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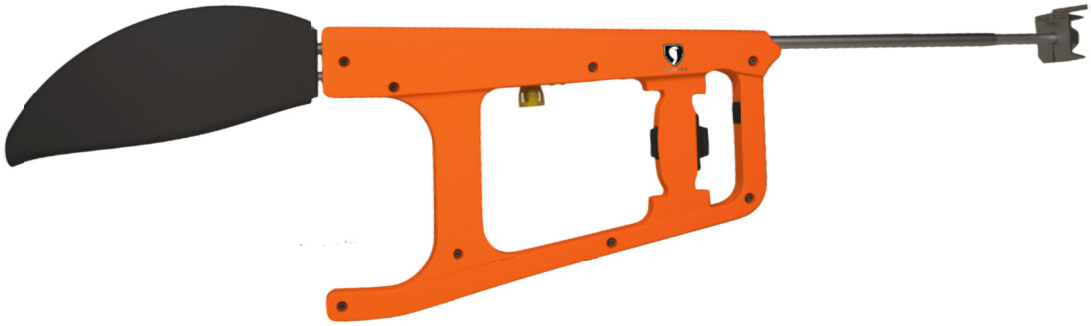

Redesign of a cutting extinguisher

Development of a new lance with a focus on usability

Master of Science Thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY

Göteborg, Sweden, 2011

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Cover:
A rendered picture of the new lance.

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Abstract

Cutting extinguishing is an up-coming method in firefighting, a lance uses an abrasive-water mix to cut through wall and extinguish the fire inside the room. The cutting extinguisher's lance has had the same design for over ten years. The use of the cutting extinguisher has developed a lot since the first lance was introduced on the market; thus, the lance is in need of redesign to meet the users' requirements. New technical possibilities, such as electrical wire control, now exist that the new lance must be able to be manipulated.

With these prerequisites in mind, interviews and use-studies of firefighters were used in parallel as the inputs for the design of the new lance. Sub-solutions were developed with CAD-tools and physical prototypes. By scoring matrices and discussions, the sub-solutions successively merged into a final solution.

The final solution initially appears very similar to the original design of the lance due to the fact that all the beneficial properties of the original were retained. However, a closer look reveals the differences: the trigger functions are electrified and the shell position is adjustable and more ergonomic.

To take this prototype to a full-scale production, various testing and optimization methods need to be performed. These methods examined the tolerances and materials choice that will fit Cold Cut System's vision of the new lance.

Keywords: cutting extinguisher, lance, firefighting, water jet, fire equipment

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Contents

1 Introduction

A cutting extinguisher is a tool that makes it possible to fight a fire inside a building without entering the room on fire. The tool consists of a high-pressure system that mixes water with an abrasive material. This water-abrasive mix cuts through the wall and the water mist is spread in the room to cool down the fire gases. Figure 1 shows an animated illustration when the COBRA, the model name for the cutting extinguisher's lance, is used.

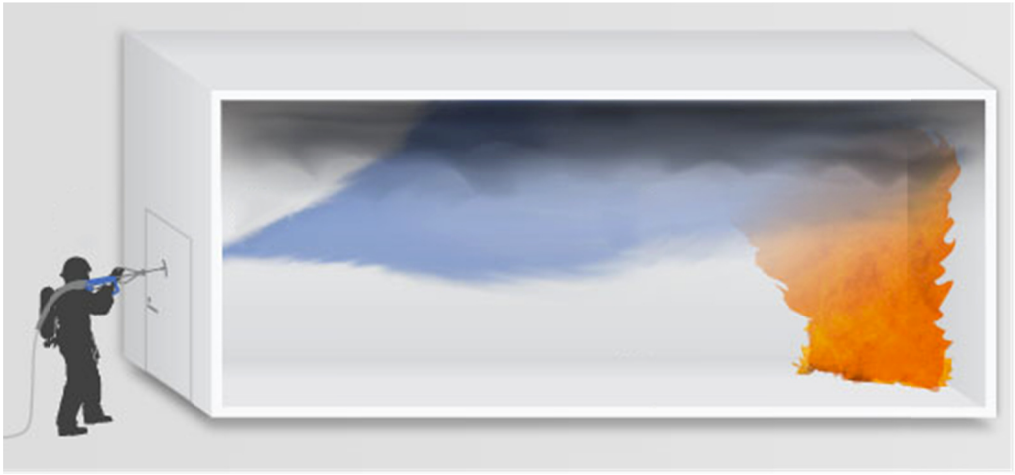


Figure 1 Cutting extinguisher in use.

