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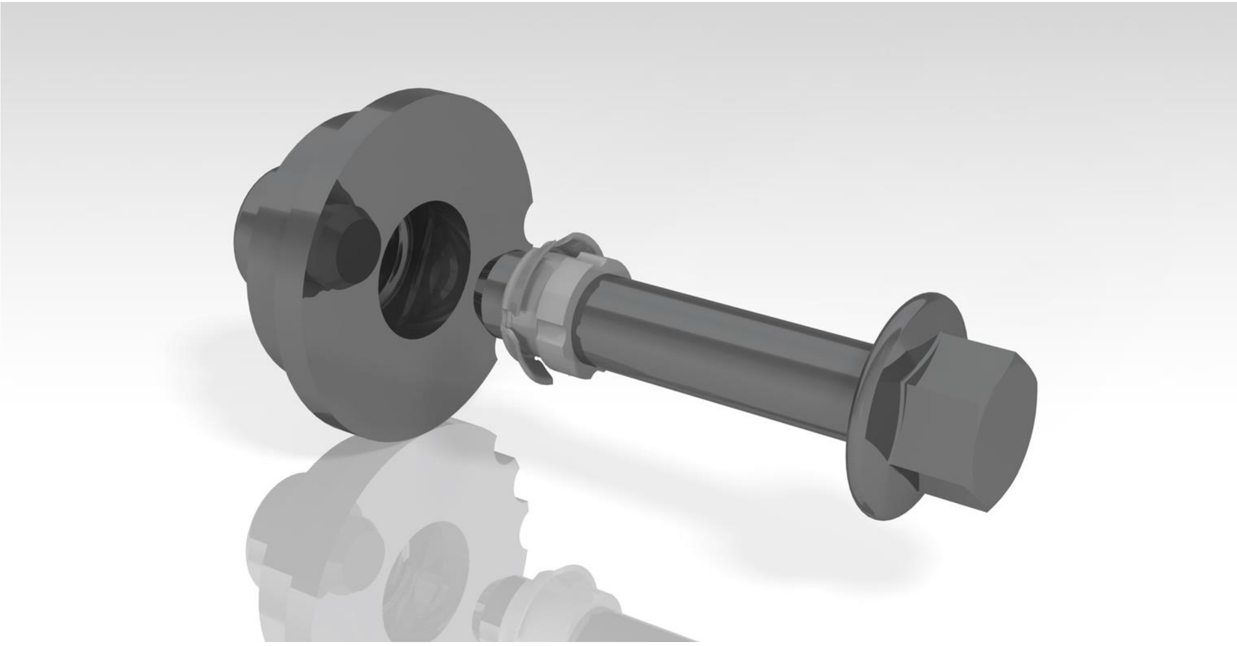

Conceptual Development of a Standardized Curtain Airbag Interface

With regards to safety, ergonomic assembly and compatibility across vehicle models

Master's thesis in Industrial Design Engineering

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DEPARTMENT OF INDUSTRIAL AND MATERIAL SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER'S THESIS 2025

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Cover: The final concept *Snap-fit ring*

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Abstract

Curtain airbags are currently assembled manually onto the car body above the side windows, placing them in an ergonomic red zone for operators. Despite the use of specially designed fixations to facilitate the assembly process, there is no standardized design across Volvo Cars' vehicle range. Consequently, the attachment points on the curtain airbags and the corresponding hole patterns on the car body vary between models, which is both time and resource inefficient. Therefore, a new curtain airbag fixation design is developed in this thesis, featuring an interface that is optimized for adaptability across a wide range of vehicle models. The development process included benchmarking existing solutions, gathering input from stakeholders and developing conceptual designs and initial prototypes. Key findings from the gathered data indicated that using a screw in the fixation is the most suitable option from a Volvo Cars perspective. Critical requirements that were considered were the need for low push-in forces, traceability and durability during deployment. The proposed solution is a plastic snap-fit ring that fits around the screw. The ring snaps into a hole in the car body and a specially designed weld nut, milled wider at its base, gives space for the ring to secure itself. The final concept achieves the goal of standardization because it can fit various car models due to its simple footprint, which consists solely of a round hole.

Airbags · Curtain Airbag · Fixations · Third-hand · Push-In Forces · Ergonomics · Standardization · Automotive · Body in white · Safety

Abbreviations

BiW – Body in White

CAB – Curtain Airbag

CAD – Computer Aided Design

EOP – End of Production

FMEA – Failure Mode and Effects Analysis

GDL – Group Design Leader

HTA – Hierarchical Task Analysis

IC – Inflatable Curtain (synonymous to curtain airbag)

ME – Manufacturing Engineering

OEM – Original Equipment Manufacturer

PLM – Product Lifecycle Management

TC – Teamcenter

TC Vis – Teamcenter Visualization

VCC – Volvo Car Corporation

VCS – Volvo Cars Standard

VP – Verification Prototype

Dictionary

Curtain airbag (CAB)	Airbag located above the side doors of the car, that falls down to protect the passenger during side collision and rollovers.
Attachments (of the CAB)	The components of the curtain airbag that are used to attach it to the body in white: fixations, gas generator bracket, and strap with strap buckle.
Fixation	The attachments of the curtain airbag that connect the bag to the body in white. A curtain airbag has several fixations. Sometimes, 'fixations' is used to explicitly refer to the attachment mechanism, for example the third-hand and screw combination, or airbag clip. Other times, 'fixation' is used to describe both the hanger and the fixation, as it is the most important aspect of the whole in the context of this thesis.
Third-hand	Many fixations include a separate third-hand feature, that keeps the fixation in place during assembly. This is used in fixations that include a screw, which means that both hands are needed to use a screwdriver and the curtain airbag cannot be held in place manually by the operator.
Hanger	The part of the fixation that sits on or around the curtain airbag and connects it to its fixation mechanism. Different suppliers use different hanger designs, made of different materials such as plastic or metal. The word is used to explicitly exclude the fixation mechanism and focus only on the material between the airbag and fixation mechanism.
Gas generator	A metal capsule that upon ignition inflates the curtain airbag.
Gas generator bracket	A metal bracket to attach the gas generator to the body in white.
Strap	The strap is either connected to the front-end of the curtain airbag (at the front of the car), or at the front and the back, depending on the car model. It allows for the curtain airbag to unroll and therefore twists upon deployment.
Strap buckle	A buckle sitting at the end of the strap to connect it to the body in white.
Body in white (BiW) / car body	The pressed sheet metal structure of the car, without the panels and headlining, etc.
Cantrail	The part of the body in white that runs across the side of the car, above the side doors. It is the edge part of the roof adjacent to the side of the car.
Footprint	Hole pattern in the body in white, used for attaching components to the car body. For example, the footprint of a screw is a circular hole in the car body.
Interface (CAB/BiW)	All components that connect the curtain airbag to the body-in white: the footprint, the fixations, the gas generator bracket, and the strap buckle.
Push-in forces	The force that the operator exerts to assemble the fixation to the body in white on the assembly line. If a screwdriver is used, this is not included in the push-in force. In that case, the push-in force revers to the third-hand feature. In case of an airbag clip, not requiring a screw, the push-in forces refer to the assembly force required to push in the airbag clip into the body in white.

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Linn Marcusson, Anne Roorda, Gothenburg, June 2025

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1. Introduction

This chapter introduces the background and problem description to the study, research questions and aim as well as the scope and limitations.

1.1 Background

The automotive industry plays an important role in current society and personal vehicles are the most common form of transportation in Sweden (Statista, 2024). Nonetheless, it is also one of the most dangerous ways of travelling as approximately 1.19 million people die every year because of road traffic crashes (World Health Organization, 2023). Volvo Cars are actively working to save lives on the road and have been a leader in car safety for decades (Volvo Cars, 2023a). With innovations such as the three-point safety belt, the rearward-facing child seat and the inflatable curtain, Volvo Cars claims to have contributed to saving over one million lives (Volvo Cars, 2023b). This project aims to focus on the inflatable curtain interface and therefore reaches a purpose beyond aesthetics and convenience, playing a part in advancing this critical safety feature.

The inflatable curtain (IC), also known as curtain airbag (CAB), is one of around ten airbags that can be found in the Volvo Cars vehicles. It was introduced in 1998 and is the first airbag system that offers protection for occupants both in the front and rear seats (Volvo Cars, 2023a). In case of a side impact or rollover scenario, the purpose of the curtain airbag is to protect the occupant's head from both impact and glass shards. The curtain airbag is positioned along the roof above the side windows.

1.2 Problem description

Currently, the curtain airbag is manually assembled onto the car body, also called Body in White (BiW). There is no standard interface for the curtain airbag/BiW assembly at Volvo Cars, which means that the attachments on the curtain airbag and the hole pattern or footprint on the body look different for every car model, which is both resource and time inefficient. For an overview of the interface and parts included see Figure 1.1. The interface includes all the components ensuring that the car body and curtain airbag are connected: the footprint, the fixations, the gas generator bracket, and the strap buckle. The fixations are shown in more detail, where the third-hand feature is indicated. The fixation refers to the components connecting the airbag to the car body as a whole: the third-hand feature and screw, or any alternative connection system. The hanger is the part connecting the airbag to the fixations. As the fixation is the most important part for this thesis, it is also used when referred to the hanger and fixation as a whole.

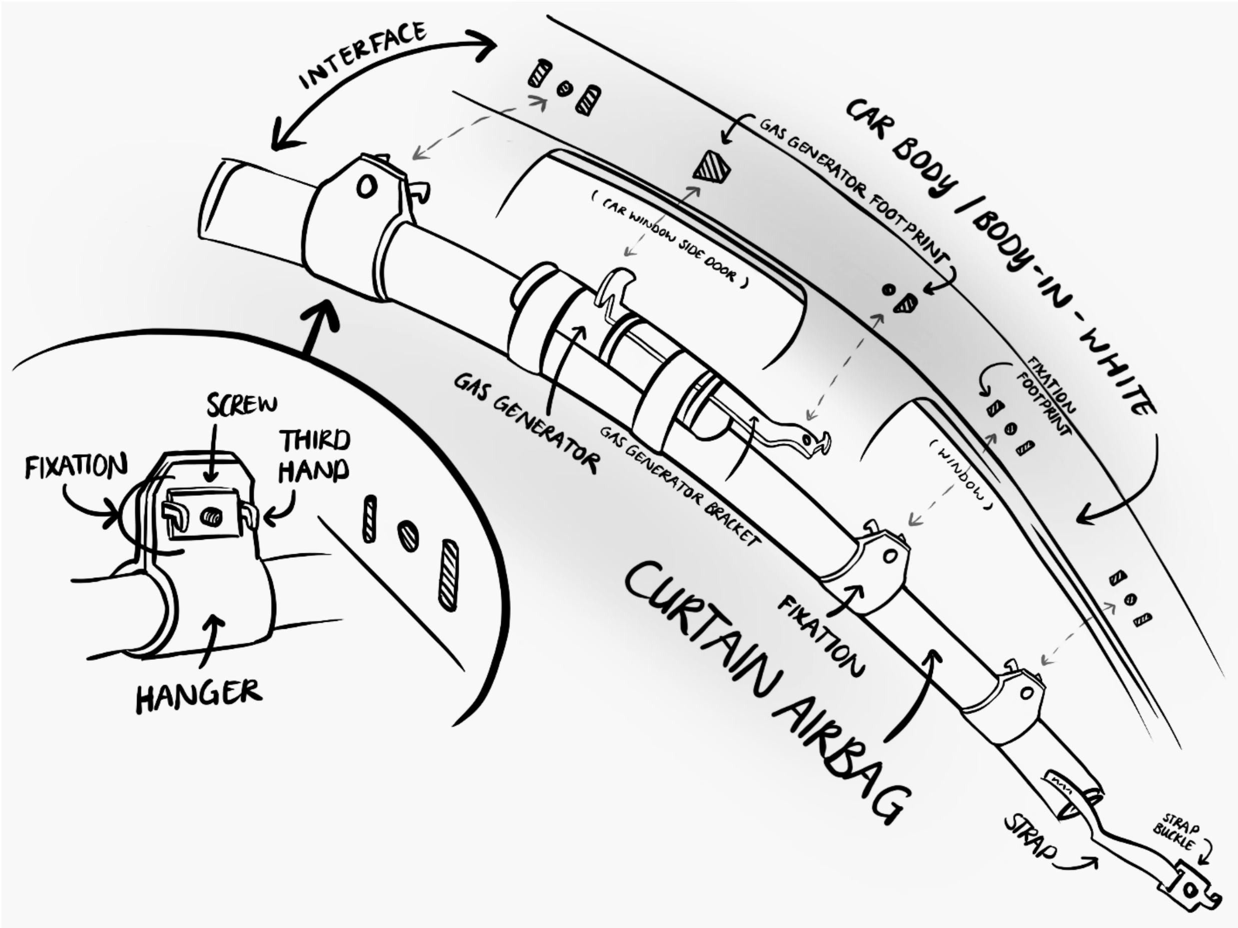


Figure 1.1: Overview of the curtain airbag terminology used during this report, schematically indicated in a simplified illustration of the CAB/BiW interface. Author illustration.

Often the design of the attachments is controlled by the suppliers that provide the curtain airbag. Depending on the material the suppliers work with and the shape of the attachments, the hole pattern in the car body must be customized. If the holes need to be different shapes, tooling costs increase. When it comes to the attachments, there is a multitude of requirements at Volvo Cars, which means that the attachments from the supplier need to be customized to fit Volvos needs. This, in combination with need to customize for the new car model, means that many iterations over a longer time period are needed before the design can be frozen and the vehicle project can move to the next phase.

In addition to the resource and time inefficiencies, the lack of standardization poses a problem for the assembly line workers. They need to learn new attachment steps for every new model, which increases training time and complexity. Additionally, the curtain airbag is assembled onto the roof, which means that the workers have to work with their arms above their head. This instantly places the curtain airbag assembly an ergonomic red zone. Furthermore, the push-in forces when mounting the curtain airbag are currently too high, which leads to pain in the operators' hands and fingers.

To summarize, because there is no standardized interface today, each car model requires significant additional work to integrate the curtain airbag with the car body. This lack of standardization not only increases assembly time but also introduces potential quality and compatibility issues. Additionally, assembly line workers must learn different attachment steps for each model, adding to training time and overall complexity, while the work positions and high push-in forces contribute to poor ergonomics.

1.3 Aim and research question

The goal of the thesis is to develop a conceptual solution for a standardized interface for attaching the curtain airbag to the body in white. This will contribute to the aim to make new car projects at Volvo Cars more effective by being able to freeze the car body design earlier. Furthermore, the standardized solution aims to make the push-in forces for the fixations lower to improve the ergonomic conditions for the assembly workers. To achieve an optimal standard interface, requirements have to be defined for different parameters such as ergonomic assembly, footprint, service and supplier demands. Benchmarking has to be performed both within Volvo Cars but also when it comes to competitors, and prototypes have to be created to be able to evaluate the solution.

Based on this, the main research question is formulated as follows:

- How can the interface of the curtain airbag attachment to the car body be standardized to ensure optimal safety, ergonomic assembly and compatibility across different vehicle models?

The sub research questions are as follows:

- What are the critical needs for the interface?
- Which attachment designs already exist on the market?
- How can the attachment be easy and ergonomic to assemble?
- How can the attachment be strong enough to survive the impact of the airbag deployment?
- How can the attachment be suitable for various different car models and thus measurements?
- How can the prototype be tested to ensure that the safety requirements are met?

1.4 Scope and limitations

The research is restricted to the Volvo Cars facilities in Gothenburg and therefore does not consider manufacturing plants and assembly worker conditions in other countries.

The report will only focus on the curtain airbag interface which includes fixations, gas generator attachments, strap buckle and car body footprint. This means that the ergonomic situation will only be addressed within this interface and no additional physical measures for improved ergonomics will be considered.

The solution for the project is the interface between the curtain airbag fixations and the car body, which means that the hanger that the fixation is attached to is out of the scope, since those are designed by the curtain airbag supplier. The same goes for the curtain airbag itself.

Additionally, the focus of the thesis is on the fixations. The redesign of the fixations is prioritized over that of the gas generator bracket and strap buckle. The latter two are regarded, but less extensively. The reason for this is because the fixations have the most influence over the interface and the solution for the fixations can potentially be included in the gas generator bracket and strap buckle. The fixations have the most potential for change and improvement whereas the gas generator bracket and strap buckle are more limited in their design.

There are limits to the extensiveness to the physical prototype tests. Initial prototypes will be used which means that they might not reflect the final material. A realistic assembly test with an actual car body and screw fastening with tracking screwdrivers will not be performed because of practical limitations.

The main purpose of the thesis is to explore what an optimal standardized interface could look like. Further implementation will be executed by Volvo Cars if it comes to it. Material selection and manufacturing considerations will be touched upon but not in extensive detail due to time constraints. Instead, the focus is more on the conceptual development of a functional solution, and less on the implementation.

2. Theoretical framework

This section provides a theoretical framework on joining methods, the curtain airbag, body in white footprint and error-proofing methods. As this thesis is all about joining parts together, this chapter commences with a general regard to the act of joining and a brief introduction to what joining types exist. After looking at joints in a broader perspective, the subsequent sections return to the scope of the curtain airbag. Its different components are introduced, and background on the body in white footprint is provided. Lastly, an important aspect of curtain airbag design is elaborated upon, namely error-proofing. The concept of poka-yoke is introduced, information on anti-twist in airbags is provided, and the importance of traceability is elaborated upon. Most of the information presented in this chapter was obtained from discussions and observations at Volvo Cars.

2.1 General joining methods

The principle of connecting two or more parts is a fundamental act that dates back to ancient times (Caputo & Koivu, 2022). There are numerous possibilities for creating these connections, which can be alchemical, chemical, mechanical, or conceptual in nature. When it comes to joining parts together, the methods are diverse and plentiful. Basic fasteners include items such as dowels, plugs, pins, nails, screws, and bolts. These fasteners are commonly used due to their simplicity and effectiveness in holding parts together securely.

In addition to basic fasteners, there are various mechanical joints that serve specific purposes. These include node joints, shackles, hooks, brackets, clamps, magnets, springs, and snap-fits. Each type of mechanical joint offers unique advantages depending on the requirements of the connection.

Furthermore, products can be joined using different materials and techniques. Wood-on-wood connections, knots and knits, adhesives and sealants, and welding and fusing are all viable methods for joining parts. Each technique has its own set of characteristics that make it suitable for particular applications.

In the automotive industry, the standards for joining parts are particularly diverse and numerous. This reflects the complexity and precision required in this field, where reliable and durable connections are essential for the safety and performance of vehicles.

2.2 Curtain airbag

As mentioned, the curtain airbag is located along both sides of the car, above the side windows, see Figure 2.1. This part of the car can also be called cantrail. The curtain airbag is located underneath the headlining and when it deploys, the headlining bends outward to accommodate airbag inflation. Upon inflation, the curtain airbag deploys downward to cover the windows, protecting the passengers from impact and glass shards. Each inflatable curtain contains a gas generator with a built-in igniter. Upon deployment, the igniter activates, increasing the pressure inside the gas generator. This pressure causes the generator to break open, allowing the gas to inflate the curtain. The bag is fully inflated after about 25 milliseconds (Öhlund et al., 1998). As the curtain airbag is of especial importance during a rollover, it remains inflated up to 6 seconds.

The curtain airbag itself is produced by external suppliers in close collaboration with Volvo Cars and assembled in the car manually at an assembly line. The workers there need to be able to mount the airbag by themselves, as ergonomically as possible, which the attachments are designed to accommodate. The curtain airbag is attached to the body in white using three types of attachments: the gas generator bracket, the fixations, and the strap buckle.

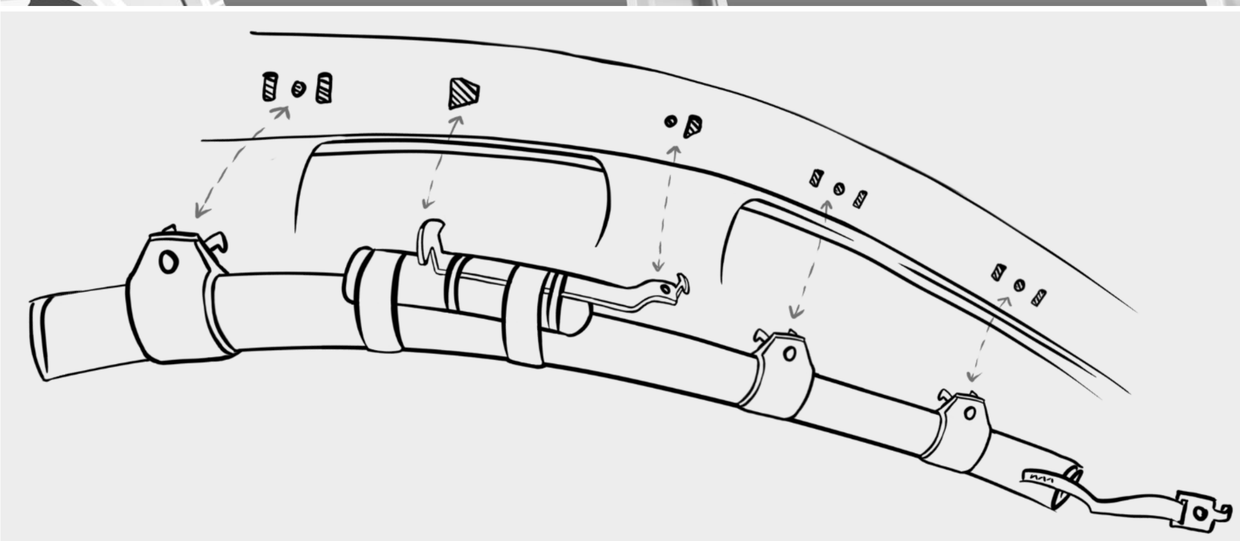


Figure 2.1: Curtain airbag mounted in the BiW. Top image: curtain airbag from XC60 mounted onto the BiW. The entire cylinder is the curtain airbag. In the center, an additional cylinder is the gas generator. Several fixations are located along the curtain airbag. On the right, the strap and strap buckle are found. Image from Teamcenter. Bottom image: schematic and simplified image of the CAD/BiW interface, depicting the components more clearly, and how they fit into the hole pattern in the car body. Author illustration.

2.2.1 Gas generator

The gas generator is the propellant that provides gas that inflates the curtain airbag in case of a crash (Öhlund et al., 1998). In the context of the attachment interface the gas generator is a heavy part located in the middle of the curtain airbag. The attachment needs a strong hook to keep it fastened during deployment as well as a third-hand to keep it in place during assembly, examples will be shown in section

5.2. In this case, a screw is not an option on both sides because one side is covered by the gas generator itself, blocking the way for screwdriver usage. During assembly, the gas generator is assembled first.

2.2.2 Fixations and third-hand

The fixations that mount the curtain airbag to the BiW can be shaped in various ways. The hangers that attach the fixation to the curtain airbag can be called lug hangers or package holders, depending on the supplier. Depending on the length of the car, the number of fixations can vary because of distance requirements. At Volvo Cars, the fixations are always mounted with screws and need to include a third-hand. The fixations are connected to the curtain airbag in various ways and can be made from materials such as plastic or metal. Different suppliers tend to work with different materials. There are various fixation types on the market, some are mounted with screws, while others use clips.

In the context of curtain airbag assembly, the third-hand is a crucial concept at Volvo Cars. A third-hand is a part of the curtain airbag fixation that makes sure that it is held in place before the screws are mounted. The third-hand can be a hook or something sticking out that can be pushed into a hole. It is also possible to integrate a third-hand into a screw. An example of hook third-hands is shown in Figure 2.2.

When it comes to screws, the standard at Volvo Cars is VCS 5511,119, the information is retrieved from Volvo Cars Standard Data Base. The screws need to be fastened with a specific torque, otherwise the car cannot exit the manufacturing plant. All screws have traceability, which means that it is possible to go back in a database and see exactly when a screw was fastened and with what torque.

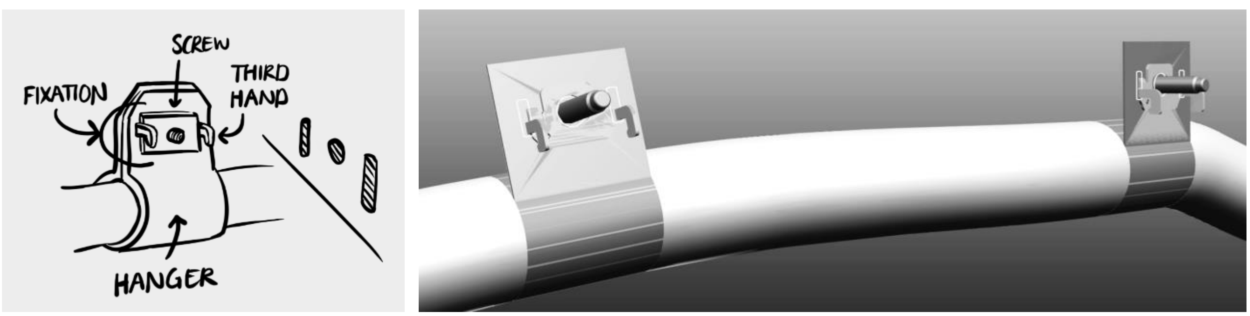


Figure 2.2: Example of a third-hand feature and screw. The two hooks function as a third-hand. Left image: sketch indicating the different parts of the fixation and the according footprint, Author illustration. Right: CAD image from Teamcenter.

2.2.3 Strap buckle

The curtain airbag interface includes a strap buckle, also called the tether bracket. The strap is either located at the front of the curtain airbag, near the A-pillar, or both at the front and the back end of the car. This depends on the car model and supplier. The strap buckle is attached to the end of the strap and is commonly made in metal. The attachment can look different, but the majority have a hole for the screw and one or two hooks that act as third-hands. The purpose of the strap is to hold the curtain airbag in place during deployment while also avoiding it being too rigid to allow for unrolling of the curtain airbag.

2.3 Footprint

The footprint is the hole pattern in the car body. This includes holes for the fixations, holes for the gas generator bracket and holes for the strap buckle. When it comes to the holes, different methods are used for different materials. The front of the car body is made in hot-formed steel and at Volvo Cars, boron steel is used to this end (P2, Personal communication, 2025). For details about P2, see Table 4.1. This steel has a very high strength, which is preferred in the case of a front crash. The sides of the car body, however, are made with cold-formed steel, usually dp600 or dp800. The reasoning for this is that the steel on the sides should be more elastic and bend in the case of a side crash. In boron steel the holes are laser cut, while in the cold-formed steel the holes are punched. This also determines which hole shapes are possible and not.

On the car body, there are certain areas reserved for the curtain airbag footprint. This is needed so that the holes do not conflict with cables and other important holes in the vicinity. Additionally, some holes have embossing, i.e. a raised part of the metal. One reason for this can be to make the holes at a certain angle, or to clearly mark out the holes for the curtain airbag. The different fixations imply a certain footprint. Currently, as different suppliers offer different attachment solutions, a template of the different existing solutions is used at the start, reserving a place for all alternatives. Only later, the definite footprint is confirmed. In Figure 2.3, an example of a footprint is shown, including the fixation and gas generator footprints on the left, and the strap buckle footprint on the right.

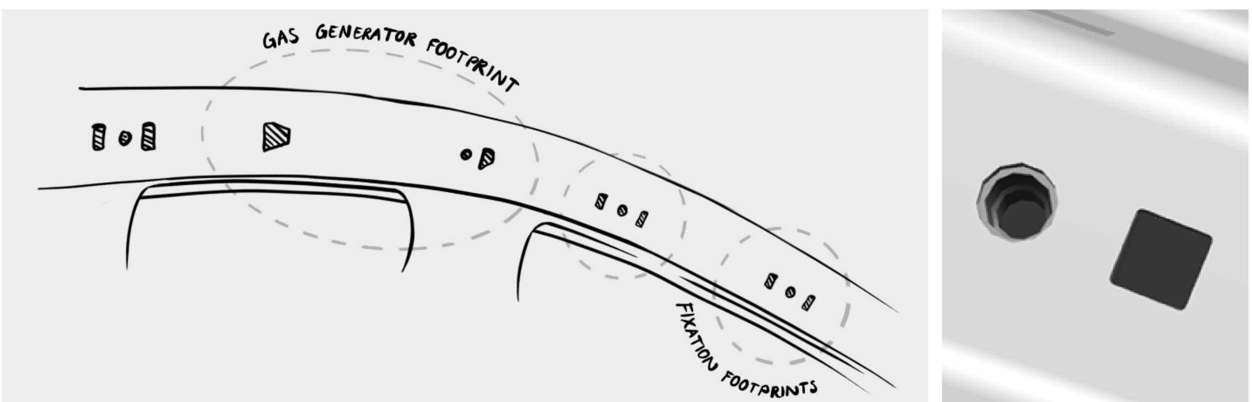


Figure 2.3: Left image: example footprint of the curtain airbag fixations and gas generator. The gas generator footprint consists of a hole for the structural hook (left) and hole for the screw with a third-hand hook (right). The fixation footprints consist of two slots for the third-hand hook and a round hole for the screw in the middle. Author illustration. Right image: example footprint for the strap buckle, consisting of a round hole for the screw and a square hole for the third-hand hook. From Teamcenter.

2.4 Error-proofing

Navigating complex products and systems cannot only take the system reliability into consideration, but also other aspects such as human reliability (Dhillon, 1989). Human error is an important factor to consider in engineering systems because their impact on a system's reliability is much greater than one might think, according to Dhillon. Two important terms are used when talking about human reliability: *human error*, which refers to the failure of performing a specific task that can lead to disruptive consequences or damage to equipment; and *human reliability*, which refers to the likelihood that humans will successfully complete a job or task at any given stage of system operation within a defined minimum time frame. During the assembly process of the curtain airbag, there are several operations where errors can occur, which is why it is important to consider human error and human reliability and integrate error-proofing by design.

2.4.1 Poka-yoke

At Volvo Cars there is a requirement that states that all restraint parts must be poka-yoke designed to secure that parts only can be assembled in correct position and eliminate mix up in the plant (P3, Personal communication, 2025). Poka-yoke is a method developed by the Japanese manufacturing engineer Shigeo Shingo (Shimbun, 1989). The term poka-yoke can be translated to "mistake-proofing", or "fail-safing" and the purpose of the term was to make previous "fool-proofing" concepts into a formidable tool. Shingo came up with the term poka-yoke since he recognized that the "fool-proofing" label could offend workers.

The goals of poka-yoke methods are to eliminate quality control inspections and produce zero defects in complex workplaces. Errors are inevitable, but poka-yoke methods aim to avoid defects, even when accidental errors are made. Some examples of poka-yoke are: guide pins of different sizes, error detection and alarms, limit switches, counters, and checklists. The basic functions of poka-yoke build on the idea that a defect exists in two states: it is either about to occur (prediction) or it has already occurred (detection). Poka-yoke has three basic functions against errors: shutdown, control, and warning.

2.4.2 Anti-twist

Another requirement at Volvo Cars concerns the anti-twist features of the curtain airbag. When assembling the curtain airbag to the car body, there is a risk that the airbag twists in between the fixing points. A twisted airbag cannot properly deploy and implementing anti-twist features is therefore crucial. One existing method relies on printed lines on the curtain airbag. The assembler is visually alerted if they would twist the curtain airbag upon assembly, as it twists the lines on the airbag. Another approach involves folding the curtain airbag in a specific, compact manner to minimize the risk of twisting.

2.4.3 Traceability

Lastly, certain vehicle components at Volvo Cars require traceability. This ensures that, for example in case of a legal dispute, it can be proven that the parts were correctly assembled. In case of the curtain airbag, it is important to verify whether all screws were attached with the correct torque. This tracking can be achieved by means of an advanced screwdriver that logs screw data. If it concerns a different type of fixation, alternative traceability solutions exist, such as QR-codes that are only scannable upon correct assembly. More on this in section 5.1.1. The data should be kept for at least 15 years after end of production (EOP).

3. Methodology

In this chapter, the process and methods for the project are presented and explained.

3.1 Process

The project follows the double diamond process, a visualization is depicted in Figure 3.1. The double diamond process involves four phases: *discover*, *define*, *develop* and *deliver* (Kochanowska & Gagliardi, 2022). The initial phase, *discover*, focuses on conducting research to get a broad perspective. Openness and empathy are important in this phase to observe and understand the user. The second phase, *define*, involves analyzing the gathered data to make sense of it. It is about understanding the information, looking for patterns, and connecting dots. After this phase, the design challenge is better understood than during the initial assumption. The third phase is the *develop* phase. In this phase, creativity and thinking outside the box is encouraged. Many solution ideas should be created regardless of their feasibility. Different methods can be used to generate ideas, and many iterations and experiments should be performed. The last phase is *deliver* and is about developing and reforming the ideas from the previous phase. This phase includes more iterations and testing, and the end result should be a detailed solution with a plan for implementation.

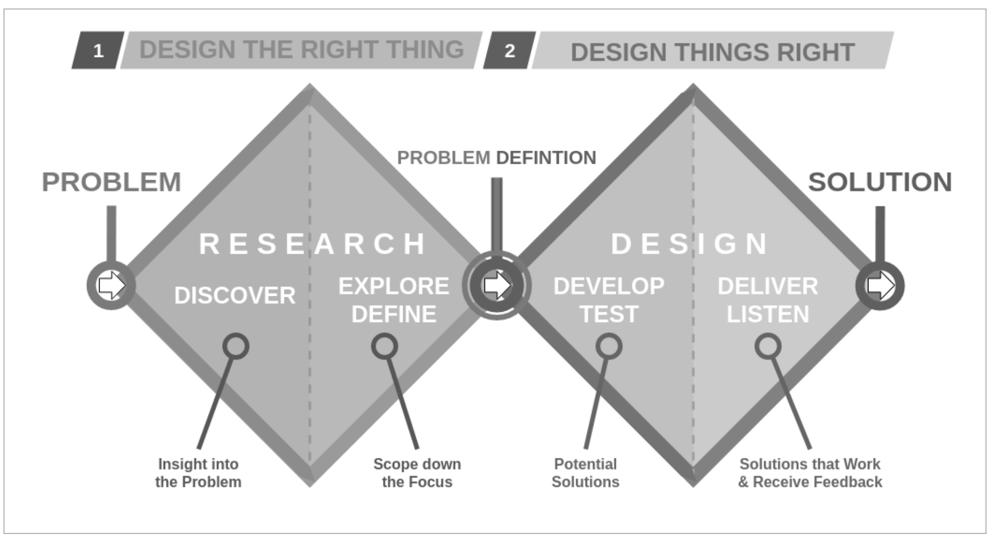


Figure 3.1: The double diamond process visualized. Reprinted with permission.

For this specific project, the *discover* phase involves the benchmarking and data collection phase. The *define* phase consists of the analysis as well as needs definition with the list of requirements. Moreover, the *develop* phase includes the idea generation as well as the concept development. Lastly, the *deliver* phase can be broken down into concept evaluations and iterations that ultimately results in the final concept.

3.2 Methods

The various methods that are used during the thesis are described in the subsequent sections.

3.2.1 Benchmarking

Benchmarking is a process where the performance of one's company is compared to the performance of other companies and competitors (Lankford, 2002). The purpose of this method is to learn from others by analyzing the strengths and weaknesses of their organization. The idea is not to copy from others, but rather to get inspiration which can lead to new ideas and improve existing concepts. Benchmarking is an efficient way to improve the performance of an organization.

3.2.2 Interviews

Interviews are a form of qualitative data collection where there is a meeting with the user (Wikberg-Nilsson et al., 2015). The purpose is to find out their experiences, attitudes, motivations, opinions and behaviors connected to a product or service. Interviews can be used during different stages of the design process. In the beginning, interviews are useful for gathering information and understanding both how current products are used and what needs the user has for future developments of the product. There are different ways to conduct an interview, they can be structured, semi-structured or unstructured (Wikberg-Nilsson et al., 2015). A structured interview is prepared with exact questions, a semi-structured interview can have some questions prepared but leaves the conversation open to what the interviewee has to say. Finally, an unstructured interview is more like a conversation with the user without any prepared questions. During an interview, it is beneficial to be in a quiet and calm environment. If the user allows it, recording is an advantage for later analysis, but notes should also be taken during the process.

3.2.3 Observations

Observations are useful for discovering problems and needs that the user might not know themselves (Wikberg-Nilsson et al., 2015). The purpose of observations is to study, listen and ask the user questions when they are performing a specific task or using a specific product. There is also self-observation which can be used to experience the user's perspective. Observations are a great support in understanding the user and what the user does intuitively without thinking. This way, the user needs can be identified. To conduct an observation, follow the user for some time while performing a specific task, take pictures, notes and ask questions during the process to get as many insights as possible.

3.2.4 Co-creation workshop

In a co-creation workshop, users within the target group, experts, or people outside of the project meet to creatively explore a specific area (Wikberg-Nilsson et al., 2015). The benefit of a workshop is that people can explore a problem together and combine their different perspectives to come up with solutions. A co-creation workshop has approximately four phases (Konrad et al., 2019). The warm-up phase is about everyone getting to know each other and getting to know the agenda. Then there is the orientation phase which is about making sure everyone understands the topic. In the working phase, the group ideates to find solutions together and make mutual innovations. Lastly, there is the conclusion where the workshop is summarized and wrapped up to effectively reflect upon the process.

3.2.5 Ergonomic assessment RULA

RULA or rapid upper limb assessment is an ergonomic assessment method to investigate the physical load of the upper body in workplaces (McAtamney & Corlett, 1993). The method is used to analyze the load on the neck, trunk and upper limbs along with muscle functions and external loads. When conducting the assessment, an operator is observed during the performance of a specific task or during a work cycle. The observer uses the RULA scoresheet and records the scores for the different parts of the body. The final score is calculated and provides an initial recommendation.

3.2.6 NASA Task Load Index

The NASA Task Load Index (TLX) is a workload assessment tool developed by Hart and Staveland (1988). The method assesses the subjective workload of operators within a human-machine system by scoring and rating subscales. These include: mental demand, physical demand, temporal demand, performance, effort and frustration. The tool is used for a specific task where the operator fills in how high the workload is for the different subscales. Then the subscales are pairwise compared and weighted.

3.2.7 KJ analysis

A KJ method involves the formulation and analysis of qualitative data (Scupin, 1997). There are four necessary steps when conducting a KJ analysis. The first step is formulating thoughts and concepts from observations and interview data and writing them down on note cards or other labels. The second step involves shuffling these notecards around and grouping them into different categories. There is no exact science to this process, instead it should be intuitive, and the categories should be formed gradually throughout the process. Next, titles are assigned to the categories and grouped as many times as necessary. Ultimately, the charted data is summarized in writing and thus more manageable than the raw data.

3.2.8 MoSCoW prioritization

The MoSCoW (*Must*, *Should*, *Could*, *Would*) analysis technique is used to assess and rank requirements (Kravchenko et al., 2022). A *Must* refers to requirements that have to be fulfilled for the solution to be considered a success. A *Should* is a requirement that is of a high priority and should be included if possible. A *Could* is a requirement that is desirable but not essential. Lastly, a *Would* refers to requirements that will not be implemented into the solution but can be considered for future developments.

3.2.9 Brainstorming

Brainstorming is a method where a group of people come up with as many ideas as possible, without any judgement involved (Johannesson et al., 2013). The idea quantity is more important than the idea quality in this method and the participants should encourage each other to develop new ideas. There are some ground rules to think about when brainstorming. Firstly, critique is not allowed, neither negative nor positive. Secondly, quantity is sought after, it is important to generate many ideas since it increases the chances that some of them are good. Thirdly, it is encouraged to think outside the box, unique ideas with some modification can result in excellent solutions. Lastly, ideas should be combined. When ideas that are generated are combined, they can complement each other and create new solutions to problems.

3.2.10 Braindrawing

Braindrawing is a creative method that is performed in a group (Johannesson et al., 2013). The method aims to first let the participants generate solutions separately based on a problem description. The ideas are sketched and described on paper, and after a few minutes the participants pass on their sheet and continue to develop the other's ideas. The papers are passed on until everyone has had the change to ideate upon each other's ideas. The purpose of this method is to get many different perspectives on a problem and use other people's solutions as inspiration for individual ideas.

3.2.11 Morphological matrix

Different methods, creative as well as systematic, can be combined to generate as many solutions as possible (Johannesson et al., 2013). One method to achieve this is to use a morphological matrix. In a morphological matrix, the sub-solutions that were generated to fulfill the requirements are put in a matrix. The sub-solutions are then combined in different ways to generate complete solutions. The purpose of the morphological matrix is that all of the complete solutions will fulfill the requirements, are feasible and have geometrical and physical compatible sub-solutions.

3.2.12 Pugh matrix

In a Pugh matrix, concepts are selected based on comparisons (Johannesson et al., 2013). The criteria that are used for the comparison are taken from the requirement specification. The concepts are then put into a matrix, together with a reference design to compare them to. This reference can be either of the concepts or most commonly, the reference is an already existing solution. All of the concepts are compared to the reference whether they are better than the reference (1), just as good as the reference (0) or worse than the reference (-1). The concepts are ranked to their total sum of points. This ranking aids in making a concept selection to further development.

3.2.13 Prototyping

Prototyping is about testing and evaluating concepts, usually by making physical models (Wikberg-Nilsson et al., 2015). The purpose of prototypes is to get a better understanding of how the concepts work, what they need to be able to do, and to gain insights for developing them further. Prototypes can be made in many different ways, one way is to use virtual prototyping (Johannesson et al., 2013). Virtual prototyping refers to modeling and simulations on a computer, such as CAD. The purpose is to be able to look at the product in 3D in the CAD-program before making a physical prototype. That way, the product can be seen from different angles which provides a more comprehensive picture than sketching. Physical prototypes can also be created to allow for a tangible evaluation of the concept (Wikberg-Nilsson et al., 2015). These may include lo-fi prototypes, such as simple cardboard models, or more hi-fi versions like 3D-printed models or mock-ups.

3.2.14 Appearance FMEA

The Appearance FMEA was developed by Forslund et al. (2009) at Chalmers University of Technology and aims to identify possible visual problems early through several steps. First, the components and the relationships between the components need to be identified. The components and relationships are listed separately, and each are considered both from a form perspective, and a color/texture/glossiness perspective. The second step is to identify possible deviations that may occur during manufacturing or ageing, usage, and environment. The third step is to estimate the error probability, its effect, and how visible it is. Each is given a score from 1-10, where 10 is the highest probability, effect, and visibility, while 1 reflects a minimal probability, effect, and visibility. Using these numbers, the risk number can be calculated by multiplying them.

$$\textit{Risk number} = \textit{Error probability} * \textit{Error effect} * \textit{Visibility}$$

The fourth and last step is to come up with a measure of action for the aspects that have a high-risk number. All steps are composed into a table like Table 3.1 depicted below.

Table 3.1: Appearance FMEA, based on the table introduced by Forslund et al. (2009).

1	2		3					4
Component	*Error possibility manufacturing*	*Aging, use, environment*	*Cause of error*	*Error proba-bility*	*Effect*	*Visi-bility*	*Risk number*	*Measure of action*
1 Form								
Color/ texture/ gloss								
2 Form								
Color/ texture/ gloss								
… …								
Relation	*Error possibility manufacturing*	*Aging, use, environment*	*Cause of error*	*Error proba-bility*	*Effect*	*Visi-bility*	*Risk number*	*Measure of action*
1-2 Form								
Color/ texture/ gloss								
1-3 Form								
Color/ texture/ gloss								
… …								

3.2.15 Sample standard deviation

In case of a repeated measurement, the dispersion of the measurements around the mean value (μ) can be expressed using the sample standard deviation (s). The formula for the sample standard deviation is shown below.

$$s = \sqrt{\frac{\sum(x_i - \mu)^2}{n - 1}}$$

Here, x_i is each of the measurement values, from which the mean μ is subtracted. These values are squared and added up. The sum is divided by the number of measurements n minus one. Taking the square root of the total results in the sample standard deviation s. Using the sample standard deviation, confidence intervals for the measurements can be calculated as well, see the formula below.

$$CI = \mu \pm t \cdot \frac{s}{\sqrt{n}}$$

Here, CI is the confidence interval, μ the mean, s the sample standard deviation, and n the number of measurements. The t-value depends on the confidence level and number of measurements and can be found in statistical tables.

4. Execution

This chapter elaborates on how the methods described previously were applied during the project. First, the execution of the benchmarking is described. This is followed by the set-up of the data collection and a section on the methods applied during the analysis of this data. The sections that follow show the steps taken during the idea generation, concept development and final concept development. The last section explains the execution of the evaluation. The results of the execution will be presented in the chapters that follow hereafter, chapter 5 – 11, in the same order.

4.1 Benchmarking

To gain better insights into what curtain airbag attachments exist on the market, the database Iceberg 3.0 was used to review competitor solutions. Iceberg 3.0 by Caresoft Global is a versatile and scalable enterprise platform for acquiring vehicle benchmarking data (Caresoft Global, 2024). The key search words used were "Curtain airbag" and "Inflatable curtain". The results were then filtered by brand and the tab called "Teardown data" was used to find images. When images of existing solutions were found that were fundamentally different to previously found solutions, they were added to a Miro board, and in the end, the categories of existing solutions were synthesized with a concise KJ analysis.

To analyze the curtain airbag attachments at Volvo Cars, the software Teamcenter (TC) and Teamcenter Visualization (TC Vis) was utilized. Teamcenter is the product lifecycle management (PLM) software developed by Siemens, used by Volvo Cars, where all car models are saved and can be visualized in the connecting software TC Vis. The advantages and disadvantages of various solutions were discussed internally with the Airbags & Steering Wheels team to better understand the strengths of competitors and the strengths of Volvo Cars.

4.2 Data collection

To gain comprehensive insights into the requirements and needs of various stakeholders and users, both qualitative and quantitative data collection methods were employed. The description of the approach is found below.

4.2.1 Expert interviews

To gain a better understanding of the needs and wishes of the different departments involved in curtain airbag fixations, several expert interviews were conducted. A semi-structured interview approach was chosen to ensure that all relevant topics would be covered, as well as allowing deviations in case other relevant aspects would come up. The interview templates can be found in Appendix A. Interviews were conducted in Swedish whenever it was the interviewee's first language, allowing them to express themselves more comfortably in their native tongue. Interviews were recorded with approval from the interviewees, to allow for further analysis. More details can be found in Table 4.1. For in-text citation of personal communication with the participant, the abbreviations in first column of Table 4.1 are used in this report moving forward. This is to ensure the anonymity of the participants.

Table 4.1: Conducted expert interviews.

Participant	*Who*	*Language*	*Medium*	*Appendix*
P1	Attribute Leader Service	Swedish	On-site	A.1
P2	Principal Engineer Upper Body Structure	Swedish	On-site	A.2
P3	Manufacturing Engineer	Swedish	On-site	A.3
P4	Assembly line workers (3 people)	Swedish	On-site	-
P5	Curtain airbag supplier	English	Teams Meeting	A.4

4.2.2 Ergonomic analysis

The NASA-TLX developed by Hart and Staveland (1988) was used to evaluate the mental workload, physical workload, time pressure and frustration of the assembly workers. Additionally, a RULA assessment was conducted to obtain measurable data on the ergonomic positioning of the upper body of the assembly workers. Both of the ergonomic analyses were performed at the test production with the assembly workers that mount the curtain airbag. Their work positions were observed during the performance of the task in order to fill in the RULA scoresheet, and afterwards the same workers filled in the NASA-TLX template by themselves. The aim of the NASA-TLX was to gain a deeper understanding of the mental and physical strain of the user, in order to know what aspects need improvement.

The method was conducted with two participants from the test production at Volvo Cars because the test production workers do not experience the same time pressure as the workers at the assembly line, since they only assemble VPs (Verification Prototypes) for testing. See also section 4.2.3 for more information on the production facilities. However, one of the participants had previous experience from the assembly line and could perform the method with that experience in mind, which made it possible to compare the different results for a more nuanced picture.

4.2.3 Observations

Observations were performed at both the test production and actual production facilities at Volvo Cars. At the test production, cars are manufactured at a relatively low pace of approximately 2 cars per day. These cars are prototypes that could for example be used in safety tests such as crash tests. The actual production or assembly line, on the other hand, happens at a much higher pace. For example, only 57 seconds is reserved for mounting one curtain airbag (P3, personal communication, 2025). During this time, the gas generator, fixations and strap buckle have to be mounted, and all of the screws need to be fastened. The difference in pace at the test production versus the actual production means that more time is available to interact with the assembly workers at the test production compared to the actual production.

At the test production, two different observations were performed. One of them was with the Autoliv hook solution and the other one was with a solution from a current VCC project. An observation of the assembly worker was performed, as well as a self-observation. By trying to assemble the curtain airbag as beginners, many problems and difficulties were discovered. Concerning the current VCC project, the observation was done during a material inspection at Volvo Cars, where a curtain airbag assembly worker was also present. A few questions were asked during the observation, and there was a possibility to try the assembly. Beside the ergonomic analysis covered in section 6.3, an observation template was used, consisting of four columns: *Problem noted, Number of people, Possible cause,* and *Severity,* as seen in Table 4.2. For the severity, the following scale was used:

0 - No usability problem (not included because it is not a problem)
1 - Cosmetic usability problem (the user did not notice it was a problem)
2 - Minor usability problem (the user noticed the problem, but it did not affect their ability to complete the task)
3 - Major usability problem (the user noticed the problem and it affected their ability to complete the task)
4 - Catastrophic usability problem (the user gets stuck and cannot complete the task)

At the assembly line, the same observation template was used to analyze the usability problems. In addition to this, brief unstructured interviews were conducted, where questions were asked at the same time as the worker assembled the curtain airbag. The types of questions that were asked were questions about ergonomical problems, problems with existing solutions and generally their insights on how to improve the assembly. To get a better overview of the assembly process and the tasks included, a HTA was used to structure up each step, for the HTA, see chapter 6.2.2.

Table 4.2: Format used as a guide for the observations at the assembly line.

Noted problem	Number of people affected by problem	Possible cause	Severity

4.2.4 Questionnaire

As explained, only limited interaction was possible with the assembly workers at the assembly line, since their work is characterized by high time pressure. To gain further insight into their reflections on their own work, a questionnaire was made in Microsoft Forms. The questions were based on the NASA-TLX factors, but as the questionnaire is stand-alone, more specific questions were asked. Posters with a QR code to this questionnaire were left in their breakroom, as seen in Figure 4.1. Free cookies were used as a motivator for those taking the effort to fill it out. The full questionnaire can also be found in Appendix B.1.

Figure 4.1: Example poster put in the production breakroom with QR code leading to the questionnaire. Image: Volvo Cars Global Newsroom. Reprinted with permission.

4.2.5 Expert co-creation workshop

An expert co-creation workshop was conducted with ten people from the Airbag & Steering Wheels team at Volvo Cars, to leverage their expertise in curtain airbag fixations. The co-creation workshop agenda is shown below.

14.00 Introduction (icebreaker and project update)
14.20 Brainstorm needs/requirements
14.40 Existing solutions and other joining methods
15.00 Coffee break
15.15 Co-creation
15.45 Evaluating ideas
16.00 End of session

During the ice breaker, participants were asked to choose an emoji that represented their current mood, as well as one for their neighbor to the right. This was followed by a project update, summarizing all findings up to that point. Thereafter, participants brainstormed the needs and requirements for curtain airbag fixations and wrote them on sticky notes. During the final activity before the break, current fixation solutions and other general joining methods were presented.

After the coffee break, participants were asked to choose a sticky note with a need or requirement to focus on and come up with ideas to address it. Pens, paper, cardboard, and other materials were provided to enable participants to create quick mock-ups of their ideas. These ideas were evaluated during the final activity, by assigning stickers with different meanings to the different ideas. The focus was on identifying the potential in the ideas.

4.3 Analysis

The data from the data collection phase was analyzed with different methods such as a KJ analysis. The KJ analysis was subsequently used as a basis for the list of requirements.

4.3.1 KJ analysis

A KJ analysis was performed to summarize the findings from the interviews. First, the most important insights from the interviews were written down on sticky notes in Miro. This was done by listening to the recordings of the interviews and writing down relevant quotes and other insights. Then all findings were grouped into different categories on the board. Sticky notes from the different interviews were spread out onto the board and the sticky notes with similar content were categorized. A legend was used with different colors assigned to the different interviews, see Figure 4.2. This method facilitated the process of synthesizing the data and laid the foundation for the list of requirements.

Figure 4.2: The legend used in the KJ analysis.

4.3.2 List of Requirements

The list of requirements was based on the categories in the KJ analysis, with some adaptations where needed. The MoSCoW method was used, as explained in section 3.2.8. The *Would* category was excluded to focus on the documentation of requirements that needed to be fulfilled. These include *Must*, *Should*, or *Could* requirements. Comments were added to certain requirements, for example measurables. Lastly, the table included a reference column, to document the sources of each requirement. The list of requirements formed a base for what to consider during the ideation, as a measure to compare concepts later on in the process, and as a way to evaluate the final concept.

4.4 Idea generation

During the idea generation, ideation sketches were made, initially focusing on the fixations. General ideation was applied, as well as braindrawing to further ideate upon each other's ideas. Several inspiration boards of existing solutions and different materials were made to spark new ideas. A morphological matrix was made as well, see Figure 4.3. Moreover, lo-fi prototypes were made to quickly test some functional aspects of the ideas, of which an example is shown in Figure 4.4.

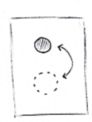
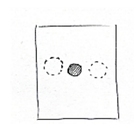
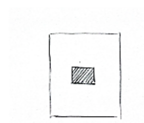
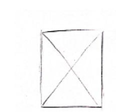
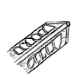
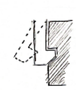
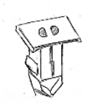
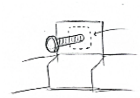
	A	B	C	D	E	F
1. Location of third hand	Above/below screw (Two holes) 	Next to screw mirrored (Three holes) 	On screw tip (One hole) 	In footprint (More complicated footprint)	In clip (Square hole) 	No-hole solutions (vaccuum) 
2. Type of third hand	Tree/elastic material 	Hook 	Snap fit/form fit/friction 	Clamp 	Clip 	Alternatives/special: vaccuum, mini hooks, etc. 
3. Location z-axis	Seperate part between BiW and tag, doubles as star washer	Integrated into tag	Between tag and screw head, through tag 	On screw tip		
4. Assembly guides	Embossing	Inward embossing	Poka yoke	Tactile feedback	Audible feedback	Semantic aids

Figure 4.3: Morphological matrix of fixations, including third-hands.

Figure 4.4: Sketching and prototyping process of fixations.

Beside the ideation focusing on the fixations, some additional ideation on the gas generator and strap buckle was performed as well. This includes a morphological matrix for the gas generator. The matrix consisted of *assembly direction*, the shape of the *structured hand*, the *third-hand*, and the *footprint* of the structural hand. The latter relies on the shape of the structural hand, but some variations still exist. The solutions found during the benchmarking were put into a matrix similar to the one depicted in Figure 4.3, in the cells of their respective partial solutions and different variations emerged. Lo-fi prototypes were made for the gas generator as well.

Focusing again on the fixations, the ideas from the idea generations were analyzed using a KJ-derived approach to gain an overview of all the sketched and prototyped ideas. Similar to a regular KJ analysis, all the sketches were discussed, and ideas were grouped based on their similarities. They were pasted into their respective categories on a Miro board, see Figure 4.5. The categories from the KJ were then reiterated upon. Some categories were selected, several other categories were combined to form new ideas. These directions were used to develop initial concepts, which were made into digital sketches to quickly communicate their function. These initial concepts were used as a starting point for the concept development explained in the next section.

