Designing a Nautical Chart Stand

Wilhelm Guarnieri

Degree Thesis

Process- och Materialteknik

2026

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Arcada University of Applied Sciences: Process- och Materialteknik, 2026.

Commissioned by:

Arcada University of Applied Sciences

Abstract:

This thesis focuses on researching and designing a nautical chart stand, as well as stress testing, analyzing vibrations and topology optimizing the nautical chart stand design. The design was made using SolidWorks® CAD- software, and SolidWorks® was also used in stress testing, vibration analyzing and topology optimizing the nautical chart stand. By running the stress test, vibration analysis and topology optimization all in SolidWorks®, clear results were possible to be obtained from the studies. The material used is Polycarbonate (PC) and the manufacturing method is injection moulding. After designing and stress testing, analyzing vibrations (with a vessel typically vibrating at 12,8- 128,6 Hz) and topology optimizing the part the results were clear. The nautical chart stand has a factor of safety of 105, only the first natural frequency might cause some resonance and a weight loss of 28% was possible to achieve thanks to the topology optimization study. Some improvements could be made for the future, mainly reducing weight even more as there is plenty of room to reduce the thickness of some supports in the design, although at the cost of more possible resonance caused by the second natural frequency. A more lightweight design could suit less extreme use better, for example in smaller vessels operated in lakes or near the coastline where waves are smaller. The original robust version is more suitable for extreme offshore usage, being designed to withstand all possible stresses it might experience.

Designande av en sjökortsställning

Detta lärdomsprov fokuserar på att bakgrundsforska och designa en ställning för sjökort, samt att utföra stresstestning, vibrationsanalys och topologioptimering av sjökortsställningens design. Designen skapades med hjälp av CAD-programmet SolidWorks®, som även användes för stresstestningen, vibrationsanalysen och topologioptimeringen av sjökortsställningen. Genom att utföra alla dessa analyser i SolidWorks® kunde tydliga resultat erhållas från studierna. Materialet som användes är polykarbonat (PC) och tillverkningsmetoden är formsprutning. Efter designande, stresstestning, vibrationsanalys (en båt vibrerar typiskt mellan 12,8- 128,6 Hz) och topologioptimering var resultaten tydliga. Sjökortsställningen har en säkerhetsfaktor på 105, endast den första egenfrekvensen kan orsaka möjlig resonans, och en viktminskning på 28 % kunde uppnås tack vare topologioptimeringsstudien. Vissa förbättringar kunde göras i framtiden, främst för att minska vikten ytterligare, då det finns gott om utrymme att minska tjockleken på vissa stöd i designen, även om det skulle kunna leda till ökad resonans på grund av den andra egenfrekvensen. En lättare design skulle kunna passa bättre för mindre extrem användning, till exempel i mindre båtar som används i sjöar eller nära kusten där vågorna är mindre. Den ursprungliga robusta versionen är mer lämplig för extrem användning till havs, då den är konstruerad för att klara alla påfrestningar som kan uppstå.

Keywords:

Nautical Chart Stand; SolidWorks®; Stress testing; Design

Contents

1 Introduction

1.1 Background

When operating a recreational vessel in rough seas navigation is of upmost importance, and this is done using two methods. One can choose between using chart-plotters or nautical charts. A chart-plotter is a screen with GPS that provides the operator of the vessel with its location, direction, surroundings and speed (Mellema, V, 2021). However, one should not blindly trust the chart-plotter, as they can show false information or fail all together. This is why nautical charts are still relevant today. A nautical chart is a chart showing the configuration of the seafloor and shoreline, as well as dangerous areas and aid to navigation (NOAA, 2024). These charts are made from paper and often fly or glide around when the vessel is rolling or shaking from interacting with the waves. If the nautical chart falls on the floor while navigating in tight passages or in areas with shallow waters, it might leave the operator of a vessel disorientated or unfocused if he needs to reach down to pick them up at the same time while operating the vessel, possibly leading to grounding of the vessel or other accidents. Additionally, having to find the right page of the nautical chart and again find one's position on the chart after picking it up takes some time and might result in the same results of an increased risk of accidents. This is why it is important to find a solution in the form of a naval chart stand, prohibiting the charts from flying or gliding around.

1.2 Objective

The objective of this thesis is to research, design, calculate stresses and come up with a final product design for a nautical chart stand. This can be more directly divided into subsections. These are:

- Design the nautical chart stand
- Calculate maximum stress and determine Factor of Safety for the stand
- Use Topology optimization to reduce weight while keeping structural integrity

1.3 Relevance to Programme

In the studies of Process- och Materialteknik, one gains plenty of knowledge of using CAD software, the ideas of mechanical design, stress testing both physical components as well as using software to calculate stresses and knowledge of mathematics in fields like mechanics of materials. All these skills are utilized in this thesis, which makes the thesis very relevant to the field of studies of Process- och Materialteknik at Arcada Univeristy of Applied Sciences.

1.4 List of symbols

σ = Stress (Pa)

$\sigma 1$ = Compressive stress (Pa)

$\sigma 2$ = Tensile stress (Pa)

τ = Shear stress (Pa)

F = Force (N)

A = Area (m^2)

σvon = Von Mises stress (MPa)

σy = Yield strength (MPa)

M = Moment (Nm)

σ max = Maximum normal stress (MPa)

c = The perpendicular distance from the neutral axis to a point that is the farthest away from the neutral axis (m)

y = Distance (m)

I = Moment of inertia (m^4)

δ = Displacement

N = Internal force (N)

L = Length (m)

E = Modulus of elasticity

τ max = Maximum shear stress in a member (Pa)

t = The width or thickness of a member (m)

$Q = y' A'$ where A' is the area of the top portion of the member's cross section, above where τ is measured, and y' is the distance from the neutral axis to the centroid of A' (m^3)

λ = Wavelength (m)

V = Shear force (N)

2 Literature Review

2.1 Mechanics of Materials

This thesis will require the usage of formulas from mechanics of materials to calculate stresses in the design of the nautical chart stand.

2.1.1 The three principal stresses

When a material is subjected to external force, stress occurs in the material. This stress may lead to failure or deformation, if exerted in too large quantities. The stress experienced by the material can be categorized as compressive stress, tensile stress and shear stress. (stressman.com, 2023). These are the three principal stresses and can be written as:

$$\sigma 1, \sigma 2, \tau$$

Eq. 1

Where:

$$\sigma 1 = Compressive\ stress$$

$$\sigma 2 = Tensile\ stress$$

$$\tau = Shear\ stress$$

2.1.2 Stress

Stress can be defined as force per area and is measured in the Pascals (Pa). Both compressive stress, tensile stress and shear stress all share the same equation. This is:

$$\sigma = \frac{F}{A}$$

Eq. 2

Where:

$$\sigma = Stress\ (Pa)$$

$$F = Force\ (N)$$

$$A = Area\ (m^2)$$

(Boston University, 2025)

2.1.3 Von Mises Stress

Von mises stress is utilized when a material experiences complex loads, as the stress cannot be determined by a single component. The Von Mises stress combines the three principal stresses acting on the material in three directions into one equation. (stressman.com, 2023). It is common to rewrite stress from Pascals (Pa) to Megapascals (MPa) for usage in equations. The formula for Von Mises stress is:

$$\sigma von = \sqrt{\frac{(\sigma 1 - \sigma 2)^2 + (\sigma 2 - \tau)^2 + (\tau - \sigma 1)^2}{2}}$$

Eq. 3

Where:

$\sigma von = Von\ Mises\ stress\ (MPa)$

$\sigma 1 = Compressive\ stress\ (MPa)$

$\sigma 2 = Tensile\ stress\ (MPa)$

$\tau = Shear\ stress\ (MPa)$

(stressman.com, 2023)

The Von Mises stress is very useful in engineering; When the Von Mises stress meets or exceeds the yield strength of the material, the material yields.

$$\sigma von \ \geq \ \sigma\, y$$

Eq. 4

Where:

$\sigma von = Von\ Mises\ stress\ (MPa)$

$\sigma\, y = Yield\ strength\ (MPa)$

(simscale.com, 2023)

2.1.4 Factor of Safety

The factor of safety (FoS) determines how durable components are. The index for Factor of Safety is 1 and upwards, the higher the number the safer the design of a product. If a component has a FoS of 1, it means that as soon as the load on the component is bigger than or equal to the design load, the component will fail. This means that no additional load can be supported by the component. Because of this, the Factor of Safety is always bigger than 1. (Safetyculture content team, 2024).

For example, the FoS value of structural steel work in bridges is 5-7, bolts 8,5, engine components 6-8 and wire ropes 8-9. (Safetyculture content team, 2024). These are all components subjected to high stresses in usage, therefore the high number of FoS. Typical values of FoS for ordinary components or products, not subjected to extreme loads or manufactured from reliable materials range from 1,3 – 4. (Safetyculture content team, 2024).

The factor of safety can be calculated mathematically, depending on the type of material.