1.1 Cold Cut Systems

Cold Cut Systems is a company located in Kungsbacka, Sweden, which is 20 km south of Göteborg. The company was founded in 1984 and, since 1997 when it received a patent, has maintained the cutting extinguishing system as their main business. Today, they have fifteen employees including both administrative and operational personnel.

1.2 Background

For Cold Cut Systems, manufacturing of the cutting extinguisher COBRA has been maintained as the primary business for the last fifteen years. The COBRA market is steadily increasing; today, there are around 400 cutting extinguisher systems installed in over thirty countries. The company believes that the reason for the COBRA's success is a combination of three factors. First, the COBRA gives the possibility for the firefighter to combat the fire from outside of a building/construction in fire; thus, the firefighters do not have to expose themselves to dangerous situations such as extreme heat or poisonous smoke. Second, the high-pressure systems of the COBRA shatter water drops into a fine mist. The mist cools down the fire in a faster and more

efficient way. Third, because of this efficient mist, the COBRA uses much less water than other systems leading to less water damage because most of the water is vaporized. In addition, a smaller amount of hazardous substances are dissolved in the slop water, which flows into the environment (Cold Cut Systems, 2008).

During the ten years the COBRA has been in use, customers have voiced many wishes and demands for improving the tool. Despite their suggestions, only several design modifications have been made over the years. Cold Cut Systems has now therefore decided to develop a new COBRA lance that meets the new requirements from the customers and while simultaneously being improved to handle several new techniques. Cold Cut Systems is conducting a parallel project in which they are developing a wire-controlled system instead of today's radio steering of the COBRA. Because the time aspect of the project is uncertain, it is important the new lance can be adapted both for wire- and radio-controlled steering.

This master thesis work describes the process of how Cold Cut Systems decided to make a new lance. Because there is an existing lance, the project involves the redesign of existing components as well as new solutions for the unaddressed needs of customers. The redesign of the COBRA lance will affect the existing main components:

- **The shell** is the part in contact with the user that also covers the mechanical and electrical parts. The shell is also the component that provides the image/shape of the product. The purpose in redesigning the shell is to make it more ergonomic and easy to maneuver for the user while simultaneously maintaining its sturdiness.
- **The trigger mechanism** controls the water, abrasive and foam functions, and it will be suited for use with either radio or electrical wire control.
- **The cutting support and splash protection** will both be redesigned to provide a better grip on the cutting surfaces but will also be designed to lighter and easier to maneuver.
- **Other parts** included in the project are protection against hose coupling failure and a support handle. An overall review of the project will also be performed to remove and refine existing parts.

1.3 Goal and purpose

The goal of this project is to generate and evaluate a number of concepts and then design a detailed solution for the new generation of the COBRA lance. The deliverables will be CAD files, pictures and drawings at the level of prototype production. The requirements for the new COBRA lance will come from Cold Cut Systems, the users of the product and from other stakeholders, such as health and safety boards and labor organizations.

The goal is to design a new product that fits both the users and Cold Cut Systems better than the previous version. As for ourselves, we hoped to gain experience in working on a real project and testing our skills we have developed during our years at Chalmers.

1.4 Targeted readers

This report is about a very narrow business area: cutting extinguishers. Thus, it contains a number of specific terms from this business area that will be explained for the unfamiliar. The text is written for a reader with an engineering background, which makes it easy to understand for a person with a technical background in any subject.