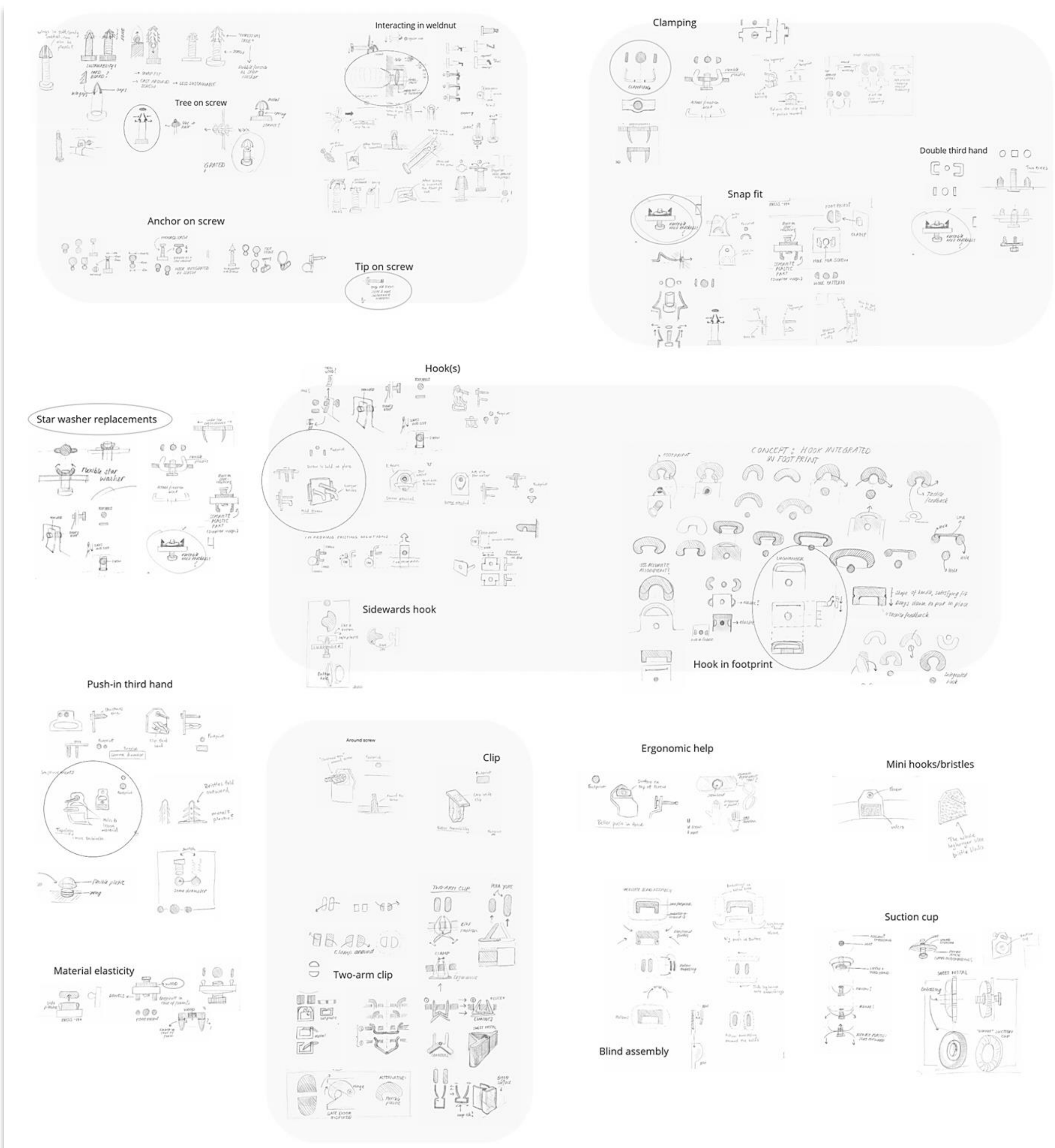


Figure 4.5: Sketch KJ analysis.

4.5 Concept development

Before evaluating the initial concepts developed during the idea generation, the existing clip solution used as a standard by other original equipment manufacturers (OEMs) and suppliers was discussed. After evaluating this existing solution, the developed concepts were assessed using a Pugh matrix. The criteria in the Pugh matrix were based on the list of requirements. However, including all individual requirements led to an unmanageably large matrix. Instead, the Pugh matrix was sorted into the requirement categories. While comparing in each category, the concepts were rated based on all of the individual requirements within the categories. One Pugh matrix was made for each of the common existing fixation methods, at Volvo Cars and other OEMs. This includes the clip-screw, tree third-hand, metal hook, and metal clip, an example of the matrix can be found in Figure 4.6.

Criteria	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Reference
Main functions											R
Ergonomics											E
Third hand											F
Assembly/context											E
Error proofing											R
Ease of assembly											E
Consistency											N
Footprint											C
Producability											E
Costs											R
Sustainability											E
After EOP											F
Total											
Rank											
Continue											

Figure 4.6: Pugh matrix template.

After evaluating the concepts in the respective Pugh matrices, the concepts were further discussed in a team meeting with colleagues that work with the curtain airbag. Using both the results from the Pugh matrix and the meeting, the concepts were narrowed down to three for the fixations, and additional ideas for the gas generator bracket and strap buckle. This selection was further developed by means of high-fidelity prototypes. CAD models were built in CATIA V5 and sent for either sheet metal laser cutting and bending, or 3D printing. See Figure 4.7 for examples. The prototypes were tested and iterated upon.

Figure 4.7: Examples of 3D-printed high-fidelity prototypes.

4.6 Final concept

After iterating upon the hi-fi prototypes, one concept with the greatest potential was selected as the final concept. This decision followed from testing the prototypes, which made apparent which prototype fit the requirements best and exhibited the least issues. Renders were made from this final prototype in CATIA V5 to clearly visualize the fixation. It was decided to make these renders in CATIA rather than a more rendering-focused software because the solution is mainly functional rather than aesthetic. The surface expression and colors are therefore not of high relevance.

In addition to the renders, Granta Edupack was used to make a preliminary material selection. This material selection was used as a starting point for the possible production techniques as well. An Eco Audit of these materials was performed in Granta Edupack as well to evaluate the sustainability. These initial reflections upon material and productions are to be seen as a starting point for further development of the concept.

4.7 Evaluation

Lastly, the concept was evaluated. The prototypes were tested on a test rig and discussed with a manufacturing engineer. The concept was also compared to the list of requirements, and an appearance FMEA was performed. Lastly, based on these evaluations, the next steps for the concept were formulated.

4.7.1 Prototype testing

To test the prototype, the footprint was 3D-printed and assembled onto a test rig available at Volvo Cars. An inert curtain airbag with prototype hangers was used, and the 3D-printed parts of the final concept were put onto its screws. The testing focused on the fixations and not the gas generator or strap buckle. The assembly was performed and discussed together with a manufacturing engineer.

In addition, the push-in forces were measured using a specific force meter tool. The push-in forces were measured 15 times from different angles, using variations of the 3D-printed final concept and weld nuts. The fixations were pushed in both carefully and more roughly, to mimic the actual assembly as much as possible. See Figure 4.8. The measurements were used to calculate a mean value and confidence interval based on a 95% confidence level, using the sample standard deviation.

Figure 4.8: Push-in force testing.

4.7.2 Comparison to requirements list

To determine if the final concept met the initial requirements outlined in the requirements list, a comparison was conducted. This involved adding a column to the requirements list and indicating whether each requirement was fulfilled by the concept. The following symbols with the following meanings were used:

✓	Fulfilled
X	Not fulfilled
—	Need further investigation
•	Not relevant to solution

The different categories in the requirements list were then discussed in relation to the final concept and why it did or did not fulfill certain requirements.

4.7.3 Appearance FMEA

An Appearance FMEA was performed as well. Slight adjustments to the table were made to make it suitable for the purposes of the concept. This includes removing the aspects purely based on the concept's aesthetics. This resulted in Table 4.3, where color, texture and gloss changes were no longer considered. The visibility factor was removed as well, as all parts end up hidden behind the car's headlining. The error probabilities and effects were estimated in accordance with a pre-defined scale, depicted in Table 4.4 and 4.5.

Table 4.3: Adjusted FMEA table

1	2		3				4
Component	*Error possibility manufacturing*	*Aging, use, environment*	*Cause of error*	*Error proba-bility*	*Effect*	*Risk number*	*Measure of action*
1							
2							
…							
Relation	*Error possibility manufacturing*	*Aging, use, environment*	*Cause of error*	*Error proba-bility*	*Effect*	*Risk number*	*Measure of action*
1-2							
…							

Table 4.4: Error probability scales

Error probability	*Implication*
10	Possibly reoccurring
8	Possibly reoccurring but seldom
6	Possibly occurs at some point
4	Possible but unlikely to occur at some point
0 – 2	Highly unlikely to occur at all

Table 4.5: Effect scales

Effect	*Implication*
10	Part cannot be used
8	Part can hardly be used
6	Part functionality somewhat affected
4	Part functionality hardly affected
0 – 2	Part functionality not affected

5. Benchmarking

This section presents the results of the benchmarking analysis, highlighting solutions from both Volvo Cars and its competitors. First, four different categories of fixations are covered: (1) metal hook; (2) tree third-hand; (3) clip-screw; and (4) clip. This is followed by findings on the gas generator. The strap buckle benchmarking is shortly covered, as solutions are quite uniform. Lastly, findings on the footprint are discussed.

5.1 Fixations

Below the existing solutions for curtain airbag fixations that were found in Iceberg 3.0 and Teamcenter are presented.

5.1.1 Metal hook fixations

The first type of fixation is made of metal and has one or two hooks that act as a third-hand during assembly (Caresoft Global, 2024). A screw kept in place by star washers is used for the final attachment of the curtain airbag hanger to the car body. Several examples of different car brands can be found in Figure 5.1, including one from Volvo Cars produced by Autoliv.

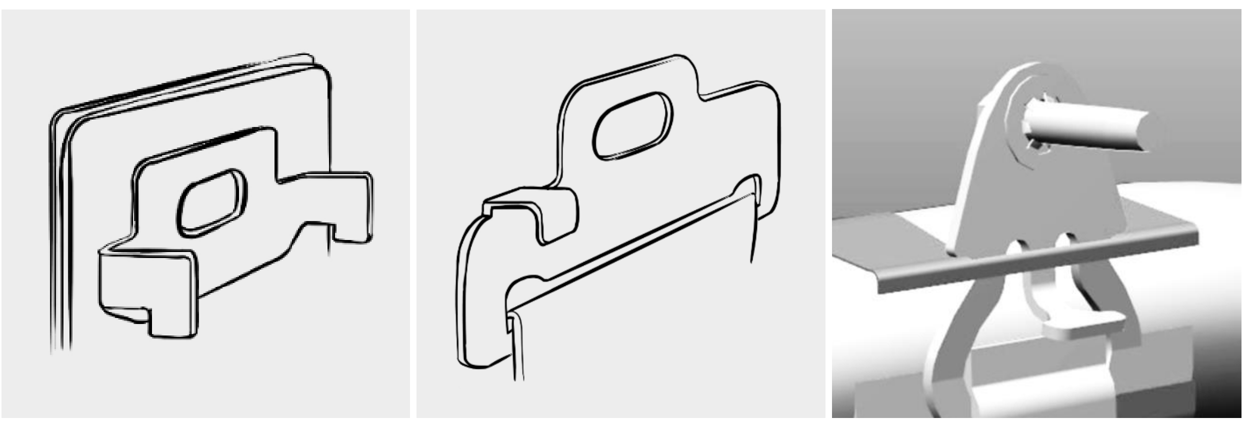


Figure 5.1: Metal hook fixations. Left: Two hooks as found in the Cadillac Escalade Sport Platinum 2021 (Caresoft Global, 2024). Similar designs can be found in Volvo's EX30. Center: One asymmetric hook, as found in the Nissan Pathfinder Plationum 4WD 2023. Author illustrations. Right: One symmetric hook, as found in project EX90, produced by Autoliv.

Two hooks create symmetry which is positive for tooling costs but also require two holes in the car body and the more holes are added the more the costs increase (P2, personal communication, 2025). When it comes to one hook, asymmetry requires either different buckles to be produced for either side of the car, or an asymmetric footprint on either side of the car body. It can also cause confusion for the assembly workers since the fixations are mounted differently on different sides of the car.

As for the Autoliv symmetric hook, it solves the aforementioned problems, but in this case is limited by the thickness of the sheet metal. Double sheet metal requires a longer hook, which the design does not allow because there is not enough material. A metal hook is relatively easy to produce but is less precise with regards to screw alignment. Additionally, the Autoliv solution requires an extra keyhole-shaped hole in the car body, which is more difficult to produce than a round hole.

No example of a hook placed above the screw could be found. This is probably due to limited space on the cantrail. The screw must be in reach to be able to use the screwdriver and therefore is located a bit above the curtain airbag, that is aligned with the cantrail. If there would be a hook placed above the screw, the cantrail would have to be very wide to account for an additional hole above the screw hole in the BiW.

An alternative design to the asymmetric hook design from Figure 5.1 can be found in Figure 5.2. As the part can be rotated to place the hook on the other side of the screw, a symmetric design across the car can be achieved without adding to tooling costs. This design can be found in the BYD Seagull Flying Edition 2023, and a similar solution is found in the Changan SL03 705 Pure Electric Version 2022 (Caresoft Global, 2024).

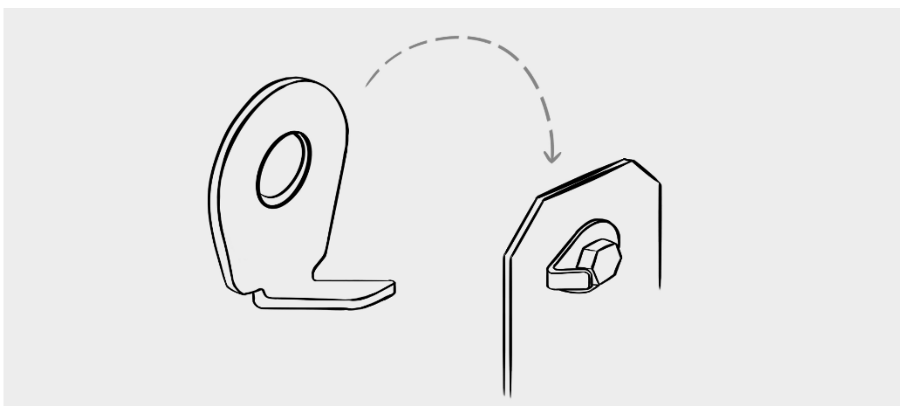


Figure 5.2: Separate part for asymmetric hook third-hand as found in the BYD Seagull Flying Edition 2023. Author illustration.

5.1.2 Tree third-hand fixations

The second type of fixation is mainly made from plastic and contains a ‘tree’ type pin that functions as a third-hand (Caresoft Global, 2024). One example of this is from Tesla, see Figure 5.3. An additional screw with star washer forms the definite connection. The tree third-hand is easy and fast to use, and the push-in force is low, therefore ensuring ergonomic assembly (P3, personal communication, 2025). An additional hole is required in the body in white, however, both holes are round, reducing tooling costs. The solution is also symmetric, meaning that the same tools can be used on either side of the car. Structural double plate at some parts of the cantrail can cause problems, as it requires greater clearance between the two holes because of oversized holes on the second plate. This means that a tree third-hand under the screw may not fit everywhere on the cantrail and would have to be next to the screw at some of the fixing points. Additionally, this would be a less consistent and asymmetric design which is negative because the same tools cannot be used for the holes, leading to increased tooling costs.

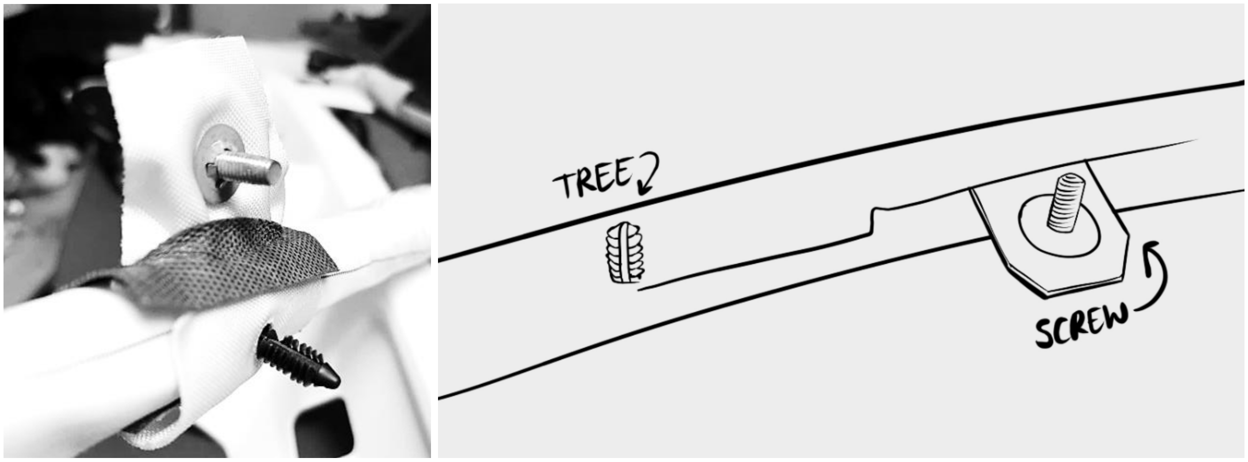


Figure 5.3: Tree third-hand fixations. Left: fixation with tree third-hand below the screw. From Tesla. Picture taken by the authors. Right: tree third-hand further along the curtain airbag, as in the Jeep Grand Cherokee L Summit Reserve 4x4 202 (Caresoft Global, 2024). Author illustration.

5.1.3 Clip-screw fixation

Another type of solution is a plastic tip on the screw that is to form the permanent connection as found in the software Teamcenter. A square plastic tip is injection molded onto a screw, with corners slightly bigger than the hole, see Figure 5.4. This integrated-in-screw solution was only found in Volvo's cars and is currently used in production (P3, personal communication). Since the solution is integrated into the screw, it can be used regardless of the material on the hanger which reduces reliance on any single supplier. Additionally, it only requires one round hole in the footprint, which is easy to produce. A downside is the high push-in force because the solution uses friction to stay in place, combined with only a small area to push on: the screw head. It also happens that part of the plastic bit breaks, making the solution hard to use.

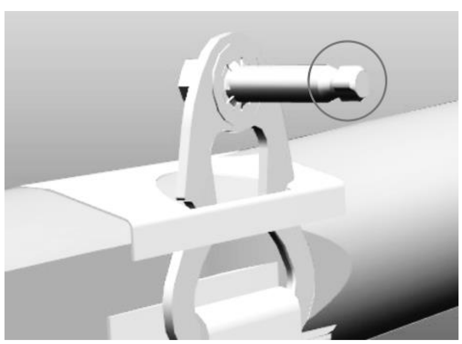


Figure 5.4: Plastic tip integrated on screw solution. Picture from Volvo's V90.

Metal clip

5.1.4 Clip fixations

The metal clip solution does not require a screw for permanent attachment (Caresoft Global, 2024), see Figure 5.5. Instead, the clip can be pushed in without the need of a screwdriver and is strong enough to stay put during airbag deployment (P5, personal communication, 2025). The clip is pushed into square-shaped holes, thus done in one step instead of a separate third-hand step and screwdriving step. The clip's design is relatively complex which could add to part costs. Additionally, it requires a high push-in force, too high for current Volvo Cars standards. Another Volvo Cars standard getting in the way of implementing metal clips is traceability as stated in the Volvo Cars Standard Data Base. Solutions do exist but require an additional infrastructure of either cameras or scanners. The solution reduces the number of holes and parts, saving both time and money. Versions with flexible legs for varying plate thickness exist. With respect to service, the clips are removed using pliers, which can be unfavorable since there is cabling nearby (P1, personal communication, 2025).

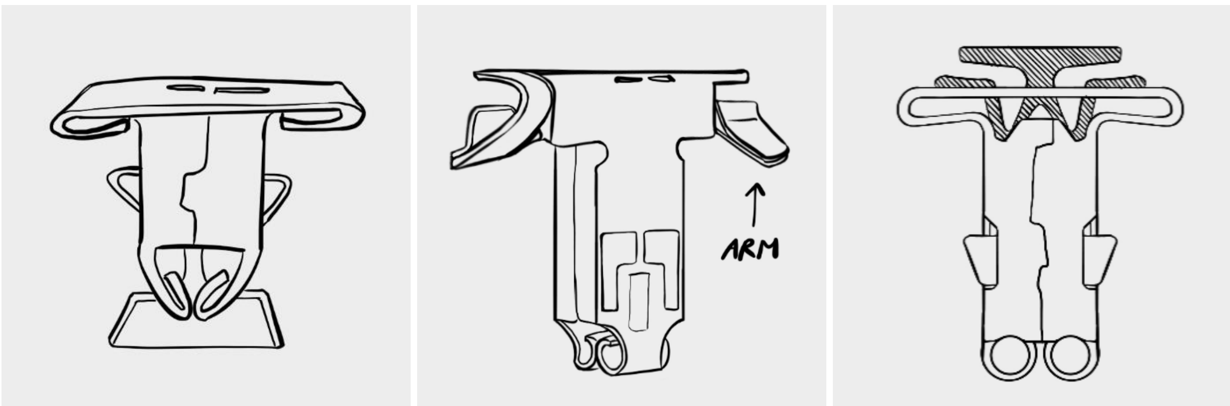


Figure 5.5: Metal clip fixations. Left: airbag clip as found in the Volkswagen ID Buzz 1st Edition 2023 (Caresoft Global, 2024). Center: BMW iX xDrive40 2022. The two arms allow varying plate thickness. Right: Metal clip with ergonomical help (marked) for easier assembly. As produced by Araymond Mobility. Author illustrations.

Plastic clip

The plastic clip solution is in many ways similar to the metal clip though bigger in size and made of plastic, see Figure 5.6. It comes with similar issues and advantages. In addition to the metal clip, the sustainability of using plastic can be considered. Using plastic could come with lower part price. As with the metal clips, removing plastic clips for service is challenging. Traceability is an issue as well.

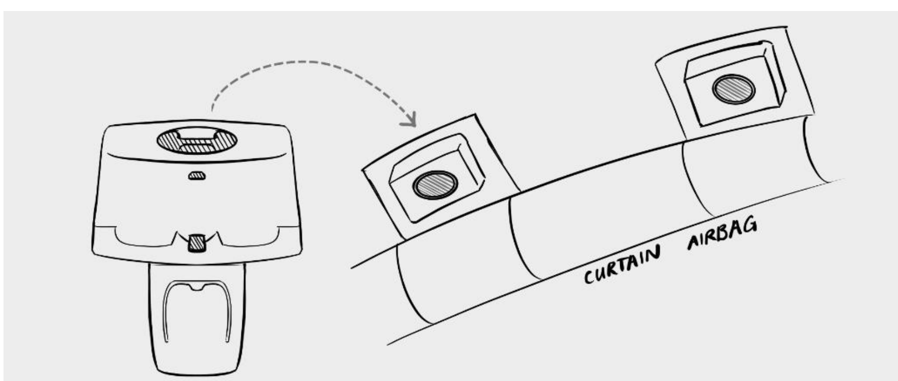


Figure 5.6: Plastic clip as found in the Toyota bZ4X Limited AWD 2023 (Caresoft Global, 2024). Also found in Lexus RX 500h F-Sport+ 2024. Author illustration.

5.2 Gas generator

During this section, the gas generator bracket is considered. Variations between different car models are less common compared to curtain airbag fixations, and therefore a more general explanation of the bracket attachment is provided. First, how the gas generator is attached to the BiW is covered. Then, assembly-related considerations are mentioned.

The gas generator is attached through its gas generator bracket. This bracket generally contains two hooks, one on either side, which are different in shape. One hook is structural, because the gas generator is in front of it, which makes it impossible to add a screw as the screw head would not be in reach. The other hook functions as a third-hand and is accompanied by a hole for a screw. This side of the bracket is longer than the gas generator and thus allows for a screw to be mounted to achieve a strong connection (P2, personal communication, 2025).

The hooks need to be guided into the holes of the footprint and the different hooks belong to differently shaped holes, ensuring poka-yoke assembly. Different car brands have different shape hooks, but their main function appears to be largely the same, an example is found in Figure 5.7. Sometimes a bolt is used as the structural hook, see Figure 5.8. Lastly, a few exceptions use different types of brackets, see Figure 5.9.

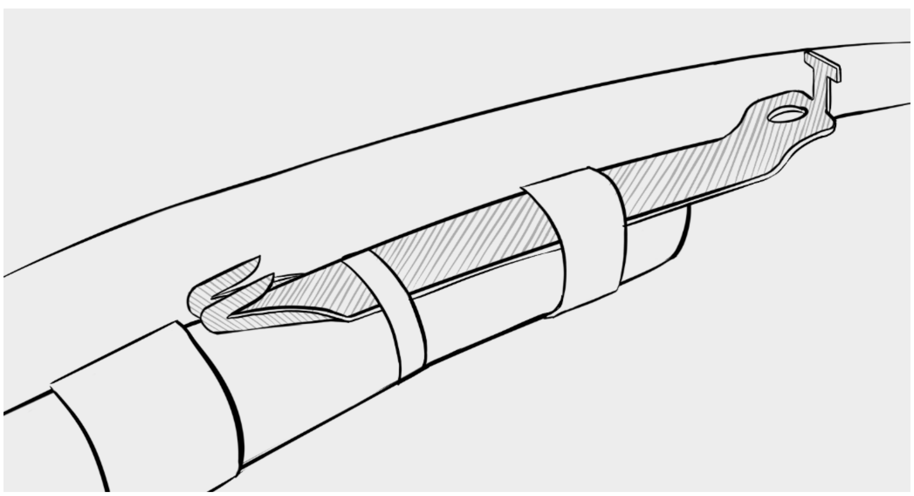


Figure 5.7: Example of a typical gas generator bracket. The structural hook is depicted on the bottom left, the third-hand hook with screw hole on the top right. As found int the Audi Q4 e-tron 50 Quattro 2022 (Caresoft Global, 2024). Author illustration.

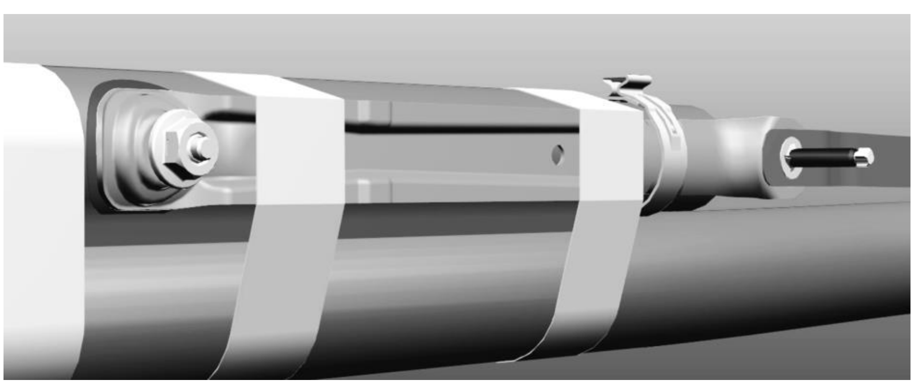


Figure 5.8: Bolt as structural hook, from XC60. On the right, the screw can be seen. Here, a clip-screw serves the third-hand feature instead of a metal hook. From Teamcenter.

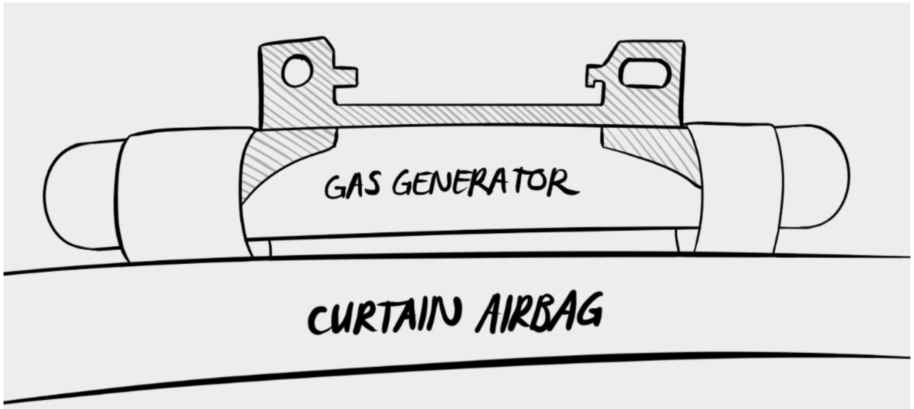


Figure 5.9: One of the few exceptions to the rule, where the backet is placed above/below instead of behind the gas generator. From the BMW iX xDrive40 2022 (Caresoft Global, 2024).

5.3 Strap buckle

Similarly to the gas generator bracket, the strap buckle designs differ less between different car models than curtain airbag fixations (Caresoft Global, 2024). Generally, the design is a strap with a bracket consisting of a hook at the top and a hole for the screw in the middle. The complexity of this top hook varies slightly, see Figure 5.10 left and center. This design was used at Volvo Cars as well and worked well combined with the clip-screw. When new third-hands were designed for the fixations, the screw of the strap buckle was replaced with a regular screw. The single hook design does not seem to work as well without the clip-screw and tends to fall out or cause issues when the screw is fastened with a screwdriver (P3, personal communication, 2025). For that reason, Volvo Cars now uses a double hook design as depicted in Figure 5.10 right.

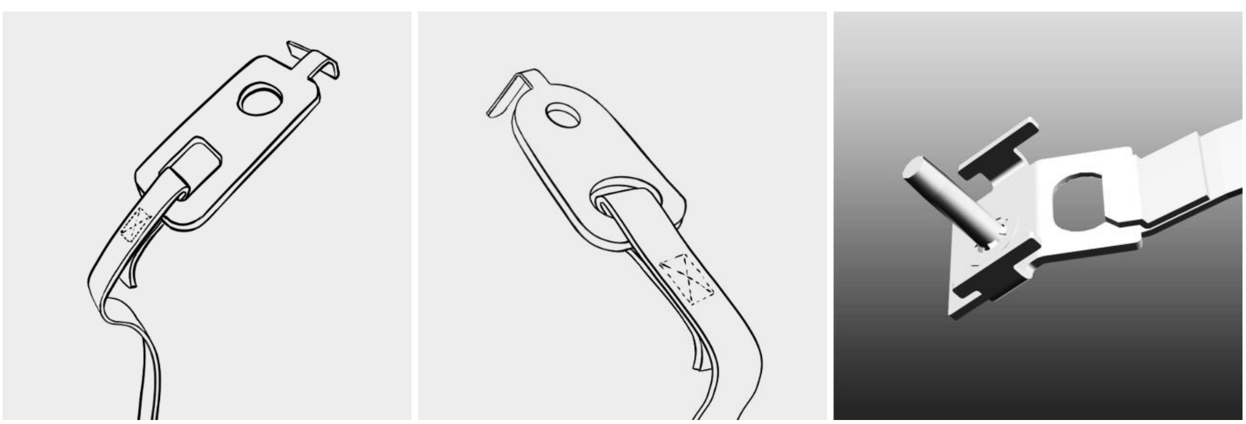


Figure 5.10: Strap buckle designs. Left: as found in the Tesla Cybertruck AWD foundation series 2023 (Caresoft Global, 2024). Strap buckle with a hook at the top. Center: as found in the Avatr 12 650 Three-Lidar AWD GT Edition 2024. Strap buckle with a simple hook. Author illustrations. Right: from the EX90. Strap buckle with double hook, so it cannot fall out or move when the screw is fastened. From Teamcenter.

5.4 Footprint

Some different footprints found in existing Volvo cars and cars from competitors are presented below.

5.4.1 Fixation footprints

The appearance of the footprint can vary based on the how the fixations looks. The fixation with one metal hook in the center has a corresponding footprint consisting of a keyhole shaped hole and a hole for the screw, see Figure 5.11 left. Alternatively, if there is only one asymmetrical hook, the footprint consists of a round hole for the screw and a rectangle hole for the hook, see Figure 5.11 center. When it comes to fixations with two hooks, the corresponding footprint has a rectangle hole on either side, see Figure 5.11 right.

Figure 5.11: Hook fixation footprints. Left: footprint of fixation with a centered hook. Center: footprint of single asymmetric hook. Right: footprint of symmetric, double hook. From Teamcenter.

The tree third-hand that is used by Tesla among others, has a different corresponding footprint. The footprint consists of a hole for the screw, and a bigger hole for the tree third-hand (Caresoft Global, 2024). The footprint can be seen in Figure 5.12 left. As for the clip-screw, the footprint is simply a round hole, see Figure 5.12 right.

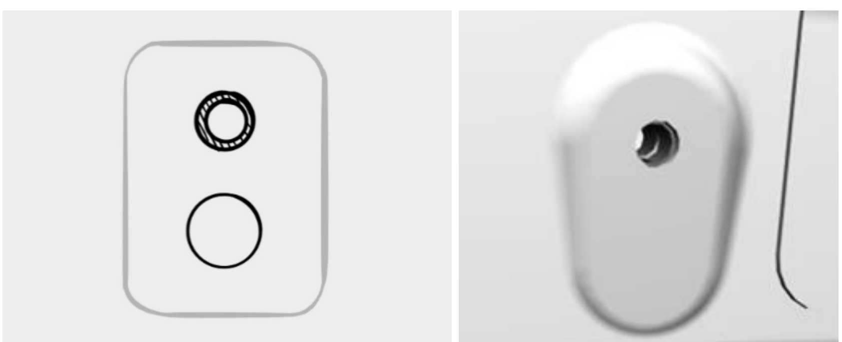


Figure 5.12: Left: tree third-hand fixation footprints. Right: clip-screw footprint.

The footprint varies slightly from the other fixations when using metal or plastic clips. There is no round hole for a screw since no screw is needed. Instead, the footprint is in the form of a square or a rectangle, see Figure 5.13.

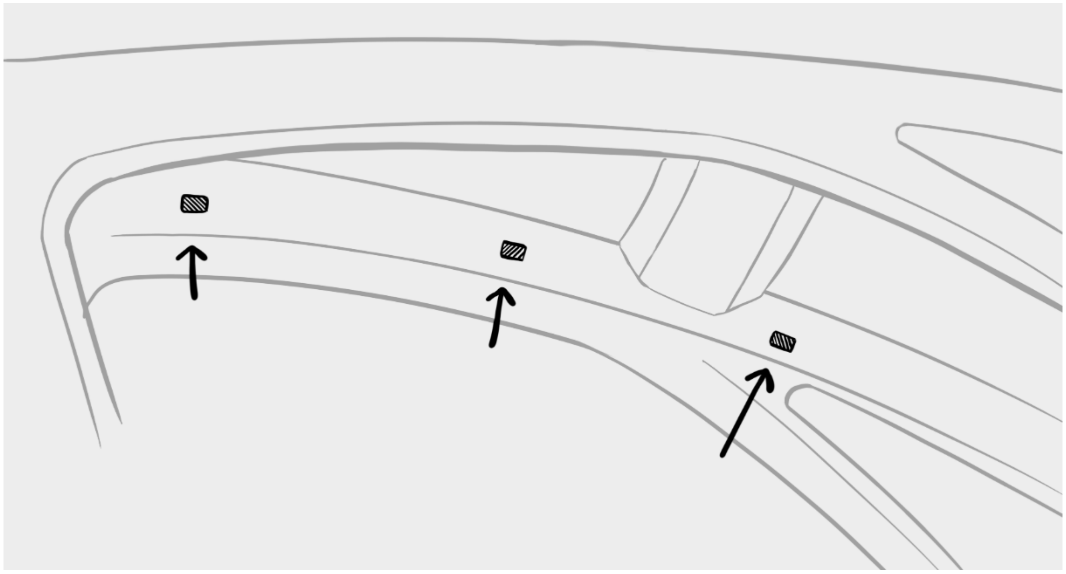


Figure 5.13: Square footprints for metal clip fixations. From Volkswagen ID.3 1st Edition Max 2021 (Caresoft Global, 2024). Author illustration.

5.4.2 Gas generator footprints

The gas generator footprint most commonly consists of two different holes. The shapes of these holes vary depending on whether there are two hooks or only one hook and one third-hand fixation. In the case of two hooks, the holes commonly look the same on both sides except that the hole for the structural hook is bigger than the hole for the third-hand hook. A hole for the screw is included as well. In the case of one hook and one third-hand fixation, such as a clip-screw, there is a hole for the structural hook and in case of a clip-screw, only a round hole on the other side. Some different variations of different holes that are part of the gas generator footprint can be seen in Figure 5.14. Generally, having one structural hook and one third-hand fixation would be preferrable because it is much easier to guide into the footprint, rather than having to align two hooks in at once (P4, personal communication, 2024).

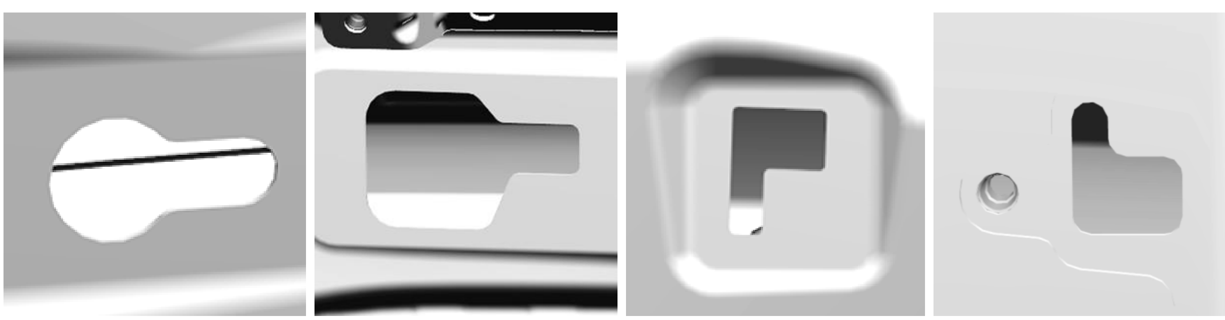


Figure 5.14: Gas generator footprints. Left: keyhole shape for structural bolt. Center left: hole for structural hook, variation one. Center right: hole for structural hook, variation two. Right: for third-hand hook with screw. From Teamcenter.

5.4.3 Strap buckle footprints

The strap buckle footprints are uniform across most car models, for both competitors and Volvo Cars. The footprint has a round hole for the screw and then either one or two rectangles to accommodate for the hook third-hand(s). See Figure 5.15 for the strap buckle footprints. The footprint for one hook is beneficial because less holes save costs (P2, personal communication, 2024).

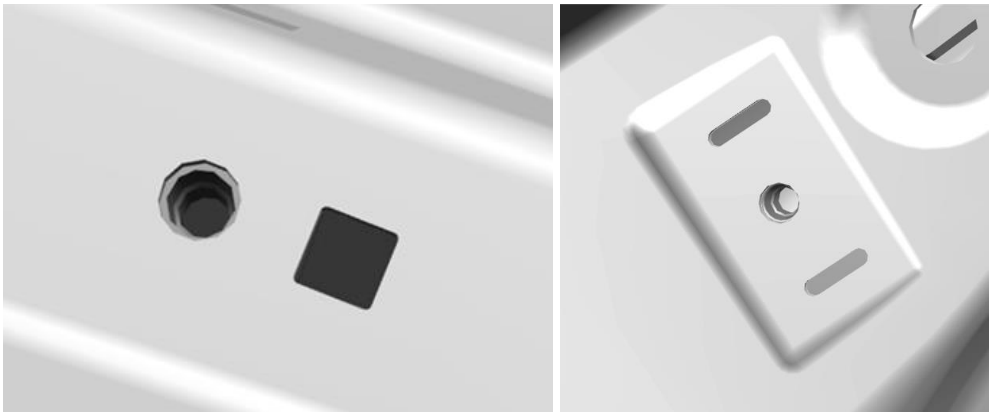


Figure 5.15: Strap buckle footprints. Left: one hook. Right: two hooks. Image from Teamcenter.

6. Data collection

In this chapter, the results from the data collection phase are presented. The insights from the expert interviews are summarized, the ergonomical analyses that were made with the users are presented, as well as the observation data. Lastly, the questionnaire answers and the co-creation workshop results are presented.

6.1 Expert interviews

A summary of the insights from the expert interviews can be found below. The answers from the interviews were later compiled into a KJ-analysis which is described more in depth in section 7.1.

6.1.1 Attribute Leader Service

The interview with an Attribute Leader for Service at Volvo Cars resulted in many insights and needs for service of curtain airbag attachments. The interview yielded information about when the curtain airbag needs service and how many times it should be exchangeable. The interviewee emphasized the importance of having a robust third-hand that does not break during the service process. On the other hand, the interviewee pointed out that the third-hand should not be fastened too tightly so that it leads to difficulties when demounting it. Ultimately, the curtain airbag should be durable for more than 15 years after end of production.

6.1.2 Principal Engineer Upper Body Structure

The interview yielded what different hole patterns are possible to manufacture, as well as the different manufacturing methods. Insights were gained about what materials the car body consists of, and which holes works for what material. Furthermore, the interviewee showed where on the car body the curtain airbag holes usually are located and which surrounding holes must be taken into consideration. Ultimately the requirements and preferences about hole shapes from an economical and spatial perspective were covered. At the end of the interview, the interviewee showed a car body storage. A notable observation there was that on one car body, the curtain airbag was removed, but the clips were left in the footprint.

6.1.3 Manufacturing Engineer

The information from this interview was crucial in understanding what needs to be improved with regards to the assembly workers. The interviewee communicated which requirements there are to ensure ergonomic assembly, but also highlighted that the curtain airbag assembly is one of the worst assemblies in the car from an ergonomical perspective. There was emphasis on the importance of a third-hand and that the push-in force should not be too high. Moreover, the interview yielded information about the assembly process: how it works, what the assembly workers do, and the time limits. The concept of poka-yoke was also mentioned, and the importance of preventing errors by design. Furthermore, insights about costs, screw requirements, traceability requirements, tolerances and other technical information was communicated.

6.1.4 Curtain airbag supplier

The main insight from the interview with the curtain airbag supplier was that adjustments to current solutions can be made, but that these adjustments require new tooling, thus adding to costs. They also highlighted that their standardized solutions are optimized and that customizing them could be a disadvantage. The standard solution that the supplier provided seemed to have many benefits. However, this solution poses some challenges with respect to Volvo-specific requirements.

6.1.5 Assembly line workers

The interviews with the assembly line workers were unstructured and conducted simultaneously as the workers assembled the curtain airbag, which made it possible to watch the process and ask questions during it. One additional short interview was conducted with a worker in the break room. These interviews gave important insights about what problems the user actually face in the practical context. The answers of the interviewees were fairly similar, for example that the gas generator was difficult to mount, that the push in forces affected their hands and fingers, and that the Autoliv solution for the XC90 car was the solution with the most problems. Problems with the clip-screw were also discussed, with the main take-aways being that the push-in forces are too high and that the plastic tip on the screws can break and cause issues.

6.2 Observations

Observations were performed at Volvo Cars with the purpose of noticing problems and/or errors that the users themselves might not think about. The result of the observations made are presented below. Observations were made both at the test production and the assembly line. Further analysis of the observations can be found in chapter 7.2.

6.2.1 Test production

One observation was made with the Autoliv hook solution, see Figure 6.1, and another one was made with an unreleased current VCC project. From these observations, several issues were identified. One of the most prominent issues was the difficulty of inserting the gas generator. This task required the simultaneous alignment of two hooks. Limited visibility, often obstructed by the gas generator itself, complicated the hook alignment, as it made it hard to see the mounting footprint clearly. Moreover, the workers had difficulties inserting the cable into the gas generator without a flashlight.

Another common problem involved aligning the screw with its designated hole. On the one hand, this was caused by the screw sitting loosely on its curtain airbag hanger, making precise alignment difficult. A second cause was the third-hands sitting too loosely in its footprint. The hook could be difficult to insert and pull down into the keyhole-shape hole, because the hook is fairly short. It sometimes sat too loosely and spontaneously detached, requiring readjustment.

From an ergonomic perspective, some problems were identified. One problem was that the workers had to twist their body in a way that is not ergonomic to reach inside the car body. Another problem was that the force from the screwdriver was high and therefore the workers have to push on top of the screwdriver head. Furthermore, it was observed that the tether at the end of the curtain airbag dangled and got caught on cabling and other parts in the car body.

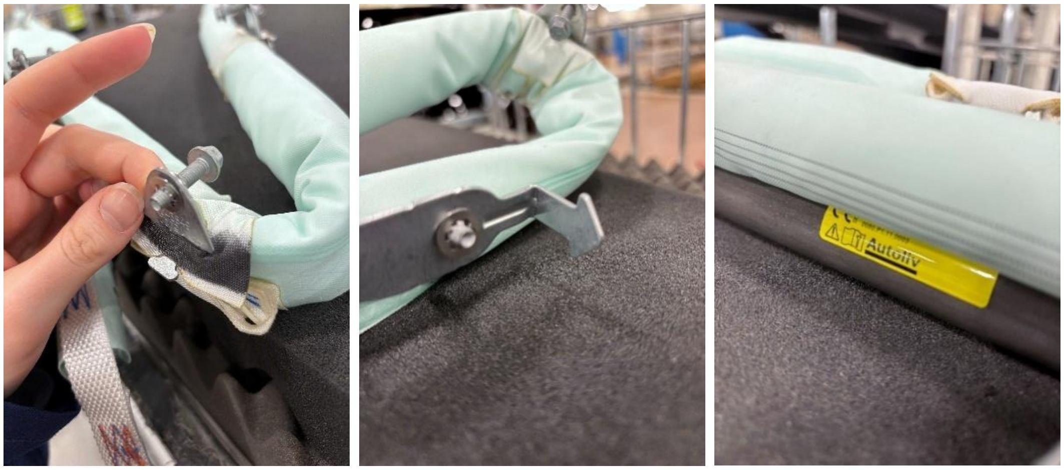


Figure 6.1: *Pictures of the Autoliv hook solution from the observation for EX90. Pictures taken by the authors.*

6.2.2 Assembly line

The observations that were performed at the assembly line yielded similar results as the observations from the test production, with the difference that there was higher time pressure. The solution that was looked at here was the clip-screw. The assembly line workers were observed during the assembly of the curtain airbag, and some questions were asked to the experienced workers that could mount the curtain airbag simultaneously. A major difference with this observation compared to the test production observations was that the assembly line workers mounted the curtain airbag from the outside of the car, i.e. blind assembly, instead of doing it from the inside. They stood outside of the car body and put the curtain airbag through the windows, then they moved it up to the cantrail and inserted it with their arms through the windows.

Similarly to the test production observations, the assembly line workers had difficulties inserting the gas generator. They stated that the gas generator with one structural hook and one clip-screw was easier to insert than the bracket with two hooks. Additionally, the operators mentioned that the gas generator could pop out and they had to push it in a second time. During the assembly, the strap at the end of the curtain airbag could move a lot. Because of this, the operators chose to mount the strap buckle before the fixations in the front, which deviates from the instructions, in order to prevent damaging the car body's paint. Regarding the third-hand, there were some difficulties with its insertion because of various reasons, for example: hindrance from foam in the car body, challenges with regards to varying angles, inability to see the hole because of blind assembly, and difficulties aligning the third-hand with the hole.

From an ergonomic perspective, the blind assembly is more beneficial than the assembly at the test production because the operator does not have to work with their arms over their head. However, the current fixations that are in use have a higher push-in force than desired. The operators mentioned that their fingers are hurting because of this, especially when they just started their job. Other than that, some observations were made that the operators had to twist their torso to reach certain spots within the car body.

A hierarchical task analysis (HTA) was made to break the process down into different tasks, the HTA can be seen in Figure 6.2.

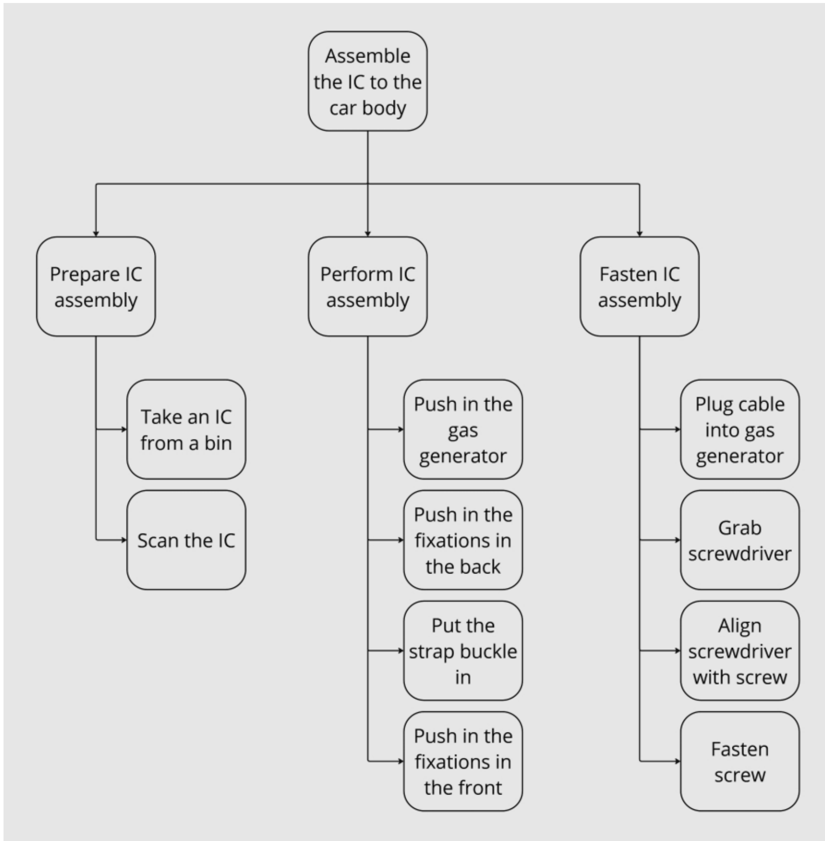


Figure 6.2: HTA that breaks down the curtain airbag (IC) assembly process.

6.3 Ergonomic analysis

To better understand the problems that the users face, two different ergonomical analyses were conducted. A NASA-TLX was performed to gain an understanding of the cognitive and physical demands of the user during curtain airbag assembly. The RULA method was used to further analyze the physical strain of the upper body.

6.3.1 NASA Task Load Index

The results from the NASA-TLX are presented below. Participant 1 performed the analysis with assembly at the test production in mind, while participant 2 performed the analysis with their experience from the assembly line in mind.

Participant 1

Participant 1 has been working at the test production for a little while and has some experience with mounting the curtain airbag. While filling in the NASA-TLX, they shared their reflections upon the questions. Regarding the mental demand, they stated that a bit of thinking is required. When problems arise, decisions need to be made, and solutions need to found. The physical demand is fairly high because of working with arms above heart-height, a position that can cause strain. As only two cars are manufactured per day at the test production, no time pressure or temporal demand is experienced. Participant 1 expressed that frustration arises when something goes wrong, as seen in Figure 6.3, where the attribute frustration has the highest demand. Overall, participant 1's perceived level of workload received a score of 47,7. This score is considered as a somewhat high workload (Prabaswari et al., 2019).

	Rating	Tally	Weight
Mental Demand	30	4	0.2666666666666666
Physical Demand	50	2	0.1333333333333333
Temporal Demand	10	0	0
Performance	20	1	0.0666666666666667
Effort	50	3	0.2
Frustration	65	5	0.3333333333333333

Overall = 47.666666666666664

Figure 6.3: The results from the NASA-TLX performed with participant 1 focusing on the test production.

Participant 2

The second participant worked at the assembly line for 15 years before starting at the test production. During the NASA-TLX, they performed the method with their experience from the assembly line in mind. Participant 2 stated that the mental workload is a little high because you have to think about the process and remember things. Similarly to participant 1, they thought that there is a physical demand because of the arm position and working with the arms over the head. Furthermore, the temporal demand is very high on the assembly line, because of the moving line and only having 57 seconds to finish the curtain airbag assembly. Lastly, participant 2 stated that it is not difficult to succeed, but that it is not easy either. It was expressed that the assembly takes a bit of effort, but that they experience low frustration. The overall score for the perceived workload level of participant 2 is 68,7 which is considered a high workload (Prabaswari et al., 2019).

	Rating	Tally	Weight
Mental Demand	70	2	0.1333333333333333
Physical Demand	75	3	0.2
Temporal Demand	90	5	0.3333333333333333
Performance	40	2	0.1333333333333333
Effort	45	3	0.2
Frustration	25	0	0

Overall = 68.66666666666667

Figure 6.4: The results from the NASA-TLX performed with participant 2 focusing on assembly at the assembly line.

When comparing the two different results, it is apparent that the temporal demand is substantially higher at the assembly line compared to the test production. However, there is also a difference in how much frustration the participants feel. This can possibly be explained by differences in level of experience with the assembly between participant 1 and 2. The conclusion from these results is that the curtain airbag assembly has a somewhat high to high workload depending on where the work is performed.

6.3.2 RULA template

To get a deeper understanding of the working position and physical demand of the assembly workers, a RULA analysis was performed. Observations were made at the test production facility, where there was enough time to observe the positions of the upper body. The analyses yielded that the position of the upper arms is critical since they are located above the operator's head and the lower arm is bent. Furthermore, the wrist positions are not ideal since the wrist is bent from the midline and can also be twisted. The force put on the arms is around 2 kg. When it comes to the neck and trunk, the analysis showed that the neck is bent, and that the trunk can be bent and twisted. Overall, the RULA score for both the left and right sides of the body was 7, on a scale of 1 to 7, indicating the lowest level of ergonomics. The entirety of the RULA scoresheet can be found in Appendix C. Because of confidentiality, no pictures were taken of the worker's position, and all assessment was performed on the spot.

6.4 Questionnaire

The responses to the questionnaire were few, though they did offer a channel for less experienced assembly line workers as they could not answer our questions on the assembly line. There are around eight workers that mount the curtain airbag and five replies were collected. The five replies that did come in were gathered between the 21st of February and 11th of March.

The results showed that 20% of respondents have worked at the assembly line less than a year, 40% have worked for 1-5 years, and 40% have worked 5-10 years as seen in Figure 6.5. The workers had varying experiences, with four people answering that they do it automatically and one person answering that they are just learning how to do it. The respondents have used the metal hook and screw solution as well as the clip-crew solution, which is the current one used in the Torslanda plant. Furthermore, the questionnaire showed that everyone uses blind assembly, mainly because it is more comfortable physically and because it is common practice at the Torslanda plant.

Regarding ergonomics, the majority of the assembly workers answered that the assembly is most physically demanding on the hands and fingers, see Figure 6.6. Additionally, most of them (3 out of 5) use gloves. The most physically demanding steps in the assembly process turned out to be assembling the gas generator and fixations. Besides the fixations, the majority think that the gas generator takes a long time to assemble and often causes issues. The question about common issues had an interesting answer that read as follows:

"Sometimes you don't get any feedback (click) when the screw is in position."

All questionnaire answers can be found in Appendix B.2.

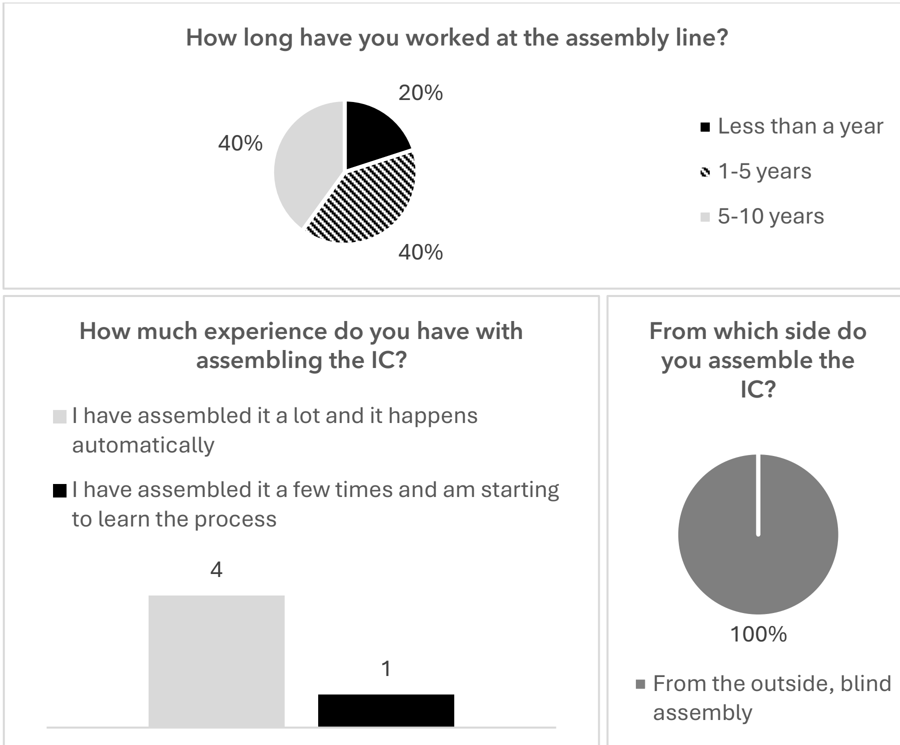


Figure 6.5: Questionnaire results about experience and assembly details.