FoS for brittle materials:

$$Factor\ of\ Safety = \frac{Ultimate\ stregth\ (MPa)}{Allowable\ stress\ (MPa)}$$

Eq. 5

(testbook.com, 2023)

FoS for ductile materials:

$$Factor\ of\ Safety = \frac{Yield\ strength\ (MPa)}{Allowable\ stress\ (MPa)}$$

Eq. 6

(testbook.com, 2023)

2.1.5 Flexure formula

When calculating the normal stress of bending beams with a rectangular cross- section, the flexure formula can be used. The formula is:

$$M = \frac{\sigma max}{c} \int_{-c}^{+c} y^2 \, b \, dy$$

Eq. 7

Where:

$$M = Moment\ (N \times m)$$

$$\sigma \max = \ The\ maximum\ normal\ stress\ in\ the\ beam\ (MPa)$$

$$c = Perpendicular\ distance\ from\ the\ neutral\ axis\ to\ a\ point\ that\ is\ the\ farthest\ away\ from\ the\ neutral\ axis. This\ is\ where\ \sigma \max acts.\ \ (m)$$

$$y = Distance\ (m)$$

$$F = Force\ (N)$$

$$b = width\ of\ the\ rectangle\ (m)$$

(Hibbeler, R.C, 2023)

When solving for σ max the formula can be rewritten as:

$$\sigma \max = \frac{Mc}{I}$$

Eq. 8

Where:

$$\sigma \max = the\ maximum\ normal\ stress\ in\ the\ beam, (Pa)$$

$$M = Resultant\ internal\ moment\ (N \times m)$$

$$c = Perpendicular\ distance\ from\ the\ neutral\ axis\ to\ a\ point\ that\ is\ the\ farhtest\ away\ from\ the\ neutral\ axis. This\ is\ where \sigma \max acts.\ \ (m)$$

$$I = Moment\ of\ inertia\ of\ the\ cross - sectional\ area\ about\ the\ neutral\ axis\ (m^4)$$

(Hibbeler, R.C, 2023)

σ max / c = - σ / y, and therefore the normal stress at any distance y can be determined from the equation

$$\sigma = \frac{-My}{I}$$

Eq. 9

Where:

$$\sigma = Normal\ stress\ (Pa)$$

$$M = Resultant\ internal\ moment\ (N \times m)$$

$$y = Distance\ (m)$$

$$I = Moment\ of\ inertia\ of\ the\ cross - sectional\ area\ about\ the\ neutral\ axis\ (m^4)$$

(Hibbeler, R.C, 2023)

2.1.6 Axial load

When a bar has a constant force applied, is made of a homogenous material and has a constant cross- sectional area the displacement under load of the bar can be calculated using the formula:

$$\delta = \frac{NL}{AE}$$

Eq. 10

Where:

$$\delta = Displacement\ of\ the\ right\ end\ of\ the\ bar\ relative\ to\ the\ left\ (m)$$

$$N = Internal\ force\ (N)$$

$$L = Original\ legth\ of\ the\ bar\ (m)$$

$$A = Cross - sectional\ area\ (m^2)$$

$$E = Modulus\ of\ elasticity\ (Pa)$$

(Hibbeler, R.C, 2023)

2.1.7 The shear formula

The shear stress at a sectioned straight member can be calculated using the shear formula. This formula is:

$$\tau = \frac{VQ}{It}$$

Eq. 11

Where:

$$\tau = \text{The shear stress in the member located at a distance } y' \text{ from the neutral axis } (Pa)$$

$$V = \text{The shear force } (N)$$

$$I = \text{The moment of inertia of the entire cross} - \text{sectional area calculated about the neutral axis } (m^4)$$

$$t = \text{The width of the member's cross section, measured at point } y' \text{ where } \tau \text{ is to be determined } (m)$$

$$Q = y' A', \text{where } A' \text{ is the area of the top portion of the member's cross} - \text{section, above where } \tau \text{ is measured, and } y' \text{ is the distance from the neutral axis to the centroid of } A' \; (m^3)$$

(Hibbeler, R.C, 2023)

2.2 Vibration Analysis

A vibration analysis is a measurement method that analyses frequencies occurring in machines, components or other assemblies or products. Depending on the analysis method, abnormalities in frequencies or inconsistent vibrations and resonance can be measured. This can be helpful to understand how a part or assembly reacts to vibrations it is exposed to, to prevent fatigue and premature failure. (twi.com, 2025)

For this thesis, the vibrations are not from machinery of a vessel such as its engine, but from the vessel interacting with the waves. The vibrations generated by a smaller vessel's engine are so minimal that they do not play an effect on vibrating the nautical chart stand. However, the vibration of the vessel is caused by interacting with the waves.

The frequency of waves can be calculated using the formula:

$$Wave\ frequency = \frac{2\pi}{\lambda}$$

Eq. 12

Where:

$$\lambda = Wavelength\ (m)$$

(Florida Center for Instructional Technology, 2005)

Using this formula and the regular wavelengths (0,5 – 5 m) that can be observed in Finland, we get a range of frequencies for typical waves to be from approx. 1,25 Hz to 12,5 Hz. Then, multiplying the speed of the vessel over the wave frequency will give the approx. frequency that the boat shakes from interacting with the waves. A typical vessel speed of 20 knots (10,29 m/s) over a wave frequency of 1,25 – 12,5 Hz gives a window of 12,8 Hz – 128,6 Hz as the frequency, in which a vessel will shake when travelling over typical Finnish seas.

2.3 Finite Element Method

Finite element method (FEM) is the method how to calculate finite element analysis (FEA). Finite element analysis is usually conducted on computer software, because of its complexity. Finite element method works by dividing a component into small sections or so- called "finite elements", with the corners of the element being called "nodes". By creating this meshing of finite elements, equations can be derived, and software is able to solve the equations, graphically displaying the results. (Harish. A, 2024)

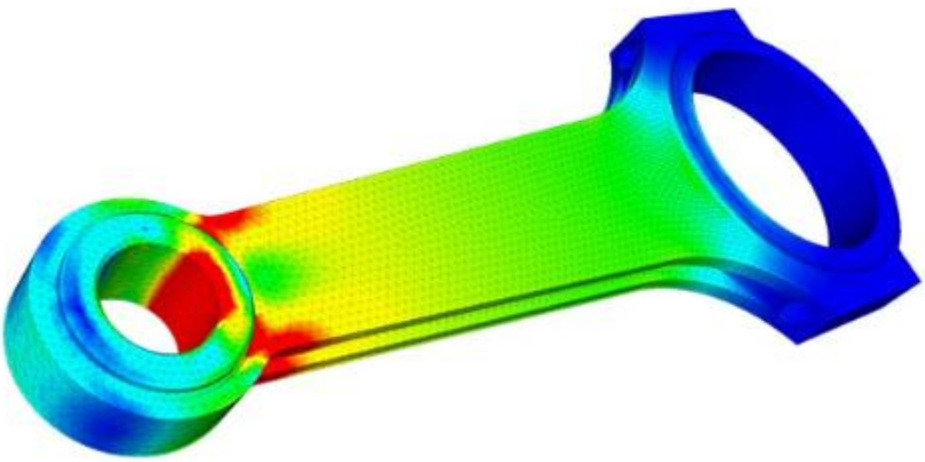

Figure 1. results of finite element analysis on a connecting rod (SimScale, 2024)

As can be seen in fig x. the meshing of the connecting rod into small triangles or finite elements allows for computer software to calculate stresses of the component and graphically display them.

2.4 Product Design

Product design is a complicated process consisting of several different scopes. One can look at product design from many different perspectives, depending on one's involvement with the product. Customers look at user experience and visual design, engineers at designing and its different challenges and retailers look at costs and profit. Combining all these factors into a single product is therefore important, to satisfy everyone with the best results. (Interaction Design Foundation, 2025).

2.4.1 User Experience Design

When designing a product for user experience the process starts long before a finished product is in your hand. It includes everything from the finished product to branding, packaging and purpose. To deliver the best user experience and a good product, all the concerns need to be met. (Interaction Design Foundation, 2025).

A big part of designing for user experience is the product itself. It needs to be visually appealing, easy to use, fun and/or serve its purpose as intended. Since people's emotions can't be controlled, the design needs to be appealing in as many ways as possible. When designing a product for a specific purpose, the designer can control things like weight, ease of use, fitment and visual appearance. By optimizing every criterion for its purpose, solutions can be found that provide good ideas for design and better experience for users. The product also needs to serve a purpose, otherwise nobody would buy it. (Interaction Design Foundation, 2025).

2.4.2 Design For Manufacturing (DFM)

Design for Manufacturing (DFM) is the idea of designing parts or products to be easy to manufacture to lower costs and increase quality. This can be achieved by considering simplicity and optimization in the design process. (East West Manufacturing, 2020)

According to East West Manufacturing, there are five principles in Design for Manufacturing. These are:

- Process
- Design
- Material
- Environment
- Compliance and testing

Process

To find the right manufacturing process for a product you need to consider the costs of different methods, material to be used, complexity of the part as well as required tolerances. The manufacturing process doesn't need to be over the top, that would just end up costing unnecessary money. The manufacturing method should match the criteria for the finished product, both in cost, finish and quality. (East West Manufacturing, 2020).

Design

The design should be suitable for the manufacturing method chosen, so that complex shapes in design don't prove troublesome in manufacturing. The limitations of production machinery need to be kept in mind. For example, a part that has constant thickness of walls, simple transitions from one feature to another and no complex shapes that would hinder a mold from opening are suitable for injection moulding. (East West Manufacturing, 2020).

Material

Material properties need to be considered in the design phase, to ensure strength, desired properties in things like heat resistance and water resistance, as well as color of the material. (East West Manufacturing, 2020).

