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Heavy Duty exterior casing for navigation systems on truck trailers

Designing of a rugged enclosure for automotive application

Master's thesis in Product development

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Cover: Sensor enclosure developed for navigation systems on truck trailers

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Abstract

This report details the development process of a new iteration of a sensor enclosure. The sensor unit is supposed to aid the navigation of trucks with ungainly trailers. These kinds of trucks operate in many harsh environments thus the demand put on such enclosure are particularly high. Besides withstanding the harsh conditions on the road, the enclosure has to endure high pressure water jets and harsh chemicals when the truck is being cleaned. The development of this enclosure uses an already developed prototype as a reference. The goal is to redesign the current enclosure and tailor it toward a casting process for mass production. The main problem to be solved is the designing of a casing that takes the suggested production process into account and supports the intended functions of the sensor unit.

The development effort included a pre-study to fully understand the problem at hand, an iterative concept developing process followed by an extensive optimisation process of the included components. To achieve this various product development methods were used together with software such as *CATIA V5, ANSYS, CES Edupack*.

The result of this thesis was a design that meets the demands of the stakeholders whilst improving on the old prototype. Improvements made were a weight reduction of 51% and the assembly process was simplified by replacing many screws with snap joints as the joining method. This made the new design better from a DFA and DFM point of view. A material selection analysis has also been performed where new materials for the enclosure are suggested with performance and environmental aspects taken into consideration. Since this project is part of a much larger development effort the final design will most likely undergo further iteration. However, the findings of this project should aid in future decisions and take the product closer to its market release.

Keywords: Sensor, Sensor enclosure, Ingress protection, IP69K, Product development, FEM, optimisation, snap joints, CATIA V5, ANSYS, CES Edupack, ÅF technology.

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Niklas Reck, Kristoffer Zietek Krohn, May 2019

Table of Content

1 Introduction

This chapter serves the purpose of detailing the background and the problem statement, including the limitations, of this project.

1.1 Background

This project was conducted by two students from the product development master at Chalmers University of Technology. The work was carried out at ÅF Technology in Gothenburg together with the team at *Hyttsatelliten* and was part of an on-going development project.

This development project has the goal to make the manoeuvring of large and ungainly trucks easier, and above all safer. Hence, the possibility to assist the drivers of these trucks with additional sensors was investigated. These sensors intend to measure the tilt, angle and the distance to the trailer in relation to the truck. This information is especially important when reversing, parking or attaching the trailer to the truck since these trucks tend to be very heavy leaving little to no room for mistakes. This system is planned to be used as part of an auxiliary system to both new and old trucks.

1.1.1 Company Project status

This thesis did not start the development of the sensor enclosure from scratch meaning that the team at ÅF had been working on both hardware and software for some time. The development of the electronics and the software for the sensor where prioritised higher than the enclosure leaving a less optimized but fully functional, enclosure for this thesis to work with. Currently, the project is in the phase of testing and evaluating the concept with the main focus being the functionality of the software and electronics. A prototype of the sensor unit has been designed and it will be the starting point for this thesis. A more detailed description of the prototype can be found in appendix A.

1.2 Problem

The sensor of this concept is supposed to be placed in an exposed position where the harsh environment of the road calls for an especially well sealed casing. This environment includes not only harsh weather and temperatures but also everything else a truck may be exposed to during its use on the road e.g. high-temperature pressure washing, rock falls, impacts by tools or other blunt objects and exposure to chemicals ranging from hash cleaning agent and degreasers to diesel fuel.

To ensure a functioning sensor the international protection marking aimed for is IP69k which is the highest classification dust and waterproofness of an enclosure for electronic components. The on-going development efforts have mainly been focused on providing functional hardware and software. A prototype of the sensor casing was also developed but needs more effort to get the concept closer to a market release. The areas that need to be investigated is the production process for the sensor meaning that a suitable material needs to be decided upon and the design of the sensor needs to be tailored to be feasible for chosen process. Furthermore, the design needs to be analysed and tested to ensure the sensors durability.

This master thesis will focus on the development on the enclosure of said sensor. This includes the development of the design features, material choice and manufacturing method for the included parts.

The deliverables are set to be the following:

- A near production ready 3D-model of the design in CATIA V5 including 2D-drawings and detailed documentation explaining the design choices
- Material selection analysis
- Durability analysis

1.3 Methodological approach

The project was from the beginning divided into several stages which were design to support a structured product development process. The stages included in this Master Thesis are a *Pre-Study*, an iterative process of *Concept Generation*, *Concept Evaluation* and *Detail design*, as well as a final *Evaluation*.

The project was stared of by the *Pre-Study* to give insights about the task at hand and the already developed prototype, and to get an overview of common industry standards regarding enclosures. This initial phase used a *Black Box Modell* and a *Function Flow* diagram to understand the intended function of the concept as well as various *Scenario Descriptions* to visualise the situations the sensor is used in. The Pre-Study also included a search for similar products with similar features and update of the requirement.

The *Concept Generation* and *Concept Evaluation* was inspired by the approach described in Ulrich & Eppinger's *Product design and Development (2012)* together with various tools: Concepts were generated using *Brainwriting*, *Stop n' Go* and *Daily Brainstorming* and *Morphology matrices* (see section 3.2) to generate a number of concepts. These concepts were evaluated using a *Pugh Matrix* (see section 3.4) and, after gathering more data, a *Kesselring Matrix*.

The *Detail Design* and final *Evaluation* was done with input from supervisors, the team at *Hyttsatelliten* and literature. Lastly, the ethical and environmental consequences of this project were discussed within the project group as part of the final evaluation. *Rotary's 4-way test* served as a guideline for this discussion.

1.4 Delimitations

This project will encompass the development process of a new and improved version of the current casing design. This project will not do a complete redevelopment the basic design unless deemed necessary. Furthermore, the project will only be focusing on the casing containing the sensor unit. Other surrounding systems will not be considered unless changes to the sensor casing would impede the function of these systems.

It is also not within the scope of the project to alter the electrical components such as the PCB as well as its software. This project will use the pre-defined hardware as starting point and tailor the new design to it. The project is however allowed to alter the positioning of the hardware and come with ideas of improvement if some are discovered during the project.

Since this is a development project some of the details surrounding the project are classified. Information regarding the specific technology, electronic components and features are therefore not allowed to be discussed in this thesis. The information presented within this thesis is approved by supervisors and other stakeholders.

2 Theory

This chapter will shine a light on different theories and information needed to understand and solve the task at hand.

2.1 Electronic enclosures

An enclosure for electrical components can be defined as a cabinet for electrical equipment that prevent electrical shock to potential users and protects the delicate content from environmental factors. An enclosure is not only bound by utilitarian requirements but also be ergonomic features which serve the purpose of making the enclosure suited for human interaction. Since the enclosure is the only thing visible to the outside world it also needs to fit into its environment, communicate its intention and if desired, it should also be nice to look at.

Besides the demands put on an enclosure by its intended uses there are certain standards, rules and regulations to be met when designing an enclosure for a certain industry. Countries who are members of the *International Electrotechnical Commission (IEC)* use IEC60529 or the ISO 20653 standard to classify the IP-class of an enclosure. The later one will be referred to in this project since it is carried out in Sweden, which is an IEC-member.

2.1.1 IP-classification

The IP-code, International Protection Marking, classifies the degree of protection an enclosure has against intrusion. This encompasses protection against dust, water, more mechanical intrusion attempts (e.g. with hands and fingers) as well as the protection against accidental contact with brittle/hazardous components.

The classification itself is defined in the SS-ISO 20653:2013 standard which explains each digit in the IP-code as well as the correct testing methods. The IP-code is formatted as IPXX together with a set of letters to specify the classification if necessary. Figure 1 shows the different components of the code.

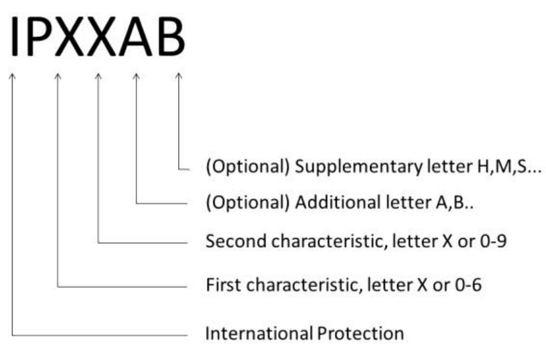

Figure 1: IP-code structure.

The first characteristic refers to the protection against dust and objects, the second characteristic refers to the protection against water where the letter X indicates that no data regarding the level of protection is available and 0-9 indicate the level of protection (a higher number means better protection). The optional letters at the end refer to the protection against e.g. high-pressure water jets (additional letter K) or indication that the protection level is maintained during the movement of movable parts during water tests (supplementary letter M) [1].

One may note that different product sometimes come with multiple IP certifications. This is due to the differences in how the certifications are tested e.g. an enclosure featuring the IP69K classification does not necessarily meet the demands of an IP68 classification since the test for IP69K only features high temperature and high-pressure water jets compared to the IP68 classification, which testes the enclosure by submerging it into water at least 1 meter deep for a prolonged period of time.

2.1.1.1 IP69K

The classification that is demanded for this sensor is the highest possible classification: IP69K. This is a special degree of protection specifically developed for road vehicles who undergo regular cleaning with high pressure water jets e.g. trucks and construction equipment. The code itself means the following [1]:

- **IP6x:** *No ingress of dust whilst a vacuum is applied over durations of up to 8h.*
  The test dust, Arizona dust (A2) according to ISO 12103-1, is used in a dust chamber with air-dust mixture according to IEC 60068-2-68 unless otherwise agreed upon.

- **IPx9K:** *No ingress of water with applied close-range high pressure, high temperature water jet.* The test is done at a distance of 100-150 mm with a water flow rate of 14-16 l/min, a water temperature of 80±5 °C and a pressure of approx. 8000-10000 kPa (80-100 bar). The water jet is applied a total of four times, each time from a different angle (0°, 30°, 60° and 90°) with a duration of 30s per position.

2.1.2 IK-Rating

IP-classifications focus mainly on the ingress protection from water and dust but overlook the protection against mechanical impacts. The European standard EN62262, equivalent to the international standard IEC 62262 (2002), relates the mechanical impact protection of an enclosure to a numeric classification code, the IK Code. Previously the IK-Code was part of the IP-code as an occasional added nonstandard number before it became its very own standard in 1995. Nowadays enclosures come with both IP and IK classifications to specify both features [2].

The IK-classification of an enclosure is defined by the amounts kinetic energy (Joules) an enclosure can resist without compromising the function of the product. The EN62262 standard specifies the testing conditions and the mounting of the enclosure, the atmospheric conditions, amounts of hits and their distribution, the type of hit, material of the hammer etc. The impacts energy and their corresponding IK-code can be seen in Table 1 [2].

Table 1: IK-code and corresponding impact energy

IK Code	IK00	IK001	IK02	IK03	IK04	IK05	IK06	IK07	IK08	IK09	IK10
Impact energy (joules)	-	0.14	0.2	0.35	0.5	0.7	1	2	5	10	20

2.1.3 Enclosure ventilation

When tightly sealing an enclosure, the airflow is completely or heavily restricted. The lack of ventilation can cause issues regarding moisture and gases inside the enclosure. Water and moisture can in several ways penetrate even IP69K classified enclosures if it is given enough time. Condensation can then form on the inside which will harm exposed electronics if the moisture is not removed. Furthermore, some plastics can desorb gases or moisture up to a percentage of their total weight. The amount of water absorbed depends on the surrounding environments humidity and temperature as well as the materials water absorption properties [3] [4] [5]. The material can later when the environmental conditions change release the water it previously absorbed. Water can also diffuse through plastics, although at a small rate [6].

Due to temperature and altitude changes the air pressure inside an enclosed area can fluctuate, this can create a pressure difference between the outside environment and enclosure. A positive pressure inside will cause the enclosure to bulge outwards and a negative pressure inside will create a vacuum which will compress the casing as well as sucking air and moisture in. These pressure differences also put stress on potential gaskets used to seal the enclosure. A common method for dealing with these challenges in outdoor enclosures is discussed below.

2.1.3.1 Expanded polytetrafluoroethylene membrane

Polytetrafluoroethylene which is more commonly known as Teflon can be expanded quickly forming a microporous structure (also known as e.g. Gore-Tex). Membranes made using ePTFE allow moisture and gas to diffuse through while blocking water and other particles from passing [7]. Membranes made from ePTFE are often utilized when ventilation of enclosed spaces where particles and water need to be kept out, e.g. vehicle control units and IPX7+ classified phones and other electric products that are in contact with water.

2.2 Design for Excellence

The methodology to systematically design a product or a system according to a set of desired characteristics is called *Design for Excellence* (DFX) and summarises many different design guidelines. These guidelines can be categorized in different sub-genres, summarising different design targets e.g. Design for Environment (DFE) targets the reduction of the overall environmental and human health impact of a product system or service throughout its lifecycle.

This project will utilize a couple of the subgenres included in DFX to target excellent manufacturability (DFM), easy assembly (DFA) as well as recycling/disassembly of the materials and reusable components at the end-of-life of the product (DFEoL).

2.2.1 Design for Manufacturing

Design for Manufacturing, DFM, means that a part or product is designed in such way that it is favourable to manufacture. This general engineering practice exists in almost every category of engineering and is a key element in product development. What features a design has to have is highly dependent on what manufacturing process is to be used as well as the mechanical, thermal and chemical load the product has to endure. The main goal with DFM is to optimize/minimize the manufacturing cost which in turn is a key factor when determining the economic success of a product. Simply put, the economic success depends on the difference between the manufacturing cost and the selling price, the profit margin, as well as the number of units sold. The manufacturing process is mainly determined by how well the product is tailored to the process in use. The sales price as well as the number of units sold is on the other hand determined by the overall quality of the product.

DFM activities often demand for the involvement of the entire development team as well as outside experts thus making it an interdepartmental task. These kinds of activities are most effective to already be included early in the development process, where changes to the design are still easy and cheap. The DFM process, according to Ullrich & Eppinger, consists of the following five steps [8]:

1. **Estimate the manufacturing cost.**
   Inputs include raw materials, purchased components, labour cost, tooling cost and running cost (electricity, rent etc.). The result is usually represented as *cost per unit* and includes both variable and fixed costs from the above-mentioned inputs.

2. **Reduce the costs of components.**
   This can be done in several ways: reduce processing steps, remove unnecessary steps (e.g. an aluminium part that is not visible may not need painting), combine several forming steps through substitution of another process step (e.g. casting may replace several cutting and drilling operations), use standardized parts and processes etc.

3. **Reduce the cost of assembly.**
   Utilize design for assembly (DFA) as a subset of DFM. DFA is described in more detail in section 2.2.2.

4. **Reduce the cost of supporting production.**
   An example of supporting production is the demand on increased inventory management as the number of parts increases which in turn would increase the number of workers required for production. Reducing the cost of support for the main manufacturing can be done by minimizing the complexity of the transforming systems (e.g. the casting process that transforms raw material no near-net shaped parts could eliminate a complex machining operations) or by error proofing the manufacturing/assembly (e.g.by utilizing Failure Mode and Effects Analysis (FMEA) to discover where the production may go wrong).

5. **Consider the impact of DFM decisions on other factors**
   As previously mentioned, the economic success of a product is not only determined by a cheap manufacturing process but by the overall quality of the product. Consider that DFM activities may ad developing cost to the product and changes in the production system may introduce a change in quality.

2.2.2 Design for Assembly (DFA)

This design guideline focuses on the reduction of the assembly cost of a product by decreasing the assembly time and complexity. For most products the actual assembly represent a relatively small part of the total cost. However, by having a well thought out and cheap assembly process yields indirect benefits to the product. These indirect benefits are often showing up as cheap labour cost since an easy assembly process requires less work/workers, lower supporting cost where an overall lower number of parts keeps the demand for inventory management and the part diversity low.

A common practise when utilizing DFA is to integrate parts. If a part is not deemed to be necessary, it may as well be integrated in another part. More than often integrated parts are beneficial both from a manufacturing cost point of view as well as an environmental point of view since it keeps the material diversity low which makes for a less work intensive recycling process. One common example of integrated parts is snap-joints which replace screws in a product and leaves the assembly tool-less and potentially automated. Snap-joints are further discussed in section 2.3.

Another common practice is to make the assembly process as easy as possible by making parts self-aligning, by making part require only one hand for assembly or by removing the need for tools etc. Another possibility is to design the product where the customs can complete the assembly process themselves. This calls for an especially easy assembly process since uneducated customers may ignore complicated directions and thus compromising the products intended function. IKEA is a well-known example of such assembly process.

2.2.3 Design for End-of-Life (DFEoL)

Designing a product for its afterlife, or End-of-Life (EoL), can be a tricky thing but is one of the most important aspects of modern product development. The initial phases of a product development process typically include the definition of scope, information gathering, brainstorming, concept development and much more. But besides tailoring a product for a specific use, product developers must think about the environmental aspects of what they are developing during its lifecycle. Reducing the environmental impact can be a corporate strategy to pursue a better brand image and economics, in line with abiding the latest rules and regulations imposed on companies by e.g. EU-Directives. Especially interesting for the sensors PCB is the Waste Electrical and Electronic Equipment (WEEE) directive introduced by the European Union (EU) in 2003. This Directive concerns the treatment of electronic waste by placing the responsibility to provide a sufficient collection system on the producers of the electronics themselves. Even though thus focuses on the PCB of the sensor it might still affect the enclosure if they are not separated, or disassembled, before entering the collection system [9].

Up to 70% of the cost of a product is assumed to be determined early in the product development process. This strengthens the argument that considering the entire lifecycle of a product from the very beginning of its design phase is of utmost importance. When designing a product for its End-of-Life the goal is to avoid waste, reduce the need of landfill and reduce the toxicity when a product has fulfilled its purpose and is considered waste [10].

The management of waste is defined in “Lansinks’ Ladder”, which is a hierarchically ordered list of generalized EoL options and shown in Figure 2. It classifies the options according to how environmentally preferable they are [10] [11].

Figure 2: Lansink's Ladder by recycling.com

A. **Reduce:**
   The best option from an environmental point of view is to reduce and avoid waste from the very beginning. This can be done by excluding toxic, non-recyclable materials and instead use biodegradable and completely recyclable materials e.g. use canvas bags instead of single use plastic bags.

B. **Re-use:**
This is the most preferable from an environmental point of view if waste is unavoidable. Product may not even be reused in the same application as they originally were intended to e.g. old bricks can be reused as filament in roads. Re-using a product preserves the energy and material put into the product.

C. **Recycling:**
This is the most common practice. The product is sorted according to its material and destructively disassembled. The shredded materials are the sorted according to its kind and recycled as raw material for new products. Downcycling is a type of recycling where the material is reused as a lower grade material in another application e.g. newspaper often consists of other recycled paper that previously was a higher quality product.

D. **Energy recovery:**
This type of recycling involved the complete destruction of the product by incineration. The energy that is released can be used as district heating, or as process heat.

E. **Incineration:**
This may sound rather similar to the previous energy recovery but with the difference that no energy can be produced by burning the waste. The purpose of this is to dispose waste by incineration in order to prevent it from being stored on landfills.

F. **Landfill:**
A landfill is basically a place where waste material is buried in the ground. This is by far the least preferred option since the use of landfills only has disadvantages. The waste does not generate any energy or other beneficial matter but instead causes heavy pollution.

Option A-C, often called the three R’s, are the most preferable ones. However, all these options depend on the way a product can be recovered. One key part of a successful and feasible recovery is the way a product can be disassembled. This includes the separation of potentially re-usable parts as well as the sorting of the recyclable materials. There are lots of different solution for this one being the reduction of material diversity within the product to reduce the time and cost of the separation. Another solution would be to exclude permanent assembly mechanism, such as glue, and instead utilize screws or snap-joints [11].

2.3 Snap joints

Snap joints are a quick and economical way of joining two components and are often associated with DFA design strategies. All snap joints work with the principle of having a protruding part of one component which is temporarily displaced during joining before it snaps into place in an undercut of the other component. The protrusions can be in the form of a hook, stud or bead and the undercut can be in the form of a groove or gap. After joining the components can be inseparable or separable depending on the shape of the undercut. The force required for joining and if possible, to separate also depends entirely on the design of the snap joint. Due to the deflection taking place during joining elastic materials are used, usually different plastics, but different materials can also be used. Generally snap joints can be divided into four categories, cantilever, annular, torsion and U-shaped snap joints.

Cantilever snap joints are the most common and use a cantilever design with a hook on the end. It bends during assembly and then returns to its original shape when reaching its corresponding undercut.

Depending on the undercuts design and the hooks angle it can be inseparable or separable. Separation can also be aided by having a window or hole where the cantilever can be pushed to detach the hook. Angular hooks can also be utilized to make separation require less force, se Figure 3.

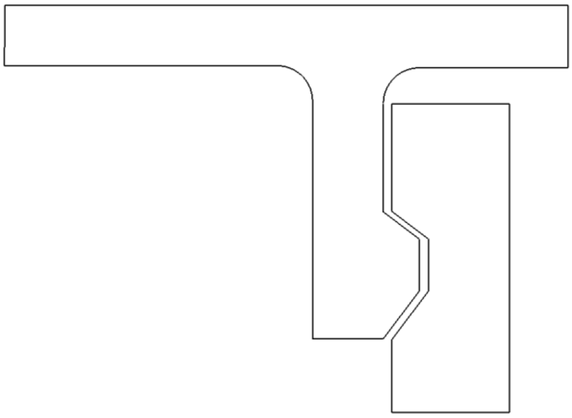

Figure 3: Illustration of how a cantilever snap joint can look.

Annular snap joints have one component with a bump or ridge around its circumference and the other component having a groove. During assembly both components flex inwards or outwards until the bump and groove meet. Whether separation is possible depends on the design in a similar manner as the cantilever snap joint. Annular snap joints are best suited for cylindrical profiles but also work for non-cylindrical profiles. Furthermore, the force required to assemble and disassemble annular snap joints is the highest of the snap joints as a result of the joint encompassing the entire circumference. It is also advised to use the same materials or materials with the same characteristics when designing annular snap joints. See Figure 4 for an illustration of how an annular snap joint can look.

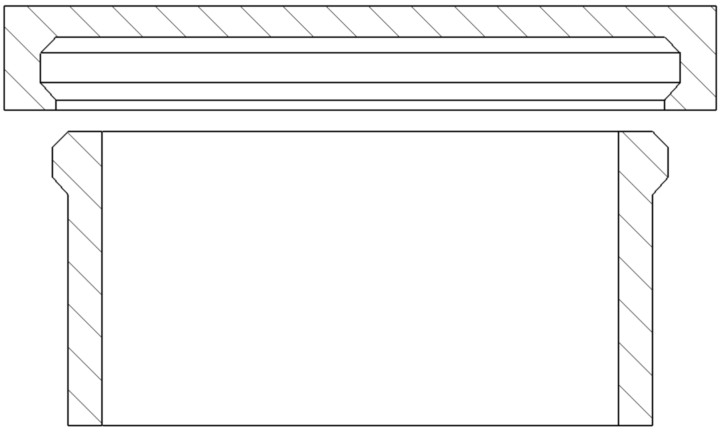

Figure 4: Illustration of how an annular snap joint looks.

Torsion snap joints are very similar to cantilever snap joints but are held in place by a torsion rod instead of the stress in the cantilever. Torsion snap joints are easier to detach due to there often being a lever along with the lower force developed by the torsion rod, compared to bending the entire cantilever. Separation of the parts is however not possible until the lever is pressed unless the force is large enough to break the joint. This provides a secure attachment to forces trying to separate the components but allows the user to easily detach them by simply pressing the lever, see Figure 5.

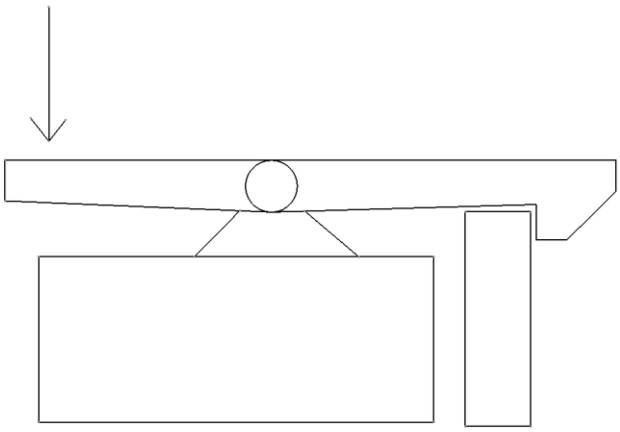

Figure 5: Illustration of torsion snap join mechanism.

U- or L-shaped joints are shaped as the name suggests and makes assembly and separation easier by having more material that can deform. The additional material also reduces the overall deformation that occurs during use which opens for use of stiffer materials. These joints are generally used when the design space restricts the use of normal cantilever snap joints because they would pass the yield strength of the chosen material, see Figure 6.

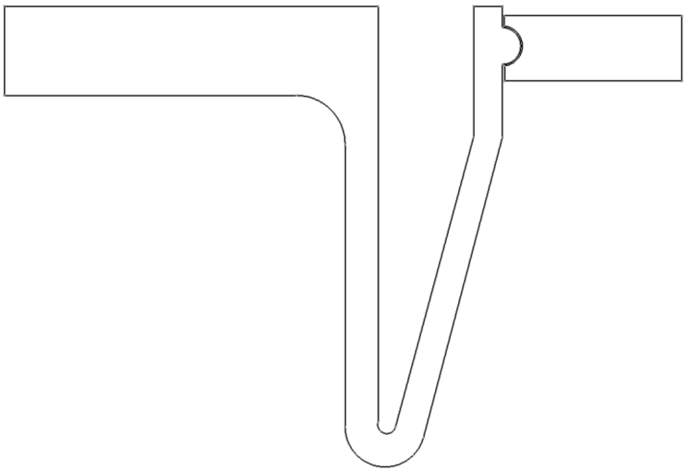

Figure 6: Illustration of U-shaped snap joint mechanism.

2.4 Materials

Every product in our surrounding is made from some kind of material. The material must support and endure whatever loads the product is intended for without being damaging, or toxic, to its environment or cost too much. Besides having a suitable set of properties for the application the material also needs to partner up with a suitable manufacturing process to give it the desired shape. This makes the choice of material a rather complex job with many different variables to be balanced.

2.4.1 Material science

The modern menu of engineering materials can be categorized into 6 different categories as shown in Figure 7 [12].

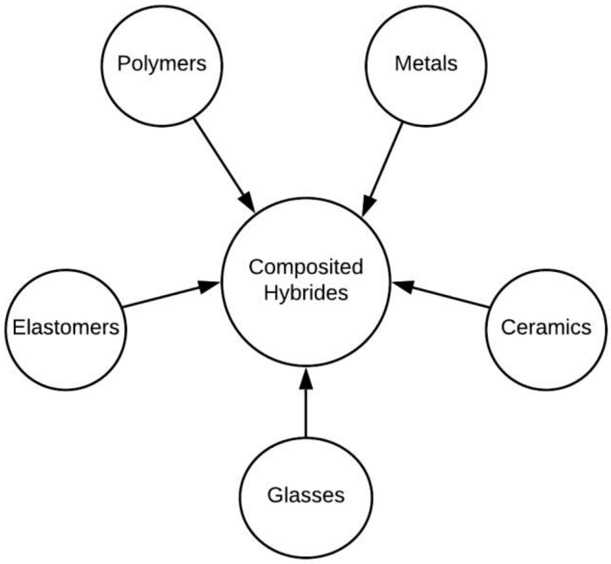

Figure 7: material classes

These different material classes all have different properties which specify the materials response to a specific event. The properties can be categorized as mechanical, electrical, chemical, thermal, magnetic, and optical. The scale of the reaction determines the materials characteristics thus determining the performance of the material for a certain application [13]. The most interesting materials mentioned for snap joints are metals and polymers meaning that the selection process will focus on these two. Previous documentation about the development of the prototype also suggests these two material-groups.

2.4.1.1 Metals

Metals are present in almost every aspect of modern life. In short, metals are tough materials with a high fracture toughness and superb mechanical properties. Pure metals are usually soft and easily deformed thus they are often alloyed, and heat treated to get the desired mechanical properties. This means that metals can be tailored towards a specific application by adjusting its strength, hardness, ductility etc. making them versatile materials for many different structural applications. Besides having superb mechanical properties, metals are also good electrical and thermal conductors and if the alloy contains iron, also magnetic.

Metals are categorized into ferrous, such as wrought iron or steel alloys, and non-ferrous metals such as aluminium or magnesium. The difference between them is defined by their iron content where non-ferrous metals contains little to no iron which often leaves them non-magnetic.

The downside of metals is their reactivity, chemical or electrochemical, with oxidants in their environment. This reaction is called corrosion and can be summarized as the process of converting a refines metal to a more chemically stable oxide, hydroxide or sulphide. The most common type of corrosion is rust, which deteriorates exposed metals over time [13].

Corrosion can be prevented by alloying iron with e.g. chrome which forms a protective layer on the surface of the metal or by using a different type of metal that does not corrode in the intended environment. Aluminium is a commonly used metal which, similar to chrome, forms a protective layer that corrodes much slower than the bare metal [13].

2.4.1.2 Polymers

The word polymer often includes plastics and elastomers. Polymers are long chains of monomers which in turn is a molecule that can be bonded to other identical molecules. Simply put, a polymer is a gigantic molecule made from smaller identical molecules. Similar to metals, polymers can be tailored for the intended application by mixing additives to an either naturally occurring or man-made polymer. Polymers can be categorized into three categories: Thermoplastics, thermosets and elastomers.

Thermoplastics are known to become pliable or mouldable with an increasing temperature making them somewhat reusable whereas thermosets cannot be reused or reshaped with heat. Thermoplastic is usually softer and weaker than thermosets which are stronger but more brittle. A typical thermoplastic is polyvinyl chloride (PVC) used in water bottles and a typical thermoset is polyurethane (PU) typically used in car parts. From an environmental point of view thermoplastics is the preferable type of plastic since its ability to be remoulded with heat makes them recyclable.

Elastomers are polymers with viscoelastic properties, meaning that they are both viscose and elastic. They are usually weak, have low young’s modulus but feature a rather high failure strain. Elastomers are commonly used in seals, O-rings, tyres, adhesives or flexible moulds and are commonly referred to as rubber.

The main benefit of polymeric materials is the freedom of shape and properties they offer. Meaning that by adding different additives to the polymer slurry different characteristics can be achieved. The most common additives are fibres to reinforce the polymer, colorants, stabilizers, processing aids such as lubricants, fire retardants and filler.

The main drawback of plastics is their production process and the management of plastic waste. The production of polymers is a chemical process where different liquids are mixed with additives according to the recipe of a specific polymer. This process often involves the use of strong, toxic chemicals; especially the additives are usually very toxic. Especially the environmental aspects of polymers need extra attention when utilizing this material group [12] [14].

2.4.2 Material selection

Many times, the material selection is dictated by the design. But choosing a material cannot be made without making the choice of process by which the design, and/or the material is made with. Thus, it is often the case that the choice of material and process is made before the design-work is finished. This gives the developers the chance to tailor fit the design to the production system. This is especially beneficial when a company already have a certain production process in use and the huge investment needed for a new one is not justifiable.

The menu of engineering materials as presented in Figure 7 comprises more than 160 000 different materials. This vast number of different options makes the material choice a complex task that often requires a systematic approach. This systematic approach can be summarised into four steps [12].

1. Translation of design rules to material properties
2. Screening of material that do not pass threshold values
3. Ranking the materials that passes threshold values according to their capabilities
4. Search for supporting/complimentary information that supports the chosen material

To start the selection process the intended design need to be analysed. This analysis is used to answer the questions stated in Table 2 which serve the purpose of translating products functions and attributes to material properties [12].

Table 2: Problem analysis template

Function	What does the component do?
Objective	What non-negotiable conditions must be met? What negotiable but desirable conditions must be met?
Constraints	What is to be maximised or minimised? What threshold values need to be met?
Free variables	Which design variables are free?

When deciding on which demands and constrains to be put on the material one needs to differentiate between hard and soft constrains. Hard constrains, like stiffness and strength, are absolute requirements whereas soft constraints such as cost might be negotiable and are not influencing the basic functions of the product.

Defining material attributes and threshold values does not help the screening and selecting of potential materials. The next step in the selection process demands a detailed database with materials and their attributes to screen against. The database of choice for this project will be the *Cambridge Engineering Selector (CES)* which is a software-based database containing material data, process data and environmental information. This software can be used to produce Ashby-charts, named after Michael F. Ashby, who developed the software together with Granta Design. These charts are scatter plots displaying one or more properties of many materials or material classes. Ashby-charts are useful when comparing the ratio between different properties thus making it easier to find the e.g. stiffest and lightest material [15].

To start the screening process with *CES Edupack* the defined attributes need to be rewritten and derived into performance indices. A performance index is an equation that numerically quantifies the desirability of a material for a specific application. The better the performance index, the better suited is the material. The performance index is utilized together with the Ashby-chart and visual inspection will reveal the best performing material for the application. A Performance index can be minimized or maximized depending on the set objective.

2.5 Manufacturing process

The process is a method used to join, shape, or finish a material to its final form. The optimal choice of process for a particular product or part depends on the shape, size precision and production volume of the design. These requirements, often called design requirements are used in a similar fashion to the material requirement, to screen the available processes.

The available processes are categorized into different process families; Primary shaping, secondary process, joining and surface treatment. Primary shaping such as casting is used to get a near-net shape to the raw material. The secondary process e.g. machining is often used to get the necessary tolerance in the case that the primary shaping is not sufficient enough. Lastly the parts need to be joined together with e.g. snap fits or welding and undergo a surface treatment such as anodising or painting to protect the raw material from the environment.

Selecting a process utilizes the same four steps as the material selection:

1. Translation of design rules to process properties
2. Screening of processes capabilities that do not pass threshold values
3. Ranking the processes that passes threshold values according to their capabilities
4. Search for supporting/complimentary information that supports the chosen material.

Besides these four steps designers should be aware of the economic aspects of the process selection because an important part of how much a component will cost is the manufacturing costs. Therefore it is important to choose a process that keeps the manufacturing cost to a minimum. This means that the design of a new product needs to be tailored towards a company's existing manufacturing process to avoid expensive purchases of new equipment. Another process might be a better choice for a certain product, but it might not be profitable for the company in the long run.

To avoid unnecessary costs, it is therefore advised to keep the following things in mind when choosing a process [12]:

- **Keep things standard.**
  It will almost certainly be cheaper to buy a standard screw, metal profile, rod, tube etc. instead of manufacturing your own customized design.

- **Keep things simple.**
  Think about how the process works and try to minimize the steps needed e.g. avoid using multiple radii to avoid the need for the CNC-operator to change tool.

- **Make parts easy to assemble**.
  Minimize the number of parts, design the part to be self-aligning and use snap-fits instead of screws or adhesives.

- **Do not specify more performance than necessary**.
  Performance equals cost, meaning that the tighter the tolerance the more expensive will the process be.

2.6 Testing and approval for automotive use

Before a product can be commercially used on the roads in Europe it needs to get certified according to the demands set by the European Community Whole Vehicle Type Approval. The certification encompasses all components situated on vehicles and its purpose is to ensure that vehicles meet relevant environmental safety and security standards. Part of the ECWVTA approval encompasses Electromagnetic compatibility which is relevant for any signal emitting components. These demands are very extensive thus this thesis will not ensure or test if the product will achieve the ECWVTA approval but will keep the demands in mind during development.

3 Product Development Process

This section describes the product development process used when developing the concept. Both methods and results are described in chronological order.

As mentioned before, the development project has been going on for some time. This means that this thesis has the task to evaluate and iterate the current solution and come up with new ideas and improvements. The upper row in Figure 8 shows the stages of a generalized product development process. The lower flowchart shows the process of this project and where it fits into the bigger picture.