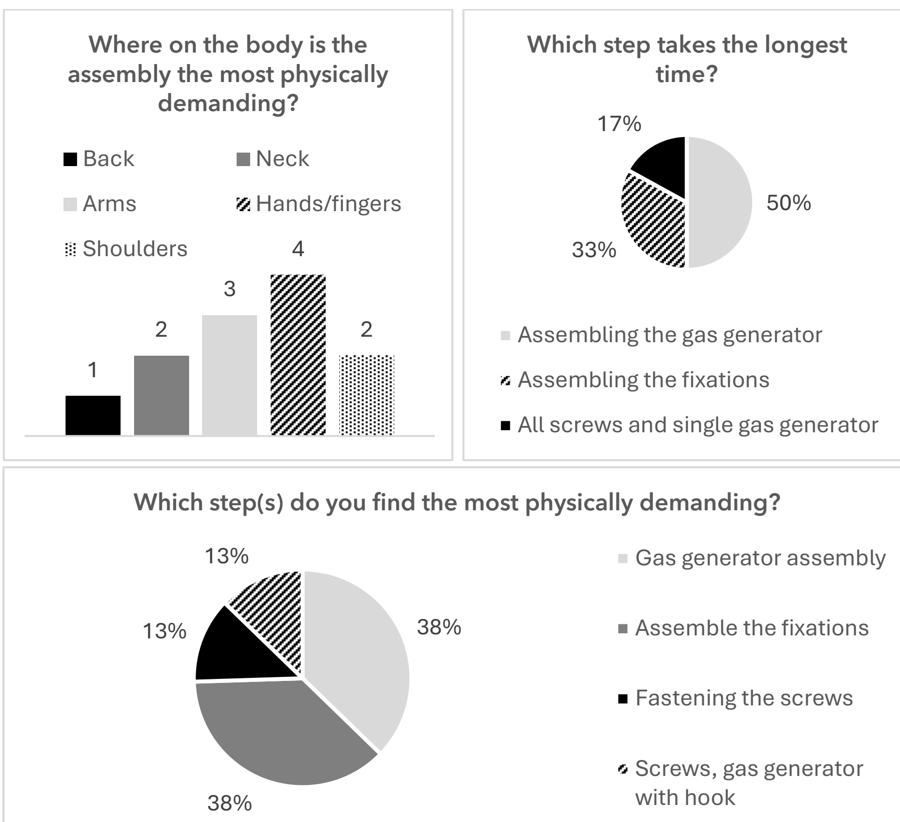


Figure 6.6: Questionnaire results about ergonomics and assembly steps

6.5 Co-creation workshop

The purpose of the co-creation workshop was to leverage the knowledge within the team and as a transition into the idea generation phase. Ten engineers from the department Airbags and Steering Wheels at Volvo Cars attended the workshop to share their insights and knowledge. After the initial icebreaker, the first task that was performed was to brainstorm requirements and write them down on sticky notes. This step confirmed some requirements that had already been thought of, as well as providing some new requirements, for example: low sustainability impact. A summary of the brainstormed requirements and needs can be found in Figures 6.7, 6.8 and 6.9.

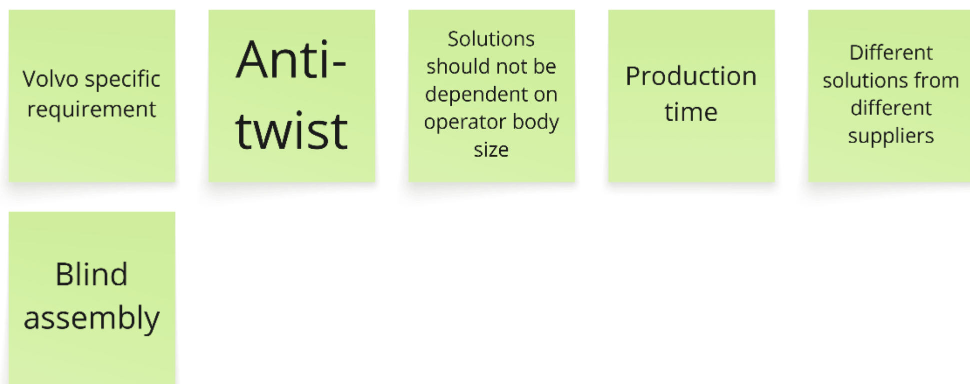


Figure 6.7: *Needs, requirements and open problems brainstormed by team green. "Volvo specific requirement" refers to the stronger requirements on for example ergonomics and traceability that Volvo has compared to other car manufacturers.*

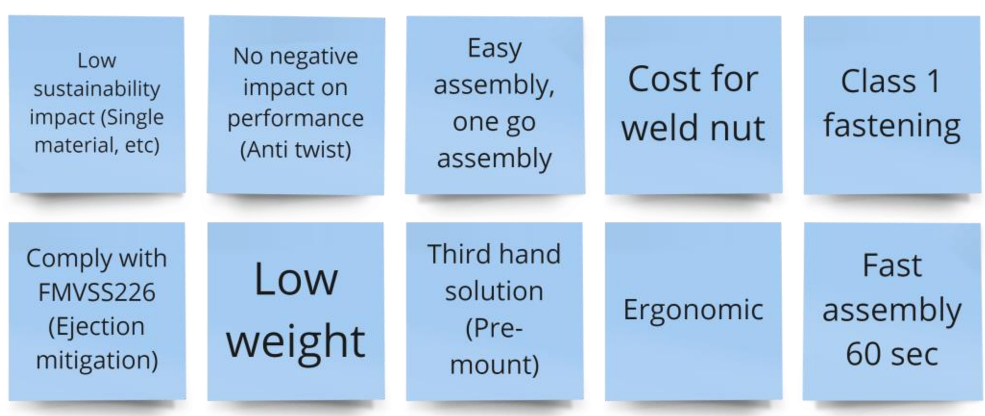


Figure 6.8: Needs, requirements and open problems brainstormed by team blue. "Class 1 fastening" is a requirement at Volvo Cars and refers to that the fastenings must be traceable.

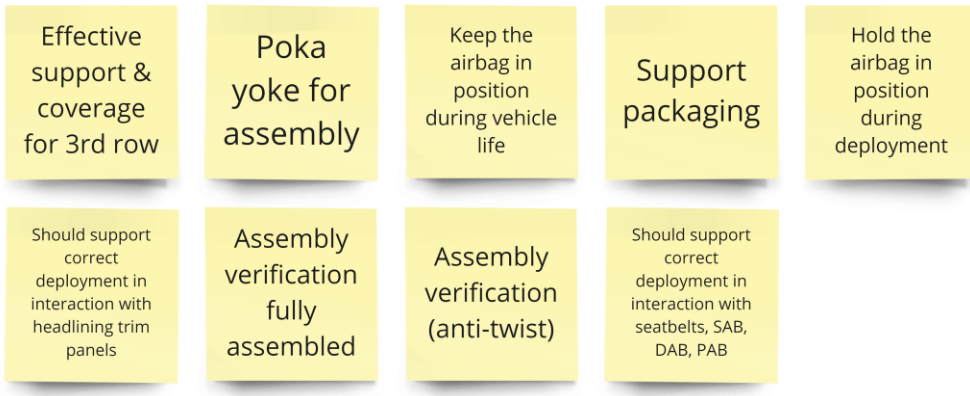


Figure 6.9: Needs, requirements and open problems brainstormed by team yellow. SAB: Side Airbag, DAB: Driver Airbag, PAB: Passenger Airbag.

The next task was for the group to rate the existing solutions, see Figure 6.10. The results were as follows. Generally, hooks were considered more ergonomic to mount than push-in clips. With regards to sustainability, single material designs were prioritized, and plastic was largely omitted. With regards to costs, simple designs were rated less expensive. Additional factors proposed by the participants included *traceability*, *over-engineering*, *process costs* as opposed to *part costs*, *verified assembly*, *automated assembly*, and *supplier independence*. The latter stresses the advantage of having a clip or a third-hand integrated in the screw.

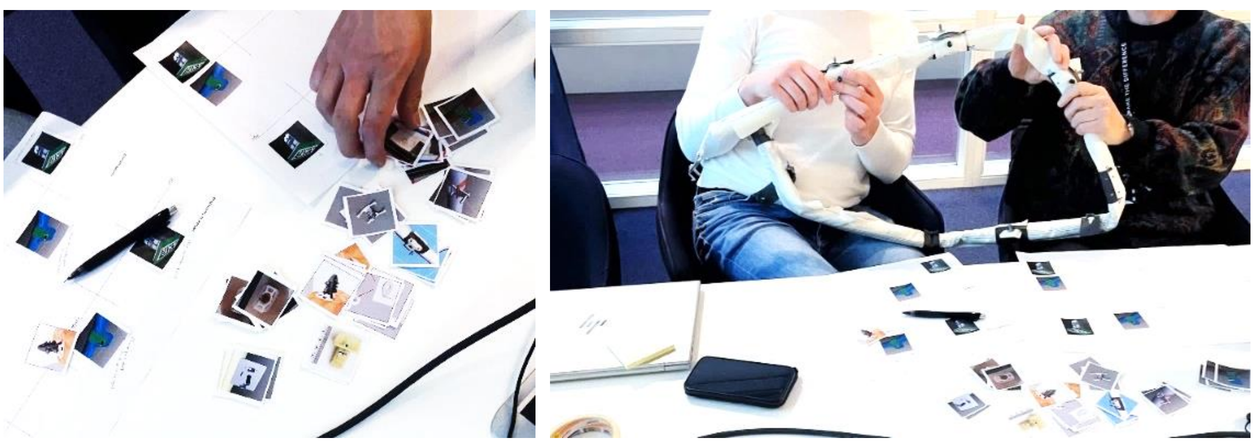


Figure 6.10: Rating the existing solutions.

After rating the current solutions, the groups selected some of their sticky notes with requirements and needs that they previously wrote down and started to idea generate solutions. The participants made prototypes, sketched, and used materials such as paper, Lego, pens and clay, see Figure 6.11. Ideas included different ways to mount the curtain airbag. Both more conventional solutions and out-of-the box ideas were thought of. Some examples of ideas include fixations based on suction cups, utilizing air pressure, and including rotation. Other ideas include some sort of combined clip and screw solution, and screws with wings at the end to be fastened in the weld nut. The session ended with some discussions, concluding that the suction cup idea was the most creative and out-of-the-box, while the clip and screw combination had the greatest potential to be implemented.

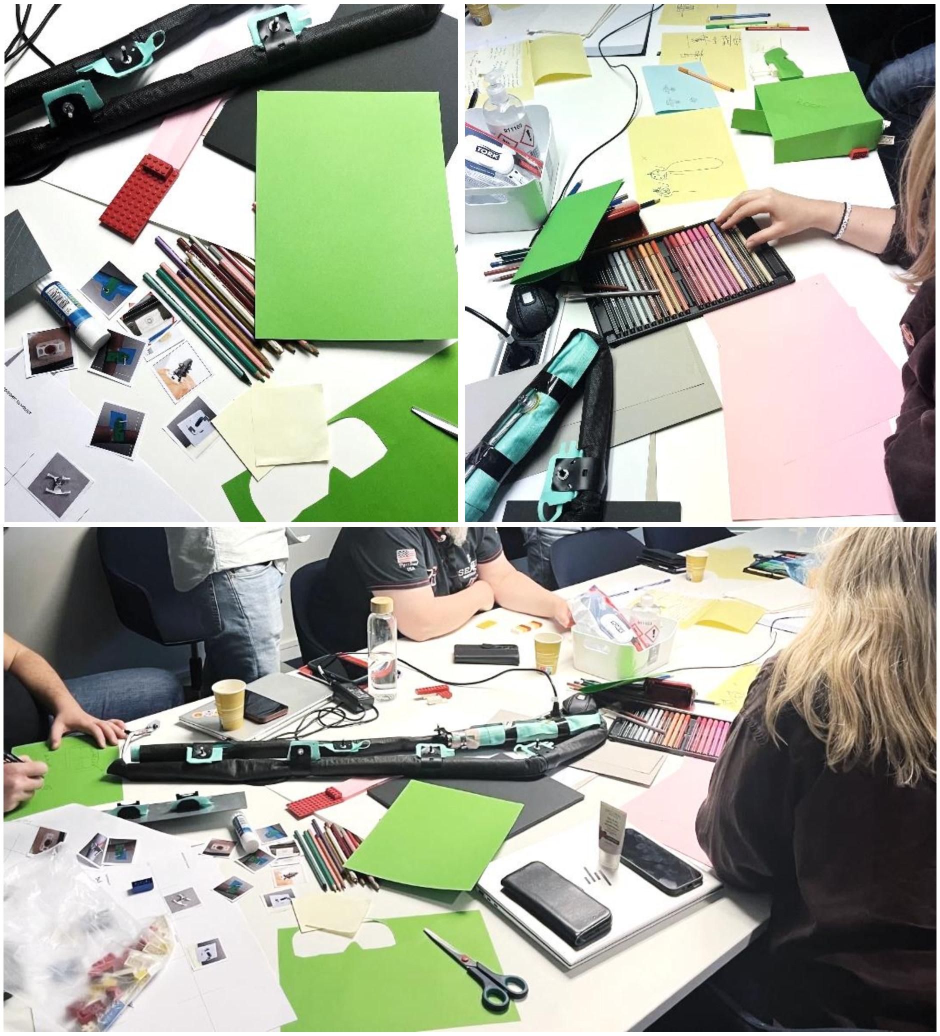


Figure 6.11: Pictures from the co-creation session.

7. Analysis

The results from the analysis phase are presented below. The synthesized data from the KJ analysis is presented first, thereafter the observation templates are shown and lastly, some results from the list of requirements are presented.

7.1 KJ analysis

The result of the KJ analysis is presented below by going through the categories that formed during the method. A description of the interview data that the categories were based on is also provided.

7.1.1 Ergonomics

Physical ergonomics

In the interviews, ME (Manufacturing Engineer), the suppliers, service, and the assembly line workers communicated that the physical ergonomics of the curtain airbag assembly is problematic. The reason for this is that the curtain airbag is assembled above the operator's head which causes physical strain for the arms. According to ME, everything that is mounted onto the ceiling is a red zone immediately. However, at the Torslanda plant, the workers work around this by mounting the curtain airbag from the outside of the car. But even if this method improves the ergonomics, it poses challenges with regards blind assembly, which means that the workers cannot see the footprint in the car body and have to mount the curtain airbag by feeling. The assembly workers mentioned that the assembly causes strain on the arms and neck. ME also mentioned that the inflatable curtain (IC) is the worst assembly in the car.

"The IC is our worst assembly in the car." - Manufacturing Engineer

Push-in force

Another problem that was mentioned was the push-in force. According to ME, it is required that the third-hand should not be pushed in with more than 15 N per finger, and that the force ideally should not exceed 20 N overall. However, the problem is that the current solution in production, the clip-screw, has a higher push-in force since it relies on friction to stay in place. The assembly workers communicated that their fingers hurt from pushing in the curtain airbag fixations, especially when they had just started working with the assembly. Meanwhile, the interview with the suppliers yielded that the clips need to be pushed in with around 35 N, which is a too high force according to ME.

Cognitive ergonomics

The cognitive ergonomics were analyzed from the interviews and observations at the test production, as well as from the NASA-TLX method. Key insights revealed that the interface was initially challenging to comprehend, and assembly line workers required time to learn the correct techniques. Reliance on memory and cognitive effort during assembly led to strain and fatigue. Observations from the assembly line highlighted significant time pressure, as workers needed to mount the curtain airbag within 57 seconds. This was also confirmed by the ME interview.

"It takes some time to learn [the assembly] but you learn in the end." – Assembly line worker

7.1.2 Assembly

Context

When it comes to the assembly, some problems were discovered. There are many cables located close to the curtain airbag assembly, so the workers have to be careful not to interfere with the cabling. The cabling is also one of the reasons why magnets are not preferable, along with the fact that metal dust can get stuck to the magnets and make a mess. Observations during the visit to the assembly line yielded that some workers wear gloves when assembling, which means that the design of the fixations should take into account the use of gloves.

Third-hand

The third-hand that is currently used in the Torslanda plant is the clip-screw. When talking to the assembly workers about this solution, they stated that the plastic tip could sometimes arrive broken, which made it challenging to insert into the car body. Additionally, as mentioned before, the clip-screw has too high push-in forces, which results in pain in the fingers for the assembly line workers.

"[Hard] to push in the screws on all models." – Assembly line worker

Gas generator

According to the assembly line workers, the most difficult part to assemble is the gas generator. The gas generator is what takes the most time and can be tricky to insert into the footprint depending on how it looks. The interface that consists of two hooks that has to be inserted into the car body at the same time was the one that was considered the worst, while the interface with one hook and one third-hand was considered better and easier to assemble. It was stated that the gas generator is positioned above the rear door for ergonomical reasons, and this should remain the same in future designs. According to ME, a 6 mm distance between the gas generator and BiW should be ensured to allow for comfortable assembly and the hooks cannot clash with other geometry as the gas generator slides into place.

"Make all IC curtains like the design of the XC60/V60. Easy, brilliant. The XC90 is not as good." – Survey respondent (Assembly line worker)

Strap buckle

The most crucial problem discovered with the strap buckle was that the long strap moves around a lot, which means that there is a risk that the metal strap buckle can damage the paint on the car. Because of this, the workers mounted the strap buckle before the fixations in the front. This is not how it is supposed to be done according to ME. The order in which the assembly should be done is by first mounting the gas generator, then the fixations in the back, followed by the fixations in the front, and lastly the strap buckle.

7.1.3 Errors

During the assembly, there are several errors that can occur. The fixations can be inserted the wrong way, the curtain airbag can be twisted, and the screws can be fastened at a wrong angle. If the operator fails to hook in one hook and continues with the rest of the fixations, they have to demount everything and assemble it again. When it comes to errors, it is very important to have poka-yoke integrated by design according to ME. This means that the parts are designed in a way that it is not possible to assemble them incorrectly. At the Torslanda plant it is of special importance that the fixations are mounted correctly despite of blindly assembling them.

"If it is possible to make a mistake, people will make a mistake, it is only a matter of time." – Manufacturing Engineer

7.1.4 Existing solutions

Metal clips

The metal clips act as a third-hand and permanent fastener in one. However, there are some problems with the metal clips from a Volvo perspective. According to ME, the metal clips require a too high push-in force. The requirement for push-in force at Volvo is that it cannot supersede 30 N for pushing with two fingers, which can also be translated to 15 N per finger. The metal clip however has to be pushed in with around 40 N and only about two fingers fit on the surface area. Another challenge with the metal clips is the traceability aspect. At Volvo, correct assembly is logged with special screwdrivers and since the metal clips are not fastened with a screwdriver, the traceability aspect becomes complicated. Furthermore, the clips have to be removed with pliers which is negative from a service perspective, since it is not preferable to have pliers close to cabling.

"Oh, we don't like that, I can tell you. […] We have cabling running along there as well, and using tools and pliers in this area against an IC is not favorable" – Attribute Leader Service

Clip-screw

During the observations at the assembly line, the current fixations were analyzed. The clip-crews that are used work in practice, but there are a few disadvantages. After talking to the assembly line workers, it turns out that some of them experience pain in their fingers by inserting the screws because of the high push-in force. They also experienced that the plastic tip at the end of the screws could come broken, which complicated the assembly process.

Hooks

During the data collection, only one type of hook was studied. The Autoliv fixation which consists of a screw and a hook sticking out underneath it. The discovered problems were that the hook was short which resulted in the fixation being hard to assemble, and the third-hand was too loose which made it pop out of the footprint. Other than that, screw alignment is important to consider, as the screw ends up misaligned if the hook is not inserted all the way into its footprint. The screw can also complicate insertion as it sticks out and may interfere with the car body before aligning with its hole in the footprint.

Tree third-hand

The tree third-hand observed on the Tesla solution has some benefits but also some drawbacks. Benefits include that there is a low push-in force and good traceability since a screw is involved. The serviceability is also good because the third-hand does not sit too tightly. However, since the third-hand sits loosely, there is risk that it moves out a bit before the screw is fastened. Additionally, the screw alignment might not be optimal. Another important aspect to consider is that the footprint for the tree third-hand has two holes in a vertical direction. This means that the footprint will not fit on small areas of the cantrail.

7.1.5 Footprint

The interview with the Principal Engineer at Upper Body Structure provided the information that when there is double sheet metal, the holes on the outer sheet need to be larger than the holes on the inner sheet.

This is so that the holes do not become smaller due to minimal misalignment. However, this can become a problem when there is too little space, for example if there are two holes vertically. Since the holes need to be larger on the outer sheet, it can mean that they do not fit on a small part of the cantrail. In a situation such as this, a unique fixation might have to be developed. This takes both time and is costly, so it is beneficial to avoid this. The Principal Engineer recommended for the holes to not be too close to each other in the areas with double plates. For the gas generator a keyhole shape is preferred.

"So, it can be a bit problematic sometimes when we have double plates. Then we prefer to have the holes a little bit apart from each other." – Principal Engineer Upper Body Structure

7.1.6 Consistency

Something that came up during the interviews was that consistency is important in the design of the fixations. Symmetry is one aspect that can be beneficial to lower costs, among other things. If the footprint is symmetrical across both sides of the car, the holes can be punched with the same tool instead of the need for two different tools. Overall, it is beneficial to be consistent when it comes to the curtain airbag fixations and footprints, as variants can confuse the workers and increase the risk for errors.

"There should be no ifs or buts. If it gets complicated to assemble or disassemble, the risk of errors increases. So, no ifs or buts. Straightforward stuff. Easy." – Attribute Leader Service

7.1.7 Producibility

Because the curtain airbag is dependent on the supplier that produces it, it is important that the fixations and components are producible by said supplier. A problem is that different suppliers work in different materials, for example ZF Lifetec generally works the most with plastic and Autoliv works with metals. This is challenging because in order to standardize the curtain airbag fixations, they need to be producible by different suppliers.

7.1.8 After end of production

An important requirement at Volvo Cars is that certain parts have to be traceable so that the data can be accessed after EOP. There are different ways to achieve this. The torque for the screws can be logged with the screwdriver that fastens them. In case of a clip instead of screw, traceability is achieved with the help of a QR-code that can be scanned only when the clip is assembled correctly. However, the interview with ME made apparent that the QR-code solution may not be optimal. Cameras that automatically scan the codes may have issues when workers stand in front of the codes or lighting is dim. This implies that the cameras need to be checked frequently and possible mistakes should be corrected, which would not be sustainable over time. An alternative could be to have workers scan the codes manually with a scanner, but this would add an extra step to the assembly process, as well as put the workers in non-ergonomic working positions. Furthermore, the interview with the Attribute Leader for Service yielded that the curtain airbag has to be serviceable and exchangeable up to ten times, and last for 15 years after EOP.

7.2 Observation template

To analyze and synthesize the data from the observations, observation templates were used. The observation template shown below was used for the observation at the test production, where the Autoliv hook was observed. The different participants were compiled into a table, see Table 7.1. Then the noted problems, the number of people who had the problem, and the severity were compiled into another table, see Table 7.2. The results include difficulties inserting the gas generator, the strap buckle getting caught in protruding parts in the car, and difficulties inserting the third-hand.

Table 7.1: User profiles

#	*Role*
1	Responsible for station, worker at test production center, worked at the assembly line for many years
2	Worker at test production center
3	Master thesis worker 1
4	Master thesis worker 2

Table 7.2: Observation template

Noted problem	Number of people	Possible cause	Severity
Difficulties inserting the gas generator	IIII (1, 2, 3, 4)	Two hooks that need to go in at the same time, hard to see the holes	2
Not being able to fasten the screws properly	II (3, 4)	Angle is a little off, the screws move outside the hole, the screwdriver is not positioned properly on the screw	3
The hook on the strap getting caught in other things	II (1, 3)	Long strap, the bracket has hooks that gets caught, the strap moves around a lot during fastening	2
Have to strongly pull the IC to the side to get the third-hand in the hole	II (3, 4)	The third-hand not aligned properly; IC has to be taught?	2
The third-hand is too loose, and the screw does not align with the hole when fastening (hanger jumps up)	II (2, 3)	The third-hand is too short, not properly put in the hole from the beginning	3
Twisting body in a way that is not ergonomic	III (1, 3, 4)	The holes cannot be seen from the outside, hard to be inside vehicle, can't reach hole	2

Difficulties reaching the screws with the screwdriver	II (3, 4)	The body is in the way, odd angles, small opening	3
Unsure what to do when the screen shows that the screws are red	II (3, 4)	User has not learned it yet and does not know how to do it	4
Have to put hands on the head of the screwdriver to get enough pressure	I (1)	Hard to get enough pressure when just holding the handle, screws need to be pushed in more	2
Hard to insert the third-hand	IIII (1, 2, 3, 4)	Foam in the way, weird angles, not possible to see the hole, hole is on a sheet that moves, third-hand is not aligned with hole	3
Difficulties inserting the cable into the gas generator	IIII (1, 2, 3, 4)	Dark, cannot see the input, difficult angle to see it, only fits in one way, did not push hard enough	3

The severity scale used is as follows: *0 – no usability problem* (not included because it is not a problem); *1 – cosmetic usability problem* (the user did not notice it was a problem); *2 – minor usability problem* (the user noticed the problem but it did not affect their ability to complete the task); *3 – major usability problem* (the user noticed the problem and it affected their ability to complete the task); and *4 – catastrophic usability problem* (the user gets stuck and cannot complete the task).

7.3 List of requirements

Ultimately, the data from the benchmarking and the data collection that was analyzed resulted in a list of requirements. The complete list of requirements can be found in Appendix D. The list was divided into different categories based on the KJ: *function requirements*; *ergonomics (physical)*; *third-hand*; *gas generator*; *strap buckle*; *context/assembly*; *error-proofing*; *ease of assembly (cognitive ergonomics)*; *consistency in design*; *footprint (BiW)*; *producibility*; *costs*; *sustainability* and *after end of production*.

To illustrate, the first category is shown in Table 7.3. The first category includes requirements of great importance, as it includes the main functions of the solution. With regards to requirement 1.4, fitting a variety of car models can be achieved by being suitable for varying car body thicknesses, varying cantrail angles and sizes, and being producible by different suppliers and the respective materials they work with.

Table 7.3: The function requirements

1. Function requirements	1.1 The solution must keep the airbag in place during its lifetime
	1.2 The solution must keep the airbag in place during deployment
	1.3 The solution must not affect the airbag performance
	1.4 The solution must fit varieties of car models

Essentially, the requirements are about ensuring safe curtain airbag deployment and about standardizing the solution to fit different car models. They summarize the findings of the analysis phase in a concise list. For example, other important requirements include:

- *The push-in force must not exceed 15 N per finger*. This means that when the fixation is pushed into the footprint, the forces have to be lower 15 N per finger, or 30 N for two fingers.
- *A third-hand must be integrated by design*. Which refers to that the curtain airbag must stay in place on the cantrail before the screws are fastened.
- *The assembly must be possible to perform with blind assembly*. Since blind assembly is used at the Torslanda plant, it is important that the solution accommodates that.
- *It must be impossible to incorrectly mount the curtain airbag*. The curtain airbag should not be possible to mount the wrong way around or in the wrong direction for example.
- *The hole(s) should fit on 50 mm in height*. The footprint should not take up too much space in the vertical direction for compatibility reasons.
- *The solution must be producible by different suppliers*. As mentioned, this ensures that the solution is producible regardless of what material the suppliers work in, for compatibility and standardization reasons.
- *The assembly data must be traceable for up to 15 years.* Correct assembly must somehow be logged and saved so that it exists if it needs to be used.

8. Idea generation

The results from the idea generation phase are presented below, including the results from the methods used. First, the ideation results are presented, followed by the prototypes and intermediate concept directions, and lastly the final concept directions are shown and explained.

8.1 Ideation

All resulting sketches from the ideation phase can be found in chronological order in Appendix E. Several idea categories of fixations resulted from the applied techniques as described in section 4.4, as well as ideas for the gas generator bracket and strap buckle. During the categorization, some sketches ended up in more than one category because of combining aspects of either category. The different idea categories are covered during the upcoming sections.

8.1.1 Screw tip ideas

The first category of ideas resulting from the ideation is a redesign of the screw tip of the main screw forming the permanent connection. Some of the ideas focused on a tree-shaped screw tip as depicted in Figure 8.1 shown below.

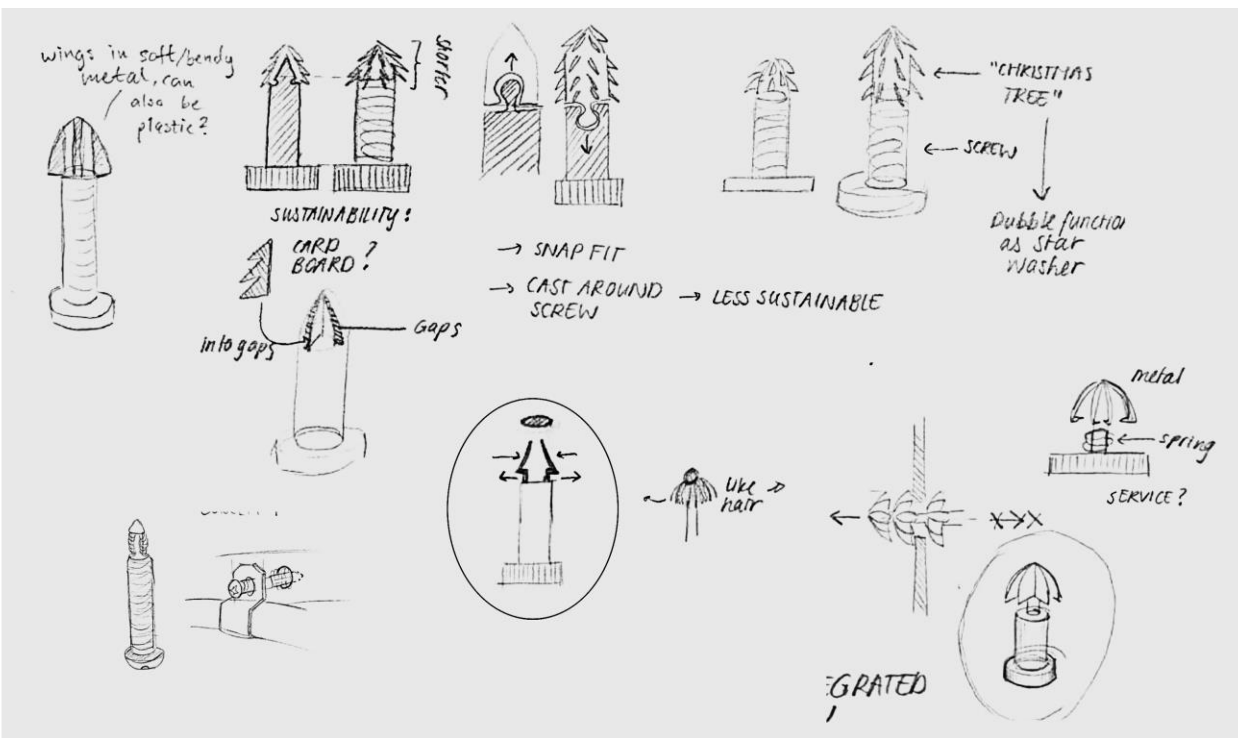


Figure 8.1: Tree on screw ideation.

Alternatively, the screw tip could have some type of anchor-shape to function as a third-hand before the screw is fastened to form the permanent connection, requiring a more complicated footprint and more complex if not impossible interaction with the weld nut. The ideation sketches are shown in Figure 8.2. Another idea is to keep the old clip-screw design and experiment with different materials to optimize push-in forces and sustainability. These sketches are depicted in Figure 8.3. Lastly, other ideation sketches focused on the specific interaction between the screw tip and the weld nut, making use of its form and properties. See Figure 8.4.

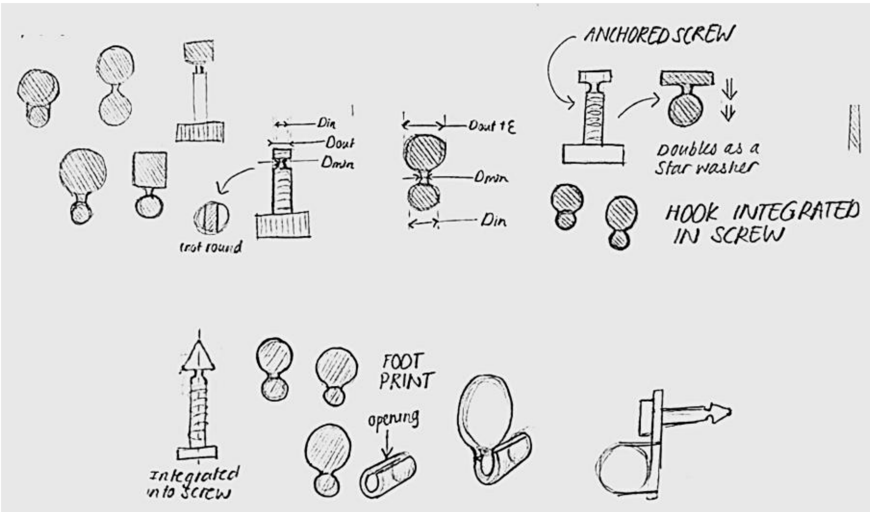


Figure 8.2: Anchor on screw ideation.

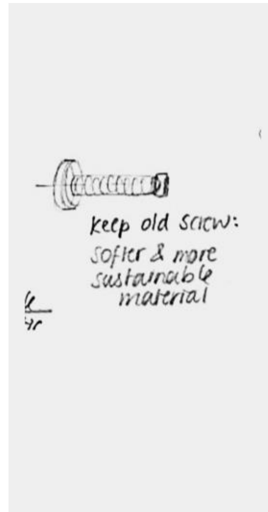


Figure 8.3: Tip on screw ideation

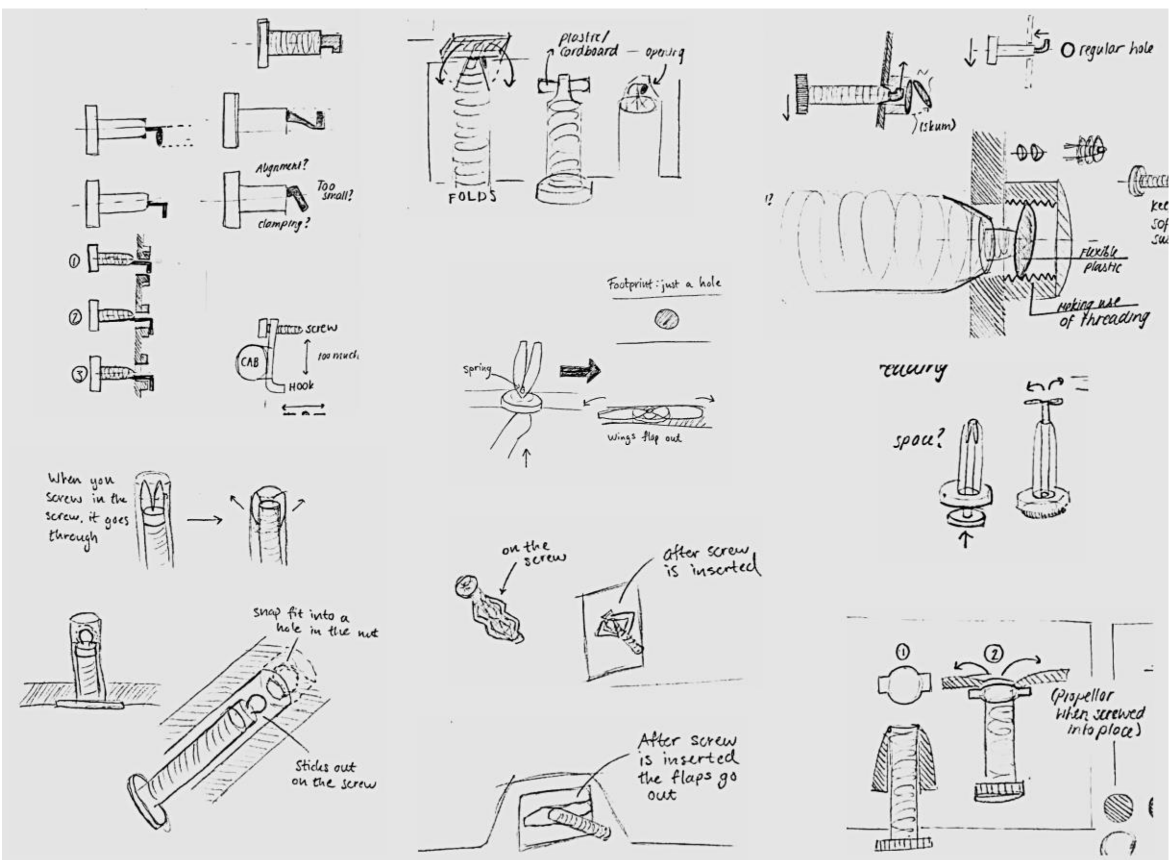


Figure 8.4: Interacting in weld nut ideation.

8.1.2 Two-armed solutions

Another category of ideas resulting from the ideation was ideas with two arms on either side of a screw forming the permanent connection. The ideas can be divided into three groups: clamps, snap-fits and double third-hands. The clamping solutions are depicted in Figure 8.5. Here, the two arms are somewhat tighter than the distance between the two holes, and in that way clamp onto the material. Different materials were considered, such as metal, wood, and (flexible) plastic.

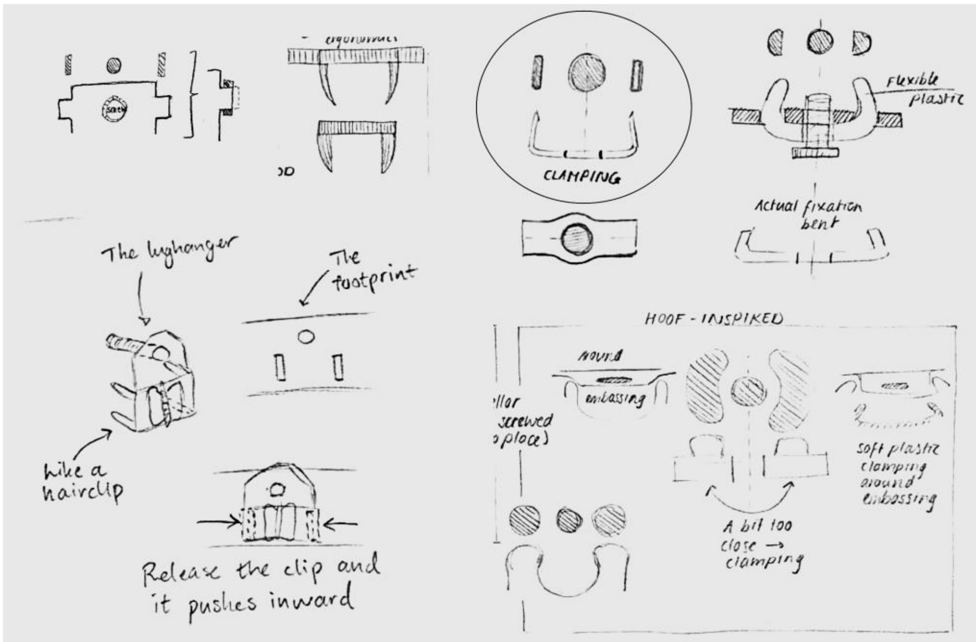


Figure 8.5: Clamping ideation.

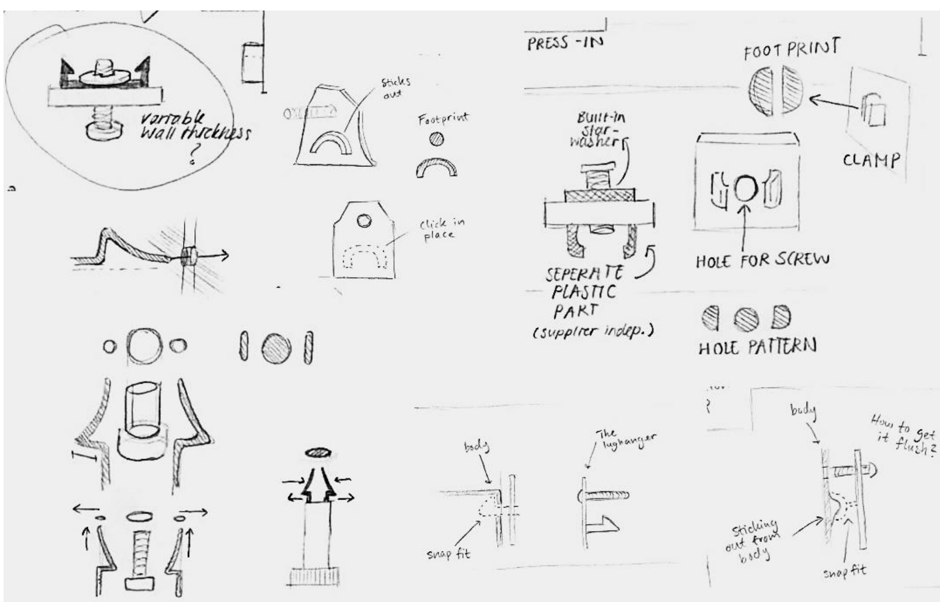


Figure 8.6: Snap-fit ideation.

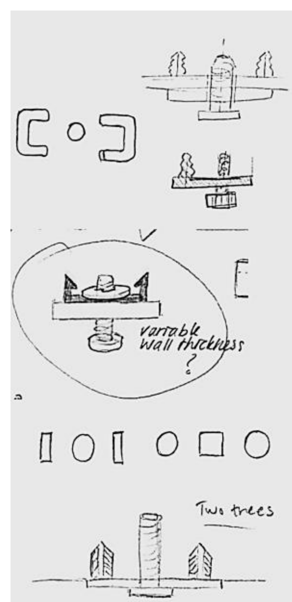


Figure 8.7: Double third-hand ideation.

The snap-fit solutions are similar in function but use a snap-fit form to hold onto the material, thus staying in place because of their form rather than active clamping once the solution is pushed through the holes. See the sketches in Figure 8.6. The last category is double third-hand solutions. The big difference here is that the function of the third-hand does not require two arms. The two arms are solely there for symmetry and alignment purposes. See Figure 8.7.

8.1.3 Hooks

The next category of solutions covers the hook designs. Figure 8.8 depicts general hook designs, consisting of either one or two hooks. Different manufacturing methods and materials are considered, including a thin wooden piece for a more sustainable design. The location of the hook is reconsidered as well, mainly focusing on the impact of moving the hook to above the screw rather than below. If there is sufficient space on the car body and the impact on the assembly require further consideration.

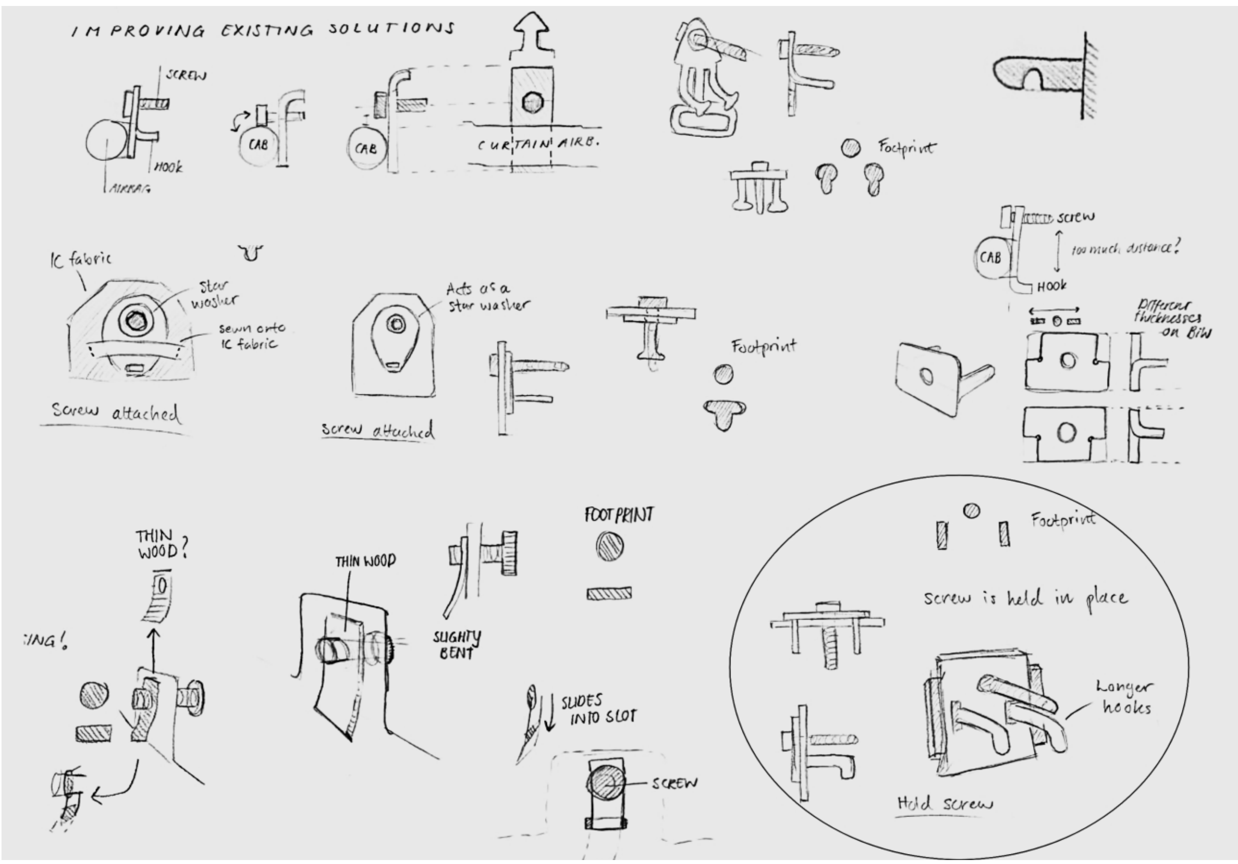


Figure 8.8: Hook(s) ideation.

Figure 8.9 depicts a sideways hook, requiring the fixation to be pulled to the side instead of downwards. Figure 8.10 depicts hooks integrated into the car body. Here, the idea is that the hook is integrated in the shape of the footprint hole, rather than on the fixation of the curtain airbag. This could offer more flexibility in material choice of the hanger and potentially be easier to mount. The complex footprint does however pose a challenge.

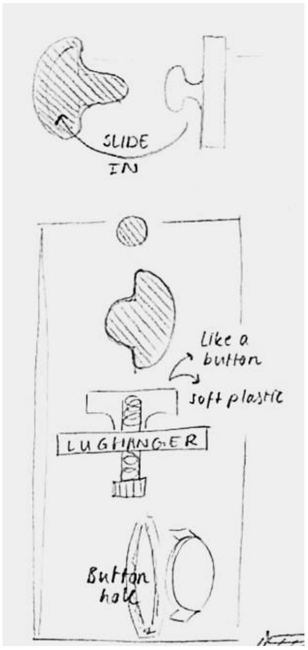


Figure 8.9: Sidewards hook.

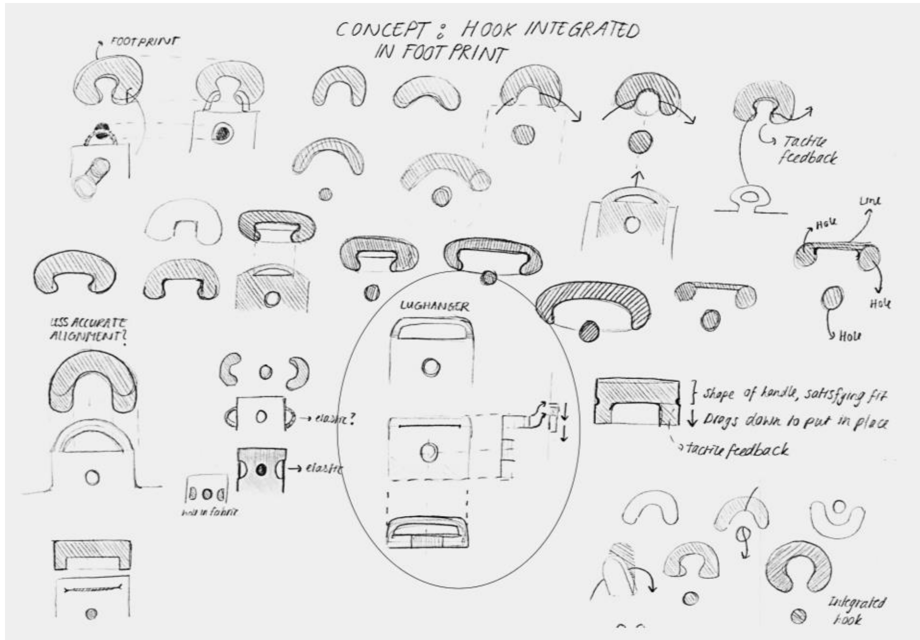


Figure 8.10: Hooks in footprint ideation.

8.1.4 Push-in third-hands

Push-in third-hands rely on a flexible or partially flexible part that holds the fixation in place near the screw. In Figure 8.11, different (tree-shaped) forms are ideated upon. In Figure 8.12, a third-hand around the screw is considered to minimize the number of holes, although it is possible that this will impede the strength of the permanent connection once the screw is being fastened. The last category considers using material elasticity as a way to create a third-hand, see Figure 8.13.

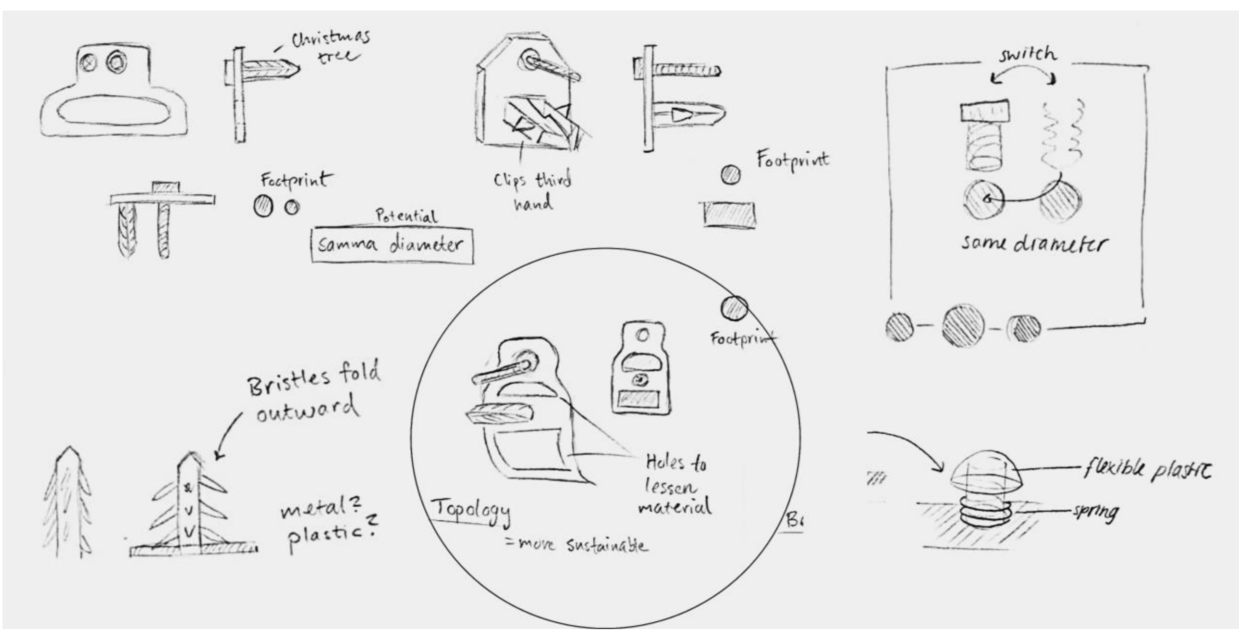


Figure 8.11: Push-in third-hand ideation.

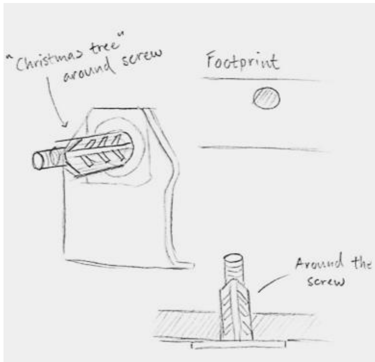


Figure 8.12: Third-hand around screw.

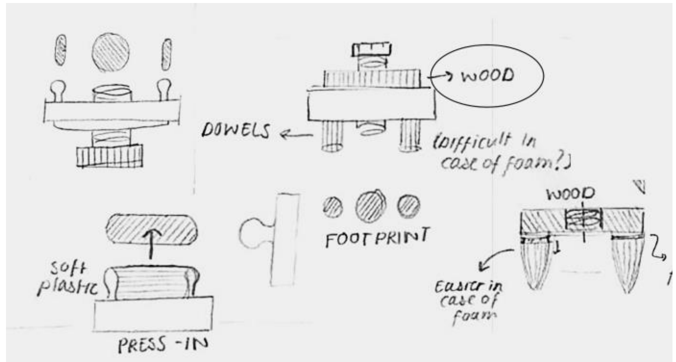


Figure 8.13: Material elasticity ideation.

8.1.5 Clips

The clips category contains solutions that do not require a screw, and rather create the permanent connection at once, without the need of a tool. An existing clip currently used by other car brands is considered in Figure 8.14, where a chip could potentially improve the traceability. More elaborate ideation was performed on two-arm clip solutions, depicted in Figure 8.15. The two arms next to each other allow for solutions to clamp around the remaining sheet metal in between them. Traceability could be ensured through a code only scannable whenever the design is clamped around it. Either a snap hinge or material elasticity could enable this.

Figure 8.14: Clip

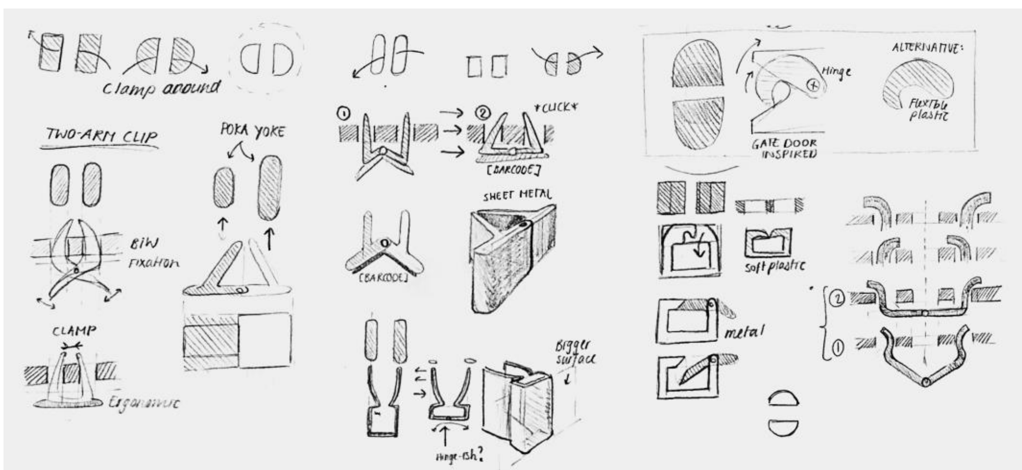


Figure 8.15: Two-arm clip ideation

8.1.6 Star washers

During the ideation, the idea to integrate the star washer into the design was developed as well. The star washer keeps the screw in place during transport and assembly and is relatively costly for its part size (approximately 1 SEK per piece). Building the third-hands onto the star washer also separates it from the rest of the fixation, which can make the solution easier to implement in different designs from different suppliers. See the ideas in Figure 8.16.

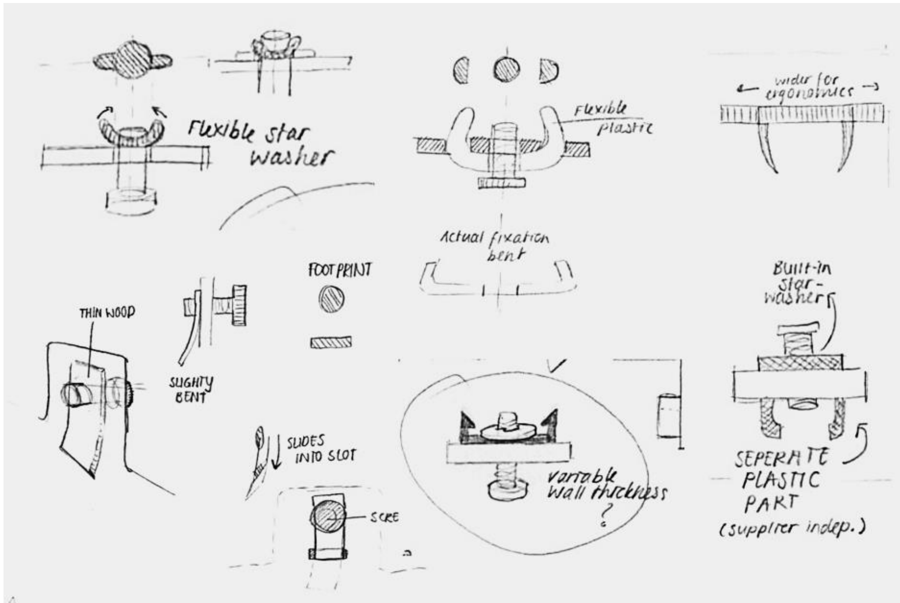


Figure 8.16: Star washer replacements ideation.

8.1.7 Alternative solutions

Entirely different ideas based on more unusual joining methods can be found in figures below. In Figure 8.17, using Velcro or bristles is considered. In Figure 8.18, a third-hand using a suction cup is ideated upon. The ideas pose challenges with regards to alignment and manufacturing but do potentially reduce the number of holes.