Environment

When designing a part or product, the strength and properties of the part must be able to endure stresses experienced in the regular usage of the product. (East West Manufacturing, 2020).

Compliance and Testing

A product or part must be up to par with safety standards. This requires testing that can often be done both internally and externally at a company. (East West Manufacturing, 2020).

If possible, these 5 principles should be considered early in the design phase, to properly influence the design. By having a good, well thought out design from the beginning, expensive costs such as late re- designs and re- tooling can be avoided. (East West Manufacturing, 2020).

2.4.3 Design for Repair

When designing a part or product, the lifetime of the product needs to be considered. When aiming for a durable and repairable design, the following things are important:

- Choosing the right material, so it withstands the wear of usage and more
- Simple design, if a product consists of multiple parts make them easily replaceable
- Using common standards for things like connectors, thread sizes and bolts
- Ease of access to parts that need maintenance
- Providing customers with repair manuals
- Avoiding permanently mounting parts such as gluing them
- Simple design, with things like screws exposed and not hard to reach

By implementing these thoughts in the design of a product or part, the product can be easily repaired, maintained and more durable. (medium.com, 2024)

2.4.4 Design to Cost (DTC)

Design to cost is the process of designing and manufacturing a part or product to a cost target without compromising quality and finish. This is done early in the design process, consider costs and make sure all processes do not exceed the cost cap. When considering the costs already in the design, the design can be tweaked to simplify the product, lower production costs and use less material. This design, however, cannot weaken the functionality or quality of the product, and therefore a balance must be found. (4cost.de, 2025).

For the entire production cycle of a product or part, all departments must collaborate to optimize the entire process and agree on where to cut costs. By having all departments from research and development (R&D), manufacturing, quality control (QC) and sales work together possible solutions from new angles can be found. (4cost.de, 2025).

By implementing the thoughts of design to cost several benefits can be seen. Reduction in material used, competitive pricing improving customer satisfaction as well as a well-optimized production process are all results that can be achieved through design to cost. (4cost.de, 2025).

2.5 Statistics on Boating

This section is focused on statistics of boating in Finland, providing the reader with a background and understanding to the boating culture, types of boats and information about navigating, including nautical charts.

2.5.1 Amounts of boats in usage

The number of boats currently in use in Finland is estimated to be around 1,7 million in 2025. This is an increase from 1,2 million in 2016 (Traficom, 2024). When considering that the population of Finland was 5,603,851 people on Dec. 31st, 2023 (Statistics Finland, 2024). This means there is one boat per approx. every 3,3 people at the moment. This is a quite large number and clearly shows that boating is popular in Finland. As there are this many boats, it is important that all boats have the proper means of navigating, to ensure the safety of everyone.

2.5.2 The average Finnish boat

The average Finnish boat is 4,6m long and 19,8 years old, equipped with a 15-year-old 35hp outboard engine and is used for 27 days during summer (Traficom, 2024). This size of boat is quite small, and not suitable for usage offshore or in rough weathers but is more often used in lakes or near the shoreline, where waters often are shallow and complex to navigate, see figure. 2. Due to their small size, these boats shake a lot even from small waves and are often not equipped with chart-plotters. If one would want to venture out of familiar waters with a small boat like this, nautical charts would be a good idea for navigating safely. Here, the need for a nautical chart stand can be identified.

Figure 2. 4,45m long boat with 15hp outboard (paro.fi, 2025)

2.5.3 Nautical Charts

Nautical charts are 470 mm wide, 345 mm high and about 10 mm thick, made from paper with plastic covers. The charts weigh approx. 700 grams, so they are not very heavy. To make a stand that holds them in place, a snug fitment is needed. Therefore, proper tolerance of the design is required.

Figure 3. Nautical chart (Wilhelm Guarnieri, 2025)

2.5.4 Larger Vessels

As mentioned in the previous paragraphs, there is a need for nautical chart stands in smaller boats, as they jump much even in what would otherwise be considered calm seas and therefore often result in naval charts flying or gliding around. The need, however, is not limited to small boats. Larger recreational vessels, typically between 25- 50 feet (7,6m – 15,2m) in length are often used in rougher seas, as they are capable of handling the larger waves safely. However big, they still shake and roll with the waves a lot. Here the same need for a nautical chart stand can be identified, as one always needs to have the nautical charts despite these larger vessels almost always being equipped with chart-plotters, due to reliability and safety concerns. See Figure. 4 for reference of one of the larger boat-types manufactured in Finland.

Figure 4. Targa 32, a 32-feet long motorboat manufactured in Finland. (targa.com, 2025)

2.6 Material Choice

2.6.1 Required Characteristics for Material

The ideal material for this purpose is lightweight, flexible, strong and water resistant. Many plastics possess these characteristics, and therefore a plastic is a good material choice. Another consideration for the choice of material is its suitability for different manufacturing processes. For this case, injection moulding would be the preferred method. Therefore, the material must be both waterproof, strong and flexible, as well as suitable for injection moulding.

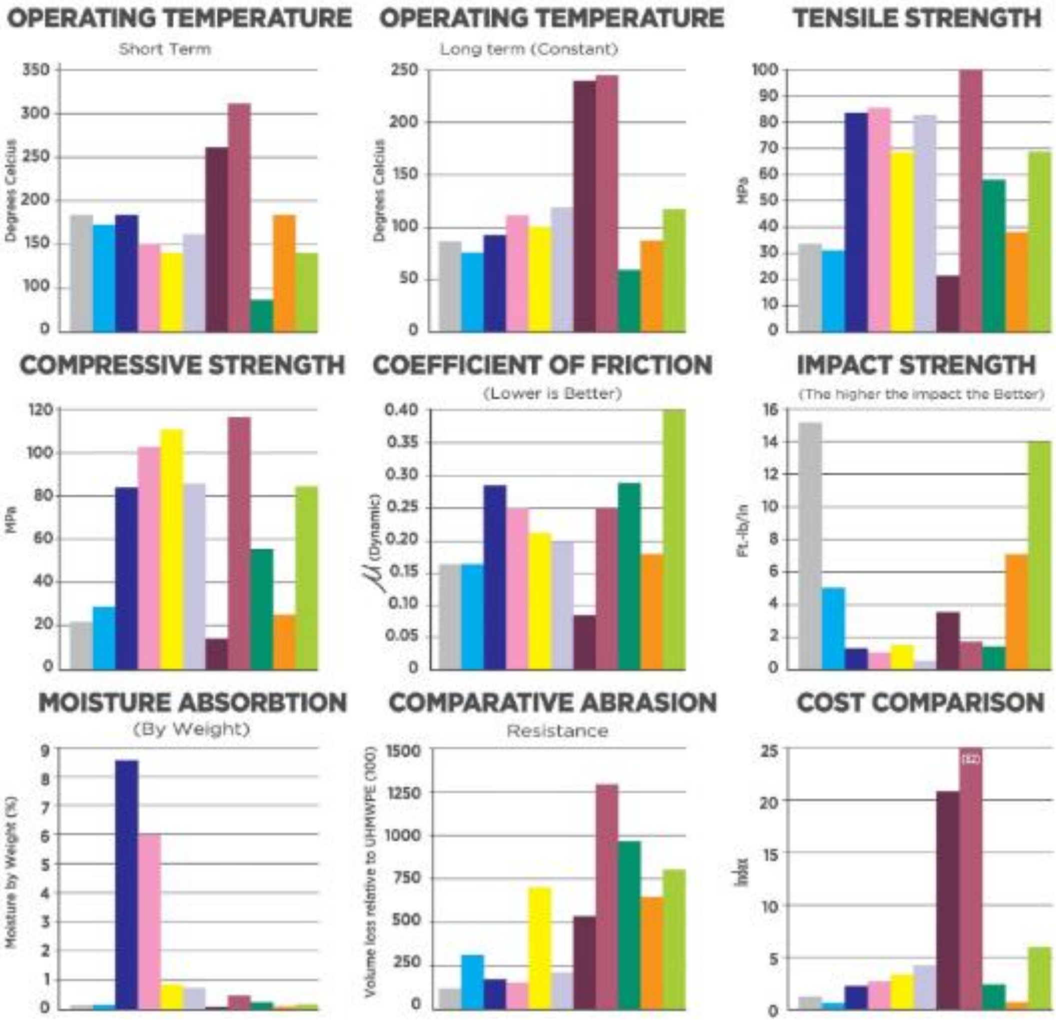

Figure 5. Table showing material properties of common plastics (gteek.com, 2025)

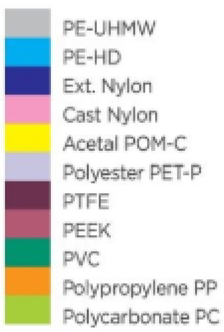

Figure 6. colours corresponding to plastics in fig 5 (gteek.com, 2025)

2.6.2 Polycarbonate (PC)

When studying figure 5. Polycarbonate (PC) can be identified as a suitable material for the nautical chart stand. It presents excellent tensile, compressive and impact strength, has minimal moisture absorption and is still cheap to produce. Polycarbonate would be a good material for the nautical chart stand. Additionally, Polycarbonate is transparent, making for a pleasing visual experience and minimalistic look, things to keep in mind when designing a product. See figure 7.