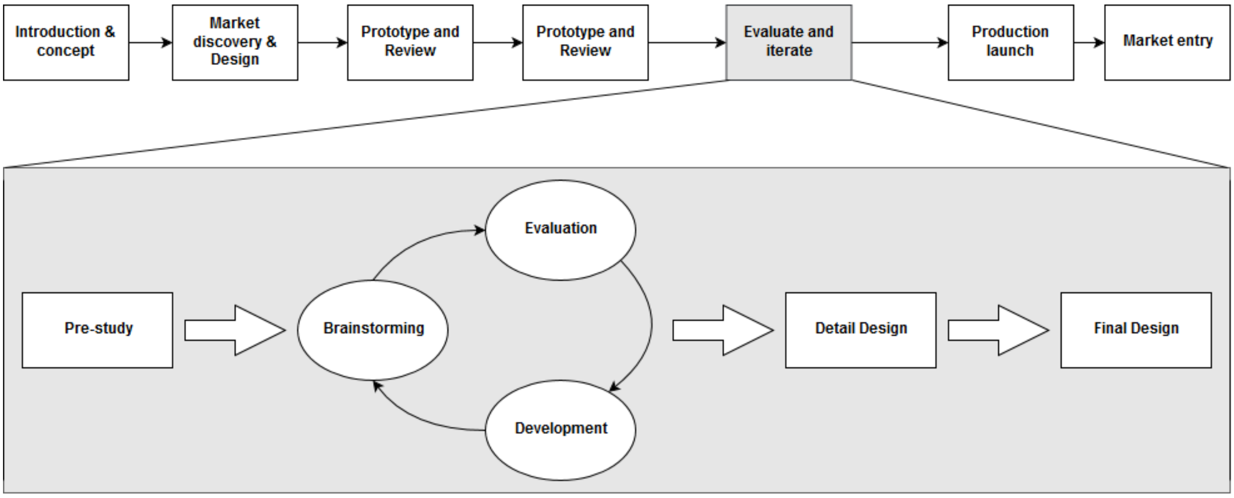

Figure 8: The development process

3.1 Pre-study

The initial stage of the development process started with a more or less unstructured pre-study which later turned in a more target-oriented literature study as the project learned more about the task at hand.

3.1.1 Black box Modell

In order to get a brief overview of how the already developed concept works and what in- and outputs the system has a black-box model was created. This served the sole purpose of visualizing and understanding the product architecture and functions of the concept, se Figure 9.

The inputs into the radar sensor:

- Electricity to power the electrical components inside the casing.
- Radar reflection, the reflection from the previously transmitted radar signal.
- Vibrations, which are transferred to the casing from the truck during operation.
- Impacts from foreign objects, such as gravel from the road and accidental hits by a snow shovel.
- Environmental factors, such as snow, rain, sunlight, cleaning solvents and salt from the road.

The outputs from the radar sensor:

- Heat generated from the electronics inside the casing.
- Radar signal sent by the radar PCB.
- Trailer position signal which calculated with the PCBs is sent to the truck.
- Environmental factors being removed or reflected from the casing.

The reasoning behind environmental factors being both an input and output is that it is desired to remove for example snow from the casing, so it does not disturb the function.

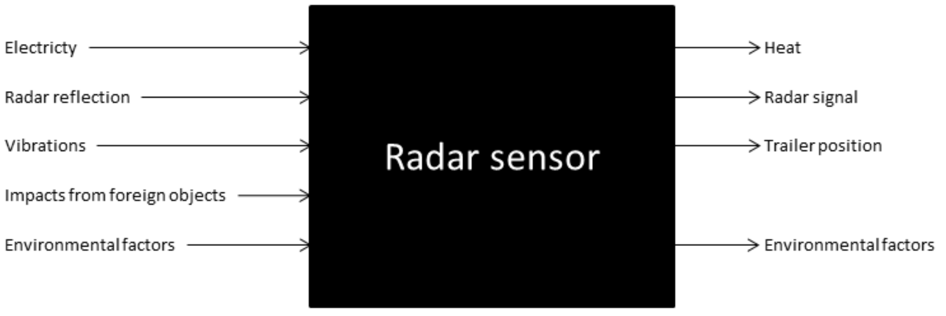

Figure 9: Black box model illustrating the inputs and outputs of the radar sensor unit

3.1.2 Function Flow diagram

To more thoroughly understand the sensor units' inputs, outputs, functions and how they interact, a Function flow diagram was made. The inputs and outputs were previously identified using the black box method and used unaltered in the function flow diagram. The functions were identified by examining drawings of the current concept, reading informational slides and meeting with the previous project owner and other project associates [16].

To also illustrate how the sensor unit interacts with the auxiliary systems power source, visualization tool for the driver and the signal reflectors they were also included in the diagram. Those were however simplified, and the diagram only handles the functions performed that are vital to the sensor unit.

In the diagram the auxiliary systems are marked with a grey box and the sensor unit's system limit is marked by a dotted line. All inputs and outputs pass over the system limit and all functions performed by the sensor unit are within it, see Figure 10: Function flow diagram illustrating how the different functions of the radar system interact

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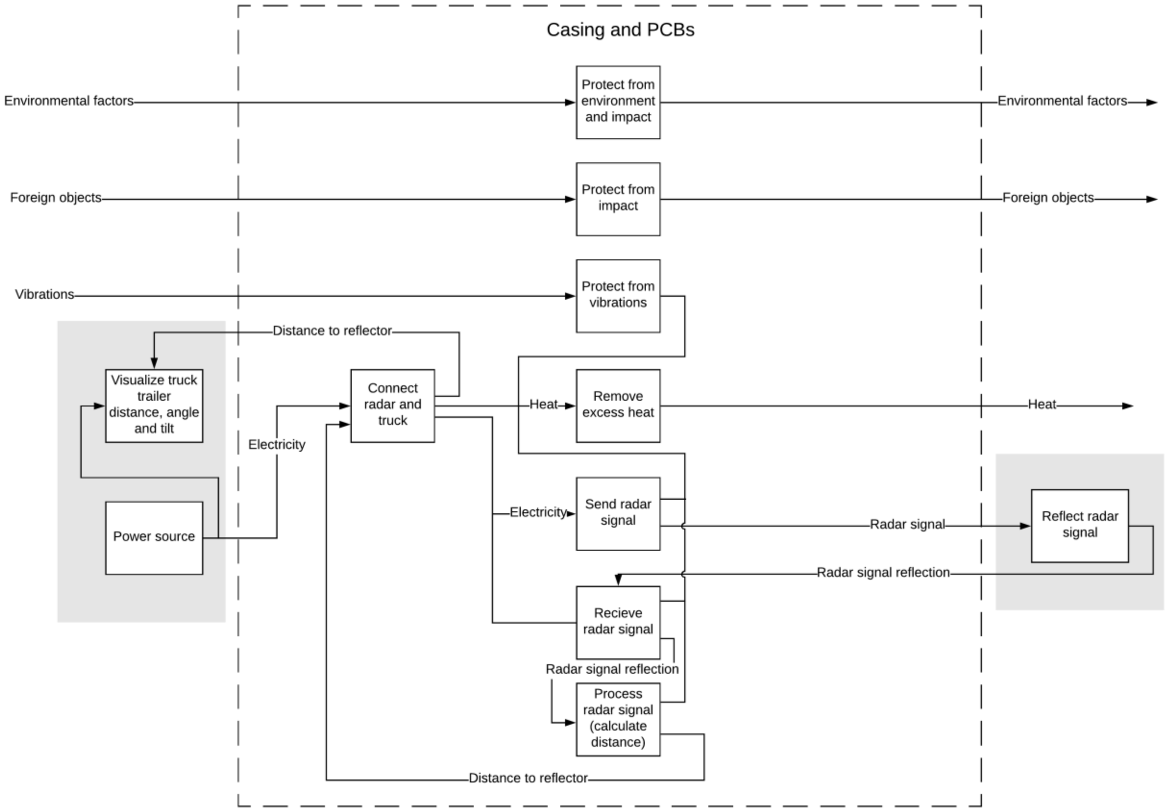


Figure 10: Function flow diagram illustrating how the different functions of the radar system interact

3.1.3 Scenario descriptions

By making simple sketches together with scenario descriptions one can easily visualise the environment the casing is mounted in. This serves the purpose of understanding the different loads the enclosure must cope with. Not every possible scenario is discussed but the selected scenarios cover what was assumed the most strenuous for the enclosure.

3.1.3.1 Scenario 1 – Harsh weather

The box is to be mounted on the lower parts of the rear bumper on a truck. The type of truck can vary from delivery trucks in hot and humid cities to timber trucks delivering wood to a remote sawmill in near arctic temperatures. The scenario at hand is therefore the usage in harsh weather. See Table 3, Figure 11 and Figure 12 for how the environment could be in these conditions.

Table 3: Loads of scenario 1

Loads:	• Temperatures (-30°C to +85°C) • Water from the road • Possible ice built up • Direct sunlight • Dust

Figure 11: Picture of a truck in a warm and dusty environment taken from [17]

Figure 12: Picture of truck in artic environment as taken from [18]

3.1.3.2 Scenario 2 – Cleaning the truck

Trucks tend to get rather dirty when used in a variety of different road conditions. This means that the trucks are getting cleaned every now and then. Usually an industrial grade pressure washer together with some kind of soap or degreaser is used to get the truck clean again. This method of cleaning puts heavy mechanical and chemical loads on involved parts. See Table 4 and Figure 13 for how the environment could be in these conditions.

Table 4: Loads of scenario 2

Loads:	• Temperature (up to 80°C) • Water pressure (up to120 bar) • Chemical loads from cleaning agent • Possible hits from brooms or brushes

Figure 13: Picture of truck in a truck wash

3.1.3.3 Scenario 3 – Winter corrosion

This scenario encompasses both the corrosive environment of coastal areas as well as similar man-made environments such as the use on salted roads in the winter. The prolonged exposure to salt can be particularly stressful for metal parts. See Table 5 and Figure 14for how the environment could be in these conditions.

Table 5: Loads of scenario 3

Loads:	• Chemical loads of being covered of a layer of salt. • Wet and cold conditions.

Figure 14: Picture of a road in winter conditions.

3.1.4 Similar products

An important input to a development process is to look at similar product in similar applications to gather valuable knowledge and inspiration to the development effort. During the pre-study phase a few products were discovered to have similar attributes as the sensor prototype and where further analysed in a benchmarking. The different products range from radar sensors on cars and rugged cameras to auxiliary lights on construction vehicles.

3.1.4.1 Rugged camera

A rather similar application to the sensor is cameras mounted on vehicle e.g. backup cameras, cameras for autonomous vehicles and cameras mounted for film production. These cameras need to keep a rather delicate piece of equipment safe from mud, dust, mechanical impacts and vibrations.

One interesting manufacturer is *Dotworkz* who offer a modular camera casing called BASH, which stands for *Ballistic Anti-Shock Housing*. This casing is highly adaptable for many different applications and can be tailored to suit many different cameras and sensors and applications. It features amongst others an exchangeable lens, different mounting solutions for cameras and internal heating for arctic applications. Lenses are available as clear, tinted, metalized, dome-shaped or even with ballistic properties [19].

Figure 15: Backside of BASH camera housing

Figure 16: Fronstide of BASH camera housing

Figure 17: Lens options for BASH

Table 6: Relevant features of BASH

Relevant features of the *BASH* housing [19]
IP68 Sealed per IEC 60529
Vibration resistant per MIL-STD-810G
IK10+ Protective lens element
TYPE III Hard Anodized 6061-T6 Aluminium Alloy
Polycarbonate + Polyester thermoplastic blend for strength and chemical resistance
316 Stainless Steel fasteners for corrosion resistance

The interesting choice of design with a back plate with cooling fins and the material choice are especially interesting and will be used as input for the brainstorming.

3.1.4.2 Auxiliary light on vehicle

Many different utility vehicles have auxiliary light sources. These light sources often come as separate add-ons that are mounted on the exterior of the vehicle. The placement of these lamps exposes them to the same kind of scenarios as the earlier presented prototype. Similar to the sensor prototype, the hardware in auxiliary lamps needs cooling which is usually solved by integrating some sort of cooling fins into the casing itself.

Manufacturer of these lamps offer different designs for different applications. Lamps for off-road use or construction equipment often have a higher IP- and IK-classification compare to models aimed at road cars. One example of auxiliary lamp for off-road use is shown in Figure 18 and Table 7.

Figure 18: Hella RokLUME 380 N [20]

Table 7: Relevant features of Hella RokLUME 380 N [20]

Relevant features of *Hella RokLUME 380 N*
Integrated DT connector (similar model as the prototype)
IP6K9K / IP6K8
Sturdy aluminium casing
Die casted aluminium bracket
Passive heat dissipation of the LED electronics with cooling ribs
High impact hard coated PC lens
Double insulated silicon supply cable with DT Connector

The manufacturing process and the material choice are particularly interesting since these lights are produced in high numbers for a similar market. The lamps often come with either a fixed extension cord that is sealed with a cable gland or some sort of connector. The RokLUME 380 N features a version of the DT-connector which is the same type used on the sensor prototype.

3.1.4.3 Automotive sensors

The modern car features many kinds of sensors. Certain models feature a radar sensor as part of a collision warning system. The radar sensors of these cars are often positioned in or around the front grill thus exposing it to the harsh environment of the road. Different car manufacturers have different solutions, sensors and mounting solutions e.g. Volvo who has chosen to place a radar sensor just behind the front grill on the earlier models featuring radar whilst Volkswagen chose to place it lower to the ground, almost underneath the vehicle, see Figure 19. Certain similarities to the previously described sensor prototype can be noted e.g. the Volvos sensor features a vent similar to the prototypes. Volvos sensor can be seen in Figure 20 and Figure 21 [21] [22].

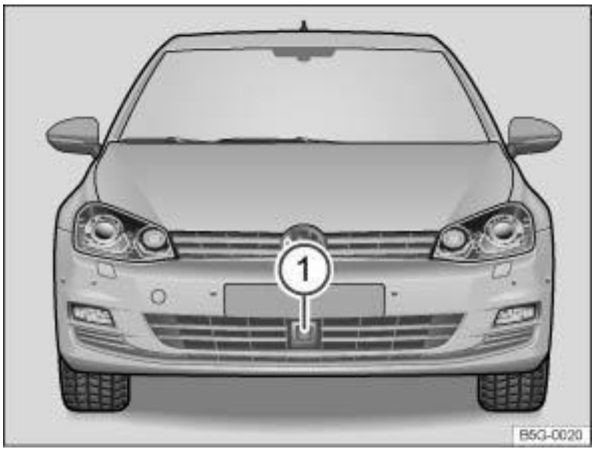


Figure 19: Volkswagen radar sensor position

Figure 20: Placement of Volvo radar sensor


Figure 21: Closer view on Volvos sensor unit

3.1.5 Update of requirements

The demands and requirements provided to the project group were rather sparse and lacked a proper summary. The existing requirements were therefor updated with new standards and demand and summarised into a product specification that can be found in appendix B.

3.2 Concept Generation

The first iteration of the concept generation started of early into the project in order to catch the initial thoughts of the project group before any biases from the company or others were induced. A multitude of different methods were used including *Stop n' Go* and *Brainwriting* for an unstructured brainstorming as well as a *Morphology matrix* for a more structured approach. Besides this, the group adapted a daily brainstorming session to their daily routine meaning that each member was obliged to write down one idea every day.

3.2.1 Stop n'Go and Brainwriting

The initial brainstorming session utilized two different methods together, at the same time. The first one is called *Stop n'Go* and basically allowed the participants to rest, think and reflect in between each idea generation session. Every idea generation session was divided into two blocks of 4 minutes each. One block to actively document the ideas and one block to reflect and think about the generated idea or the session in general.

The second method used in combination to *Stop n'Go* was *Brainwriting*. This method involves every participant to write or draw their ideas on a paper, without interruption of others, and pass them on to the next participant who can use the previous ideas to generate new ones. The method was used to document the ideas generated in the first block of *Stop n'Go*. The focus of each Brainwriting block was put on one function/attribute at a time. This means that each session should generate ideas for solving one of the following questions:

- How to connect the sensor to the truck?
- How could the design and the assembly process look like?
- How can the enclosure offer cooling for the PCB?
- How can the casing offer protection against impacts?
- How can the enclosure protect the PCB from the environment?

By utilising both methods and combine them, the participant were treated to a more structured way of Brainwriting with proper brakes between each session to gather and organize new thoughts.

3.2.2 Daily brainstorming

Both *Stop n'Go* and *Brainwriting* are organized methods where participant had a limited amount of time to freely generate ideas and where influenced by each other's ideas. To contrast this, a more relaxed method called *Daily brainstorming* was used. This method lacks any hard-set rules and allowed the participants to generate and document ideas however they please. The only rule is that at least one idea or thought had to be documented per day. This daily routine was adapted over the duration of the concept development and the concept evaluation.

3.2.3 Morphological matrix

This technique provides a more systematic and structured approach to concept development compared to the other methods. The goal with this method is to consider every possible combination of the generated ideas and generate as many complete concepts as possible.

By putting each function to be solved in the columns of the matrix and each functions solution on the rows it becomes easy oversee the process of combining each solution. The large number of possible combinations makes both the generation process and evaluation process a time-consuming task.

3.2.3.1 Sub-solution evaluation - Elimination Matrix

An Elimination Matrix was utilized to aid the generation of complete concepts with the Morphological matrix. If all generated ideas were to be used the amount of possible combinations would have been to many to properly investigate. By sorting out ideas that are too far-fetched or simply fail to meet the needs and demands the amount of possible combinations could be reduced to a more manageable level. This method used was, as the name implies, a matrix featuring every generated sub-solution and grades them whether they were feasible or not according to a set of criterions. The chosen criterions where the following:

1. Does it solve the problem?
2. Is it realizable?
3. Is it economically feasible?
4. Does it suit the product image?
5. Do we have enough information about it?

Each sub-solution got graded with a pass (+), fail (-) and uncertain (?) for each of the mentioned criterions. The grades then determined if the concept would be further investigated or discarded. Each concept graded with (?) underwent further investigation and new data was gathered to eliminate any uncertainties.

This evaluation process gives a rough estimation of which solutions are the most promising by combining hard evidence and the gut feeling of the involved parties. This still means that the very best ideas and concepts are to be discovered but gives the effort a certain direction to head in.

3.3 Concepts

At this stage eight promising concepts had been developed. The demands put on the concepts by the PCB and the requirement specification caused them to be rather similar in shape and size. The major differences between each concept are found in the way the lid is attached to the bottom part. Every concept was visualized as a CAD model for further evaluation.

3.3.1 Concept A – Internal snap-joints

This very first concept resembles the older prototype in many ways. A metal bottom casing together with a polymer lid forms the two main components of the enclosure. The lid is attached with internal snap-joints in comparison to the screws used in the prototype. The intention with internal snap-joints is to keep them protected from mechanical wear and to keep the design as clean as possible.

Two versions of concept A featuring different mounting solutions where discussed. The first one resembles the mounting solution of the prototype whilst the other one is more integrated into the metal component. Figure 22 shows concept A with the mounting solution of the prototype. Figure 23 shows concept A with 4 different pads, one in each corner, where threaded holes allow fasteners to attach directly to the casing. The concepts where considered to be too similar to each other to be separated as two different ones.

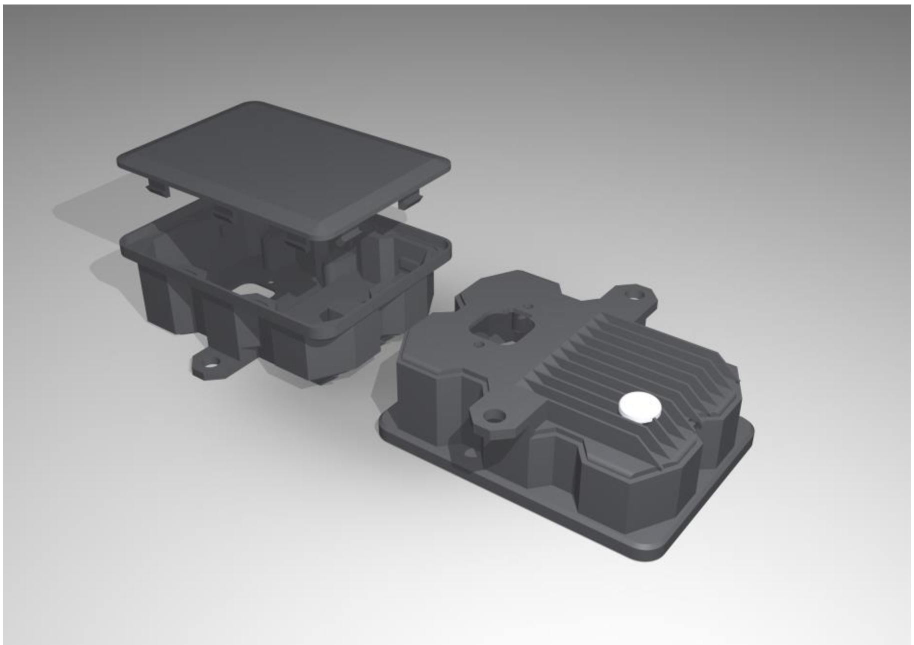


Figure 22: Concept A with ears as mounting solution

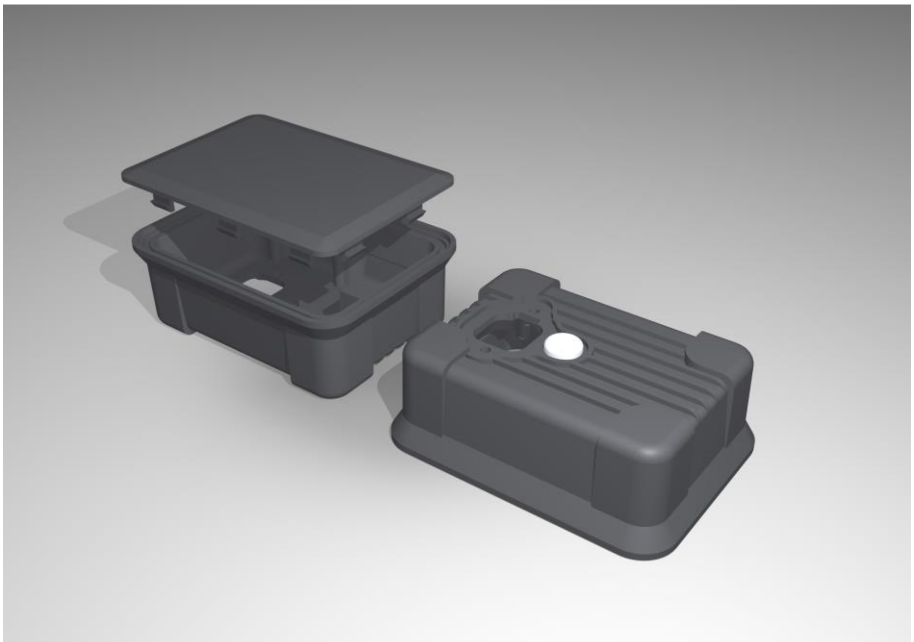


Figure 23: Concept A with Cone shaped holes for self-threading screws as mounting solution

3.3.2 Concept B – Slim fit

During the investigation of the prototype it was discovered that there was a lot of dead space around the PCB. The intention of concept B was to eliminate this space and tightly wrap the enclosure around the PCB. To further reduce the size of the assembly the possibility of gluing the lid to the bottom casing was discussed. The fastening solution for mounting the sensor to a truck was also integrated into the bottom casing to minimize the width of the casing. Concept B is visualised in Figure 24.

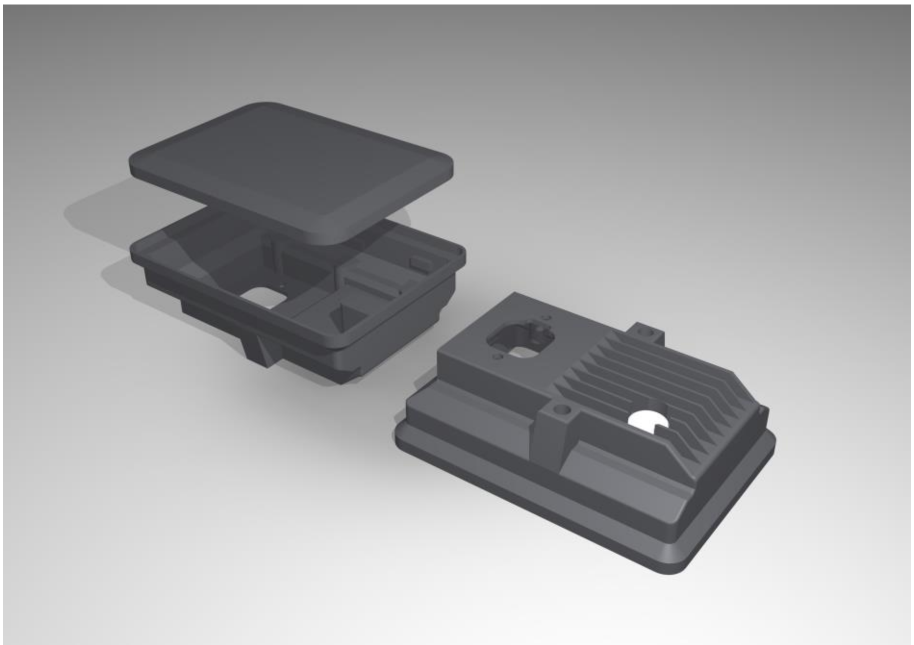


Figure 24: Concept B as a simplified CAD model

3.3.3 Concept C – Sandwich

Concept E is inspired by the BASH camera presented in Section 3.1.4.1. Multiple components assembled in a sandwich makes it possible to customize each component towards certain features. The middle part of the sensor could be made from another material than the back plate making the sensor lighter and perhaps even cheaper. A metal ring surrounding and supporting the lid would offer impact protection and stiffness leaving the possibility to make the lid itself out of a material with tailored electrical properties. The concept is visualized in Figure 25.

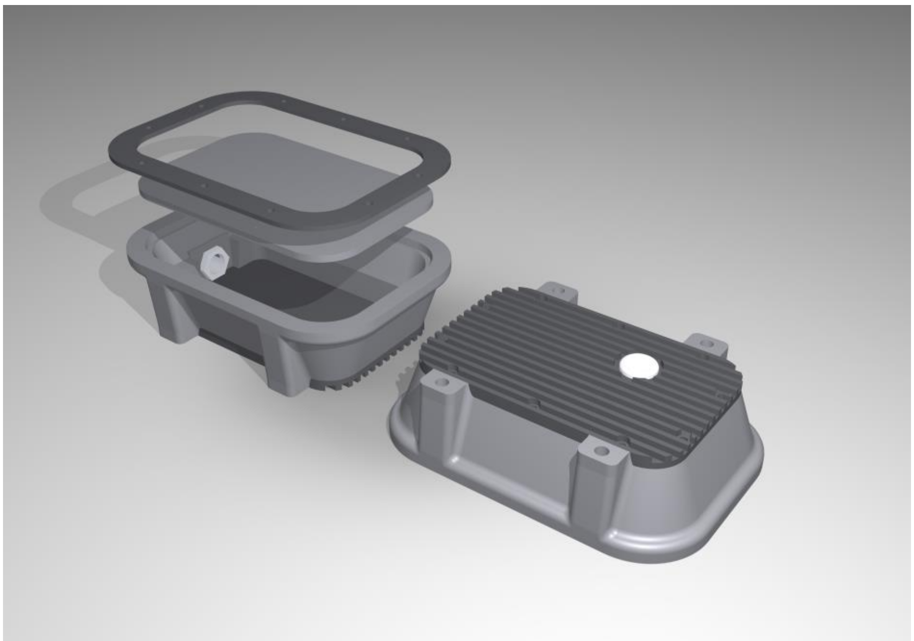


Figure 25: Concept C visualized as a simplified CAD model

3.3.4 Concept D - Screws

The intention with concept D was to keep screws as fastening method but to reduce their number. The reason why the prototype used so many screws is the need of an evenly compressed O-ring. Reducing the number of screws in the less stiff prototype would make it difficult to seal if the design is not altered. This concept would increase the stiffness of the lid whilst keeping screws as a proven and simple fastening method without the need of complex snap-joints. Concept D is visualized in Figure 26.

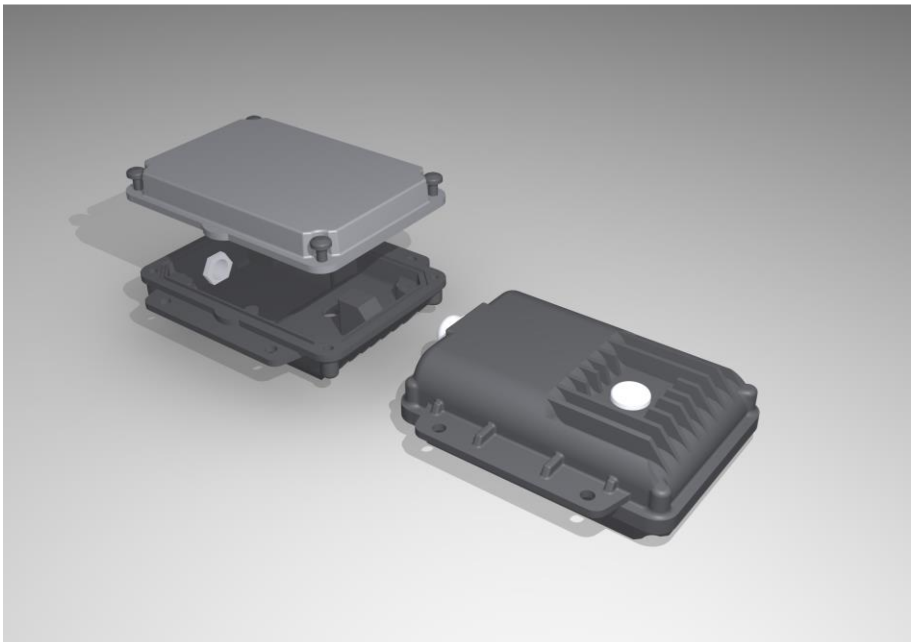


Figure 26: Concept D visualized as a simplified CAD model

3.3.5 Concept E – Outwards snap-joints

Concept E is rather similar to concept A with the difference that the snap-joints attach in the outside of the casing. The benefit of these types of snap joint, compared to internal or hidden ones is easier quality control meaning that a worker can clearly see if the snap-joints are seated correctly or if there were any defects during the assembly process. This design does, however, leave the snap joint exposed meaning they could be accidentally opened by a mechanical impact directly on the joint. On the other hand, such easily excusable snap-joint would make the disassembly process less time consuming. Concept E can be seen in Figure 27.

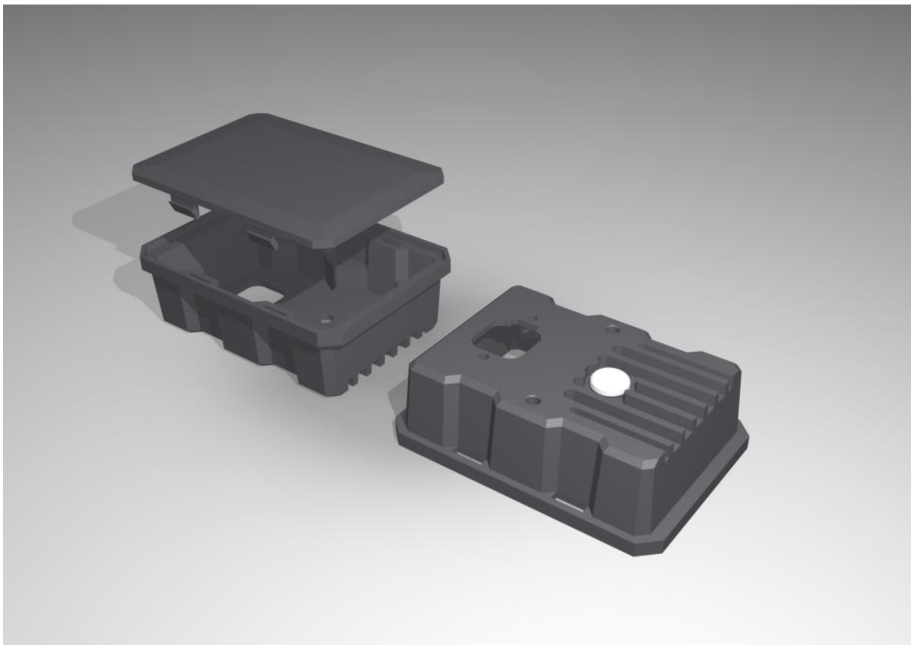


Figure 27: Concept E visualized as a simplified CAD model

3.3.6 Concept F – inward snap-joints

This concept is similar to concept E. It has similar features, but the snap fittings are design without the protective outer rim that is protecting the snap fittings of concept E. By excluding the protective outer rim, the casing gets a much simpler geometry around the upper edge. This is supposed to lower the manufacturing cost of the casing. Another difference is that instead of having multiple smaller snap fittings the design features a few larger ones to make the O-ring compress more evenly. Concept F is can be seen in Figure 28.

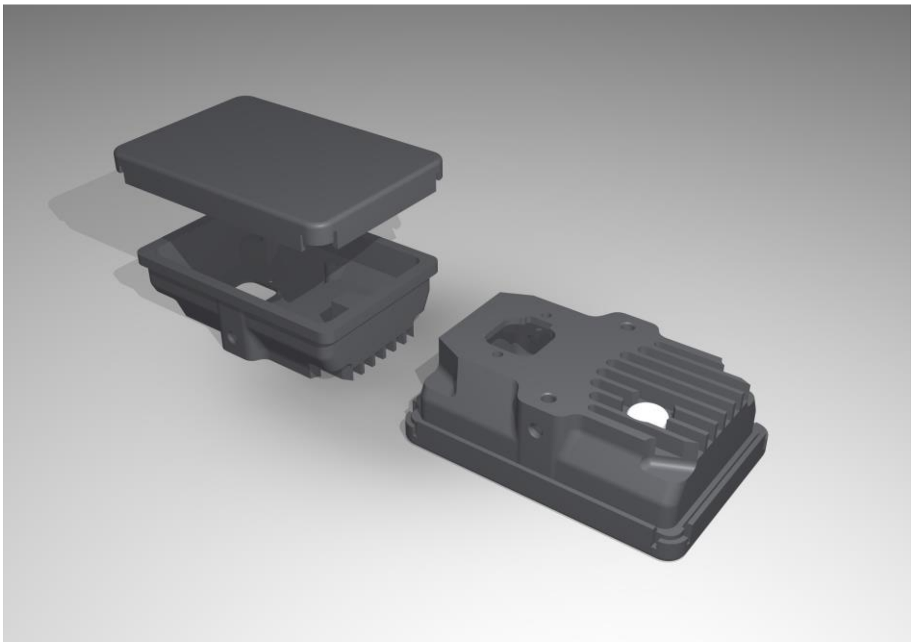


Figure 28: Concept F visualized as a simplified CAD model

3.3.7 Bonus Concept I – Metal Clips

This concept was developed after the others and focuses solely on the fastening mechanism of the lid to the casing. The idea utilizes metal clips to snap the lid and casing together. This could reduce the complexity of the lid and the bottom casing leading to reduced manufacturing costs. The clip could also be made out of a stronger material that is led prone to creep whereas the material of the lid could be optimized for the needed electrical properties. Similar solutions are found on e.g. Volkswagen's radar sensor presented in section 3.1.4.3.

3.3.8 Bonus Concept II

This concept was developed during the daily brainstorming and it intends to improve upon the previous prototype by reducing the amount of screws needed during assembly. It does this by having longer screws that fixate both the PCB and the lid. The intention is to minimize the size of the sensor unit without the use of potentially toxic glue.

3.4 Concept evaluation

After developing the concepts an evaluation process needed to be utilized to systematically screen them for a superior solution. This is often rather hard to carry out due to varying quality of information about each concept.