1.5 Limitations

The scope of the project was to gather customer suggestions and to design the new lance; it does not contain any economical analysis, market strategies, marketing plans or market research. It will neither lead to any physical prototype of the final concept; however, some prototypes were tested and some subsystems were compared herein.

1.6 Users

The major users of this product are firefighters; however, they do not all have the same needs in terms of fighting fires. The users differ from conventional firefighters in municipal duty to part-time firefighters. There are large differences in their daily work dependent on in which field they operate. For example, some users are located in an industry with large areas to extinguish, while firefighters on at a ship at sea must focus on the aspect of extinguishing the fire in a short amount of time.

COBRA users are spread worldwide, but most are located in the Nordic region and Europe. Asia is an expanding market consisting of users with slightly different needs such as firefighting in skyscrapers and offensive units able to advance in congestion to a greater extent than in Europe.

2 Present solution of the COBRA lance

The present-day lance, shown in Figure 2, was designed over ten years ago. It still remains much the same. The few upgrades that have been performed are limited to added functions, such as a button to activate foam or a protective frame around the safety catch. Features such as these have been added due to problems that have developed throughout the years. To satisfy customers' suggestions that have arisen throughout the years, a redesign of the COBRA lance has become necessary. The current state of the COBRA lance subsystems of the COBRA lance are presented below.

Figure 2 The present-day lance.

2.1 Shell

The shell, shown in Figure 3, is molded using two parts of ABS-plastic and is held together with screws from both sides, which are combined with a threaded distance. The space between the pieces is sealed with a rubber strip. Both parts rest against the branch without being attached to it. Despite the fact the shell is not attached to the branch, it is designed in a manner so that the branch prevents rotation and translation.

Figure 3 The present-day shell.

The COBRA shell is the part that comes in contact with the user; it provides support against their shoulders and also gives an opportunity for a grip to the support hand. Neither the transmitter nor the trigger mechanism is attached to the shell, but the

shell has been adapted to provide space for both of these applications. Changing the design of the shell is the most important part in changing the user ergonomics. A protective hose sleeve was designed to secure against any accident with small jets if cracks arise and to keep the hose in a safe position if the coupling breaks. The sleeve is made of three layers of a Kevlar-like material and can withstand a small jet for one minute. As shown in Figure 4, the sleeve runs over the hose part of the COBRA and attaches to the shell.

Figure 4 Protective hose sleeve

2.2 Trigger handle

The grip for the trigger handle is designed from a standardized clamp, as shown in Figure 5. The figure also shows the holder for the radio and the foam regulator. Both the trigger and the radio holder are attached to the branch (and not to the shell). It is possible to control two regulators from the triggers of the grip: one controlling the flow of water and one controlling the abrasive. To use foam, a regulator from the side of the radio holder must be switched. All three regulators are linked to the radio by mechanical connectors, which simply push the buttons on the radio panel. The transmitter then communicates with the high-pressure pump to obtain the desired mixture. Both foam and abrasive are needed in the casting-off of water.

Figure 5 The present-day trigger handle.

2.3 Branch

The branch is a seamless and acid-proof tube that runs from the hose to the nozzle. The ends are beaded against the hose coupling and the nozzle to give extra protection against leakage. Figure 6 shows the beaded branch with the attachment for the radio and the trigger. There are several locking rings on the branch that makes it possible to attach the trigger mechanism, radio transmitter and the cutting support. The branch is reinforced with an extra pipe between the trigger mechanism and the cutting support. Because of the beaded ends, it is not possible to change any parts once mounted.

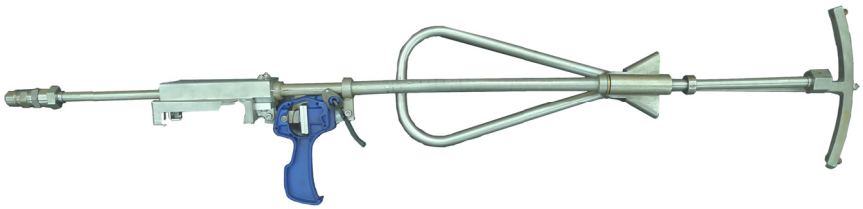


Figure 6 The present-day branch.