Figure 7. Sheets of Polycarbonate (wallisplastic.com, 2025)

2.7 Manufacturing Method

For consistency, good finish and rapid production injection moulding is a suitable manufacturing method. This method would be optimal to produce high- quality products. Another possible manufacturing method would be 3D- printing, but for this application injection moulding is more suitable. The manufacturing itself is beyond the scope of this thesis, this is just finding a theoretical manufacturing process that would work for the product.

2.7.1 Injection Moulding

Injection moulding is a manufacturing method commonly used to manufacture plastic components. An injection moulding machine work by getting plastic pellets from a hopper into a cylindrical barrel with a turning screw. The screw presses the plastic pellets forward in the barrel, and the barrel is heated to melt the plastic pellets. At the end of the barrel is a nozzle feeding the molten plastic into the mould. (Essentra Componets, 2023)

The mould consists of two halves, clamped together for injection and released for the part to be removed. Once the molten plastic has reached the end of the barrel, the mould clamps shut and is connected to the barrel by the nozzle. When enough pressure has built up at the nozzle it opens, forcing the molten plastic into the mould, and then closes. The mould remains clamped down for some time (from milliseconds to minutes depending on material) for the material to form properly and cool down. (Essentra Components, 2023)

After this, the mould opens, and an ejector ejects the part from the mold halves. After this, the part is finished. Depending on component, additional polishing or post- processing might be required. (Essentra Components, 2023)

2.7.2 Polycarbonate and Injection Moulding

Injection moulding requires the material used to be suitable for the manufacturing method to work. Polycarbonate is not only strong, lightweight and waterproof but also one of the most commonly used materials for injection moulding (Essentra Components, 2023). This makes the material choice of Polycarbonate and the manufacturing process of injection moulding an excellent combination.

2.8 Computer Aided Design (CAD)

Computer Aided Design (CAD) is the usage of computer software to design objects in 2D and 3D spaces. From this point onward in the text, Computer Aided Design will be referred to as “CAD”. By using CAD software real products, parts and assemblies can be designed and developed without the need for a physical prototype. Additionally, CAD software may be able to perform stress calculations, optimizations and manufacturing simulations, to help find areas of weakness and help improve design before manufacturing of a product or part begins. By doing the designing on a computer instead of on paper as previously, designs can be changed rapidly without the need to totally re- design everything.

2.8.1 SolidWorks®

The nautical chart stand is designed using SolidWorks® Computer Aided Design (CAD) software.

SolidWorks® is a CAD- software developed by Dassault Systèmes, a French multinational corporation. SolidWorks® is used for product design, development, simulations, stress testing and modeling. (Solidworks.com, 2025). The choice to use SolidWorks® for designing and optimizing of the nautical chart stand is due to the program’s excellent features like topology optimization, stress analyses and possibility to design complex parts and assemblies easily. The program is easy and quick to use, offering the possibilities of rapid prototyping, fast re-designs and endless design opportunities. Additionally, Arcada University of Applied Sciences offers student licenses to SolidWorks® for its students, making an otherwise very expensive program available for use.

2.8.2 SolidWorks® Topology Optimization and Stress Testing

SolidWorks® also contain features like topology optimization and stress testing, allowing for stress analyses and topology optimizations to be carried out by the software. (Solidworks.com, 2025). These features drastically help in the designing process, by giving smart and fast ways to analyze stresses and shapes while designing a part or product, helping to find weak spots and smarter design ideas.

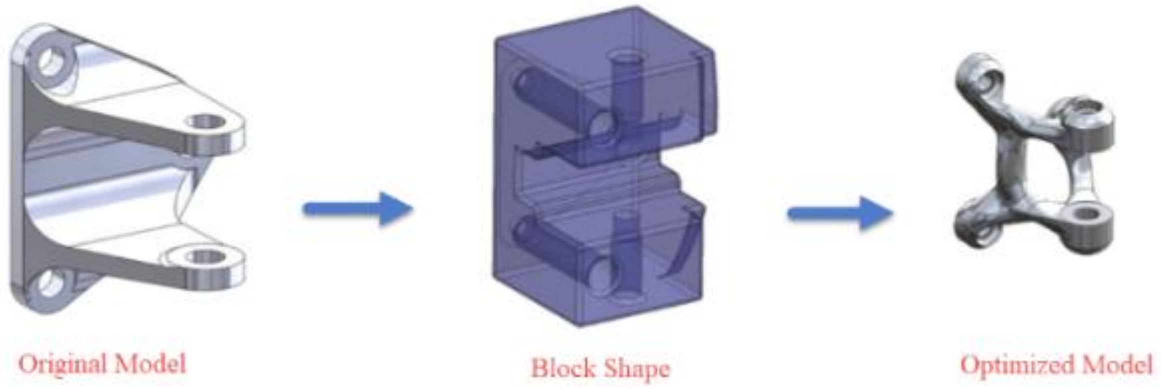

Figure 8. Example of topology optimized part in SolidWorks® (Sithambaram, S, 2018)

3 Method

3.1 Design

The design of the nautical chart stand was made using SolidWorks® CAD- software. The design has a focus on simplicity, robustness and user- friendliness. The stand is composed of a single piece, to make manufacturing easier and remove unnecessary bolts and fixtures that could rattle loose in usage. The stand has thick supports from the bottom, ensuring resistance to vibration and extreme durability, and is angled towards the user to make reading the nautical charts easier.

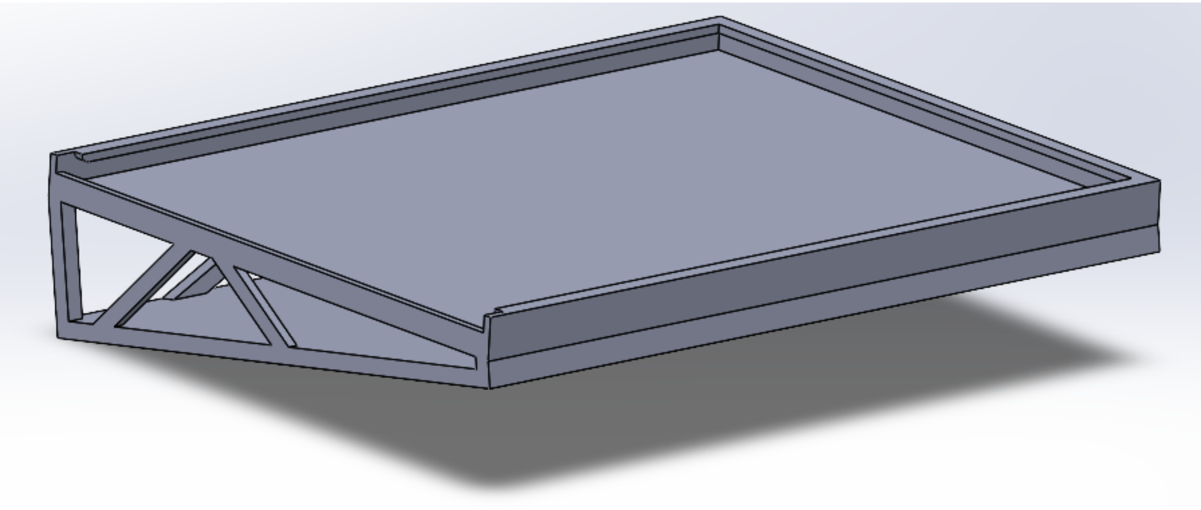

Figure 9. The first design of the nautical chart stand (Wilhelm Guarnieri, 2025)

The supports from the bottom are on three sides, as in the front the “bed” of the stand mates with the bottom. These supports are designed to be durable and save a lot of weight yet look sleek and do not compromise aesthetics.

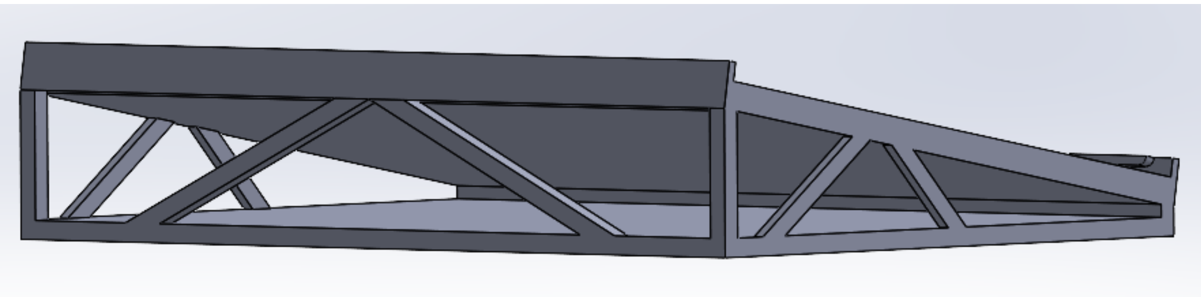

Figure 10. The supports from the bottom clearly shown from the rear-left side (Wilhelm Guarnieri, 2025)

3.2 SolidWorks® Topology Optimization

To conduct a Topology optimization, first the maximum force the nautical charts can exert on the stand is to be determined. This can be done by using the formula:

$$Impact\ force = \frac{mass \times gravity \times fall\ height}{distance\ travelled\ after\ impact}$$

Eq. 13

(Johnson, L, 2022)

For this study, fall height will be given as 5 m, as this is the largest wave height recorded outside Helsinki, during a storm in 2001 (ilmatieteenlaitos.fi, 2024). This is extreme as normally waves do not reach these kinds of heights, but the stand is designed to withstand them anyways. Distance travelled after impact will be given as 0 m, since the stand can't buckle under the load.