3.4.1 Pugh matrix

This simple but effective method scores each concept relative to a reference. Each concept is evaluated according to the following six criterions:

1. Complexity
2. Material usage
3. Durability
4. Assembly time
5. Recyclability
6. Size

When another concept outperformed the reference, it was given the grade (+1), if it was equal it was graded (0) and if it performed worse the grade (-1) was awarded. The points are then summed up and the concepts can be ranked. The one with the highest points is considered the most promising concept. This process can be repeated multiple times with different references eliminating one or more inferior concept each time. The entire process needs to be supported by facts, but a decision may very well be based on the gut feeling of involved parties.

For the first round the current prototype was used as reference. The matrix can be seen in appendix C. Concept C and extra concepts I and II where ranked as the three last concepts thus eliminating them from further evaluation.

Another Pugh-matrix was then made with the same criteria but with concept A as a reference instead since it was one of the highest ranked concepts in the first matrix. Concepts A and D ranked the lowest and were eliminated. Concept D elimination was largely because of screws as fasteners. However, the design of the Lid was very promising in terms of its potential stiffness, so it was passed on as an idea for the detail design of the enclosure. This left concept B, E and F as the most promising contenders. The second Pugh matrix can be seen in appendix D.

To further investigate the different fastening alternatives of the lid to the casing itself a comparison of the assumed pros and cons was made to motivate and explain the choice of winning concept. Table 8 shows this comparison.

Table 8: Comparison between different solutions for joining the lid and casing

Solution	Pros	Cons
Internal snap joints (Concept A)	+Protected from external factors +Not visible from outside +Fast assembly	-Complicated moulding process -No easy way to confirm the snapping joints are all attached/functional
Adhesive (Concept B)	+Allows for a smaller casing design. +No need for an O-ring	-Longer assembly time and larger investment in production. -Less recyclability. - cannot be opened.
Screws (Concept C and D)	+Fast/easy to disassembly +Easy to manufacture	-Assembly time -Increased number of components
External snap joints pointing outwards (Concept E)	+Easy to produce with moulding +Fast assembly +Easier to disassembly	-Vulnerable to hits -Easy to re-open
External snap joints pointing inwards (Concept F)	+Fast assembly +No metal rims	-Vulnerable to hits -May requires thicker plastic material to cope with mechanical wear

The conclusion of the comparison is that although adhesives might result in a smaller enclosure, it might not be the best options in terms of serviceability and recyclability. In terms of serviceability, internal snap-joints suffer from similar problems. If the enclosure needs to be opened in the feature adhesives and internal snap-joints are the least suitable choices.

This leaves screws, and external snap-joints as the most promising options. Screws, who offer an easy and safe way of keeping the enclosure shut, were previously ranked lower than snap-joints (see the second Pugh matrix) due to their time-consuming assembly/disassembly and because of the need for increased inventory management. A snap joint is simply more suited towards a DFA focused product making it the top contender for this enclosure.

3.4.2 Kesselring evaluation

To further strengthen the findings of the Pugh matrices and the comparison of the joining solutions a Kesselring matrix was utilized. It works in a similar fashion as the Pugh matrix but has five intervals of which a criterion can be judged along with all criteria being weighted. The score on each criterion is calculated by taking their weight and multiplying it with their score. A concepts final score is equal to the sum of the scores of all criterions.

The five criteria used were:

1. Manufacturability, how easy it would be to manufacture the design depending on the shape and complexity of the design [23].
2. Size, how much smaller or bigger the design would have to be for each solution.
3. Recyclability, how easy it is to recycle the parts depending on design.
4. Design for assembly, how fast, cheap and easy it is to assemble depending on design.
5. Failure risk, a combination of the risk, severity and easy of discovery of encapsulation failure due to design.

When trying to judge the concepts it was discovered that too much information was uncertain or lacking surrounding multiple criterion. This information would however become more available later in the project. Therefore, it was decided to only evaluate the joining method between the lid and casing, along with their consequences for the final design of the enclosure.

The joining method is also the biggest factor for how the rest of the casing has to be designed. Small details such as placement of vent and exactly how the casing should be mounted to the truck would be easy to alter during detail design phase as customer need would be better defined. Furthermore, the different shapes of the casing were very similar to each other and would receive similar scores on most factors. The shape of the casing is also a less adaptable feature since the given PCB is a fixed parameter.

After scoring concept E which uses external snap joints pointing outwards, emerged as the clear winner of the evaluation. Due to the snap joints being on the outside of the casing and pointing outwards it received good scores on *Manufacturability*, *Recyclability* and *Design for assembly* which distinguished it from other concepts.

Concept D which uses screws to fasten the lid scored second highest due to the overall reliability of the design. It did however score lower on recyclability and design for assembly due to additional materials and services needed when using screws. Although the assembly time for screws can be considerably higher than with snapping joints it still scored highly on *Design for assembly* due to the simplicity of the solution.

The other three concepts were eliminated; the other solutions utilizing snapping joints received lower scores on many criterions thus eliminating them from further development. Using adhesive looked promising since it would result it the most compact solution but since it would require additional equipment and stages during assembly for the adhesive to be applied and setting. It also received a lower score on *Failure risk* since if one part of the seal fails it is compromised. Screws and snap joints on the other hand relies on multiple points and one screw or snap joint failing does not mean the seal is compromised.

When considering the environmental aspects of the evaluated solutions adhesives would rank lower than the others as well. This is due to the potentially toxicity of the adhesive and the lower recyclability (as explained in section 2.2.3). Screws may also rank slightly lower compared to snap-joints since using screws induce a higher material diversity and a more time-consuming disassembly of the part at its end-of-life. The complete Kesselring matrix can be seen in appendix E.

3.5 Detail design

The next phase of the development process is to further refine and optimise the selected concepts. Before starting the design work a couple of guidelines where set up to aid the design-work:

- **Keep things simple**
  Basic interfaces, simple geometries etc. will make things easier to seal.

- **Avoid complex interfaces/seals**
  A more complex interface will make it harder to achieve the required gasket compression.

- **Tortuous and indirect path to the seals**
  To keep the seals as protected as possible the path towards them should be full of steps and walls and not directly expose them to the environment. This contradicts the first guideline but is a necessity to seal the enclosure for prolonged periods of time.

3.5.1 Seal Design

The demands on seals for automotive applications are numerous and under constant change as technology advances. The most important factor to consider when designing a seal for automotive use is the temperature, the compatibility with chemicals and the interface that is to be sealed.

The following summarises the demands on the seal of the enclosure:

- The seal needs to be compatible with the set chemical demand presented in Appendix F.
- The seal needs to suit a low pressure, static applications since no mowing part are to be sealed and no pressure is above or below atmospheric pressure due to the vent.
- The seal has to work in temperatures specified in the product specification (specification 1.6-1.7) in Appendix B.

The following three types were found to be the most suitable alternatives:

- Casted seal
- Solid O-ring
- Hollow O-ring

A casted seal would be the safest option. The seal is casted directly in a grove on the part thus the demand off a pre-machined grove can be omitted. Whilst a casted seal still demands a grove to be casted into said groove can make do with considerably lesser tolerances compared to regular O-rings. Compared to a regular O-ring a casted seal can be made into intricate shapes whilst regular O-rings would have trouble being seated correctly around tight bends and sharp corners. The downside of a casted seal is the costly casting equipment needed for this process.
The regular O-ring is available in many different materials and sized suitable for many different applications. Both the solid and the hollow O-ring demand a precision machined grove for an even adequate seal. O-rings are available in many different shapes and sizes, the most common being solid and hollow. The solid O-ring demands a considerably higher force to reach the necessary compression rate compared to the hollow design. This means that in a situation that demands for a harder elastomer the needed compression force can be reduced considerably to a more manageable amount by choosing a hollow design.

The choice of material is mostly reliant on the chemical demand. The demands on the seal were cross-referenced with different O-ring materials commonly used in automotive applications. The complete result can be seen in Appendix G. From the six different materials that were investigated two were selected as suitable materials for the sensor enclosure; Nitrile (NBR) and Hydrogenated Nitrile (HNBR). Fluorocarbon (FKM,FPM) was ranked similar to Hydrogenated Nitrile (HNBR) but was discarded due to its high price and unsuitable service temperature [24] [25].

3.5.1.1 Nitrile and Hydrogenated Nitrile

Both materials have similar properties and attributes but with some deviations. Nitrile is the most commonly used material for O-rings because of its low cost, good mechanical properties and resistance to many common chemicals used in automotive applications. Hydrogenated Nitrile has better mechanical properties, can withstand harsher chemical loads and is more resistant to weathering compared to regular nitrile. The drawback of Hydrogenated Nitrile is its working temperature which is between -32°C to +149°C whereas regular nitrile has a temperature range from -55°C to +121°C [25].

These values are generalized and may not apply to specific mediums and applications. Due to the vast number of available additives, recipes and mixes it is generally recommended to test the specific polymer in the intended application and environment.

The material of choice for the sensor enclosure both Nitrile and Hydrogenated Nitrile is a solid choice. Both materials are fairly cheap if compared to other contenders with Hydrogenated being the most expensive out of the two. If a higher cost is defendable Hydrogenated Nitrile would be the better choice since it offers a better compatibility with the chemical demands and superior resistance to weathering. The slightly lesser low-temperature ability of Hydrogenated Nitrile is considered acceptable since the intended application is static rather than dynamic and the extreme temperatures are considered to be rare and short term.

3.5.1.2 Compression load

To get a correct and tight seal a compression load is needed to compress the O-ring. The amount of compression, often called squeeze, is specified as a percentage of the cross section of the O-ring. A static seal usually adopts a squeeze of 30%. The force required to reach said squeeze is depended on the cross section, the Shore hardness of the compound as well as the amount of desired squeeze. For most applications, compounds with a Shore A hardness of 70 to 80. Static, low pressure applications can make do with less hard compounds since abrasion wear and extrusion, when the O-ring gets pushed out of its groove due to pressure, is less lightly.

> ***Shore A hardness***
>
> The hardness of the elastomeric O-ring is measured with a Shore A type durometer. Similar to other hardness tests, the indentation into the material by a given force applied on a standardized object is measured. The Shore durometer is commonly used for measuring the hardness of polymers and a total of twelve different types are recognized by the ASTM D2240 standard. Type A is the one commonly used within the rubber industry [24].

The actual compression force can be simulated but is usually provided by the manufacturer e.g. an Ø3.53mm O-ring from the company Parker with a Shore A hardness of 60 and a 30% squeeze would require 17-28.5 pounds per linear inch of seal (approx. 300 to 510 kg/m) [24].

A hollow O-ring could be utilized to lower the compression force. Parker mentions an example of a regular solid O-ring with Ø6.35mm, Shore A hardness of 70 and a compression rate of 30% who would require 70 lbs/in (approx. 1250 kg/m) of compression force. The same O-ring would only require 20 lbs/in (approx. 357 kg/m) or 2 lbs/in (approx. 35.7 kg/m) if it would be hollow with an inner hole diameter of Ø2.29mm or Ø4.32mm [26].

3.5.1.3 Compression set

Compression set is a phenomenon where air-aging is lowering the O-rings ability to recover after a specific squeeze and temperature is applied over a prolonged time period. This is often referred to as relaxation and is often presented as a percentage of the original thickness/diameter of the O-ring. 0% compression set means that the elastomer has fully recovered, 100% compression set means that that the seal just contacts the mating surface without any compression force.

Although it is generally desired to have the least possible compression set it is not as critical as one might think. By selecting the correct material for the applications the compression set can be counteracted e.g. if the O-ring has a compression set of 20-25% but the medium causes the O-ring to expand 20% which would result in a rather small amount or even no compression set at all due to the volume changes.

Compression set is often a bigger issue when approaching mediums at higher temperatures. At lower temperatures the issue is less prominent e.g. less than 10% for a shore A 70 nitrile with a squeeze of 25% over 70h at <75°C [24].

3.5.1.4 O-ring and groove sizing

The size of an O-ring and its groove is determined by the choice of material and tolerance of the surfaces that are to be sealed. In general terms, a bigger sized O-ring tends to have better resistance to compression set, tends to swell less, and is less likely to leak if surfaces are scratched. A smaller O-ring tends to have better physical properties and require less space but demand tighter tolerances.

When sealing two surfaces against each other with an O-ring in between the worst-case scenario is the situation where no compression force is applied because of thermal expansion/shrinkage, compression set or warping. This means that the distance of the compression (30% of the diameter as previously mentioned) needs to be equal to the maximal amount of deflection the two surfaces can have during use. By having a larger O-ring this distance is larger as on a smaller diameter O-rings. The amount of allowed deflection under the compression load will direct the demands on stiffness of the enclosure's lid, casing and snap-fits [24] [27].

The seal for the sensor enclosure was chosen to be a hollow design with an outer diameter of 3.52mm and an inner diameter of 1.78mm. Together with a Nitrile compound from Parker engineering this would result in approximately 4lbs/in (71.4 kg/m) compression force at 30% compression. A hollow design would mean that the seal is produces as a continuous seal that will need cutting and splicing. The chosen O-ring, with the chosen deflection rate, would give approx. 1mm of possible deflection before a gap would form at 0% of compression set [26].

The groove for this O-ring design is often specified by the supplier. For the chosen hollow O-ring multiple attachment options and seal designs are available. To keep DFEoL and DFM in mind when designing the seal, the goal is to have a tool-less assembly without the need of potentially harmful and toxic adhesives. Therefore, the groove for the O-ring will be a friction-fit which means that the groove is slightly undersized to allow the seal to be pushed in place. This type of attachment is not possible with regular O-rings since there is a concern about overfilling the gland. An overfilled gland would cause the O-ring to be extruded out of its intended place leading to major damage and compromised sealing ability. A hollow O-ring does not share this concern due to the smaller cross-section area.

Parker engineering specifies the measurements of the chosen O-ring and groove the following [26]:

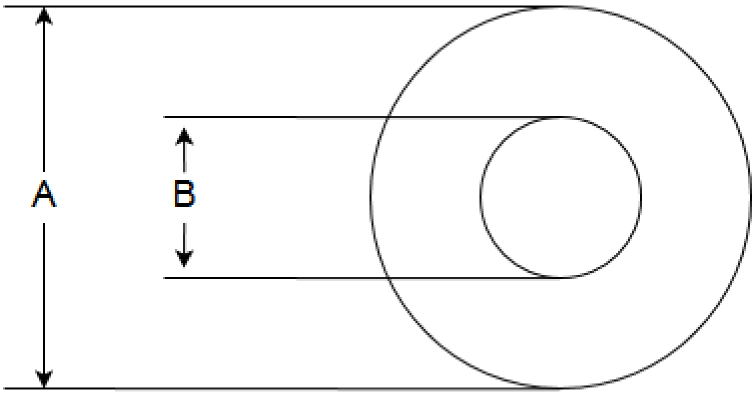


Figure 29: O-ring cross-section

Table 9: O-ring and groove dimensions

A Outside Diameter		B Inner Diameter		Groove Depth				Groove Width				Groove fillet radius*	
				Min.		Max.		Min.		Max.		Min.	Max.
Inch	*mm.*	*Inch*	*mm.*	*Inch*	*mm.*	*Inch*	*mm.*	*Inch*	*mm.*	*Inch*	*mm.*	*Inch*	*Inch*
0.139	3.52	0.070	1.78	0.098	2.49	0.102	2.57	0.126	3.20	0.130	3.30	0,010	0,025

**Corner radius for the O-ring gland: 2,5 – 3 times the outer diameter (A) for hollow cross sections.*

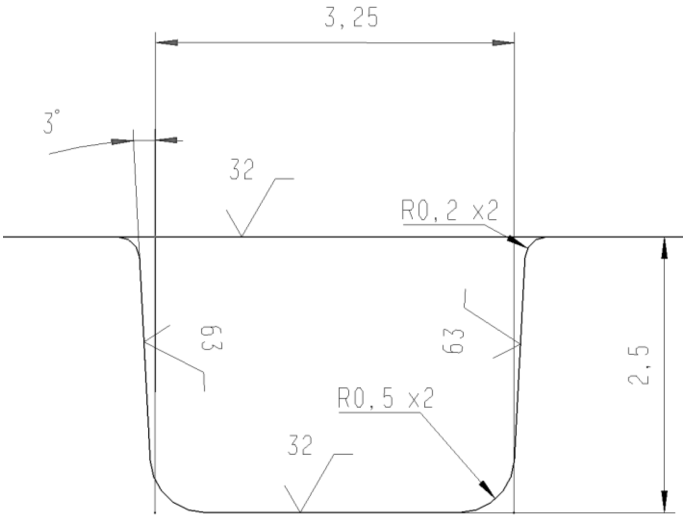


Figure 30: Measurements and surface tolerances of the O-ring groove.

Of course the specific compound and final dimensions of the groove and O-ring will need discussing with the potential supplier. This selection is based on the design guides and catalogues of Parker Engineering with input from other seal manufacturers.

3.5.2 Enclosure ventilation

The ventilation of enclosures often comes as a pre-bought solution that is either a snap-in solution, a threaded solution or an adhesive patch. Each of these solutions has different properties making it suitable for different applications. There are many different designs available with different IP-classifications, but the three mentioned vent styles are the main vent types available for this application.

3.5.2.1 Snap-in vent

This is a simple solution where the ventilation is provided by a plastic design that is easily mounted in a pre-drilled hole. The benefits with this vent is that it is easy to install either automated, semi-automated or manually and it is a rugged and reliable construction. These vents feature a membrane of expanded polytetrafluoroethylene (ePTFE), which is described in more detail in Section 2.1.3, that lets air pass through but keeps out any moisture. These vents are classified up to IP69K, depending on the vent geometry [28].

Figure 31: Snap in vent from Gore.

3.5.2.2 Screw in vent

This type of vent is very similar to the snap-in vent but instead of a snap-fitting is has a threaded body that is screwed into the enclosure instead. The main benefit with a threaded vent is that it can be made out of metal since it does not rely on the elasticity of the material (snap-fit) to be mounted properly. This means that these vents can handle more abuse than its snap-in counterpart. This style of vent does also feature an ePTFE membrane to let air thru and keep moisture away. These vents are available with an IP-classification of up to IP69K as well as IK rating up to IK10 [29].

Figure 32: Screw in vent from Gore.

3.5.2.3 Adhesive vent

The third type of vent comes as a patch that is glued over a small hole in the casing. The patch is made out of a polymer cloth with similar properties as the ePTFE membrane found in the other vents. The main benefit with this style of vent is that it needs less space to be mounted and it is simpler to mount. This style of vent is suitable to be mounded both externally and internally. However, the drawbacks are that these patches are rather delicate and not as rugged as the other vent styles. This means that this style of vent is more common in less demanding applications. A bracket may be used in combination to protect the vent from damage. With the right geometries and brackets the vents are capable of IP-classification of up to IP68 [30].

Figure 33: Adhesive vent from Gore.

3.5.2.4 Placement of the vent

Although these vents can handle some abuse, they are still prone to leak if the conditions are all too stressful. This requires the vent to be placed in a position that whilst providing the intended functionality of the vent does not put it in harm's way. Definitions of the different positions are presented in Figure 34.

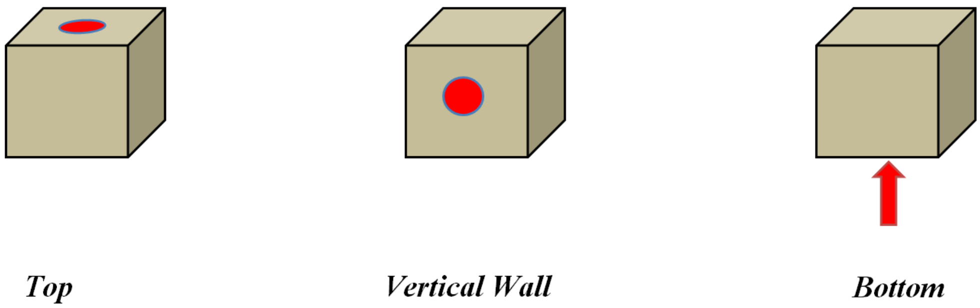


Figure 34: definition of the vent placement

Table 10 lists the pros and cons of a vent mounted on the ***top*** of a casing [31].

Table 10: Pros and cons of a top mounted vent

	Pros	**Cons**
Snap-in/screw in vent	-	Water can accumulate and block the vent.
Internal adhesive vent	-	Water and dust can accumulate and block the vent. For IPx6 a hole size <1mm is needed.
External adhesive vent	-	Same as internally mounted adhesive vent. Externally mounted adhesive patch is exposed to mechanical wear.

Another possible position is the vertical sides of a casing.
Table 11 lists the pros and cons with a vent mounted in ***vertical walls*** [31].

Table 11: Pros and cons of a vent mounted on vertical walls

	Pros	**Cons**
Snap-in/screw in vent	Water can wash dirt thru/alongside the vent/ membrane	-
Internal adhesive vent	With a bracket IPx6 can be achieved with larger holes than 1mm in this position	Rain and dirt can block the small hole.
External adhesive vent	Same as above.	Mechanical abuse can compromise the vent. May be solvable with bracket.

Lastly, the pros and cons with a vent mounted on the ***bottom*** of a case are listed in Table 12 [31].

Table 12: Pros and cons with a vent mounted on the bottom

	Pros	**Cons**
Snap-in/screw in vent	Often the preferred position. Rain and dirt cannot fall on the vent. Drop-edge may keep water from accumulating.	Heavy rain can collect in the vent cap.
Internal adhesive vent	Rain cannot block the vent. Drop-edge can keep water from accumulating	Fungi can grow since the placement leaves the vent in a position where rain dries later/accumulates.
External adhesive vent	Same as above	Same as above. The vent may also be especially exposed to mechanical damage when setting the box down on the ground.

According to these findings the two vent styles suitable for this application are the screw-in and the snap-in vent mounted on vertical walls. Both vent styles are available with IP classifications up to IP69K and the screw-in went is also available with an IK10-rating [29]. Upon looking at the manufacturers recommended installations guidelines and on the retail prices the discovery was made that the snap-in vent is both cheaper and smaller. A screw-vent with the adequate classifications would be 17mm in diameter whereas a similar snap-in vent only measures 14mm as well as being approx. 30% cheaper [32]. Furthermore, the higher IK-rating of the screw in vent was disregarded since the vent can be well protected from impacts by placing it in a hard-to-reach area e.g. near a connector or by surrounding it with cooling fins. These facts favour the snap-in vent which became the vent of choice for the enclosure.

3.5.2.5 GORE PolyVent AVS 200

The PolyVent AVS 200 from GORE would be a suitable model for the enclosure and is especially designed for automotive applications. It features the necessary IP-classifications and has been thoroughly tested by GORE according to many different standards ranging from Temperature testing to corrosive gas testing [28].

Figure 35: PolyVent AVS 200 from GORE.

The snap-in vent is design to be installed from the outside and is simply pushed in place manually or with an automated process. The geometry of the hole for the vent is specified by the manufacturer and can be seen in Figure 36.

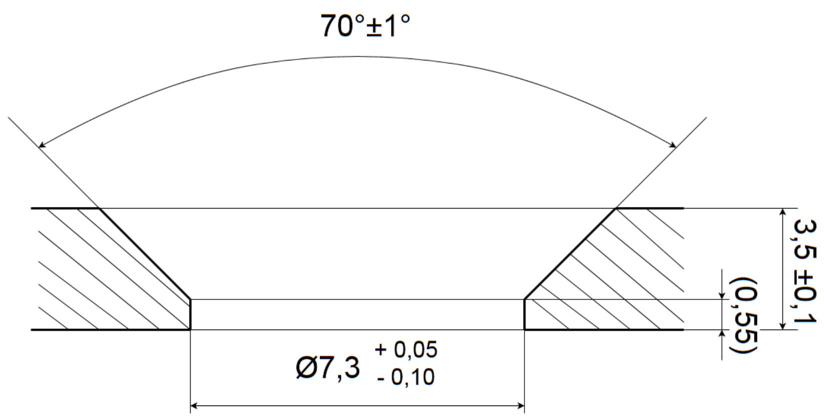


Figure 36: Hole Geometry for the PolyVent AVS 200 from GORE.

3.5.3 Lid

The demands on the lid, specified in the requirement specification in appendix B, suggests a polymer as material for the lid. This will most likely result in a material with significantly lower elastic modulus than the casing itself.

When the lid and casing are assembled the force from the O-ring will act on both, the casing which will be made from metal will barely flex back. The casing however, which is made out of plastic will have an elastic modulus lower than the metal, will flex back from the force applied by the O-ring. If the lid flexes back to much the seal could be compromised and water could leak in. Keeping the deflection of the lid to a minimum to prevent leakage and create an even pressure on the O-ring is therefore paramount.

The material assigned to the lid unless otherwise specified in simulations in this chapter was *CATIAs* predefined plastic material which has an elastic modulus of 2.2 GPa. The same load case is also used when simulating the deflection of the lid resulting from the O-ring. A force of 300N, corresponding to 71kg/m acted on the lids on an edge where the O-ring would realistically be placed (see Section 3.5.1 for further information). A simplification was made for this force, in reality the force applied from the O-ring would decrease as it expands, similar to a spring, but in the simulations, it was simplified to a constant force unaffected by the deflection of the lid.

The deflection of two lid designs was compared using the FEM capability of CATIA. One design was inspired by Concept D and the other one resembles a similar design as the prototype features. The lids were both held in place by four clamps acting as screw holes located in the corners of the lid.

Not surprisingly, the flat lid from the prototype deflected significantly more than the other design. The design inspired by Concept D deflected 0,3 mm compared to the 2,2 mm of the flat lid. The maximum deflection also appeared in the same location for both lids, see Figure 37.

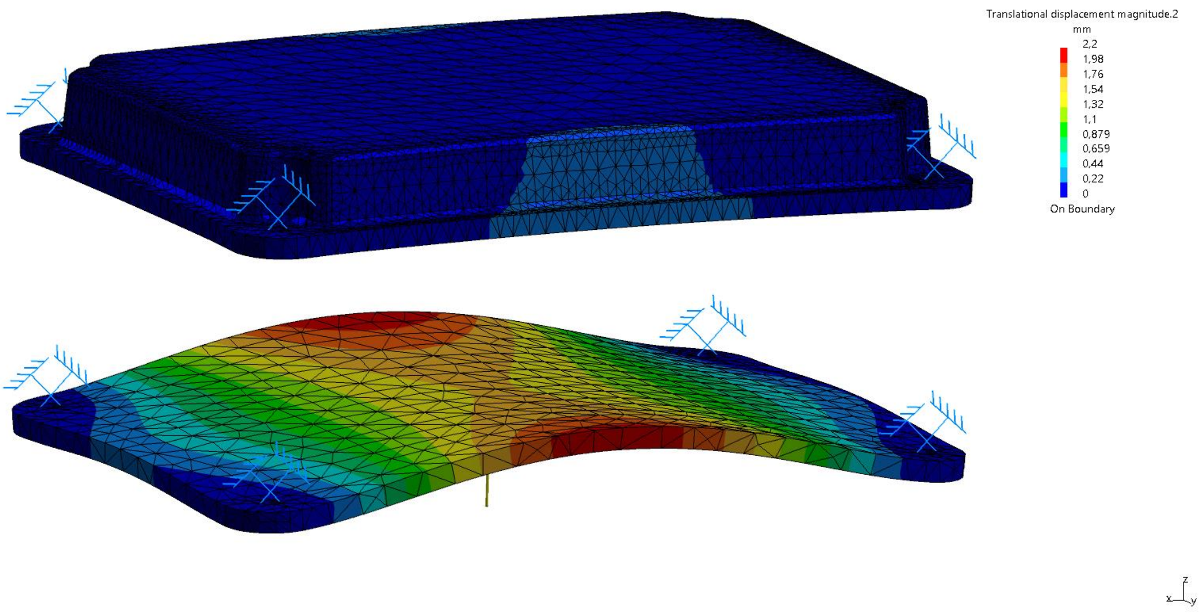


Figure 37: FEM-simulation deflection results for two different lid designs.

Both designs would benefit from adding additional fastening points in areas where the most deflection occurs. To get more input for how the optimal design could be made topological optimisation was utilised. This is a mathematical method which maximises the performance of the shape towards a specific goal depending on the design space, loads and boundary conditions. The goal with the Topology optimisation was to maximise the stiffness of the lid. The software used to conduct the optimisation was *ANSYS*.

Different approaches to how the constraints and design/exclusion area are configured were experimented with. Two methods for how the forces are applied were used. In the first approach the force was applied on the area where the O-ring would be and where the snap-joints are fixated. The second approach did it the opposite having the force instead act on the snap-joints and having the contact area with the O-ring fixated. Both approaches did however result in very similar results. Ultimately the first approach was used when simulating.

The final thing that was varied was the starting volume of the optimization, in other words, the solid block of material that is to be shaped. In the first configurations the simulation was very restricted and was not allowed to change the area over where the sensor will be situated. It was also experimented with to have the entire lid flat on the top. This produced unsatisfactory results since it seemed to favour the volumes restricted from change, resulting in very little to no changes in the surrounding geometry.

The design area was then altered so that the simulation could change the areas where the sensor would be situated. The results then became much more interesting and showed areas where additional material would be most impactful. The results showcase how more material would be needed in the edges and on the sides, especially between snap joints, see Figure 38.

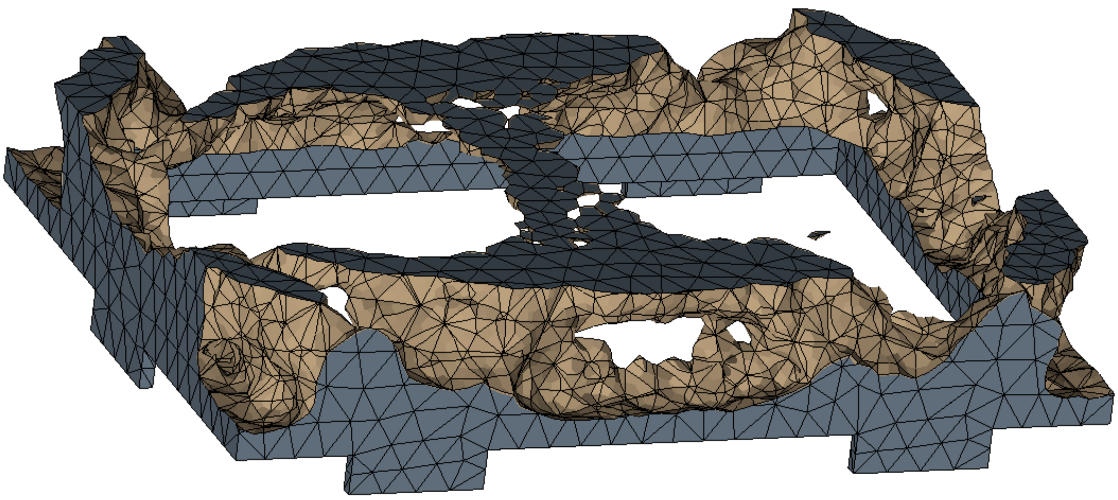


Figure 38: Simulation results with restrictions for PCB space.

Lastly the program was allowed to change all of the volume and the space taken by the PCB. The only requirement was to keep the area connected to the O-ring flat. During this simulation additional material was also removed. Overall the results were very similar to the previous simulation and the volume previously restricted was barley utilised. The main difference is that the bridge in the middle was removed, this was however due to the program removing more material. If constrained to remove less material the bridge once again appeared. The results can be seen in Figure 39.

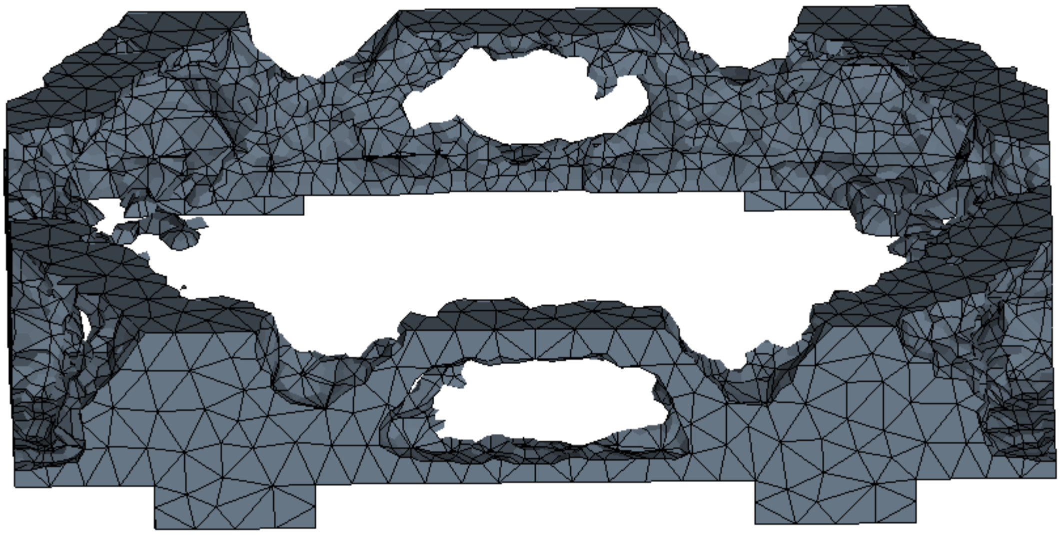


Figure 39: Simulation results with lower kept volume and no restrictions.

These simulation results should however be taken in provisory since the lid is subject to other demands and load cases. Combining the results from the simulations with demands for manufacturability and functionality is vital to make a realistic and robust component.

After taking the results from the simulations into consideration along with the demands present a new model was developed which featured many stiffeners on the sides and two long stiffeners on the inside, see Figure 40.

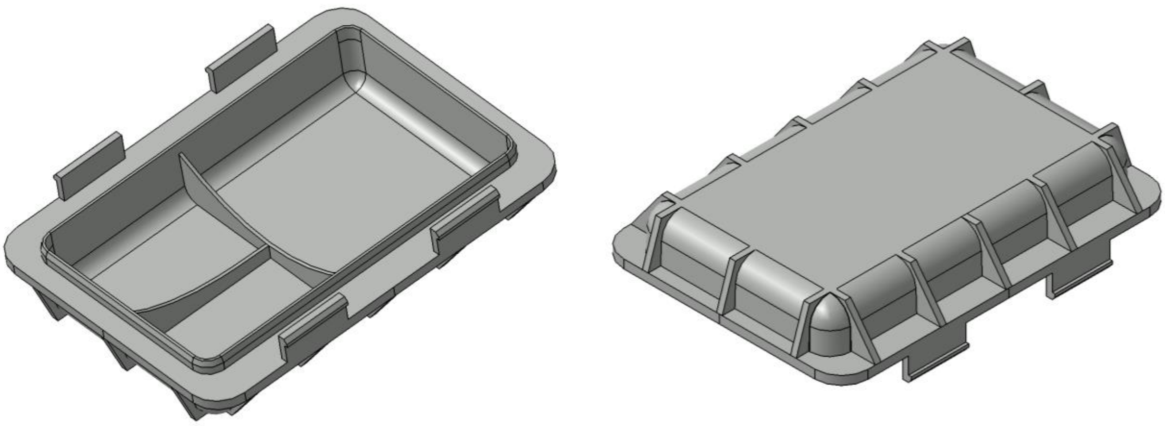


Figure 40: CAD model of the lid viewed from below to the left and from above to the right.

3.5.3.1 Deflection simulation

To test how the lid performed when assembled a FEM simulation was done. The same load case as in the previous FEM simulations was used where the snap joints are fixated and a load of 300 N was applied to where the O-ring would be located. The results showed that the deformation close to the snap joints was very low and high the furthest away on the short sides of the lid. Contrary to what was expected the stiffeners on the inside barely did anything to reduce the displacement on the short side of the lid, see Figure 41.