2.4 Cutting support

The cutting support is used to extend the distance between the nozzle and the wall and also to provide a grip to keep the water jet in the right position. There are two different kinds of cutting supports: one anchor-shaped support that provides extra support when cutting loose material and one four-point support suited more for penetrating a hole. Both cutting supports are shown in Figure 7, in which the anchor is shown on the left and the four-point support is shown on the right. The anchor-shaped support has an integrated handle for the support hand. When using the four-point support, an extra handle must be attached to the branch. Because the four-point support has a large surface, it also serves as splash protection, while the anchor support needs removable splash protection. All new lances are delivered with the anchor cutting support. Because the ends are beaded, it is impossible to remove the brackets for the anchor without cutting them off.

Figure 7 The present-day cutting support.

2.5 Splash protection

Splash protection protects the user from the splash of water, abrasive and foam that bounce back against the wall during use of the COBRA. When the lance is equipped with the four-point cutting support, no extra splash protection is available. However, when the anchor-shaped cutting support is used, a soft transparent plastic protection can be used as an optional protective device, as shown in Figure 8.

Figure 8 The present-day splash protection.

These sections describe today's solution, which will be reused, redesigned, refined or removed during the project.

3 Methods

The product development process utilizes various tools for different steps in the product development process. The use of the tools and their purpose are explained in this document together with the outcome from the tools. The project follows a typical product development process. The process described in the book, *Product Design and Development*, by Eppinger and Ulrich is the groundwork upon which this process is built. The following sections are in consecutive order: the identification of customer needs, product specifications, concept generation, concept selection and, finally, the detailed design of the product.

3.1 Stakeholders of the new lance

Current COBRA users are in the fields of conventional, naval and industrial firefighting. Among these, the requests of the conventional firefighters have top priority, followed by those of the navy and then by those of the industrial users. The reason for the low priority of industrial users is there are few of them and not a priority for the company; many of their wishes is also the same as the rescue services' wishes. It can be difficult for a user to express problems and wishes when they do not have much rescue experience for comparison. It is therefore important to not just listen to their suggestions for improvement but also to understand their personal technique in using the cutting extinguisher (Lindstedt & Burenius, 2006) (Eppinger & Ulrich, 2008) (Bergman & Klefsjö, 2003). If you know the manner in which the customers use the product, it is possible to draw conclusions for improvement possibilities.

In addition to the users, Cold Cut Systems, governments that set the prevailing laws and working organizations need to be regarded as important stakeholders. Cold Cut Systems demands mostly focuses on the desire for a product that fits well into the company's image and one that expands upon the existing technique. The prevailing laws and working rules are gathered from different standards and government documents, for example *Maskindirektivet* by Swedish Standards Institute.

3.2 Identification of need for a new lance

To determine an optimal solution, it is important to really know what the different stakeholders want and how they use the product. To obtain as much background information as possible about the expectations of the lance, several interviews and customer investigations were performed. The objective of the user study was to assemble a list of users' needs and then transform these needs in to a requirements specification.

3.3 User investigation

Cold Cut Systems has already performed some studies regarding the cutting extinguisher. In 2005, a survey of forty firefighters from twenty fire stations was conducted. The firefighters were asked about the advantages/disadvantages and for improvement suggestions for the COBRA lance (Cold Cut Systems, 2005). Also in existence is a document providing a detailed analysis of the COBRA lance with development suggestions from the Rescue Service of Southern Älvsborg (SÄRF) from 2006 (SÄRF, 2006). In 2009, the Swedish defense material organization (FMV) conducted a technical requirement specification for naval use (FMW, 2009). These earlier studies are used in this project, but because they are several years old, it is possible that new requirements may have arisen in recent years. The fact that the studies are old makes a complementary study necessary. This new study is conducted by interviewing experienced users in both the rescue services and navy. To get as broad of an understanding as possible regarding the manner in which the lance is used, users from Norway, Sweden and England were surveyed. Customer needs were divided into the categories of spoken and unspoken needs. The unspoken needs were not expressed because they are either taken for granted or unknown (Lindstedt & Burenius, 2006). The unspoken needs encompass "unknown needs" that the operators are unaware of because they are so well adjusted to the product as it is currently designed. Thus, they work around problems instead of identifying them directly. To determine unspoken needs, the questioners and interviews mostly focused on how the product is used rather than asking for improvement suggestions. The design of the questionnaire and the outcome are described in Appendix A. It is a questionnaire built up of specific questions with alternatives to fill in. There is also room for comments to collect individual thoughts.