Using these values the impact force can be calculated to be 34,3 Newtons. The stand must endure at least double that, so the topology optimization will be conducted with 70 N as the force.

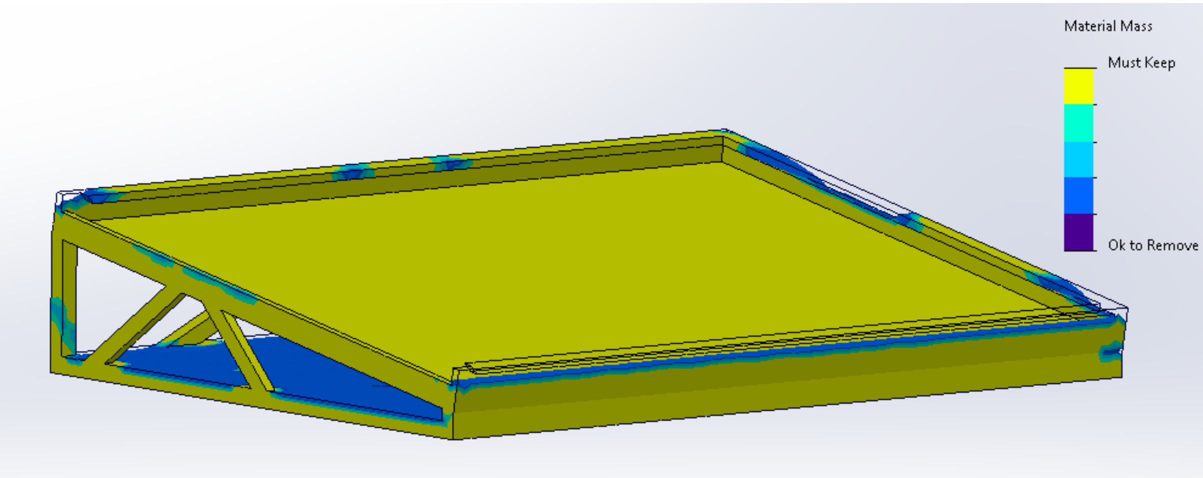

Figure 11. Topology study of nautical chart, target 30% weight removal (Wilhelm Guarnieri, 2025)

From figure 11 it can be noted that the largest amounts of material that can be removed is located at the bottom of the nautical stand.

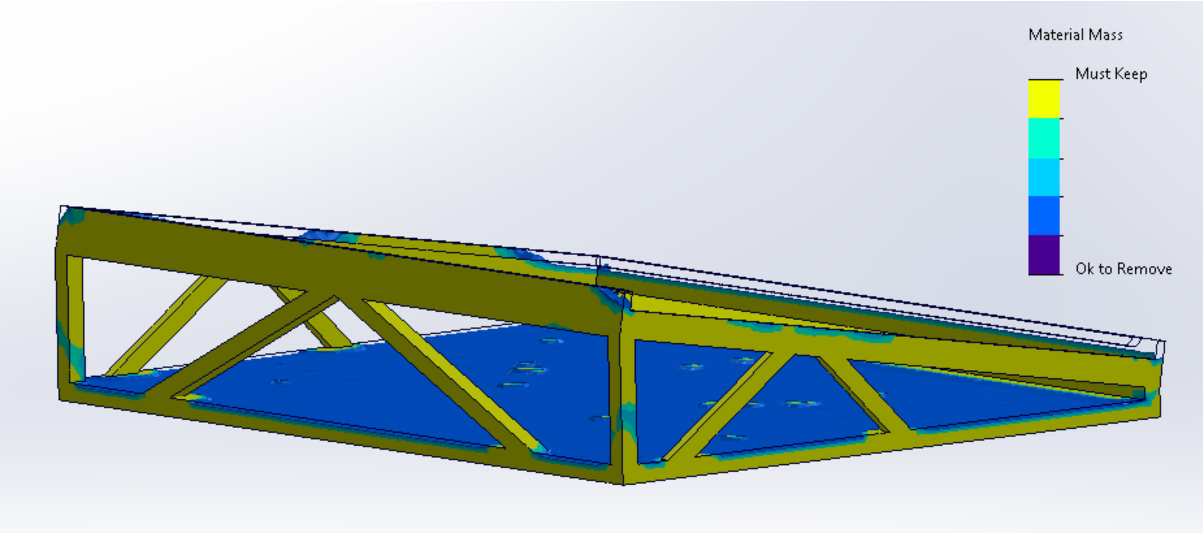

Figure 12. The Topology study from behind, showing blue where material can be removed. (Wilhelm Guarnieri, 2025)

As can be more clearly seen in figure 12, the most eligible material for removal is on the bottom of the stand. The topology study provides valuable information, as now the design can be manually re-done to remove material from the bottom section in a neater way.

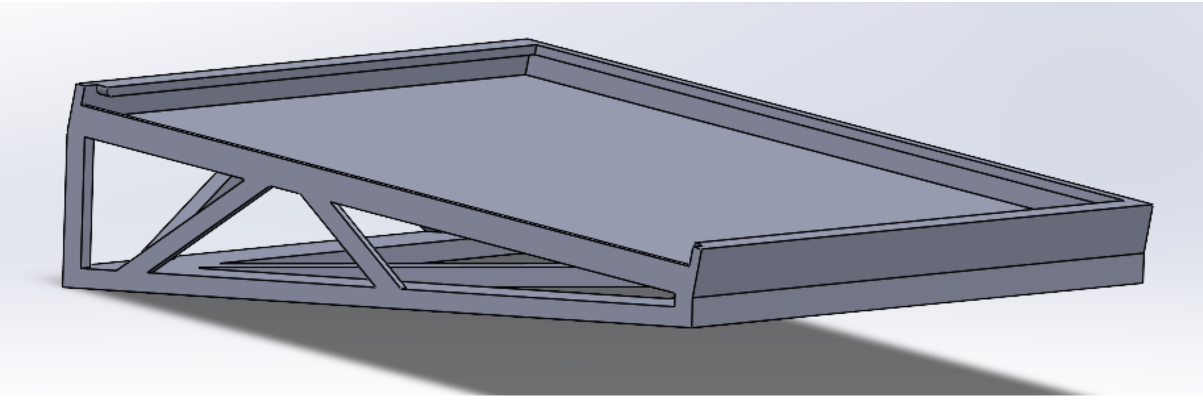

Figure 13. Design tweaked for weight reduction at the bottom part of the stand (Wilhelm Guarnieri, 2025)

This is the final design of the nautical chart stand, where material has been neatly removed from the bottom part of the stand as the topology optimization suggested. This can more clearly be seen in figure 14, where the bottom part now has two large reliefs while maintaining structural integrity due to the beam going across the bottom. This gives the part a weight reduction of about 28%, from 3366 g to 2419 g.

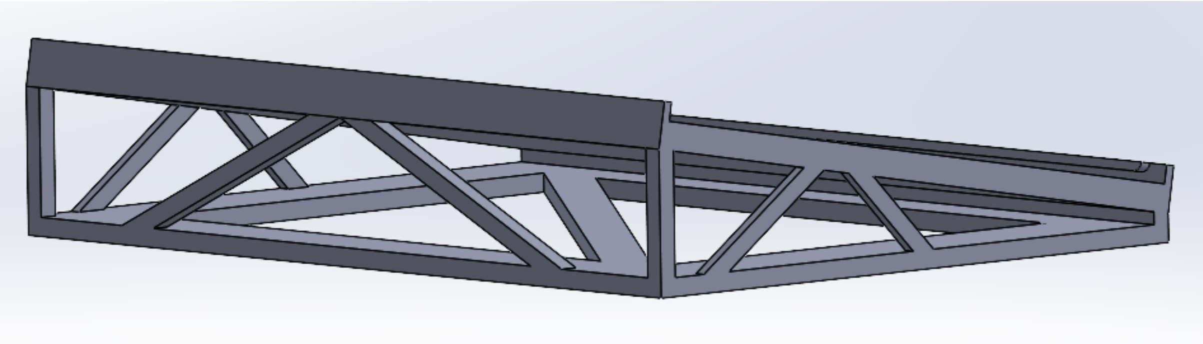

Figure 14. The design of the nautical chart stand clearly showing the reliefs in the bottom (Wilhelm Guarnieri, 2025)

3.3 Stress testing

To calculate stresses in the nautical chart, stand and verify its structural integrity the SolidWorks® Simulation can be utilized to find the maximum Von Mises stress in the stand. Again, the force acting on the stand is 70 N.