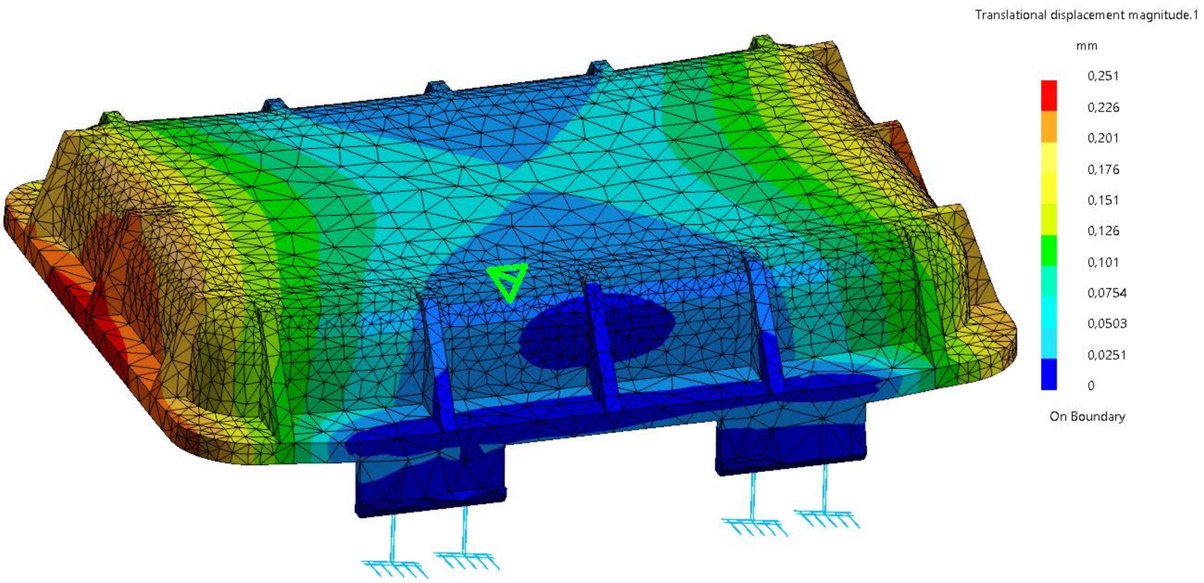


Figure 41: FEM simulation results for the lid with four snap-joints.

To further investigate how the external and external stiffeners affect the deflection a lid with no stiffeners was simulated. The maximum deflection was now 0,377 mm, see Figure 42.

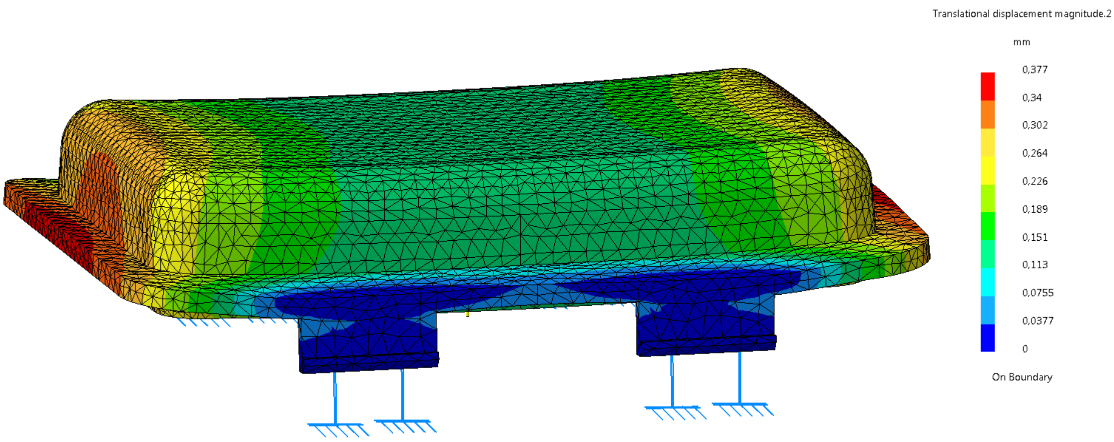


Figure 42: FEM simulation results for a lid with four snap joints and no stiffeners.

Aggressive internal stiffeners were then added to the model in Figure 43, but they did not affect the deflection very much. The side with the aggressive stiffeners did deflect less, but only by 0,024 mm which is very little compared to amount of added material. If the stiffeners were allowed to cover both sides of the casing, they most likely would have been more effective but the demand for a flat lid above the sensor makes this unfeasible. On the side with no internal stiffeners (Point A) the deflection was 0,377 mm and on the side with stiffeners (Point B) it was 0,353 mm.

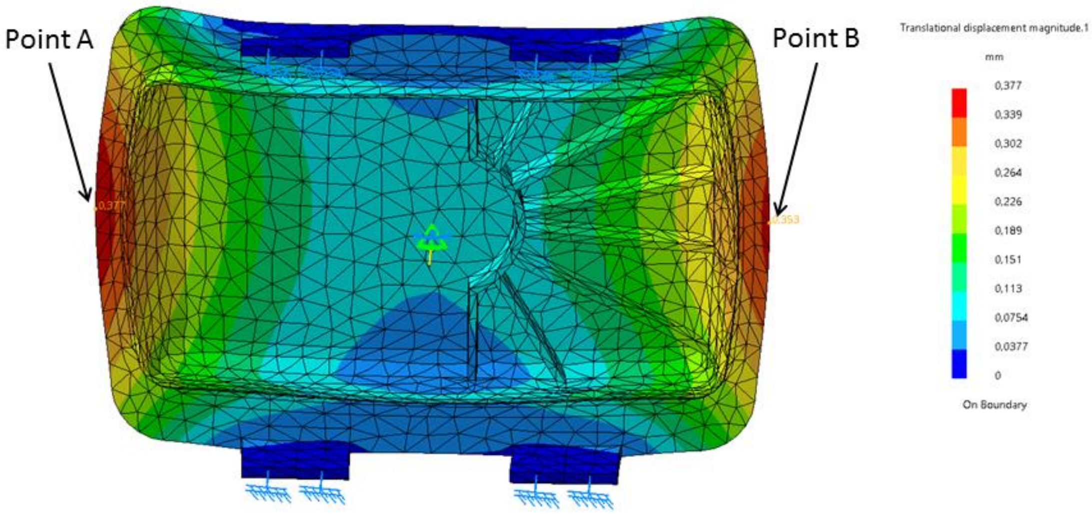


Figure 43: FEM simulation with aggressive stiffeners on the inside and no stiffeners on the outside.

Comparing the results from the lid with no stiffeners to the first model simulated shown in Figure 41 it can be seen that the external stiffeners contribute greatly to reduce the deflection. In the first model the maximum deflection was 0,251 mm resulting in a reduction of 32% or 0,126 mm in deflection.

When one snap-joint was added on each short side the maximum deflection was reduced by 60% from a quarter of a millimetre to one tenth. The maximum deflection also now occurred in the corners of the lid, see Figure 44.

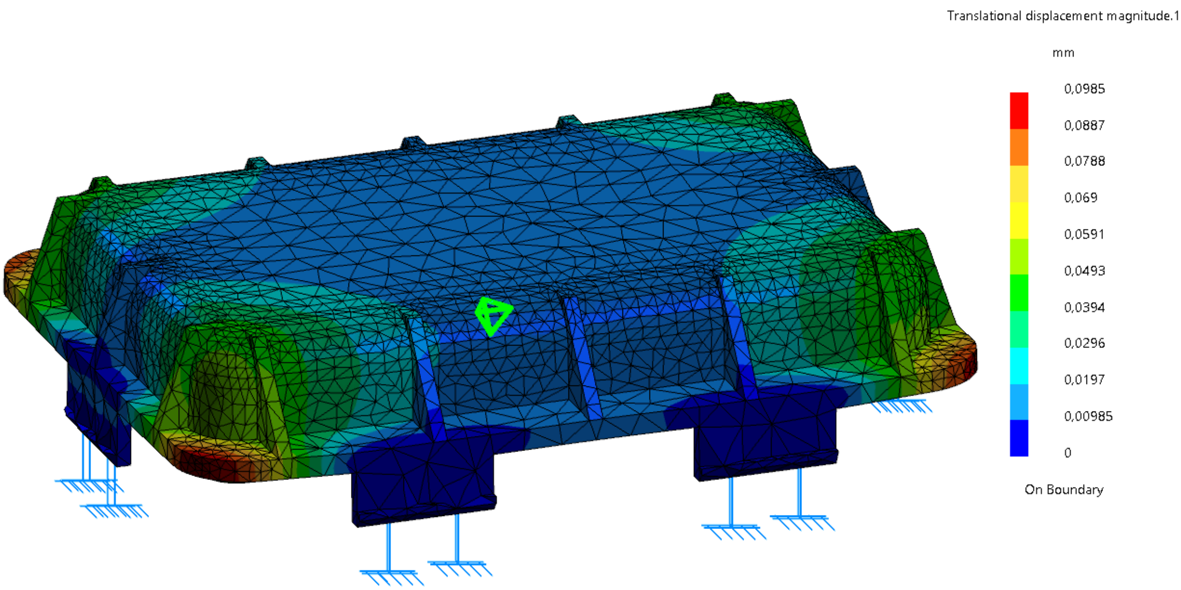


Figure 44: FEM simulation results for the lid with six snap-joints

The deformation could be even further reduced by splitting the snap on the short side into two and placing them further out towards the edges. The deformation now was as low as 0,019 mm, one fifth of the previous configuration. The maximum deformation did still take place in the corners, see Figure 45.

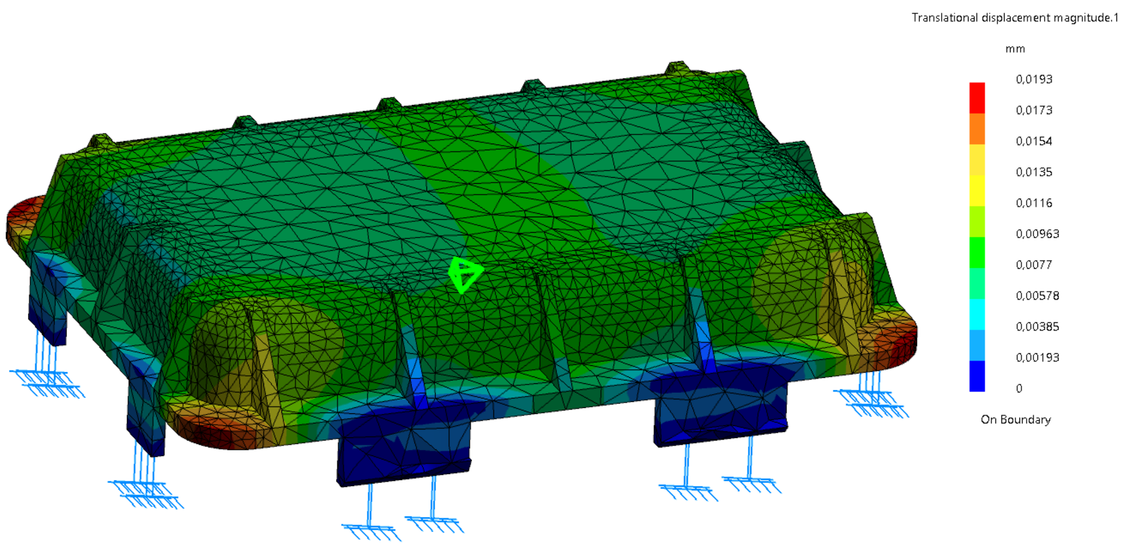


Figure 45: FEM simulation results for lid with eight snap-joints.

3.5.3.2 Robustness simulations

To test the robustness of the lid towards snap-joint failure, one snap-joint on the long side was simulated as unattached. The configuration with only four snapping joints predictably performed the worst and had a deflection 0,816 mm, see Figure 46. The O-ring allows for up to 1 mm of deflection, meaning that although there won't be a gap, it is very close to compromising the seal. The configurations which utilises six and eight snaps performed better having a maximum deflection of 0,0883 mm and 0,0541 mm, see Figure 47 and Figure 48.

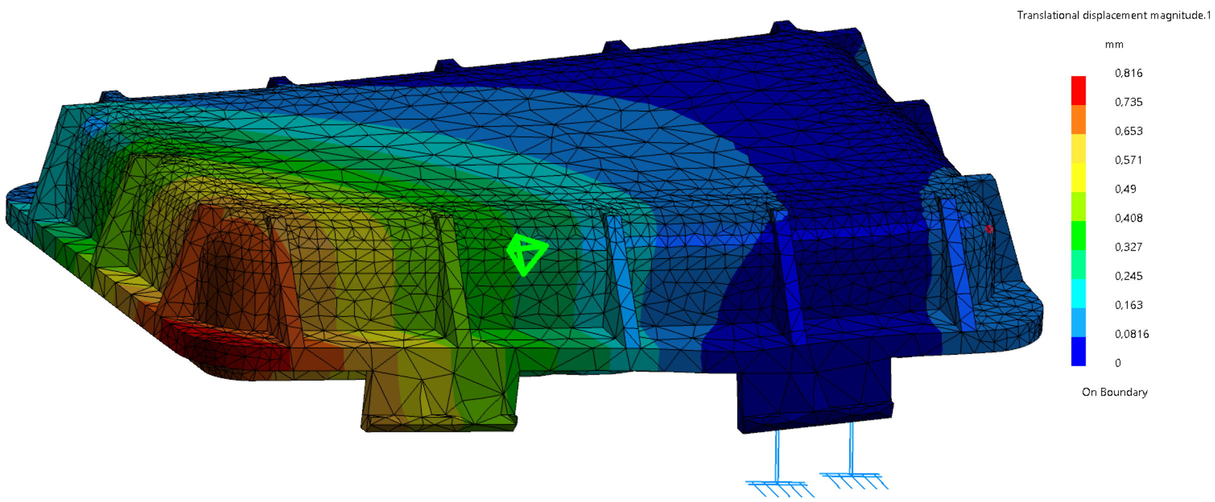


Figure 46: FEM simulation for when one snap-joint fails in a four snap design.

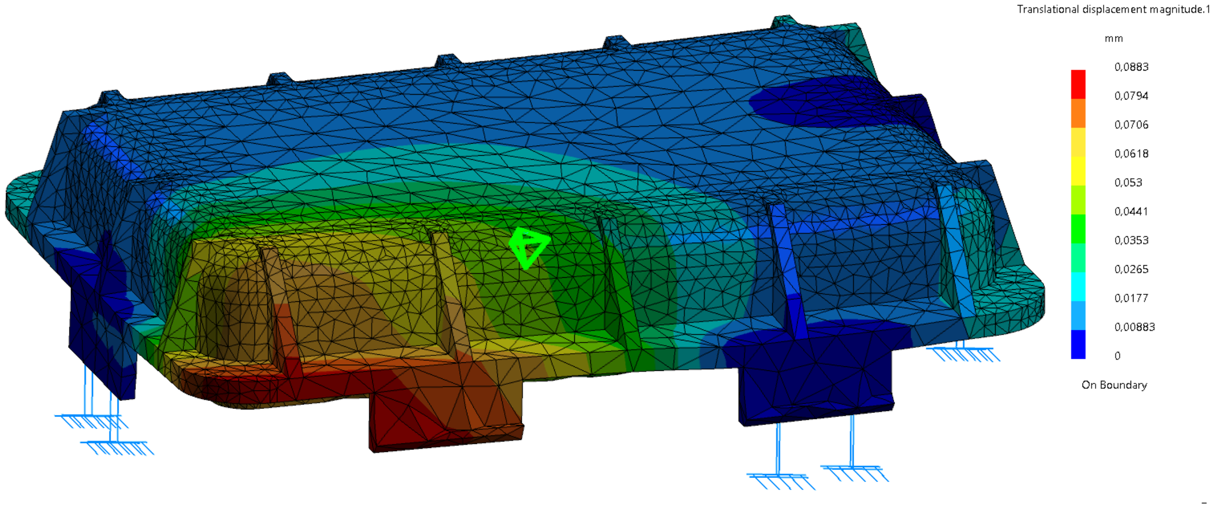


Figure 47: FEM simulation for when one snap-joint fails in a six snap design.

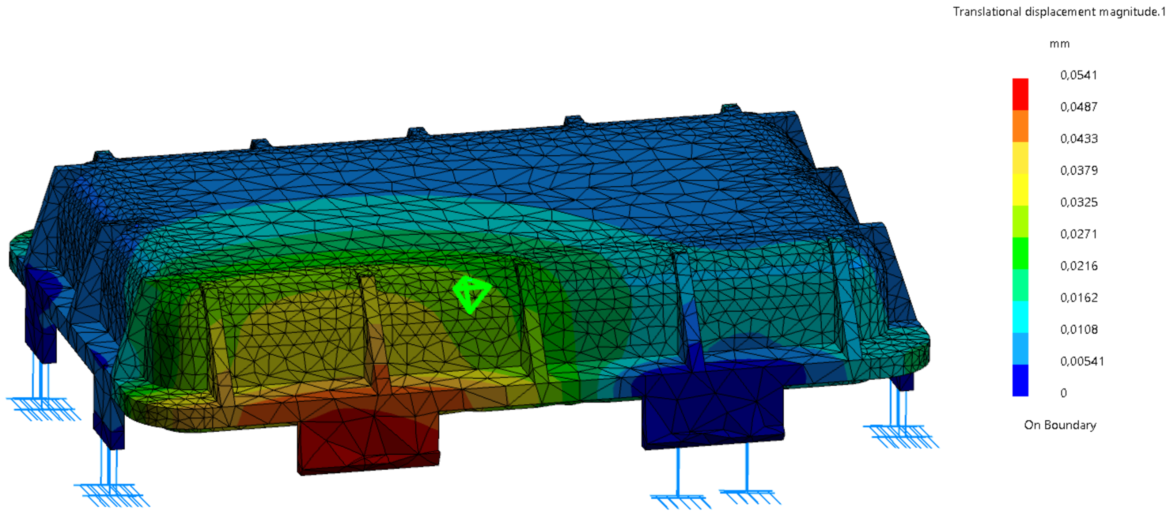


Figure 48: FEM simulation for when one snap-joint fails in an eight snap design.

3.5.3.3 Assembly simulation

A load case which emulates the circumstances when the lid is assembled to the casing or when an object hits the casing was also simulated. A force of 500 N was applied to the middle of the casing and two constraints were put on the lid. The force was estimated by measuring how much force a normal person was able to exert on a pressure plate scale. These simulations also used the predefined plastic material in *CATIA* with an elastic modulus of 2,2 GPa.

The first constraint was applied on the same area as the force, it restricts movement along the X and Y-axis and rotation around the Z-axis. This was done in order to emulate how a hand for example would hold the lid in the place while pressing down along the Z-axis.

The second constraint was applied to the area under the lid where it would rest against the casing and restricted movement along the Z-axis as well as rotation around the X and Y-axis. Two different designs were tested, one with and one without stiffeners on the inside of the casing. Although the internal stiffeners gave barley any advantage earlier when examining the deflection when assembled they do reduce the deflection resulting from forces on the top of the lid. Having internal stiffeners reduced the deflection from 1,98 mm to 1,40 mm, see Figure 49 and Figure 50.

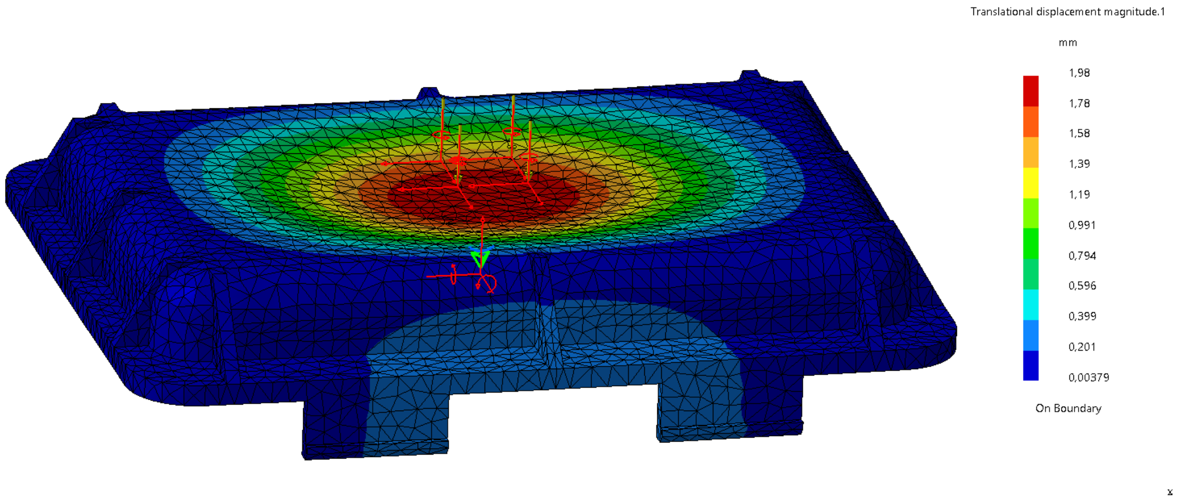


Figure 49: FEM simulation of the deflection during assembly with no stiffeners inside the lid.

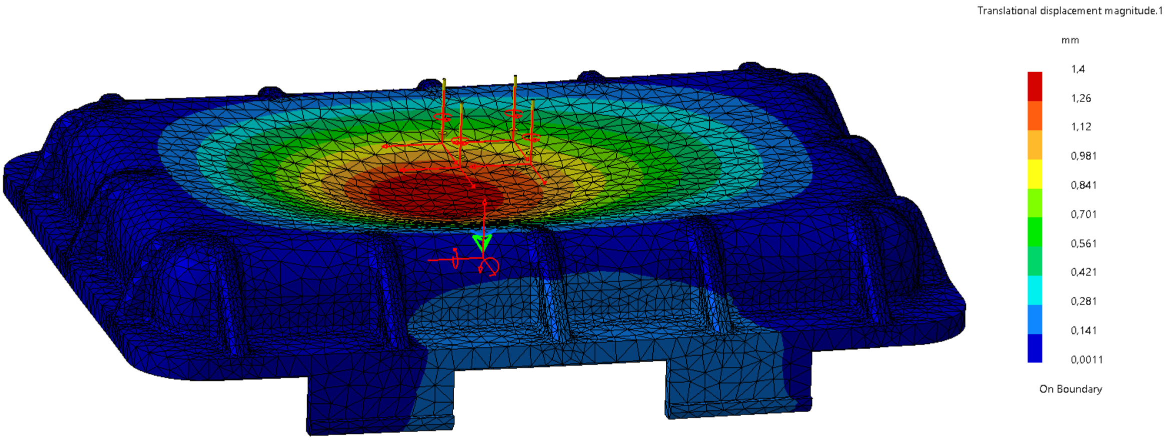


Figure 50: FEM simulation of the deflection during assembly with stiffeners inside the lid.

3.5.3.4 Snap-joint design

When designing the snap-joints the goal was to achieve an even pressure on the gasket. The pressure exerted being even depends on three factors:

- Lid and casing stiffness
- Position of the snap-joints
- Size and form of the snap-joints

The static force exerted on the snap-joints after assembly also has to be considered. Having more and bigger snap-joints would be the obvious choice but doing so also increases the force required to assemble the lid and casing. Furthermore, the tension in the snap-joints increases the thicker the joint is due to more strain taking place when being bent during assembly.

The amount of retraction or displacement the joint needs to undergo during assembly is decided by the overhang depth. The mating force during joining is decided by the inclination of the entrance side, see Figure 51 [33] [34].

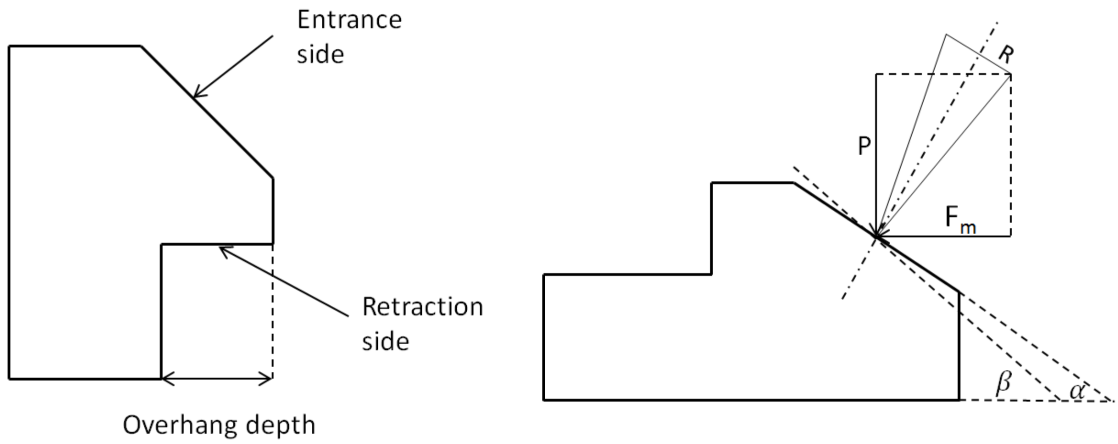


Figure 51: Snap joint measurements and important surfaces

The force required to assemble the snap-joint F_m can be estimated with the following equation:

$$F_m = P * \frac{\mu + \tan\alpha}{1 - \mu * \tan\alpha} \qquad 3\text{-}1$$

The force P that the snapping joint exert when fully bent during assembly can be calculated with a cantilever beam deflection formula:

$$\delta = \frac{PL^3}{3EI} \rightarrow P = \frac{3\delta EI}{L^3} \qquad 3\text{-}2$$

Inserting equation 3-2 into 3-1, the expression for F_m can be rewritten to:

$$F_m = \frac{3\delta EI}{L^3} * \frac{\mu + \tan\alpha}{1 - \mu * \tan\alpha} \qquad 3\text{-}3$$

The input parameters for the equation are deflection of the snap joint δ, the elastic modulus E, bending area moment of inertia I, length of the snap joint L, the friction constant between the materials μ and the inclination of the entrance side α. The deflection force can be further reduced by having a cross-section that gets smaller.

The amount of deflection δ possible and the elastic modulus E both depend on the material properties that the joint is made from. The maximum deflection can be calculated depending on the maximum allowable strain ε in the material.

$$\delta = \frac{\varepsilon L^2}{Ct} \qquad 3\text{-}4$$

A form factor Q can be introduced into the equation which accounts for the decreasing thickness of the cantilever beam and the surrounding geometry. The value if Q can be obtained from graphs in the design manuals where the value of Q depends on the placement of the snap joint and the ratio between L/t [33] [34]. Inserting Q and equation 3-4 into equation 3-3 yields the following equation for the mating force F_m:

$$F_m = \frac{1}{Q}\frac{3EI}{L^3} * \frac{\varepsilon L^2}{Ct} * \frac{\mu + \tan\alpha}{1 - \mu * \tan\alpha} \qquad 3\text{-}5$$

The graphs do have limitations and only cover situations where t is halved or when b is quartered. To account for factors such as the thickness of the hook on the snapping joint and varying thicknesses the Finite element method can be used. Before simulating the snap joints with FEM software, the assembly force was calculated with 3-5 to get a quick overview of the forces. Although the results from the calculations wouldn't be as accurate as the FEM-analysis, it is much faster and can be used to quickly estimate good candidates before simulating them. A good configuration was found using the calculations by tweaking the numbers and comparing the numbers with the CAD model, see Table 13. The entire calculation table can be seen in appendix H.

Table 13: Part of table showing the measurements of a snap-joint and the resulting forces based on equation 4-5.

L	b	t	my	alfa	Delta	E	Strain	Form FactorQ	Calc_L	P	Fm
8,6	20	2	0,3	40	1,5	5140	0,0417	2,5	6,56237	436,5	664,5
8,6	20	2	0,3	40	1,5	5140	0,0348	3	6,56237	363,8	553,75
8,6	20	2	0,3	40	1,5	5140	0,0287	3,63	6,56237	300,6	457,65

The results from the calculations were then compared to FEM results of the lid where a force P of 300 Newton was put on the snap-joint. This resulted in the displacement δ of around 1,5mm at the base of the hook, see Figure 52.

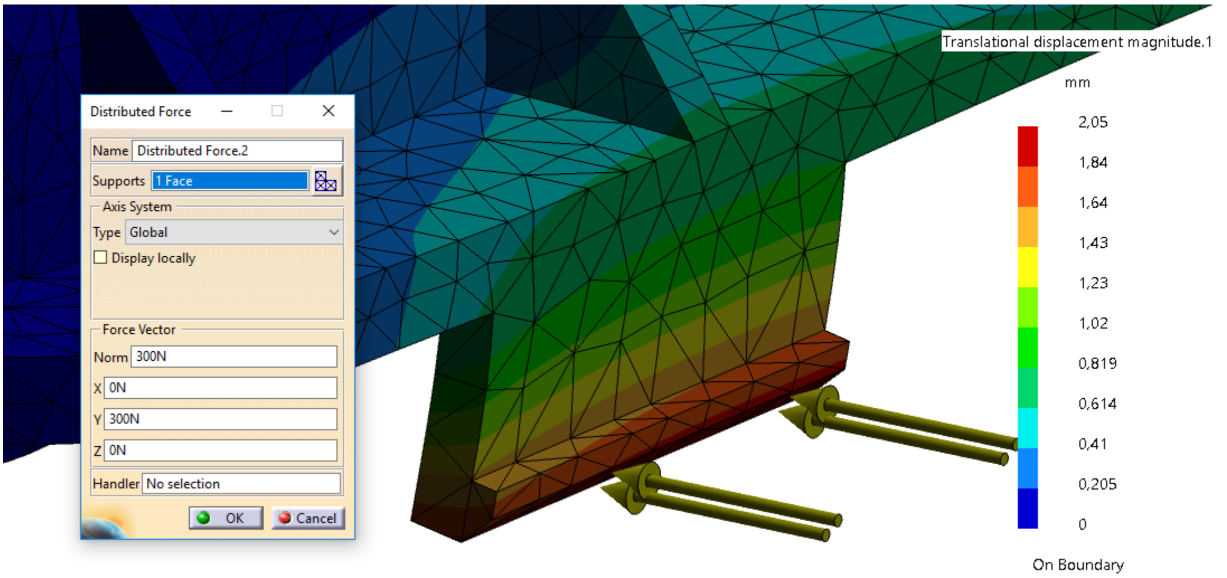


Figure 52: Deflection results for snap-joint when a horizontal force of 300N was applied.

Taking the form factor Q straight from the graphs in the design guide gave it a value of around 2.5 to 3. With this form factor the force displayed in the table would be higher than in the simulation. This leads to the assumption that the lid flexes more from the assembly forces than the graphs indicate. When adjusting the form factor to match the results from the FEM simulation it gets a value of around 3,6.

A snap length of 9,2 mm with a base of 20 mm and a tapered thickness going from 2 mm to 1 mm was modelled and simulated. This time radiuses were added to reduce stress concentrations in sharp corners. A force of 150 N was estimated by the table but it was found that a force of 160N was more accurate for 1,5 mm of displacement. The elastic modulus used was around 5 GPa along with a poison’s ratio of 0,37. The restraints used were different in order to closer mimic the real load case during assembly of the lid. The force was applied in the same way as before but now the lid was clamped on the other side as if it were pushing against the edge of the casing. This means that only one side’s snap-joints would be engaged at a time. The results show the stress in the snapping joints between 20 to 50 MPa in most of the snap joint and a stress concentration of 73MPa in one of the edges, see Figure 53. The mesh size was 5 mm with a sag of 1 mm in all parts except the snapping joints where a smaller size mesh size of 0,25 mm was used.

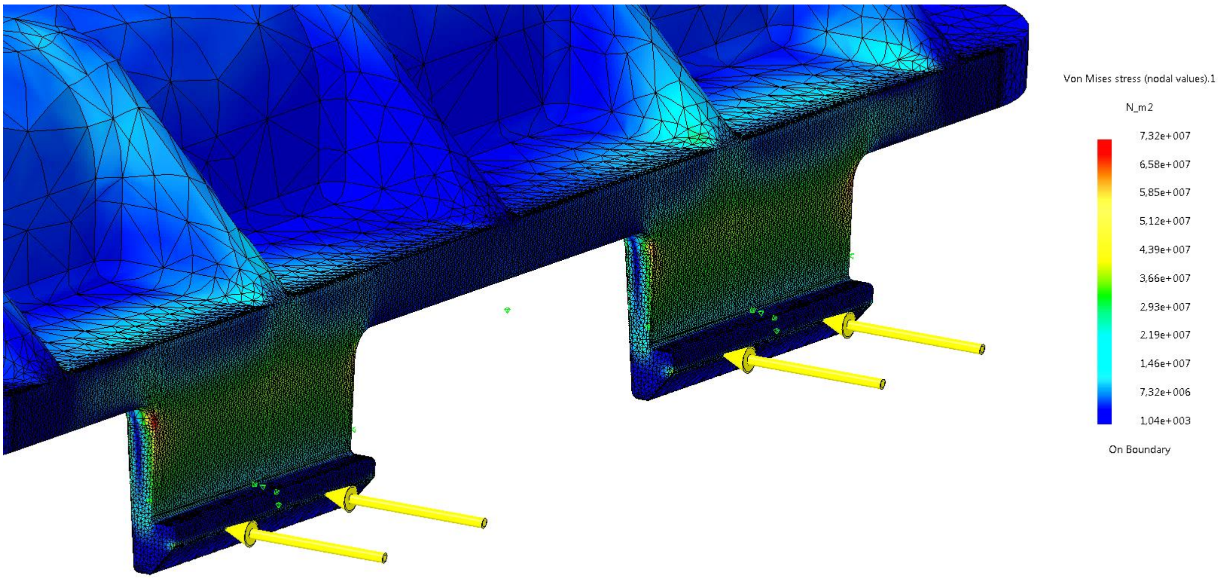


Figure 53: Stress results for snap-joint when a horizontal force of 160N was applied.

3.5.4 Mounting Solution

Attaching a sensor to a vehicle can be done in many different ways. Most of the options involve some kind of bracket to be made suitable for the specific vehicle. Since the intent for the sensor is to be mountable on many different models the mounting solution needs to be kept versatile and adaptable. The goal is therefor to have a simpler interface on the sensor and adapt brackets to fit different vehicle models and mounting positions. The bracket is not considered to be a part of the scope for this project but the interface on the sensor enclosure will be designed in similar fashion as the one on the prototype.

3.5.5 Connection to vehicle electrics

The scope of this project was limited to the enclosure only, meaning that the electronic components will not undergo any modification. However, different suggestions on how to improve the design are allowed. During the project two different alternatives of connecting the sensor to the vehicle were further investigated: Connector directly on the PCB and a cable gland with an extension cord. Both methods are common methods of connecting an auxiliary device to vehicle e.g. auxiliary lamps are available with either connection method. More about possible options regarding the connector are discussed in Section 5.1.

Since the existing hardware includes a commonly used automotive connector, the DT15-6P connector, the goal is to design the enclosure for that specific connector. A detailed drawing of the recommended cut out for the connector can be found in Figure 54. The measurements were found on the homepage of a manufacturer of the current connector that is being used [35].

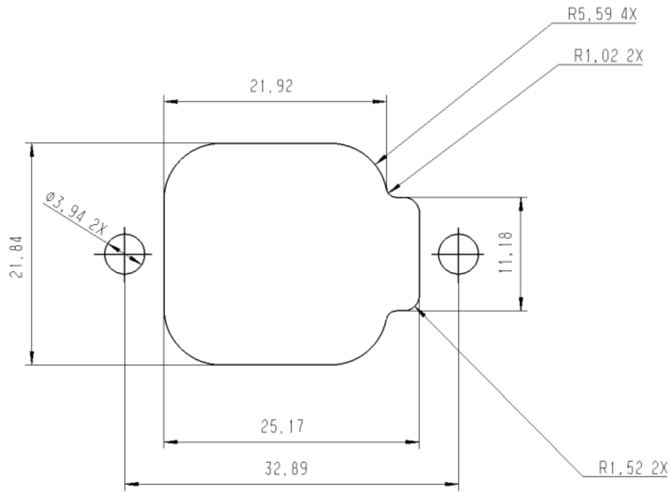


Figure 54: cut-out measurements of the DT15-6P connector from Mauser connectivity [35].