To obtain a deeper knowledge in how the CORBA is used, we have also participated in a two-day introduction course for the cutting extinguisher. Figure 9 shows a picture taken during the course. The close contact with Cold Cut Systems provides continuous feedback during the project, thus ensuring that users' requirements are addressed. To fulfill the laws of both governments and working organizations, many standards from SIS and SS-EN, Swedish Standards Institute, were consulted, including documents from the Swedish National Board of Occupational Safety and Health (Swedish Standards Institute, 2010).

Figure 9 The project members in action during introduction course.

3.4 Needs and requirements specifications

The requirement specifications are developed from the needs expressed from the stakeholders and our own experience when using, investigated and observing the COBRA lance (Bergman & Klefsjö, 2003) (Eppinger & Ulrich, 2008) (Lindstedt & Burenius, 2006). The expressed needs were evaluated and sorted according to the user category and how congruent the needs were with others' wishes. The most important needs will be transformed into product requirements. The requirements are then divided into groups according to the different subsystems, which are expressed under the "Concept" section. To differentiate and determine the importance of each requirement, they are weighted using a scale ranging from 1 to 5, where 5 is the most important (Lindstedt & Burenius, 2006).

3.5 Concept generation

During concept generation, it is important to focus on a wide spectrum in the beginning to narrow the spectrum down in the end, to ensure no promising solutions are missing (Wheelright & Clark, 1992). The present-day COBRA as well as products that are derivatives of the COBRA lance was investigated to determine how to fulfill the users' requirements. To produce as many solutions as possible, each group member brainstormed ideas individually. These ideas were then compared and discussed; in many cases, these discussions led to even more ideas that in next step were refined to complete solutions.

3.5.1 Subsystems and subsolutions

To be able to work more freely and to maximize the outcome of the concept generation, the lance was divided into different subsystems (Eppinger & Ulrich, 2008)

(Johannesson, Persson, & Pettersson, 2004). Identification of the subsystems was important to solve problems individually and to not be restricted by solutions to other problems. The subsystems, for which new solutions were developed, were adapted from the parts and functions of the existing lance. Figure 10 shows a present-day COBRA lance divided into different subsystems. The solutions for the different subsystems are evaluated during the process to identify if there is a possibility to re-use, reduce, refine or make any other change to enhance the way the sub-function contributes to the total function (Lindstedt & Burenius, 2006).

Figure 10 The circled areas in this present-day lance represent the coupling protection, body support, trigger mechanism and branch, from left to right.

A functional model was established to show the process of cutting extinguishing and has worked as a mind-map during the project to make sure that the main function always is in focus, the functional model is shown in Figure 11 and is based on the principles in (Lindstedt & Burenius, 2006).

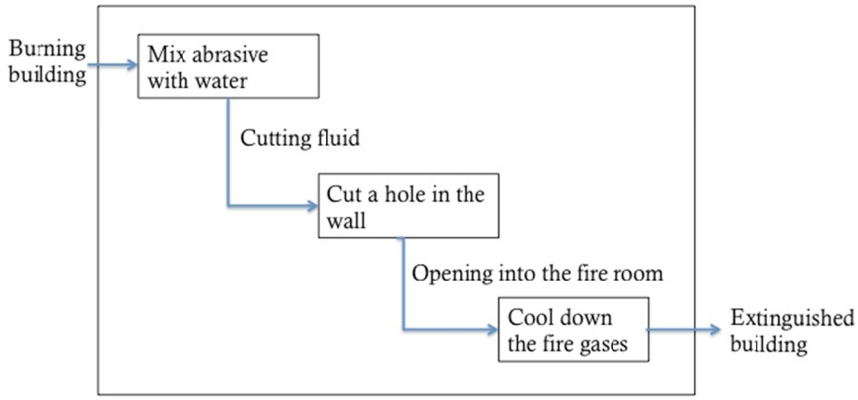


Figure 11 Functional model of the cutting extinguishing process.