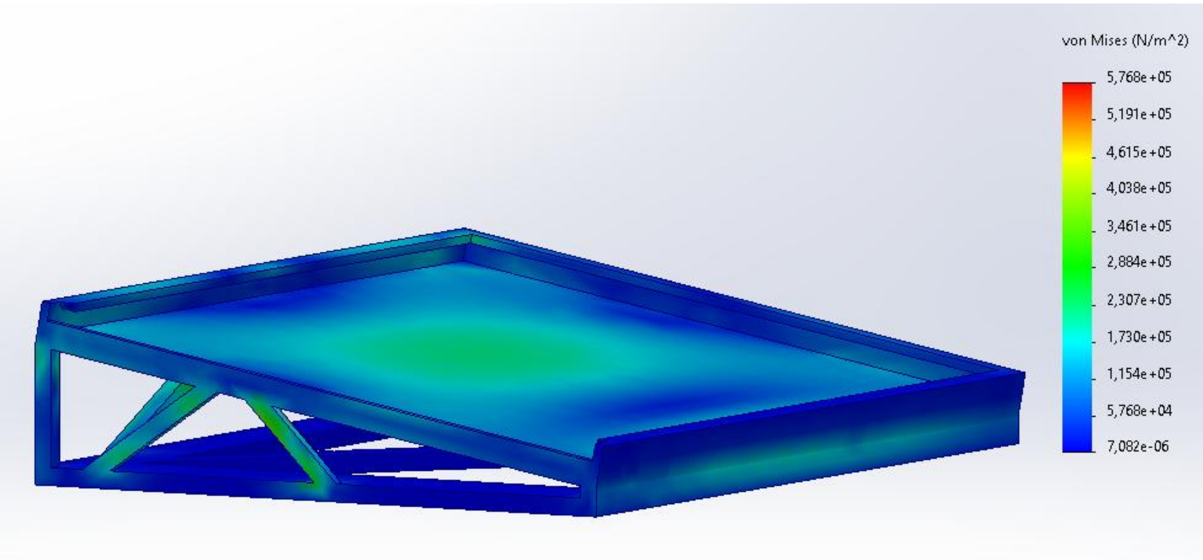

Figure 15. Stress test result from SolidWorks® Simulation (Wilhelm Guarnieri, 2025)

As can be seen in the stress test from SolidWorks®, the stress in the stand (Von Mises) is $5{,}7 \cdot 10^5$ N/m^2. This translates to 0,57 MPa. This stress is found in the top section of the two rear support beams running from the bottom of the stand to the top.

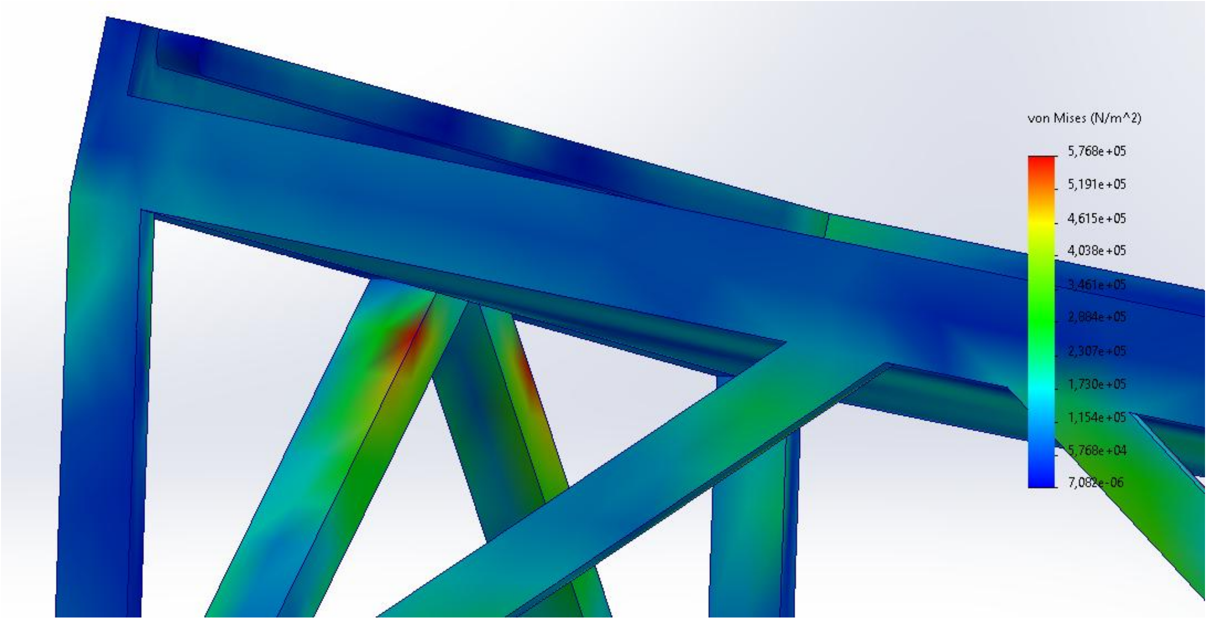

Figure 16. Close up where the highest stress occurs in the nautical chart stand (Wilhelm Guarnieri, 2025)

As now the maximum Von Mises stress is known, the factor of safety can be calculated. This can be done by using Eq. 6. By using 60 MPa as yield strength (designerdata.nl, 2025) and the Von Mises stress of 0,57 MPa we get the factor of safety to be:

$$Factor\ of\ safety = \frac{60}{0.57}$$

Calculating this, we get a value of 105 as factor of safety. This is a quite high number, but since the cost of Polycarbonate is low and the overall amount used is not that big, there is not a need to scale down the supports or change design. Making the support beams thinner would in theory decrease weight while keeping a high number as factor of safety but would make the support beams prone to cracking if the stand is dropped and would weaken the resistance to vibration. The aim of the design is to create a robust, fool-proof design that can endure everything and more thrown at it.

The stress testing is conducted to make sure the maximum impact force of the nautical charts under different movements cannot exceed what the stand can withstand, as well as to see how much stress the impact force could expose the stand to.

3.4 Vibration Analysis

In order to find out how the nautical chart stand reacts to vibration; a vibration analysis has been conducted in SolidWorks®. The study was set up by fixing the stand from the bottom in the program and running it through vibration frequencies from different directions up to 262 Hz to see which ones resonate and at what Hz.

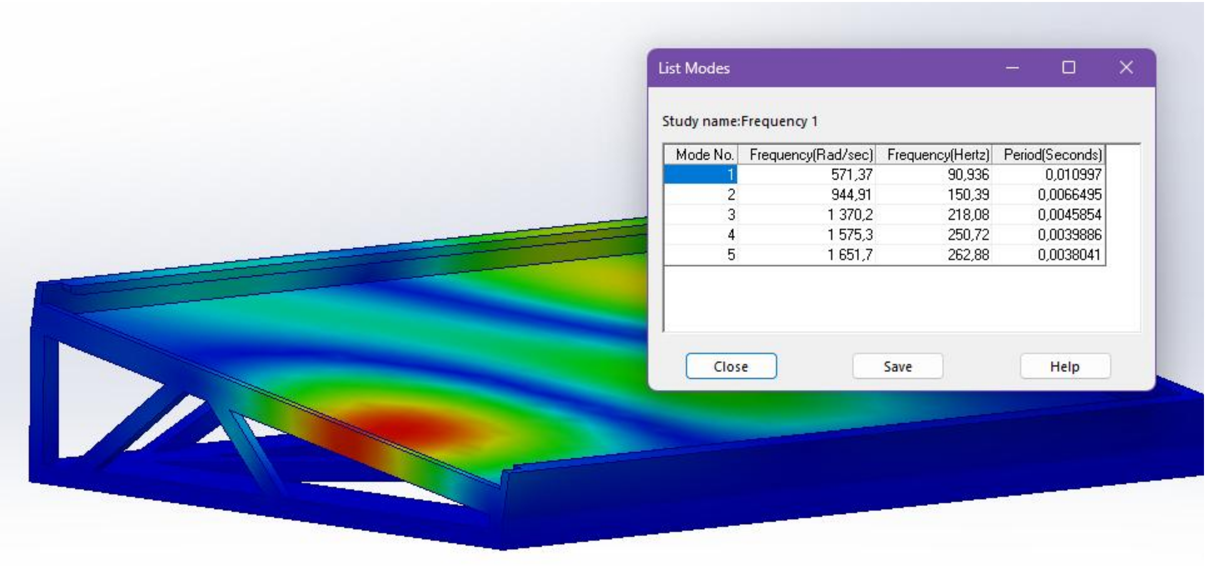

Figure 17. Resonance frequencies of the nautical chart stand (Wilhelm Guarnieri, 2025)

As can be seen in figure 17, the resonance frequency of the first five natural frequencies varies from 90,9 Hz to 262,9 Hz. As the vibration frequencies experienced by boats are typically 12,8 Hz – 128,6 Hz (see section 2.2) only the first natural frequency will produce some possible resonance in the stand.

As the frequency at which a vessel shakes varies by both its speed as well as the frequencies of the waves, the first natural frequency 90,9 Hz in theory falls into the possible category for vibration under normal operation. However, as mentioned previously, this is to be expected, and possible resonance is not critical to the design. As a vessel usually shakes and rattles a lot, everything inside is exposed to the same vibrations. Some of the vibration could also be dampened by mounting the stand with rubber washers between the stand and mounting surface.

The 90,9 Hz can also occur at different vessel speeds depending on the frequency of the waves, but in order to cause resonance just the right circumstances need to be met.

3.5 Final Design

After verifying the structural suitability of the design, some fillets were added to eliminate sharp corners and the risk to injury, as well as water drainage holes, a clamp to hold a pen and a mount for a flashlight, in case of use in the dark.