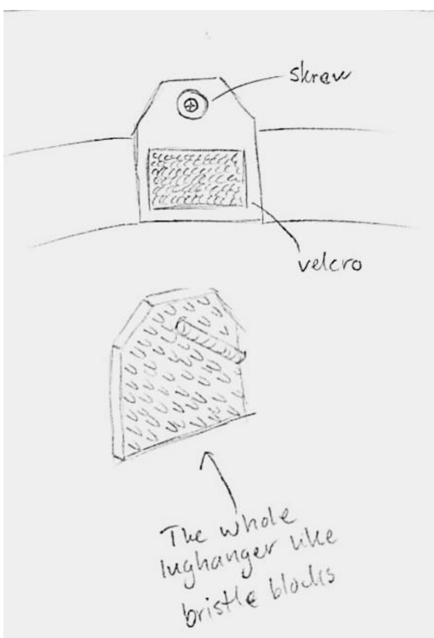


Figure 8.17: Mini-hooks and bristles

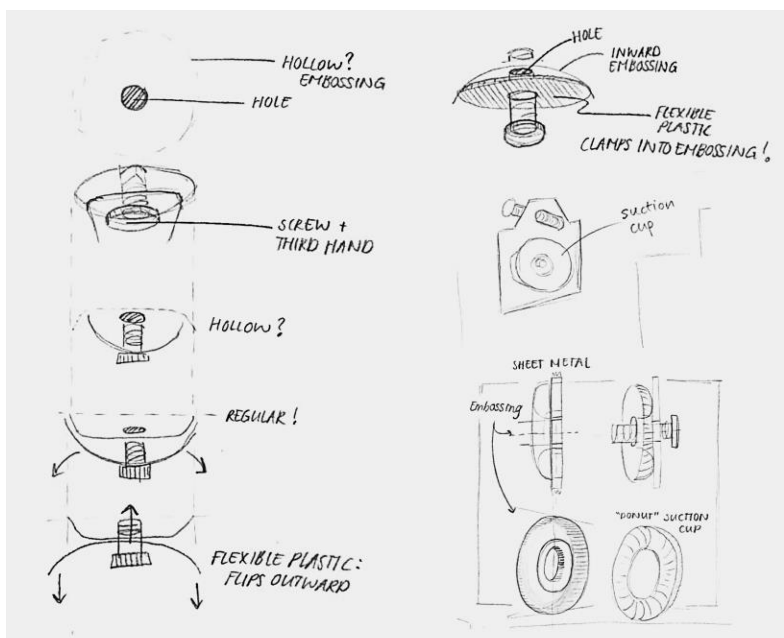


Figure 8.18: Suction cup ideation

8.1.8 Assembly aids

Some ideation on solely making the assembly easier was performed as well. Ergonomic aids were ideated upon, depicted in Figure 8.19, mainly focusing on increasing the push-in area and thus reducing the push-in force per finger. Different embossing designs are depicted in Figure 8.20, aiming to guide blind assembly.

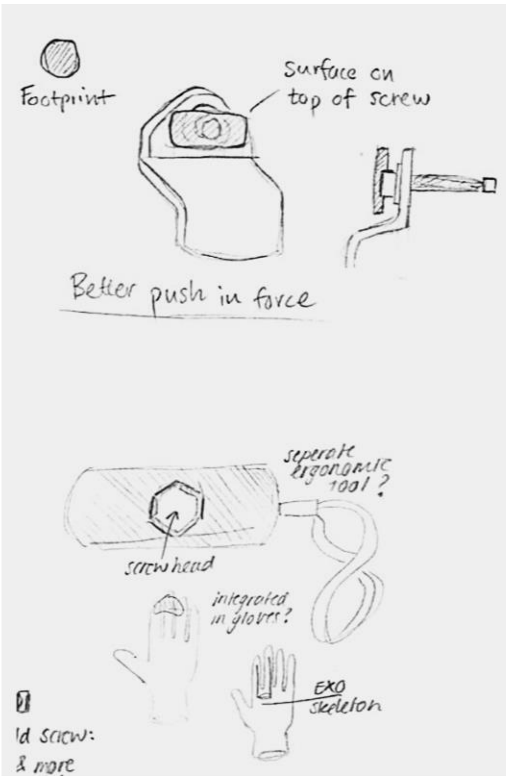


Figure 8.19: Ergonomic tool ideation

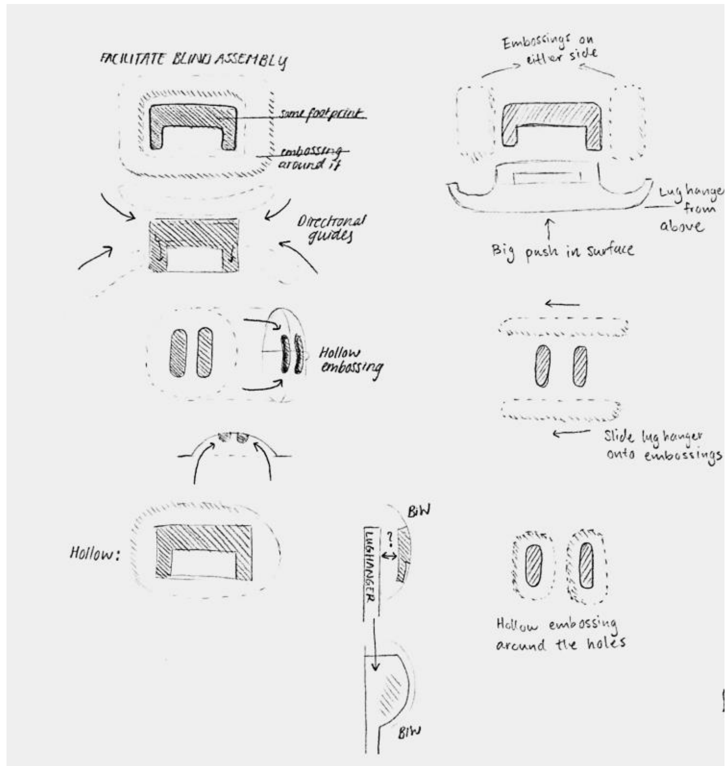


Figure 8.20: Blind assembly guides

8.1.9 Gas generator bracket

The gas generator bracket ideation was performed separately from the fixation ideation. One example of a sketch is shown in Figure 8.21. The sketches mainly focus on challenges resulting from the screw on the right sticking out, and the inaccessibility to the structural hook on the left-hand side, as it is located behind the gas generator. In addition, ease of assembly is aimed to be improved through increased allowance for assembly from various angles. Increasing this allowance is one way to solve the issue of a screw sticking out, as it can simply be assembled at an angle away from the screw. Additionally, local indents on both the bracket and the footprint are proposed. Another idea includes a hinge, and different structural hooks were ideated upon as well, with the goal to reduce friction.

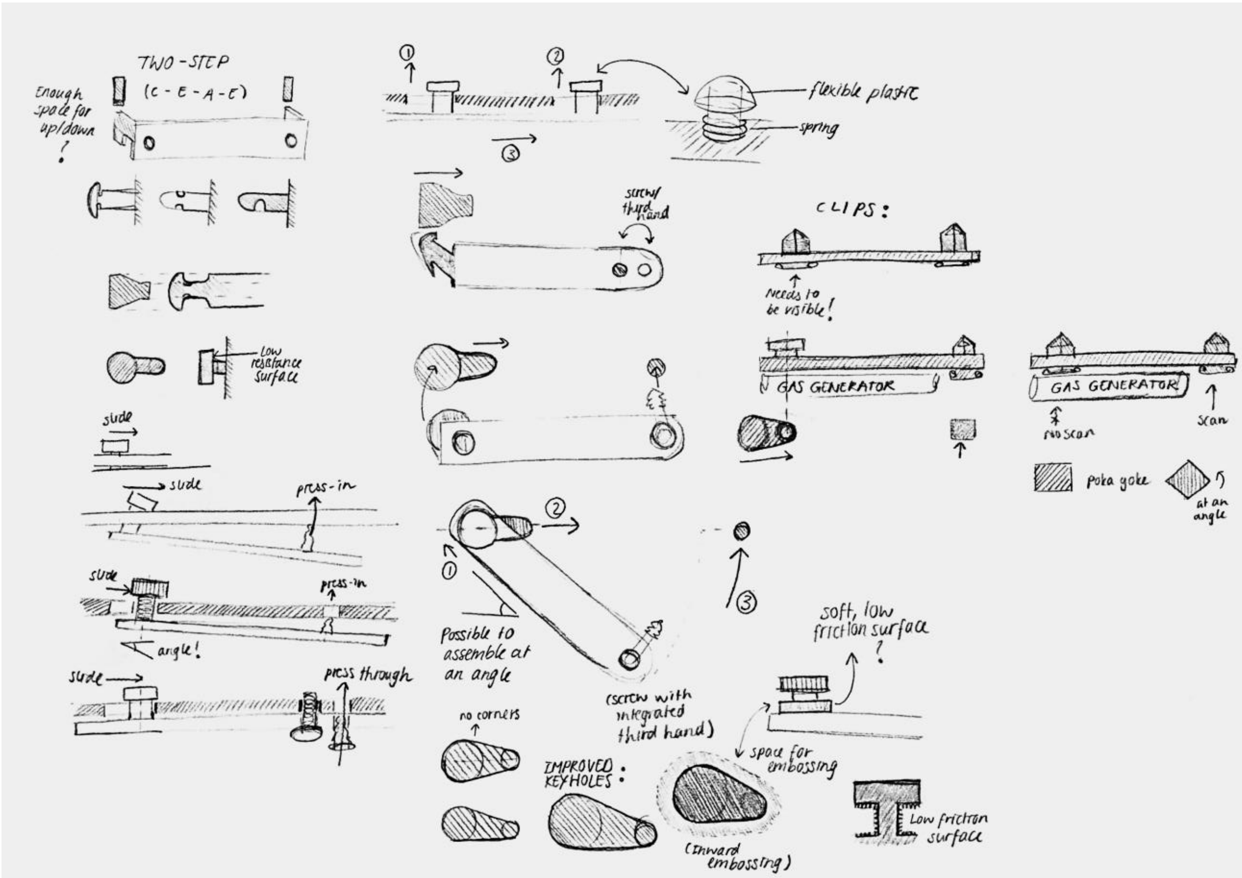


Figure 8.21: Gas generator ideation.

8.1.10 Strap buckle

Lastly, improved solutions for the strap buckle were ideated upon, depicted in Figure 8.22 and 8.23. The main problem identified for the strap buckle is that it dangles freely during assembly, risking damaging the car. Additionally, a single hook on the strap buckle does not always suffice, and sometimes the buckle falls out. This depends on the third-hand solution: if there is a third-hand integrated in the screw, one hook suffices. Without an integrated third-hand, two hooks are required to ensure stability. The ideation focuses on solutions to reduce the dangling of the strap. Different ideas to reduce strap length during assembly are proposed, such as elasticity, folding, and rolling. Temporary attachment to the side of the airbag is also considered.

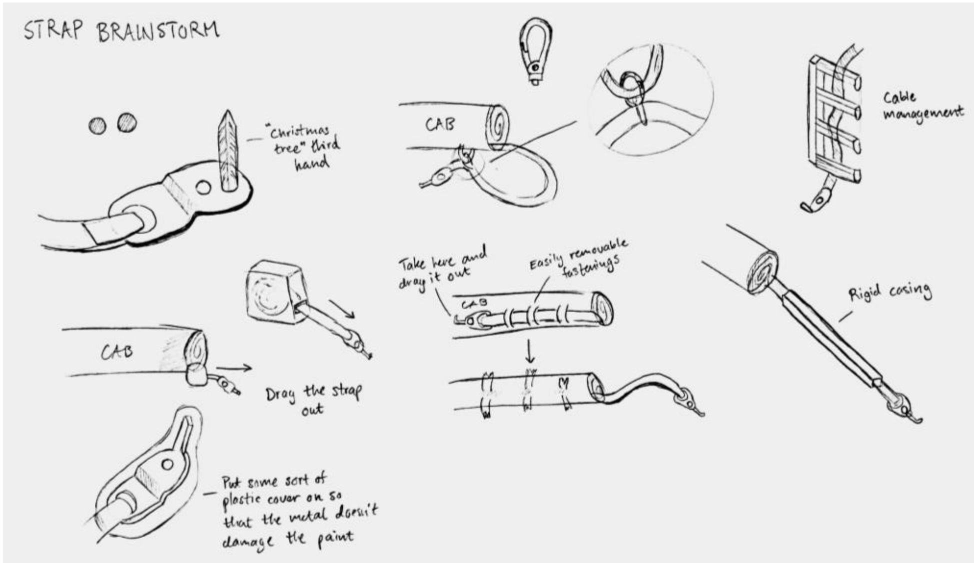


Figure 8.22: General improved strap buckle ideas.

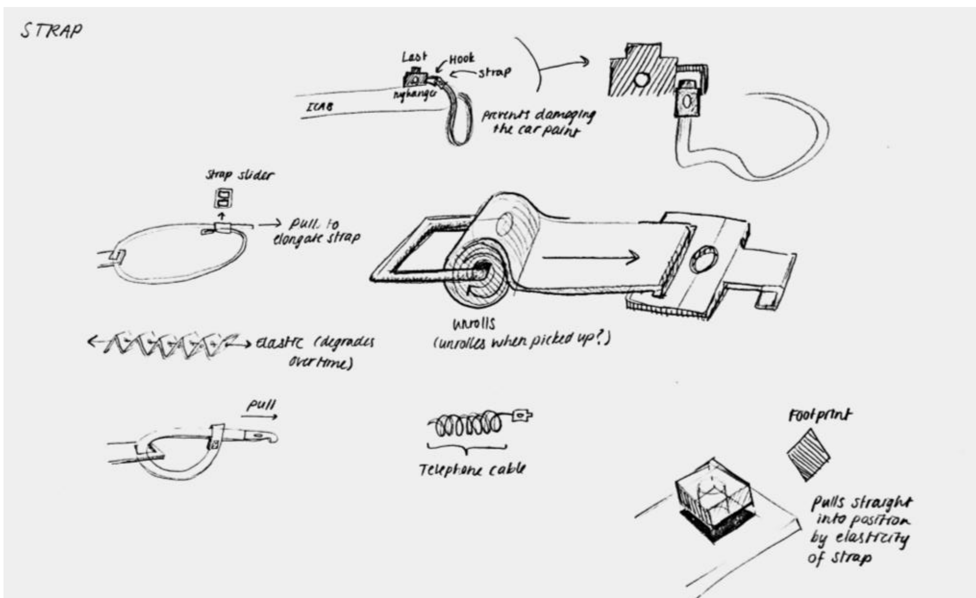


Figure 8.23: Improved strap length for strap buckle.

8.2 Lo-Fi prototypes

After ideation through sketching, lo-fi prototypes were made to test some of the functional aspects of the ideas. All lo-fi prototypes can be found in Appendix F. In the upcoming sections, the most important findings are covered.

In Figure 8.24, some prototypes with third-hands on the screw tip are shown. The main challenge identified was its scale and interactions with the weld nut.

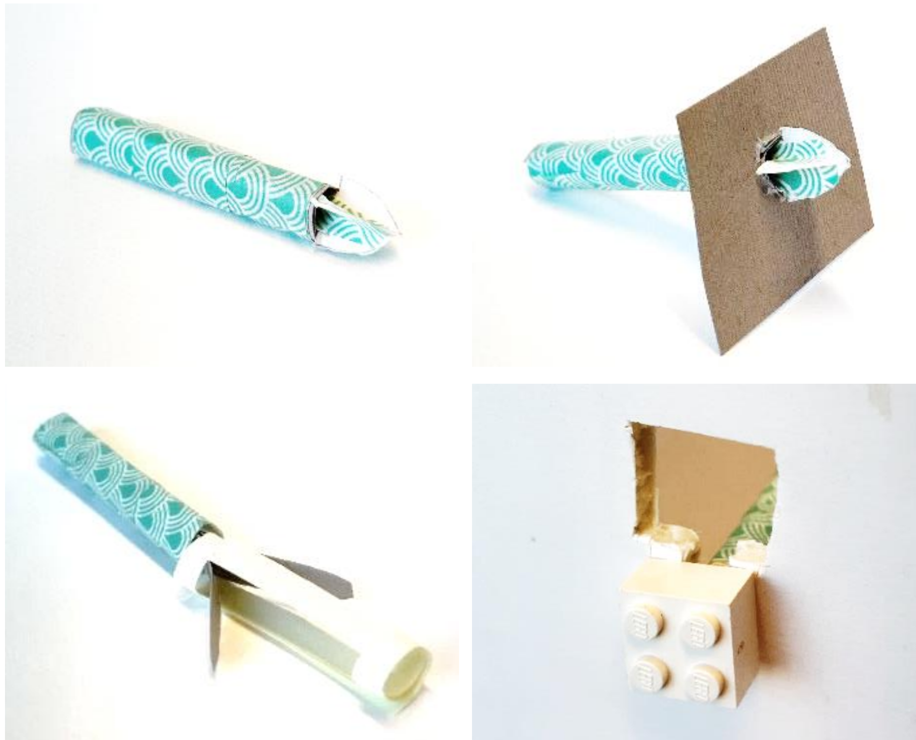


Figure 8.24: On screw tip.

During the lo-fi prototyping of the clamp, different clamp shapes and sizes were tested. Especially its effect on footprint hole size became apparent. Also potential issues with regards to serviceability were identified, since snap-fits can only be inserted in one direction and are difficult to remove when pulled in the opposite direction. Lastly, the prototyping also gave insight into potential manufacturing techniques. See Figure 8.25.

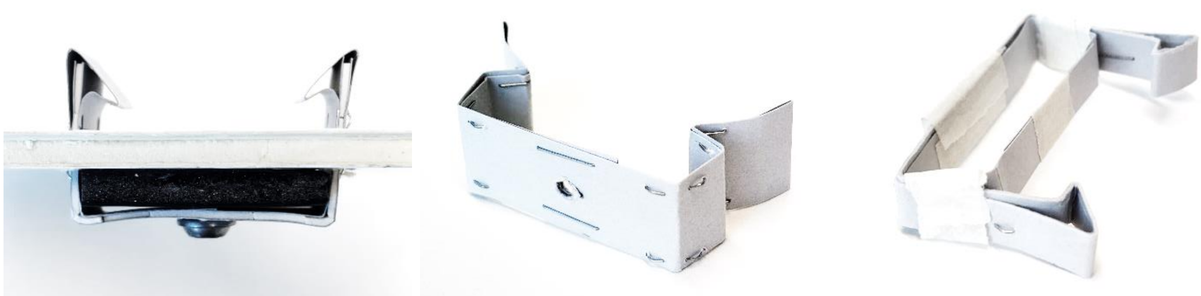


Figure 8.25: Clamping prototypes.

When prototyping different hooks, the amount of space needed to place the hook above the screw became apparent. It was concluded that a hook above the screw would not work because of this. The influence on footprint size was explored here as well. See Figure 8.26.

Figure 8.26: Hook prototypes.

The snap-fit clip was prototyped as well. Here, the challenges with regards to service are of even greater importance, as the permanent clip needs to sit a lot more strongly. This would likely make it impossible to remove for service. See Figure 8.27.

Figure 8.27: Snap-fit clip prototype.

Lastly, a prototype of a third-hand with a hinge was made. The idea turned out difficult to assemble. See Figure 8.28.

Figure 8.28: Hinge third-hand prototype.

8.3 Intermediate concept directions

A reiteration of the ideas from the sketch-KJ and prototypes resulted in eleven intermediate concept directions for the fixations. Those include o*n screw tip*, *clamp snap-fit*, *two-arm clip*, *improve (double) hook*, *footprint hook*, *improved tree*, *integrated in weld nut*, *rotation*, *ergonomics, improved hook,* and *wood/cork concept*.

The ideas concerning a redesigned screw tip were grouped as one initial direction. The symmetric clamp or snap-fit third-hand was chosen as a second concept direction, and a two-arm clip as the third. A new idea combining the snap-fit and the two-arm clip arose as well. Several ideas to improve the (double) hook were chosen as a direction, including the idea to integrate it into the star washer. The footprint hook was also chosen as one of the directions.

Additionally, ideas to improve the tree third-hand were grouped. Because of limited space on the car body, the idea was that placing the third-hand beside the screw hole horizontally is preferable. It would be manufactured as a separate piece that can be turned so no new tooling is required to mirror the design to the other side.

A new idea integrating the third-hand into the weld nut emerged after reconsideration of the ideas, see also Figure 8.29. The idea behind the design is similar to a dish cloth holder or zip tie. The small scale of the design may be challenging, but it would be supplier independent and not require any special screw.

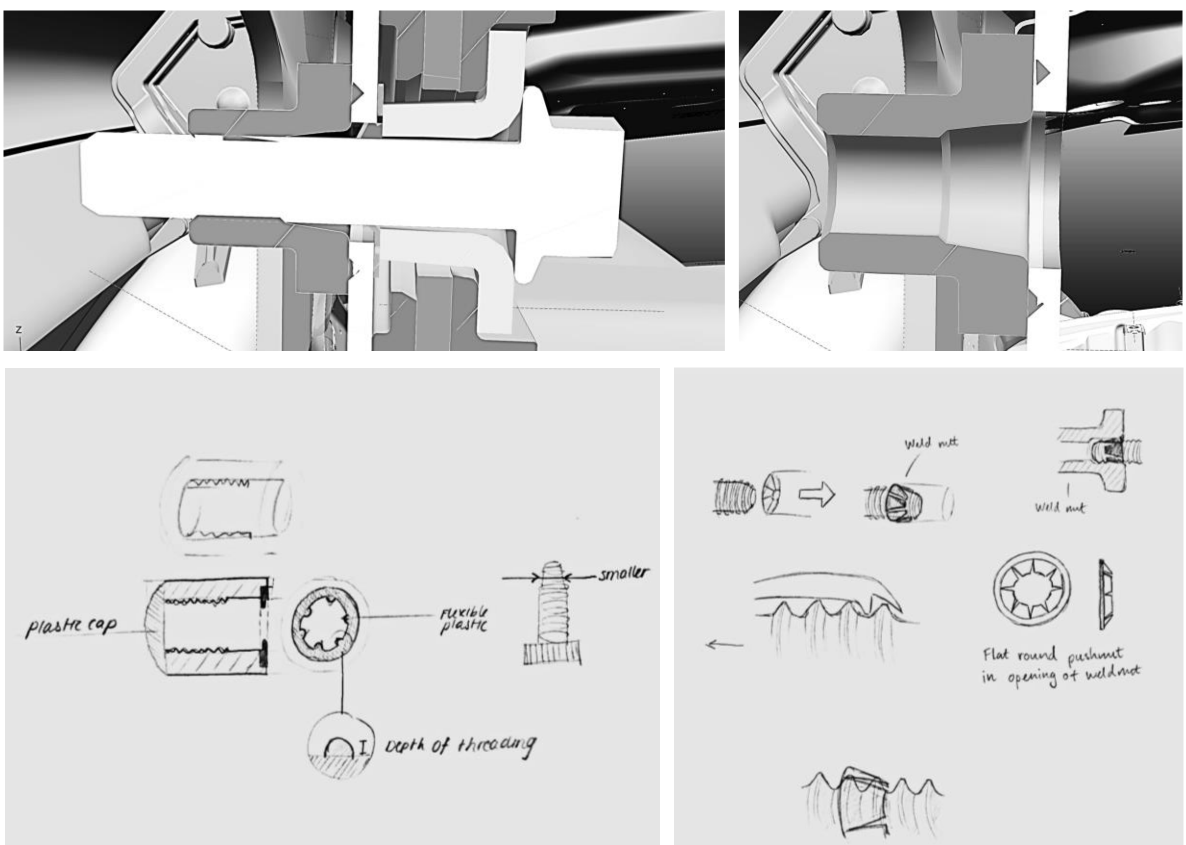


Figure 8.29: Third-hand integrated in weld nut idea. Top: current weld nut. Bottom: ideas including zip-tie inspired locking systems.

Moreover, new ideas regarding rotation emerged. Some solution involving ergonomics was made into a separate category. Lastly, a wood and cork concept direction was included, which resulted from the material brainstorm performed during the ideation.

8.4 Final concept directions

From these initial concept directions, final concept directions were defined, depicted in the digital sketches in Figure 8.30 – 8.42.

8.4.1 Screw tip concept

The first concept direction combines the screw tip, wood and cork, and ergonomic idea directions. The tip of the screw is either made from a more elastic and sustainable material such as cork or wood, or is injection molded into a more form-efficient screw tip. The concept is extended with an ergonomic star washer tool to reduce push-in forces even more. See Figure 8.30.

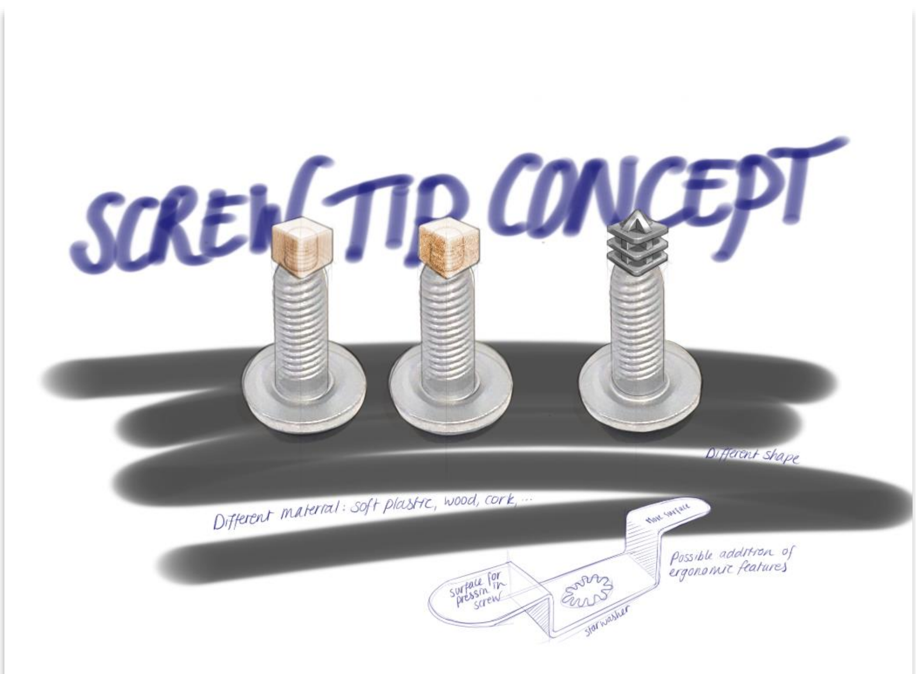


Figure 8.30: Screw tip concept direction.

Considerations concerning this concept include improvement in error-proofing, as well as making the assembly easier and more intuitive. It is also considered to combine this idea with the weld nut, possibly preventing mistakes. Ways to reduce the costs could be further investigated. Additionally, serviceability may be improved.

8.4.2 Snap-fit concept

The second initial concept direction developed into the snap-fit concept direction depicted in Figure 8.31. It is designed as a plastic add-on to the curtain airbag fixation so that it remains supplier independent. It sits on the hanger on the side of the screw head, and the arms of the snap-fit sit through the hanger. The hole is threaded to double as a star washer and goes through an opening in the hanger. A small offset of the holes in the car body ensures the clamping and form fitting of the concept. The snap-fitting provides tactile and audible feedback to the assembler.

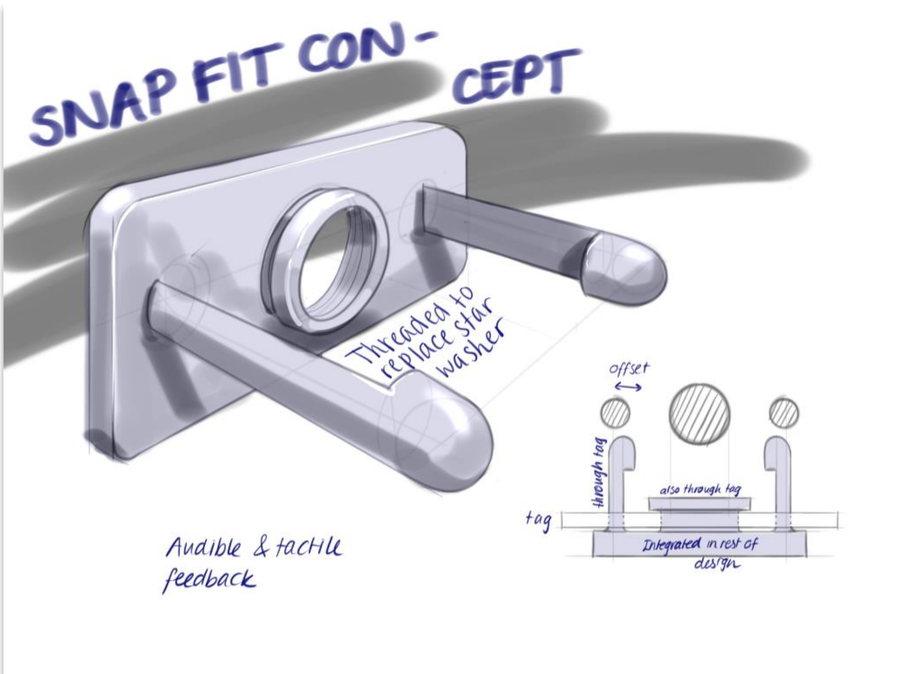


Figure 8.31: Snap-fit concept.

Several potential points of improvement for this concept are listed. Firstly, the design could be made more poka-yoke by moving the holes on the side down a bit, so it can no longer be assembled upside down. However, since the gas generator is assembled first, if the gas generator is in the correct position, it would be difficult to assemble the fixations in the wrong way. The idea should be tested on different sheet metal thicknesses, and serviceability and removability should further be researched. The three holes take up relatively much space on the car body, at getting both pins in simultaneously may prove challenging. Further optimization for injection molding should be performed. Lastly, metal needs to be included against the car body and the screw head to prevent relaxation.

8.4.3 Two-arm clip concept

The hinge third-hand was discarded because of the complexity that a hinge would add and because it proved ineffective during the prototyping. Therefore, the next concept directions are two-arm clips. Two two-arm clips were developed, the first one is presented in Figure 8.32. Upon assembly, the two arms point straight forward to be moved through the two sloths in the car body. Then the clip is clipped into place, flattening the backside of the clip. This side could be covered in a barcode only scannable upon right assembly, when the surface is flat.

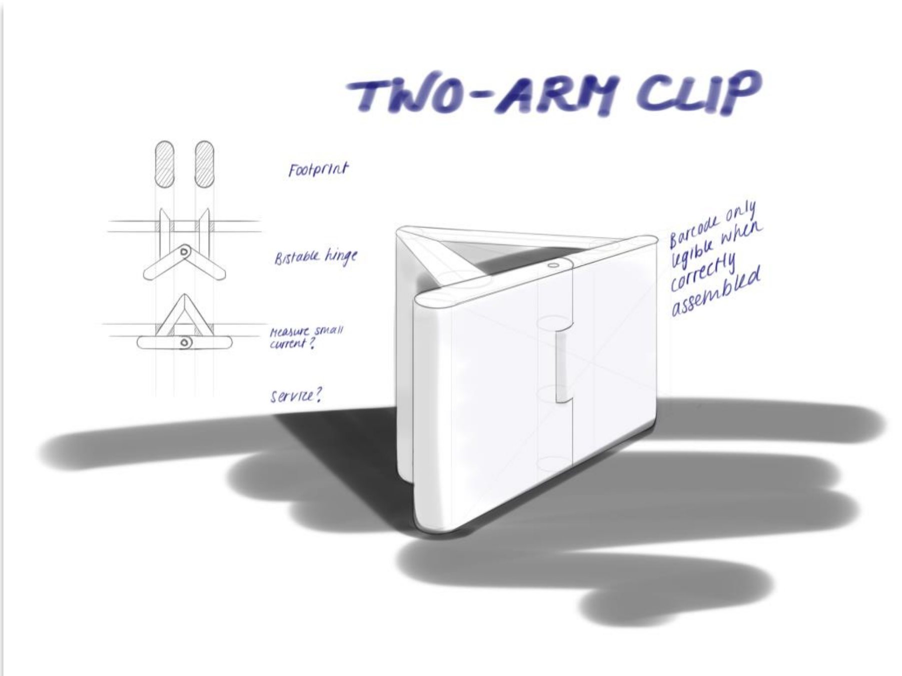


Figure 8.32: Two-arm clip concept direction.

It is of great importance that the barcode is only scannable upon correct assembly with regards to the traceability requirement of Volvo Cars. It should only be possible to scan when closed and assembled to the BiW and not when it is closed apart from the BiW. The bi-stable hinge should also be of great strength so that it does not release upon airbag deployment. Yet, it should not be too strong during assembly because of ergonomic considerations.

8.4.4 Carbine clip concept

An alternative clip concept was developed based on a carbine clip, see Figure 8.33. The clip is pushed into the specially shaped footprint, which opens the lever. Once the carbine clip is pushed all the way through, the lever jumps back in place, resulting in audible feedback to the assembler that the clip is in place.

The advantage over the previous concept is that it is assembled by pushing it straight in, which will bend the hinge out of itself. The inward rather than outward movement of the hinge does also make the clip more stable during airbag deployment, as that will produce outward forces. The tiny hinge could be a weak spot in the design, however.

Its challenges include traceability. A thread through the clip could potentially be tested for closeness through running a tiny current through it, ensuring correct assembly. But also in this case, the traceability requirement poses challenges. Also servicing could be challenging, as the hinge disappears behind the car body and is therefore difficult to reach once mounted. An extra lever could be added for this purpose.

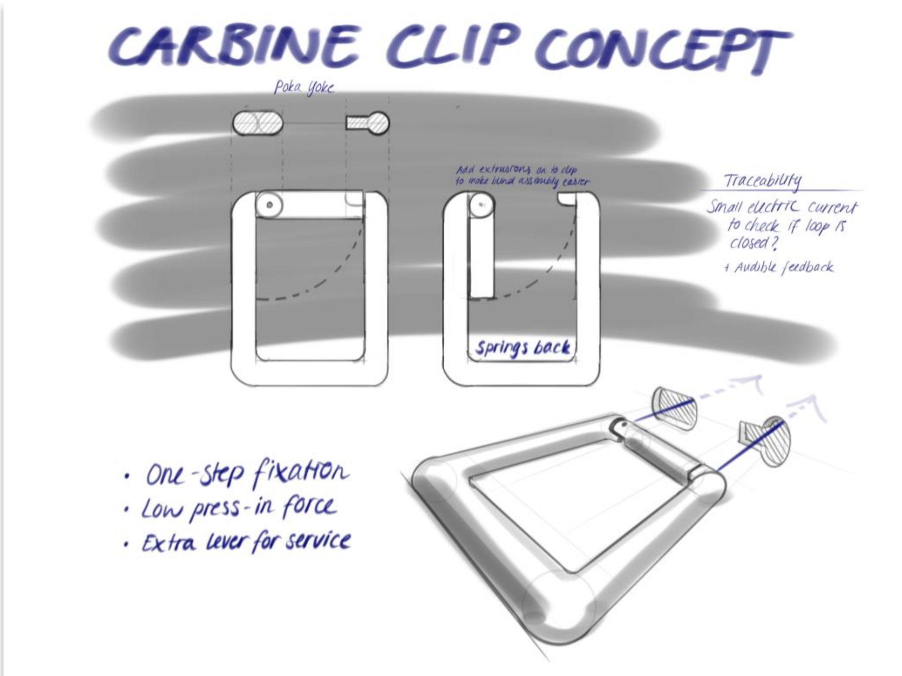


Figure 8.33: Carbine clip concept direction

8.4.5 Double hook concept

Improving the double hook idea resulted in the double hook concept depicted in Figure 8.34. The star washer is extended to include two metal hooks bent from a single metal sheet depicted on the top of the sketch. It sits behind the hanger and is hooked into a fitting footprint. As it is a separate part, it is also relatively supplier independent.

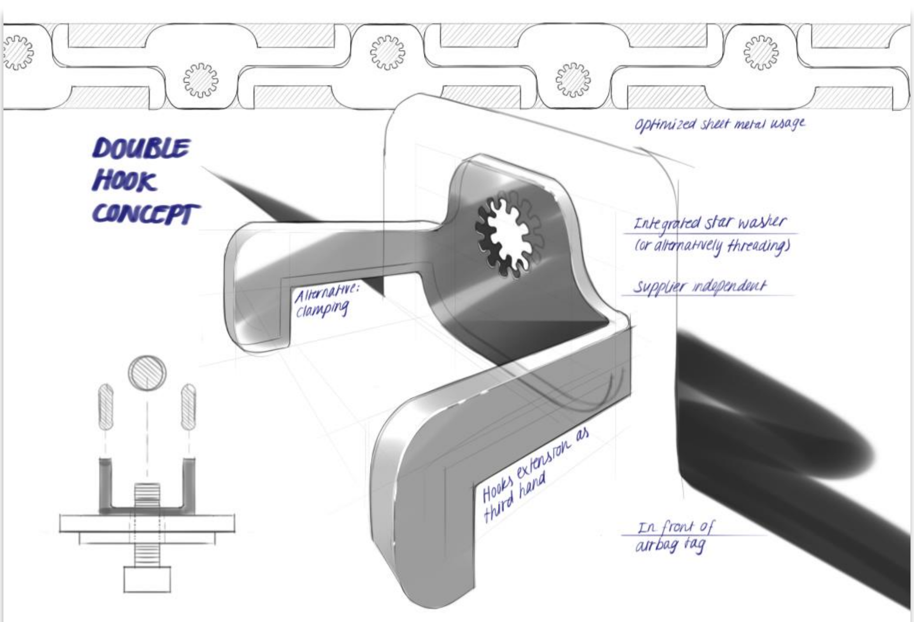


Figure 8.34: Double hook concept direction

As the solution is two-armed, it could be more complicated to mount it, as both arms need to be aligned. The hooks should also work for varying car thickness. Also, the fact that it is attached to the screw and not the curtain airbag fixation could make it less stable and more difficult to mount.

8.4.6 Hook angling concept

During the development of the improved double hook concept direction, it was realized that the screw sticking out can complicate the hooking in. When a third-hand is pressed in linearly, the part of the screw sticking out ends up directly at the opening before the weld nut. However, the motion of inserting a hook misaligns the screw with the weld nut. To counter this issue, a rotational hook was thought of, see Figure 8.35. Here, the screw is aligned with the screw hole directly, whereas the arm of the design can be hooked into the footprint through a rotational motion. This design is also replacing a star washer.

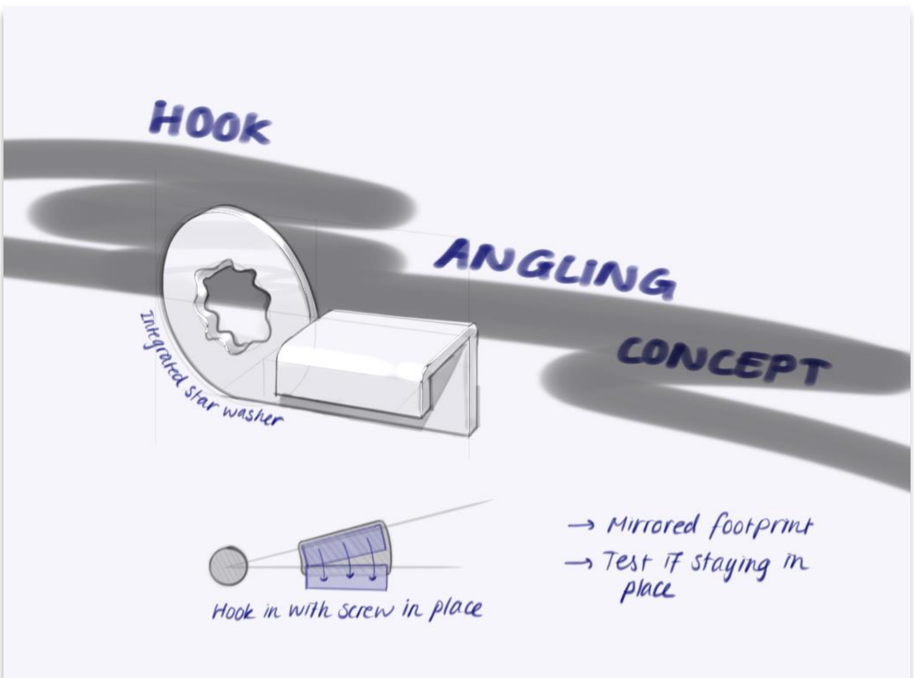


Figure 8.35: Hook angling concept

In the case of this concept, it should be tested if the one arm actually suffices to keep the curtain airbag in place until the screws are fastened. The design may also be experienced as counter intuitive and difficult. The design is asymmetrical as well, which implies either a different part on either side of the car, or an asymmetric footprint.

8.4.7 Hook integrated in footprint

The next concept direction is based on the hook integrated in footprint idea, see Figure 8.36. The handle is put through the car body at top of the footprint and pulled down into place. The handle for the hooking is placed under the screw hole to ensure sufficient space on the car body. Its location also ensures that the fixation will slightly face downwards instead of upwards once hooked to the car body, as the screw sticks out a bit. Internal threading in the screw hole makes any star washer redundant. The fixation and its handle can both be made of metal and plastic, making it less reliant on suppliers.

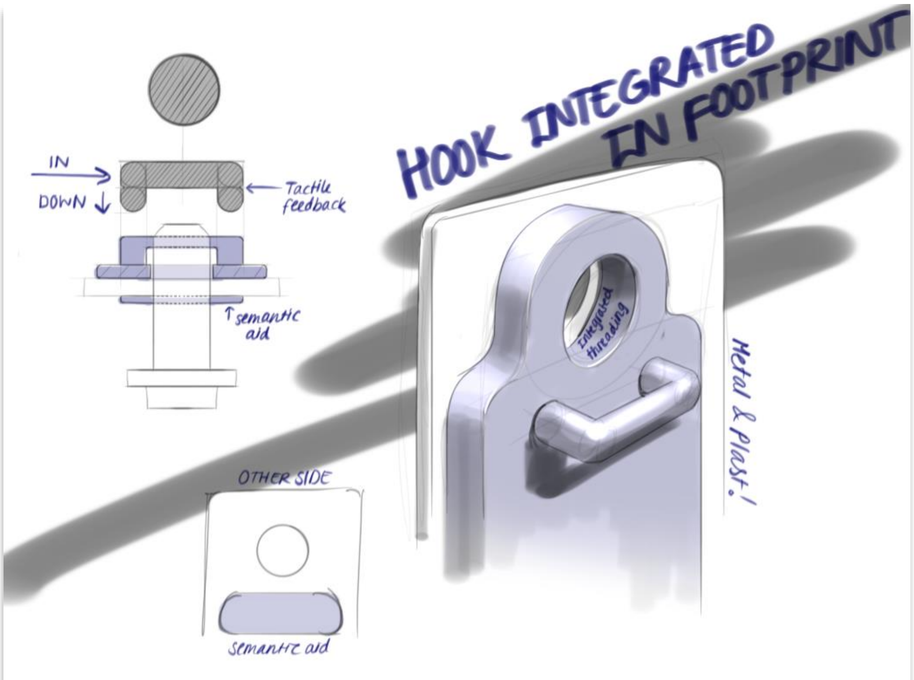


Figure 8.36: Hook integrated in footprint concept direction.

The main downside is the large and unconventionally shaped footprint. It possibly does not fit everywhere on the cantrail, especially at places with double sheet metal, requiring oversized holes. It should also be tested if and how much more convenient the integrated hook is in assembly compared to a regular hook.

8.4.8 Improved third-hand concept

The idea to improve the third-hand resulted in the sketch depicted in Figure 8.37. Also here, the design is a separate part that is added to the fixation through the screw. Once added, the third-hand is pushed in a hole in the footprint and keeps the airbag in place until the definite connection with the screw is made. No extra tooling costs apply to the fixations on the other side, as the solution is simply rotated to get the mirrored part. This also means that the footprint is symmetrical on either side of the car.

The third-hand is placed next to the screw as it was concluded that there is not enough space to have the tree below it on certain cantrails. For consistency, having the tree besides the screw everywhere is therefore preferred, but this design also allows for having the tree below the screw at fixations where there is enough space. This also does not add to any tooling costs, as the part can simply be rotated 90 degrees to achieve this.

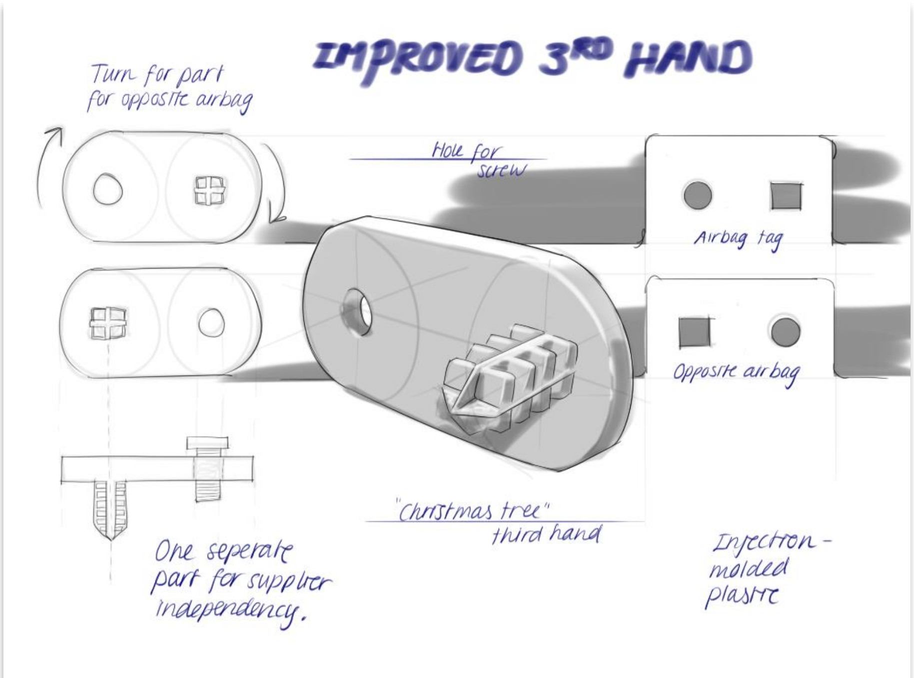


Figure 8.37: Improved third-hand concept direction.

A downside to having the tree beside the screw, is that the fixation will be facing a bit to one side. This is caused by the screw sticking out slightly behind the fixation. This could make it a bit more difficult to fasten the screw. The concept direction also adds an extra part to the curtain airbag fixation, though it is aimed to replace the star washer. It still adds a lot of material for a part that only exerts its function in the few seconds between it is put into place and when the screw is fastened. Furthermore, the service after deployment should be tested, to see what happens with respect to shape deformation of the plastic tree, potentially obstructing servicing.

8.4.9 Weld nut concept

The weld nut concept direction is a new direction that emerged from the reiteration during the initial concept direction brainstorming. The core idea is to integrate the third-hand into the weld nut instead of on the screw or fixation, see Figure 8.38. Initially inspired from a dish cloth hanger, the ridges inside the weld nut bite into the threading of the screw and function as a zip tie does. The shape of the ridges is optimized for low push-in forces and high pull-out forces. It would mean that the curtain airbag fixation would only consist of a standard screw, making it possible to be produced by any supplier. Additionally, only one hole in the car body is required.

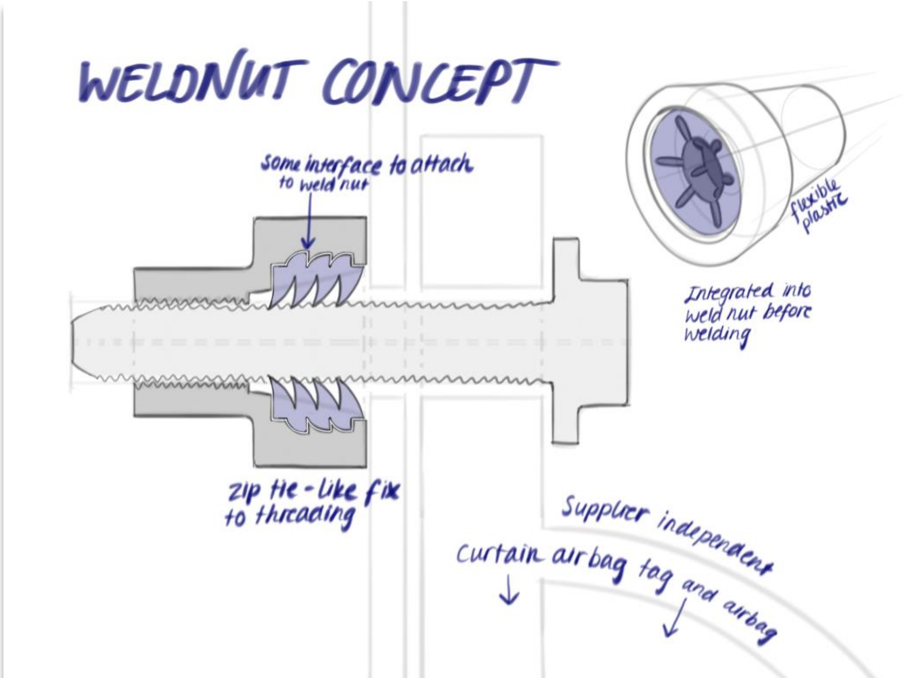


Figure 8.38: Weld nut concept direction.

As the weld nut was not extensively researched during the analysis phase, some open questions around this concept remain. For example, does the design stay intact when the weld nut is welded onto the car body? Furthermore, it should be tested if the connection at this scale is strong enough to keep the airbag in place. It should be looked into in what ways the robustness of the design can be improved. The scale of the design could also imply additional costs, and ways to reduce these costs could be considered.

For further development, it is considered to in some way combine the screw tip concept direction with the weld nut concept direction to achieve a simpler design. Such a screw tip-weld nut combination could even be standardized beyond the curtain airbag and be used in other parts of the car where a third-hand could come in handy. This is possible as the design is independent of the design of the curtain airbag itself.

8.4.10 Rotation concept direction

The last concept direction for the curtain airbag fixations is the rotation concept direction. Sketches are depicted in Figure 8.39 and the final concept direction in Figure 8.40. The idea behind this concept direction is that rotation and shape can omit push-in forces, while obtaining high pull-out forces. Take for example a key in a door, which does not require force to turn, but once turned is difficult to linearly pull out. With respect to ergonomics though, the turning motion may cause wrist pain.

Therefore, it was aimed to achieve this key locking effect when linearly pushing in the third-hand. The shape sketched in Figure 8.39 aims to achieve this. Because of its shape, the third-hand will rotate itself as it is pushed into the footprint in the body in white. A rotational spring is tensed as this happens, resulting in the third-hand to jump back into position once the shape is all the way through. Now, the shape will keep the third-hand in place, as the back of the shape is perpendicular to the sloth in the body in white.

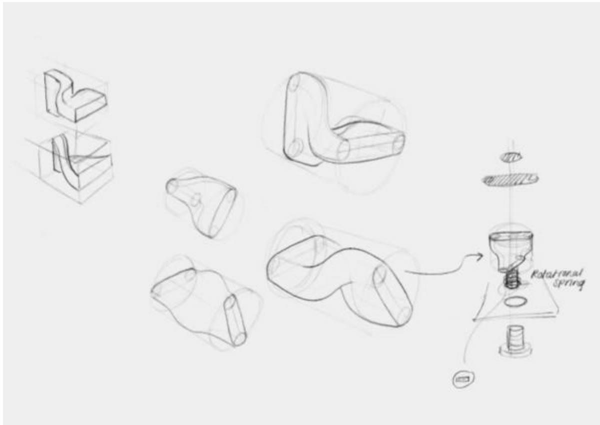


Figure 8.39: Sketches rotational concept

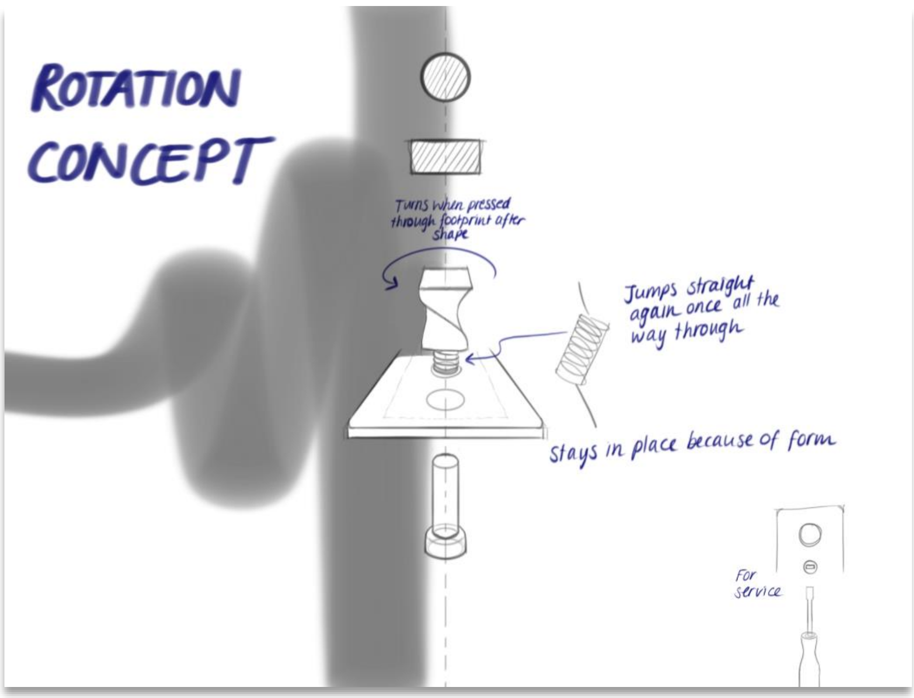


Figure 8.40: Rotation concept direction.

However, the concept is complicated and consists of many parts. Especially when considering that its function is only of importance during the few seconds between mounting it and the fastening of the screws. It could be considered to make the concept into a clip instead of third-hand, meaning without the additional screw. In that case it would be important that the fixation as a whole cannot be turned, otherwise the third-hand can be taken out without much force anyway. Furthermore, the design could be experienced as counter intuitive to the assemblers.

8.4.11 Gas generator bracket concept

After the concept directions for the fixations were created, concept directions for the gas generator bracket and strap buckle were made. The gas generator concept is shown in Figure 8.41. The structural hook is made circular to make it easy to blindly find the hole from several angles, indicated by (1) on the sketch. It is chosen to pull the gas generator to the left upon assembly, as this leaves more space when considering different angles that the bracket can be assembled at. This is shown at (2) in the sketch. The slightly outward angle is of importance as a screw will be sticking out at the other side of the bracket. When the bracket is pulled to the left, the screw on the right side can be screwed in. On this side of the bracket, a third-hand will be in place as well in accordance with the chosen concept of the fixation.

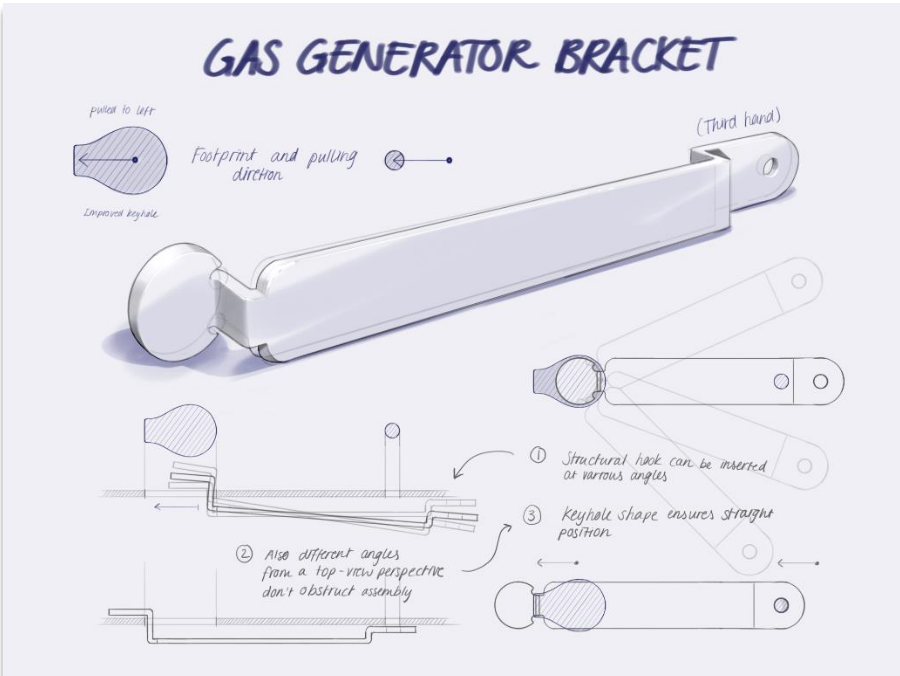


Figure 8.41: Gas generator bracket concept direction.