When generating conceptual illustrations, a compromise between distinctiveness and time must be achieved. To show the basic principles and thoughts, simple hand-drawn sketches were used first. In the next step, basic CAD models were produced to better illustrate the purpose for spectators outside the project. In Figure 12, a hand-

drawn sketch is shown. Figure 13 illustrates an example of how a sketch was transformed into CAD.

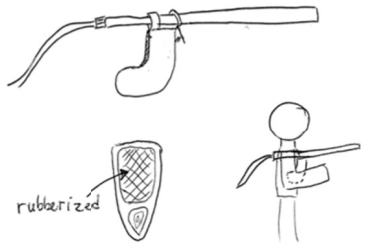


Figure 12 Hand-drawn sketches of a subsolution.

The main focus at the illustration level shown in Figure 12 is to depict how the solution(s) is going to be physically held when in use. Figure 13 mediates the concept of the proportion and appearance of the subsolution.

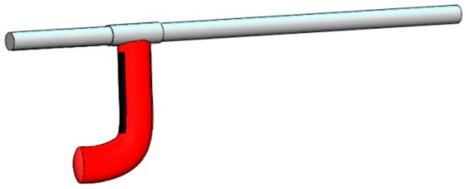


Figure 13 A CAD-converted sketch.

3.5.2 Evaluation of subsystems and subsolutions

When no new solutions for the different COBRA subsystems could be generated, the concepts were discussed and evaluated to, in an early phase, delete unreasonable concepts that do not meet the required specifications (Eppinger & Ulrich, 2008).

After evaluating the concepts for each subsystem, combinations of different subsystems were investigated to determine which ones could be combined and which ones were decoupled. The decoupled subsystems needed to be evaluated separately. The evaluations were performed by comparing the different concepts with each other and matching them against the requirements specification. In some cases, prototypes were built and tested. The intent is that only the concepts used in the final solution will remain after the screening of the decoupled subsystems. Figure 14 shows a schematic of the elimination procedure.