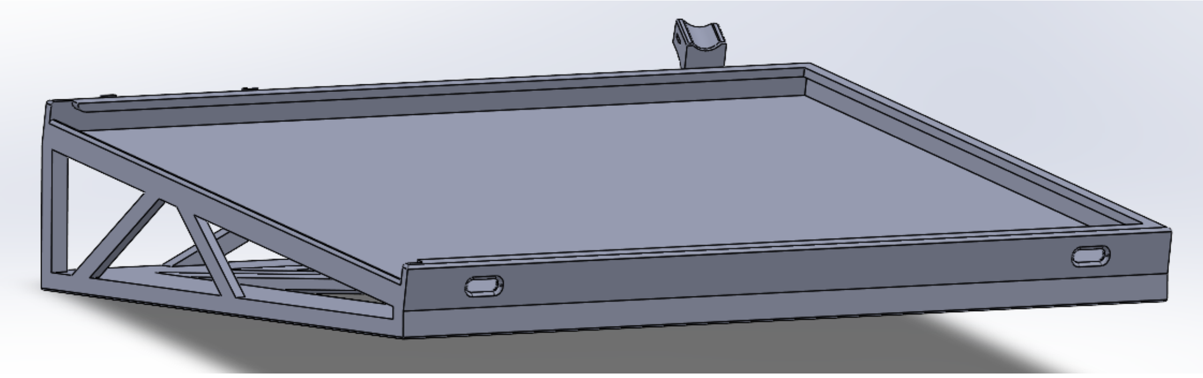

Figure 18. The final design of the nautical chart stand, with water drainage holes shown in front (Wilhelm Guarnieri, 2026)

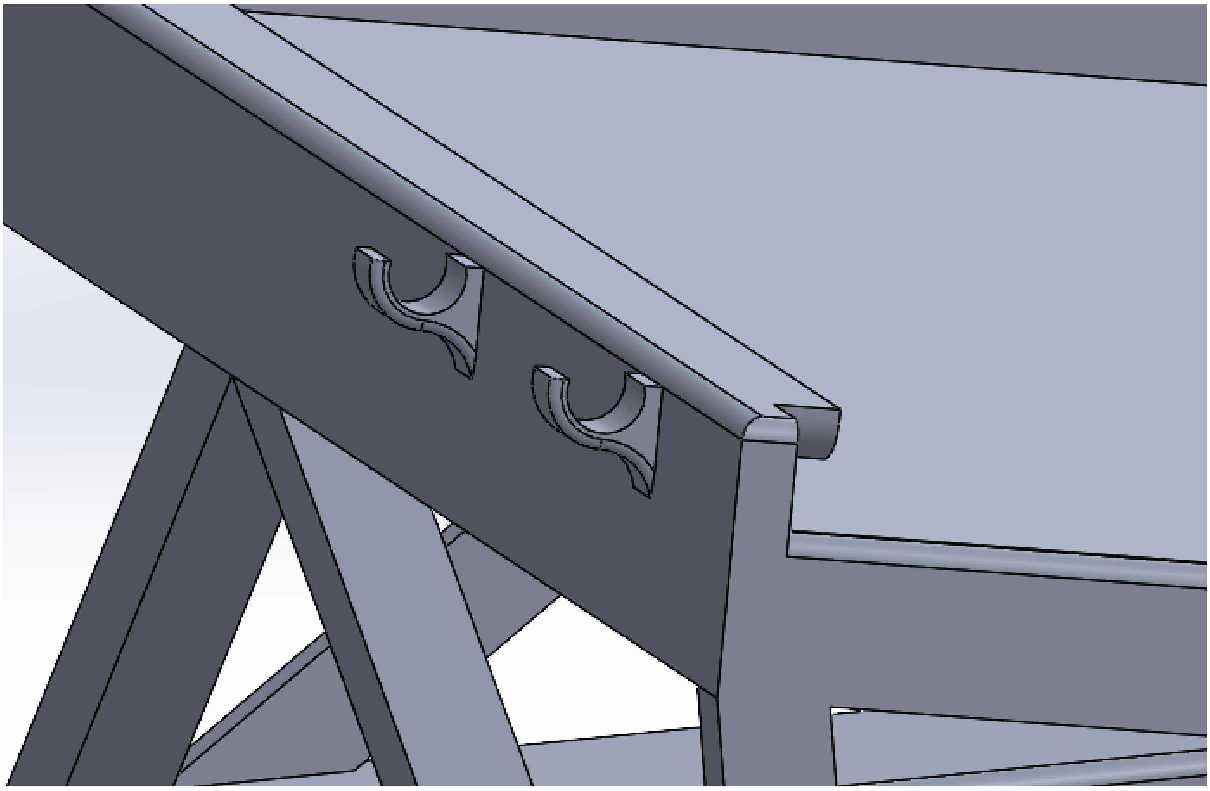

Figure 19. Close up of the pen holder at the back of the stand (Wilhelm Guarnieri, 2026)

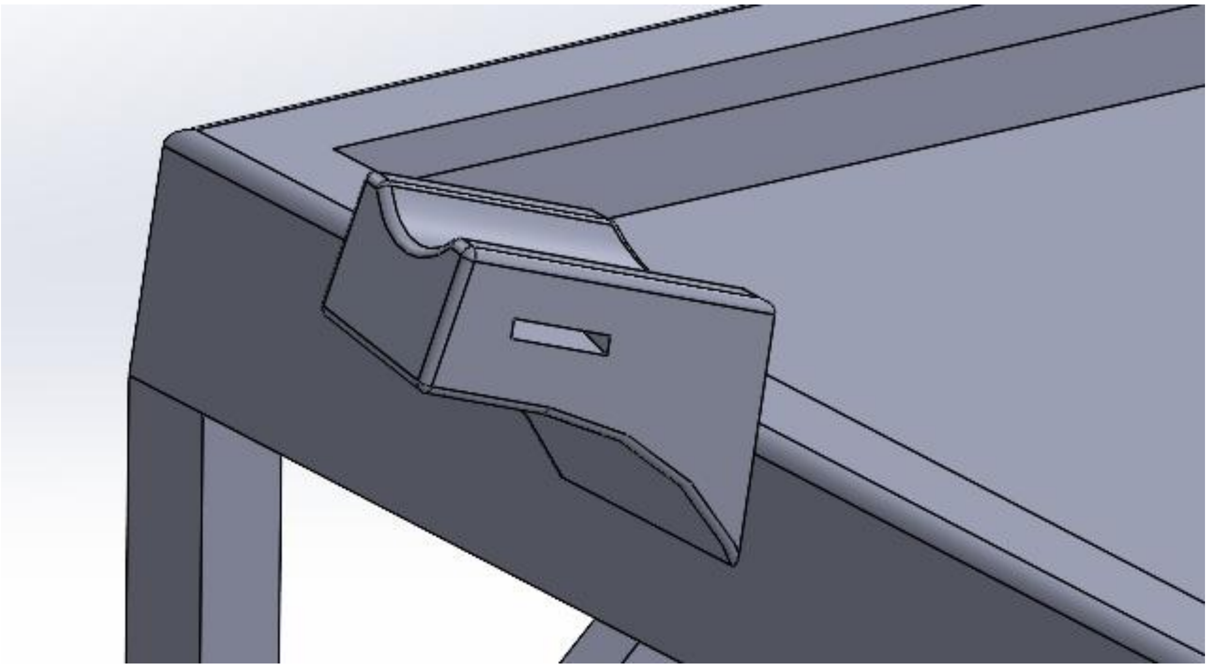

Figure 20. Close up of the flashlight mount. The flashlight can be mounted using a re-openable large zip tie, for ease of removal and quick attachment. (Wilhelm Guarnieri, 2026)

3.6 Examples of the Nautical chart stand edited onto different boats

Here are a few photos of different boats from the Helsinki boat show 2026 with the nautical chart stand edited onto them, to illustrate how the stand would look when used on a boat. Please note that these photos are edited and for illustrative purposes only.

Figure 21. The nautical chart stand on a Saxdor 320 GTC, here for the operator of the vessel to use (Wilhelm Guarnieri, 2026)

Figure 22. The nautical chart stand on a Buster Magnum, here for the co-operator of the vessel to use (Wilhelm Guarnieri, 2026)

Figure 23. The nautical chart stand on a Terhi 480, here for the co-operator of the vessel to use (Wilhelm Guarnieri, 2026)

Figure 24. The nautical chart stand on a Targa 30.1, here for either the operator or the co-operator to use (Wilhelm Guarnieri, 2026)

As can be seen in the pictures, the nautical chart stand is possible to fit to a wide range of different boats, from small to large. Depending on the boat's layout, it is possible to mount the stand for either the operator, co-operator or both to use.

4 Results

The results from the stress testing, topology optimization and vibration analysis are displayed in a table, with the results from the topology optimization being weight reduction (%).

Maximum impact force (N)	34,3
Von Mises stress (MPa)	0.57
Factor of safety	105
Resonance frequency (Hz)	90,9
Topology optimization (%)	28

Table 1. Results

The results are clear and easy to understand, proving the durability and resistance to vibration.

The maximum impact force from the nautical charts of 34,3 N is well withing the durability of the nautical chart stand. This force won't put any real stress on the stand, as intended by the design.

The Von Mises stress of 0,57 MPa is also way below the threshold of yielding for Polycarbonate, making the stand as durable as anything. Because of Polycarbonate's exceptionally high yield strength and the relatively low stress under working conditions the factor of safety becomes very high. However, this is necessary in order to prevent vibration, as now only the first natural frequency will cause possible resonance. If the supports from the bottom of the nautical chart stand to the top would be thinner, while theoretically keeping a high value of factor of safety the second natural frequency could also cause resonance.