3.5.6 Casing

When developing the casing in the concept phase the LED lamp component and its corresponding window for it to be visible were under discussion whether it was needed. The project group at the time saw no reason for the LED lamp to be present in the end product and thought that the component would only be needed on the prototype. However, it was later revealed that the component would need to stay as it would be required for calibrating the product when situated on the truck. The LED-lamp is facing backwards due to its placement on the PCB.

The electronics inside the casing need to operate in temperatures ranging from -40° to 85° C according to the product specification. For the processor to not overheat it needs to effectively dissipate the heat it produces. The most economical and simple solution is to allow it to transfer heat away through the casing. According to the manufacturer the processor will produce around 1.5 W [36]. To transfer the heat away the casing has a cooling tower which will be connected to processor with Cooling paste or a thermal pad. The heat will then be dissipated to the surrounding environment. Cooling fins are placed in the bottom of the casing close to the cooling tower to increase the surface area that can transfer the heat away through convection.

To investigate how the sensor casing would act during very warm conditions two simulations were conducted using *ANSYS Multiphysics*. The thermal case was simplified so that the casing would only transfer heat through the surrounding air. The heat transferred to the truck and heat dissipated with radiation was excluded from the simulation. The surrounding medium was specified as stagnant air with a temperature with a convection rate of 5 watts per millimetre and degree Celsius. The material for the casing was Aluminium with a high thermal conductivity of 140 W/m^2 ºC and the lid was specified as a plastic material with a thermal conductivity of 0,5 W/m^2 ºC. The simulations made were in a steady state which means the results show the casing in equilibrium.

Furthermore, due to restrictions in the license for ANSYS available simplifications to the lid had to be made. The simplified lid had the same shape but details such as stiffeners and edge rounds had to be omitted.

Thermal case 1

The first thermal case assumed that the only source of heat was the electronics inside and that it would transfer the heat generated to the cooling tower inside the casing, see Figure 55.

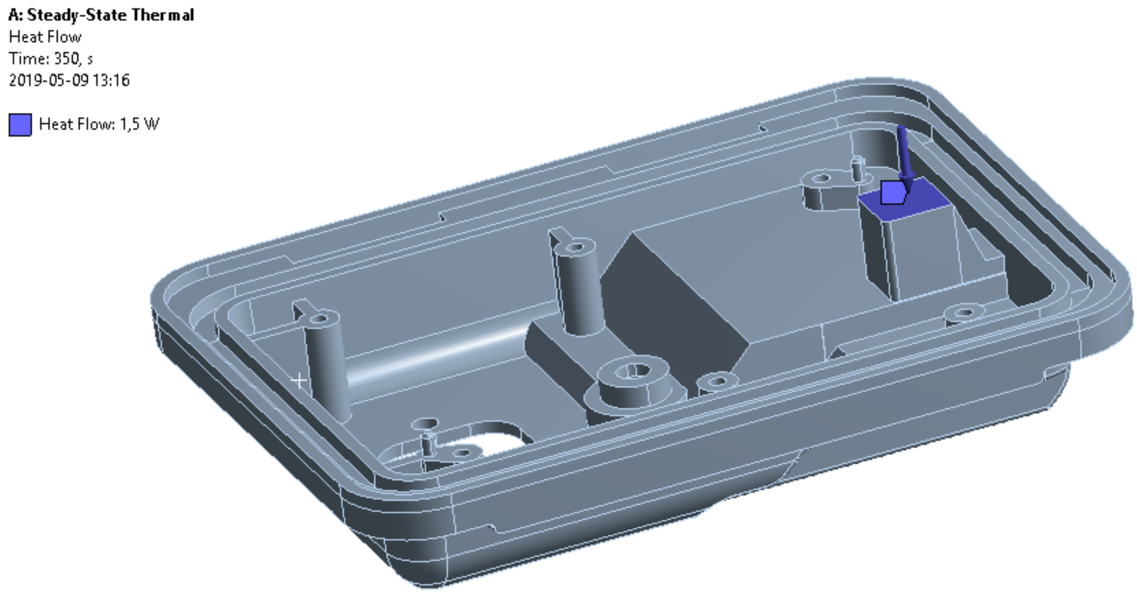


Figure 55: Steady-state thermal simulation settings.

With the electronics as the only source of heat and with an environment temperature of 55° C the casing absorbs almost all the heat generated from the electronics. The maximum temperature of 62° C occurs on the top surface of the cooling tower. The heat is then mainly dissipated by the cooling fins closest to the cooling tower, see Figure 56. When the temperature of the surrounding environment is instead set as 85° C the results are very similar in how the heat is transferred away but the maximum and minimum temperature are of course higher. The maximum temperature now is 92° C, see Figure 57.

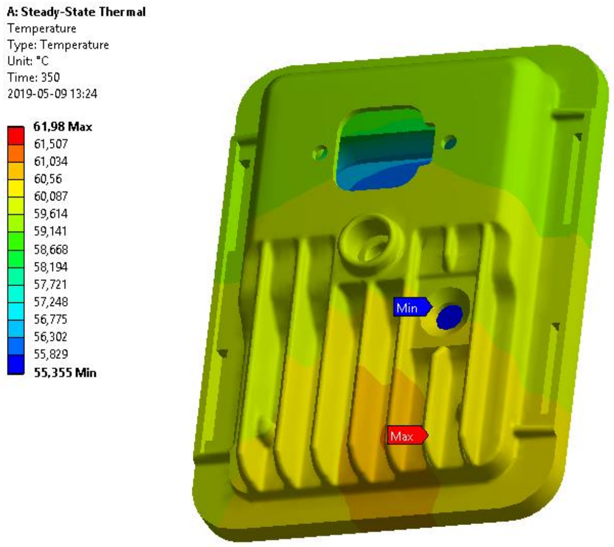


Figure 56: Simulation results for thermal case 1 with an environment temperature of 55° C.

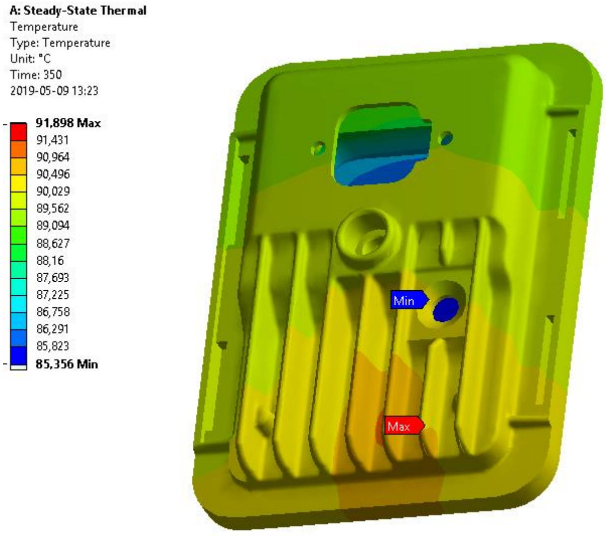


Figure 57: Simulation results for thermal case 1 with an environment temperature of 85° C.

Thermal Case 2

The second thermal case assumes that the electronics generate 1,5 W and that additional heat is transfered to the casing from the sunlight. Assuming the worst-case scenario where the lid or casing absorbs 100% of the energy from the sun. According to [37] the sun transfers a maximum of 1366 W/m2 to a given surface on the earth, with the area of the lid being around 0.01m^2 viewed from above the additional energy transferred to the casing would be around 5 W. This number is heavily approximated and would most likely be very different in reality. It should however give insight to how the casing will behave when put in a very warm climate in addition to being hit by direct sunlight. The surrounding temperature here is also put as 55° C. The approximate direction the sunlight originates from and the results from the simulation can be seen in Figure 58 and Figure 59.

Figure 58: Sunlight direction for thermal simulation 2.

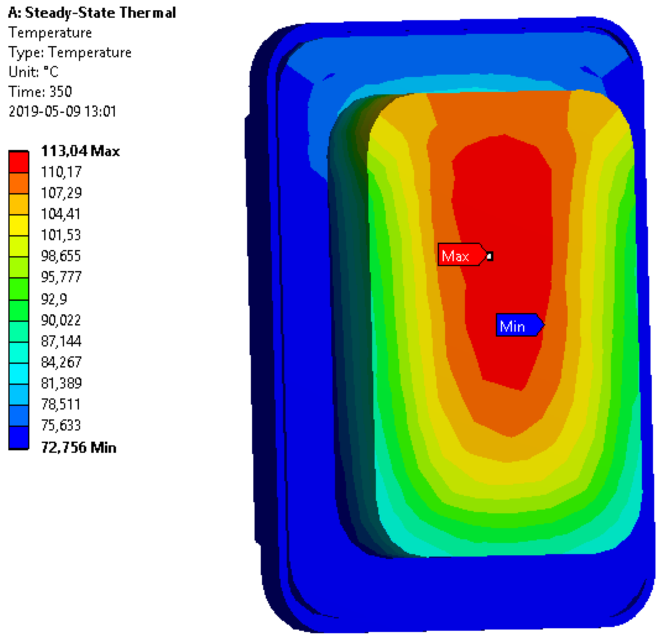


Figure 59: Simulation results for thermal case 2.

The results from the simulation show that the lid heats up much more than the casing. This is due to a larger portion of the lid being exposed to the sun. The lid has its maximum temperature of 113° C almost in the middle and then gradually cools down the closer to the casing. The casing itself does not get very warm but does heat up slightly at the cooling tower to around 80° C. The casing is shown to dissipate heat much more effectively than the lid, both due to the material having a higher heat transfer coefficient compared to the lid, and due to its larger surface area. The heat from the sun also seems to be a major factor for the temperature in the lid but does not affect the temperature of the casing too much. Thus, preserving the cooling towers function towards the electronics even when under intense sunlight. The temperature difference in the two parts can on the other hand cause issues with mismatch when thermal expansion takes place.

3.5.7 Manufacturing method and DFM

The manufacturing process for a product like this much depends on the number that is to be produced. Documentations and specifications lack a proper definition of what a manufacturing method the customer prefers, nor does it tell the expected quantity to be produced or sold. At this stage in the project a very rough estimation of how many units are to be produced will need to be enough to suggest a manufacturing process.

Known is that the intent of the product is to be an ad-on for new or old trucks. Volvo Trucks and Scania are the biggest manufacturers of trucks in Sweden. Volvo trucks annually produces approx. 98 000 unit and Scania produces approx. 49 000 units for the European market. Not all are sold in Sweden but according to statistics on registrations of new trucks (above 16 tonnes) in 2018 a total of 2788 unit were Volvo and 2670 units were Scania made. Further statistics from Transportstyrelsen (2019) show that 660 039 trucks are in use in Sweden today [38] [39] [40] [41].

This means that even if the annual sales rates are tens of thousands of units in Sweden alone, the global sales rate might be well above a hundred thousand units per year since both Volvo and Scania are well known brands all over the world. Besides that, Volvo and Scania might not be the only customers this product could be aimed at.

The conclusion of this is that a suitable production process must be feasible for at least 100 000 units/year. This means that the production process has to be suitable for mass production of the sensor. Polymer injection moulding and metal die casting are well known mass production processes that would fulfil the needed production rate. A CNC-milling process would also be viable but since the geometry of the casing is rather complex it would be a time consuming and potentially expensive alternative.

For the casing, which is assumed to be made from a non-ferrous metal, *High Pressure Die Casting* is the most interesting process. The process involves molten metal being injected into a metal die with high pressure. The often water-cooled die is pushed together by a high force and often include several moving parts making them complex and expensive tools. The assumed economical batch size between 10 000 – 1 000 000 units with a production rate of 20-600 units/h, but these numbers are highly dependent on part complexity and size as well as numerous economic factors [15].

For the lid, which is assumed to be made out of some kind of polymer, *Injection Moulding* is the most interesting process. This process is basically the equivalents of metal die casting. A molten polymer is injected into a cold steel mould under high pressure. The polymer solidifies and is ejected as a finished part. Similar to die casting, the tooling cost is rather high, and the labour cost is low. The assumed economical batch size is between 10 000 – 1 000 000 units and the possibility of multi-cavity moulds enables a production rates of up to 3 000 units/h [15].

Both processes are almost exclusively used for producing thin-walled components in large quantities and are considered very competitive within that area. An important factor that determines the cost of the mentioned casting processes is the initial tooling cost. The more complex the design is the higher will the tooling cost be. In the spirit of DFM, as described in section 2.2.2, the part design will be tailored towards an easy manufacturing process. More specifically a simple mould design to lower the tooling cost. Therefore, the parts design needs to include some or all of the following geometric features to be suitable for an easy casting process [42]:

- ***Draft angles*** – All surfaces that are parallel to the opening direction of the die need to have a draft to be easily removed from the die/mould. This does not only protect the die from potential friction forces but also improves the surface finish and tolerance of the casted part. Parts usually adopt a draft angle of around 1,5 - 2 degrees with a minimum of around 0,5 degrees. Depending on the frictional forces, surface roughness and material significantly higher draft angles can be necessary. This is especially important for the plastic lids since casted plastic components usually feature a rougher surface texture.

- ***Fillets*** – by smoothing the curvature in sharp corners the material can flow easier in the mould thus increasing the parts overall quality. Parting lines are usually left sharp.

- ***Uniform wall thickness*** – To minimize warpage, shrinkage, sink etc. when the material solidifies having a uniform wall thickness is a necessity.

- ***Ribs*** – to support and strengthen parts without increasing the wall thickness.

- ***Parting line –*** This is the point at which the two different mould sides meet. The line is almost always visible on casted parts needs to be positioned at a strategic place for aesthetical and functional reasons.

- ***Symbols –*** Letters and symbols can be included directly on the casted parts. The two primary options are to have depressed or raised symbol.

3.5.8 Material selection

The selection of the material for the lid and the casing itself follows the methodology presented in Section 2.4. The selection process is done twice, once for the lid and once for the casing.

To start the selection process a problem analysis needs to be done in order to identify what the material has to be optimized for. This analysis follows the template presented in Section 2.4.2 and is presented in Table 14.

Table 14: Problem Analysis of the Lid

Function	Flat panel loaded in bending
Objection	Maximize stiffness
Constrains	Low dielectric constant (Ref. Ultem1010 has ~3 [43]) Suitable for mass production (Polymer injection moulding in large numbers) Woking Temperature –40°C to 100°C as specified in requirement table Elongation of > 4 % according to snap-joint calculations Yield strength > 73 MPa (From FEM simulations and much dependent on snap-joint geometry) Corrosion, UV, chemical resistance according to the requirements, see appendix B and F.
Free Variables	Thickness

The load of the lid was assumed to be comparable to a *Flat panel (Loaded in bending) with stiffness, length, width, specified, Thickness free.* The material is supposed to give sufficient performance for a low cost. Therefore, the following performance index was chosen in *CES Edupack*:

$$Performance\ index = \frac{C * \rho}{E^{\frac{1}{3}}}$$

The goal is to minimize the performance index to which would result in a material with the lowest ratio between price per kg and young's modulus.

Since the material needed to have a low dielectric constant, the production process was chosen to be casting in large numbers and it needed to be suitable for snap-joints the first material that comes to mind is some sort of polymer. The theory about snap-joints mentioned in Section 2.3 also suggest polymers as suitable material giving the selection process rough idea of what to expect.

After applying the constraints from Table 14 a total of nine materials remained. The majority of these materials being blends of *Polycarbonate* (PC) or *Polybutylene terephthalate* (PBT). In Figure 60 and Figure 61, showing the relation between young's modulus and density as well as the price, the observation can be made that the stiffer options (higher young's modulus) tends to be the heavier and pricier option of the bunch.

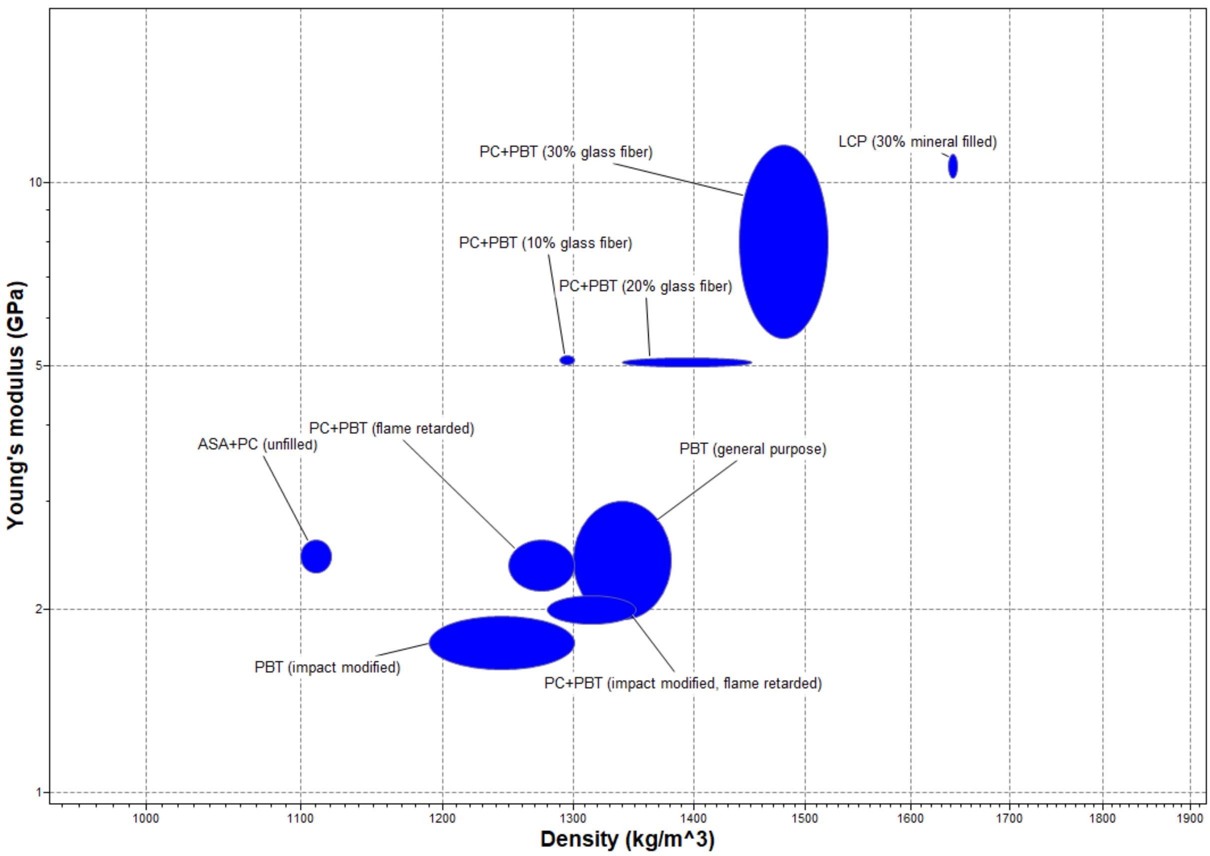


Figure 60: Young's modulus vs Density of screened polymers.

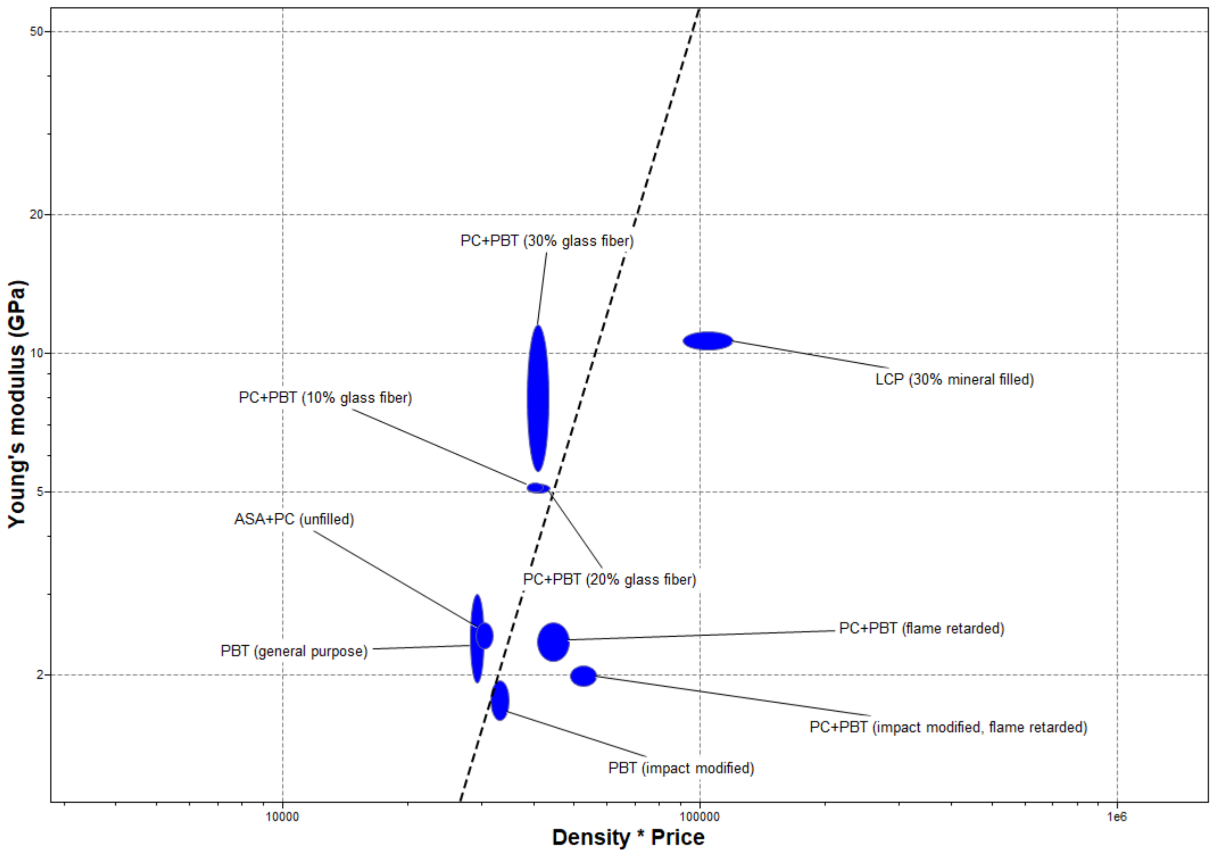


Figure 61: Young's modulus vs Density*Price of screened polymers with material index (dashed line).

One of the material properties important for the sensor to work is the dielectric constant of the material. In comparison to Ultem1010 (2,9-3-1), the material used in the prototype, all contenders have a slightly higher Dielectric constant (see Figure 62).

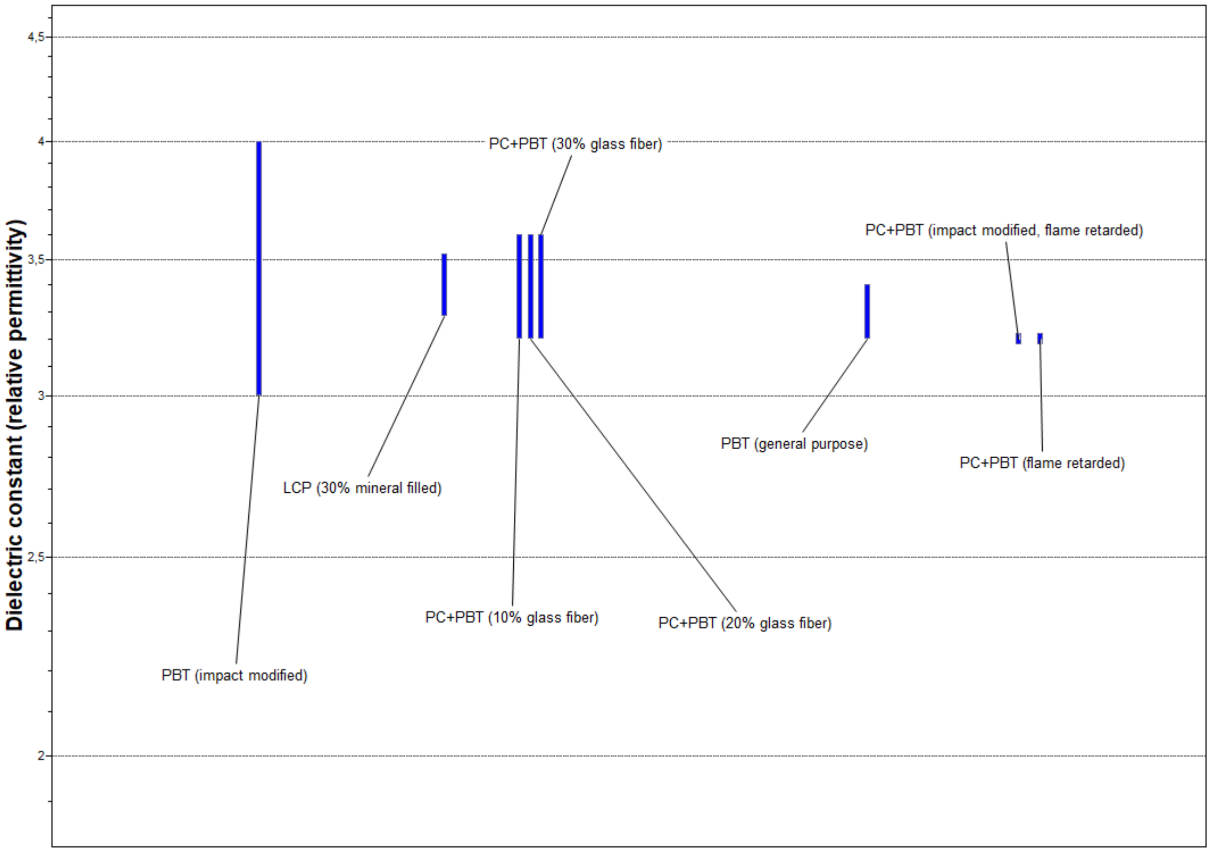


Figure 62: Dielectric constants for the screened materials

The best performing material, the one with the lowest index is to be considered the potentially best material for the job. According to Figure 63, showing each materials performance index, PC+PBT with 30% glass fibre infill is the most promising option. PBT (General purpose) might also be considered but its considerably lower young's modulus and yield strength at a somewhat similar price-point would imply an increase in thickness in order to get the same stiffness. Since a compact enclosure is desired an increased material thickness might not be acceptable.

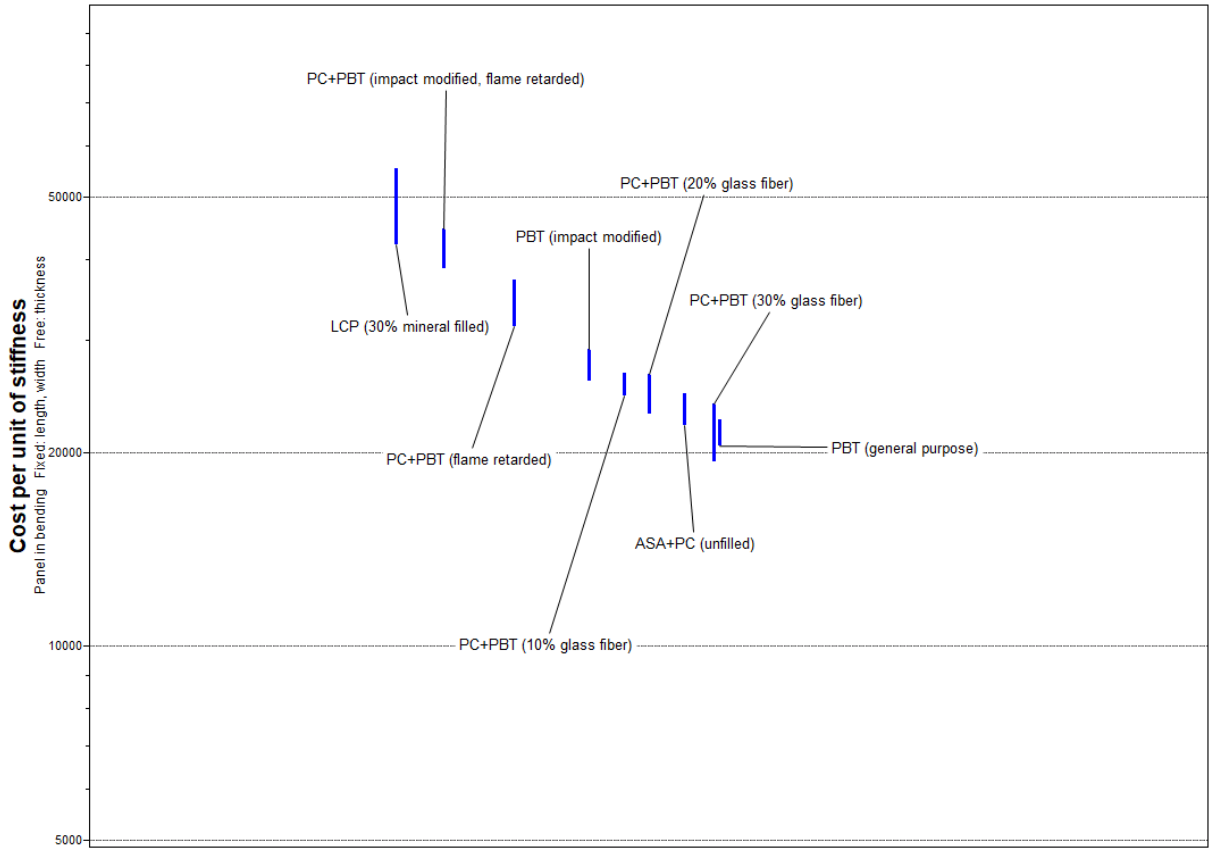


Figure 63: Material index - Lid

The most suitable material in this case is not necessarily the one with the ”best” performance index. The material selection process showed that some sort of PC-PBT blend with glass fibre reinforcement seems to be the most promising way to go. A mixture of an amorphous polymer such as PC and semi crystalline polymer such as PBT gives a material that combines the best properties of both materials. In general terms amorphous polymers are less tough and fail due to their brittle nature as they cannot withstand higher impact loads above certain levels. Semi crystalline polymers possess better resistance to impacts due to their morphology. In a blend between PC and PBT the PC contributes with its superior chemical resistance and the PBT adds its toughness and dimensional stability into the mix. The purpose of inducing fillers to the matrix is to further enhance certain properties. Some plastics can contain up to 60% reinforcing fillers of either glass or carbon fibres. In this case, carbon fibres might not be viable due to their electrical conductivity. In general fibre reinforced plastics suffer from slight losses of impact strength, ultimate elongation and are known to be more prone to warping. On the other hand, a glass fibre reinforced plastic features a much higher stiffness and creep resistance compared to unfilled plastics. Creep resistance is especially important for statically loaded snap-joint since relaxation or even necking of the material could compromise the seal of the sensor lid [14].

Besides having fibrous fillers there is also the option to have small spheres or powder as reinforcement. Non-fibrous filler also increases the stiffness of the material but not to the same degree as a fibrous one. The benefit compared to fibres is that polymers with particulate fillers are less likely to warp and feature decreased mould shrinkage [14].

The downside of glass fibre fillers is that the materials are not fully recyclable.. In the case of infilled PC+PBT the material is *downcyclable* instead of *recyclable* meaning that the material can be reused as infill on lesser grade materials. This means that the material is a bit lowed on Lansink’s ladder, presented in Section 2.2.3, as fully recyclable materials. A non-filled version of PC+PCB would be fully recyclable.

As discussed above, a higher percentage of glass fibre filler results in a material with less elongation. In order for the snap-joint to work certain elongation of the material is inevitable e.g. when assembling the sensor. When calculating the dimensions of the snap-joint on the sensor lid an elongation of 3-4 % was used. According to *CES Edupack* a polymer with 2% or lower elongation is considered brittle. PC+PBT (30% glass fibre) has a rather low elongation of 1-5% at yield compared to PBT (general purpose) which has 50-300%. PC+PBT with a lesser amount of glass fibre filler e.g. PC+PBT (10% glass fibre) is a slightly less stiff option with increased the elongations as well as lowering the young's modulus slightly. Lower glass fibre content also means that the material gets softer and more ductile resulting in slightly increased fracture toughness.

Another property to keep in mind when designing products containing multiple materials is the thermal expansion of the materials. In this case the optimal material would be a material with the same thermal expansion coefficient as the casing. The issue is discussed in section 3.5.9.

To further add to the features of the lid a non-stick coating could be considered. Although the longevity of such coating is debatable, a non-stick surface treatment would help the sensor to stay cleaner for longer. Choosing a polymer with hydrophobic and oleophobic properties might be a better and more long-lived option. But this is a discussion to be had with potential suppliers of the final material for the lid.

A selection of relevant material data found in *CES Edupack* can be found in appendix I.

The same assumption on the load case was made when choosing material for the casing. The performance index is therefore the same as for the lid but used with a different set of constrains. Similar to the lid the production process of choice for the casing will be casting. The material group that was recommended earlier in the project was non-ferrous metals. This includes materials such as aluminium, copper, lead, nickel, tin, titanium, zinc, magnesium and many more. Previous documentation points out aluminium, zinc and magnesium to be the most promising alternatives.

To further investigate this suggestion the problem analysis shown in Table 15 was used as input in *CES Edupack* to screen for available option. Figure 64 and Figure 65 show the resulting materials and their ratio between young's modulus and density as well as their price. The three stiffest and lightest materials are aluminium, magnesium and zinc which proves that the suggested materials as the most promising ones.