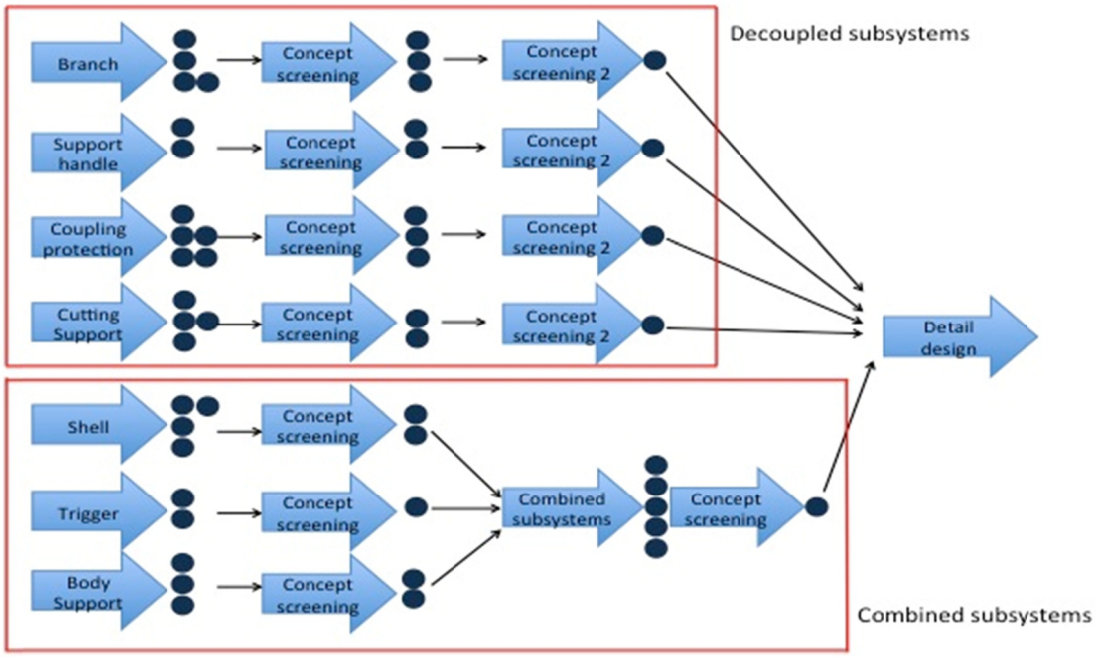


Figure 14 Schematic of the elimination procedure for new COBRA subsystems.

The combined concepts were evaluated in a different way than the decoupled. As described earlier, all the concepts in each subsystem were evaluated through discussion in the same first phase. The coupled concepts that passed through the first elimination were then combined into new concepts. These new combined concepts were first screened and evaluated in a Kesselring matrix. The Kesselring matrix was developed from the requirements specification, and each concept was rated on a scale of 1-3 for determining how well the concept fulfills the requirement (Lindstedt & Burenius, 2006). The scores were compiled and the sum of the scores was determined, providing information on how well the different concepts were able to fulfill the requirements. The best solutions were then presented for representatives from Cold Cut Systems, who will determine the most promising concept. The concept from the combined subsystem will later be merged together with the concepts from the decoupled subsystems to form overall solutions.

3.6 Detailed design

When the evaluation of the subsystems was complete, the details for all the different parts were determined. The details ranged, for example, in determining how two parts will be connected to each other to the decided dimensions of a single part. To get a geometric idea of the parts and to be able to see, feel and test how the different dimensions should be determined, simple mock-ups and prototypes were created. Figure 15 shows a simple plywood functional prototype of the shell. This simple type of model works for determining dimensions.

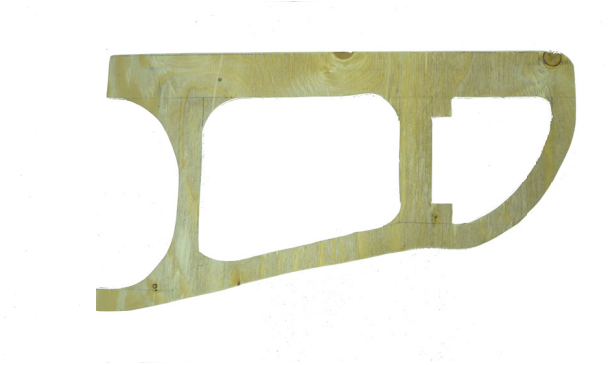


Figure 15 Mock-up of the shell for dimension test.

The detailed design consisted of two different steps. First, the individual part needed to be tested alone to determine if it fulfills its purpose. Then, the part was geometrically optimized with its surroundings. During both the design of each part and while merging various parts together, DFM and DFA were taken into consideration (Eppinger & Ulrich, 2008) (Lindstedt & Burenius, 2006) (Johannesson, Persson, & Pettersson, 2004). The main DFM issues in this project involved the molding issues associated with the geometrics, the turn and if all surfaces were reachable with regard to the tools. For the DFA, the issues focused more on the order of mounting and disassembling for service as well as on the spaces for tools. Figure 16 shows a case where DFA have resulted in a hole that enables mounting of screws.

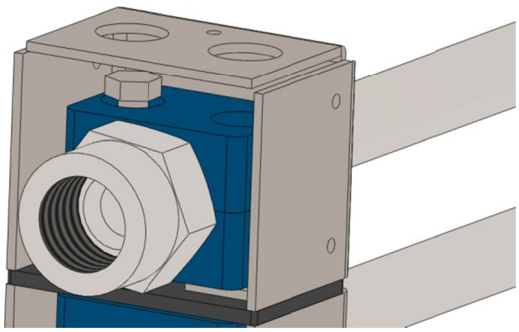


Figure 16 An example of a DFA design feature.