The Topology optimization proved valuable in showing where to remove material, and the result was a 28% reduction in weight of the nautical chart stand.

5 Discussion

The need for a nautical chart stand can clearly be found when looking at statistics on boating in Finland, the number of boats and the often tricky to navigate shallow water and tight passages in the archipelago. By having a stand to hold the nautical charts, they would not fly around even in harsher seas and would give the operator of a vessel one less thing to think about.

The design was made in SolidWorks®, and was optimized using features such as stress testing, topology optimization and vibration analysis. By conducting these studies on the nautical chart stand, a simple, robust and visually pleasing design was possible to create. The design is focused on user friendliness, robustness and ease of use.

The design of the nautical chart stand could also easily be tweaked for even more weight loss, though at the cost of increased risk of resonance from the second natural frequency. However, if not used offshore or in extreme condition, a design with much thinner supports would be totally viable option, focusing on weight reduction and strength. A design like this would be ideal for the smaller boats, often operated in lakes or near the coastline where the seas typically are much calmer.

One thing not taken into consideration in this thesis are the possible inaccuracies of the stress tests, topology optimization and vibration analysis in SolidWorks®. In order to verify these values with certainty the nautical chart stand would need to be manufactured and tested, attaching the stand from the bottom and placing the stand under the load of 70N, as well as running the stand through vibrations from 12,8- 128,6 Hz, observing the results.

6 Conclusion

This thesis had the goals of designing, calculating stresses and topology optimizing the design for a nautical chart stand. This was achieved by designing and optimizing using SolidWorks® CAD- software.

The initial design proved successful in withstanding the forces experienced under regular usage, even being much stronger than needed. The resistance to vibration and stress were great, and the topology optimization managed to remove 28% of weight from the nautical chart stand. In essence, all objectives of the thesis were met.

Designed to be both visually pleasing, easy to use yet robust, the design could also be enhanced for lighter weight, especially for vessels operating in conditions well below the severity of those the nautical chart stand is designed to withstand now. More weight could easily be shaved off, lowering manufacturing costs and making the design look even more sleek.

These are topics that could be explored in the future, possibly leading to actual manufacturing of the nautical chart stand, with different versions of the stand rated for different kinds of usages, both regarding strength and design.

7 Sammandrag

Detta examensarbete behandlar designande, analys och optimering av en sjökortsställning för användning ombord på fritidsbåtar och andra mindre fartyg. Examensarbetet har genomförts inom utbildningsprogrammet Process- och materialteknik vid yrkeshögskolan Arcada. Arbetet fokuserar på design, materialval och simulering av hållfasthet och vibrationer med hjälp av CAD- programmet SolidWorks®. Målet var att ta fram en hållbar, användarvänlig och lätt tillverkad produkt som förbättrar säkerheten och underlättar navigering genom att förhindra att sjökort flyger runt eller faller från deras plats i båten under hård sjögång.

Säker navigering är mycket viktigt vid båtfärd, speciellt i områden med grunt vatten, mycket grund, trånga sund eller i svåra väderförhållanden. Trots att moderna båtar ofta är utrustade med elektroniska kartplotter och GPS försvinner inte behovet av traditionella papperssjökort. Man ska inte lita blint på elektronisk utrustning då den kan få problem, sluta fungera, visa felaktig information eller påverkas av strömavbrott samt störningar i GPS, vilket gör papperssjökort relevanta för en säker färd.

Ett praktiskt problem med sjökort är att de lätt flyger omkring eller faller på golvet när båten gungar och smäller i vågor. Detta kan distrahera föraren, särskilt i viktiga situationer där uppmärksamheten borde vara på navigering och manövrering av båten. Att behöva leta fram och plocka upp sjökortet, leta fram rätt sida och hitta sin position igen kan öka risken för att köra på grund eller andra olyckor. Problemet kan vara tydligare i mindre båtar, som ofta saknar kartplotter och ofta skumpar betydligt mycket mera i vågor, men förekommer även i större fritidsbåtar som ofta används även på öppet hav och inte bara i den relativt väl skyddade skärgården.

För att lösa detta problem utvecklades en sjökortsställning som håller sjökorten på plats, förbättrar ergonomin vid användande och säkerställer en trygg färd.

Syftet med examensarbetet var att:

- Designa en sjökortsställning
- Analysera hållfasthet för designen
- Genomföra topologioptimering för att minska vikt utan att försämra sjökortsställningens hållbarhet

Designen gjordes för att kombinera funktionalitet och lätt användning med en estetiskt snygg design, kostnad och lätt tillverkning i tanken.

I delen litteraturöversikt behandlas relevant teori för arbetet. Detta är bland annat olika design- samt tillverkningsprinciper, relevanta matematiska formler för att räkna ut stresser i designen samt bakgrunden till materialval och tillverkningsmetod. Alla dessa påverkade designen samt hur den skulle förverkligas.

Designande har genomförts med hjälp av CAD-programet SolidWorks®, som använts både för designande av ställningen och simuleringen för hållbarhet. Designprocessen började med konceptutveckling där fokus låg på simpel design, robusthet och funktion. Designen utvecklades slutligen som en singel komponent för att undvika lösa delar, förenkla tillverkning samt för att förhindra skruvar att lösa sig under de konstanta vibrationer som upplevs i en båt.

Den färdiga designen utvecklades med hjälp av:

- Hållfasthetsanalys, för att kunna bestämma maximal stress och beräkna säkerhetsfaktor
- Vibrationsanalys, för att identifiera potentiella resonanser vid de vibrationer som uppstår när en båt rör sig i vågor
- Topologioptimering, för att identifiera områden där material kunde tas bort utan att designens hållbarhet försämrades
-

Valet av material och tillverkningsmetod var ett viktigt steg i processen. Materialet måste väga lite, ha hög hållfasthet, vara vattentåligt samt vara lämpligt för tillverkningsmetoden formsprutning.

Polykarbonat (PC) valdes som material eftersom det uppfyller dessa krav väl. Materialet har hög hållfasthet, är vattentåligt och är lämpligt för formsprutning, vilket är en vanlig tillverkningsmetod för materialet. Dessutom är polykarbonat transparent, vilket bidrar till ett diskret och estetiskt utseende som inte väcker för mycket uppmärksamhet i båten.
Tillverkningsmetoden skulle vara formsprutning, som lämpar sig bra med polykarbonat som material samt ger god kvalité på slutprodukten. Formsprutning lämpar sig även för serieproduktion.

I resultaten diskuteras hur designen tål de påfrestningar som den kan komma att uppleva under användning samt vibrationsanalysen och resultaten från topologioptimeringen.

Resultaten från hållfasthetssimuleringarna visar att sjökortsställningen är mycket hållbar. Den maximala von Mises-stressen uppmättes till cirka 0,57 MPa, vilket är långt under polykarbonatets hållbarhet. Säkerhetsfaktorn blir på cirka 105, vilket innebär att designen är betydligt starkare än vad som krävs för den stress som ställningen förväntas uppleva.

Vibrationsanalysen visade att den första egenfrekvensen är på 90,9 Hz, vilket innebär att viss resonans teoretiskt kan uppstå, då just den frekvensen är sådan som båtar kan vibrera i under vanlig operation. Resonansen är inte kritisk, eftersom vibrationer av denna typ är vanliga ombord på båtar och designen är dimensionerad för att tåla dem.

Topologioptimeringen möjliggjorde en viktminskning på cirka 28 %, främst genom materialborttagning i den nedre delen av designen. Detta kunder göras med hjälp av att hålla kvar små stödbalkar för att inte påverka designens hållbarhet.

Som slutsats kan det konstateras att sjökortsställningen är mer än tillräckligt tålig för de stresser som den förväntas uppleva i användning, samt att ställningen skulle kunna göra sjöfarande tryggare och lättare tack vare att sjökorten skulle hållas på plats och inte flyga runt i båten.

Vidareutveckling skulle fortsättningsvis kunna förbättra designen, ytterligare minska vikt samt göra designen mera sirlig. Olika versioner av produkten kunde även tillverkas, som till exempel en lättare version som inte är lika hållbar, menad för användning vid kusten eller på sjöar där vågorna inte blir så stora och därmed skulle ställningen inte utsättas för lika stora stresser.

En begränsning i detta examensarbete är att analyserna är baserade på simuleringar. För att med säkerhet kunna verifiera resultaten skulle tillverkning av en fysisk prototyp samt testande av denna prototyp i verklig miljö krävas.

Examensarbetet har uppfyllt de utsatta målen genom att ta fram en design för en sjökortsställning som är hållbar, lätt att använda samt möjlig att tillverka med hjälp av formsprutning. Med hjälp av SolidWorks® har hållfasthetsanalys, vibrationsanalys och topologioptimering genomförts och resultaten har iakttagits i designen.

Den slutliga designen är en kombination av hållbarhet, god ergonomi och minimalistisk design. Examensarbetet visar hur moderna CAD- och simuleringsprogram som till exempel SolidWorks® kan användas effektivt för att optimera design för produkter redan före produktion har börjat, och hur till exempel hållfasthetsanalys kan hjälpa med att göra beslut inom designen med tanke på hållbarhet.

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