Table 15: Problem Analysis of the Casing

Function	Flat panel loaded in bending
Objection	Maximize stiffness
Constrains	Good thermal conductivity EM shielding Excellent castability Corrosion, UV and chemical resistant according to requirements, see appendix B and F.
Free Variables	Section area

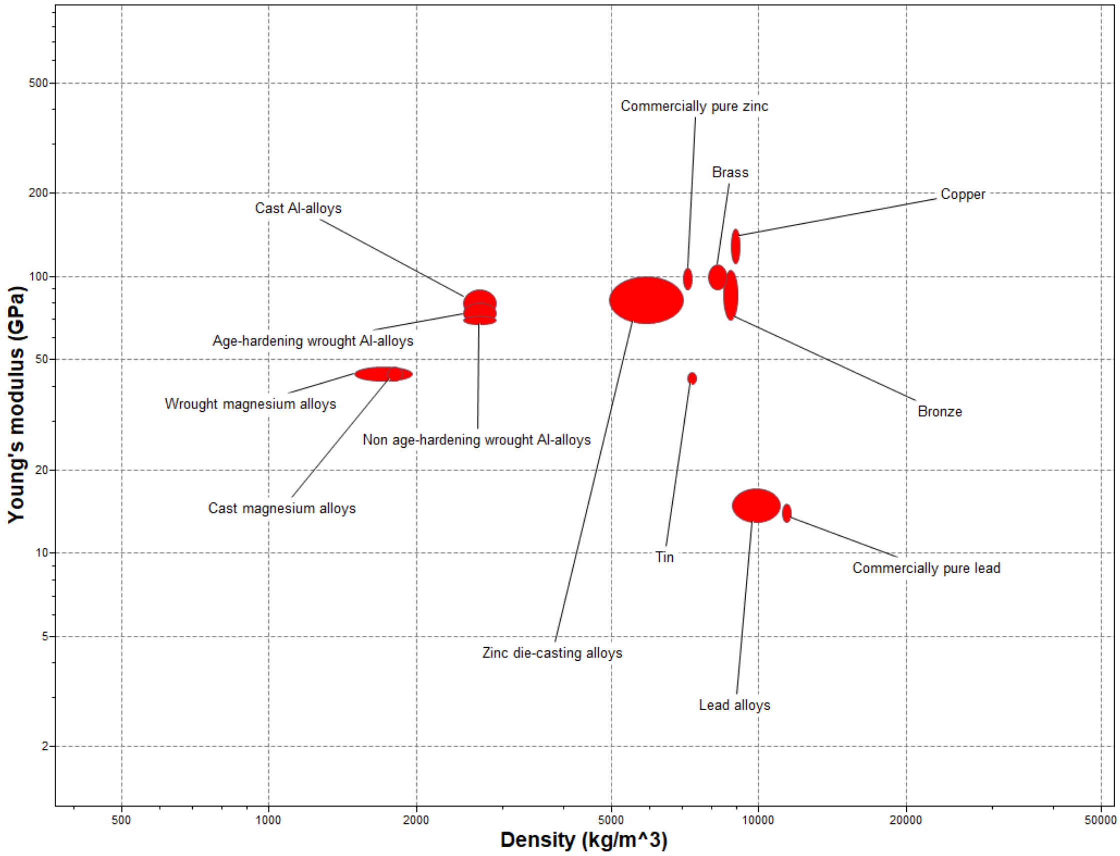


Figure 64: Casting alloys - Young's modulus vs desity

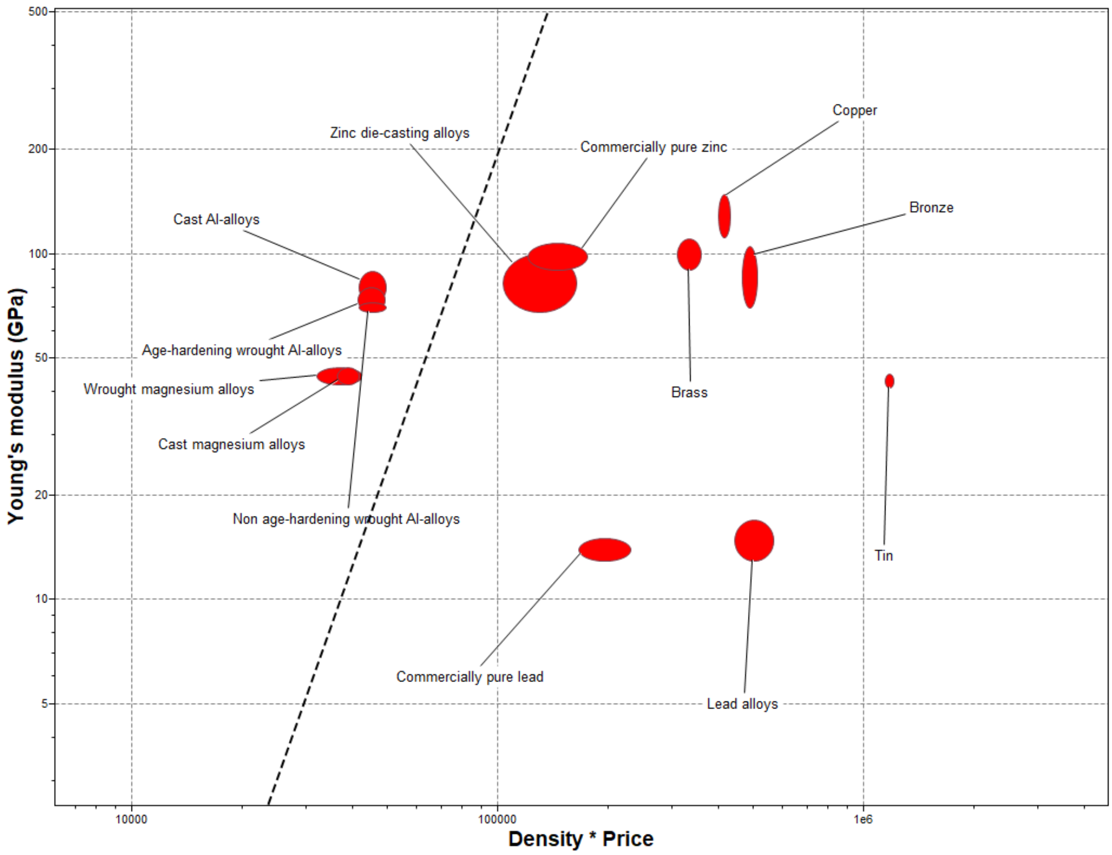


Figure 65: Casting alloys - Young's modulus vs. density*price with the material index (dashed line) visible.

All three materials are common alternatives for casting of strong and durable products. The most promising material for this application is in similar fashion as with the lid the material with a minimized performance index. In Figure 66 a listing of the indices for different materials are shown. Aluminium features the lowest index followed by some of the magnesium alloys.

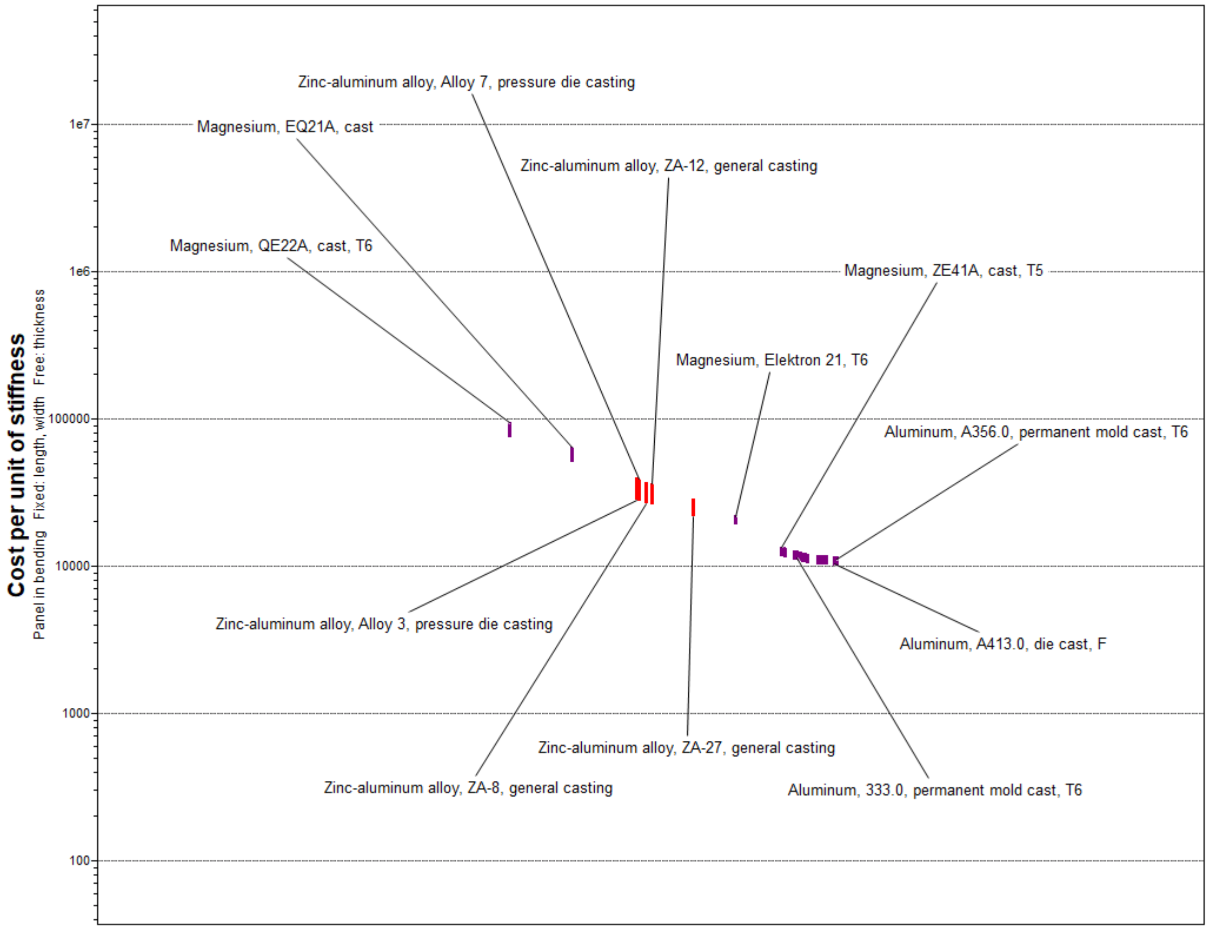


Figure 66: Material index - casing

Since the sensor will feature a heat sink the thermal conductivity needs to be considered. See section 3.5.6 for details about the cooling properties of the casing. Figure 67 shows the screened materials and their thermal conductivity. A higher thermal conductivity will result in a better performing heat sink. The material with the highest thermal conductivity out of the three is aluminium.

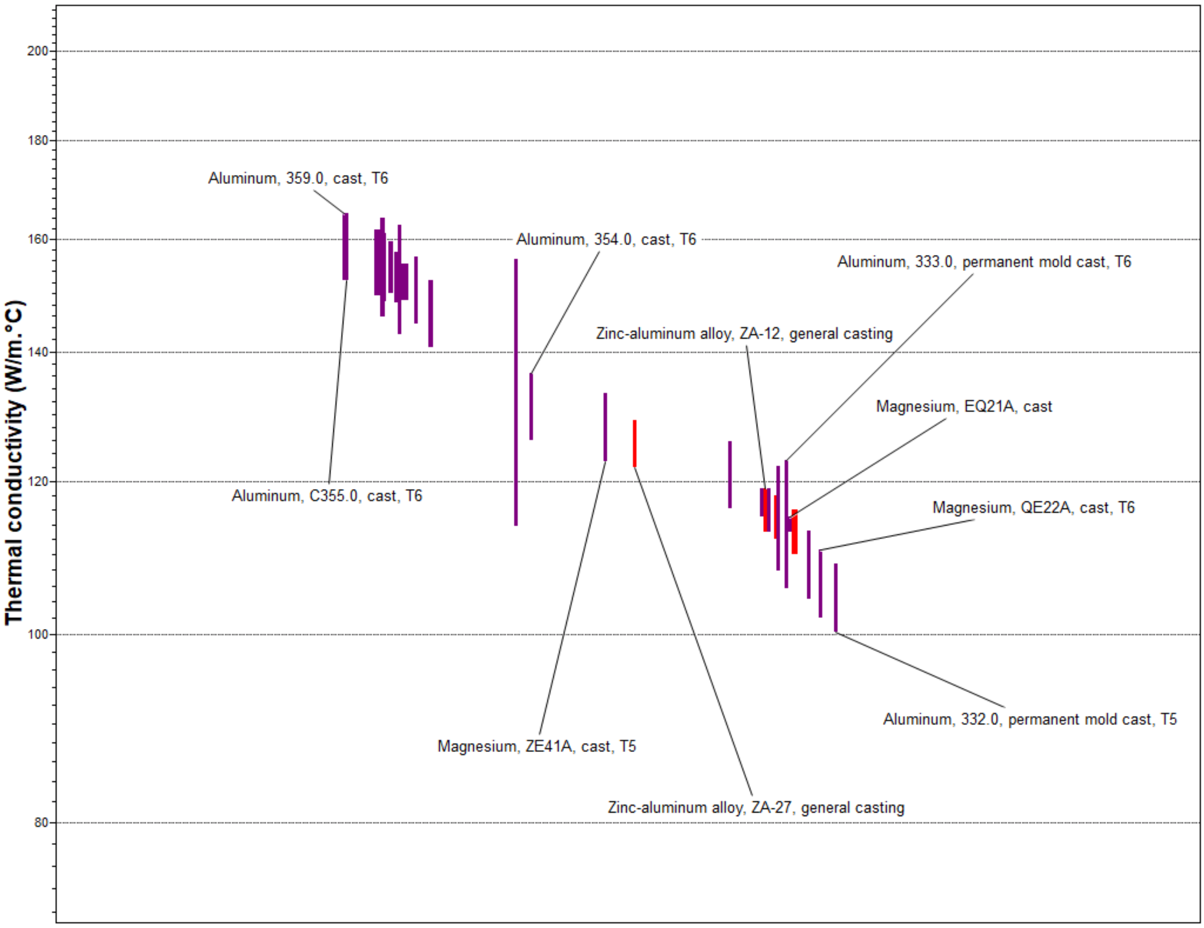


Figure 67: Thermal conductivity of aluminium, magnesium and zinc casting alloys

To further investigate which material is the most promising choice material data, economical aspects and processability need to be considered.

Aluminium is the most commonly used casting alloy since its strength, superb corrosion resistance and price makes it a solid option to use in high-volume casting. The extensive number of available alloys makes aluminium suitable for almost any industry demanding a strong and lightweight component.

Aluminium alloys are available with high service temperature ranges, superb weight-to-strength ratio, excellent thermal and electrical conductivity, excellent EMI and RFI shielding properties as well as the ability to be fully recyclable. In casting applications, a minimum wall thickness of 0,89 mm can be achieved making it suitable for complex shapes. The cast parts are usually not heavier than 32 kg. Aluminium is less castable if compared to Zinc and Magnesium due to the demand for higher temperatures and prolonged solidification time resulting in increased tooling cost [44].

Die casting thin-walled aluminium parts is often associated with a set of problems. Although aluminium has good casting properties it is a rather viscous material when in molten state. Casting large parts can therefore be problematic since a viscous fluid needs longer time to fill the entire die. The higher melting point of aluminium in comparison to other non-ferrous metals causes it to cool quickly meaning that the window in which the aluminium is castable is rather narrow. Despite these issues, thin walled aluminium is commonly used to cast e.g. notebook casing with thin wall-thicknesses of 0,7-1,5mm [45] [46] [47].

Another commonly used material for casting applications is Zinc in various alloys. These alloys can be found in numerous decorative and functional applications within many different industries. The key advantages of casting zinc alloys is the ability to make thin walled, tight tolerance casted parts. The casted parts are usually limited to a minimum wall thickness of 0,63mm and a maximum weight of 34 kg. Overall zinc is a bit more expensive than aluminium and magnesium but also offers superb corrosion resistance as well as a higher toughness than the other two materials [44].

Zinc features a lower melting temperature than aluminium and magnesium making it possible for hot-chamber casting which is less expensive and faster than conventional die casting. The lower melting temperature also meant that the dies last a lot longer than dies used with magnesium or aluminium.

Casting magnesium is also a widely spread practice for applications that demand a lightweight part. Magnesium is the lightest casting alloy when compared to aluminium and zinc and is often used to replace heavier aluminium parts in applications that do not require the corrosion resistance of aluminium. Magnesium alloys do however require a surface treatment since the magnesium corrodes easily when exposed to moisture and especially in salt environments. Painted, oiled or otherwise treated part can, however, last a very long time even in more exposed applications. Magnesium alloy parts are limited to a maximum weight of 20kg and a minimum wall thickness of 1,27mm [15] [44].

These statements lead to the conclusion that aluminium is the most promising material for the casing. A specific alloy with tailored properties for the final design needs to be discussed together with potential suppliers. Although zinc offers better tolerances compared to aluminium it might not be enough to meet the demands of the O-ring groove or the vent. This means that some machining might be inevitable meaning that a casting process with lesser tolerances might be acceptable.

The final design will most certainly involve a surface treatment of the part due to functional and aesthetical reasons. Many different coating options are available ranging from regular paint to a hard anodizing. As an example, the previously mentioned BASH camera housing has a Type III hard anodizing which gives the camera an exceptional good scratch and wear resistance. Surface treatments are also available with electrically conductive properties if the final design of the PCB demands grounding through the framework of the vehicle.

3.5.9 Failure Modes and Effects Analysis (FMEA)

The purpose with a failure mode and effects analysis is to evaluate and design for failures that can occur before them occurring. This gives insight into how the failures can be prevented and mitigated. With the help of experience, imagination and simulations potential failures that the product can experience can be found. These failures are ranked by giving three factors severity, occurrence and detectability a score from 1 to 5.

- Severity, where a low score means the failure does not have any influence on the product function and a high score means that the failure would permanently disrupt the product function.
- Occurrence, a low score means it happens rarely and a high score means it could occur very often.
- Detectability, if the failure is easy to detect and fix before failure it is given a lower score and a high score when the failure is hard to detect and fix.

The failures Risk Priority Number is calculated by taking the product of the Severity, Occurrence and Detectability which will range from 1 to 125. The RPN is used to prioritise which failures are most important to mitigate.

The most serious failure mode identified was the O-ring temporarily deforming when put under high water pressure, thus allowing water to penetrate the casing. It had the highest severity rating since water coming into contact with the PCB would most likely break it. The casing will also come under high pressure water many times during its lifetime due to the truck being washed. Furthermore, the failure would be very hard to detect or to prevent before it occurs. To mitigate this failure the O-ring should be put in a protected location where water cannot directly impact it reducing the pressure and force it has to withstand. Furthermore, ensuring that the lid and casing do not mismatch or deform in a detrimental manner when water impacts them is also very important.

This is also connected to another failure mode where the lid would expand or shrink due to being heated or cooled. This can be mitigated by giving the lid room to expand and contract, but at the same time making sure the snap-joints stay engaged. Since both the casing and the lid will expand or shrink with changing temperatures having similar thermal expansion ratios is a very good way of mitigating mismatch issues. Choosing two materials with similar expansion ratios can be difficult due to plastics often having a higher expansion ratio. PC+PBT 30% glass fibre's thermal expansion is however somewhat close to the aluminium due to the high grade of glass fibre. Aluminium's thermal expansion varies between 16,5 – 24 µstrain/ºC compared to PC+PBT 30% glass fibres 21-30 µstrain/ºC. PC+PBT 10% glass fibre for example has 77 µstrain/ºC, this would increase the chances of a mismatch when the lid and casing are heated or cooled. Having a glass fibre infill also aids in reducing the relaxation or creep of the material which is important for the snap joints due to them being under constant force.

Many other failure modes were connected to the O-rings capability to keep a tight seal and the design controls for these failures were also similar. To reduce risk with the product effort should be focused on ensuring that the details in connection with the O-ring are robust. The complete table with all failure modes can be seen in appendix J.

4 The Final Product

This Chapter will present the final outcome of the development effort.

The final design of the heavy-duty enclosure features a two main parts; the lid and the casing. To seal these two parts together a hollow O-ring is utilised together with a pressure equalizing Gore-Tex valve. The parts are specifically designed with DFA, DFM and DFEoL in mind targeting a functional rather than aesthetically pleasing design. An overview picture of the sensor casing with the PCBs excluded can be seen in Figure 68.

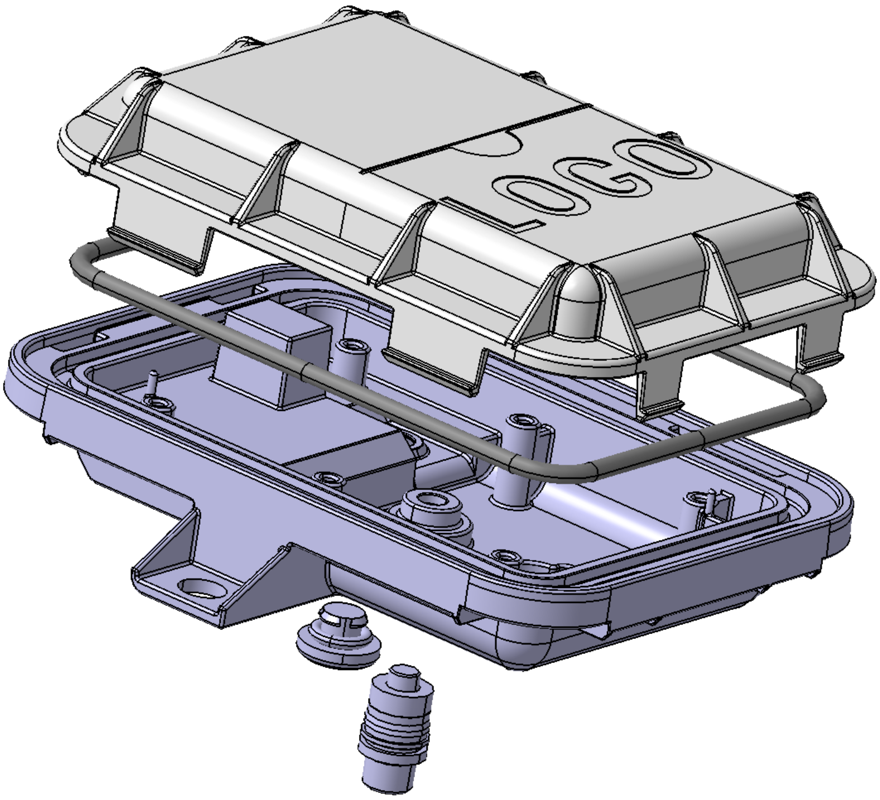


Figure 68: Rendering showing the major components developed in this project.

The final design is specifically aimed at a casting process to shorten down the production time of the rather complex geometry of the included parts. This means that the design features the necessary draft angles, a uniform thickness and the correct thickness ratios to avoid sink near stiffeners and studs. To properly seal the unit from the environment a precisely cut groove is needed for the main O-ring and the vent hence a secondary machining process will be needed to get the necessary surface finish and tolerance.

The lid features snap fits to be easily assembled or disassembled. The snap-joints allow the enclosure to be serviceable in case the internal electronics need upgrading or replacing. The placement of the snap-joints was optimised to evenly compress the O-ring even if one of the joints fails completely.

The top surface of the lid features according to demands the customer company’s logo along with a marking in the middle to indicate where certain features on the PCBs are. This marking also conveniently disguises sink marks that are created by a rib on the inside. The area marked in red is where the signals will go through the lid and is therefore completely flat on both sides, see Figure 69.

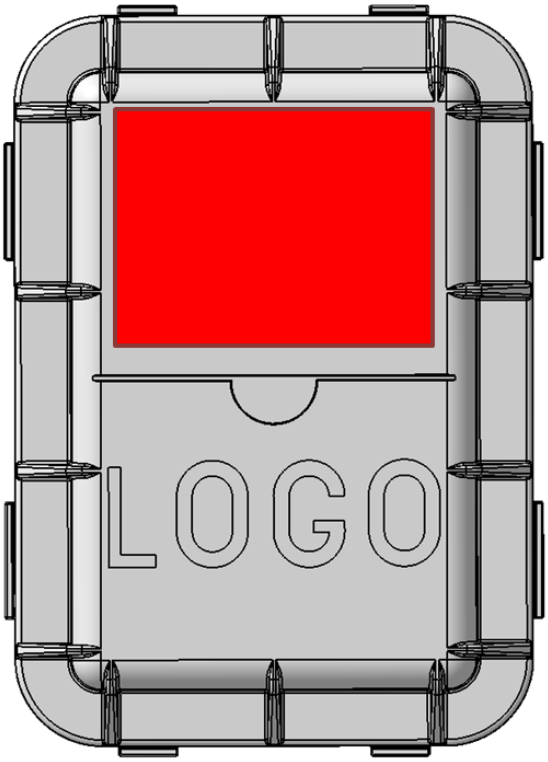


Figure 69: Rendering of the top surface of the lid with a red highlight for where it is required to be flat.

By adopting snap-joints as fasteners, as the DFA theory suggests, the assembly time gets shortens and the needed inventory management is reduced. Furthermore, the number of steps included in the assembly process of the lid is reduces to on single operation. The lid features a guiding edge with notches which only allows for assembly in the correct orientation. This is made to make the positioning of the lid fool proof, as DFM theory suggested, see Figure 70.

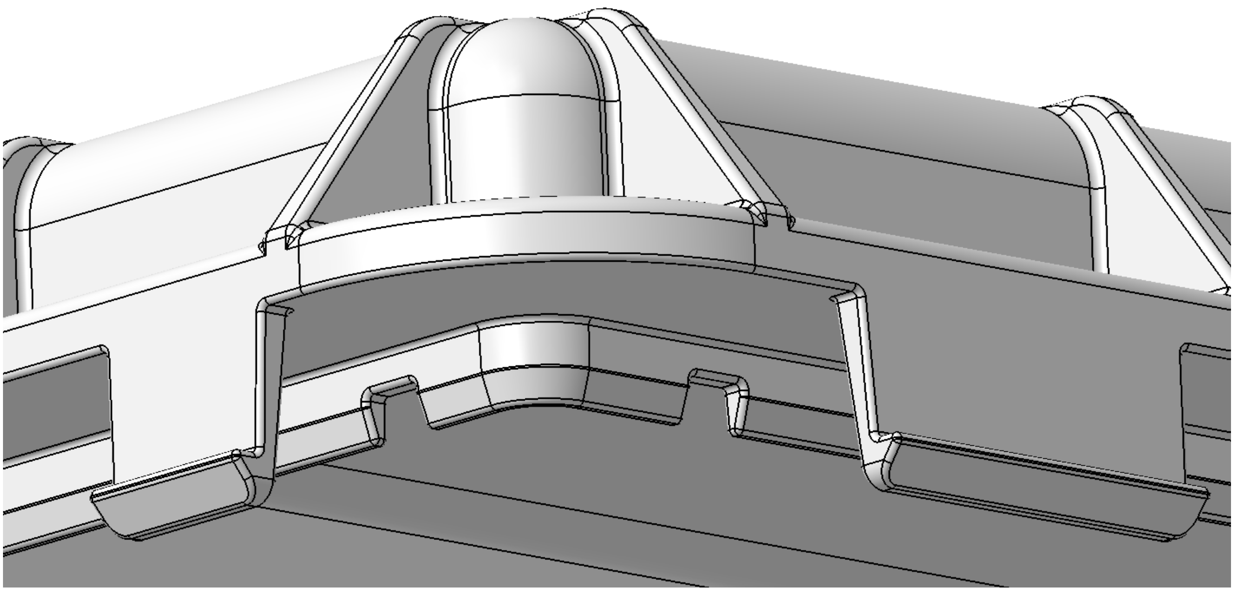


Figure 70: Rendering of the lid showing the guiding edge and notches.

The material of choice for the lid is a PC+PBT blend with a percentage of spherical glass fibre infill to provide a stiff, creep resistant material with minimised tendency to warp and shrink during casting. The excellent chemical resistance of PC combined with the toughness of PBT ensures a stiff and strong lid to maintain the paramount task of keeping the enclosure sealed.

The casing itself features a generous cooling fins to accommodate the cooling of the PCB. The size of this cooler is intentionally oversized to keep the PCB as cool as possible thus prolonging its life expectancy and to prepare for the possibility of additional components that need cooling. A hole has also been made to accommodate for the LED solution, Gore-Tex vent and connector, see Figure 71.

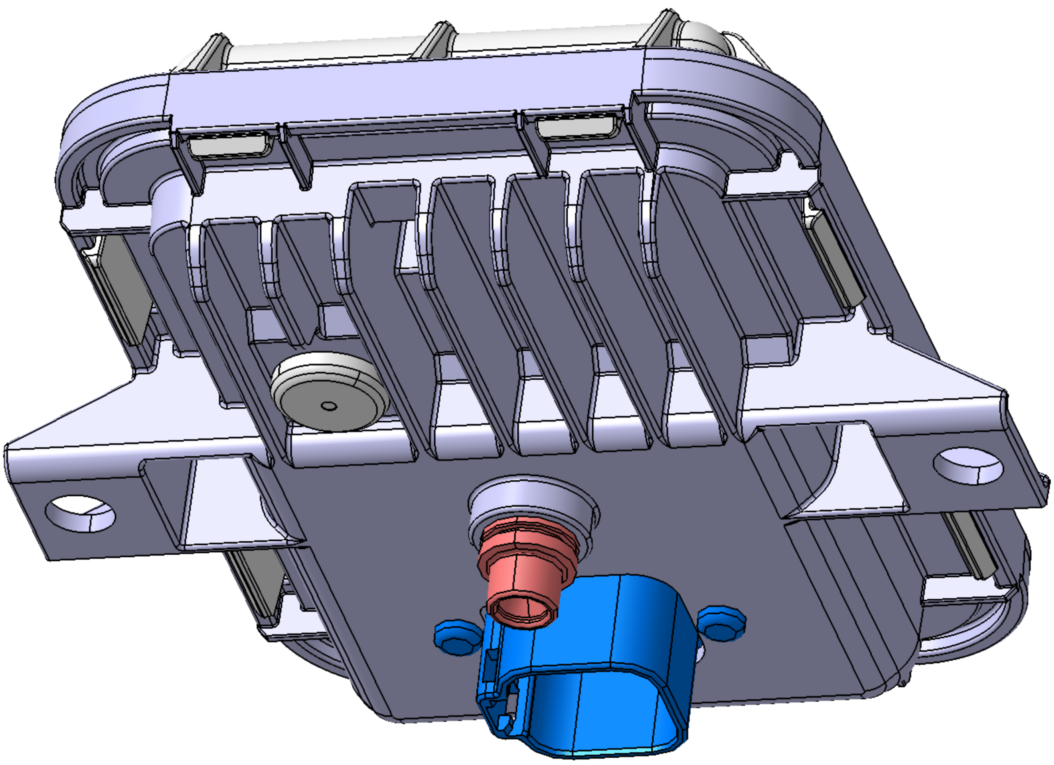


Figure 71: Rendering of the sensor casing showing the underside of where the cooling fins, LED (red), Gore-Tex vent (white) and connector (blue) are located.

The casing features an elevated edge around the perimeter of the lid to protect the plastic edge from smaller hits and to make the path to the O-ring less direct, see Figure 72.

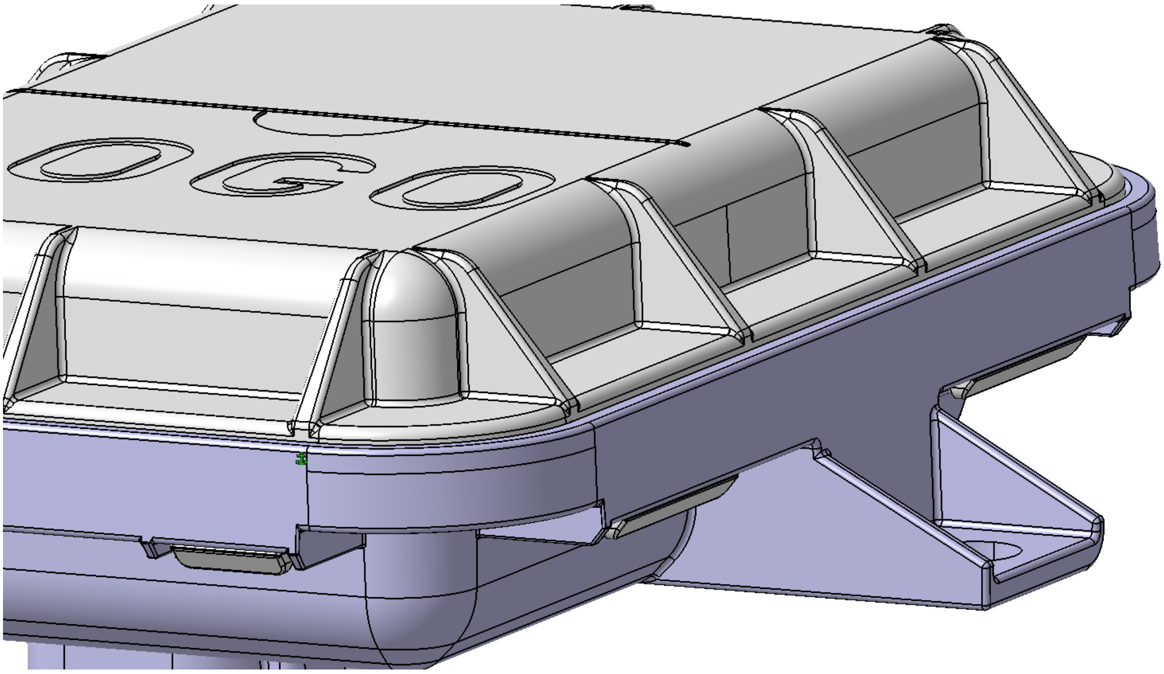


Figure 72: Rendering showing the side of the sensor casing.

The new design is around the same size as the previous prototype, but its design is much more slimmed and adjusted for the PCBs. Instead of utilising screws to fixate the lid, snap-joints are instead used. To use snap joints the stiffness of the lid had to be improved to ensure a good seal. This was done by increasing the height of the lid and adding ribs. By doing so a larger portion of the sensor casing is made of plastic. By removing the screws, reducing the fraction of metal and by having an even wall thickness the total weight of the lid and casing could be reduced by 51%. Technical drawings of both the lid and casing can be found in Appendix K.

4.1 Mass Production Process

The customer company will most likely not produce any of the components in-house and the manufacturing will be done by different suppliers. No suppliers have yet been chosen, meaning that the exact manufacturing method is not known yet. Since the exact circumstances around the manufacturing method are largely unknown the model has been made to fit a general case detailed in section 3.5.7 3.5.7.

A draft angle of two degrees has been implemented in all surfaces that would otherwise be vertical. To ensure good tolerances in the hole for the LED light the minimum draft angle of 0,5 degrees was used. Every edge in the model has been rounded, on most edges the radius 0,5 mm was used. In some places larger radiuses were used to get a uniform wall thickness since the outer radius has to be larger by an amount equal to the wall thickness.

The wall thickness is largely uniform at 2,5 mm in the casing and 3 mm in the lid. Stiffeners and ribs have a decreasing thickness due to the draft angles. The initial thickness for the cooling fins/ribs is the same as the casings wall thickness. Other ribs initial thickness is half the wall thickness to reduce sinks during solidification. Most ribs are also placed in spots where the sinks they cause are hidden and not detrimental to performance.

The lid has been designed so that it can be manufactured with a two parted mould which will split at the hook of the snap joints and the bottom edge at the base of the snap joints, see red line in Figure 73.

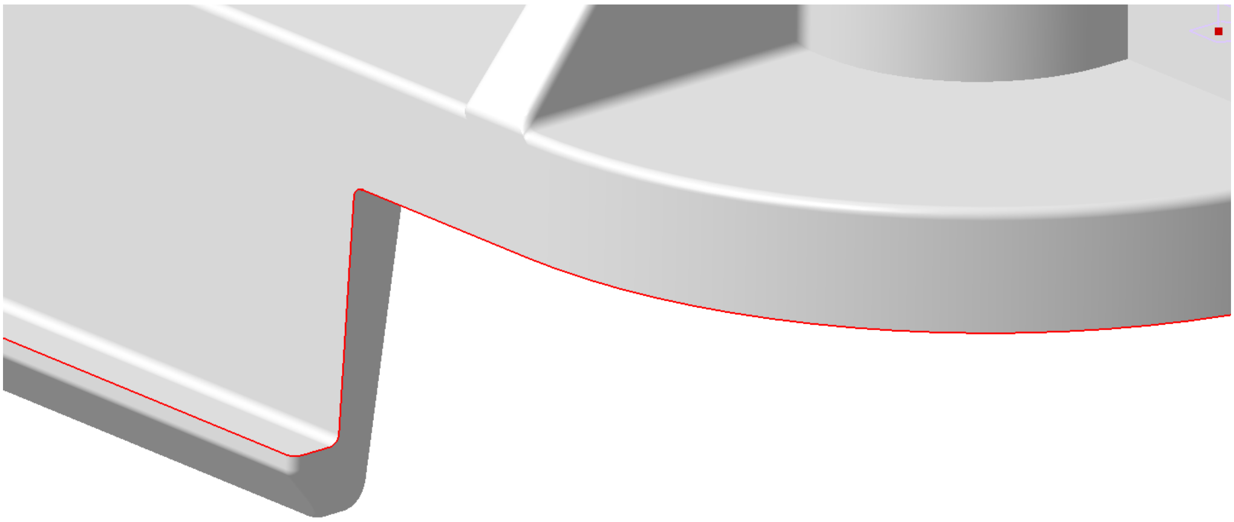


Figure 73: Split line location on the lid.

The casings split line will be located at the position furthest from the centre of the model in any given direction and will therefore be located on the lower part of the protective edge and the fasteners towards the truck. A split line not connected to the previous one will also be located in the hole for the snap joints, see red line in Figure 74.

