluminium Mount

A total of three optimized aluminum prototypes (Samples 3, 4, and 5) were evaluated. The initial visual inspection indicated no apparent macro-deformation or structural fracture. However, post-test physical measurements revealed approximately 0.1 mm of material wear on the underside of the mount, specifically at the contact interfaces against the Picatinny rail. The damage is shown in **Figure 15**.

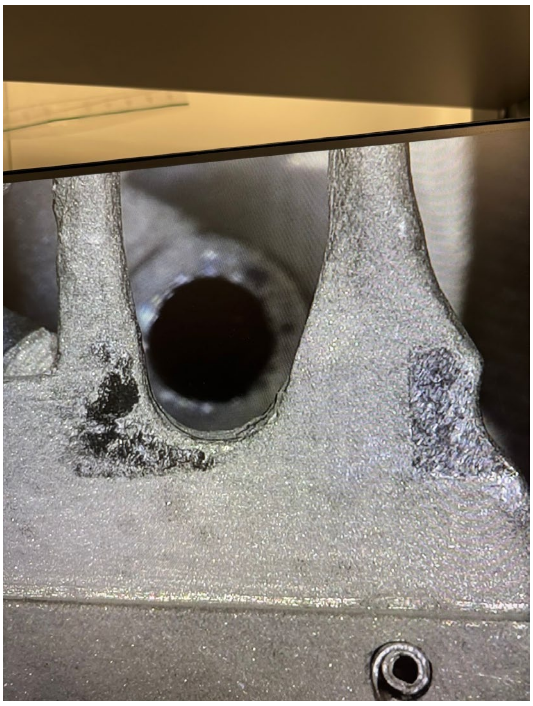


Figure 15: Observed material wear on the contact surface of the aluminum mount after mechanical testing.

The results from the mechanical testing are summarized in **Table 5**. During the mechanical shock test, all aluminum samples exhibited functional instability. Sample 3 experienced an initial reticle shift of 5.25 MOA after 5 shocks, concluding with a final total movement of 1.49 MOA. Sample 4 recorded a substantial deviation of 9.72 MOA after 5,000 shocks, increasing with additional 10.67 MOA at the 10,000-shock mark. This deviation correlates directly with the physical observation that the screws securing the sight had loosened during the dynamic loading, with one screw completely missing. Sample 5 recorded a total movement of 10.89 MOA, this specific sample was however incorrectly mounted in an inverted orientation in the test rig due to human error. By the end of the 10,000-shock cycle, the sight on Sample 5 ceased to function, and the battery compartment spring sustained damage.

The mounted drop test resulted in an immediate functional failure. Sample 3 underwent a single drop before the test was aborted, registering a severe reticle movement of 12.78 MOA. Consequently, the aluminum prototypes were deemed to have failed the acceptance criteria for functional alignment.

Table 5: *Measured reticle movement (MOA) for the aluminum mount prototypes during the mechanical shock and mounted drop tests.*

Sample	Comparison of red dot position [MOA]					
	1	5	100	5k	10k	Total
3	1,08	5,25	2,94	3,07	2,28	1,49
4	1,98	3,78	4,06	9,72	10,67	2,34
5	3,50	3,20	1,00	6,39	-	10,89

4.4 Manufacturing Outcomes

To ensure dimensional accuracy for all threaded and tolerance-sensitive features, the CAD models for all printed prototypes were prepared with only 1 mm guide holes. This strategy allowed the final hole dimensions to be accurately drilled and threaded post-printing, bypassing potential issues with hole resolution inherent to the LPBF process.

4.4.1 Titanium Mounts

The titanium prototypes (Ti6Al4V) were manufactured in-house at Chalmers University of Technology and were produced in two distinct iterations to evaluate and optimize the build process.

The first iteration consisted of three mounts printed with a layer thickness of 80 µm. These parts exhibited high surface roughness and required extensive support structures. As a result, manual filing was necessary to smooth out the functional interfaces connecting to the sight and the Picatinny rail.

The second iteration comprised four mounts printed with a finer layer thickness of 60 µm, which yielded a substantially improved surface finish. The support structure strategy was also altered to evaluate manufacturability: two mounts were printed with reduced supports compared to the first iteration, and the remaining two were printed with minimal supports, anchored only on one side to allow detachment from the build plate. Although the surface quality was finer, the functional interfaces still required manual surface treatment.