On another design, a hook is placed on the right side as well, which is pulled sideways simultaneously with the structural hook. This is therefore more ‘at once’ as compared to a structural hook and third-hand, as mounting the third-hand adds a step in the process. From the analysis followed, however, it is difficult to get both hooks in at the same time and pull them at the same time. Therefore, the choice was made to have some type of third-hand instead.

8.4.12 Strap buckle concept

The main idea for the strap buckle concept direction is depicted in Figure 8.42. The main idea is that the strap is made stretchable so that the strap is much shorter while mounting the fixations and is less likely to damage the car. The stretchability is achieved by either adding elastic threading to the strap, or by adding a zig-zag fold to the strap. Relaxation of the elastic threading should not be an issue, as the remaining strap is aimed to be like the strap as it currently is. The zig-zag fold could potentially achieve greater length reduction but may be more expensive to produce.

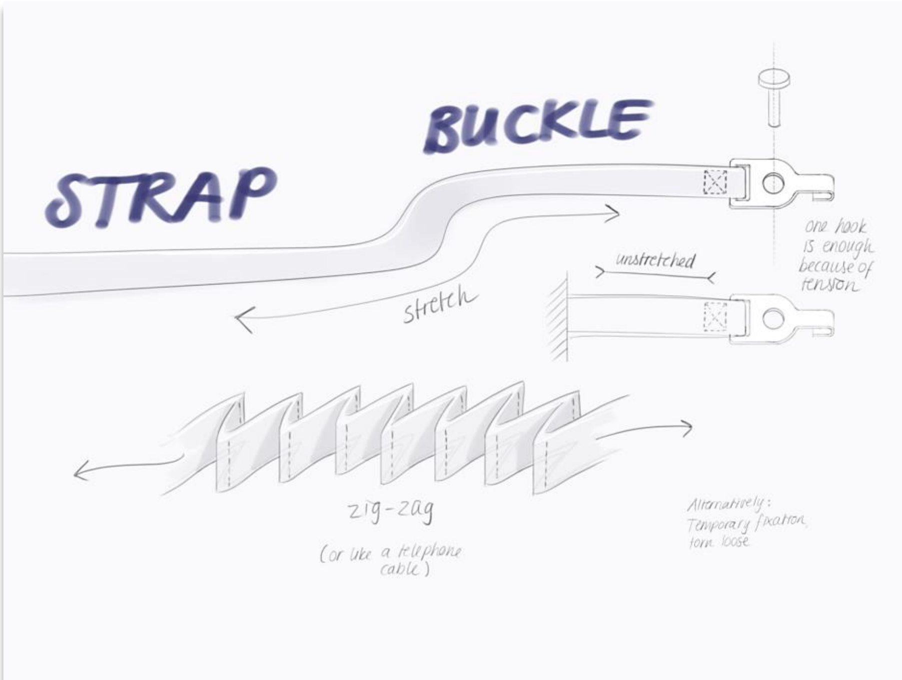


Figure 8.42: Strap buckle concept direction.

The advantage of the elastic or zig-zag strap compared to a temporary fixation onto the curtain airbag to prevent dangling, is that it exerts some tension on the buckle as well. This keeps the buckle hooked in place with one hook, even at extreme angles and without an additional third-hand on the screw. Currently, solutions without a third-hand on the screw require a double hook on the buckle to ensure it. This is in case of a strap with elastic or a zig-zag pattern potentially no longer needed.

9. Concept development

The concept development phase included concept selection and development of the chosen concepts with CAD prototypes as well as laser cut and 3D printed prototypes.

9.1 Concept selection

Firstly, the existing solution is considered, which is the clip used as a standard by other OEMs and suppliers. Then, the results of the Pugh matrices are covered, for each of the existing solutions that were analyzed. Only the most important aspects are presented, rather than each comparison. Subsequently, the main discussion points and conclusions from the team meeting are covered. Then, the final concept selection derived from both the Pugh matrix and discussion are presented.

9.1.1 Existing clip solution

Before ranking the solutions resulting from the idea generation, the standardized clip solution that is already on the market is discussed. Clips present a viable alternative, especially since the suppliers already use them as a standard. Adopting their standard could streamline processes and avoid unnecessary changes.

However, a significant drawback is the traceability requirement specific to Volvo Cars. Each clip is equipped with a barcode, and the robustness of the scanning process is crucial. If automated, the system must be regularly checked for accuracy; if manual, the process must be ergonomic. This introduces several challenges: barcodes can be obscured or poorly lit, making them difficult for cameras to scan. Additionally, human checkers might become lenient over time.

An even greater challenge is the push-in forces. Suppliers have already put a lot of effort into optimizing the push-in forces, and even the newest versions still require a 40 N push-in force with two fingers (P5, personal communication, 2025), which is higher than Volvo's 30 N for two fingers requirement. It thus seems hard to reach below the limit in the near future.

Lastly, to service the clips, a plier is needed. From a service perspective, this is not optimal because there is cabling close by that can be affected. In conclusion, the clips possess some benefits, but they are not suited specifically at Volvo Cars because of the requirements. Changing the requirements could be considered, however, this falls outside the scope of the project.

Clip-screw matrix

9.1.2 Pugh Matrices

The first matrix compares the concepts to the clip-screw currently used at the production plant at Volvo Cars. The resulting matrix can be found in Figure 9.1. The yellow notes contain key comparison notes that are covered more elaborately in the upcoming sections. For a higher resolution matrix, see Appendix G.

Criteria	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Reference
Main functions	0	0	0	0	-1	0	0	0	-1	-1	R
Ergonomics	1	1	1	1	1	1	1	1	1	1	E
Third hand	-1	0	1	-1	-1	0	-1	1	1	0	F
Assembly/context	-1	-1	-1	0	-1	0	0	1	0	-1	E
Error proofing	1	1	1	1	1	0	1	1	1	1	R
Ease of assembly	1	1	1	-1	-1	0	0	1	1	-1	E
Consistency	0	0	0	-1	0	0	0	-1	-1	0	N
Footprint	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	C
Producability	-1	-1	-1	-1	-1	0	0	-1	-1	-1	E
Costs	0	0	0	0	-1	-1	-1	-1	-1	-1	R
Sustainability	0	0	0	0	0	1	0	0	0	-1	E
After EOP	0	-1	1	1	1	0	-1	-1	-1	-1	F
Total	-1	-1	2	-2	-4	1	-2	0	-2	-6	
Rank	4	4	1	5	6	2	5	3	5	7	
Continue	No	No	Yes	No	No	Yes	No	Maybe	No	No	

Figure 9.1: Pugh matrix comparing concepts to clip-screw.

Looking at the main functions criteria, only the integrated hook and two-arm clip performed worse. The integrated hook may not fit on different varieties as its footprint is relatively large, which is an important requirement of the main functions. With regards to the two-arm clip, there are some uncertainties about whether it is able to stay in place during airbag deployment.

With regards to the footprint criteria, all concepts except for the other clip-screw concept score worse, as one circular hole is optimal. For the weld nut concept, the weld nut is regarded as part of the car body and therefore adds to its complexity, but is still optimal with regards to number of holes.

When regarding sustainability, it is only the rotation concept that is scoring worse. This is because it mixes different materials, making it perform worse than the clip-screw in this respect.

Lastly, the after end of production criteria are considered. Several of the concepts perform worse because demounting them is complicated. This includes the snap-fit concept and rotation concept. The weld nut concept may be too fragile for reuse, and the clip concepts have challenges with respect to traceability.

The best scoring concepts are the double hook concept and the screw tip concept. The double hook concept gained most of its points because of its relative robustness. The screw tip concept aims to improve the current clip-screw and therefore should have improved ergonomics, though at a higher price.

Tree third-hand matrix

The second matrix compares the concepts to a tree third-hand as seen in car models like Tesla. See Figure 9.2, as well as Appendix G for a higher resolution image.

Criteria	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Reference
Main functions	1	1	1	1	-1	1	1	1	0	0	R
Ergonomics	0	0	1	1	1	0	0	0	0	0	E
Third hand	-1	1	1	-1	0	1	1	1	1	0	F
Assembly/context	0	-1	-1	0	-1	1	1	1	1	0	E
Error proofing	0	1	0	0	1	-1	1	0	0	0	R
Ease of assembly	0	0	0	-1	-1	-1	0	1	1	-1	E
Consistency	0	0	0	-1	0	1	1	-1	-1	0	N
Footprint	1	0	0	-1	-1	1	0	0	0	-1	C
Producability	1	1	1	1	1	1	1	0	0	0	E
Costs	1	1	1	1	-1	0	-1	-1	-1	-1	R
Sustainability	1	1	1	1	0	0	0	0	0	-1	E
After EOP	1	-1	0	0	0	0	0	-1	-1	-1	F
Total	5	4	5	1	-2	4	5	1	0	-5	
Rank	1	2	1	3	5	2	1	3	4	6	
Continue	Yes	Maybe	Yes	No	No	Maybe	Yes	No	No	No	

Figure 9.2: Pugh matrix comparing concepts to tree third-hand.

With regards to main functions, most concepts score better as it is expected that the tree third-hand does not fit below the screw on the cantrail of certain car models. An exception is the integrated in footprint concept, as its footprint takes up even more space, making it unsuitable for even more possible car model variations.

When it comes to the assembly and context criteria, most concepts scored worse than or equal to the tree third-hand concept. Exceptions include the screw tip concept and weld nut concept, as a screw sticking out does not cause any misalignments. Also, the clip concepts that do not require any screw do not face this issue and therefore gain a point.

The sensitivity to errors is similar to the tree third-hand for most concepts. The snap-fit concept gains a point here as it provides audible and tactile feedback. The screw tip concept loses a point, as it is possibly relatively easy to force the screw tip clip into a different hole. But most notably, the weld nut concept is very error proof. When trying to push the screw into a different hole, it would likely just fall out as there is no internal structure there to keep it in place. This makes this concept gain a point over the tree third-hand concept.

With respect to producibility, most concepts scored better than the tree. This is because the tree must be made of plastic, which greatly limits which suppliers it can be produced by. Only solutions requiring multiple materials were scored at the same level, namely the clip solutions and rotation concept.

With regards to after end of production, the improved third-hand was given a point over the tree design, because of being a separate part added to the curtain airbag fixation. It is thereby also made easier to just replace the third-hand in service if needed. Compared to the snap-fit and rotation concept, the tree design is easier to remove for service. Clip concepts loose points on limitations with regards to traceability, as they are lacking a screw.

From this Pugh matrix, the highest scoring concepts are the improved third-hand concept, the double hook concept, and the weld nut concept. The double hook gains points on having the holes in the body in white next to each other, which is more space efficient. It also potentially improves screw alignment. The assembly is less straightforward, as it is not linear and requires two arms to be put in the footprint simultaneously. The weld nut sticks out because of screw alignment and having no issue with the screw sticking out, as well as its advantages with respect to error-proofing.

Low-scoring concepts include the integrated footprint and rotation concept. Especially the rotation concept does not appear to have any advantages over the tree. It rather adds complexity and different materials to the design.

The third matrix compares all the concepts to the metal hook as currently applied in certain car models from Volvo Cars. It is depicted in Figure 9.3 and a higher resolution version can be found in Appendix G. The results are very similar to that of the tree third-hand matrix and are therefore discussed in less detail. The similarity can be explained by the similarities between the tree and hook solutions: both consist of a screw and a third-hand located below it.

Metal hook matrix

Criteria	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Reference
Main functions	1	1	1	1	-1	1	1	1	0	0	R
Ergonomics	1	1	0	-1	1	0	0	1	1	0	E
Third hand	1	1	1	-1	1	1	1	1	1	1	F
Assembly/context	-1	0	0	1	0	1	1	1	1	0	E
Error proofing	0	0	0	0	0	-1	1	0	0	0	R
Ease of assembly	1	1	0	-1	0	1	1	1	1	-1	E
Consistency	0	0	0	-1	-1	1	1	-1	-1	0	N
Footprint	1	1	1	0	-1	1	1	0	0	0	C
Producability	1	1	1	1	0	1	1	1	1	-1	E
Costs	1	1	1	1	-1	0	-1	-1	-1	-1	R
Sustainability	0	0	0	0	0	0	0	-1	-1	-1	E
After EOP	-1	-1	0	0	0	-1	-1	-1	-1	-1	F
Total	5	6	5	0	-2	5	6	2	1	-4	
Rank	2	1	2	5	6	2	1	3	4	7	
Continue	Maybe	Yes	Yes	No	No	Maybe	Yes	No	No	No	

Figure 9.3: Pugh matrix comparing concepts to hook fixation.

Therefore, the hook solutions will be compared in more detail to each other instead. The lowest scoring hook solution is the integrated in footprint concept. In many ways, it functions and therefore scores the same as a regular hook. It has, however, a larger footprint, affecting the footprint and therefore also factors like consistency and costs. Its advantage is that it is less dependent on material and therefore supplier, and ergonomics may be improved.

The rotational hook performs the same as the regular hook fixation. Some of it advantages follow from it being attached to the star washer, and thus a separate part. This includes the criteria producibility and costs. It also solves the issue with the screw sticking out and therefore scores higher for the assembly/context criteria. It does come with uncertainties about stability and ergonomics, because of the small hook and rotational movement respectively.

Lastly, the double hook scores better than the original hook. It is also part of the star washer, and its two hooks makes it more stable, though possibly more challenging to align to the footprint blindly, as both arms need to be aligned.

The snap-fit and washer solution scored even higher than any of the hook solutions. Their advantages include their linear assembly and simple footprint. End of production considerations like service score worse. Here, a hook is optimal as it is hooked out as easily as it was hooked in. With respect to the washer, its costs may be higher.

Lastly, the concepts are compared to the clip as used in several other car models from Volkswagen for instance. The matrix is found in Figure 9.4 and a higher resolution version in Appendix G. Notably, this clip scored higher than the other clip concepts.

Clip r

Criteria	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Reference
Main functions	-1	-1	-1	-1	-1	0	0	-1	-1	-1	R
Ergonomics	1	1	1	1	1	1	1	1	1	1	E
Third hand	-1	-1	-1	-1	-1	-1	-1	0	0	-1	F
Assembly/context	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	E
Error proofing	1 Poka yoke	1	1 Poka yoke	1 Poka yoke	1	-1	1 Falls out	1 Poka yoke	0	1	R
Ease of assembly	0	0	0	-1	-1	-1	0	1	1	-1	E
Consistency	1	1	1	0	1	1	1	-1	0	1	N
Footprint	-1	-1	-1	-1	-1	1 Round hole	1 Round hole	-1	-1	-1	C
Producability	0	0	0	0	-1	0	0	0	0	-1	E
Costs	0	0	0	0	0	-1	-1	-1	-1	-1	R
Sustainability	1	1	1	1	1	1 Less material	1 Less material	0	0	0	E
After EOP	1	1	1	1	1	1	1	0	0	1	F
Total	1	1	1	-1	-1	0	3	-2	-2	-3	
Rank	2	2	2	4	4	3	1	5	5	6	
Continue	Yes	Yes	Yes	No	No	No	Yes	No	No	No	

Figure 9.4: Pugh matrix comparing concepts to clip fixation.

With respect to the first criteria, none of the concepts score higher than the clip because of how little space it takes on the car body and therefore how easy it is to apply to different car models. Even the screw tip concept and weld nut concept are not given more points. Although their round footprint is preferred over the square footprint of the clip, a weld nut is required.

The second criteria makes evident what the great downside of the clip is, namely its high push-in forces. Other concepts are likely to have lower push-in forces and therefore score higher. For the third and fourth criteria, the clip scores better again, as it being a single clip is the most efficient third-hand, and not needing a screw reduces a step in the assembly.

With respect to consistency, other concepts are preferred over the clip as they use screws. There is already an infrastructure in place with screws. This includes traceability, but it also has advantages with respect to spare parts and tooling available at service, to name some examples.

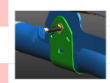
The footprint of the clip, however, is more optimal with regard to most concepts, as it is just one square. As mentioned, only the round holes score more points.

With regards to sustainability, most other concepts score higher. The clip mixes material as it needs an additional plastic part for ergonomical and traceability purposes. This is therefore estimated to have a higher sustainability impact.

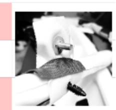
With regards to end of production, most other concepts score higher as well. The clips appear quite challenging to remove, and a plier is needed to this end. Information derived from interviews with the Attribute Leader for service stated that this is far from preferred. Clips are often left in place or removed with much effort, as was observed in one of the car bodies in the storage at Volvo Cars. Although practice could potentially improve this, screw-based solutions are better in this respect.

Total

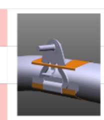
In Figure 9.5, the total points of the concepts are shown. The five highest scoring concepts include the improved third-hand, the snap-fit, the double hook, the screw tip, and the weld nut concept.



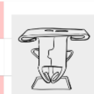
Total	-1	-1	2	-2	-4	1	-2	0	-2	-6
Rank	4	4	1	5	6	2	5	3	5	7
Continue	No	No	Yes	No	No	Yes	No	Maybe	No	No



Total	5	4	5	1	-2	4	5	1	0	-5
Rank	1	2	1	3	5	2	1	3	4	6
Continue	Yes	Maybe	Yes	No	No	Maybe	Yes	No	No	No



Total	5	6	5	0	-2	5	6	2	1	-4
Rank	2	1	2	5	6	2	1	3	4	7
Continue	Maybe	Yes	Yes	No	No	Maybe	Yes	No	No	No



Total	1	1	1	-1	-1	0	3	-2	-2	-3
Rank	2	2	2	4	4	3	1	5	5	6
Continue	Yes	Yes	Yes	No	No	No	Yes	No	No	No

Total	10	10	14	-2	-9	10	12	1	-3	-18
Rank	3	3	1	5	7	3	2	4	6	8
Continue	Yes	Yes	YES	No	No	Yes	Yes	No	No	No

Figure 9.5: Total points from Pugh matrices.

9.1.3 Team discussion

In addition to the Pugh matrices, the concepts were discussed with colleagues from the team Airbags & Steering Wheels at Volvo Cars who are specialized in curtain airbags. The team discussions yielded many insights that are presented below.

The improved third-hand and snap-fit may be challenging due to issues with plastic relaxation. The screw must be surrounded by metal on the front and inside of the hanger, all the way to where it meets the body in white. This means that even more parts need to be added to a part that is already an add-on to the airbag itself. The snap-fit could be realized in metal instead.

A threaded hole to replace the star washer would therefore also be in metal. This has been tried by Autoliv in the past but has never been continued on. Integrating a star washer into the part is possible as well.

The double hook concept is optimized for production. The two arms can also improve the anti-twist properties of the design. It was also discussed whether the hooks could be moved to above the screw, concerning both the double hook and integrated hook concepts. However, this would likely not fit on the car body and make the fixation face up instead of down, when taking into consideration how the screw sticks out.

Reducing the friction of the clip-screw was also discussed. Previous tests showed that reducing the friction in turn reduces the strength of the clip-screw, making the screw fall out. The clip-screw worked better with internal threading in the weld nut, but this was removed because of assembly considerations. Before that, there was a better clip-screw that interacted with this threading.

Furthermore, previous tests with alternative weld nut designs have been carried out. These have not succeeded, mainly because of challenges with treatments performed on the entire car body. One of the weld nut designs also relied on material elasticity, but this elasticity was lost in the electrolytic anti-oxidation bath the body in white is dipped into.

The discussion about the clips covered the usual subject of challenges with regards to traceability. The idea of using a carbine-inspired clip was mentioned as a solution that could have potential.

Lastly, the rotation concept was discussed. Although the current design was overcomplicated, potential was seen in the idea of using rotation. As also the gas generator bracket was discussed, rotation was considered here. It was mentioned that a possibility would be to apply rotation to the gas generator bracket instead of sliding it to the side.

Taking all this into consideration, the double hook, snap-fit, screw tip, weld nut, carbine clip, and rotation concepts were seen as having the greatest potential.

9.1.4 Final concept selection

For the final concept selection, both the results from the Pugh matrix and the team discussion were considered. This is visually represented in Figure 9.6. From the Pugh matrices result, only the improved third-hand is disregarded after considering the issue with plastic relaxation.

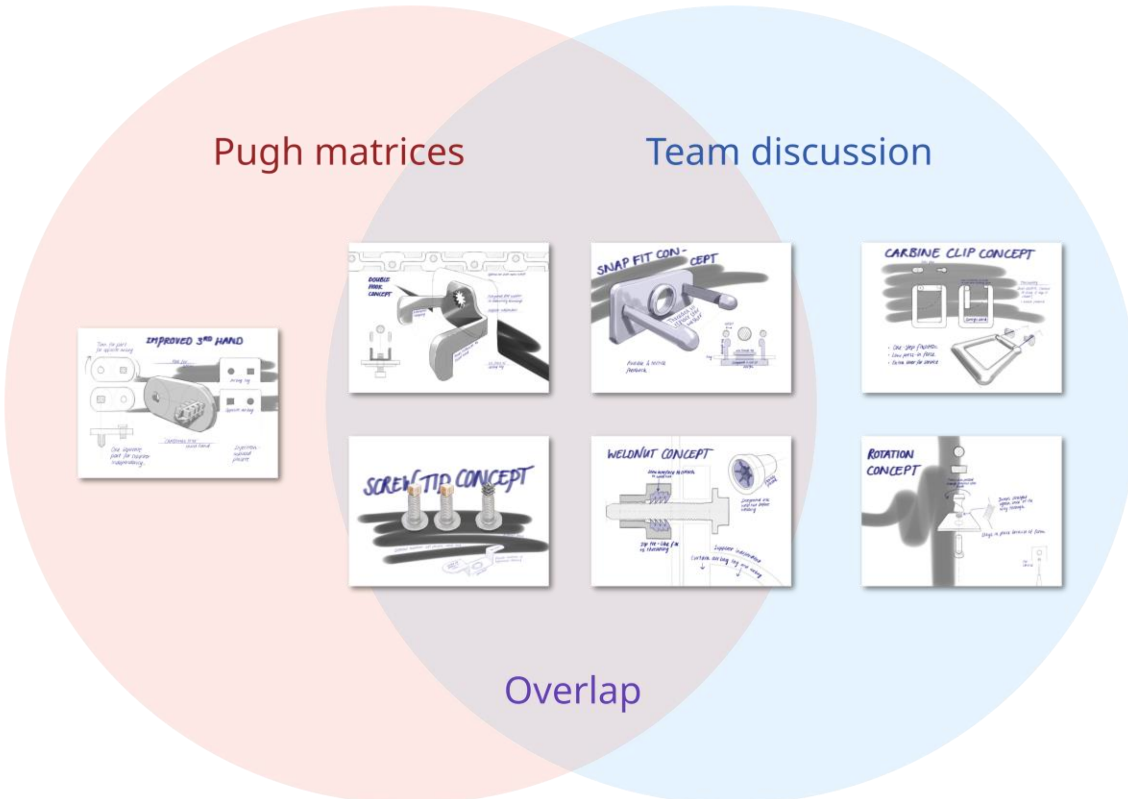


Figure 9.6: Concept selection.

In the end, the carbine clip was not chosen because the force during deployment could possibly be too high for the spring. There are also traceability issues, since there is currently no way to trace the data without a screwdriver at Volvo Cars, a new way would have to be developed. The rotational concept was disregarded because it was too complex for such a small part which could possibly make it too expensive. As discussed in the team meeting, the plastic part with the tree third-hand has problems related to relaxation. There would have to be extra metal parts included to make sure metal sits against the screw head and the car body, adding more parts and complexity and defeating the purpose of the concept.

To summarize and conclude, the other concepts not shown in Figure 9.6 are addressed. The clips were not chosen due to Volvo-specific requirements, including excessive push-in force and traceability problems. The clamp's reliability was uncertain, and it likely would not perform as well as a screw. The footprint hook was discarded due to its challenging footprint. Lastly, the angular hook concept was dismissed due to concerns about its stability.

9.2 Developing the concepts

The chosen concepts were then developed with CAD models and manufactured into initial prototypes. The results are shown below.

9.2.1 Hook washer concept

The purpose of the hook washer concept is to combine the third-hand with the star washer to reduce the number of parts needed. To enable easy manufacturing, the part can be made of sheet metal, whereafter the arms are bent outwards. The hooks can easily be inserted into the car body without much force. The first iteration of the concept was made in CAD and laser cut in sheet metal, see Figure 9.7 and 9.8 respectively. This iteration included simple hooks and another idea which was to have arc-shaped hooks that could be rotated into the footprint from the bottom up. During the testing of the prototype some problems arose. The ends of the hooks were too short, and the radius was too large, which resulted in the hooks falling out easily for footprints at an angle, see Figure 9.9. Similarly, the idea with the arc-shaped hooks ended up falling out as easily as it was inserted. Another problem was that the sheet metal was too thick to accommodate the star washer function. However, the thickness of the part (0.6 mm) seemed to work well for sufficiently robust arms.

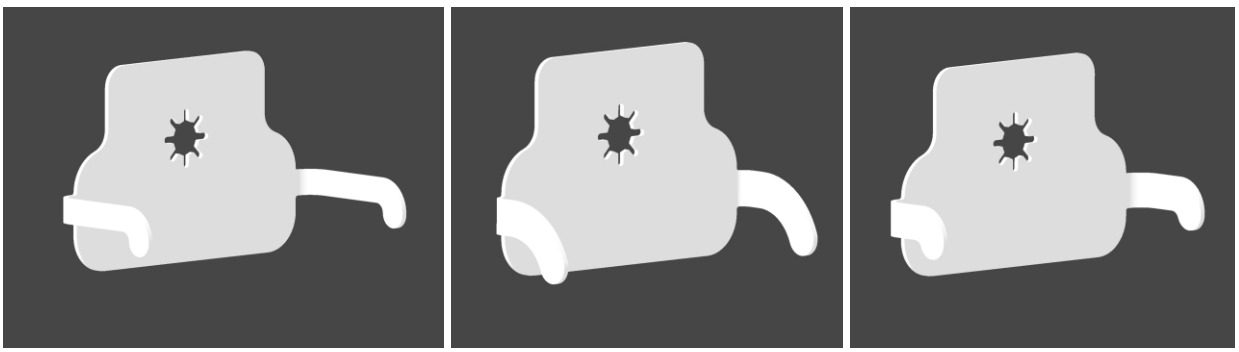


Figure 9.7: First iterations of hook washer concept.

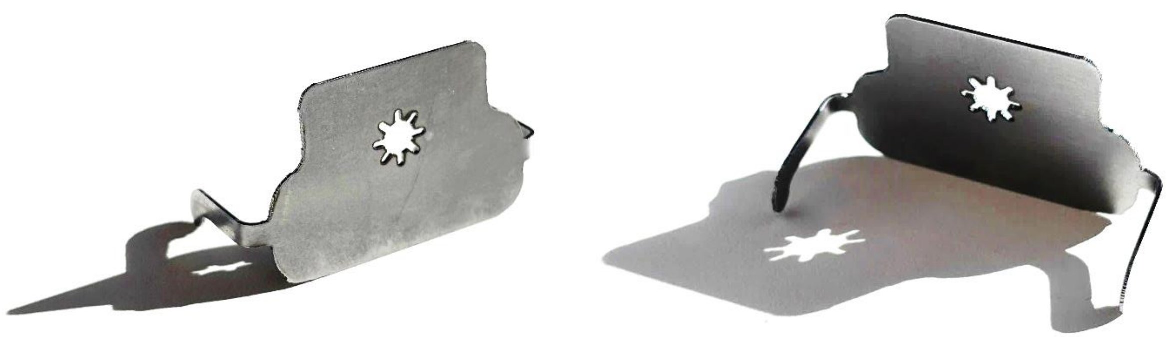


Figure 9.8: Laser cut prototype of hook washer concept.

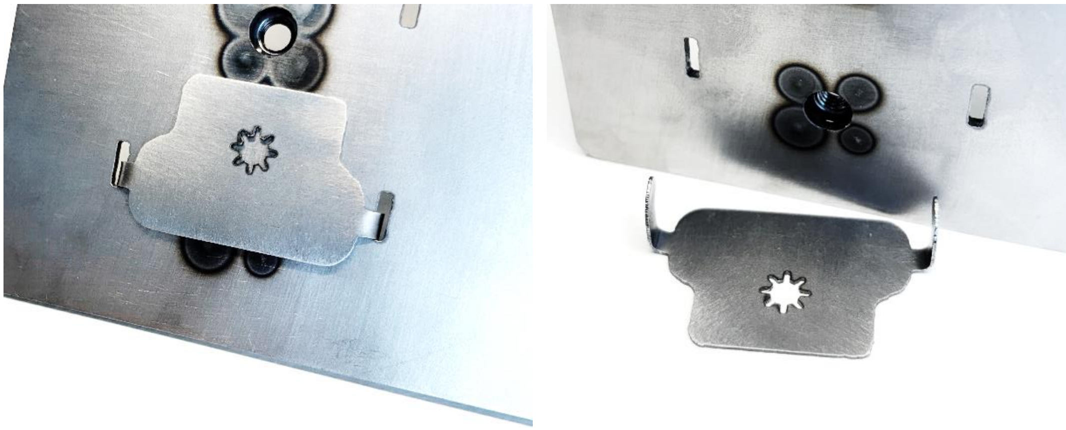


Figure 9.9: The prototype falling out during testing.

After testing the prototype, a second iteration was made where the hooks were improved with longer ends and a smaller radius, see Figure 9.10. The thickness of the part remained the same, but an indent was added around the star washer part to make it the same thickness as current star washers, which is 0.3 mm.

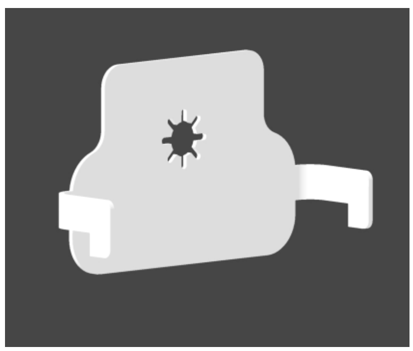


Figure 9.10: Second iteration of hook concept.

This concept fulfills the requirement of fitting different car models which makes it suitable for standardization. Since it is a separate part, it works for both suppliers that work in metal and suppliers that work in plastic. However, the second iteration was tested with prototypes, and even if it stayed in place better than the first iteration, it still fell out when the angle became too great.

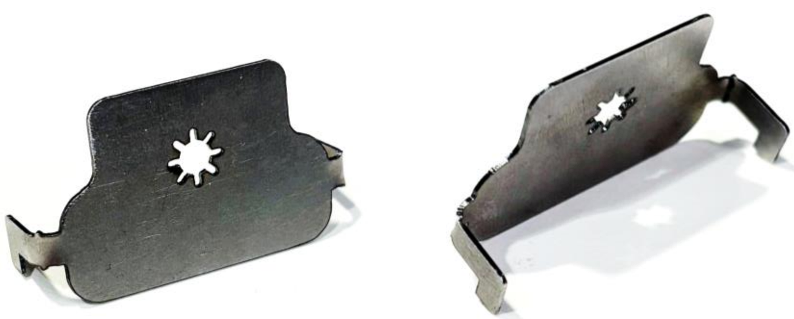


Figure 9.11: Laser cut prototype of second iteration of the hook concept.

9.2.2 Snap-fit washer concept

The second concept is the snap-fit washer. As discussed, the snap-fit washer is made of metal instead of plastic. To simplify the production of the snap-fit washer, the arms are made to bend outwards instead of inwards. Otherwise, the part itself would be in the way while making the last bend inward using regular metal bending tools, and welding would be required. Two prototypes and according to footprints were ordered, with different tolerances, see Figure 9.12 left and 9.12 right. The prototypes were made in 0.5 and 0.6 mm stainless steel.

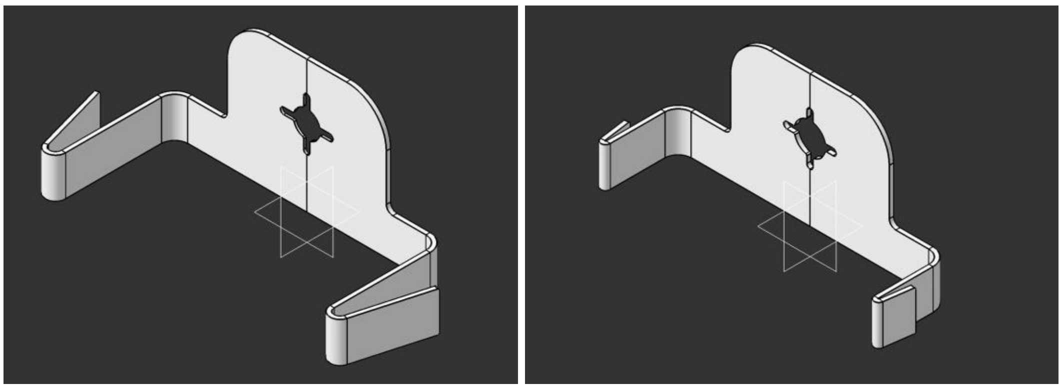


Figure 9.12. Left: First iteration, in 0.6 mm stainless steel. Right: Second iteration, in 0.5 mm and 0.6 mm stainless steel.

In addition to the ordered prototypes, hand-cut prototypes were made as well, see Figure 9.13. This was to test some different material thicknesses and materials, including steel, galvanized steel, and aluminum. The main challenge with regard to material choice was achieving high impermanent deformation (elasticity) without high permanent deformation (plasticity). Spring steel would be optimal in this regard. However, low plasticity also complicates the production process, as permanent deformation is required then. Stainless steel appeared to be the right balance between the two and was therefore the chosen material for the prototypes. A thickness of around 0.5-0.6 mm seemed to provide sufficient elasticity without becoming too bendable as is the case for thinner sheets.

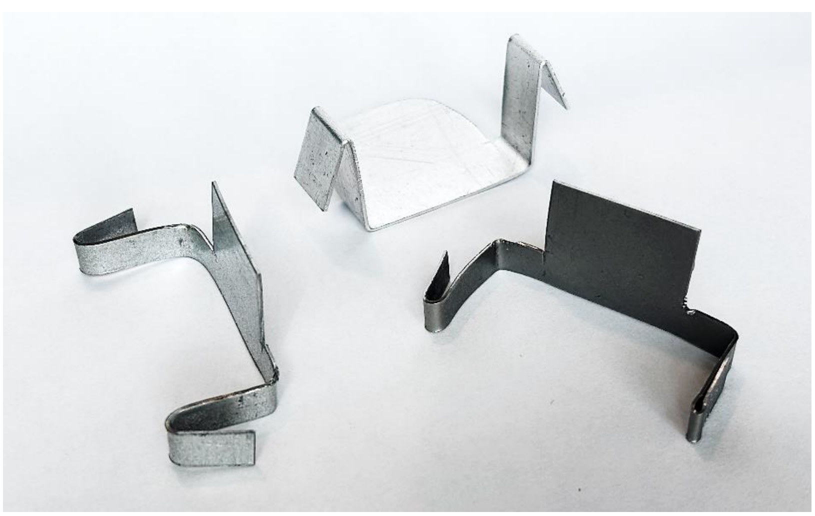


Figure 9.13: Hand-cut metal snap-fit prototypes.

The first iteration prototypes are shown in Figure 9.14. Upon testing these, it was discovered that the margins of the footprint allowed the snap-fit to slide to the side after being pushed in. Once slid to the side, one arm easily falls out again. See Figure 9.15, 9.16 and 9.17.

Figure 9.14: Metal snap-fit prototypes.

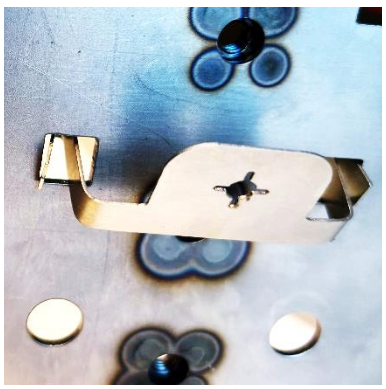


Figure 9.15: Pushed in with two arms simultaneously.

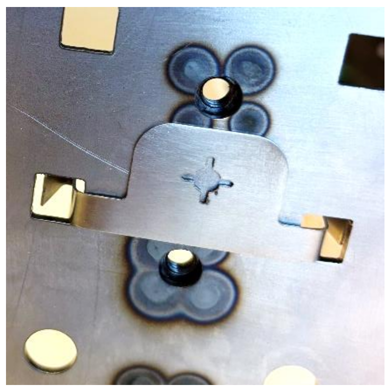


Figure 9.16: Clicked into the footprint, possible to slide to the side.

Figure 9.17: Easily falls out once slid to the side.

The second iteration prototypes are shown in Figure 9.18 and 9.19. Here, the hooks of the snap-fit are reduced in size, therefore the footprint holes margins are smaller as well. This, however, did not solve the above-mentioned issue. The smaller hooks also make it easier for them to fall out. Smaller margins with bigger hooks would increase the push-in force too much. A more elastic material or thinner sheet metal would make the arms more flexible as well. Thinner stainless steel would, however, also be more plastic. The arms of the part may bend a bit, which complicates the assembly as it greatly relies on precise margins. Additional images are shown in Figure 9.20.

Figure 9.18: Second iteration snap-fit washer prototype, 0.5 and 0.6 mm.

Figure 9.19: Second iteration snap-fit washer prototype, in footprint.

Figure 9.20: Snap-fit washer sliding out.

Having the material of the hanger from the curtain airbag between the snap-fit washer and the footprint did help to restrict its degree of freedom, but the whole could slide to the side nonetheless and slip out. It was also considered if the outward bent arms rather than inward bent arms were causing the issue with the snap-fit moving to the side and falling out. But inward bent arms would require an outward margin to allow the arms to slightly bend outward upon clicking it in place.

Instead, changing to spring steel would probably solve the issue, as it allows for easy temporary deformation without causing permanent deformation, ensuring a form-stable part with a low push-in force. Small margins could therefore be reduced without resulting in too high push-in forces, and while still ensuring a form-stable part. However, using spring steel complicates the production of the part, but can be considered anyway in future steps.

In its final form, the snap-fit washer would thus be made of spring steel. It can sit either in between the hanger and the body in white and have a star washer hole, or sit between the screw head and the hanger, and have a threaded tunnel to ensure a metal-to-metal connection. In case of a metal hanger, the washer in front can add extra stability to the screw position.

9.2.3 Screw-weld nut concept

The starting point of the second concept was to either add a third-hand to the screw tip, integrate it in the weld nut, or a combination of the two. As mentioned, a third-hand on the screw tip currently exists but results in high push-in forces. Reducing the push-in forces by changing material or margins in turn makes the third-hand too weak to carry the airbag. A third-hand solution integrated into the weld nut was also discussed with the team. It was pointed out that previous experimentation with it had taken place years ago and had not led to any success. The weld nut must withstand additional steps such as an electrolyte bath together with the rest of the body in white. These steps strongly limit the design possibilities of the weld nut.

This leads to combining the two. Because of the design limitations of the weld nut, it was opted to simply add an internal groove to hook a redesigned screw tip into, see figure 9.21 and 9.22. The main downside of such a design is that it requires both new weld nuts and screws. The interface with the screw is though made to be the same as the current clip-screw. Consequently, concerns with regards to the forces required to fasten the screw tip through the weld nut arose during development. Screw alignment could also pose challenges.

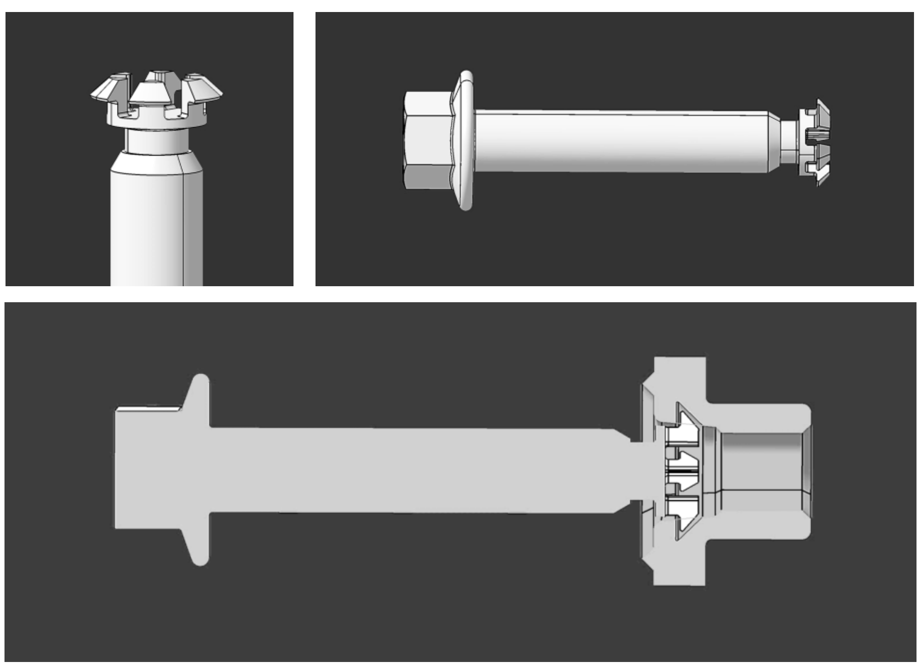


Figure 9.21: CAD models of a snap fit at the tip of the screw

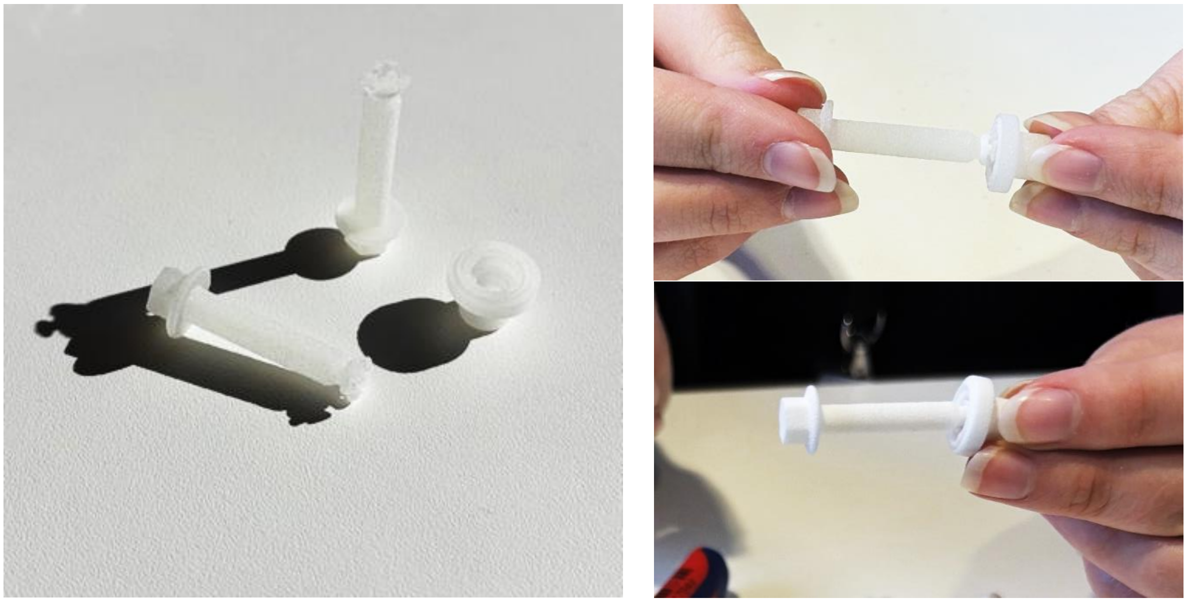


Figure 9.22: Prototypes with three and four-armed versions

These challenges were resolved all at once in a redesign with a plastic ring around the screw instead of a plastic part manufactured onto the screw, see Figure 9.23 and 9.24. The plastic ring sits at the end of the screw, as depicted on the top left of Figure 9.23. It is screwed onto the screw and sits in its screw thread. The ring hooks into a groove that is located on the inside of the weld nut. When the screw is screwed in, the ring stays put as the screw goes through it. This design solves the issue of needing both a special screw and weld nut, as the ring is put around a standard M5 screw. The plastic no longer needs to be screwed through the weld nut, so it also solves that. Even screw alignment is likely improved, as the screw sits closer to the actual threading.

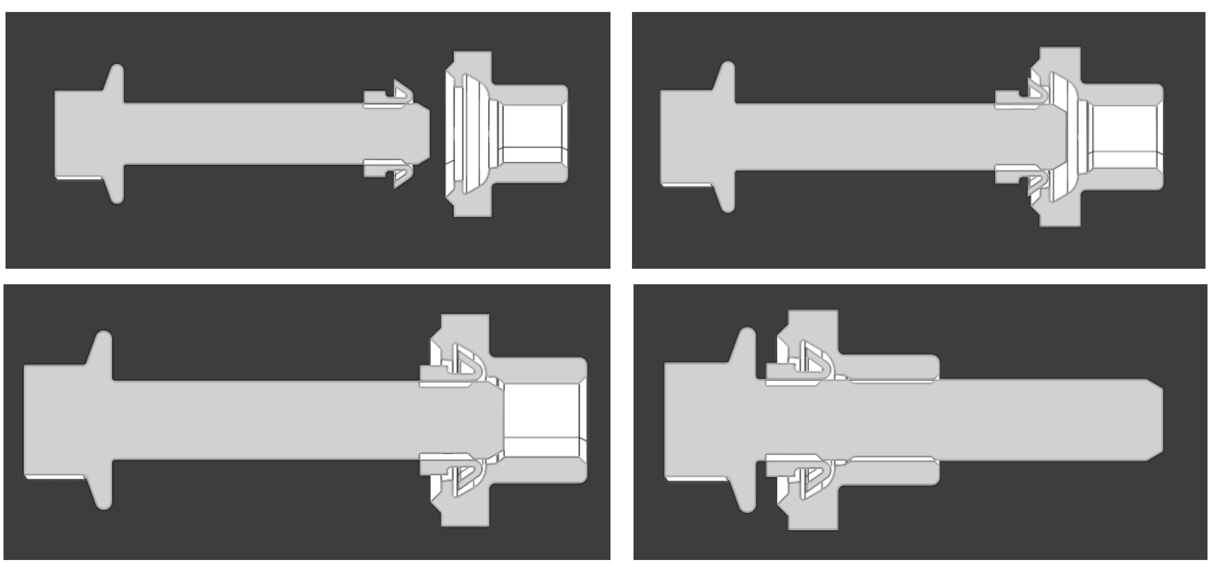


Figure 9.23: CAD model of a snap-fit around the screw.

Figure 9.24: Plastic ring prototypes.

The new weld nut could be challenging to produce, because of the groove. Revision of this design led to the design depicted in Figure 9.25. Instead of a groove, the weld nut is simply a bit wider at its opening, and the ring hooks behind the slightly smaller hole of the body in white. Some extra space behind the ring, deeper into the weld nut, is added to allow for the solution to have enough space at places where the car body is thinner as well. This design also leaves more space inside the weld nut, not hollowing it out as much as the previous design. This means that the ring may be able to be made a bit bigger.

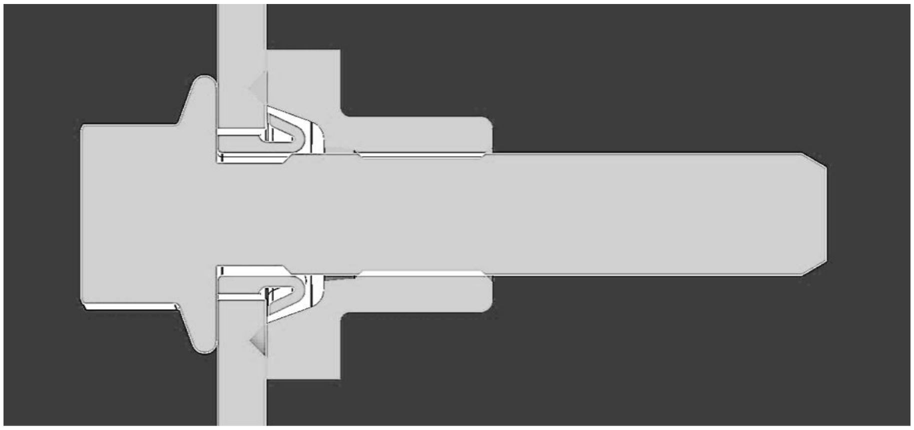


Figure 9.25: CAD model of iterated concept

The 3D-printed prototypes of the iterations are shown in Figure 9.26, 9.27 and 9.28. Different shapes for the ring were tested, with either two, three, or four gaps. The gaps ensured that the ring could more easily be deformed. Especially the 3D-printed PA12 parts were hard as stone in the first iteration with the gapless ring. The rings with three and four gaps turned out to work the best. The four-gap rings are a bit easier to take out as two gaps end up exactly opposite each other. This can be seen as both an advantage for service and a disadvantage. Besides sitting stronger, the three-gap ring is a bit more stable as the edges are a bit wider.

The PA12 parts turned out better than the PP parts, as the 3D printing works better with PA12 at a smaller scale. Most of the PP parts ended up as simple rings yet still worked surprisingly well. In case the intricate design of the current ring ends up too difficult to produce, working with a simple ring could be further iterated upon. Even a silicone ring was tested, to see how the concept worked with a more flexible material. An earphone bud was cut to shape to this end. However, a softer material gives less feedback upon assembly and may sit less tight.

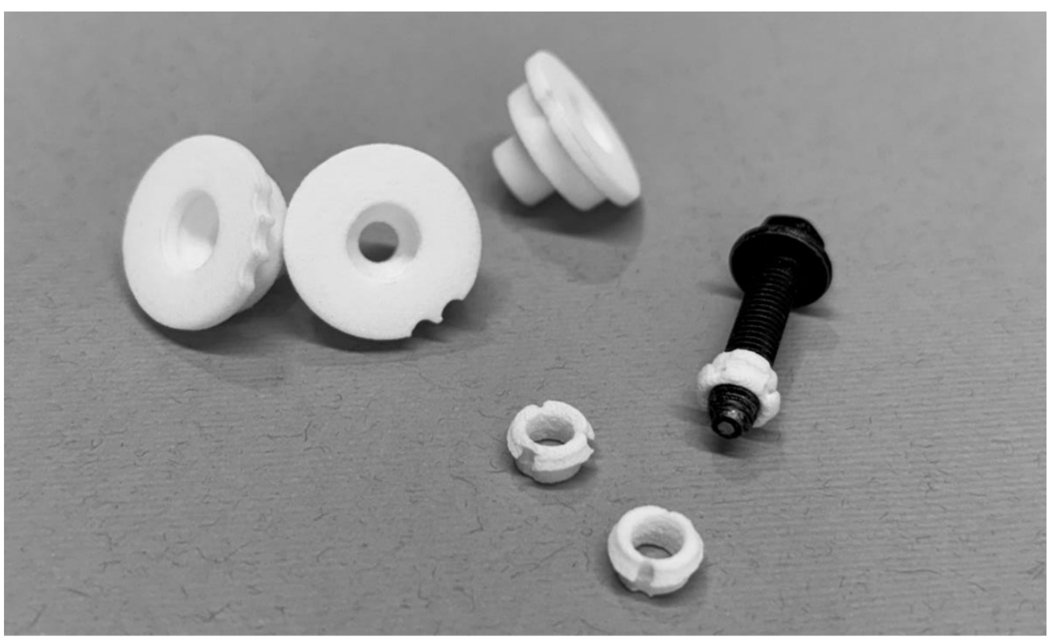


Figure 9.26: PA12 prototypes

Figure 9.27: PP

Figure 9.28: Silicone ring

The solution could also potentially double as a star washer, thus keeping the screw in place in the hanger during transport and assembly. Its assembly is familiar to the assembly workers as well, as it is in essence not that different from the current clip-screw. Traceability follows from the screws. The little amount of material makes it a relatively sustainable solution. For service, the ring either stays put in the weld nut as the screw is screwed out, or the screw needs to be wiggled a bit to get it out with the ring on it. As the ring is a separate part, it can be replaced seperately.

An open issue may be the scale of the part, with regards to manufacturing, but probably more so with regards to strength. Furthermore, the margins of where the ring sits on the screw for the concept to work are quite limited. If the ring sits to much at the tip of the screw, the threading cannot contact the weld nut tunnel and will only spin when the screwdriver is used. If the ring sits too far onto the screw, it may not fit into the weld nut because the screw bottoms out.

9.2.4 Gas generator bracket concept

Two gas generator bracket ideas are further developed in the upcoming sections: a round structural hook concept, and a rotational assembly concept. The first concept idea is a continuation of the concept direction introduced in section 8.4.11. The other concept builds on the idea of assembling with rotation instead of pulling in different directions. This idea originated from the team discussion

Round structural hook

The first iteration has a round structural hook on one end and a third-hand on the other. The idea is that the third-hand is consistent with the fixation third-hands, whether that be hooks or something added to the screw. The hook is circular for the purpose of being inserted from different angles both along the y and z-axis, as explained in section 8.4.11. The CAD model is shown in Figure 9.29 and is created as a simplified version of the gas generator bracket in order to show the functionality.

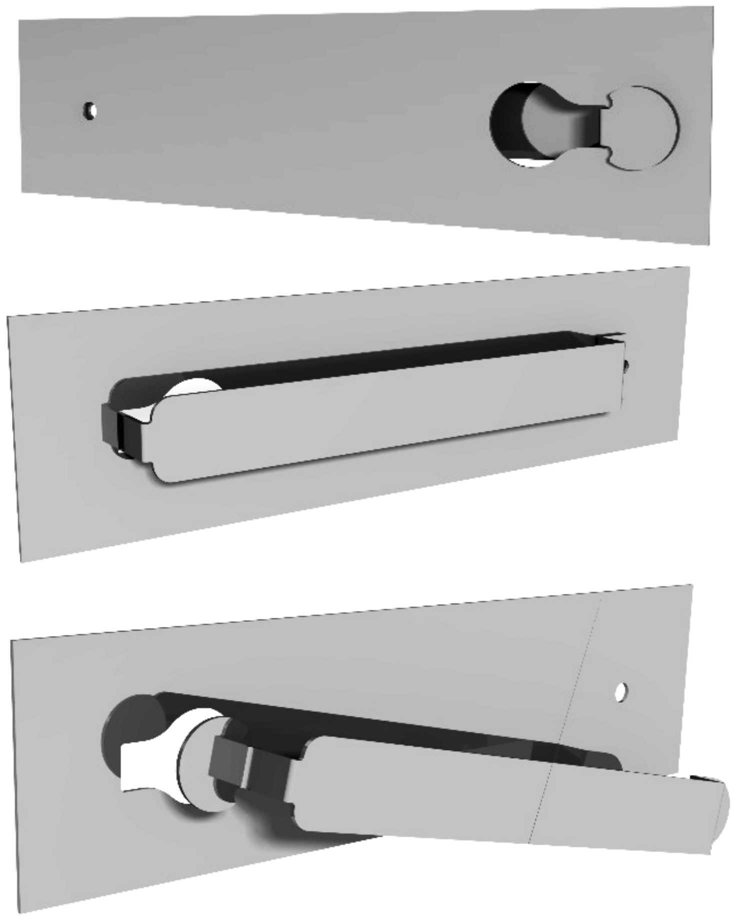


Figure 9.29: CAD model of rotational gas generator bracket and footprint.

While making the CAD model and upon receiving the prototype, it was discovered that the design was unstable at the side of the structural hook, see Figure 9.30-9.33. The hook can be pushed further into the footprint hole after assembly. With the screw in place, the bracket cannot fall out, but the structural hook can still move through the elasticity of the material. This can cause unpredictable behavior upon airbag deployment and rattling when assembled in a driving car.

Figure 9.30: Front view of gas bracket prototype.

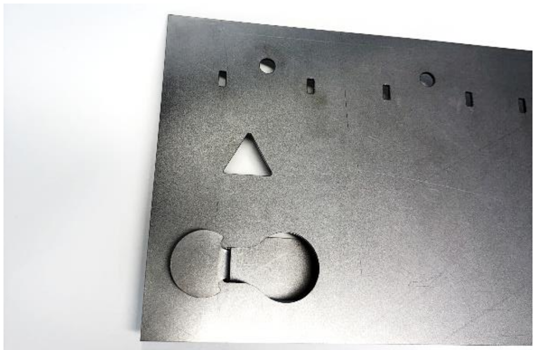


Figure 9.31: Back view of gas bracket prototype.

Figure 9.32: Too much space to move for the structural hook.

Figure 9.33: Degree of freedom in structural hook, top view.

Rotation nut

The other concept uses the rotational principle in the form of a triangle, see Figure 9.34. The bracket is inserted at an angle where the triangular hook is inserted into the triangular hole. The bracket is then rotated so that the triangle is locked behind the footprint and the gas generator lays horizontal. This is depicted in the prototype Figures 9.35-9.37. The triangular shape was chosen as it results in relatively big corners to hook behind the footprint. The hooks of for example a square shape are relatively small. The bottom of the circular part of the triangle bolt also aligns with lower edge of the triangular footprint, the preventing the bracket from moving down.