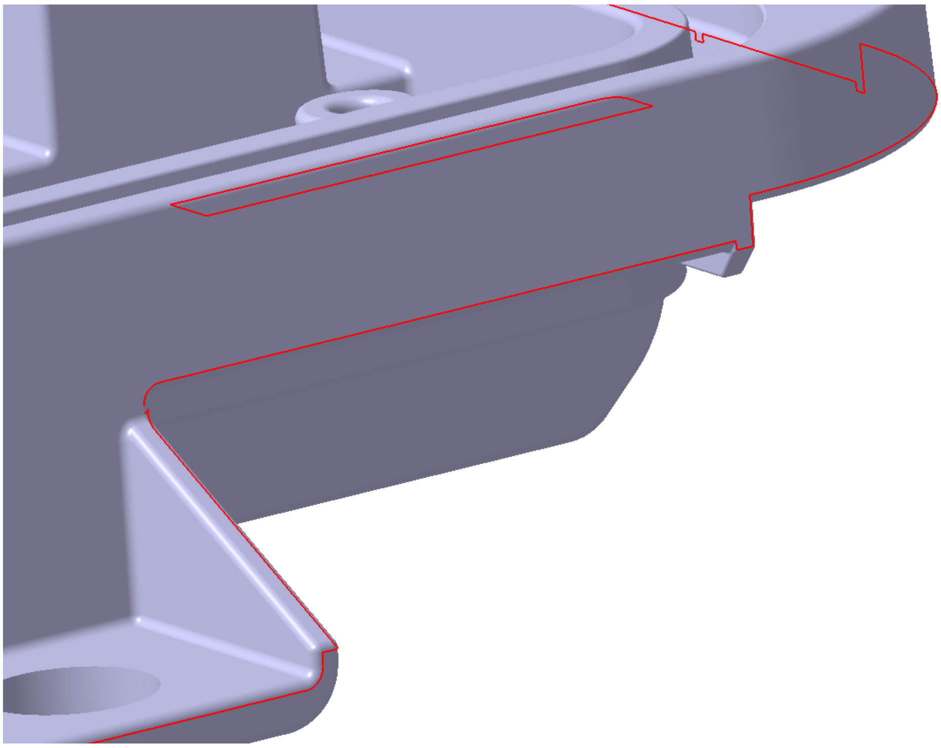


Figure 74: Split line location on the casing

The casing can also be produced by a two parted mould but would require additional operations for creating the threads in the PCB connection points. This could be avoided by implementing threaded inserts in the mould which would automatically thread the holes when the mould is opened. This would require a more complex die casting process but could be beneficial compared to the extra operation required in threading the holes afterwards. The hole for the Gore-Tex membrane and the grove for the O-ring could also require additional machining to achieve the necessary tolerances.

4.2 Assembly process

The assembly process consists of five main stages which will be explained below with corresponding pictures

Step 1:
The Sensor casing is assembled by first inserting the LED light guides and the Gore-Tex vent into their appropriate holes. The light guides are pressure fitted and the Gore-Tex vent is fixated with snap joints.

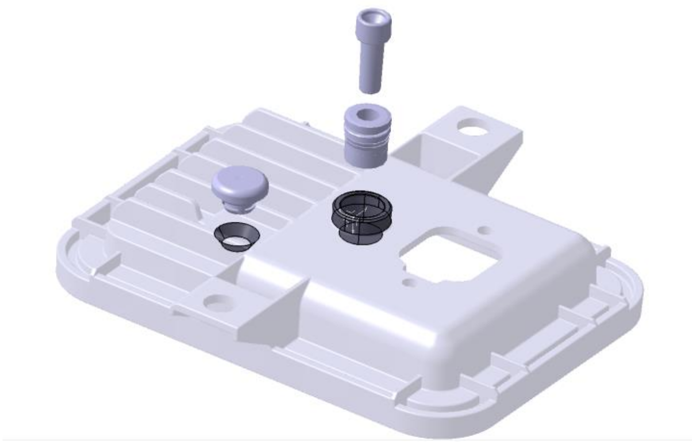


Figure 75: Assembly step 1.

Step 2:
Turn the casing over and place the O-ring in its grove.

Figure 76: Assembly step 2.

<u>Step 3</u>:
Apply a cooling pad or paste to the cooling tower.

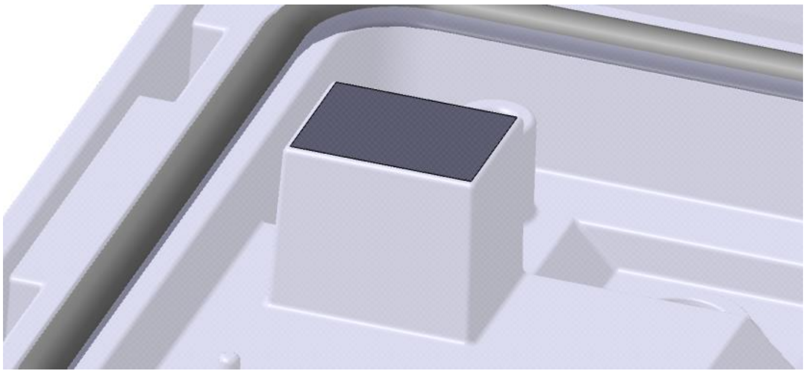


Figure 77: Assembly step 3.

<u>Step 4</u>:
Fixate the bottom PCB and connector to the casing using eight screws and the two guiding pins.

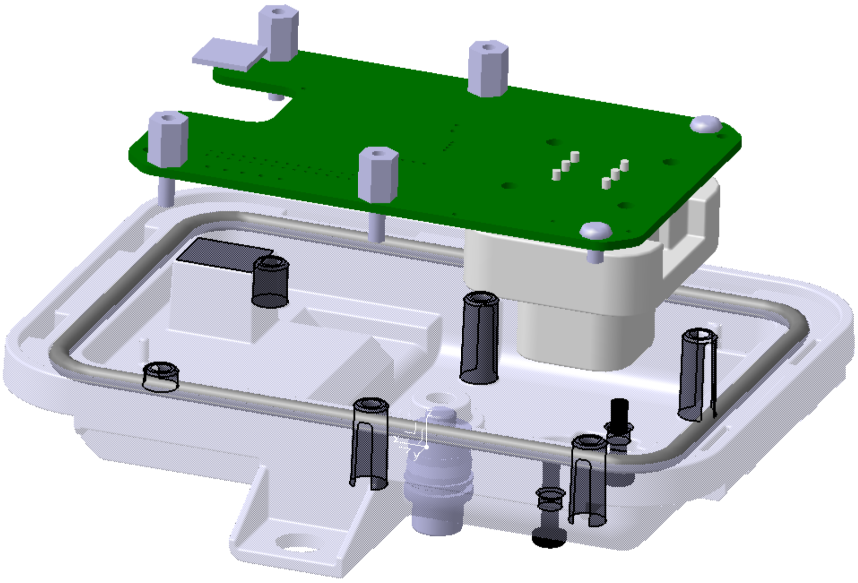


Figure 78: Assembly step 4.

<u>Step 5</u>:

Fixate the top PCB to the bottom PCB using four screws, then attach the lid by placing the snap joints on one side into their corresponding holes and then snap the other side into place.

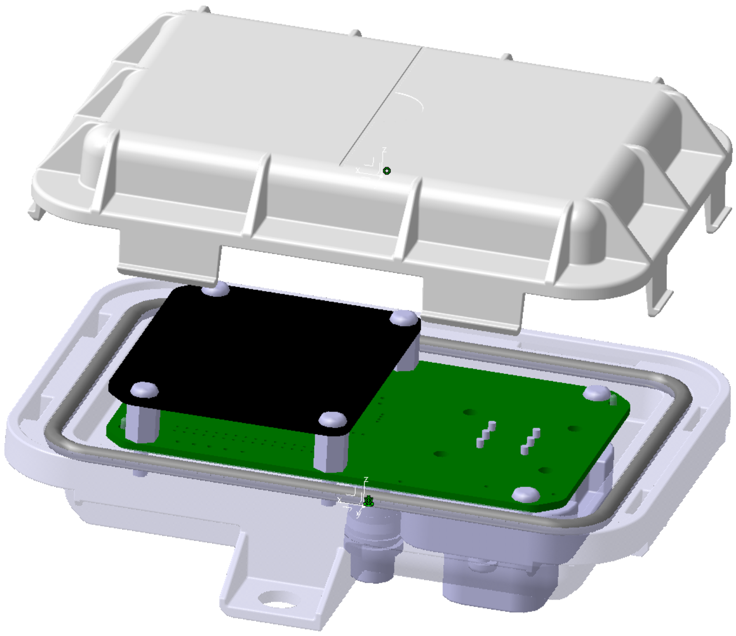


Figure 79: Assembly step 5.

A wish of the customer company was to reduce the time it takes to assemble the casing. Although the new assembly process is similar to that of the previous prototype two major improvements have been made. Firstly, the O-ring now has a straighter and simpler form making it easier to insert into the grove and now has potential to be automated. Secondly, the lid attaches to the casing with snap joints which saves a large amount of time. Previously ten screws had to be placed and tightened with a torque of 1 Nm and if not equally tightened the lid could deform, which affects the sealing ability. The assembly time is therefore greatly reduced by eliminating many assembly steps and combining them into one.

5 Discussion

The following chapter will present a discussion about the developed product.

As mentioned in the introduction, this project was part of a much larger project conducted by multiple groups from multiple companies. The internal electronics and connectors were developed by another project group at ÅF, the software and the ownership of the project was handled by another company. This means that multiple projects worked with different areas of the product that all affected each other's work.

A highly valued ambition for the sensor unit was to reduce its current size. This task involved changes in the design of the PCB and the enclosure meaning that two different project groups got to re-design interdepended components. Concurrent engineering only works if there is a good exchange of information and overall communication between the different groups. Unfortunately, the communication was slow and scarce hence the decision to disregard later changes of the PCB and other electronic components. This greatly limited the potential for a reduced size since the work would use the current PCB as reference.

The project has been a very typical product development project and the methods used during it reflect this. However, since this project is a part of a larger development effort much of the groundwork had already been made, such as customer interviews and initial specification. Much of the knowledge was produced by the previous project group and handed over to this project group.

This information, including details regarding the previous prototype and specifications were taken at face value. This also meant that the methods we used were influenced by previously produced information. All this information could have been produced by this project and would most likely have given the project group a deeper understanding of the customers wishes or the exact problem the customer wishes to solve. However, this would have taken a considerable amount of time giving less available time for other tasks, such as the optimisation process. In general, the chosen methods served this project very well and supported the set deliverables.

5.1 Connector options

During the initial evaluation of the prototype it was evident that the connector itself was a big reason behind the size of the sensor. By simply replacing it with a smaller connector could potentially reduce the size of the sensors quite a bit. Approx. 30% of the current height of the sensor consists of the connector which is quite much compared to other components.

The current connector (DT15-6p) is a bit to hefty for the sensor and the possibility of exchanging said connector with either a M8/M12 connector or an extension cable with a cable gland were discussed. M8/M12 connectors are used for many different applications e.g. cameras and sensors in the mining industry and extension cords and cable glands are commonly used for auxiliary aftermarket lights on cars and other vehicles. Both options include a reduction in size and are available with adequate IP and IK classifications.

Which connector is the better one depends on the desired application and mounting method for the sensor. If the sensor is supposed to be retrofitted to older trucks a cable gland with an extension cord might be the cheaper and easier option. On the other hand, if the sensor unit is supposed to be mounted on a production line at the factory where the truck is being assembled a connector might be better.

When designing a product an assembly line it is important to think about the steps needed to install the piece. Since an assembly line is constantly moving it might be hard to assemble a unit that demand multiple time-consuming steps being carried out in one go e.g. fastening the sensor and routing the extension cable needs to be done in one assembly step since these pieces are not separable. By having the cable and the sensor as separate units it becomes much easier to divide the assembly into two separate operations conducted by two different workers. This would in turn save both time and money.

A third option to consider is a connector that is casted directory into one of the enclosure components. The sensor From Volvo (see Section 3.1.4.3) features a variant of this. This will most likely involve major changes in the design of both PCB and casing but could potentially result in a much smaller unit.

5.2 LED light

Another component that contributed to the overall height of the sensor was the LED bushing on the back side of the sensor. The placement, size and overall design of it is debatable for a sensor of this size.

It was explained that the LED is intended to be used when calibrating the system were the LED indicates the status of the process. The placement of the sensor and the LED demands for the operator to lean underneath the truck to assess whether the calibration was successful or not. To fully understand the procedure further explanation is needed.

However, from the very beginning of the project the opinion of both the project group and other involved parties questioned the usability and overall customer value of having the LED placed in that position. The LED would not only be hard to see due to dirt but would also involve a non-ergonomic operation for the operator. A solution to this problem would be to place the LED on the lid, pointing away from the vehicle. This option was discussed but was found to violate Swedish traffic laws.

5.3 Die casting thin walled aluminium

Die casting aluminium into thin-walled components is possible, no question. But the question to discuss with potential suppliers is its economic feasibility and what properties the available materials will have. Some drawbacks are to be expected for a more fluid material but will need to be further investigated.

An alternative to thin-walled casting would be to slightly increase the thickness to 3 mm. According to the experience of the team at ÅF thicknesses of 3 mm is usually no problem even for larger components. The drawback with a thicker casing is that its overall size also increases slightly.

5.4 Ethical and environmental considerations

In the start of this project it was discussed whether this product would be an ethical one. No concern was then found. At the end of the project the ethical question was raised once again. This time *Rotary's 4-way test* was used to examine the results produced in this project. A fifth question is also asked which focuses more on the environmental aspect of the product.

1. ***Is it the truth?***

Yes, all results are presented, and negative results are also presented to show the full picture. The methods used to procure the results obtained has been presented and critically analysed and when the results are uncertain or not a complete reflection of reality this was also noted.

2. ***Is it fair to all concerned?***

We have not found any reason the product would not be fair to any concerned parties.

3. ***Will it build goodwill and better friendships?***

The project has delivered a new design to the customer company which compared to the previous prototype is much more adjusted to mass production making it less costly to produce, both environmentally and monetary. This increases the value of the product and since this project was made at the expense of ÅF it should build goodwill and better friendships.

4. Will it be beneficial to all concerned?

The new design will through its more efficient manufacturing method reduce the cost of producing the product. The value provided to the customer should therefore be higher, which in turn makes it a better product.

5. Is the Product environmentally justifiable?

The purpose of the Sensor casing is to aids the driver of trucks with trailers and by doing so increasing the efficiency of navigating the truck. This in turn could aid in reducing the emissions of driving the truck. Lansink's ladder as shown in section 2.2.3 was as a reference for material choices. The most valued action according to Lansink is to see to that the product fulfilled one of the "*three R:s*" meaning it waste should be avoided all together, components should be re-usable or the material should be recyclable.

By utilizing a casting process the amount of waste can be reduced, especially for the casing itself. A milling process produces a lot of aluminium chip that require energy to be melted to new aluminium products. A casting process does not produce as many chips and could even use aluminium scrap as raw material for the process. Since the components of the enclosure are tailored to suit this one PCB, and no other, it would probably be very hard to re-use the process. The most likely scenario is that the sensor gets disassembled and the material gets recycled or downcycled. The "*three R:s*" can only be achieved if the waste is collected properly according the WEEE directive or similar. If this is not the case, the environmental aspects become much more crucial. All things considered the work performed in this project was done with the environment in mind but a future Life cycle analysis (LCA) could provide useful information regarding the actual environmental effects of the sensor.

6 Proposal for future work

This chapter presents a set of suggestions for further work with the design and presents areas of interest that need further attention.

Due to the early stage of the project, no supplier for material or production was contacted during the project. The information regarding the design for casing etc. was provided by literature, design guides or the expertise of the people in *Hyttsatteliten* at ÅF and not by a casting specialist. Some features, radii or stiffeners might therefor not be the best option for casting and will need some alteration before the enclosure is ready for production. The project group charged with revaluating the PCB might also make significant changes to the architecture of the PCB meaning that a re-designing of the enclosure is inevitable. In that case many of the facts and details from this project could be used as guidelines for a new design. The choice of material, designing of the snap-joints, and the selection process of the O-ring could provide useful input for the future.

The following steps are proposals for the future work with the enclosure:

- Better communication between the design team of the enclosure and the PCB should be established to concurrently engineer the PCB according to the customer's wishes.

- Consult a casting specialist with the design and get input on how to optimize the features and materials to best suit a casting process.

- Build a prototype and perform test to verify the sealing capability of the enclosure and other requirements.

- The final step is to certify the product according to the rules and legislations and start a pilot production/evaluation procedure working closely with key customers to get input on how the enclosure performs. But only time will tell what actual steps are needed before the product is ready to be released.

7 Conclusion

In the problem statement of the project three deliverables were set:

1. A near production ready 3D-model of the design in CATIA V5 including 2D-drawings and detailed documentation explaining the design choices
2. Material selection analysis
3. Durability analysis

The first deliverable has been met by redesigning the older prototype and tailoring it towards a casting process. Whilst all the features of the prototype are preserved, the new enclosure has become both smaller and lighter. Furthermore, the included components all underwent a material selection were suitable alternatives were analysed and discussed. The material selection process was done in conjunction with a durability analysis where the components underwent optimization in both ANSYS and CATIA's FEM tools.

The new design encompasses multiple new wishes and demands presented by the involved stakeholder resulted in a product much closer to a market release. Depending on the future of the project, many of the findings can be directly used or adapted to future revisions of the PCB.

Bibliography

[1] International Organization for Standardisation, "SS-ISO 20653:2013: Road vehicles - Degree of protection (IP-code) - Protection of electricla equipment against foreign objects, water and access," 2013. [Online]. [Accessed 2019].

[2] International Electrotechnical Comission, "IEC 62262 - Degrees of protection provided by enclosures for electrical equipment against external mechanical impact (IK code)," 2002. [Online]. [Accessed 2019].

[3] G. Rebecca and C. Dr Andrew, "A Review of Outgassing and Methods for its Reduction," Edwards Global Technology Centre, Innovation Drive, Burgess Hill, UK RH15 9TW, 2017.

[4] A. J. Saleh and A. L. Elizabeth, "Effects of water absorption on physical properties and degree of molecular orientation of poly (ethylene terephthalate)," Polym Eng Sci, 26: 620-625. , 1986.

[5] ASTM INTERNATIONAL, "ASTM D570 - 98 Standard Test Method for Water Absorbtion of Plastics," 1998. [Online]. [Accessed 2019].

[6] J. Markos, "Mass Transfer in Chemical Engineering Processes," InTech, Janeza Trdine 9, 51000 Rijeka, Croatia, 2011.

[7] W. G. Robert and B. A. J. Samuel, " Waterproof laminate". United States of America Patent US4194041A, 29 06 1978.

[8] K. T. Ulrich and S. D. Eppinger, Product Design and Development, New York: The McGraw-Hill Companies, Inc., 2012.

[9] Naturvårdsverket, "WEEE-direktiv i Sverige," 2009. [Online]. Available: https://www.naturvardsverket.se/Documents/publikationer/978-91-620-5969-9.pdf. [Accessed 2019].

[10] J. R. Peeters and K. Dewulf, "Design For End of Life: A design methodology for the early stages of an innovation," in *International Conference on Engineerign and Product Design Education*, Antwerpen, Belgium, 2012.

[11] Recycling.com, "Waste Hierarchy Lansinks ladder," 2016. [Online]. Available: https://www.recycling.com/downloads/waste-hierarchy-lansinks-ladder/. [Accessed 2019].

[12] M. Ashby, Material Selection in Mechanical Design, 4th edition, Butterworth-Heinemann, 2011.

[13] M. Ashby, H. Shercliff and D. Cebon, Materials Engineering, Science, Processing and Design, 3th edition, Butterworth-Heinemann, 2014.

[14] L. W. McKeen, The Effect of Temperature and Other Factors on Plastics and Elastomers (Third edition), Oxford: Wiliam Andrew Publishing, 2014.

[15] Granta Design, "CES Edupack," 2018.

[16] B. Peter and E. K. Peter Flodin, Interviewees, *Project status consultation.* [Interview]. 01 2019.

[17] "Pixabay," [Online]. Available: https://pixabay.com/images/search/truck%20lorry/. [Accessed 11 05 2019].

[18] J. Clark, "Media.defense.gov," [Online]. Available: https://media.defense.gov/2015/Mar/06/2001104542/-1/-1/0/025901-P-SGN39-608.jpg. [Accessed 9 05 2019].

[19] Dotworkz, "Bash IP68 camera housing," 2019. [Online]. Available: https://www.dotworkz.com/bash-ip68-camera-housing/. [Accessed 2019].

[20] Hella, "RokLUME 380 N," 2019. [Online]. Available: http://www.myhellalights.com/index.php/products/auxiliary-lamps/led/rallye-4000-x-led-2/. [Accessed 2019].

[21] Volkswagen, "Volkswagen Golf Owners Manual: Radar Sensor," 2019. [Online]. Available: http://www.vwgolf.org/radar_sensor-291.html. [Accessed 2019].

[22] Volvo Cars Coorporation, "Global Newsroom," 2019. [Online]. Available:

https://www.media.volvocars.com/global/en-gb. [Accessed 2019].

[23] K. G. Swift and J. D. Booker, Process selection: from design to manufacture, Oxford, England ; Boston : Butterworth-Heinemann, 2003.

[24] Parker Hannifin Corporation, Parker O-ring Handbook - ORD 5700, Cleveland, OH, 2018.

[25] Parker Hanifin Corporation, “Sealing Solutions for Automotive and Heavy Duty Equipment,” 2014. [Online]. Available: http://www.parker.com/literature/O-Ring%20Division%20Literature /Parker_TechSeal_Sealing_Solutions_for_Automotive_and_Heavy_Duty_TSD%205442.pdf. [Accessed 2019].

[26] Parker Hannifin Corporation, “ParFabTM Design Guide - Extruded and Hot Vulcanized Gaskets,” 2014. [Online]. Available: https://www.parker.com/literature/. [Accessed 2019].

[27] Parco Inc., “Parco O-ring Size Chart,” 2007. [Online]. Available: http://www.allsealsinc.com/ParcoO-RingSizeChart.pdf. [Accessed 2019].

[28] W.L. Gore & Associates, Inc. (GORE), “Automotive Vents for Snap-Fit Installation,” 2017. [Online]. Available: https://www.gore.com/sites/g/files/ypyipe116/files/2017-07/03_GORE_Automotive_Vents_Data_Sheet_Snap-Fit-Vents_AVS_14_67_70_200.pdf. [Accessed 2019].

[29] W.L. Gore & Associates, Inc. (GORE), “Protective Vents - Screw- in Series,” 2018. [Online]. Available: https://www.gore.com/system/files/2018-06/PTV_Datasheet-Screw-In-Vents_EN_1.pdf. [Accessed 2018].

[30] W.L. Gore & Associates, Inc. (GORE), “Protective Vents - Adhesive Series,” 2017. [Online]. Available: https://www.gore.com/sites/g/files/ypyipe116/files/2017-08/GORE_PTV_AdhesiveVents_EN_WEB.pdf. [Accessed 2019].

[31] W.L. Gore & Associates, Inc. (GORE), “Protective Vents - Optimal Vent Positioning,” 2014. [Online]. [Accessed 2019].

[32] ELFA Distrelect AB, “Tryckutjämningselement,” 2019. [Online]. Available: https://www.elfa.se/sv/inkapslingar/hoeljes-och-racktillbehoer/tryckutjaemningselement/c/cat-DNAV_PL_06040108. [Accessed 2019].

[33] Bayer MaterialScience, Snap-Fit Joints for Plastics, Pittsburgh, PA, 1998.

[34] BASF Corporation, Snap-Fit Design Manual, 2007.

[35] MAUSER electronics, “DT15-6P - Documents,” 2019. [Online]. Available: https://www.mouser.se/ProductDetail/TE-Connectivity-DEUTSCH/DT15-6P?qs=vkMqrgFpRairOlMBPMX7lA==. [Accessed 2019].

[36] NovelIC, “Information exchange with supplier,” 2019.

[37] Q. Fu, “Radiation (Solar),” Elsevier Science Ltd, Seattle, 2003.

[38] Volvo Group, “Annual and sustainability report,” AB Volvo, Göteborg, 2016.

[39] Scania AB, “The Scania Report 2018 - Annual and Sustainability Report,” Scania AB, Södertälje, 2018.

[40] BIL Sweden, “Nyregistreringar,” BIL Sweden, Stockholm, 2019.

[41] Transportstyrelsen, “Fordonsstatistik,” 2019.

[42] North American Die Casting Association (NADCA) , “Design,” 2019. [Online]. Available: https://www.diecastingdesign.org/. [Accessed 2019].

[43] Sabic, “UltemTM Resins,” 2019. [Online]. Available: https://www.sabic.com/en/products/specialties/ultem-resins/ultem-resin. [Accessed 2019].

[44] North American Die Casting Association (NADCA), “FAQ - Alloy properties,” 2012. [Online]. Available: https://web.archive.org/web/20130606062843/http:/www.diecasting.org/faq/alloy_prop.htm. [Accessed 2019].

[45] Dynacast, “Casting Aluminium with Thin Walls,” 2019. [Online]. Available: https://www.dynacast.com/blog-thin-wall-cast-aluminum. [Accessed 2019].

[46] C.-S. Kang , J.-I. Chao, C.-Y. Jeong, S.-W. Choi and Y.-C. Kim, “Thin-Wall Aluminum Die-Casting Technology for Development of Notebook Computer Housing,” *Journal of Materials Science and Technology*, 2008.

[47] L. Luoxing, Z. Liqiang and Z. Biwu, *Simulation Study on the LPDC Process for Thin-Walled Aluminum Alloy Casting, Materials and Manufacturing Processes*, 2009.

[48] International Organization for Standardisation, “ISO 16750-5 Road Vehicle - Environmental conditions and testing for electrical and electronic equipment, Chapter5: Chemical loads,” 2010. [Online]. [Accessed 2019].

[49] ACE GLASS Inc., “O-Ring Chemical Compatibility,” 2018. [Online]. Available: https://www.aceglass.com/downloads/eccc.pdf. [Accessed 2019].

[50] Marco Rubber and Plastics, “Rubber O-Ring Chemical Compatibility Chart - O-Ring Material Resistance Guide,” 2019. [Online]. Available: https://www.marcorubber.com/o-ring-chemical-compatibility-chart.htm. [Accessed 2019].

Appendix

A – The prototype

The development project is currently in the stage of evaluating and testing an early prototype of the sensor unit. This design is by no means optimized for a cheap and easy production process but features all the intended functions and attributes. This means that the current design, although somewhat bulky, is a fully functional design suitable for testing and evaluation.

A.1 The design

The built prototype consists of twelve different components, see Table A.1. A figurative picture of the sensor enclosure can be seen in Figure A.1. The actual design of the enclosure is confidential, more about this in Section 1.4.

Table A.1: Prototype component list

Number	***Component***
1	Screw M4x12 (10 pcs.)
2	Lid
3	O-ring/Gasket
4	Screw M3x5 (6 pcs.)
5	Spacer bolt (4 pcs.)
6	PCB
7	Thermal gap filler
8	Case
9	Connector
10	Light guide
11	Snap-in vent
12	Screw pan-head 6-19x12 (2 pcs.)

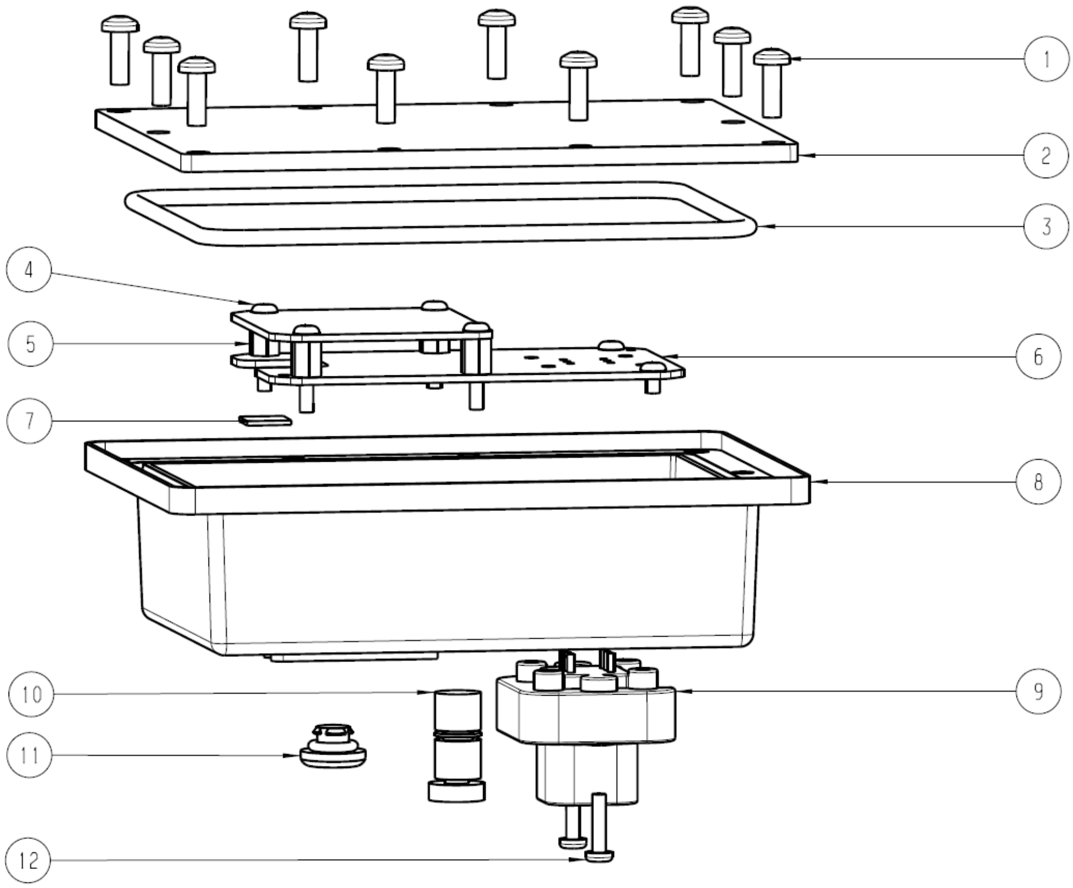


Figure A.1: Figurative picture of the sensor prototype

A.1.1 Case

The case is the biggest part of the prototype and its main functions are to transfer heat away from the *Printed Circuit Board (PCB),* attach to the truck as well as house and protect the other components.

The design features brackets and holders for the electronic components to attach to, a cooling tower to transfer excess heat from the components to integrated cooling fins and a number of cut-outs and holes for the connector, the vent and the LED. Also included is a groove for the O-ring that seals the electronics from the outside world. Furthermore, the case features a mounting solution in the form of two ears enabling a simple fastening method with bolts and nuts.

The vent is used to equalize the pressure difference between the inside of the casing and the atmosphere to ease the load on the O-ring. Further explanation regarding the vent is found in section 2.1.3.

A.1.2 Lid

The lid of the prototype has the purpose of both sealing the electronics in a water and dust tight compartment and letting the sensor signal pass through. This puts special demands on the material for the lid. The prototype utilises a polymer specified as Ultem1010. This material is described to have superb mechanical and chemical properties as well as the necessary electrical properties needed for the sensor technology to work. The most important property of the material is the exceptionally low dielectric constant which is the property affecting how well the sensor signals can pass through the lid.

The lid is also designed according to specific demands on its geometry meaning that is needs a specific thickness and is to be places at a certain distance to the sensor for optimal performance. The Lid is mounted on the casing with a total of 10 screws evenly places near the perimeter of the component.

A.1.3 PCB

The centrepiece of the prototype is the PCB inside the enclosure. The electrical components are classified and will not be described in detail. Some details such as the general size, design and the connection to the vehicle will have to be discussed as they significantly influence the design of the casing itself. A heavily simplified version of the PCB, with some dimensions, can be seen in Figure A.2 and Figure A.3.

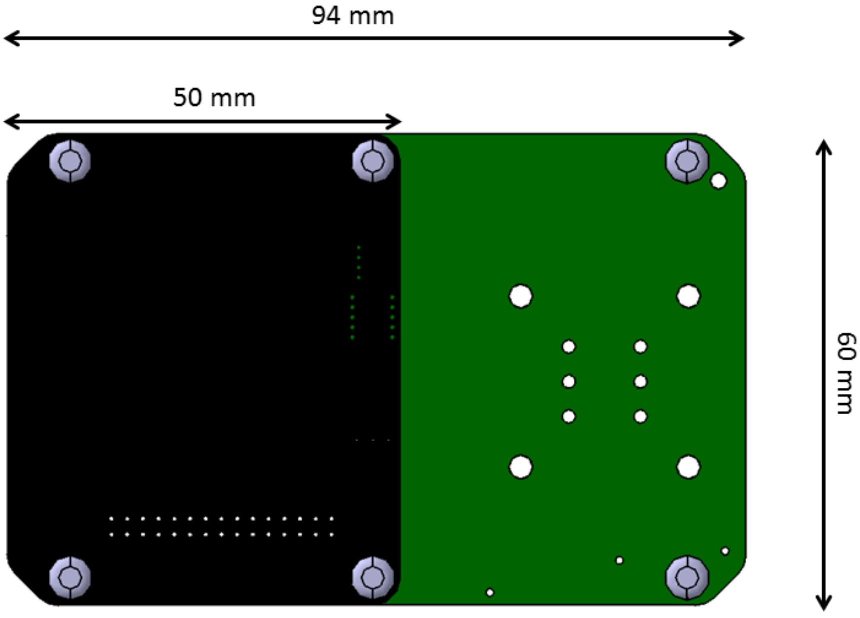


Figure A.2: PCBs viewed from above.

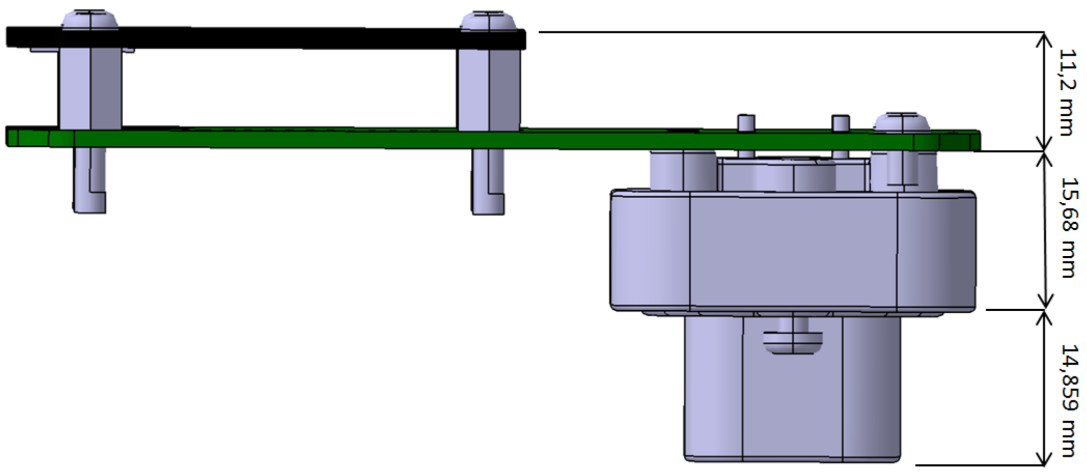


Figure A.3: PCBs and connector viewed from the side.

The PCB is attached to the vehicle with a C-DT15-6P-99 connector which is a heavy-duty connector often used in similar applications. The side effect of the operation of the PCB is heat and therefor the PCB is reliant on the casing for appropriate cooling.

Furthermore, a LED is also included on the PCB communicating the status of the sensor unit to the user. In the current design, this LED is visible on the backside of the prototype.

A.1.4 Seals and Gaskets

The cover and the casing are sealed with one continuous gasket that is placed near the perimeter of the Lid. Tests have shown that the current design is compliant with set demands on the encapsulation (IK69K) but does not fulfil the chemical demands. In the documentation of the prototype a concern was mention regarding the gasket being of a rather hard (60 shore) material if it is to comply with the chemical demands. The concern is regarding a harder gasket needing more force to maintain a proper compression of the O-ring.