To evaluate finishing possibilities, one of the 60 µm prototypes underwent a complete manual grinding and polishing process. The flat surfaces were easily polished to a high finish, but the complex organic structures in the middle neck region proved challenging to access, although a satisfactory aesthetic result was ultimately achieved.

4.4.2 Aluminium Mounts

The three aluminum prototypes (AlSi10Mg) were manufactured by an external supplier. Consequently, the specific LPBF process parameters were not monitored in-house. The components were delivered with a very fine surface finish, strongly indicating that the supplier utilized sandblasting as a post-processing method. Due to the high quality of the delivered surfaces, manual post-processing was minimal and strictly limited to grinding and adjusting the recoil lug located on the top mounting interface.

5 Discussion

5.1 Analysis of Physical Validation

The physical validation highlighted a critical engineering insight where structural survivability in a virtual environment does not automatically guarantee functional success in physical applications. In the FEA simulations, both the optimized aluminum and titanium models demonstrated sufficient structural integrity under the simplified static representations of the recoil load and remained well within their respective elastic regions. However the experimental testing revealed a substantial divergence in functional performance between the two AM materials.

5.1.1 Titanium Mount Evaluation

The physical validation confirmed that the optimized mounts printed in titanium could withstand the mechanical shock test and the mounted drop test without critical failure. Sample 1 maintained exceptional alignment with a 1.35 MOA total shift which is well within the set acceptance criterion. The 5.02 MOA deviation recorded for Sample 2 must be critically evaluated as an assembly failure rather than a geometric deficiency. Due to a missing Nordlock washer the locking nut unscrewed itself under dynamic loading. This indicates that while the optimized geometry is fundamentally sound the interface stability remains highly dependent on auxiliary locking features to prevent vibration induced relaxation.

5.1.2 Aluminium Mount Evaluation

The uncoated aluminium prototypes experienced immediate functional failure culminating in a severe 12.78 MOA reticle shift after a single drop. This instability correlates directly with the physical observation of a 0.1 mm material loss on the contact interfaces against the Picatinny rail. Geometric calculations confirm that a 0.1 mm reduction at this interface translates to a theoretical reticle deviation of approximately 7.5 MOA.

The remaining discrepancy of over 5 MOA indicates that the failure mechanism is driven by a combination of compounding factors rather than a single isolated cause. A highly probable sequence is that dynamic impact and high frequency vibration triggered initial screw relaxation causing the securing screws to loosen. Once the initial clamping force was lost the resulting structural play between the mount and the rail subjected the assembly to significantly higher internal G-forces during subsequent impacts. Because printed AlSi10Mg is relatively soft compared to titanium these elevated dynamic forces likely caused localized plastic deformation and accelerated interface wear. Consequently uncoated aluminum appears highly susceptible to this destructive feedback loop of vibration induced screw loosening and subsequent material deformation.

5.1.3 Geometry and Design Optimization Reflections

An important reflection regarding the manual optimization process is that the titanium and aluminum mounts shared the exact same geometry. The titanium prototypes were explicitly manufactured using the aluminum optimized design as a proof of concept, to isolate and compare material behavior and to evaluate the feasibility of LPBF for precision optics components. It is critical to note that even though nominal material data is available, there is always an inherent uncertainty regarding whether these theoretical values align perfectly with reality due to the nature of LPBF processing and simulation limitations.

Because the titanium mount performed exceptionally well and operated with a massive safety margin, the leg structures could undoubtedly be optimized further to reduce mass even more if a separate optimization loop had been conducted. However, to achieve substantial weight reductions beyond this point, future work must look past the leg structures and reevaluate the baseline component itself. The current LRP 39mm spacer contains several integrated features that heavily restrict the optimization space, particularly on the right side of the component which accommodates the quick release locking mechanism. The rapid locking lever system is inherently bulky and contributes significantly to the total weight of the assembly. Replacing this entire moving mechanism with a more permanent, simpler clamping solution, such as a direct screw to clamp cross bolt system, would unlock a major untapped weight saving potential. Furthermore, optimizing a completely bespoke mount designed specifically for lightweight additive manufacturing from scratch, rather than

retrofitting an existing commercial model with fixed height spacers and profile requirements, would allow for an even more aggressive material reduction.
Both mounts can be seen in **Figure 16** below.