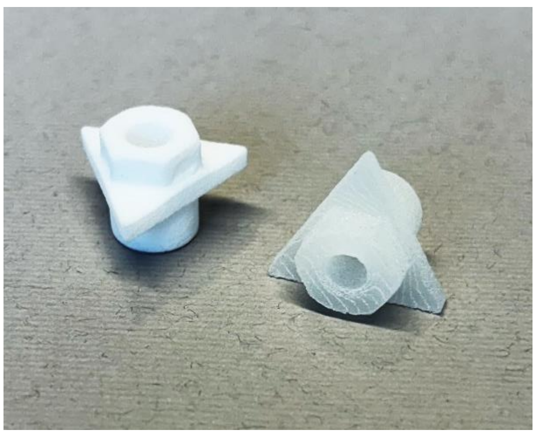


Figure 9.34: 3D-printed parts in PA12 (left) and PP (right), to be screwed onto an existing bracket.

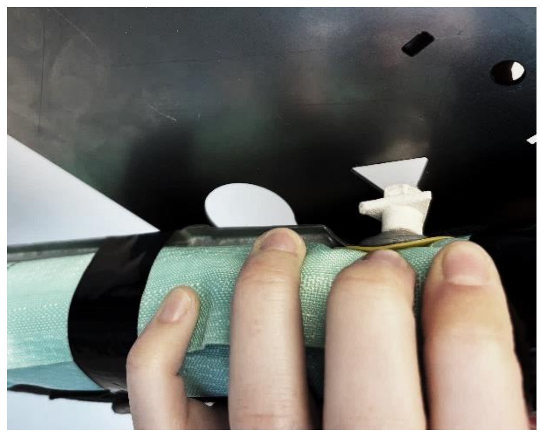


Figure 9.35: Assembly of triangular nut, front.

Figure 9.36: Assembly of triangular nut, back.

Figure 9.37: Gas generator is aligned straight, hooking the corners of the triangle into place.

Two issues were identified while testing the prototype. One refers to the triangular footprint preventing the bracket from moving down, as mentioned before. This is indeed the case, as can be seen in Figure 9.37. The nut leans on the horizontal bottom edge of the triangular footprint. However, it can still move up with some force, which may cause issues in the car upon airbag deployment or rattling in a driving car.

The other issue is depicted in Figure 9.38. It depicts the angle at which the gas generator is to be assembled. It sticks out quite a lot and would therefore interfere with the roof of the car body, making it impossible to assemble. Even a redesign that only uses only a small rotation could run into this issue due to the very limited margins. Instead, the point of rotation could be moved all the way to the end of the gas generator, thus requiring a bigger bracket.

Figure 9.38: Showing how the inflator would interfere with the roof, imagining the roof right above the footprint.

9.2.5 Strap buckle concept

The most apparent problem with the tether and strap buckle that was discovered was that the strap moved around too much. This resulted in the strap buckle getting stuck or sometimes damaging the paint of the car. To counter this problem, the strap buckle concept explored having an elastic strap instead of a rigid one. Not only does it make the strap shorter, but it also creates some tension when the strap buckle is inserted. No prototypes were made due to time constraints.

10. Final concept

In this chapter, the final concept is presented with motivations and visualizations. The material choice is also presented with analysis of material properties and sustainability impacts.

10.1 Final concept

The main focus of the final concept is on the fixations, however, the solution for the fixations also influences the final concept of the gas generator and strap buckle.

10.1.1 Fixations

The final concept for the fixations is a snap-fit ring that is put around the screw and inserted into a weld nut. When the ring is inserted into the weld nut, the car body metal keeps it in place. Visualization of the ring can be seen in Figure 10.1. The idea behind the concept is that because of the snap-fit, less force has to be applied to insert the screw, compared to the clip-screws that are in use today that utilize friction. The idea is that the ring is put onto the screw by the suppliers and sits tightly on the screw with the thread on the inside.

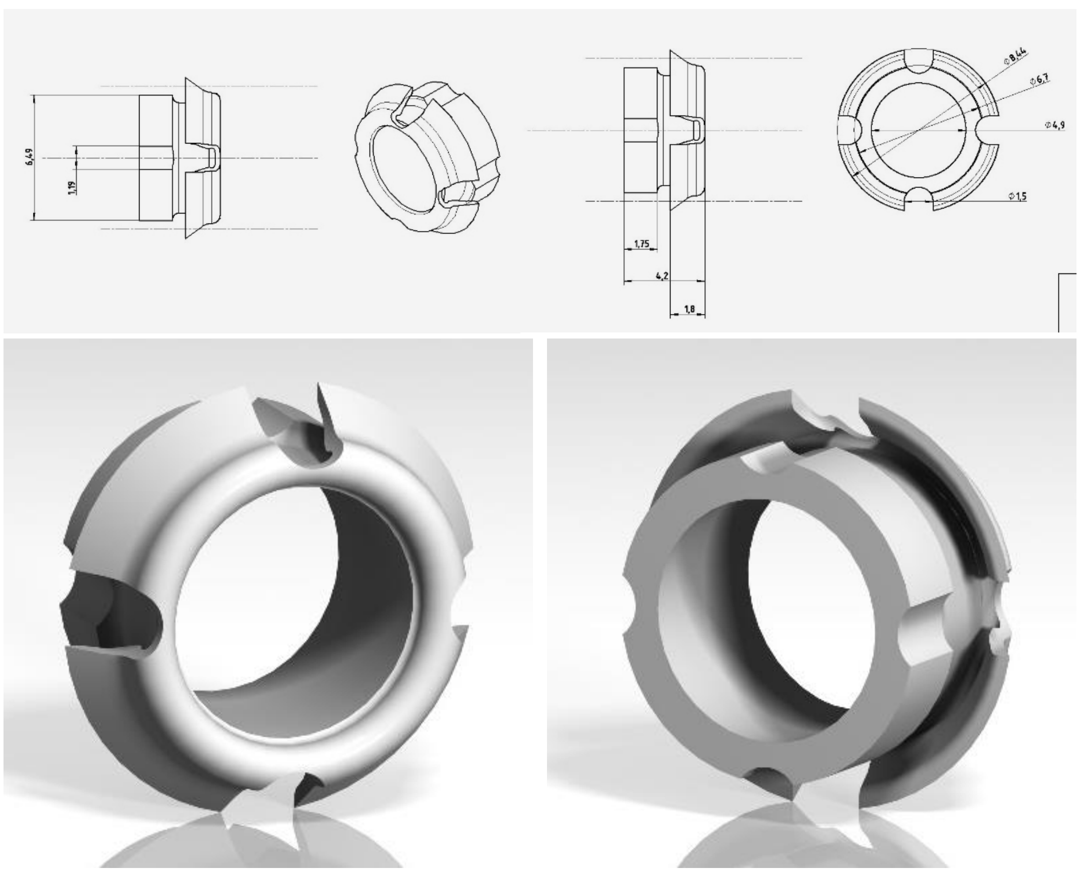


Figure 10.1: The snap-fit ring

The weld nut concept is based off the weld nut that is currently in use at Volvo Cars. However, it is modified to have a slightly bigger opening at the start of the opening to accommodate the snap-fit ring. The weld nut, together with the smaller hole in the car body creates the fixation point for the snap-fit. The weld nut can be seen in Figure 10.2 and 10.3.

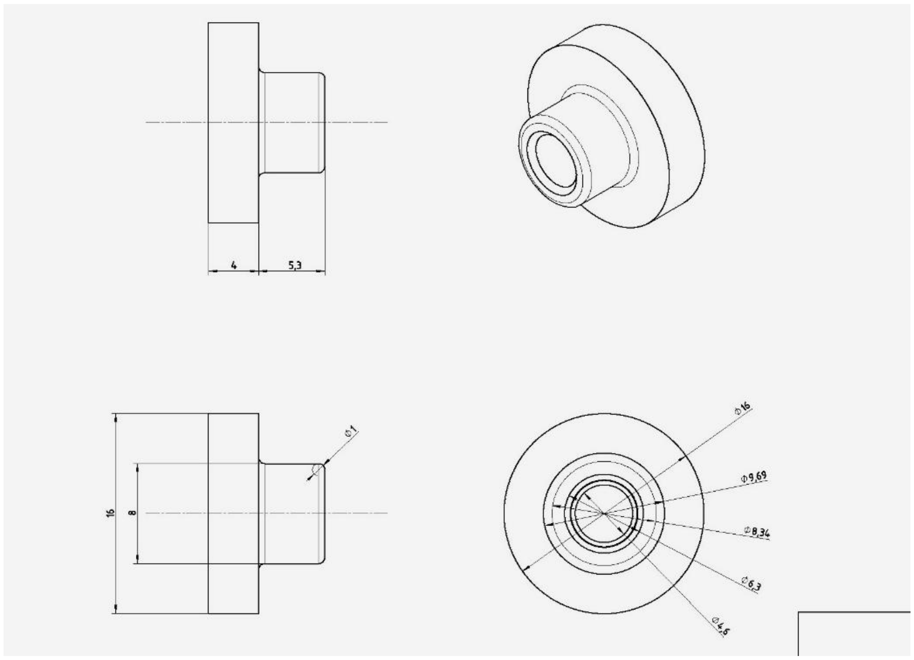


Figure 10.2: Technical drawing of the weld nut.

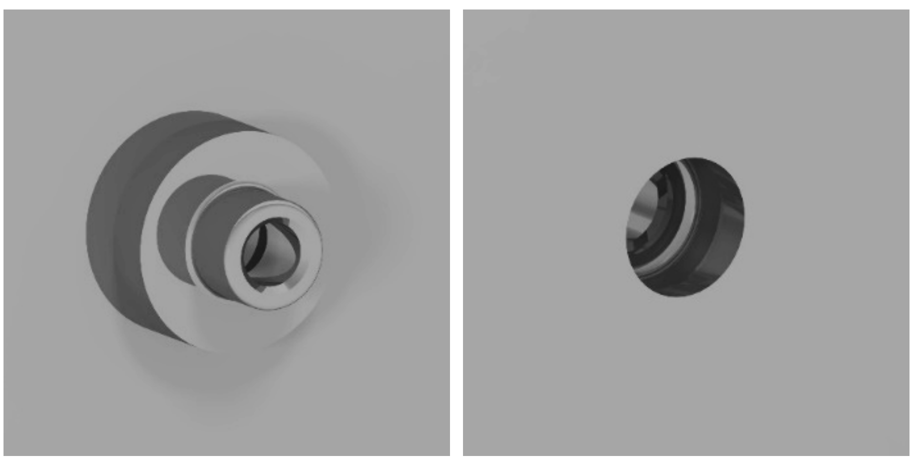


Figure 10.3: Rendering of weld nut shown from the back of the car body (left) and the front (right).

Figure 10.4 shows the entire assembly and the different stages of inserting the screw into the weld nut. First, the tip of the screw is pushed in and the snap-fit ring at the end snaps into the weld nut. Then when the screw is in place, it is fastened with a screwdriver while the snap-fit ring stays in place in the weld nut.

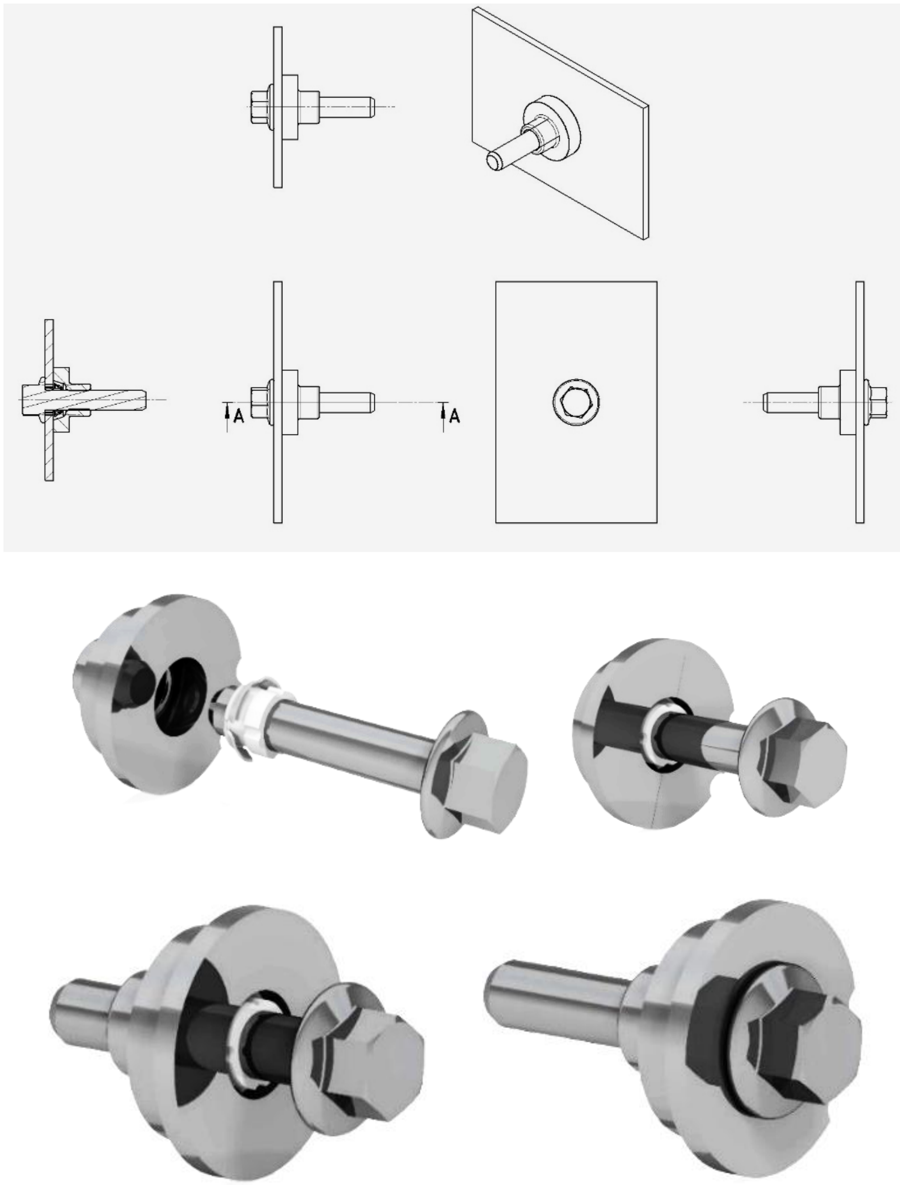


Figure 10.4: The assembly (top) and insertion step-by-step (bottom).

The footprint is an important aspect of the interface, and with the solution the footprint is made to be optimal for standardization. An example of what the footprint can look like is seen in Figure 10.5. The picture is of the cantrail for the XC60 that is currently out on the market and the footprint for the curtain airbag fixations are just in the form of one simple hole. This is a footprint that can easily fit on any current and future car models and not take up too much space. Whether embossings are needed for the footprint depends on the car model and differs from model to model.

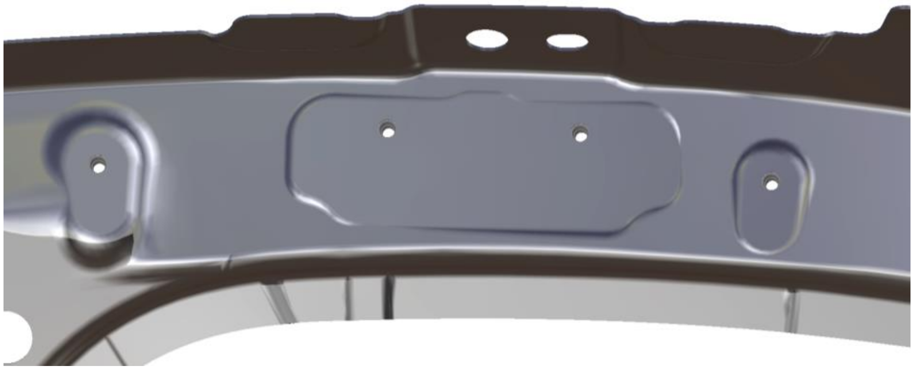


Figure 10.5: An example of what the footprint can look like.

To put the solution in context with a curtain airbag, a visualization and prototype can be seen in Figure 10.6 and 10.7 respectively, where 10.7 shows the test rig and physical prototypes that were made. The design of the hanger for the curtain airbag is decided by the supplier, but no matter how the hanger is designed, the solution is compatible as long as a screw is included. Since the ring sits on the screw, it also hinders the screw from falling out of the hanger, thus the solution has an additional purpose and can replace the star washers that are used today, to make sure the screw does not fall out. This does however have to be explored further in a real-life transportation scenario.

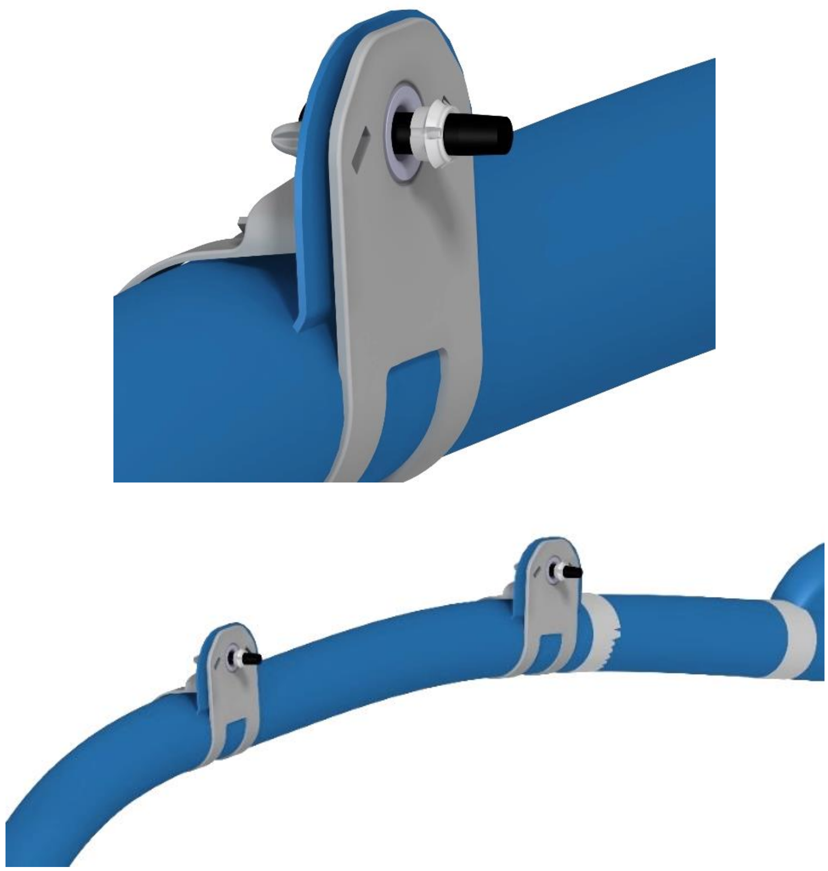


Figure 10.6: Top:a detailed image of the hanger with the snap-fit ring on the screw. Bottom: the snap-fit ring in context with a curtain airbag.

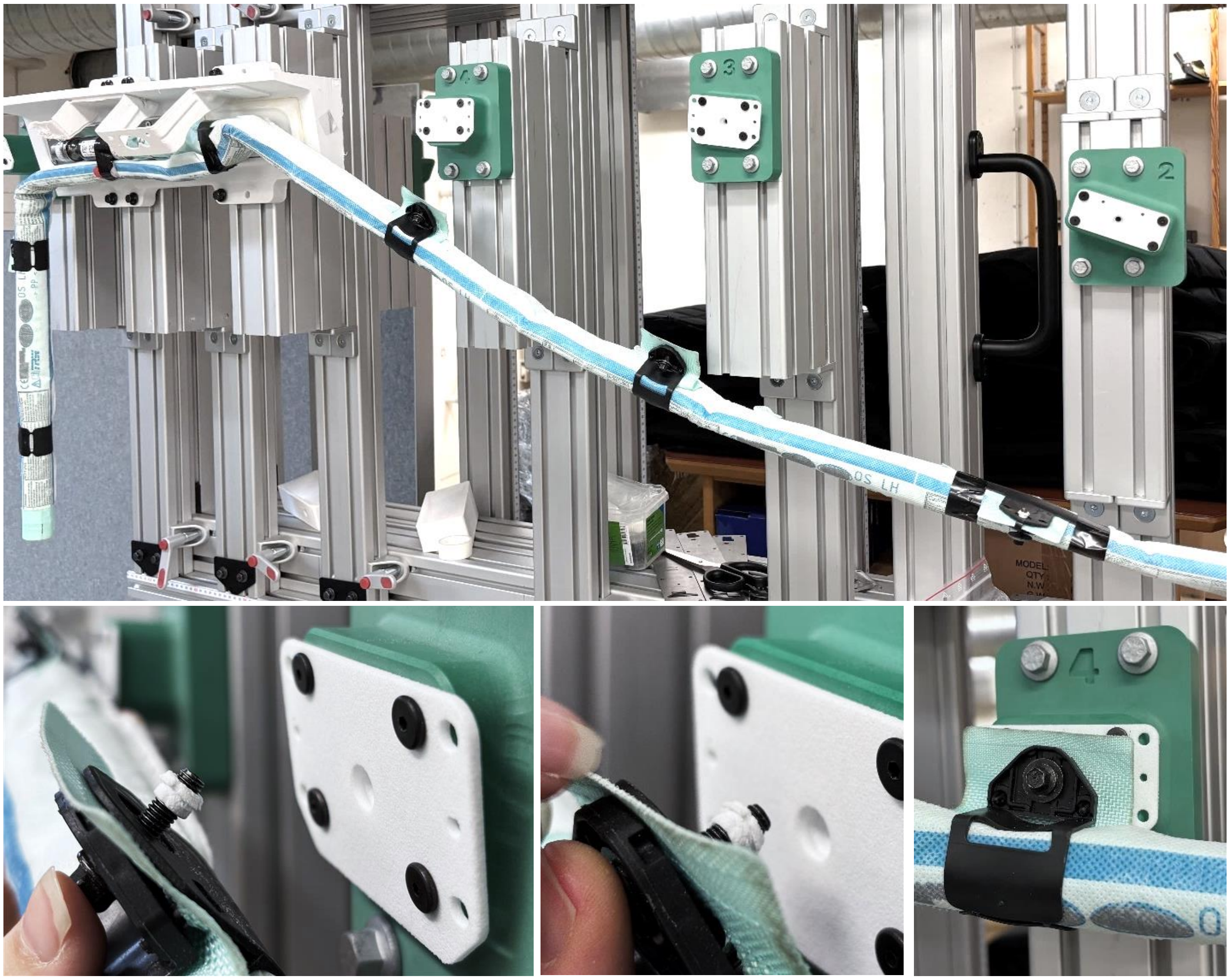


Figure 10.7: Physical prototype of the fixations on a test rig

10.1.2 Gas generator bracket

Different alternatives for a gas generator bracket concept were explored, specifically concepts that were based on rotational assembly. But during testing, it became apparent those concepts did not work out in practice. However, inserting the gas generator with a rotational movement compared to pulling movement has many benefits. Since two ends of the gas generator have to be inserted, a rotational movement allows for one end to be inserted at a time rather than inserting them simultaneously. This approach was based on the information collected from interviews and observations at the assembly line.

The concept with a triangle nut can be seen in Figure 10.8. The triangle is inserted into the footprint and then rotated to lock into place. The problem that was discovered during testing of the prototype was that the angle of the gas generator when rotating it was too large and caused the gas generator to interfere with the roof. This could be countered by designing a nut with a shape that does not require as big of an angle. Alternatively, the triangle nut could be placed at the very end of the gas generator, but this would require a longer gas generator bracket.

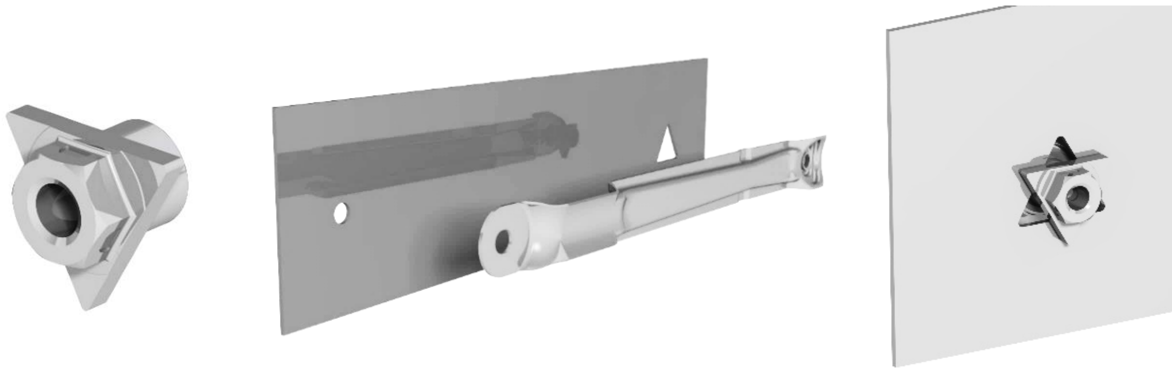


Figure 10.8: Triangle nut concept.

An alternative recommendation is to standardize the gas generator interface with the solution used for the XC60 model, seen in Figure 10.9. During the data collection, it was evident that the assembly line workers preferred the XC60 interface of the gas generator compared to the XC90 one. The gas generator has a nut on one end that goes into a keyhole footprint and is pulled to the side. A keyhole footprint is also preferred with respect to the production of the car body. On the other end there is a kind of third-hand a screw that is easily inserted into a hole. An important aspect if this solution were to be implemented, is to standardize the pulling direction. A recommendation would be to pull it in the direction of the structural hook, as angling because of the screw sticking out opens up in that direction.

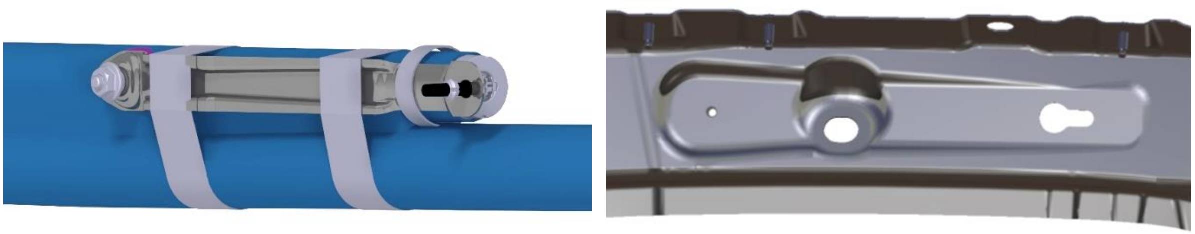


Figure 10.9: The gas generator interface for the XC60 with snap-fit ring solution and corresponding footprint.

10.1.3 Strap buckle

The final concept for the strap buckle focuses on shortening the strap to counter the problems that occur when a long strap is dangling during assembly. The idea is to make the strap elastic so that it is creased until it is manually extended and mounted. For an interface with the snap-fit ring, only one hook is needed for the strap buckle. Figure 10.10 shows what the strap buckle can look like with the snap-fit ring third-hand as well as the corresponding footprint.

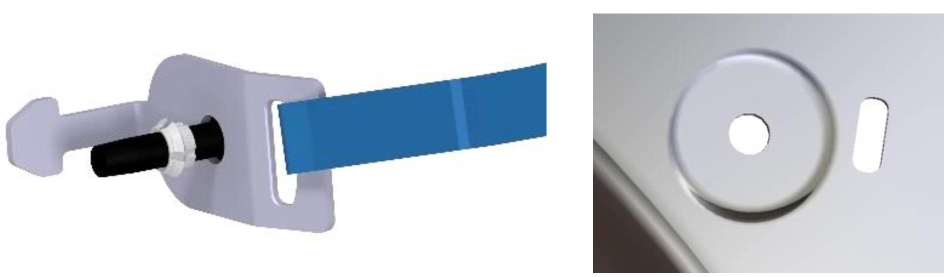


Figure 10.10: The strap buckle and footprint.

10.2 Material and production

Material selection for the final concept was made with analyses in Granta Edupack. A manufacturing suggestion is presented, and the sustainability of the materials are analyzed.

10.2.1 Material and manufacturing weld nut

The material for the customized weld nut remains the same as the weld nut used today, the reason for this is that as few changes as possible should be implemented to save time and costs. The material used for the weld nut today is a grade 8 steel, this information was taken from Teamcenter. Grade 8 steel is often used for weld nuts and nuts because of their medium strength and high tensile strength (Metal Zenith, 2025).

When it comes to manufacturing the weld nut, a simple solution could be to use the existing weld nut and mill into it to make the opening bigger. However, further investigation is required to determine whether that would leave sufficient material on the edges for welding the weld nut onto the body in white. If not, the weld nut edges would have to be made wider.

10.2.2 Material selection snap-fit ring

For the material selection, Granta Edupack is used, level 2 database. Thermoplastics were selected as the first filter. Young's moduli were compared to moldability. A sufficiently low Young's modulus ensures that the part is not too brittle, and the ring has some elasticity to click into the weld nut. High moldability is of importance as it is a small part with a tiny section thickness, more on that in the production section. The resulting graph is shown in Figure 10.11.

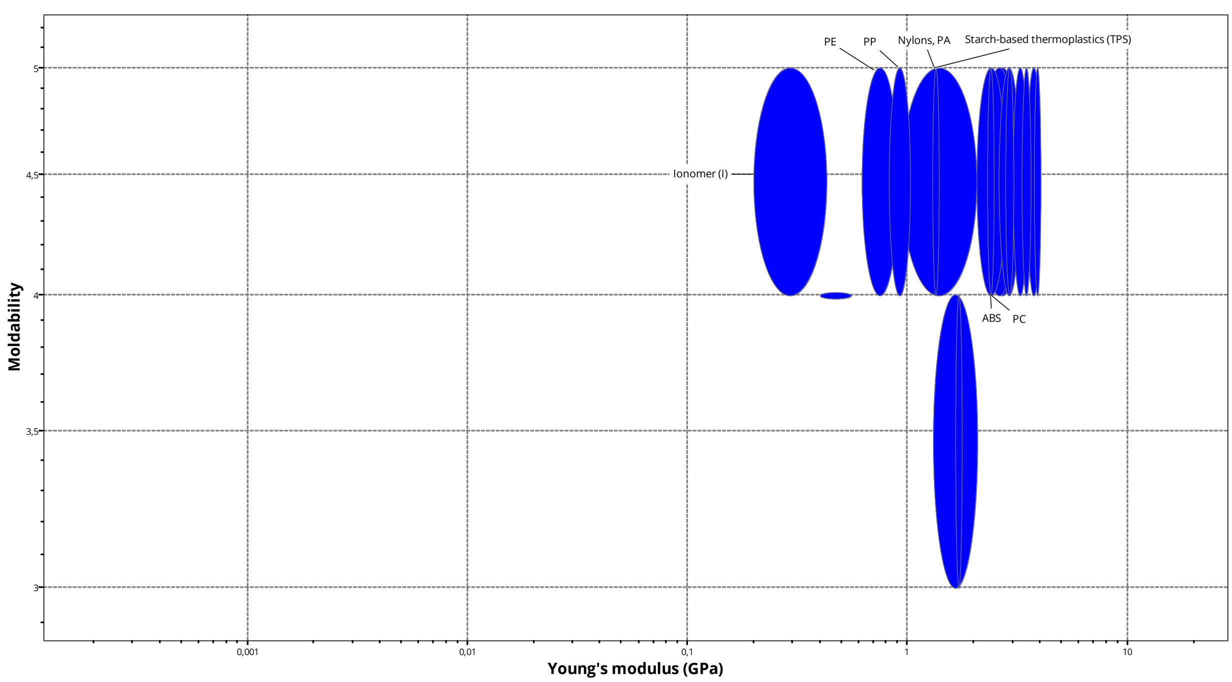


Figure 10.11: Graph of materials with respect to moldability and Young's modulus.

Some materials with high moldability and low Young's modulus are marked. From the prototyping phase, a Young's modulus around that of PP up to that of PA appeared to work well. Besides PP and PA, starch-based thermoplastics (TPS) also found to have a similar elastic modulus. This could be an alternative made from renewable resources.

Next, a moldability of at least four was added as a filter and price was considered, resulting in the graph in Figure 10.12. Here can be seen that ionomers are relatively expensive, and PA is more expensive than PP. The TPS is cheaper than PA and could therefore even be a cheaper alternative to PA with a similar Young's modulus. When considering TPS, factors like biodegradability should be considered. More on sustainability is found in section 10.2.3.

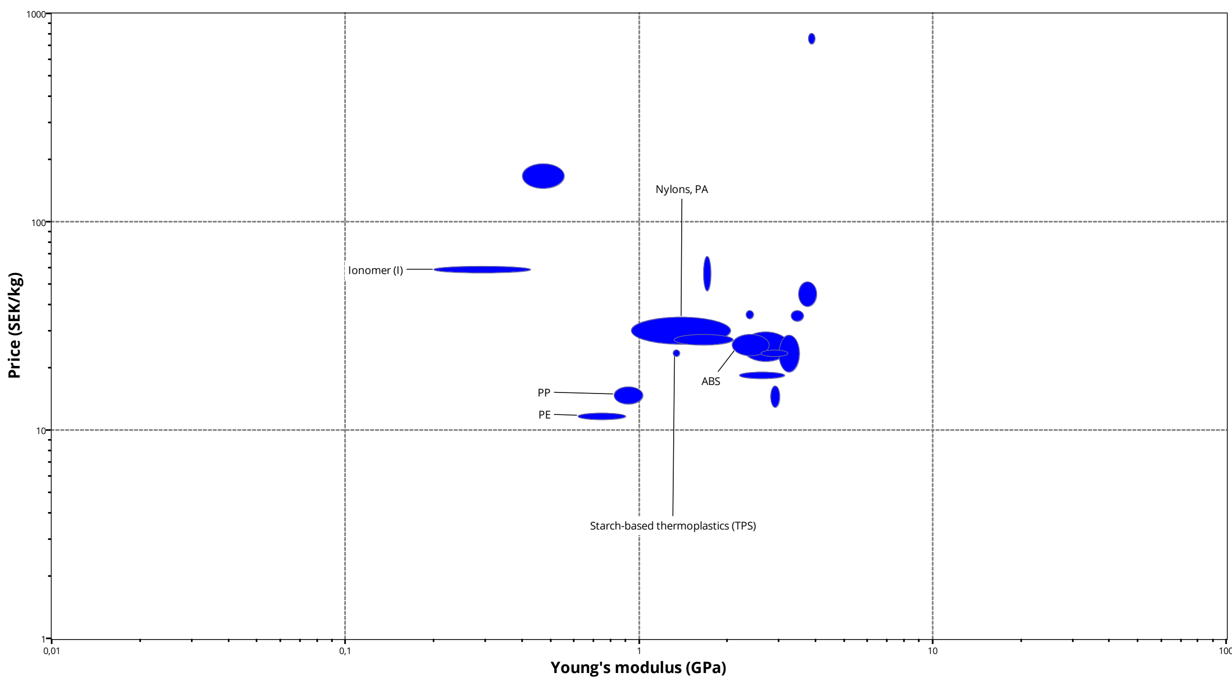


Figure 10.12: Graph of materials with respect to price and Young's modulus

From these considerations, it is concluded that PP is best-suited, followed by TPS and PA. It is cheap and has a suitable Young's modulus. Its suitability for the thin-wall injection molding production needs to be further researched. More on manufacturing considerations is covered in section 10.2.4.

10.2.3 Sustainability snap-fit ring

In order to evaluate the sustainability of the different material choices, an Eco Audit was performed in Granta Edupack. The chosen materials for the comparison were polypropylene (PP), Polyamide (PA) and Starch-based thermoplastics (TPS). Both the CO_2 emissions and the energy consumption during material extraction and manufacturing were explored for the materials. The input was the weight of the snap-fit ring, and the materials were assumed to be virgin. The result can be seen in the graphs shown in Figure 10.13 and 10.14.

Results show that PA is the material with the highest impact during material extraction and manufacturing with a noticeable spike in material extraction. PP is shown to have the second highest impact, with a slightly higher number for energy consumption. However, the manufacturing is almost the same as for the PA, but slightly lower. Lastly, the starch-based plastic is shown to be the best alternative from a sustainability perspective because the numbers are lower in all areas for both CO_2 emissions and energy consumption. In conclusion, the starch-based thermoplastic would be the best choice of material from a sustainability perspective. However, more analysis would be needed to verify its long-term effects with respect to durability, function fulfillment, and sustainability.

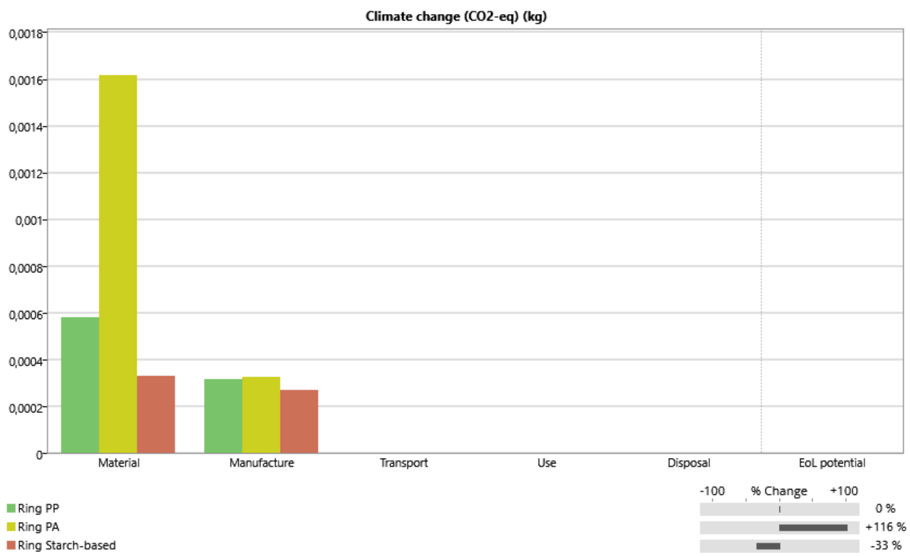


Figure 10.13: Graph showing CO_2 emissions.

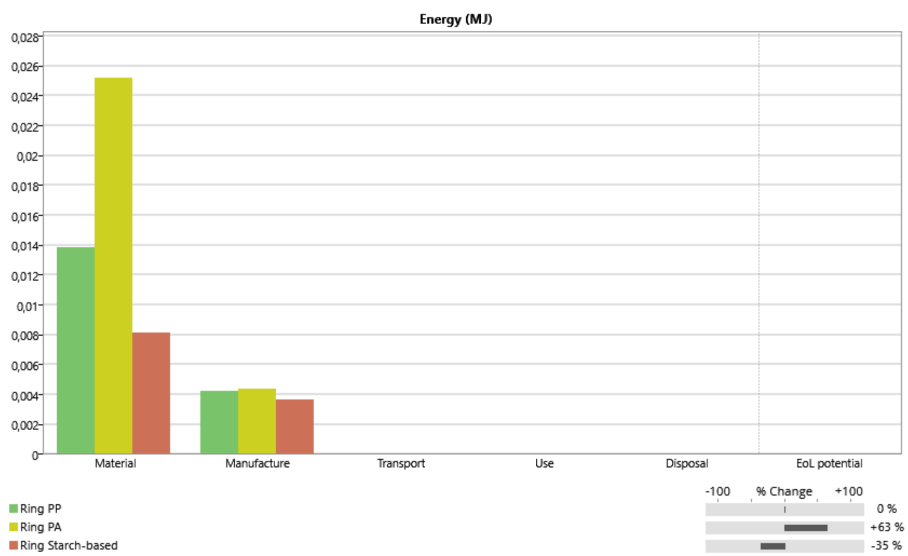


Figure 10.14: Graph showing energy consumption.

10.2.4 Manufacturing snap-fit ring

Injection molding is deemed most suitable considering the part's shape. Its small scale does, however, pose a challenge, as the filling capability of the molten polymer declines rapidly with the reducing of section thickness (Song et al., 2007). Because the overall size of the part is small, the limited reach of the molten polymer needs not to be any issue, as the material does not need to flow into the mold very far to fill it all the way. A sketch of a potential injection mold and required draft angels is shown below in Figure 10.15.

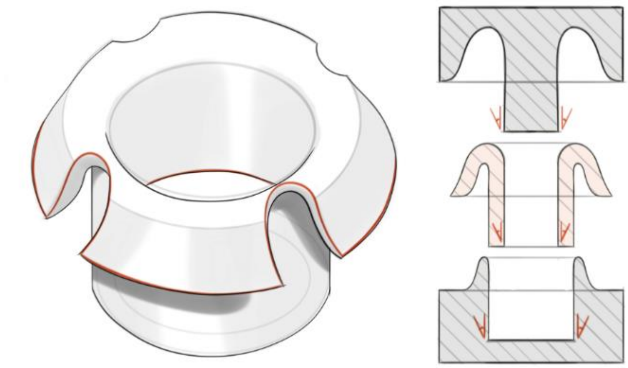


Figure 10.15: Example of injection mold. Locations and directions of the draft angles are indicated by the V-symbols.

A possible alternative could be to injection mold the ring directly onto the screw. This would make the assembly and manufacturing process easier as well as ensuring the precise location of the ring onto the screw. It also prevents that the ring is put onto the screw in the wrong direction. However, this might create difficulties when fastening the screw into the weld nut. If the ring is stuck onto the screw, it can hinder the screw from going through it. Furthermore, one part of the screw becomes thicker which means that it can be hard to fit it through the hole on the hanger produced by the suppliers.

10.2.5 Metal ring alternative

Another alternative for the snap-fit ring was explored where it was made in metal instead of plastic. The function is the same, but the shape and material is different. The metal ring would have to be made in either stainless steel or spring steel, since those have sufficient elasticity for a snap-fit. The manufacturing of the metal ring in stainless steel would be to laser cut the shape and afterwards use bending to get the right angles for the flaps. If the part would be manufactured in spring steel, an alternative bending method to cold bending needs to be chosen, as cold bending only deforms the spring steel temporarily. A prototype of the metal ring can be seen in Figure 10.16.

Figure 10.16: Prototype of metal ring.

11. Evaluation

The evaluation of the final concept is presented below. It includes testing the prototype, comparing the final concept to the list of requirements and an FMEA to analyze potential risks and failures.

11.1 Prototype testing

The prototype testing includes observations and assembly of the prototype. First, the observations performed with a Group Design Leader are discussed, then, the results from the testing of push-in forces are shown and a mean value was calculated using a sample standard deviation. Lastly, the observations and measurements of the push-in forces performed together with a manufacturing engineer are presented.

Observations GDL

Observations were made together with a Group Design Leader at Occupant Safety. The curtain airbag with the snap-fit ring prototypes were assembled onto the test rig with the 3D printed footprints attached. The GDL had a generally positive attitude to the solution when trying it. However, one concern that came up was that star washers might be needed to stabilize the screw and make it more rigid, which in turn would facilitate guiding it into the hole. The GDL also mentioned that since it is only a small screw and a small hole, guiding it in might prove difficult. It was discussed that it could perhaps be solved with embossings around the hole.

Push-in forces

The results from measuring the push-in forces are depicted in Table 11.1. Summing up all the values and dividing by 15 results in a mean push-in force of μ = 15.15 N. The sample standard deviation is calculated in accordance with the first formula provided in section 3.2.15.

$$s = \sqrt{\frac{\sum(x_i - \mu)^2}{n-1}} = \sqrt{\frac{143.46}{14}} \approx 3.201\, N$$

Next, the certainty interval (CI) is calculated for a 95% certainty. For a 95% certainty and sample size equal to 15, the *t*-value as introduced in section 3.2.15 equals $t \approx 2.145$. This means that the interval equals:

$$CI = \mu \pm t \cdot \frac{s}{\sqrt{n}} \approx 15.15 \pm 2.145 \cdot \frac{3.201}{\sqrt{15}} \approx 15.15 \pm 1.773 \text{ N.}$$

In conclusion, with 95% certainty, the experience push-in force of the workers will be between 13.38 and 16.95 N.

Table 11.1: Push-in forces

#	*Force (N)*
1	17.8
2	15.9
3	19.5
4	15.2
5	16.1
6	17.6
7	14.9
8	13.1
9	10.6
10	10.8
11	15.3
12	8.6
13	19.6
14	17.0
15	15.2

An observation was also performed with a manufacturing engineer to get insights about the solution as well as test the push-in forces. The feedback from the manufacturing engineer was mostly positive towards the concept and stated that it has potential. Some constructive feedback included continuing to investigate tolerances and further developing the snap-fit ring to ensure that it stays in the correct position on the screw. The manufacturing engineer measured the push-in forces as well with great precision, using the same force meter and got as low as 4 N. They also believed that after looking into tolerances, the push-in forces could be even lower, as the pull-out forces were higher than necessary.

Observations ME

11.2 List of requirements

An updated list of requirements that include fulfillment of the requirements can be found in Appendix E. How the requirements are fulfilled is described in more detail below.

11.2.1 Main functions

The solution keeps the curtain airbag in place during its lifetime and during deployment because the solution utilizes a screw which is a method that has been in place at Volvo Cars for a long time and is proven to work (P3, personal communication, 2024). The solution does not affect the airbag performance since it is not in the way of the deployment or hinders it in any way. Lastly, the solution can easily be standardized because it suits many different suppliers, no matter the material they use. Since it is only a loose part in the form of a ring, any supplier can have them on hand and put them on the screw. The simple footprint also makes the solution fit a variety of car models easily. The round hole does not take up much space which means that the footprint does not have to be adapted if there is less space in certain models.

11.2.2 Ergonomics

The testing of the prototype for the push-in forces shows that the push-in force is around 15 N, therefore the requirement is largely fulfilled. In a real-life scenario, the fixations may be possible to be pushed in with two fingers. It was also discussed with the manufacturing engineer that improving tolerances could lower the push-in forces even more. They were also able to measure push-in forces as low as 4 N.

The solution does not impact the angle for the screwdriver, and is the screw is similar to the current clip-screw in this aspect. The snap-fit ring weighs less than a gram and does not add any significant weight to the curtain airbag. Therefore, the solution meets the requirement of the curtain airbag not weighing more than 1,4 kg. Lastly, the solution did not affect improvements regarded to assembling at different heights.

11.2.3 Third-hand

The solution has a third-hand integrated by design. The ring has a snap-fit function that snaps into the weld nut and since the hole in the car body is smaller, the ring makes the screw stay in place. The snap-fit function ensures that the curtain airbag stays in place until the screws are fastened. Since the ring is made in an elastic material, it is assumed to not break during assembly. However, if it can be assembled ten times without breaking should be investigated further. Screw-alignment is optimal because inserting the third-hand puts the screw in place in the weld nut. Since the solution is a ring that can be put on the screw and acts as a star washer simultaneously, there is no need for the third-hand to fit through a star washer.

The solution has been tested at angles from 27-90 degrees and does not fall out. Furthermore, when the solution is placed onto the car body, the curtain airbag will be at a downward angle and thereby makes fastening the screws easier. A benefit is that the third-hand can easily be pushed in linearly without having to coax it in. When it comes to service, the third-hand can either be removable or stay put in the weld nut while the screw is screwed out. No pliers are needed in the process of taking it out.

11.2.4 Assembly and context

The solution fulfills the majority of the requirements for the assembly and context. Nothing with the solution interferes with cabling and no magnets are used. The assembly with the snap-fit is possible from both the inside of the car and the outside with blind assembly. Further tests would need to be conducted to know the exact assembly time for the solution. However, assumptions will be made that the assembly time is within the required time of 57 seconds because of its straight-forward assembly. Furthermore, the screw can stick out 8 mm as the third-hand is not reliant on how much the screw sticks out from the hanger. Lastly, it can easily be assembled with gloves.

11.2.5 Ease of assembly

The solution has a clear advantage from an ease of assembly perspective because it is very similar to the solution that is already used at the Torslanda plant. This means that the assembly workers will not have to learn any new assembly steps or methods. Other than that, the solution in itself is intuitive. The ring has a clear snap-fit function, and the only assembly step is to push it straight into the footprint. The symmetry also makes it easy for the operator because the fixation is assembled consistently across the car body. Lastly, the snap-fit provides both audible and tactile feedback, which facilitates knowing when the fixation is correctly inserted. Audible feedback is in the form of a 'click' sound upon insertion, and tactile feedback follows from the fact that a snap can be felt when the snap-fit is inserted.

11.2.6 Consistency/producibility

The footprint is both symmetrical across the car and utilizes a round shape which lowers the tooling costs significantly. The ring, however, is a separate part that does not utilize the existing infrastructure of suppliers, but since it is a loose part, it is entirely supplier independent. The simple round shape of the footprint also makes it possible to produce with both laser cutting and hole punching.

11.2.7 Footprint

The footprint for the solution is optimal because it is simple and only consists of one round hole. This means that the footprint can fit anywhere, tools to create the hole already exist, and there are no problems with double sheet metal. No special accommodation has to be made for hangers at tighter areas of the cantrail.

11.2.8 Costs

There were no defined cost requirements since calculating the cost is out of the scope. However, the cost has been considered. The solution aims to lower costs by having a simple footprint that is easy to produce with already existing infrastructure. The ring itself may be relatively costly for its tiny measurements, though its material costs are therefore also low. The custom weld nut adds to costs as well, how much needs to be further investigated.

11.2.9 Sustainability

The sustainability of the fixations has been taken into consideration. During the material selection process, the CO_2 emissions and energy consumption for three different materials were assessed. Recommendations based on the analysis were to choose either starch-based thermoplastics or PP for the snap-fit ring. The choice of material determines whether the part is recyclable, however, the size also contributes to making it difficult to recycle. The concept of topology was not used in the final concept to minimize the amount of material. Although, since the part is very small, not much material is required, which is positive from a sustainability perspective.

11.2.10 After end of production

Because the solution is utilizing the standard screws already in place at Volvo Cars, traceability requirements and durability requirements after end of production are already met. Whether the ring will last for 15 years after end of production cannot be concluded without further analysis and data collection. However, there is no need for the snap-fit ring to last since it only serves its purpose between inserting the curtain airbag and fastening the screws.

11.3 FMEA

The components of the solution include: the plastic ring, the weld nut, screw, and footprint on the body in white. For the component part, only the ring and weld nut are considered, as it is those parts that are newly designed. However, their relations to the screw and body in white are important as well. Therefore, the relations that are considered is the ring to the screw, the weld nut to the body in white, as well as the ring-screw combination to the weld nut and body in white. Using the scales as introduced in section 4.7.3, the FMEA results are shown in Table 11.2 and 11.3. To clarify, an appearance FMEA was used but the aesthetic parameters were removed.

Table 11.2: Component FMEA

1	2		3				4
Component	*Error possibility manufacturing*	*Aging, use, environment*	*Cause of error*	*Error proba-bility*	*Effect*	*Risk number*	*Measure of action and notes*
Ring	Part not entirely filled	/	Low section thickness	8	8	64	Increase pressure, thicken sections, material selection
	Wrong measurements	/	Shrinkage when cooling	2	6	12	*Low error because can be compensated for*

	/	Breaking of edges	Forces on thin material	6	7	42	Thicken edges, higher quality material
	/	Loosing elasticity	Material aging	8	3	24	*Ring mainly of importance during first assembly*
Weld nut	Wrong measurements	/	Milling misalignment	2	4	8	
	/	Wrong self-threading	Wrongly held screwdriver	2	3	6	
	/	Rust	Oxidation	1	4	4	*Stainless steel*

Table 11.3: Relations FMEA

1	2		3				4
Relation	*Error possibility manufacturing*	*Aging, use, environment*	*Cause of error*	*Error proba-bility*	*Effect*	*Risk number*	*Measure of action*
Ring to screw	Wrong place of ring on screw	/	Placement error, transport, small tolerances	9	10	90	Injection molding onto screw, automation
	Ring fallen off screw	/	Transport, breakage	7	10	70	Injection molding onto screw, spare parts
	/	Ruined threading	Screwing in and out	4	2	8	
	/	Loosening of ring	Plastic relaxation	8	2	16	*Ring mainly of importance during first assembly*
Weld nut to BiW	Too small hole opening	/	Weld nut/hole misalignment	3	3	9	
	Too little groove volume	/	Groove welded shut	4	5	20	Increase contact area by enlarging weld nut
	Foam in weld nut	/	Not properly closed	5	2	10	*As long as groove is open, no issue*
	/	Weld nut breaks loose	Too little contact area	2	10	20	Increase contact area by enlarging weld nut
Screw and ring to weld nut and BiW	Does not fit into weld nut	/	Ring too far onto screw	9	10	90	Injection molding onto screw, automation
	Cannot be screwed in	/	Ring too much on the tip, no contact with threading	9	10	90	Injection molding onto screw, automation
	Ring breaks when pushed in	/	Ring fragility	6	7	42	Thicken edges, higher quality material
	/	Ring not usable for service	Aged, relaxed, decomposed	8	2	16	*Ring mainly of importance during first assembly*
	/	Ring stuck in weld nut	Screw screwed out completely	7	2	14	*Ring mainly of importance during first assembly*

In conclusion, it should be further looked into if the part is producible with its low section thickness. Thicker section and a higher quality material could be considered for a more stable part. Injection molding the ring onto the screw could be tested and considered, to achieve a more precise location of the ring on the screw. The weld nut may need to be made wider to provide sufficient contact area for welding it onto the car body.

12. Discussion

First, the reflections on the methods and executions are covered. The final concept is discussed separately in the section following it. Subsequently, future implementation is discussed. The chapter closes with a section on the recommended next steps.

12.1 Methods and execution

The different phases of the project are discussed below. Limitations and overall execution are brought up and discussed in different lights.

12.1.1 Benchmarking

The benchmarking was a foundational part of the project. The database Iceberg 3.0 gave a broad overview of many solutions that exist on the market from many different brands. Charting all of the solutions in Iceberg 3.0 took quite some time but proved worthwhile in the end. Except Iceberg 3.0, some additional sources were looked up through the search engine google to find more solutions. The searching proved to be beneficial since more details could be found for certain fixations, though did not follow any academic approach. These details were not explicitly listed in Iceberg 3.0.

12.1.2 Data collection

During the data collection, a questionnaire was conducted. The questionnaire was placed in the breakroom of the assembly line workers that mount the curtain airbag. However, the answers were few, only 5 in total. The reason for this is that there are not many people who work with assembling the curtain airbag, approximately 8 people. It is difficult to find people who do this niche task at Volvo Cars since not everyone has assembled a curtain airbag. But another reason could be that the job is demanding, which could lead to a reluctance to answer a questionnaire during breaks. Furthermore, there was a limited number of interviews. The reason for this is because of limited amount of time, but one factor was also that an external expert that was contacted did not answer. Some quick interviews were conducted with the assembly line workers, but there was no possibility of doing more in-depth interviews because of their tight work schedule and demanding tasks.

When it comes to the observation at the production, there were some limitations. The preparation was done with the intention to only observe the assembly and not considering talking to the operators. The assumption was that there could be no talking to interrupt their work. However, at the observation, skilled people who had assembled for a long time were available to talk to. Because of the lack of preparation, the interviews might not have lived up to their full potential. The questions that were asked were improvised, and although a lot of important information came up, the interviews could have benefited from some more preparation. Whether the result was affected by the unstructured interview is difficult to say, but in the end, many important insights came up that contributed to the end result, which is satisfactory. Another limitation at the observation was that data could only be collected from experienced workers and the less experienced workers were left out. Assembling the curtain airbag involves a lot of time pressure. However, some inexperienced workers answered the questionnaire which meant that their perspective was represented as well in that manner.

Regarding the performed ergonomic analyses, the RULA for the work positions received the highest score. This may not be a complete representation of reality because the observations that formed the base for the RULA were done at the test production. At the test production, they assemble the curtain airbag in a different way than they do at the assembly line. This is because there is much more time at the test production and the motions are not as repetitive as on the assembly line. The huge difference at the assembly line is that the curtain airbag is assembled blindly from the outside. This way of mounting is not accounted for in the RULA and could get a completely different result. With the blind assembly, the arms are not working above the operator's head, and their body is not twisted, so an assumption would be that the results would be better.

The co-creation workshop was a great source of inspiration and a good way to evaluate existing concepts together with experts. A limitation with the workshop was that there was not enough time. The workshop lasted two hours, but there were many tasks to go through which meant that the evaluation at the end was cut short. For a future project, the number of tasks should be shortened, or the time should be increased.

12.1.3 Analysis

During the analysis phase, there was a vast amount of data to analyze from many different stakeholders. When performing the KJ analysis, difficulties arose when sorting the data into different categories. This was because the interviews were performed with stakeholders that are specialized in a certain area and the data therefore became specific to that area. In some cases, it was hard to find common ground in the data, causing difficulties sorting it into categories.

12.1.4 Idea generation

The ideation progressed smoothly, and many ideas were created. Inspiration boards and theory about joining methods helped accelerate the process. Lo-fi prototypes helped to quickly test some of the functions and get a third dimensional view of the ideas. There were so many ideas and sketches in the end that it became difficult to gain an overview. However, this was solved by performing a sort of KJ analysis and placing the sketches into different categories.