The connector to the PCB is also sealed by an integrated gasket that is fastened by two screws against the bottom of the casing. The Gore-Tex snap-in vent is fastened by its snap-joint mechanism and sealed with an O-ring gasket. The hole for the LED-light is sealed with a press-fit mechanism and an O-ring between the plastic cartridge and casing.

A.1.5 Manufacturing of the prototype enclosure

The case is milled out of a solid block of aluminium. The documentation mentions that this is considered a rather expensive undertaking and the option of casting the part is discussed. More specifically aluminium or zinc alloys were mentioned as potential materials to cast with.

The cover is of a simple geometry and is cut out of a plate of Ultem1010. In the documentation the possibility of adding fins for a stiffer design imply the use of a different manufacturing method as the geometry gets more complex.

A.2 Prototype performance

Prior to the on-going field test the casing was tested by thoroughly spraying it with water in what the documentation specifies as a “shower test”. The test-results concluded that the enclosure was sufficiently sealed. How the software and the hardware performed is considered classified and will not be included in this thesis.

B – Product Specification

These requirements were partially discovered by the project group (e.g. during the analysis if similar products) and partially taken from an existing product specification for the entire sensor concept. The table only specifies requirements that were considered relevant for the development of the enclosure in this master thesis.

Specification		Desired Performance	R/W	Methode of verification	Source/Info
1.	General properties				
1.1	Mechanical loads	Comply with requirements set by ISO 16750-3 section 4.3 at 20+-5 degrees celsius	R	Test specified in standard	ISO 16750-3
1.2	Vibration proof	Unaffected by vibrations present in operation	R	Simulation	Prototype specification
1.3	Waterproof	IPX9K, close-range high temperature and high presure water spray	R	Test specified in standard	SS-ISO 20653:2013
1.4	Dust protection	IP6X, dust proof, dust cannont penetrate	R	Test specified in standard	SS-ISO 20653:2013
1.5	EMC-shielding	yes	R	Material Property	Needs to be discussed with the customer
1.6	Low Temperature	-40° celcius < operating temp.	R	Field test	Prototype specification
1.7	High Temperature	85° celsius > operating temp.	R	Field test	Prototype specification
1.8	Heat dissipation	1,5 W	R	Calculation/test	Prototype specification
1.9	pressure equalisation regulation	atmospheric pressure inside the enclosure	R	Field test	Prototype specification
1.10	UV-light resistance	Operational for 10+ years	R	Material Test	Prototype specification
1.11	Chemical resistance	According to chemical demands	R	Test specified in standard	ISO 16750-5, M 3327, M3447, M3249, M3082, MIL-C-16173, DIN 54245
1.12	Multifunctional mounting	More than one mounting option	W	Field test	Details need to be discussed witht he customer
2.	Lid Properties				
2.1	Low Dielectric constant	Below 3.5	R	Material Property	Prototype specification
2.2	Lid to antenna distance	1.9mm	R	Design parameter	Prototype specification
2.3	Lid surface	Flat and smooth where required by radar	R	Design parameter, tollerance	Prototype specification
2.4	Lid Thickness	n*1.09mm, n= 1, 2, 3...	R	Design parameter	Prototype specification
2.5	Chemical resistant	According to Chemical demands	R	Test specified in standard	ISO 16750-5, M 3327, M3447, M3249, M3082, MIL-C-16173, DIN 54245
2.6	UV-light resistance	Operational for 10+ years	R	Material Test	Prototype specification
2.7	non-stick property	Oilophobic, Hydrophobic	R/W	Material Data	Needs to be discussed with the customer and material supplier
2.8	Scratch resistance	Comply with requirements set by SAE J1455 4.7 Dust, Sand, and Gravel Bombardment	W	Test specified in standard	Prototype specification
3.	Manufacturing properties				
3.1	Numbers produces	N > 100 000 units	W	Talk to company stakeholder	Details need to be discussed witht he customer
4.	Life expectancy				
4.1	Life expectancy	25000 running hours	W	Field Test, Estimation	Estimated value
4.2	Shelf life expectancy	1 year in stock plus 7 years from the date delivered to end customer	W	Estimation	Prototype specification
4.3	Life expectancy	1 250 000 km on the road	W	Failure analysis, field test	Prototype specification
4.4	Failure rate	Less than 0,5% are allowed to fail at 1 500 000 km driving distance/ten years	W	Failure analysis, field test	Prototype specification
5.	Maintenance				
5.1	Serviceable	yes, 1-2 times / life expectancy	W	Test	Needs to be discussed with the customer, prototype specification
6.	Environment				
6.1	Environmentally frienly	as clean as possible	W		Needs to be discussed with the customer
6.2	Recyclable	Yes	W	Material Property	
7.	Manufacturing cost				
7.1	Cost per unit	not specified but cheaper is better	W	Talk to company stakeholder	
8.	Standards, rules and regulations				
8.1	EC-approved	Enligt vägverkets riktlinjer	R	Standard	Legistaltion
8.2	ECE-approved	Enligt vägverkets riktlinjer	R	Standard	Legistaltion
8.3	CE-marking	yes	R	Standard	Legistaltion
8.4	IP-classification	IP69K	R	Standard	Prototype specification
8.5	IK-classification	-	R	Standard	Needs to be discussed with the customer
8.6	Mijlömärkning	yes	W	Standard	Needs to be discussed with the customer

C – Pugh Matrix 1

	Reference	New concepts							
Criteria	**Current Prototype**	**A**	**B**	**C**	**D**	**E**	**F**	**EXTRA II**	**Extra I**
Complexity	0	0	1	0	0	0	0	-1	-1
Material usage	0	1	1	-1	1	1	1	-1	-1
Durability	0	0	0	1	-1	0	-1	0	0
Assembly time	0	1	-1	-1	0	1	1	1	1
Recyclability	0	1	-1	0	0	1	1	0	0
Size	0	1	1	1	1	1	1	-1	0
Sum	0	4	1	0	3	4	3	-2	-1
Ranking	6	1	4	6	3	1	3	9	8
Decision	Fail	Pass	Pass	Fail	Pass	Pass	Pass	Fail	Fail

D – Pugh Matrix 2

	Reference	Concepts			
Criteria	**A**	**B**	**D**	**E**	**F**
Complexity	0	0	1	0	0
Material usage	0	1	0	0	1
Durability	0	0	-1	0	-1
Assembly time	0	-1	-1	0	0
Recyclability	0	0	0	1	1
Size	0	1	-1	0	1
Sum	0	1	-2	1	2
Ranking	4	2	5	2	1
Decision	Fail	Pass	Fail	Pass	Pass

E – Kesselring Matrix

Criteria		Ideal		Adhesive		Internal snap joints		Screws		External snap joints pointing outwards		External snap joints pointing inwards	
	W	v	t	v	t	v	t	v	t	v	t	v	t
Manufacturability	5	5	25	5	25	3	15	5	25	5	25	3	15
Size	4	5	20	5	20	2	8	3	12	3	12	3	12
Recyclability	3	5	15	1	3	4	12	3	9	5	15	5	15
Design for assembly	5	5	25	2	10	3	15	4	20	5	25	5	25
Failure risk	3	5	15	2	6	5	15	4	12	4	12	3	9
T= sum Tj		100		64		65		78		89		76	
T/Tmax		1		0,64		1,016		0,78		0,89		0,76	
Ranking		-		5		4		2		1		3	

F - Chemical Demands

Chemical compatibility of the enclosure			
	Reagent	Standard	Reagent details acc to
AA	Diesel	ISO 16750-5 Chemical loads	M 3327
AB	Bio Diesel	ISO 16750-5 Chemical loads	M 3327
AC	Petrol/gasoline unleaded	ISO 16750-5 Chemical loads	
BA	Engine oil	ISO 16750-5 Chemical loads	M 3327
BB	Gear box oil	ISO 16750-5 Chemical loads	M 3327
BC	Transmission oil	ISO 16750-5 Chemical loads	M 3327
BD	Hydraulic fluid	ISO 16750-5 Chemical loads	M 3327
BE	Grease	ISO 16750-5 Chemical loads	M 3327
BF	Silicon oil	ISO 16750-5 Chemical loads	
CA	Battery fluid	ISO 16750-5 Chemical loads	M 3327
CC	Antifreeze fluid	ISO 16750-5 Chemical loads	M 3327
CD	Urea	ISO 16750-5 Chemical loads	M 3327
CE	Cavity protection	ISO 16750-5 Chemical loads	M 3327
CF	Protective lacquer	ISO 16750-5 Chemical loads	
CG	Protective lacquer remover	ISO 16750-5 Chemical loads	M 3327
DA	Windscreen washer fluid	ISO 16750-5 Chemical loads	M 3327
DB	Vehilce washing chemicals	ISO 16750-5 Chemical loads	
DD	Glass cleaner	ISO 16750-5 Chemical loads	M 3327
DE	Wheel cleaner	ISO 16750-5 Chemical loads	
DF	Cold cleaning agent	ISO 16750-5 Chemical loads	
DH	cleaning solvent	ISO 16750-5 Chemical loads	
DJ	ammonium containing cleaner	ISO 16750-5 Chemical loads	
DK	denaturated alcohol	ISO 16750-5 Chemical loads	M 3327
EA	Contact spray	ISO 16750-5 Chemical loads	
EE	Runway de-icer	ISO 16750-5 Chemical loads	
YY	Anti corrosion oil RL32 in accordance with M3447		M 3327
YY	Anti corrosion oil R-vci in accordance with M3249		M 3327
YY	Preservative waxes in accordance with M3082, MIL-C-16173		M 3327
YY	Isopropanol accoring to DIN 53245		M 3327
YY	All purpose cleaner based in surfactance		M 3327

G – O-ring material selection

The material selection process of the O-ring was conducted as a comparison of the chemical properties of different materials. The following materials are commonly used within the automotive industry [25]:

- Nitrile (NBR)
- Ethylene Propylene Rubber (EPDM, EPM, EP, EPR)
- Fluorocarbon (FKM, FPM)
- Fluorosilicon (FVQM)
- Hydrogenated Nitrile (HNBR, HSN)
- Silicon (VMQ. PVMQ, PMQ)

G.1 The Standard

The chemical loads specified in the chemical demands are defined in the ISO 16750-5. The standard defines the chemical reagent and whether the chemical load is applicable. Since the enclosure is to be mounted on the exterior of the vehicle not all chemical loads need to be fulfilled in order to comply with the standard. However, a company may decide that additional chemical loads are to be met according to the standard. The necessary loads and the extra loads are marked in the selection matrix [48]. Furthermore, the chemical demands are viewable in Appendix F.

G.2 The selection matrix

These materials were compared to the chemical demands set for the enclosure and graded according to the scale in Table G.1.The selection was based on a total of four datasets [15] [24] [49] [50].

Table G.1: O-ring grading scale

4	Excellent
3	Good
2	Poor
1	Not Recommended
-	Insufficient Data

			Recomeended Polymer Families for "sensor seals"						Comment.
	Reagent	applicable according to standard*	Nitrile (NBR)	Ethylene Propylrnr Rubber (EPDM, EPM, EP, EPR)	Fluorocarbon (FKM, FPM)	Fluorosilicon (FVQM)	Hydrogenated Nitrile (HNBR, HSN)	Silicon (VMQ. PVMQ, PMQ)	
AA	Diesel	No	4	1	4	4	4	3	
AB	Bio Diesel	No	3	2	4	2	3	2	fatty acids (mehtyl esters)
AC	Petrol/gasoline unleaded	No	4	1	4	4	4	1	
BA	Engine oil	No	4	1	4	4	4	3	
BB	Gear box oil	No	4	1	4	4	4	1	Texaco 3450 gear oil
BC	Transmission oil	No	4	1	4	4	4	3	
BD	Hydraulic fluid	No	4	1	4	4	4	3	
BE	Grease	No	4	1	4	4	4	1	
BF	Silicon oil	No	4	4	4	4	4	1	
CA	Battery fluid	No	3	4	4	4	3	3	
CC	Antifreeze fluid	No	4	4	4	4	4	4	
CD	Urea	yes	4	4	4	-	4	-	
CE	Cavity protection	yes	-	-	-	-	-	-	**
CF	Protective lacquer	yes	1	1	1	1	1	1	General "Lacquer" was used for this**
CG	Protective lacquer remover	yes	1	1	1	1	1	1	General "Lacquer remover" was used for this**
DA	Windscreen washer fluid	yes	3	3	4	4	3	3	
DB	Vehilce washing chemicals	yes	4	1	4	4	4	3	
DD	Glass cleaner	yes	2	3	1	1	2	4	
DE	Wheel cleaner	yes	-	-	-	-	-	-	**
DF	Cold cleaning agent	yes	-	-	-	-	-	-	**
DH	cleaning solvent	No	-	-	-	-	-	-	**
DJ	ammonium containing cleaner	yes	4	4	2	4	4	4	
DK	denaturated alcohol	yes	4	4	4	4	4	4	Oleic acid, WD40 recommends nitril gloves to be used
EA	Contact spray	No	2	1	3	3	4	1	
EE	Runway de-icer	yes	4	4	4	4	4	4	Glycole based
YY	Anti corrosion oil RL32 in accordance with M3447	yes	-	-	-	-	-	-	
YY	Anti corrosion oil R-vci in accordance with M3249	yes	-	-	-	-	-	-	
YY	Preservative waxes in accordance with M3082, MIL-C-16173	yes	-	-	-	-	-	-	
YY	Isopropanol accoring to DIN 53245	yes	3	4	4	3	3	2	
YY	All purpose cleaner based in surfactance	yes	-	-	-	-	-	-	
	Temp range		-55 to +121C	-57 to +121C	-26 to +205C	-73 to +177C	-32 to 149C	-115 to +232C	
	Price		$	$	$$$$	$$$$$	$$$	$$	
			16.8-20.8 kr/kg	16.4-16.7 kr/kg	239-252 kr/kg	541-623 kr/kg	179-196 kr/kg	37.2 - 51 kr/kg	Source: CES
		Score applicable.	30	29	29	26	30	26	* placement of the sensor on the exterios
		Overall Score	74	51	76	71	76	52	** reagent needs to be agreed upon with customer
		Rank	3	6	1	4	1	5	

H – Snap joint forces

	L	b	t	I	P_ref	my	alfa	alfa_rad	Delta	E	Max delta	Max strain	Strain	Form FactorQ	Hook_h	Calc_L	P (force)	Snaps	Fm	Fm_tot	Fm (Joint_F)	Fm_t (assem_F)
t/t=1	8,6	20	2	13,3	484,86	0,3	40	0,6981317	1,5	5140	1,79436	0,05	0,041798	2,5	0,25	6,5624	436,51	4	664,5009587	2658,003835	738,1121071	2952,448428
t/t=1	8,6	20	2	13,3	484,86	0,3	40	0,6981317	1,5	5140	2,15323	0,05	0,034831	3	0,25	6,5624	363,76	4	553,7507989	2215,003196	738,1121071	2952,448428
t/t=1	8,6	20	2	13,3	484,86	0,3	40	0,6981317	1,5	5140	2,60541	0,05	0,028786	3,63	0,25	6,5624	300,63	4	457,6452883	1830,581153	738,1121071	2952,448428
t/t=0.5	9	8	2	5,33	72,428	0,3	40	0,6981317	1	3300	1,6067	0,025	0,01556	2,07	0,25	7,5582	36,232	4	55,15695975	220,627839	110,2578977	441,0315909
t/t=0.5	6	20	2	13,3	568,33	0,3	45	0,78539816	0,93	3300	0,94697	0,025	0,024552	3	0,25	4,82	224,13	4	416,2328866	1664,931547	1055,47619	4221,904762
t/t=0.5	8,6	20	2	13,3	808,1	0,3	40	0,6981317	2,5	5140	2,82165	0,06	0,05316	3	0,25	5,3706	678,37	4	1032,68873	4130,754919	1230,186845	4920,747381
t/t=0.5	9	8	2	5,33	72,428	0,3	40	0,6981317	1	3300	1,6067	0,025	0,01556	2,07	0,25	7,5582	36,232	4	55,15695975	220,627839	110,2578977	441,0315909
t/t=0.5	6	20	2	13,3	568,33	0,3	45	0,78539816	0,93	3300	0,94697	0,025	0,024552	3	0,25	4,82	224,13	4	416,2328866	1664,931547	1055,47619	4221,904762
t/t=0.5	8	20	2	13,3	386,72	0,3	40	0,6981317	1,5	3300	1,44904	0,025	0,025879	3	0,25	5,9624	190,98	4	290,7281823	1162,912729	588,7061092	2354,824437
	100	10	10	833	82,5	0,3	50	0,87266463	10	3300	34,5	0,025	0,005535	2,07	2	89,609	153,44	4	356,2809793	1425,123917	191,5559015	766,2236062
	100	10	10	833	82,5	0,3	40	0,6981317	10	3300	34,5	0,025	0,005998	2,07	2	86,082	159,73	4	243,1595447	972,6381789	125,5906366	502,3625465
	100	10	10	833	82,5	0,3	30	0,52359878	10	3300	75	0,025	0,003064	4,5	1	81,679	168,34	4	178,6343134	714,5372536	87,54455975	350,178239
	100	10	10	833	82,5	0,3	50	0,87266463	10	3300	34,5	0,025	0,005535	2,07	2	89,609	153,44	4	356,2809793	1425,123917	191,5559015	766,2236062
	100	10	10	833	82,5	0,3	40	0,6981317	10	3300	34,5	0,025	0,005998	2,07	2	86,082	159,73	4	243,1595447	972,6381789	125,5906366	502,3625465
	100	10	10	833	82,5	0,3	30	0,52359878	10	3300	75	0,025	0,003064	4,5	1	81,679	168,34	4	178,6343134	714,5372536	87,54455975	350,178239
				(C42*D42^3)/12	3*J42*K42*E42/B42^3			RADIANS(H42)			M42*B42^2*O42/(1,5*D42)		0,92*(D42/Q42^2)*J42*1/O42			B42-(P42+J42/TAN(I42))	C42*D42^2*K42*M42*(1/(6*Q42))		R42*((G42+TAN(I42))/	T42*S42	F42*((G42+TAN(I42))/	V42*S42

I – Material Data for polymers

	Youngs modulus [GPa]	Specific stiffness [MN.m/kg]	yield strength [Mpa]	Elongation [% STRAIN] *	Thermal expansion Coefficient [μstrain/°C]	Hardness [Vickers]	Dielectric constant	Density [kg/m^2]	Price [kr/kg]
ASA+PC	2,3 - 2.6	2,07 - 2,34	45,5 - 60	65,1 - 75,3	141 - 147	14-18	3 - 3,2	1.1e3 - 1,12e3	26,3 - 28.6
PBT (general purpose)	1,93 - 3	1,44 - 2,24	56,5 - 60	50 - 300	108 - 171	17 - 18	3,2 - 3,4	1,3e3 - 1,38e3	21,3 - 22,2
PBT (impact modified)	1,6 - 1,95	1,28 - 1,58	30 - 40	26,3 - 37,9	238 - 248	9 - 14	3 - 4	1,19e3 - 1,3e3	26,1 - 27,1
PC+PBT (10% Glass fibre)	5,14	3,95 - 3,98	81 - 91	4,0 - 6,0	77	20 - 22	3,2 - 3,6	1,29e3 - 1,3e3	29,8 - 32,3
PC+PBT (20% Glass fibre)	5,1	3,52 - 3,81	78 - 94	4	40	19 - 25	3,2 - 3,7	1,34e3 - 1,45e3	28,1 - 30,7
PC+PBT (30% Glass fibre)	5,58 - 11,5	3,77 - 7,78	86 - 107	1,0 - 5	21 - 30	22 - 29	3,2 - 3,6	1,44e3 - 1,52e3	26,3 - 29
LCP(30% mineral)	10,2 - 11,1	6,22 - 6,77	107 - 119	3,37 - 4,08	12,1 - 23,9	32 - 36	3,28 - 3,52	1,64e3	55,5 - 72,7
PBT (Flame retardant)	2,15 - 2,6	1,68 - 2,04	50 - 63	50 - 100	88 - 90	12 - 14	3,2	1,25e3 - 1,3e3	32,2 - 37,8
PBT (Flam retardant, impact modified)	1,9 - 2,1	1,44 - 1,61	45 - 50	21-72	79 - 100	9 - 13	3,2	1,28e3- 1,35e3	37,4 - 42,5

* elongation at yield is the more useful property but was not included in the dataset.

** Material is downcyclable

	Fracture toughness [Mpa.m^0.5]	Toughness [kJ/m^2]	Impact strength, notched 23 °C [kJ/m^2]	Impact strength, notched -30 °C [kJ/m^2]	Impact strength, unnotched 23 °C [kJ/m^2]	Impact strength, unnotched -30 °C [kJ/m^2]	Recyclable
ASA+PC	2,27 - 6,21	2,5 - 13,3	34,5 - 65, 3	7,23 - 23,4	590 - 600	176 - 200	YES
PBT (general purpose)	1,59 - 2,75	1,09 - 3,05	3,73 - 7,44	3,1 - 6,72	134 - 161	90,1 - 108	YES
PBT (impact modified)	1,68 - 2,66	1,66 - 3,87	16,4 - 84,4	9,03 - 21,5	590 - 600	590 - 600	YES
PC+PBT (10% Glass fibre)	4,78 - 5,69	4,48 - 6,25	10 - 19	10	30 - 35	-	NO**
PC+PBT (20% Glass fibre)	4,53 - 6	4,09 - 6,94	10 - 19	10	30 - 35	-	NO**
PC+PBT (30% Glass fibre)	4,85 - 5,02	2,12 - 4,37	7,5 - 20	7 - 10	35 - 64	-	NO**
LCP(30% mineral)	5,12 - 5,32	2,42 - 2,71	8,24 - 29,4	7,62 - 8,4	50,2 - 77,4	38,1 - 42	YES
PBT (Flame retardant)	2,33 - 3,05	2,3 - 3,92	18 - 41	11 - 14	590 - 600	590 - 600	YES
PBT (Flam retardant, impact modified)	2,13 - 2,38	2,26 - 2,86	44 - 68	17 - 20	320 - 600	320 - 600*	YES

J – FMEA

Table detailing the FMEA results:

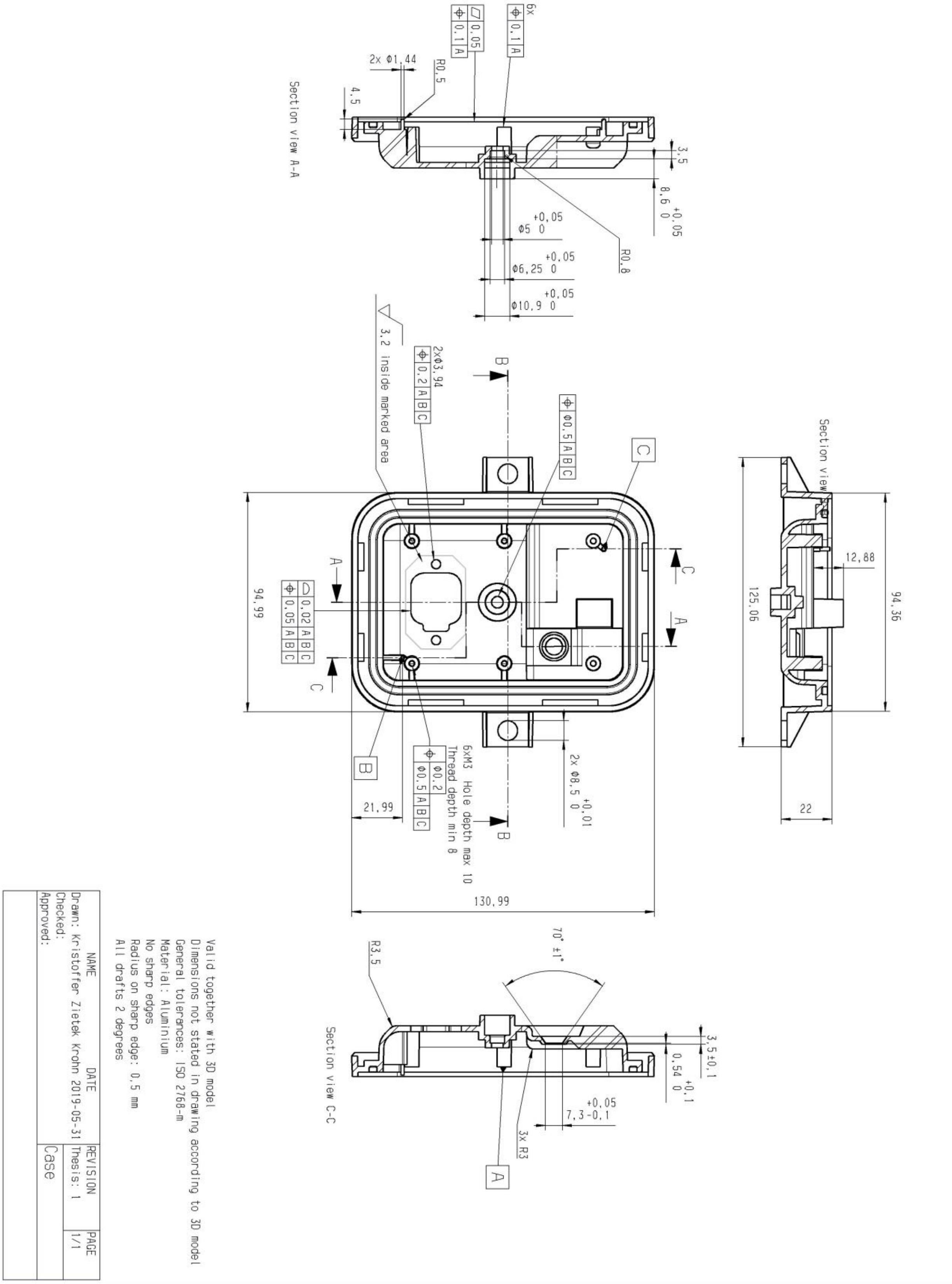
Component	Function	Failure Mode	Effect	Sev	Cause	Occ	Design Controls (Prevention)	Design Controls (Detection)	Det	RPN
Lid	Seal, protect O-ring let signal through	Dirt buildup on area above radar	Radar signal disturbed until next cleaning	2	Driving in dirty conditions	3	Coating, material, smoothness	Visual inspection, no signal from sensor	1	6
		Ice buildup on area above radar	Radar signal could be disturbed by ice until its removed or melts	2	Cold weather, snowfall, moisture gets stuck on lid	2	Heat from PCB, Coating, material, smoothness	Visual inspection, no signal from sensor	1	4
		Hole from impact	PCB damaged, open to environment	5	Sharp and heavy impact	1	Material, shape	Visual inspection	2	10
		Impact transfered to PCB	Broken PCB, damaged PCB, No signal	5	Heavy impact	2	Material, shape, stiffeners	Signal no longer working	1	10
		Thermal loads	Shrinkage	2	Cold air, water	5	Contraction space, similar thermal expansion coefficient	Simulations/tests	4	40
			Bulging/expansion, shrincage	2	Lid is heated by water/sun	5	Expansion space, heat sink, similar thermal expansion coefficient	Simulations/tests	4	40
		Scratches	Radar signal disturbed possibly	2	Sharp/hard objects hitting lid	2	Material properties, coating	Check for scratches, inaccurate signal from sensor	2	8
		Chemical wear	Brittle, compromised seal	4	Non-compatible checmicals in contact with lid	1	Material choice/coating	Visual colour change and cracks, otherwise hard to detect	4	16

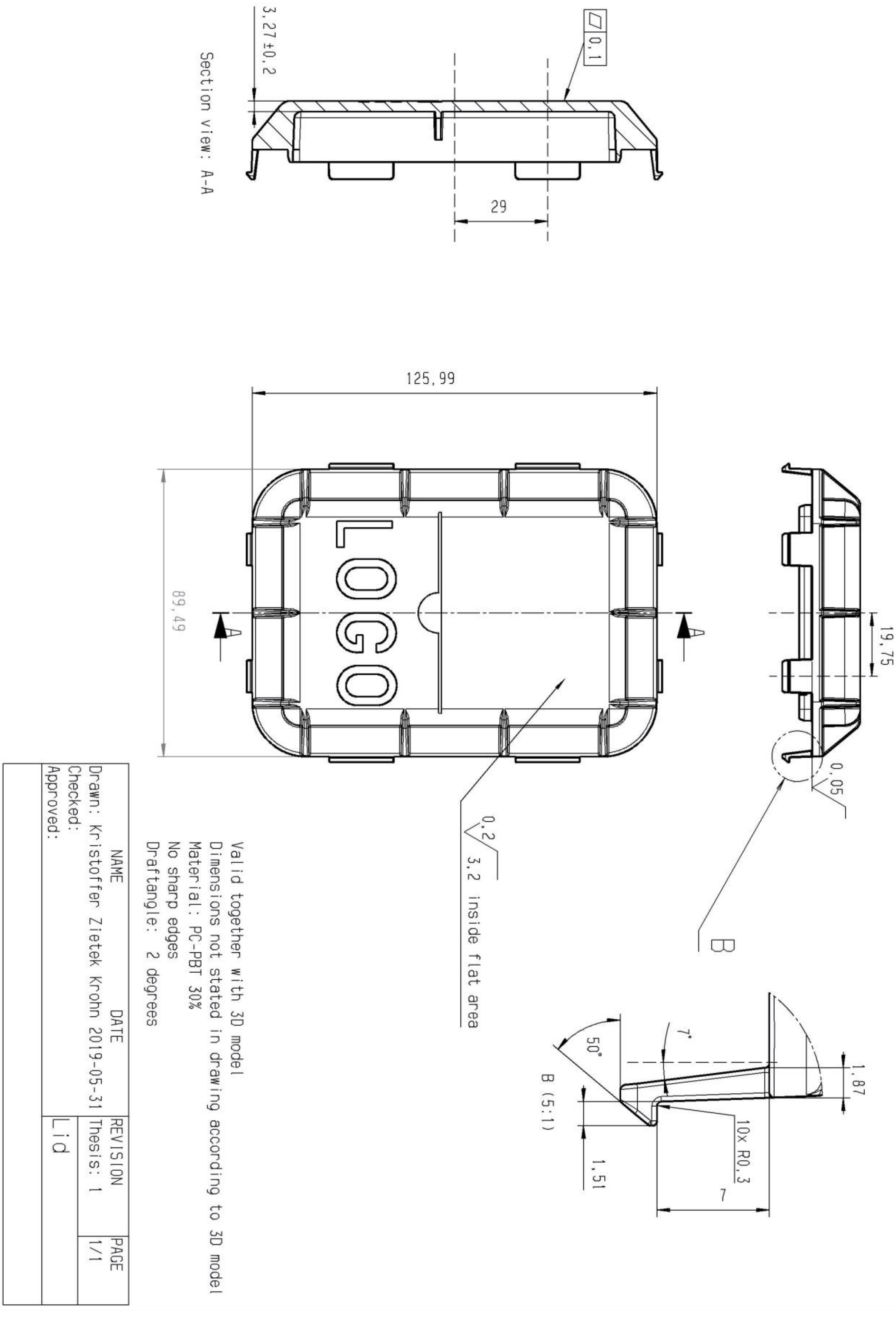
Component	Function	Failure Mode	Effect	Sev	Cause	Occ	Design Controls (Prevention)	Design Controls (Detection)	Det	RPN
O-ring	Create seal between lid and casing	Compression set exceeded	Gap between lid and O-ring	3	Dimentions	2	Tolerances and geometry	Controlled production process, measuring components	3	18
			Gap between lid and O-ring	3	Pressure difference	1	Ventilation	Hard to see	5	15
		Excesive swelling	Compromosed seal	3	Chemical incompatability	2	Correct O-ring material	Inspect before mounting	5	30
		Loss of plasticizer	Comprimised seal, loss of O-ring volume	3	Chemical incompatability	1	Correct O-ring material	Visual inspection	4	12
		Brittle O-ring	Cracks, compresion set easily overextended	3	Heat cycles, Ozone/weather degradation, oxidation,	2	Material with adequate temperature range with antioxidants	Visual inspection	5	30
		Mechanical damage	Compromised seal	3	Sharp edges in contact with O-ring, oversized O-ring, twisting/pinching, low tear resistance	1	Production process and handling	Inspect before mounting	5	15
		O-ring deformed	Temporarily compromised seal	5	High pressure water	3	Indirect access to O-ring, break water beam before it hits O-ring, good tolerances,	Hard to detect	5	75
		Loss of seal without visual evidence	Not enough compression of O-ring	5	Improper dimensions/tolerances, lid deflection	1	Tolerances	Measure O-ring, O-ring groove and lid/casing mating faces	5	25

Component	Function	Failure Mode(s)	Effects	Sev	Cause	Occ	Design Controls (Prevention)	Design Controls (Detection)	Det	RPN
Snap-joints	Hold lid in place	Mechanical failure	Reduced pressure on O-ring, Gap between lid and O-ring	5	Excessive force on snap-joints, excessive bending during assembly	1	Tapered design, hard to apply force in critical direction, many joints, stiffeners	Visual inspection	1	5
		Plastically deformed	Reduced pressure on O-ring, Gap between lid and O-ring	2	Excessive force on snap-joints	2	Tapered design, hard to apply force in critical direction, many joints, stiffeners	Gap between snap and casing could be seen, bulge, loose lid	3	12
		Failure to attach	Reduced pressure on O-ring, Gap between lid and O-ring	5	Issues during assembly, bad tolerances	2	Location and size	Visual inspection, snapping sound	1	10
		Accidental detachment	Compromised seal, reduced pressure on O-ring	4	Pressure, hit etc	1	Low set O-ring material, appropriate	inspect O-rings physical properties before use	2	8
Casing	Attachment point for all components	Mechanical failure	Reduced pressure on O-ring, Gap between lid and O-ring	4	Excesive forces on casing	2	Metal material, stiffeners	Visual inspection of truck in event of heavy impact	1	8
			Crooked form, PCB damaged	4	Excesive forces on casing	1	Metal material, stiffeners	Visual inspection of truck in event of heavy impact	1	4
Mounting	Attach product to truck	Mechanical failure	Crooked form, fatigue wear, fracture	3	Critical vibrations	2	Low amount of critical vibration values, tough material	Hard to see fatigue wear before its to late	4	24
			Crooked form, complete detachment	5	Heavy impact	2	Robust design		1	10
		Loose bolt	More vibrations, connector compromised	4	Vibrations	3	Type of bolt, moment used when tightening	Rattling sound, visual giveaway from the loose bolt	2	24

Component	Function	Failure Mode	Effect	Sev	Cause	Occ	Design Controls (Prevention)	Design Controls (Detection)	Det	RPN
Gore-tex membrane	Equalise pressure, ventilate	Liquid gathered on membrane	No ventilation, moisture buildup inside casing	2	Liquid buildup on inside/outside	1	Location and orientation of membrane	Hard to detect after mounting	5	10
		Mechanical failure	Open hole	3	Sharp objects hitting Gore-Tex	1	Protected location	Hard to see	4	12
Connector	Supply power, transfer information	Water damage	No power, short circuit	5	High pressure warm water directly on connector	1	Break water before it hits connector	No signal from sensor	1	5
		Detached	No power until attached	3	Vibrations, bolts loose, snap not engaged	1	Make sure other fasteners are operational	No signal from sensor	1	3
LED	Signal operator during calibartion	Mechanical failure	Compromised seal	5	Heavy impact	2	Protected location	Visual inspection	2	20

K – Technical drawings





Section view: A-A
3,27±0,2
0,1
29
125,99
89,49
A
A
LOGO
19,75
0,05
0,2
3,2 inside flat area
B
B (5:1)
50°
7°
1,87
10x R0,3
1,51
7
Valid together with 3D model
Dimensions not stated in drawing according to 3D model
Material: PC-PBT 30%
No sharp edges
Draftangle: 2 degrees
NAME
DATE
REVISION
PAGE
Drawn: Kristoffer Zietek Krohn 2019-05-31
Thesis: 1
1/1
Checked:
Approved:
Lid