Figure 16: *Isometric view of real life assembled mounts, left titanium, right aluminum.*

5.2 Manufacturing Feasibility

The evaluation of the print iterations proved that LPBF cannot be treated as a single step manufacturing process for components requiring strict tolerances. A major geometric bottleneck encountered during manufacturing was the recoil lug and the rail contact surfaces. To mitigate the extreme forces experienced during impact testing, the CAD model was purposely designed with tight, near zero tolerances to eliminate any initial play between the mount and the rail, as any loose fit would result in excessive G forces.

The print iterations clearly demonstrated that manufacturing parameters directly influence the final quality. By optimizing the build orientation and reducing the layer thickness from 80 μm to 60 μm, the process yielded a significantly improved surface finish and minimized the overall need for support structures. However, because the

LPBF process naturally introduces structural swelling, rough surface textures, and weld track beading, the printed dimensions slightly exceeded the nominal CAD values. Furthermore, severe thermal warping caused by residual stresses during the laser melting process led to a visible geometric distortion where the clamping arm warped outwards. This thermal warping made it physically impossible to fit the intended washer on the mount assembly during post processing. Consequently, manual grinding and precision post processing were mandatory to ensure a proper mechanical fit. Knowing that AM processes inherently yield a slight positive tolerance shift and are prone to thermal warping, future designs should compensate directly in the CAD model by introducing pre calculated offsets in critical interface dimensions to streamline production without relying so heavily on manual adjustment. Furthermore, secondary post processing operations like sandblasting and manual grinding remain a necessary bottleneck to achieve acceptable surface qualities. While flat surfaces are easily accessible, the internal cavities of the complex organic leg geometry present a practical challenge for post print cleaning and tool accessibility.

5.3 Methodological Limitations and Overall Success

The original plan for the project was to use automatic topology optimization to reduce the weight of the mount, and Tosca Structure was investigated as a possible tool. However the available workflow was based on an implicit setup, which could not be used directly since the recoil load was treated as a dynamic load in Abaqus. Converting the dynamic recoil to a static load would have given a less realistic representation of the force situation. Because of this, the decision was made to not rely on automatic software tools. Instead, the topology optimization was developed and executed as a manual simulation driven process.

This manual approach required iterative redesign back and forth between SolidWorks and Abaqus, relying heavily on engineering judgement alongside the simulation results to guide the material removal. A primary limitation of this manual topology optimization method is that the resulting geometry might not represent the absolute mathematical optimum. Furthermore, the number of design iterations was limited due to the time constraints of the project and the available simulation capabilities. The computational model also required several simplifications to run efficiently. For instance, the full locking arm was not included and was instead represented by an equivalent clamping force, which means that certain complex mechanical interactions were not fully captured in the FEA.

Despite these methodological limitations, the project achieved its main objectives and demonstrated overall success. The true success of the project lies in proving that AM physically enables this type of complex organic geometry to be manufactured, while unlocking a substantial weight reduction potential that is impossible to achieve with traditional methods. It is important to emphasize that this design is strictly a proof of concept, meant to explore these boundaries, rather than a final production ready construction. The combination of iterative simulations and physical validation successfully proved that a material efficient design can be developed and manufactured without compromising the required mechanical performance of the sight mount.

5.4 Future Work

Based on the findings of this project, several areas are recommended for future investigation to take the optimized sight mount from a working prototype to a fully realized product.

5.4.1 Long Term Durability and Fatigue Testing

The physical validation in this project focused on immediate structural integrity under isolated impacts and repeated shocks. However, to fully guarantee the reliability of the additively manufactured mounts, it is recommended to evaluate their long term fatigue properties. Future testing should subject both the titanium and aluminum versions to extended fatigue cycles to understand how the printed material behaves over years of active use and thousands of stress cycles.

5.4.2 Dynamic Field Testing and Live Firing

While the mechanical shock test and drop test provided valuable baseline data, laboratory environments cannot fully replicate the complex dynamic forces experienced on a real weapon system. Live firing tests are highly recommended as a next step. Testing the mount on actual firearms will evaluate how the assembly handles true recoil impulses, continuous weapon vibrations, and thermal transfer from the barrel, which will also help verify if the loosening of the locking nut remains an issue in a real world scenario.