12.1.5 Concept development

Concept development proved more challenging. Compressing all the ideas into several viable concepts was in the end achieved through several iterations. This resulted in an extensive list of initial concepts to be further considered. The number of initial concepts caused the process to take a lot of time. When the final three concepts were selected, time was still a challenging aspect, because of the ordering time of prototypes, limiting the number of possible iterations.

Lastly, dividing focus between the fixations and both the gas generator and strap buckle sometimes proved challenging. In the end, the ideas from the fixations did affect the designs of the gas generator and strap buckle in such a way that tied it all together.

12.1.6 Evaluation

The measurements performed during the evaluation had quite high uncertainty intervals. This may be due to the various variables that where changed, including various rings, weld nuts, and assembly angles. In hindsight, changing one at a time could have resulted in more clarity in what causes the greatest variations. In addition, it is difficult to say to what extent the measurements accurately represent the assembly styles of the people at the assembly line that experience time pressure. It was tried to not always perform the measurements too carefully, as that will not be accurate to the real case.

With respect to the list of requirements, it was sometimes difficult to objectively verify the extent to which they were fulfilled. This was either because there was no measurable objective or because the idea was still in a conceptual state that made measurement impossible.

With respect to the FMEA, the technique was derived from an Appearance FMEA, which, as the name suggests, is focused on visual aspects. This is, however, not of great importance in the case of the curtain airbag fixation, that disappears behind the headlining of the vehicle. The advantage of the technique was its focus on the interfaces or relations between components, which is a relevant aspect of the design. Though, in hindsight, a more traditional FMEA technique could have been considered, that focusses more on function and does not require adjusting.

12.2 Reflections on final concept

The final concept successfully achieves the main objective. The snap-fit ring simplifies standardization, as it is compatible with numerous car models due to its compact design, requiring only a single hole. The concept also fulfills most of the requirements that were included in the requirements list. Some exceptions need further investigation to ensure that the requirement is met. However, it is of importance to note that the appearance and functionality of future cars are unknown, which means that there is no guarantee that the main objective will be fulfilled for future vehicle models.

Another important aspect at Volvo Cars is the traceability of their parts. This is a non-negotiable requirement and with the final concept, that requirement is fulfilled. This is done by continuing with the way traceability is ensured today, which is by logging torque data with the screwdriver. Due to this, the final concept can be easily implemented and fits into the already existing infrastructure. Another aspect of this is that the final concept is similar to the clip-screw that is used on the assembly line in Torslanda today. This is a benefit for the operator because it means that they do not have to relearn the process.

On the other hand, there are some disadvantages with the concept that can be discussed. The snap-fit ring, being a small component, may pose challenges in terms of cost and manufacturing. Additionally, its small size could lead to issues with it becoming loose or misaligned during the manufacturing process. The tolerances for where the ring can be placed on the screw are also small. If the ring sits too high on the screw, it cannot be inserted into the weld nut since the screw is obstructed by the threads. If the ring sits too low on the screw, the threading on the screw will not be able to reach the threading in the weld nut.

Furthermore, the concept requires a special weld nut. This is a downside from a cost perspective since the standard weld nuts that are already in use, cannot be utilized.

Some further investigations also need to be made to make sure that the ring can act as a washer during transport and to test if it provides enough stability during assembly. Otherwise, a star washer might be needed anyway, and that cost will not be reduced.

Lastly, when it comes to sustainability, the final concept is a very small part which makes it difficult to recycle. During disassembly the part can disappear easily and the effort to recycle it may not be sufficiently lucrative to ensure sufficient motivation. The part is also made of plastic, and even if analyses were made to find the most sustainable type of plastic, it affects the environment. The little amount of material is positive from a sustainability perspective.

12.3 Future implementation

For future implementation, one critical aspect to consider is the process of blind assembly. This involves understanding the differences between how production is planned and how it is actually executed on the assembly line. While planning is essential, real-world conditions often present unforeseen challenges that can impact the assembly process. Therefore, it is crucial to develop flexible and adaptable assembly methods that can accommodate these variations.

Furthermore, a significant challenge lies in the fact that the design and requirements of future cars are largely unknown. This uncertainty means that there is no guarantee that the suggested solution will work for future cars. A forward-thinking approach is important to solve this problem.

Looking ahead, the future of assembly processes is likely to be heavily influenced by automation. Automated systems can enhance precision, efficiency, and consistency in production. Automation can also help mitigate the impact of human error and adapt to the complexities of modern vehicle designs. As we move towards automation, the need for a third-hand when assembling curtain airbags will become obsolete. No ergonomic considerations are necessary, and the optimal solution might become to simply mount with a clip or a screw.

In summary, the future implementation of this project will require a balanced approach that considers the realities of in-car assembly, the uncertainties of future vehicle designs, and the potential changes connected to automation. By staying adaptable and forward-thinking, robust assembly processes that are well-equipped to meet the challenges of tomorrow can be developed.

12.4 Recommended next steps

In the next phase of this project, a detailed cost analysis will be essential to evaluate the costs of each proposed material and process. The use of biodegradable materials should be investigated as alternatives to the currently used thermoplastics, exploring options such as wood or continuing with metal. Additionally, material aging tests will be necessary to assess elasticity over time, ensuring both longevity and sustainability. However, if the elasticity does not hold over time, the ring can just stay in the weld nut upon disassembly and then be replaced by another ring. Furthermore, investigations of the effectiveness of the star washer during transport should also be conducted to see if a star washer is needed or not. To improve the method of guiding the screw into the hole, the option of adding embossings around the hole could be explored.

For the ring and screw assembly, the possibility of injection molding the ring onto the screw should be evaluated to ensure that it fits through the star washer with good margins. Alternatively, the ring can be screwed onto the screw post-production, but assessments need to be done to make sure the ring is not applied in the wrong direction. It is also crucial to test if the ring remains securely attached to the screw throughout the entire process.

Experimenting with different materials, tolerances, and shapes will help optimize the push-in force required for assembly. Service tests should be conducted to evaluate the ease of reassembly, addressing the current limitation of brittle prototypes and exploring the possibility of making components removable without the need for pliers.

Additional time should be allocated for testing the gas generator and strap buckle to ensure functionality and safety. The necessity of the hook should also be assessed when using a snap-fit ring for the strap buckle, considering the potential for an extendable strap and the risk of metal scratching the car body.

Finally, tests should be conducted for the process of milling the weld nut and welding it onto the car body to ensure a secure and durable connection. Tests should also be conducted to ensure that the injection molding of the thin walls of the snap-fit ring is feasible.

13. Conclusion

This thesis aimed to come up with a standardized solution for the curtain airbag fixations at Volvo Cars, as currently the attachment points on the curtain airbags and the corresponding hole patterns on the car body vary between models, which is both time and resource inefficient. The development process included benchmarking existing solutions, gathering input from stakeholders, and developing conceptual designs and initial prototypes. Key findings from the data indicated that using a screw in the fixation is the most suitable option from a Volvo Cars perspective. Critical requirements considered included the need for low push-in forces, traceability, and durability during deployment.

The proposed solution is a plastic snap-fit ring that fits around the screw. This ring snaps into a hole in the car body, and a specially designed weld nut, milled wider at its base, provides space for the ring to secure itself. The final concept achieves the goal of standardization, as it can be adapted to fit various car models due to its simple footprint, which consists solely of a round hole. In the following sections, answers to the sub research questions will be provided first. In the second and last section, the main research question of this thesis will be answered.

13.1 Sub research questions

What are the critical needs for the interface?

The interface must keep the airbag in place during its lifetime and possible deployment. It should not affect the airbag performance and must fit a variety of car models. Secondly, the interface should facilitate ergonomic assembly. Push-in forces should not exceed 15 N per finger and 30 N for two fingers, but preferably less. Where a screwdriver is used, the interface must be designed so that it can be operated from the position of the assembly worker. A third-hand must be integrated into the interface design if a tool is required to form the permanent connection. This third-hand must keep the airbag in place during assembly and be robust enough to be reassembled 10 times. It must align the screw or other permanent fastener to its respective footprint.

The interface must have its gas generator located above the rear door, and its bracket must also be strong enough for deployment. A consistent mounting pulling direction must be ensured over different vehicles. The gas generator bracket must also stay in place during assembly until the screw or other permanent fastener is used. The strap buckle must stay in place both vertically and horizontally, also before the screw is fastened. The assembly of the interface must not interfere with the cabling and must be possible for blind assembly and assembly from the inside. It must be completable within 50 seconds. If a screw is used, the assembly should be possible with the screw sticking out 8 mm from the airbag hanger. It must be impossible to incorrectly mount the curtain airbag or to mix up the components of the interface.

The interface design must account for double sheet metal and a weld nut in case a screw is used. The holes in the double sheet metal must be oversized. Sufficient distance between the holes of the interface is required. The holes are to be placed only on flat areas, any embossing must be away from the edge. It is required that the holes in the body in white can be laser cut and hole punched. The solution must be producible by different suppliers and their respective materials. The assembly data of the interface must be traceable for at least 15 years after end of production, and the interface design must be serviceable. The interface design and materials are to last 15 years.

Which attachment designs already exist on the market?

Most attachment designs contain a third-hand and a screw, that either includes a metal hook, a tree third-hand, or a plastic bit on the screw. The metal hooks either have two hooks with a screw in the middle, only one hook on the side besides the screw, or a hook below the screw. The tree third-hand can be placed below the screw, as well as beside the screw. The screw with the plastic bit on the end that works as a third-hand is used by Volvo Cars and is called a clip-screw.

In addition to the solutions consisting of a third-hand and a screw, several clip solutions exist. Most common is the metal clip, that is pushed in by hand and therefore does not need a third-hand, though the push-in forces are relatively high. The metal clip can be extended with a plastic part to increase its ergonomics, or to include a barcode for traceability. In addition to the metal clip, a plastic clip design also exists.

With respect to the gas generator and strap buckle, the designs are more uniform. The gas generator brackets generally consist of a structural hook and a smaller hook that functions as a third-hand, which has a screw next to it. The structural hook is either a large hook or a nut that is pulled into a keyhole-shaped hole. Designs with two screws that lack the structural hook exist but are uncommon. The strap buckle generally has a screw and one or two hooks that function as a third-hand.

How can the attachment be easy and ergonomic to assemble?

With regards to ease, consistency of the design is of great importance. Both within the interface design of one car, as well as between cars. An intuitive, self-explanatory design increases ease, and can optionally be complimented through semantic aids. Embossings can also be used to visually and tactilely clarify the assembly. Regarding ergonomics, the push-in forces is the most important factor affected by the attachment design. Reducing the push-in forces reduces the strain on fingers and hands. Facilitating blind assembly can also improve the ergonomic conditions, as the posture of blind assembly is better than assembly from inside the car. Facilitating the use of gloves or possible ergonomic tools can improve the ergonomic conditions even more.

How can the attachment be strong enough to survive the impact of the airbag deployment?

This sub-question was ultimately not further researched, as the final concept incorporates an already used fastener in the form of a screw. The use of screws has proved an effective way to achieve strong attachment and uncomplicated assembly. Including a screw as the permanent way of attaching therefore ensures that the design will hold during deployment. Alternatively, other fasteners that are rigorously tested can be used to replace the screws, such as the existing metal clip.

How can the attachment be suitable for various different car models and thus measurements?

When it comes to standardizations, four aspects are to be considered. Firstly, how much space the solution takes up on the cantrail, especially in the vertical direction. A footprint consisting of two holes arranged vertically potentially does not fit on smaller parts of the cantrail. Cantrails may be designed even smaller in future models, risking that such solutions no longer fit. Secondly, the angles of assembly vary among cars. To ensure that the attachment is suitable for any car, enabling assembly at extreme angles ensures a future-proof design. Thirdly, the plate thickness can vary, and when there are double plates, the holes on the inner plates need to be oversized. By creating a simple footprint to accommodate this, the solution fits different car models with different plate thickness.

Lastly, the suppliers should be considered. Curtain airbags are delivered by different suppliers for different car models, working with different materials. Especially the hangers of the curtain airbags should be considered, as different suppliers have different designs and use different materials. A design that is not dependent on supplier is therefore optimal. This can be achieved by means of a design that can be produced in different materials, or that is included in the fastener, such as the clip-screw, the metal clip, or the concept that is argued for in this thesis: the snap-fit ring screw.

13.2 Main research question

How can the interface of the curtain airbag attachment to the car body be standardized to ensure optimal safety, ergonomic assembly and compatibility across different vehicle models?

The interface could potentially be standardized by the concept introduced in this report. By using a snap-fit ring that fits around the standard M5 screw near its end, the screw can click behind the footprint hole. The weld nut behind the hole is milled a bit wider at its opening to allow for this. This way, the screw sits exactly in place until the screw is fastened into place by a tracking screwdriver. As the screw is fastened, the ring stays in place in the weld nut and the screw rotates through it. The screw forms the permanent attachment, that keeps the airbag in place during its lifetime and possible deployment.

With regards to safety, it is not about the curtain airbag itself or deployment, but rather about ensuring correct assembly and a poka-yoke design. The snap-fit provides audible and tactile feedback when it is clicked in. It only fits into the holes with the specially designed weld nut. For regular M5-holes, the ring will not fit into it. For larger holes, it may be possible to push the screw into it, but it will fall out again as it has no edge to snap behind, ensuring poka-yoke assembly. Airbag twisting may be prevented as the screw cannot reach the right hole upon twisting, as it will shorten the bag. In addition, as a screw is used, the tracking screwdriver verifies that the screw is fastened with the right amount of torque. It also ensures that the correct assembly can be verified years afterwards.

With regards to ergonomic assembly, the concept ensures a minimal push-in force to limit the strains on hands and fingers. The use of gloves is not obstructed by the design since it can be pushed in both with the use of gloves and without. Embossings may be added to facilitate blind assembly, which ensures a more ergonomic posture.

Compatibility across different vehicles follows from the footprint of the concept. It requires only one relatively small hole, taking up relatively little space. An assumption is that it would therefore fit even on the smallest of cantrails in future car designs. The snap-fit ring solution works independent of the angle of assembly, keeping the airbag in place even if assembled hanging from a roof. It also works irrespective of the plate thickness of the car body. Lastly, it should be producible by different suppliers, as the snap-fit ring is not affected by the airbag hanger design or material.

In conclusion, the concept introduced in this report enables standardized assembly by using a snap-fit ring around a standard M5 screw, which clicks into a specially milled weld nut. This ensures the screw stays in place until final tightening with a tracking screwdriver. The design supports correct assembly through audible and tactile feedback, prevents incorrect fitment in non-matching holes, and allows for torque verification and traceability. Ergonomic assembly is facilitated through minimal push-in forces. The compact footprint and independence from assembly angle or supplier-specific materials make it suitable for various vehicle designs, thus fulfilling the aim of this thesis.

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Appendix

A. Interview Template

A.1 Attribute leader service

Setup: semi-structured interview

Berätta vad vi gör

1. Kan du ge lite bakgrund till ditt jobb och vad du gör?
2. Vad är den största anledning till att en IC behöver service?
    a. Hur ofta?
3. Vilka services genomför du specifikt för IC:n
    a. *Visa? Förklara dem?*
    b. Hur lång tid tar det? Tidspress?
    c. Vilka verktyg använder du?
4. Vad är mest ansträngande med att genomföra service på IC:n
    a. Hur mycket kraft känns bra för dig när du drar ut IC:en?
5. Vilka nuvarande problem med att byta ut IC:en finns?
    a. *… och med andra services*
6. Vad fungerar bra i nuläget?
7. Vad tycker du är viktigt med IC-infästningar? Vad skulle de nya infästningarna i alla fall ha med?
8. Finns det krav för vilken kraft man ska kunna ta bort ICn med?
9. Har ni någon kommande ”teardown”, skulle man kunna få vara med på det?

Tusen tack!

A.2 Principal engineer upper car body

Setup: Interview

Berätta vad vi gör

1. Kan du berätta lite om er avdelning och vad ni gör?
2. Kan du berätta om processen när det kommer till IC footprintet? Hur kommunicerar ni med airbags & steering wheels, när, hur många gånger?
3. Hur går processen till när ni gör hålbilden i karossen?
    a. Hur lång tid?
    b. Vilka problem kan man stöta på?
    c. Vilka hålformer är lättare/billigare att göra och vilka är svårare/dyrare? Vilka verktyg används?
    d. Vad är möjligt, vilka former?
    e. Vilka möjligheter finns för att ändra vinklar? T.ex. att lägga till en extrusion på karossen.
4. Upplever ni att det är ett problem att karossen inte kan frysas så tidigt i processen och att footprintet ofta ändras?
5. Var på karossen finns det hål reserverade för IC, vilka hål finns runtomkring att ta hänsyn till?
6. Vilka variationer i tjocklek av karossen finns det runtomkring IC:n? Och vilka material?

Tack!

A.3 Manufacturing engineer

Setup: Interview

Berätta vad vi gör

1. Kan du ge lite bakgrund till ditt jobb och vad du gör?
2. Hur ser upplägget/processen ut under assemblyn av IC:n?
    a. Hur gör man monteringen så smidig som möjligt?
    b. Vilka problem uppstår oftast?
3. Vad är viktigt att tänka på under planering av IC infästningen?
4. Med hur mycket kraft ska man max trycka in den med? Finns det något optimalt spann?
    a. Finns det något mått på kraft den ska motstå?
5. Vilka krav finns det t.ex med utrymme mellan gas generator och kaross osv.
6. Vilka konkurrentlösningar skulle inte fungera utifrån de krav som finns på Volvo?
    a. *Visa några.*
7. *Fråga om vi kan göra…*
    a. *... observationer på monteringen;*
    b. *... en ergonomisk analys på testmontering.*

Tack!

A.4 Supplier

Setup: ostrukturerad intervju

Berätta vad vi gör

1. Kan du ge lite bakgrund till ditt jobb och vad du gör?
2. Vilka material jobbar ni med?
    a. Metall, plast, varför?
3. Vilka verktyg och processer erbjuder ni?
    a. *Injection molding osv.*
    b. Har ni någon särskild expertis inom tillverkning?
4. Vi har lärt oss mycket om hur Volvo utvecklar deras IC/CAB. Kan du berätta lite om er sida av processen? Hur jobbar ni när ni får en sådan uppgift från t.ex. Volvo?
5. Vilka lösningar erbjuder ni för IC/CAB infästningar nuförtiden?
    a. Vilka designfunderingar har ni kring era designs?
    b. Tänker ni på ergonomi och isåfall hur implementerar ni det i era lösningar?
    c. Vilken är den vanligaste typen av infästning?
6. Hur tillverka ni era infästningar?
    a. *Material, verktyg*
    b. Vad är svåraste/dyraste att tillverka, och lättaste/billigaste
    c. Vad är de största utmaningar med hänsyn till tillverkning? Några viktiga trade-offs?

Stort tack!

B. Questionnaire

B.1 Questionnaire questions

Share your insights on the assembly of the Inflatable Curtain Airbag (IC)!
Hello! We are two Chalmers students writing our thesis here at Volvo Cars in the Airbags & Steering Wheels department. The thesis is about standardizing the attachment for the IC, and that is why we would like your input regarding the assembly.
Thank you for your help!

Experience

1. How long have you been working at the assembly line?
   - o Less than a year
   - o 1-5 years
   - o 5-10 years
   - o 10-20 years
   - o 20+ years

2.How much experience do you have with assembling IC curtains (Choose the option that fits the best)
   - o I have done it a lot and do it automatically
   - o I have done it and know how to do it without thinking too much
   - o I have done it a couple of times and I'm starting to understand the process
   - o I have done it but I don't feel very sure
   - o I have not done it much at all

3. Which IC fixations have you assembled?
   - ☐ Metal hook and screw
   - ☐ Screw with plastic around it
   - ☐ Just screw
   - ☐ I don't know

4. Optional question: If you chose multiple options, do you have any reflections about the differences? Which fixations are better/which are worse to assemble?

About you

5. From what side do you assemble the IC?
   - o From inside the body
   - o From the outside, blind assembly

6. Why do you prefer to assemble the IC in this way? (Choose one or more statements that apply to you)

- ☐ I want to be able to see what I am doing
- ☐ It is too tight to sit inside the car
- ☐ It feels more comfortable physically
- ☐ It is faster and more effective in the process

7. How tall are you? Approximately.

---

8. What tools/support do you use during the assembly? Apart from screwdriver and other mandatory equipment.

- ☐ Gloves/hand protection
- ☐ Stool
- ☐ Knee protection
- ☐ Joint protection
- ☐ Nothing

Physical demand

9. How physically demanding do you think the IC assembly is?

0	1	2	3	4	5	6	7	8	9	10

Not demanding at all Extremely demanding

10. Which steps do you think are the most physically demanding?

- ☐ Assemble the gas generator
- ☐ Push in the fixations
- ☐ Push in the straps
- ☐ Drive the screws in

11. How physically demanding is your body position during the assembly?

0	1	2	3	4	5	6	7	8	9	10

Not demanding at all Extremely demanding

12.Which part of the body is affected the most?

- ☐ Back
- ☐ Neck
- ☐ Arms
- ☐ Legs
- ☐ Hands/fingers

Time pressure

13. Is it difficult to finish the assembly in time?

0	1	2	3	4	5	6	7	8	9	10

Not at all Extremely difficult

14. In which step is the most time lost?
- ☐ Assemble the gas generator
- ☐ Push in/hook in the fixations
- ☐ Push in the straps
- ☐ Drive the screws in

15. In what step can things go wrong which causes you to lose time?
- ☐ Assemble the gas generator
- ☐ Push in/hook in the fixations
- ☐ Push in the straps
- ☐ Drive the screws in
- ☐ There is no step where things usually go wrong

16. Optional: If there are things that usually go wrong, what goes wrong?
- o Screws that get stuck
- o Hooks that get stuck in cables for example
- o The fixations cannot be pushed in

Mental demand

17. How stressed do you feel during the assembly?

0	1	2	3	4	5	6	7	8	9	10

Not stressed at all   Extremely stressed

18. Do you feel that you have to think a lot during the assembly? (For example remembering things, solving problems)

0	1	2	3	4	5	6	7	8	9	10

I do not need to think   I have to think a lot

19. How much frustration do you experience during the IC assembly?

0	1	2	3	4	5	6	7	8	9	10

No frustration   Extreme frustration

Final reflections

20. Do you have any additional reflections/considerations/wishes when it comes to the IC fixations?

___

B.2 Questionnaire answers

Dela dina insikter om Inflatable Curtain Airbag (IC) montering!

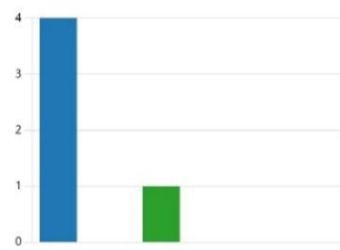
5 Responses | 07:01 Average time to complete | Closed Status

1. Hur länge har du jobbat här på produktionsbanan?

Mindre än ett år	1
1-5 år	2
5-10 år	2
10-20 år	0
20+ år	0

2. Hur mycket erfarenhet har du med att montera IC gardiner? (Välj alternativet som passar bäst)

Jag har gjort det mycket och de...	4
Jag har gjort det en del och vet ...	0
Jag har gjort det några gånger ...	1
Jag har gjort det men känner mi...	0
Jag har inte gjort det mycket alls	0
Other	0



3. Vilka IC infästningar har du monterat?

Metall krok och skruv	5
Skruv med plast kring den	3
Bara skruv	0
Jag vet inte	0
Other	0

4. Valfri fråga: Om du valde flera alternativ, har du några reflektioner kring skillnader? Vilka infästningar är bättre respektive sämre att montera?

1 Responses

Latest Responses

"Skriven med mutter på är mycket enklare att montera. Kroken på xc90 åker ...

5. Från vilket håll monterar du IC gardinen?

Från insidan av karossen	0
Från utsidan, blind montering	5
Other	0

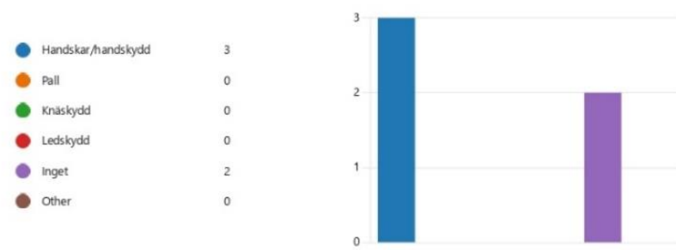
6. Varför föredrar du att montera IC gardinen på detta sätt? Välj en eller fler påståenden som stämmer in på dig.

7. Hur lång är du? På ett ungefär.

5
Responses

Latest Responses
"190"
"178"
"180 cm"

8. Vilka verktyg/stödmedel använder du under monteringen? Utöver dragare och andra obligatoriska saker.



9. Hur fysisk ansträngande tycker du det är att montera IC gardinen?

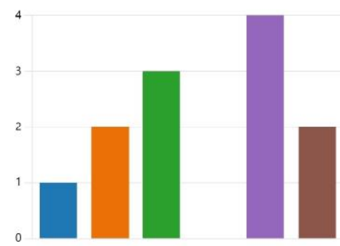
10. Vilket/vilka steg tycker du är mest fysisk ansträngande?

11. Hur fysiskt krävande är din arbetsställning?

Promoters	0
Passives	0
Detractors	5

12. Var på kroppen är det mest ansträngande

Rygg	1
Nacke	2
Armar	3
Ben	0
Händer/fingrar	4
Other	2



13. Är det svårt att hinna klart IC monteringen i tid?

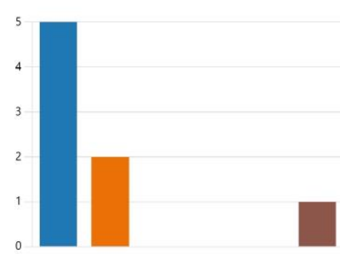
Promoters	0
Passives	0
Detractors	4

14. Vilket moment går mest tid åt till?

Montera gas generator	3
Trycka/kroka i fästen	2
Kroka i repen	0
Dra i skruvarna	0
Other	1

15. Vilket moment kan saker gå fel som gör att du förlorar tid?

Montera gas generator	5
Trycka/kroka i fästen	2
Kroka i repen	0
Dra i skruvarna	0
Det finns inget moment att sake...	0
Other	1



16. Valfri: Om det finns saker som brukar gå fel, vad är det som går fel?

Skruvar som fastnar	0
Krokar som fastnar i t.ex kablage	0
Fästena går inte att trycka/kroka i	3
Other	2

17. Hur stressad känner du dig under monteringen?

Promoters	0
Passives	0
Detractors	5

18. Känner du att du måste tänka mycket under monteringen? (T.ex komma ihåg saker, lösa problem)

Promoters	0
Passives	1
Detractors	4

19. Hur mycket frustration upplever du under IC monteringen?

Promoters	0
Passives	1
Detractors	4

20. Har du några ytterligare reflektioner/funderingar/önskemål när det gäller IC infästningen?

1
Responses

Latest Responses
"Gör alla IC gardiner till designen som Xc60/v60 är. Lätt, genial. Xc90 är helt ...

C. RULA Scoresheet

Osmond Ergonomics

ergonomics.co.uk
0345 345 0898

Rapid Upper Limb Assessment (Right & Left Sides)

Right side:

RULA Score (Right): 7

Action level 4: Further investigation and changes are required immediately

Left side:

RULA Score (Left): 7

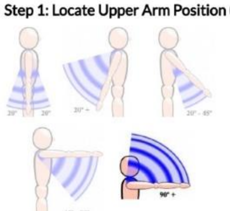
Action level 4: Further investigation and changes are required immediately

Personal details:

Assessee:
Assessor:
Email:
Department/Location:
Company/Organisation:
Date: 2025-02-11

Answers seleted:

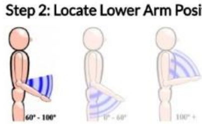
Step 1: Locate Upper Arm Position (Right)



Step 1a: Also tick the following boxes if appropriate

- Shoulder is raised
- Upper arm is abducted (away from the side of the body)
- Leaning or supporting the weight of the arm

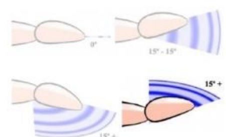
Step 2: Locate Lower Arm Position (Right)



Step 2a: Also tick the following box if appropriate

- Is either arm working across midline or out to side of body?

Step 3: Locate Wrist Position (Right)



Step 3a: Also tick the following box if appropriate

- Is wrist bent away from midline?

Step 4: Wrist Twist (Right)

Step 5: Arm & wrist - select the force and load that most reflects the working situation (Right)

Score 0
- No resistance
- Less than 2 kg intermittent load or force

Score 1
- 2 - 10 kg intermittent load or force

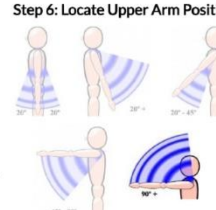
Score 2
- 2 - 10 kg static load
- 2 - 10 kg repeated loads or forces
- 10 kg or more, intermittent load or force

Score 3
- More than 10 kg static load
- 10+ kg repeated loads or forces
- Shock or forces with rapid buildup

Step 5a: Select this box if it reflects your muscle use

- Score 1
  Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute.

Step 6: Locate Upper Arm Position (Left)



Step 6a: Also tick the following boxes if appropriate

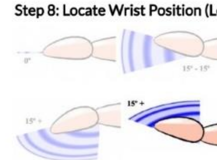
- Shoulder is raised
- Upper arm is abducted (away from the side of the body)
- Leaning or supporting the weight of the arm

Step 7: Locate Lower Arm Position (Left)

Step 7a: Also tick the following box if appropriate

- Is either arm working across midline or out to side of body?

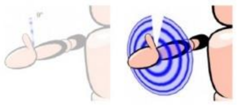
Step 8: Locate Wrist Position (Left)



Step 8a: Also tick the following box if appropriate

- Is wrist bent away from midline?

Step 9: Wrist Twist (Left)



Step 10: Arm & wrist - select the force and load that most reflects the working situation (Left)

Score 0
- No resistance
- Less than 2 kg intermittent load or force

Score 1
- 2 - 10 kg intermittent load or force

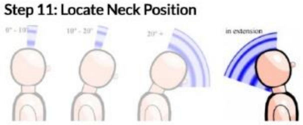
Score 2
- 2 - 10 kg static load
- 2 - 10 kg repeated loads or forces
- 10 kg or more, intermittent load or force

Score 3
- More than 10 kg static load
- 10+ kg repeated loads or forces
- Shock or forces with rapid buildup

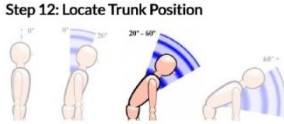
Step 10a: Select this box if it reflects your muscle use

- Score 1
  Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute.

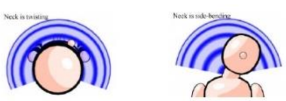
Step 11: Locate Neck Position



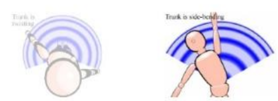
Step 12: Locate Trunk Position



Step 10a: Also tick the following box if appropriate



Step 12a: Also tick the following box if appropriate



Step 13: Legs

Legs and feet are NOT evenly balanced and supported.

Step 14: Neck, trunk & leg - select the force and load that most reflects the working situation

Score 0
- No resistance
- Less than 2 kg intermittent load or force

Score 1
- 2 - 10 kg intermittent load or force

Score 2
- 2 - 10 kg static load
- 2 - 10 kg repeated loads or forces
- 10 kg or more, intermittent load or force

Score 3
- More than 10 kg static load
- 10+ kg repeated loads or forces
- Shock or forces with rapid buildup

Step 14a: Select this box if it reflects your muscle use

- Score 1
  Posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute.

Table scores:

If you are familiar with the manual version of RULA, Table A and Table B values are indicated below.

Part A:

1. Upper Arm (Right):	4
2. Lower Arm (Right):	2
3. Wrist (Right):	4
4. Wrist Twist (Right):	2
5. Muscle Use + Force/Load (Right):	1
6. Upper Arm (Left):	4
7. Lower Arm (Left):	2
8. Wrist (Left):	4
9. Wrist Twist (Left):	2
10. Muscle Use + Force/Load (Left):	1
Posture Score - Right (Table A):	5
Posture Score - Left (Table A):	5
Final Arm & Wrist Score - Right:	6
Final Arm & Wrist Score - Left:	6

Part B:

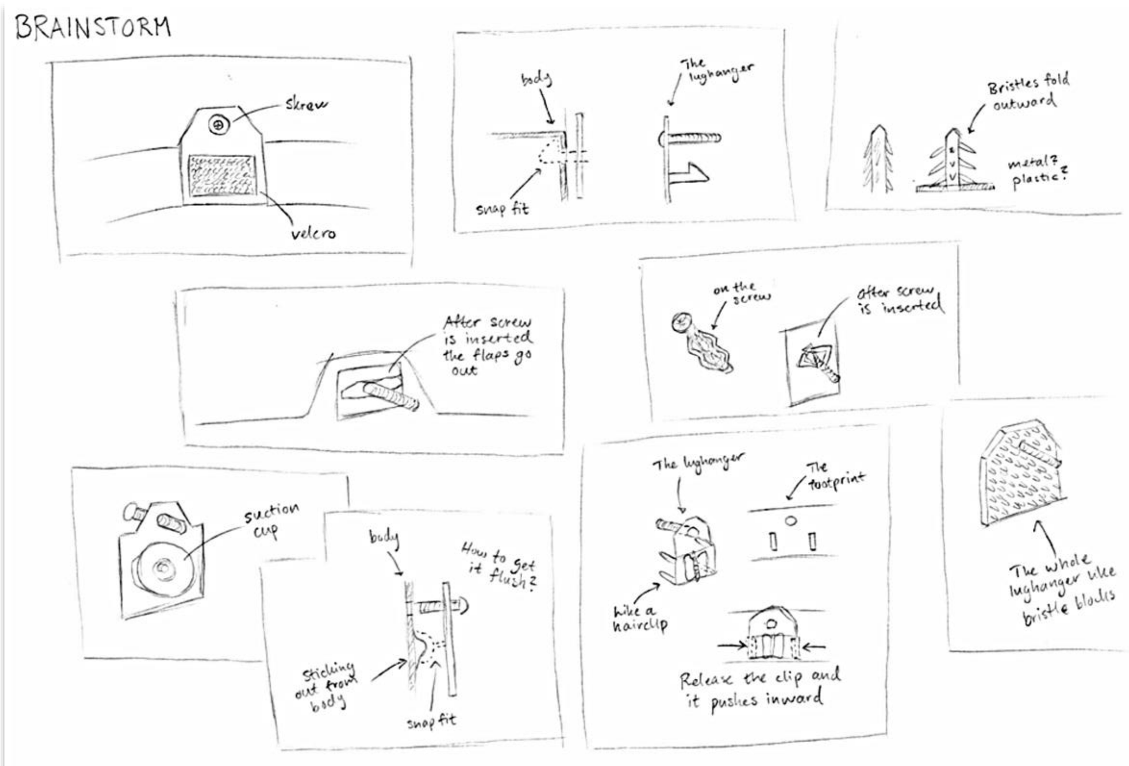
11. Neck:	6
12. Trunk:	4
13. Leg:	2
14. Muscle Use + Force/Load:	1
Posture Score (Table B):	9
Final Neck, Trunk & Leg Score:	10

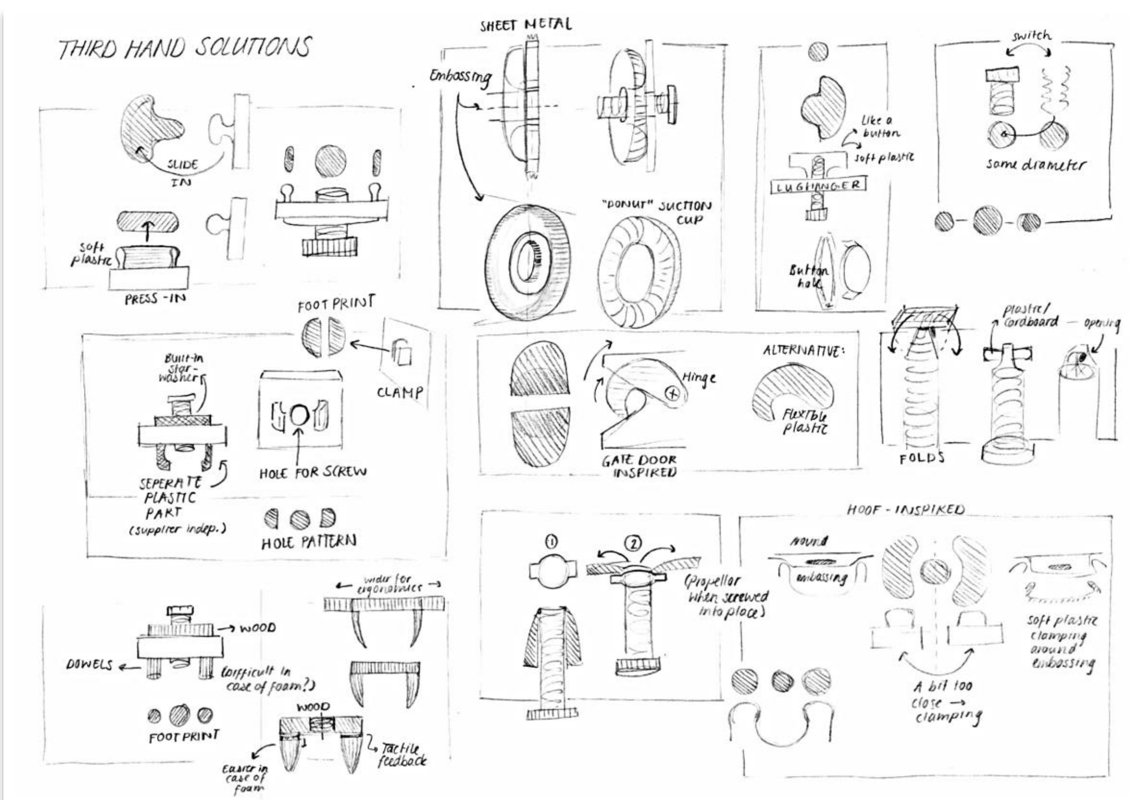
D. List of requirements

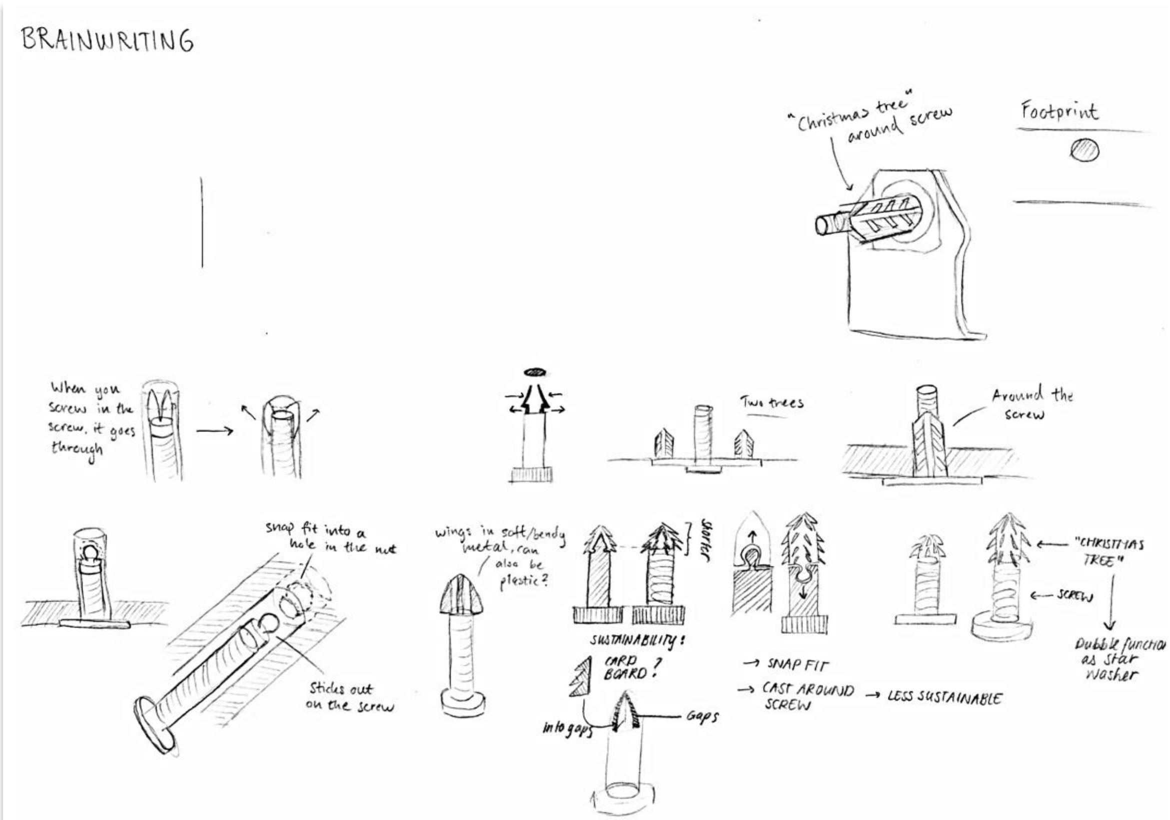
	Requirements	M/S/C	Comment	Reference	Fulfilled
1	**Main functions**				
1.1	The solution must keep the airbag in place during its lifetime	M		Co-creation	✓
1.2	The solution must keep the airbag in place during deployment	M	How much force should a clip be able to endure?	Co-creation	✓
1.3	The solution must not affect the airbag performance	M		Assignment description	✓
1.4	The solution must fit varieties of car models	M		Assignment description	✓
2	**Ergonomics (physical)**				
2.1	The press-in force must not exceed 15N per finger, 50N for the whole hand	M	In theory	ME interview	✓
2.2	The press-in force should not exceed 20N for the whole hand	M	In practice, taking sub-optimal angles and foam into account	ME interview	✓
2.3	The screw driver must be possible to operate from the position of assembly worker	M	For example, it should not press into their stomach	ME interview	✓
2.4	The complete IC should not weigh more than 1.4 kg	S	Not more than current solutions which is 1.4 kg	Co-creation	✓
2.5	The assembly should be ergonomic for height varieties between 150 to 195 cm	S	Blind or in-car assembly depends on height (150-195 cm) and experience	ME interview	—
3	**Third hand**				
3.1	A third hand must be integrated by design	M		ME interview	✓
3.2	The third hand must be able to keep the airbag in place during assembly	M	The weight of the fixation itself (and a little bit more), and should not pop out	Production interview	✓
3.3	The third hand must be robust enough to reassemble 10 times	M	Survive press-in force, service	Service interview	—
3.4	The third hand must align the screw with the hole	M		Personal communication	✓
3.5	If the third hand sits on the screw, it should fit through a star washer	S		Personal communication	—
3.6	The third hand should work at 90-27 degree angles towards the z-axis	S	Angle of last fixation of EX90 - VCC110	Personal communication	✓
3.7	The third hand should be placed so that it faces the fixation at a downward angle	S	Third hand located below screw, not above	Personal communication	✓
3.8	The third hand could be removable without pliers	C		Service interview	—
3.9	The third hand could be pushed in linearly	C	Straightforward push-in, not like a hook	Production interview	✓
4	**Gas generator**				
4.1	The gas generator must be located above the rear door	M		Design prerequisites	✓
4.2	The gas generator bracket must be strong enough for deployment	M		Design prerequisites	✓
4.3	The gas generator footprint must provide consistent mounting pulling direction	M		Production interview	✓
4.4	The gas generator bracket must stay in place during assembly	M	Not pop out	Production interview	✓
4.5	There should be a 6 mm gap between the gas generator and BiW	S	Mountability, account for non-flat surfaces	ME interview	—
4.6	The gas generator bracket should be quick to mount	S	Currently, a lot of assemblers indicate that they loose most time on the gas generator	Production survey	—
4.7	The gas generator could have a structural hook on one side and third hand on the other side	C		ME interview	✓
4.8	The footprint for the gas generator could be keyhole shaped	C		Car body interview	✓
5	**Strap buckle**				
5.1	The strap buckle must stay in place both vertically and horizontally	M		Personal communication	✓
5.2	The strap buckle must stay in place when the screw is drilled into it	M	One hook with on-screw solution, two hooks with regular screw	Personal communication	✓
5.3	Dangling of the strap during assembly could be reduced	C	For example, extendable strap	Test production observation	—
5.4	Scratching of the buckle against the BiW during assembly could be reduced	C	For example, by grinding or covering edges	Production interview	—
6	**Context/assembly**				
6.1	The assembly must not interfere with the cabling	M	No magnets	ME interview	✓
6.2	The assembly must be possible for blind assembly and assembly from the inside	M		Production observations	✓
6.3	The complete assembly must be done in 50 seconds	M	Differences between factories, 57s in Gothenburg, depends on car model as well	ME interview	✓
6.4	Assembly must be possible with the screw sticking out up to 8 mm	M	Tolerences 6.4 +- 1.6 mm	Supplier interview	✓
6.5	The assembly should minimize the chance to damage the car	S		Production interview	✓
6.6	The IC should be able to be assembled with gloves	S		Production observations	✓
7	**Error-proofing**				
7.1	It must be impossible to incorrectly mount the curtain airbag regardless of experience	M	Poka yoke can be applied to this end	ME interview	✓
7.2	It must be impossible to mix up components during assembly	M		ME interview	✓
7.3	The solution should not allow for the IC to be twisted	S	Anti-twist, guideline, fixations 250 mm apart	ME interview	—
7.4	Mounting should be self-guiding to accomodate blind assembly	S		Production observations	X
7.5	Feedback could be provided when a mistake is made	C	Visual, tactile or audible	Design prerequisites	✓

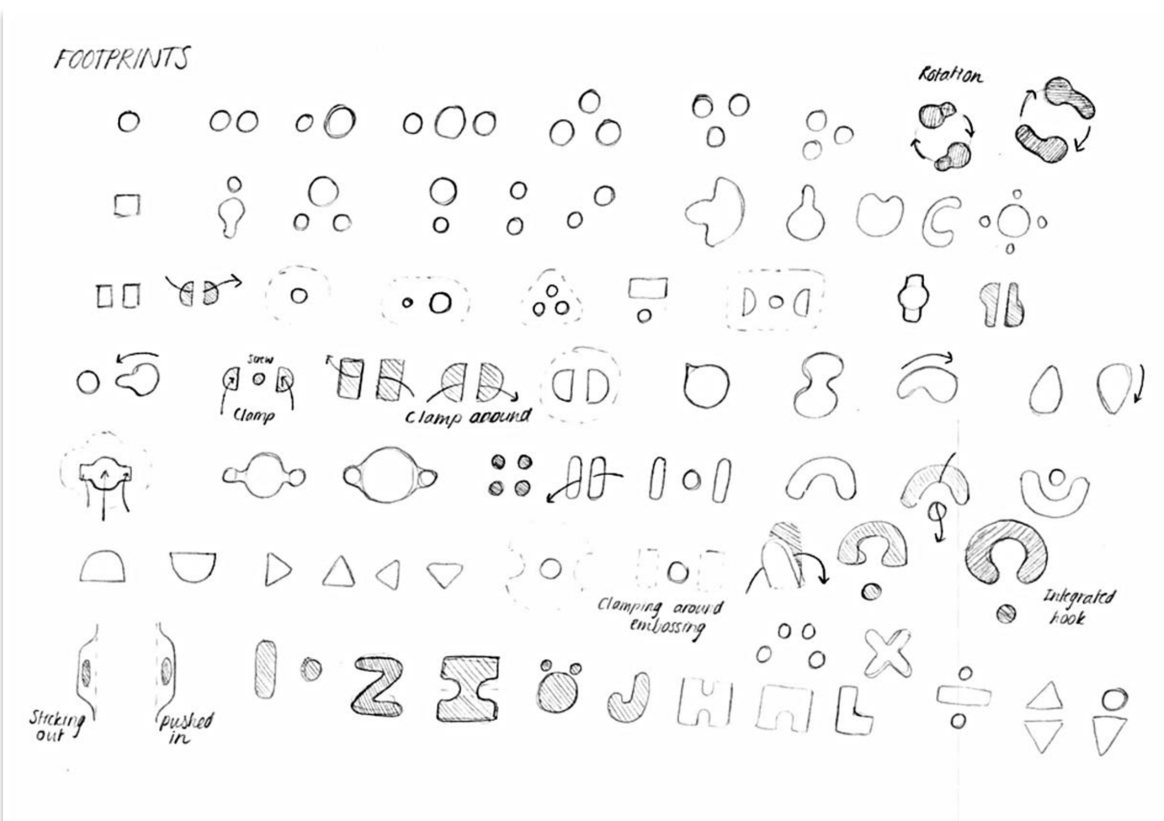
8	**Ease of assembly (cognitive ergonomics)**				
8.1	The design should be intuitive, self-explanatory and include semantic aids where needed	S		Test production	✓
8.2	The design should avoid overcomplication that could increase the chance of error	S		ME interview	✓
8.3	The fixations should be consistent to reduce confusion during assembly	S		Personal communication	✓
8.4	The assembly should be learned quickly	S	PII (PKI), practice live	ME interview	✓
8.5	The joints should be integrated and reduce loose parts	S		ME interview	✓
8.6	The joints should be easy to guide into the car body	S	Star washers can be used for stability	ME interview	—
8.7	The joints should be at a consistent angle	S	Embossing could be used, different angles when switching position to new window migl	ME interview	•
8.8	The design could be symmetric to reduce confusion during assembly	C	And could serve as 'cheat sheet' to person opposite	ME interview	✓
8.9	Embossings could be used to clarify assembly	C		Car body interview	X
9	**Consistency in design**				
9.1	The design should be symmetric to reduce tooling and part costs	S		Car body interview	✓
9.2	The design should leverage the existing production infrastructure as much as possible	S	For example, standard screws	Car body interview	✓
9.3	The design could use standard shapes to reduce tooling costs and increase access to spare parts	C	For example, round holes	Car body interview	✓
9.4	The design could leverage the existing external supplier production infrastructure	C		Supplier interview	✓
10	**Footprint/BiW**				
10.1	The design must account for double sheet metal	M	Sheet thicknesses between x and x mm	Car body interview	✓
10.2	The design must account for a threaded hole	M	In case of screws	Personal communication	✓
10.3	Holes in double sheet metals must be oversized	M		Car body interview	•
10.4	Holes must have sufficient distance between them	M		Car body interview	•
10.5	Holes must be placed on flat areas	M	With respect to production and to enable flush assembly	Car body interview	✓
10.6	Embossings must be away from the edge	M		Car body interview	•
10.7	The holes should fit on 50 mm in height, taking into account clearance in case of double plate	S		Personal communication	✓
10.8	The number of holes could be minimized	C		Car body interview	✓
10.9	Holes could be next to eachother instead of above	C	If more than one hole	Car body interview	•
11	**Producability**				
11.1	The solution must be producable by different suppliers and according materials	M		Supplier interview	✓
11.2	The BiW holes must be possible to lasercut and hole punch	M	For example, no sharp corners for hole punching	Car body interview	✓
12	**Costs**				
12.1	Costs could be taken into consideration	C		Personal communication	✓
13	**Sustainability**				
13.1	The CO2 footprint of the material could be minimized	C		Personal communication	—
13.2	The solution could be recyclable/circular	C	For example, single material	Co-creation	—
13.3	Use of non-degradable plastic could be minimized	C		Co-creation	—
13.4	The energy consumption of the material could be minimized	C		Personal communication	—
13.5	Topology optimization could be included	C		Personal communication	X
14	**After end of production**				
14.1	The assembly data must be traceable for at least 15 years after end of production	M		Service interview	✓
14.2	The design must be servicable	M		Service interview	✓
14.3	The design and materials must last 15 years	M		Service interview	✓
14.4	The design could last as long as the car is in use	C		Service interview	—
14.5	When servicing, all curtain airbag fixation parts should remain attached to the curtain airbag	S	For example, screws should remain attached to the curtain airbag	Service interview	—

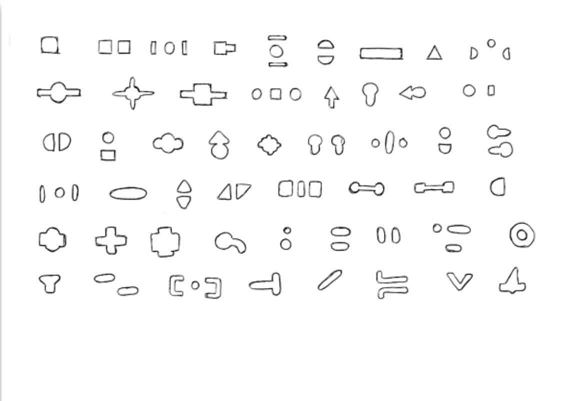
E. Ideation sketches

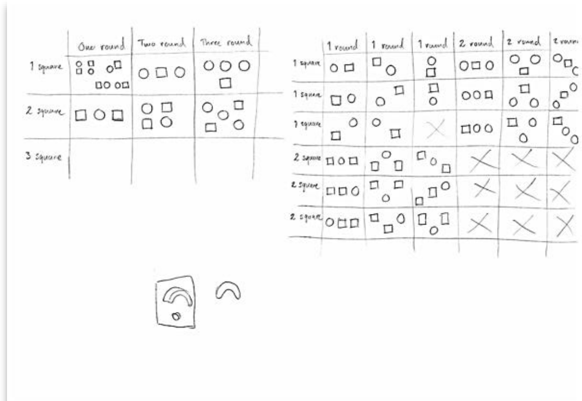


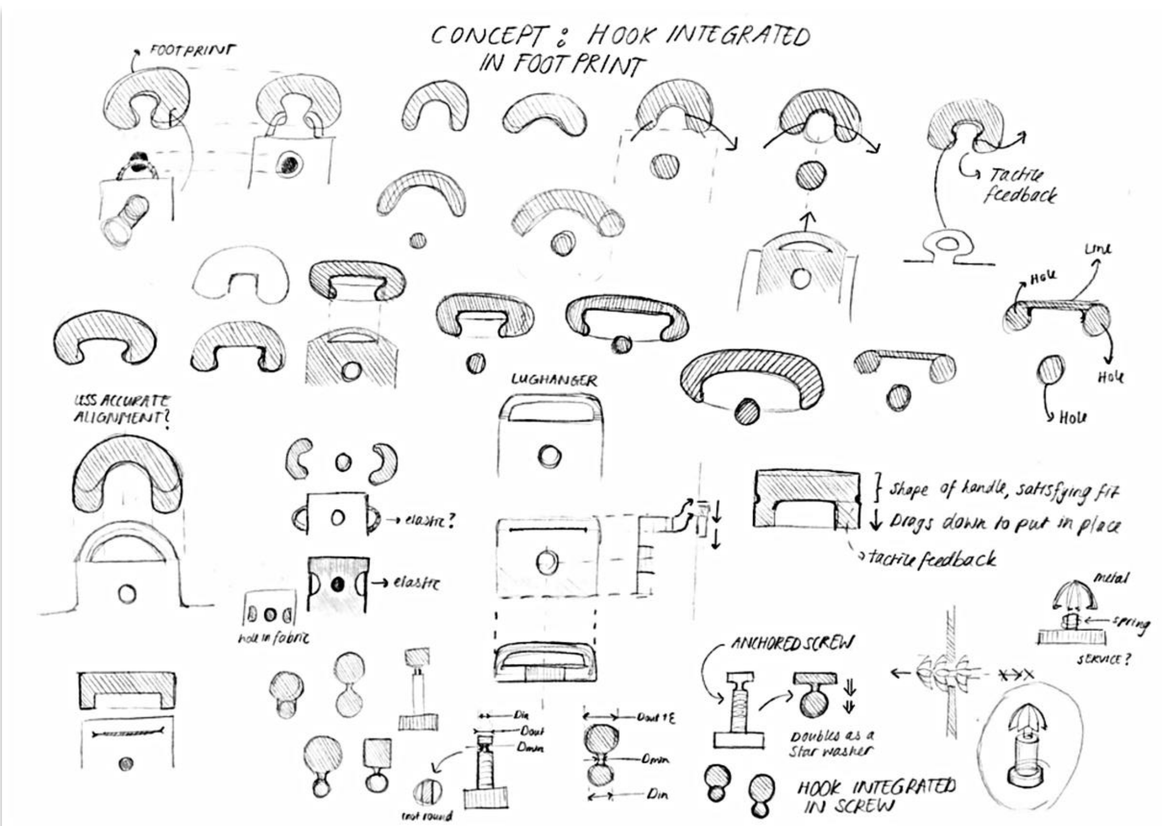


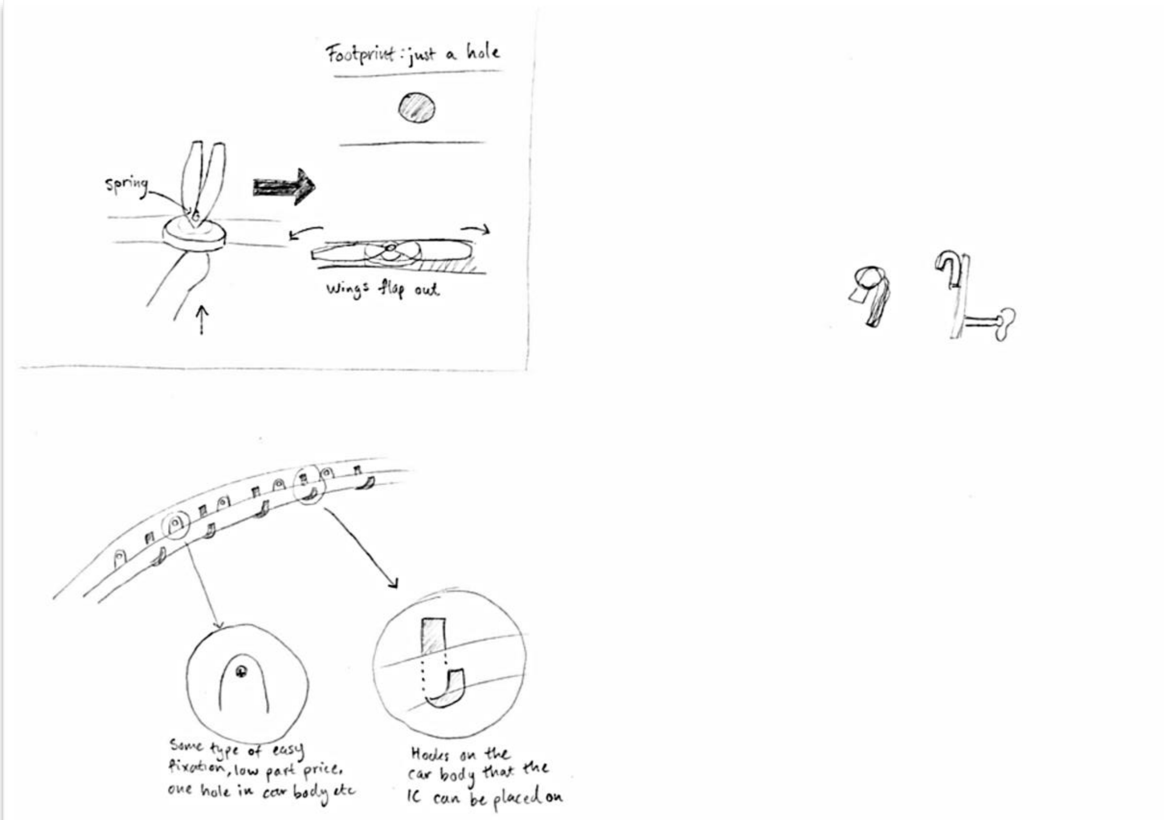

BRAINWRITING
"Christmas tree" around screw
Footprint
When you screw in the screw, it goes through
Two trees
Around the screw
snap fit into a hole in the nut
Sticks out on the screw
wings in soft/bendy metal, can also be plastic?
starter
SUSTAINABILITY!
CARD BOARD?
Into gaps
Gaps
→ SNAP FIT
→ CAST AROUND SCREW → LESS SUSTAINABLE
"CHRISTMAS TREE"
SCREW
Dubble function as star washer