5.4.3 Investigation of Surface Coatings

To improve the functional and aesthetic properties of the printed mounts, various surface treatments and coatings should be investigated. Implementing a protective surface treatment, such as a hard coat anodizing or plasma electrolytic oxidation, is strictly required if the aluminum design is pursued further. This would form a hard ceramic oxide layer on the soft aluminum surface, effectively mitigating the abrasive wear against the rail and securing the localized interface stability. Reinforcing the screw holes with hardened steel thread inserts would also prevent screw loosening during high frequency vibration without adding noticeable weight.

5.4.4 Market Application and Product positioning

A practical consideration regarding the optimized design is its suitability for different user markets. The topology optimization resulted in an organic structure with complex surfaces and small cavities. While this significantly reduces weight, it makes the mount more difficult to clean and maintain compared to a traditional milled component. In military applications, equipment is exposed to mud and harsh environments, making easy maintenance a strict requirement. Therefore, it is recommended that Aimpoint targets the dynamic sport shooting market with this specific design. In dynamic shooting, reducing the overall weight of the weapon system is a high priority for competitive performance, and environmental exposure is generally less severe.

5.5 Evaluation of Research Questions

RQ1: To what extent can the weight of a traditionally manufactured sight mount be reduced through a simulation-driven design optimization process?

The manual simulation-driven optimization process achieved a maximum theoretical mass reduction of 51.4% for the aluminum configuration and 19.4% for the titanium configuration. Both designs successfully preserved the essential macro-structural integrity and functional mounting interfaces of the original component under simulated recoil forces.

RQ2: How do the optimized additively manufactured designs perform in terms of strength, stiffness, and functional stability compared to the original design?
The optimized titanium design performs exceptionally well, behaving practically rigid and maintaining functional alignment with a total reticle shift of 1.35 MOA, which is well within the set acceptance criterion. Conversely, the uncoated aluminum design exhibits severe functional instability, suffering a 12.78 MOA shift due to localized interface wear and dynamic screw relaxation under impact loading.

RQ3: What geometric and manufacturing constraints must be considered when adapting a sight mount for laser powder bed fusion?
The primary constraints include dimensional swelling, thermal warping, and severe surface roughness, which prevent precision interfaces from being printed directly to final size. Consequently, CAD models must incorporate pre-calculated tolerance offsets to mitigate material expansion, and designs must account for mandatory post-processing bottlenecks such as sandblasting, manual grinding, and thread reinforcing.

RQ4: To what extent is metal additive manufacturing a technically and practically viable alternative for production of weight-optimized sight mounts?
Metal AM is highly viable from a technical standpoint, but it is only practically viable for this application when utilizing titanium. Uncoated aluminum is practically unviable due to structural softness and poor thread retention under dynamic conditions. Furthermore, due to the maintenance and cleaning challenges of the organic leg structures and cavities in harsh environments, this specific design is best positioned for the civilian dynamic sports shooting market rather than military applications.

6 Conclusion

This project has investigated the feasibility of utilizing manual simulation-driven topology optimization and LPBF to design and manufacture a weight-optimized sight mount. Based on the finite element analyses, manufacturing iterations and physical evaluations, the following conclusions can be drawn.

6.1 Viability of Manual Optimization

A simulation-driven manual design process is highly effective for mass reduction. The method successfully achieved a theoretical weight saving of up to 51.4% for the aluminum configuration and 19.4% for the titanium configuration, while maintaining the critical structural integrity under simulated recoil forces.

6.2 Material Performance and Suitability

Titanium is technically and practically viable for additively manufactured sight mounts, exhibiting high functional stability with a total reticle shift of 1.35 MOA, which is well within the set acceptance criterion. Conversely, uncoated aluminum is practically unviable due to localized interface wear and dynamic screw relaxation under impact loading, resulting in immediate functional failure with a 12.78 MOA shift.

6.3 Manufacturing and Post-Processing Constraints

LPBF cannot be treated as a single-step manufacturing process for components requiring strict mechanical tolerances. AM naturally introduces dimensional swelling and severe thermal warping, which requires future CAD designs to incorporate pre-calculated tolerance offsets. Secondary post-processing operations, such as manual grinding and thread reinforcement, remain mandatory bottlenecks.

6.4 Proof of Concept and Market Positioning

The developed design serves as a successful proof of concept, proving that AM physically enables complex, organic and material efficient geometries to be realized.

Due to the cleaning and maintenance challenges associated with the organic leg cavities in harsh environments, this specific design is best positioned for the civilian dynamic sports shooting market rather than military applications.

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