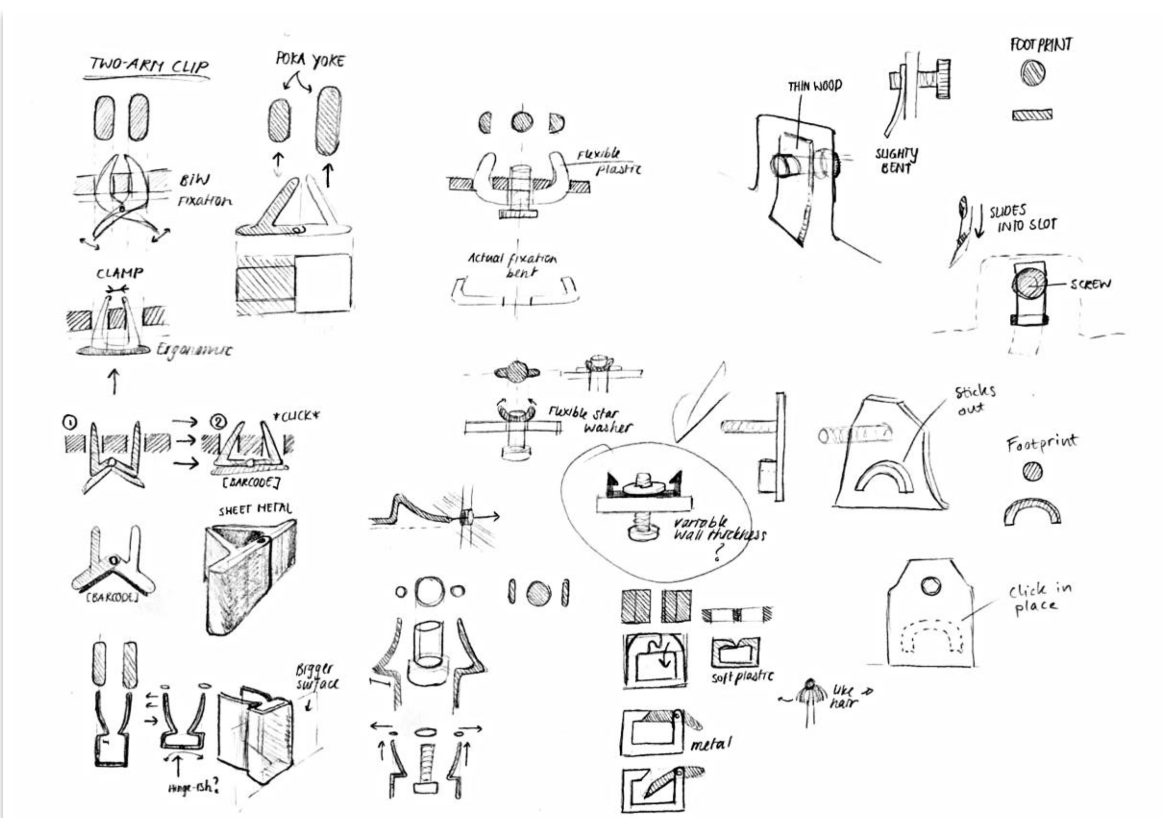

FOOTPRINTS
Rotation
Screw
Clamp
Clamp around
Clamping around embossing
Integrated hook
Sticking out
pushed in

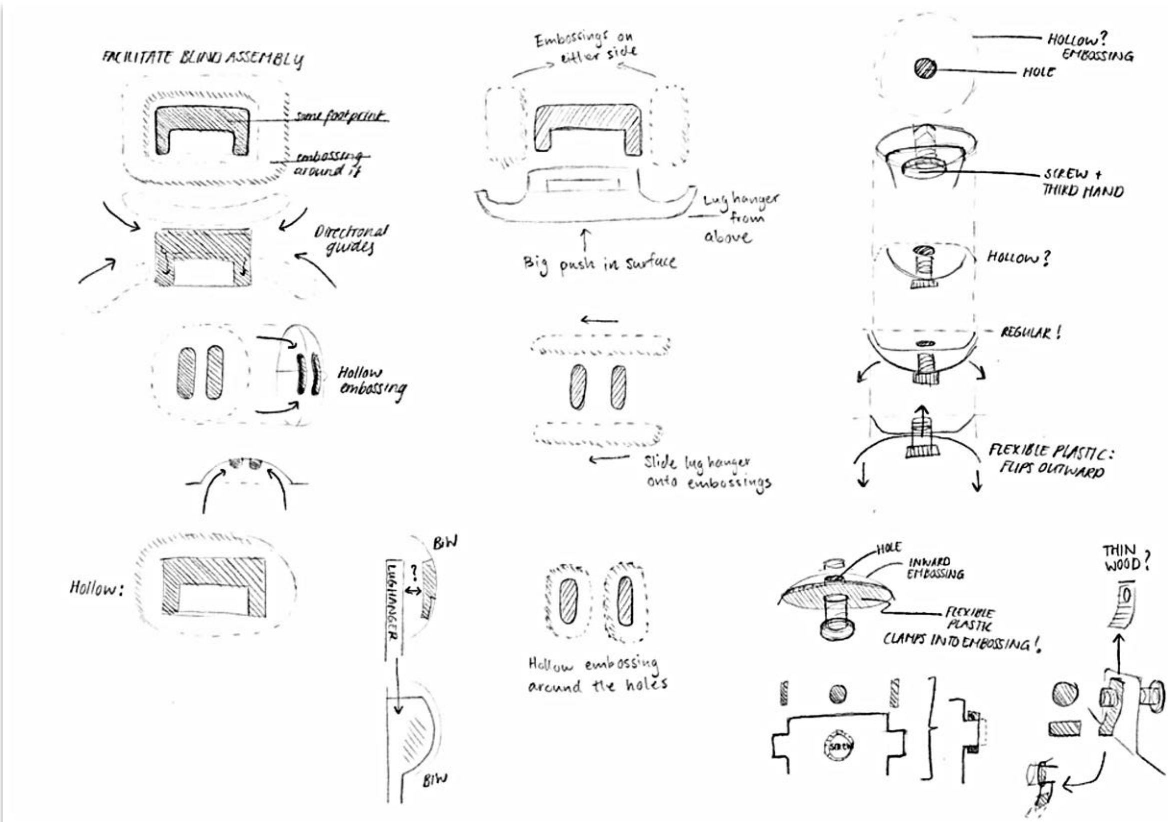


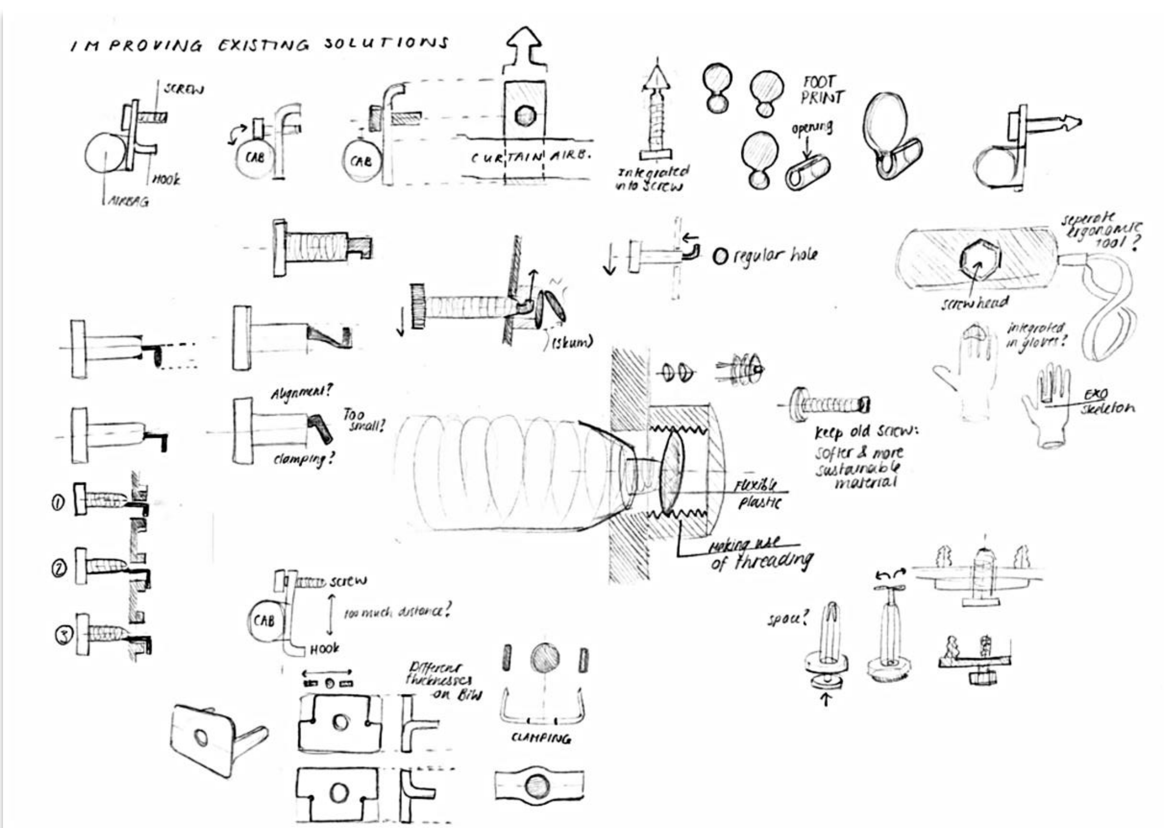

One round
Two round
Three round
1 square
2 square
3 square

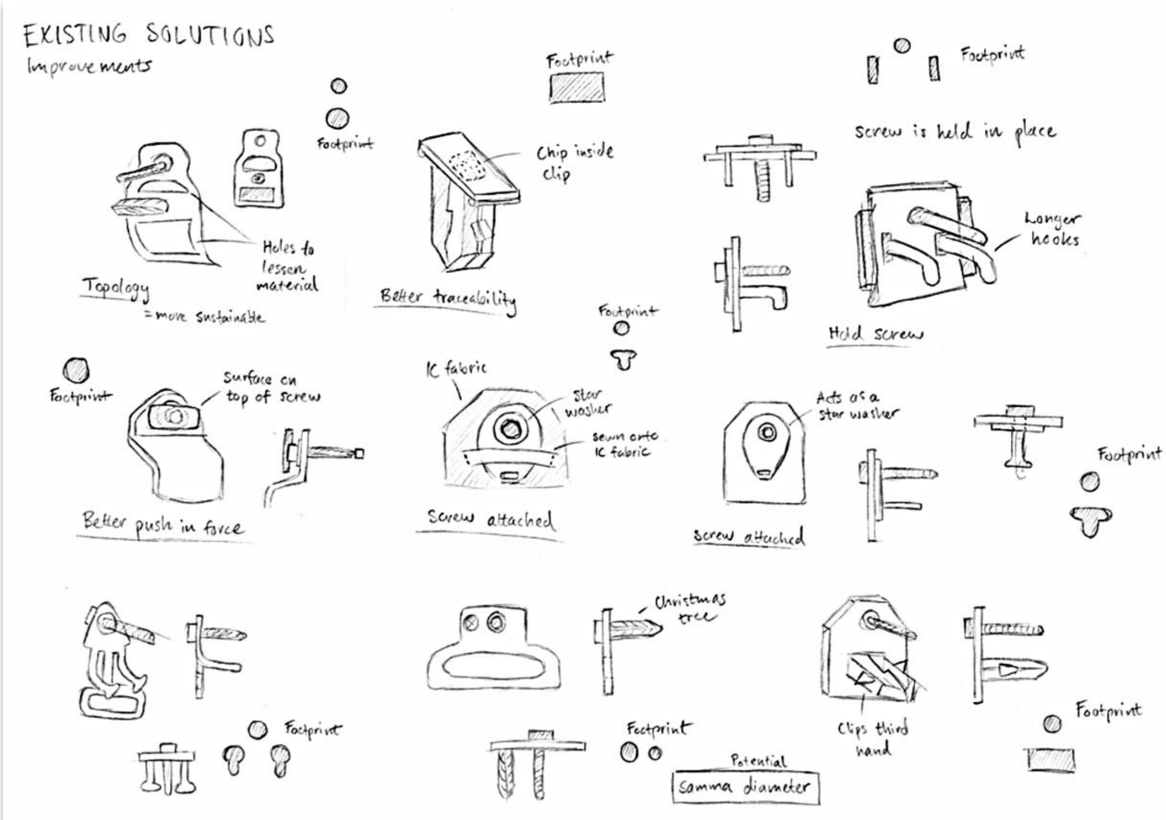

CONCEPT : HOOK INTEGRATED IN FOOT PRINT
FOOTPRINT
Tactile feedback
Line
Hole
Hole
Hole
Hole
LUGHANGER
LESS ACCURATE ALIGNMENT?
elastic?
elastic
hole in fabric
Shape of handle, satisfying fit
Drags down to put in place
tactile feedback
metal
spring
service?
ANCHORED SCREW
Doubles as a Star washer
HOOK INTEGRATED IN SCREW
Din
Dout
Dmin
Dout +E
Dmin
Din
test round

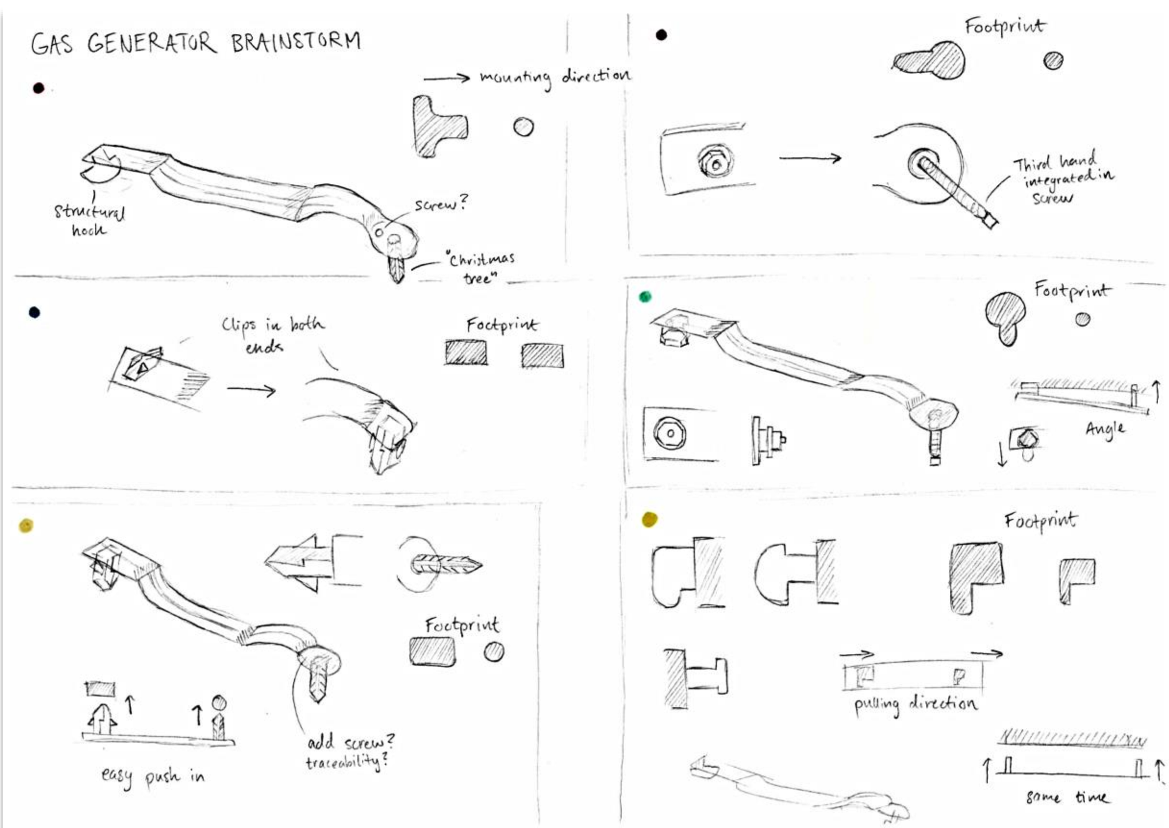

Footprint: just a hole
Spring
Wings flap out
Some type of easy fixation, low part price, one hole in car body etc
Holes on the car body that the IC can be placed on

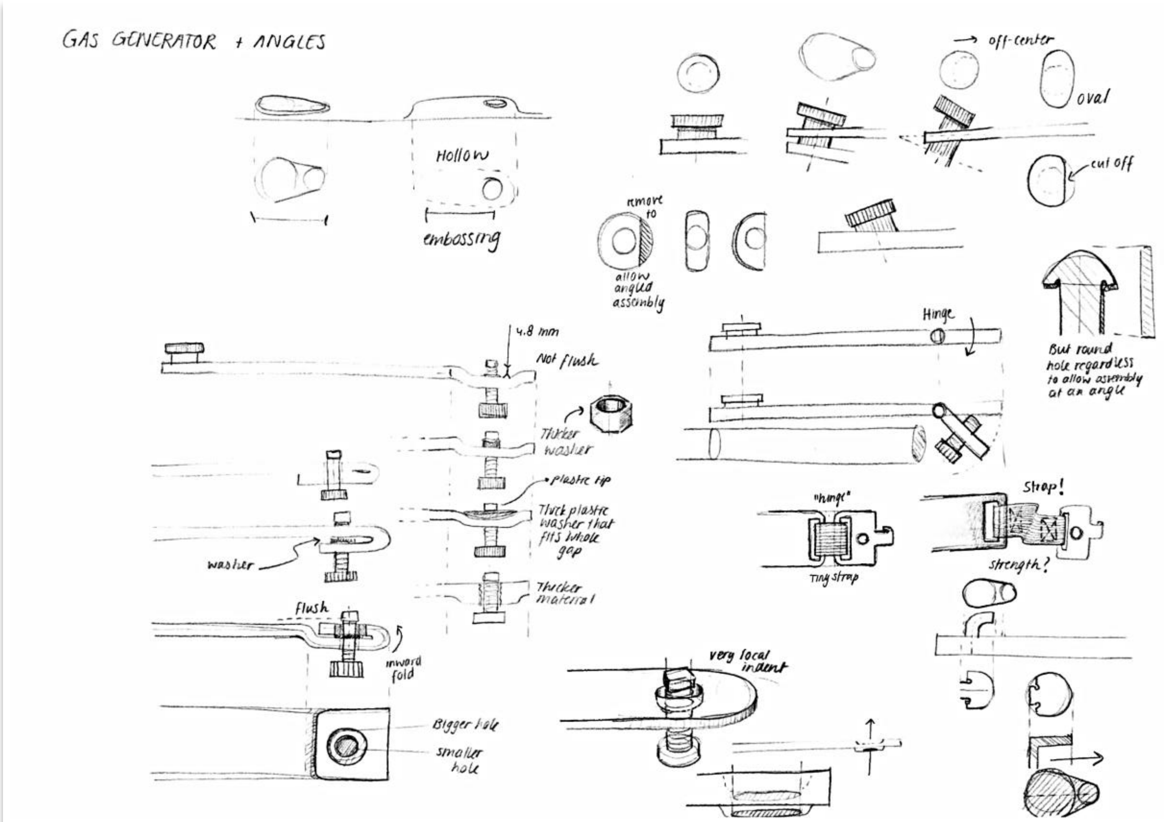

TWO-ARM CLIP
POKA YOKE
BIW fixation
CLAMP
Ergonomic
CLICK
[BARCODE]
SHEET METAL
[BARCODE]
Bigger surface
Hinge-ish?
Flexible plastic
Actual fixation bent
Flexible star washer
Variable wall thickness ?
THIN WOOD
SLIGHTY BENT
FOOTPRINT
SLIDES INTO SLOT
SCREW
Sticks out
Footprint
Click in place
soft plastic
Like hair
metal

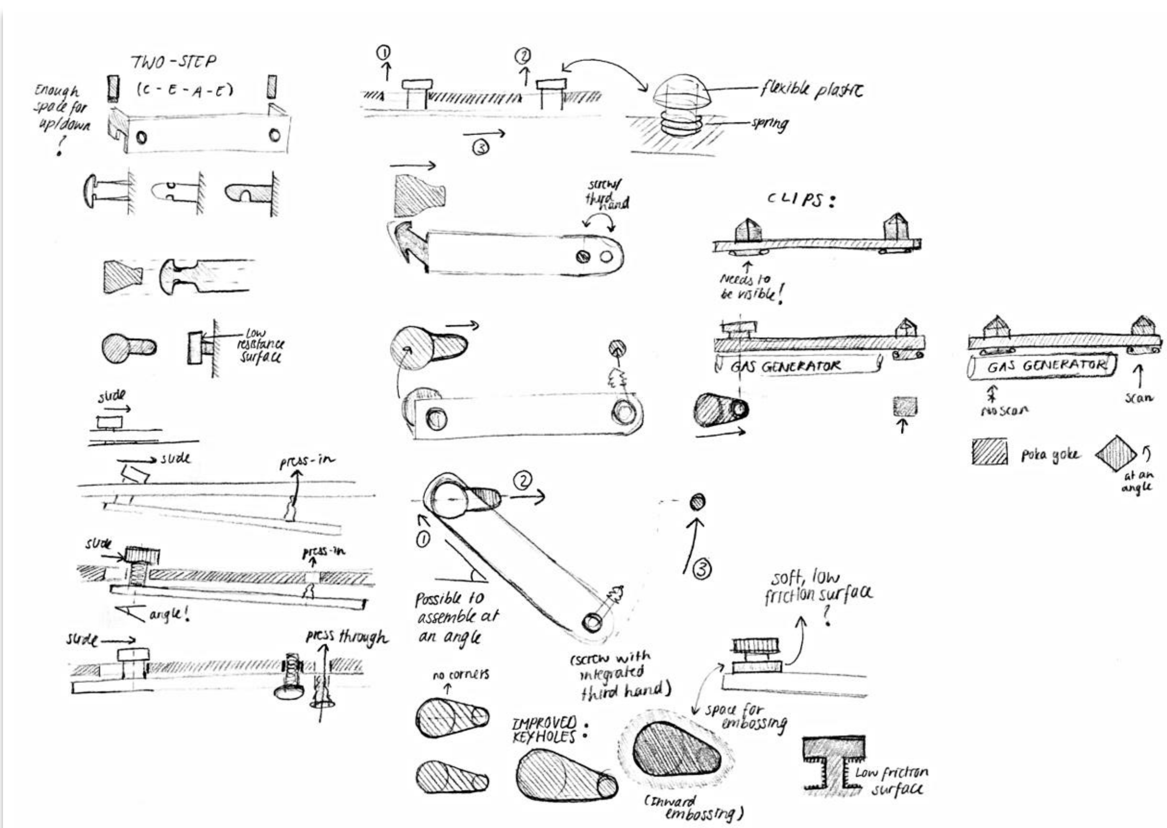

FACILITATE BLIND ASSEMBLY
same footprint
embossing around it
Directional guides
Hollow embossing
Hollow:
Embossings on either side
Lug hanger from above
Big push in surface
Slide lug hanger onto embossings
Hollow embossing around the holes
B/W
LUG HANGER
HOLLOW? EMBOSSING
HOLE
SCREW + THIRD HAND
HOLLOW?
REGULAR!
FLEXIBLE PLASTIC: FLIPS OUTWARD
INWARD EMBOSSING
FLEXIBLE PLASTIC
CLAMPS INTO EMBOSSING!
THIN WOOD?

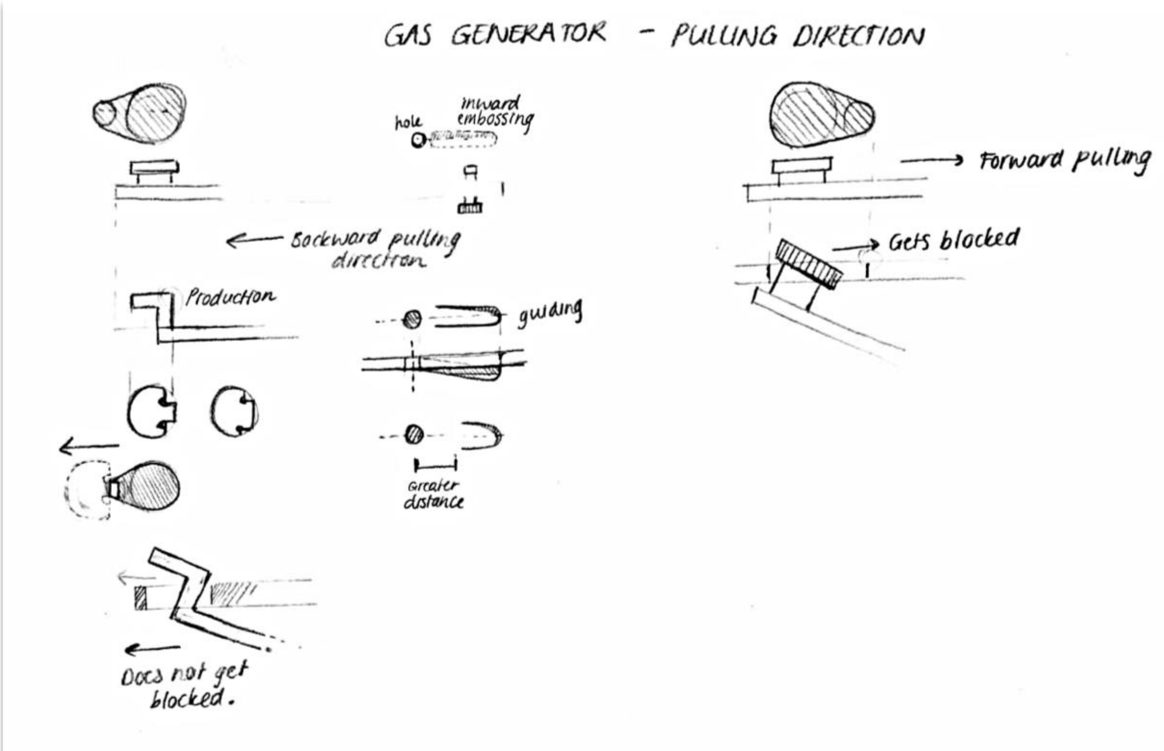

IMPROVING EXISTING SOLUTIONS
SCREW
HOOK
AIRBAG
CAB
CURTAIN AIRB.
Integrated into screw
FOOT PRINT
opening
regular hole
(skum)
Alignment?
Too small?
clamping?
keep old screw: softer & more sustainable material
flexible plastic
making use of threading
screw
too much distance?
HOOK
Different thicknesses on B/W
CLAMPING
seperate ergonomic tool?
screw head
integrated in gloves?
EXO skeleton
space?

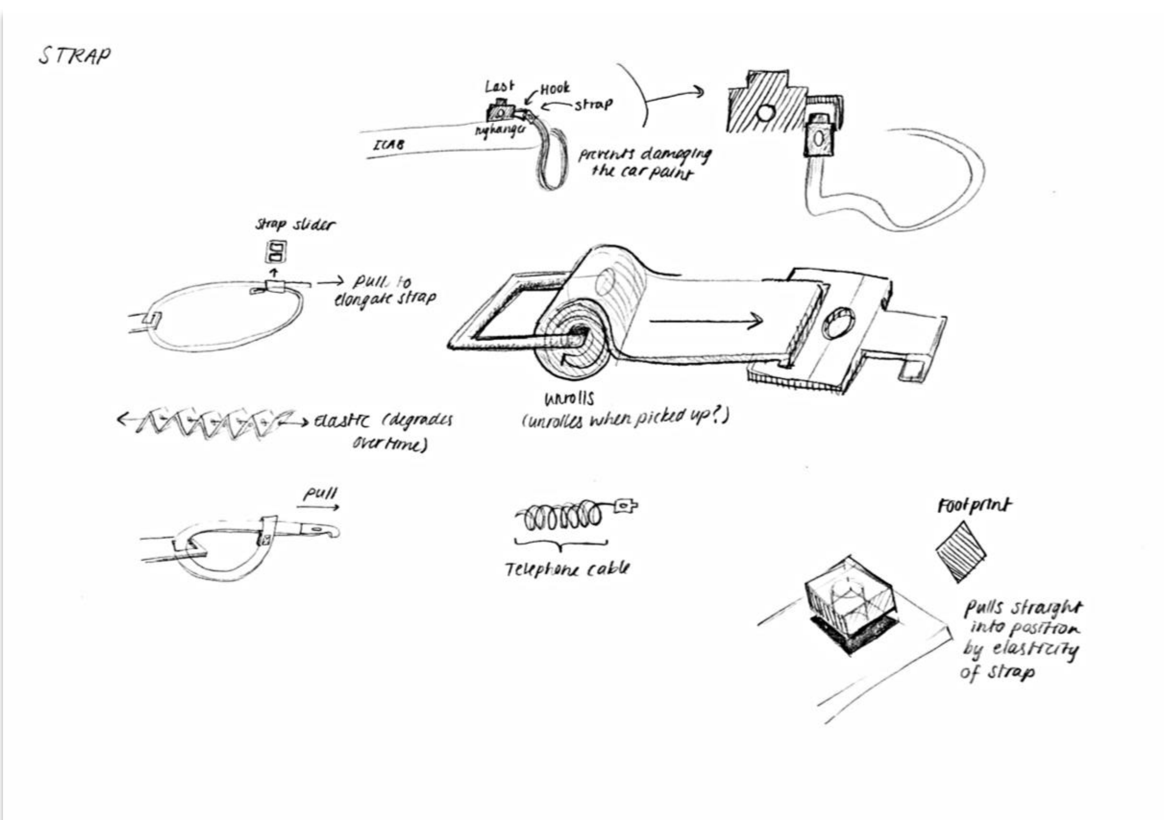

EXISTING SOLUTIONS
Improvements
Footprint
Footprint
Footprint
Chip inside clip
Screw is held in place
Holes to lessen material
Longer hooks
Topology
= more sustainable
Better traceability
Footprint
Hold screw
IC fabric
Footprint
Surface on top of screw
Star washer
Sewn onto IC fabric
Acts as a star washer
Footprint
Better push in force
Screw attached
Screw attached
Christmas tree
Footprint
Footprint
Clips third hand
Footprint
Potential
Samma diameter

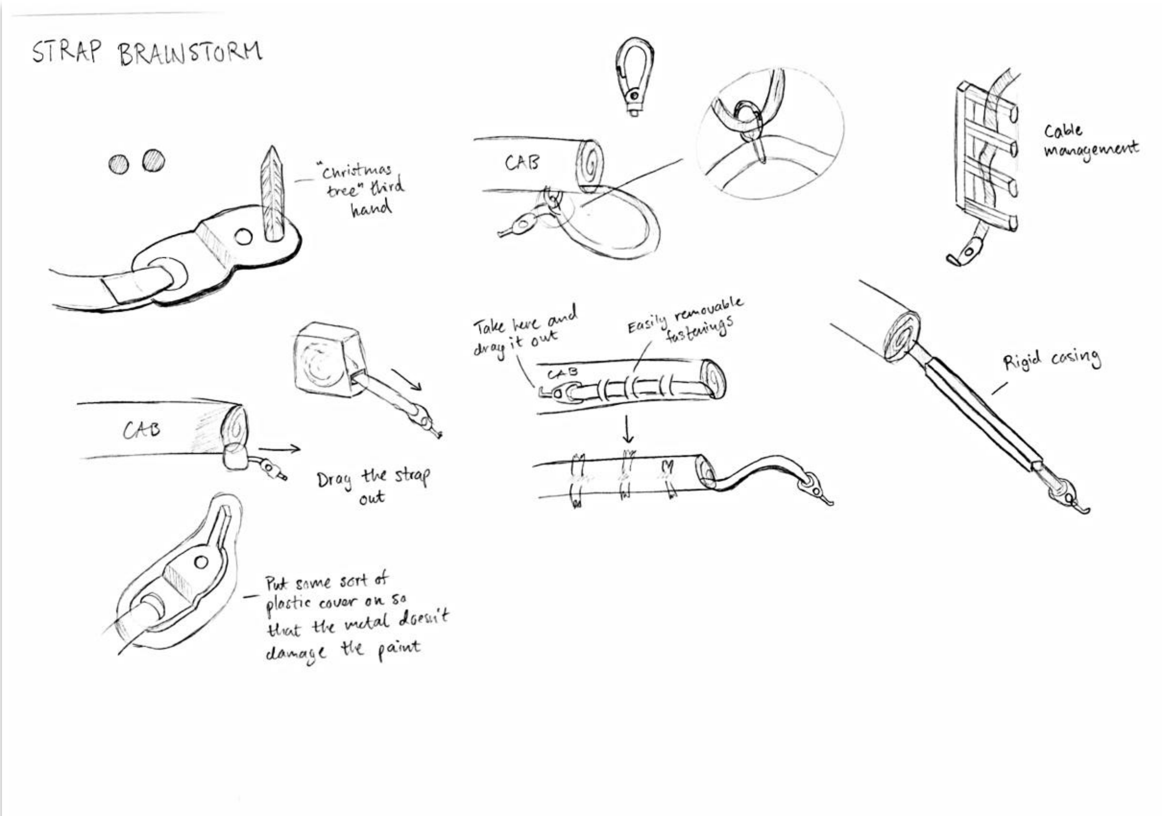

GAS GENERATOR BRAINSTORM
mounting direction
Footprint
Structural hook
Screw?
"Christmas tree"
Third hand integrated in screw
Clips in both ends
Footprint
Footprint
Angle
Footprint
easy push in
add screw? traceability?
Footprint
pulling direction
same time

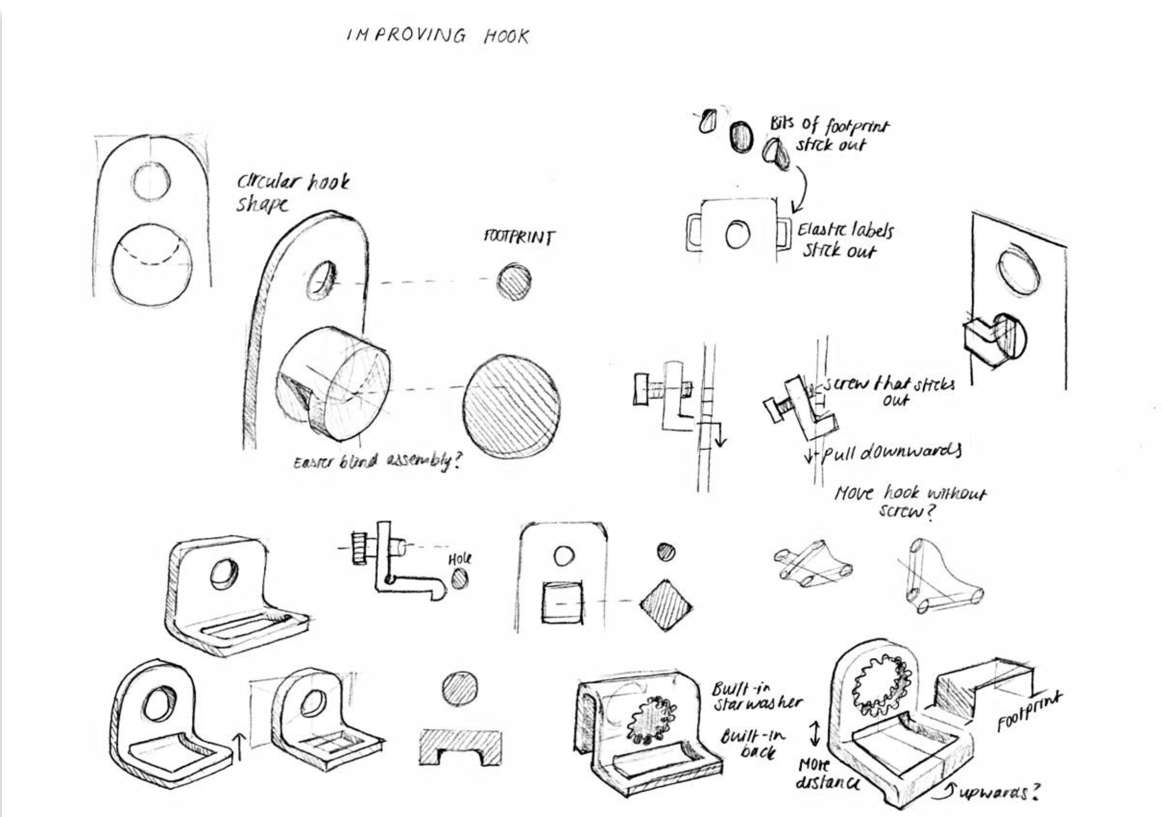

GAS GENERATOR + ANGLES
off-center
oval
cut off
Hollow
embossing
remove to allow angled assembly
Hinge
But round hole regardless to allow assembly at an angle
4.8 mm
Not flush
Thicker washer
plastic tip
Thick plastic washer that fits whole gap
Thicker material
washer
Flush
inword fold
Bigger hole
smaller hole
"hinge"
Tiny strap
Strap!
strength?
very local indent

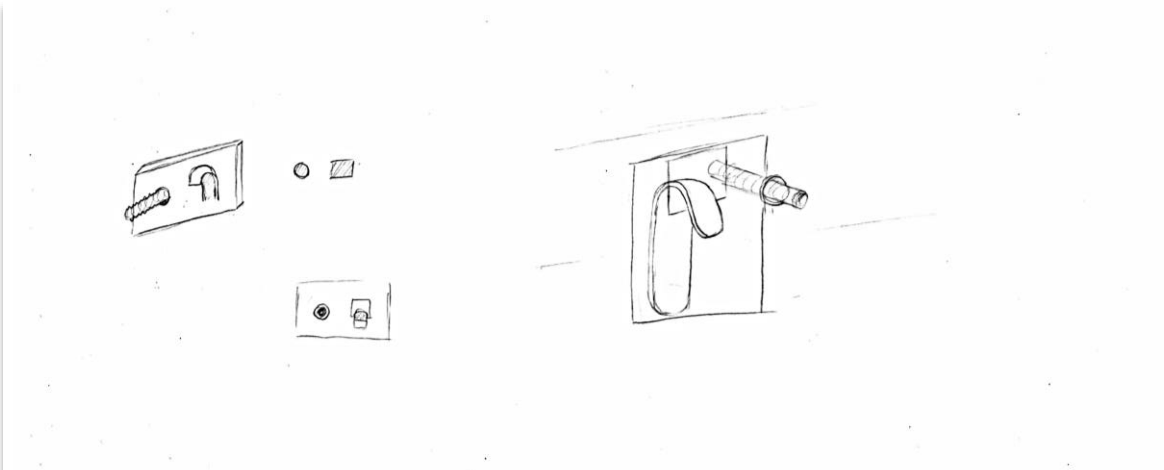

TWO-STEP (C-E-A-E)
Enough space for up/down?
flexible plastic
spring
screw/third hand
CLIPS:
Needs to be visible!
Low resistance surface
GAS GENERATOR
GAS GENERATOR
no scan
scan
poka yoke
at an angle
slide
slide
press-in
slide
press-in
angle!
slide
press through
Possible to assemble at an angle
(screw with integrated third hand)
soft, low friction surface?
no corners
IMPROVED KEYHOLES:
space for embossing
(inward embossing)
Low friction surface

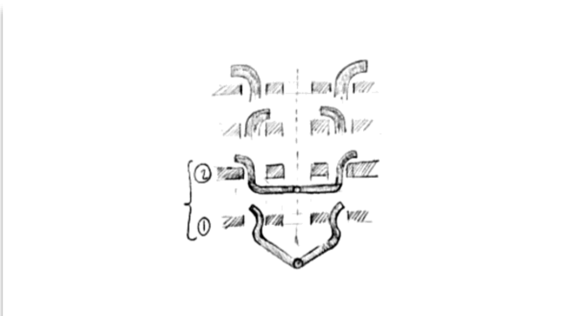

GAS GENERATOR - PULLING DIRECTION
hole
inward embossing
Backward pulling direction
Production
guiding
Greater distance
Does not get blocked.
Forward pulling
Gets blocked

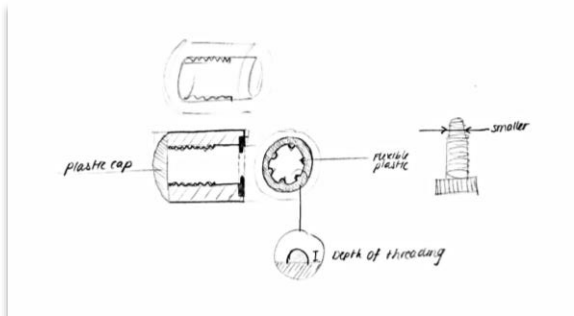

STRAP
Last
Hook
strap
hybanger
ICAB
prevents damaging the car paint
strap slider
pull to elongate strap
unrolls
(unrolles when picked up?)
Elastic (degrades over time)
pull
Telephone cable
Footprint
Pulls straight into position by elasticity of strap

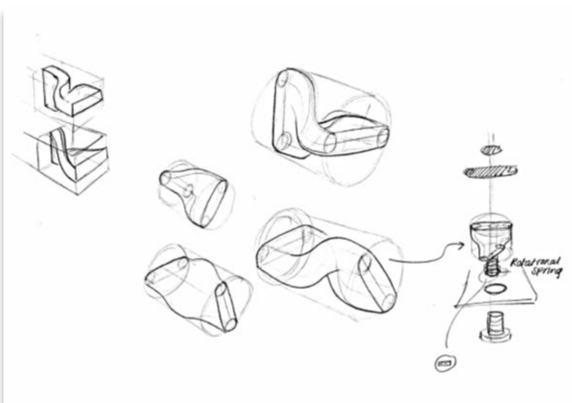

STRAP BRAINSTORM
"christmas tree" third hand
CAB
Cable management
Take here and drag it out
Easily removable fastenings
CAB
Rigid casing
CAB
Drag the strap out
Put some sort of plastic cover on so that the metal doesn't damage the paint

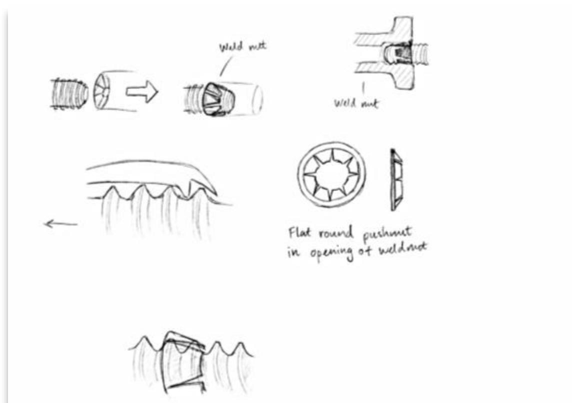

IMPROVING HOOK
Circular hook shape
FOOTPRINT
Bits of footprint stick out
Elastic labels stick out
Easier blind assembly?
Screw that sticks out
Pull downwards
Move hook without screw?
Hole
Built-in starwasher
Built-in back
More distance
Footprint
upwards?



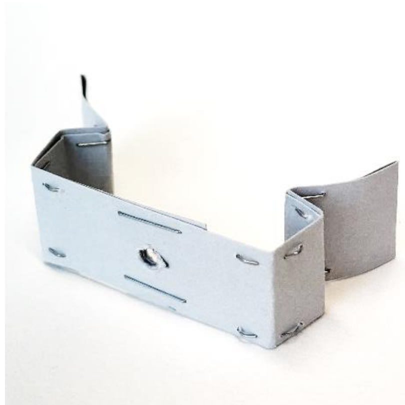
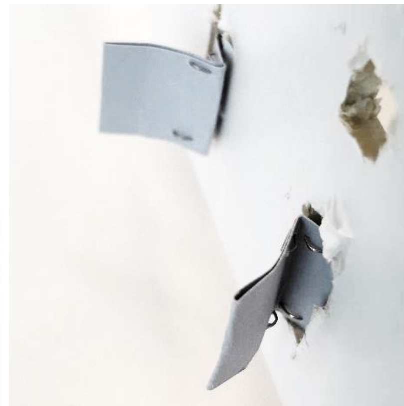


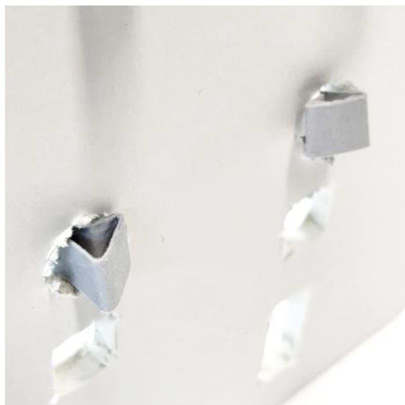

plastic cap
flexible plastic
smaller
Depth of threading


Rotational spring

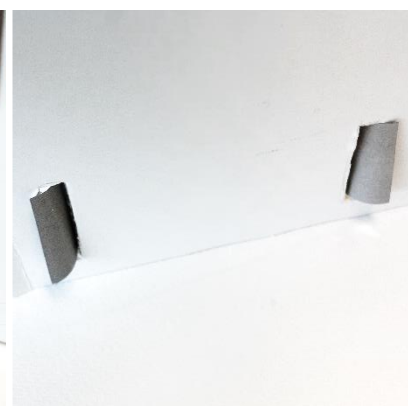

Weld nut
Weld nut
Flat round pushnut
in opening of weldnut

F. Lo-Fi prototypes

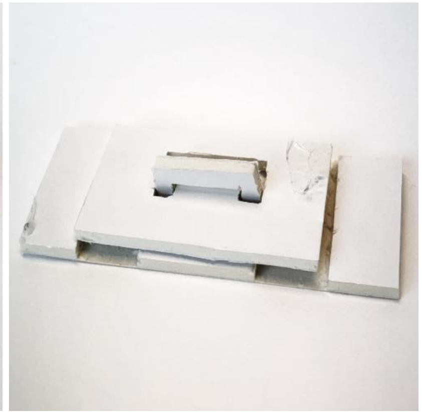








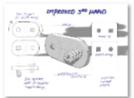
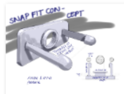
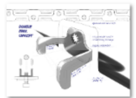
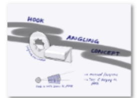
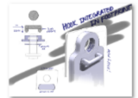
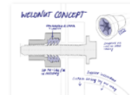
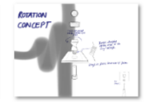
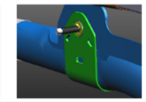




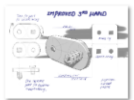
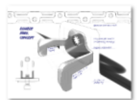
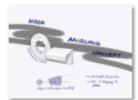
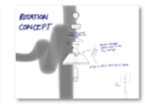
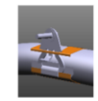


G. Pugh matrices

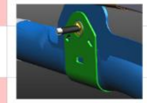
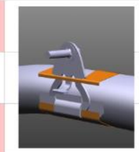
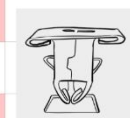
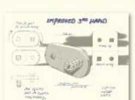
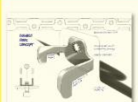
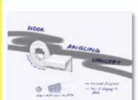
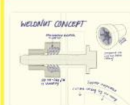
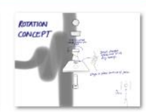
Criteria	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Reference
Main functions	0	0	0	0	-1	0	0	0	-1	-1	R
Ergonomics	1	1	1	1	1	1	1	1	1	1	E
Third hand	-1	0	1	-1	-1	0	-1	1 (Integrated third hand)	1 (Integrated third hand)	0	F
Assembly/context	-1	-1	-1	0	-1	0	0	1	0	-1	E
Error proofing	1	1 (Feedback)	1	1	1	0	1	1	1	1	R
Ease of assembly	1 (Visual third hand)	1 (Visual third hand)	1 (Visual third hand)	-1	-1	0	0	1	1	-1	E
Consistency	0	0	0	-1	0	0	0	-1	-1	0	N
Footprint	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	C
Producability	-1	-1	-1	-1	-1	0	0	-1	-1	-1	E (Optimal)
Costs	0	0	0	0	-1	-1	-1	-1	-1	-1	R
Sustainability	0	0	0	0	0	1	0	0	0	-1	E
After EOP	0	-1 (Service)	1	1	1	0	-1	-1	-1	-1 (Service)	F
Total	-1	-1	2	-2	-4	1	-2	0	-2	-6	
Rank	4	4	1	5	6	2	5	3	5	7	
Continue	No	No	Yes	No	No	Yes	No	Maybe	No	No	

Criteria	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Reference
Main functions	1 (Next to screw so fits on more car models)	1 (Next to screw so fits on more car models)	1 (Next to screw so fits on more car models)	1 (Next to screw so fits on more car models)	-1 (Also under screw and even bigger hole)	1	1	1	0	0	R
Ergonomics	0	0	1 (No press-in force)	1 (No press-in force)	1 (No press-in force)	0	0	0	0	0	E
Third hand	-1 (Worse alignment, angle not downwards)	1 (Better screw alignment)	1 (Possibly better alignment)	-1 (Same alignment, angle not downward)	0	1	1	1 (Extra point for not needing a third hand)	1 (Extra point for not needing a third hand)	0	F
Assembly/context	0	-1	-1	0	-1	1 (No issue with screw sticking out)	1 (No issue with screw sticking out)	1	1	0	E
Error proofing	0	1 (More feedback)	0	0	1	-1 (Force in wrong hole)	1 (Falls out if not in right hole)	0	0	0	R
Ease of assembly	0	0	0	-1	-1	-1	0	1	1	-1	E
Consistency	0	0	0	-1 (Asymmetry)	0	1	1	-1	-1	0	N
Footprint	1	0	0	-1	-1	1	0	0	0	-1	C
Producability	1	1	1	1	1	1	1	0	0	0	E
Costs	1	1	1	1	-1	0	-1	-1	-1	-1	R
Sustainability	1	1	1	1	0	0	0	0	0	-1	E
After EOP	1	-1 (Difficult to get out)	0	0	0	0	0	-1	-1	-1	F
Total	5	4	5	1	-2	4	5	1	0	-5	
Rank	1	2	1	3	5	2	1	3	4	6	
Continue	Yes	Maybe	Yes	No	No	Maybe	Yes	No	No	No	

Criteria	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Reference
Main functions	1	1	1	1	-1	1	1	1	0	0	R
Ergonomics	1	1	0	-1	1	0	0	1	1	0	E
Third hand	1	1	1	-1	1	1	1	1	1	1	F
Assembly/context	-1	0	0	1	0	1	1	1	1	0	E
Error proofing	0	0	0	0	0	-1	1	0	0	0	R
Ease of assembly	1	1	0	-1	0	1	1	1	1	-1	E
Consistency	0	0	0	-1	-1	1	1	-1	-1	0	N
Footprint	1	1	1	0	-1	1	1	0	0	0	C
Producability	1	1	1	1	0	1	1	1	1	-1	E
Costs	1	1	1	1	-1	0	-1	-1	-1	-1	R
Sustainability	0	0	0	0	0	0	0	-1	-1	-1	E
After EOP	-1	-1	0	0	0	-1	-1	-1	-1	-1	F
Total	5	6	5	0	-2	5	6	2	1	-4	
Rank	2	1	2	5	6	2	1	3	4	7	
Continue	Maybe	Yes	Yes	No	No	Maybe	Yes	No	No	No	

Criteria	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Reference
Main functions	-1	-1	-1	-1	-1	0 Needs a weldnut	0	-1	-1	-1	R
Ergonomics	1	1	1	1	1	1	1	1	1	1	Too high press-in forces E
Third hand	-1	-1	-1	-1	-1	-1	-1	0	0	-1	F
Assembly/context	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	E
Error proofing	1 Poka yoke	1 Tactile feedback	1 Poka yoke	1 Poka yoke	1	-1	1 Falls out	1 Poka yoke	0	1	R
Ease of assembly	0	0	0	-1	-1	-1	0	1	1	-1	E
Consistency	1 Screws!	1 Screws!	1 Screws!	0	1	1	1	-1	0	1	N
Footprint	-1	-1	-1	-1	-1	1 Round hole	1 Round hole	-1	-1	-1	C
Producability	0 Can be ordered separately	0 Can be ordered separately	0 Can be ordered separately	0 Can be ordered separately	-1	0 Can be ordered separately	0 Can be ordered separately	0	0	-1 Can be ordered separately	E
Costs	0	0	0	0	0	-1	-1	-1	-1	-1	R
Sustainability	1	1	1	1	1	1 Less material	1 Less material	0	0	0	E
After EOP	1	1	1	1	1	1	1	0	0	1	F
Total	1	1	1	-1	-1	0	3	-2	-2	-3	
Rank	2	2	2	4	4	3	1	5	5	6	
Continue	Yes	Yes	Yes	No	No	No	Yes	No	No	No	

Total	-1	-1	2	-2	-4	1	-2	0	-2	-6	
Rank	4	4	1	5	6	2	5	3	5	7	
Continue	No	No	Yes	No	No	Yes	No	Maybe	No	No	
Total	5	4	5	1	-2	4	5	1	0	-5	
Rank	1	2	1	3	5	2	1	3	4	6	
Continue	Yes	Maybe	Yes	No	No	Maybe	Yes	No	No	No	
Total	5	6	5	0	-2	5	6	2	1	-4	
Rank	2	1	2	5	6	2	1	3	4	7	
Continue	Maybe	Yes	Yes	No	No	Maybe	Yes	No	No	No	
Total	1	1	1	-1	-1	0	3	-2	-2	-3	
Rank	2	2	2	4	4	3	1	5	5	6	
Continue	Yes	Yes	Yes	No	No	No	Yes	No	No	No	
Total	10	10	14	-2	-9	10	12	1	-3	-18	
Rank	3	3	1	5	7	3	2	4	6	8	
Continue	Yes	Yes	YES	No	No	Yes	Yes	No	No	No	
											

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