Prototypes were also used to test if a function works correctly; examples of a prototype and its testing can be seen in Figure 17. Experiments were performed to test new solutions at an early phase, thereby minimizing the amount of time spent on non-working concepts. The prototypes were built in the Cold Cut Systems workshop and were tested in their test facility. These tests are compiled into the *Test Protocols* section in Appendix E.

Figure 17 Splash protection and testing.

Finished parts were mounted together in the SolidWorks assembly program and measured for best fit. During both the construction and assembly phases, continuous discussions with both the engineers and the mounting personnel were held. The discussion was so productive that dimensions from the detailed design of this project have been implemented in other parallel Cold Cut Systems development projects. This cooperation between different divisions and projects will most likely result in a better product. (Wheelright & Clark, 1992)

4 Results

The "Methods" chapter describes the workflow and how the development process for the new COBRA proceeds. The outcome from the steps in the workflow is presented in this chapter together with arguments and motivations for the choice of concepts and functions.

4.1 Outcome of the need collection

Appendix B lists all the expressed customer needs. The needs judged as relevant were then transformed into requirements and gathered into a requirement specification, as shown in Appendix C. During the user investigation, it became clear that the majority of the users use the product in the same way and also have same thoughts and directions for improvement. However, some needs differed. The most relevant and important needs discussed when forming the requirements specification are described below:

In a couple of areas, the opinions about the current lance were very positive. The users both liked the current solution and even discovered new ways using it. The body support is an example of such an area; For example, the majority of user found the body support was helpful and preferred to use the lance in a position over the shoulder. Some users also used the COBRA against their hip, under their arm and even in other uncommon postures.

An area that has changed since the lance came onto the market is how to cut into various materials. In the beginning, the purpose was to make a large hole in a material to be able to bring something through the hole. During this study, it was determined that users almost exclusively used the lance to penetrate and spray water through a wall to extinguish a fire. Most users preferred the four-point support because it is much lighter, more robust and gives a better grip than the anchor shaped support.

Because the respondents mostly hold the lance over their shoulder and against a surface for penetration, the placement of the hands is important. The respondents liked the adjustable grip for the support hand when used together with the four-point support because this grip is able to adapt the lance to fit different individuals with different arm lengths.

Users are very satisfied with the robustness of the shell; cracking and other damage to the shell have been infrequent.

One area in which the users experienced problems with the lance was, among others, the radio communication, where the linkages between the trigger mechanism and the

radio, and also to the on/ off button have failed. Other common opinions include the observation that the lance was heavy and had a misplaced center of mass. Additionally, users thought it was difficult to keep the lance in the correct position during the penetration of hard materials. Depending on the position and angle, the lance felt unstable against the shoulder for some users. The branch sometimes felt too long, especially when using it in odd situations, such as on roofs, ladders and in confined spaces. As a result of the instability against the shoulder and the too long branch some of the users felt it hard to handle the recoil. Another problem was the bound back of liquids.

The National Board of Occupational Safety and Health in Sweden's body of law prescribes that the distance between the shoulder and nozzle must be larger than 750 mm (Arbetarskyddsstyrelsen, 1995). To secure against any accident with a small jet, in the case of a crack in the coupling, an extra coupling protection was needed.

These are the most important needs in a bulleted list:

- Able to place the lance over the shoulder.
- Four-point cutting support preferred.
- Center of mass closer to user.
- Flexible length of the branch.
- Reduce the water splash.
- Stable handling of the recoil.
- Distance between nozzle and shoulder must be 750 mm.
- Extra coupling protection.

4.2 Subsystems

The lance was divided into seven different subsystems. The most important functions were separated from each other, making it easier to generate more unique solutions. Figure 18 shows the location of some of the subsystems:

1. Coupling protection
2. Body support
3. Trigger handle
4. Branch

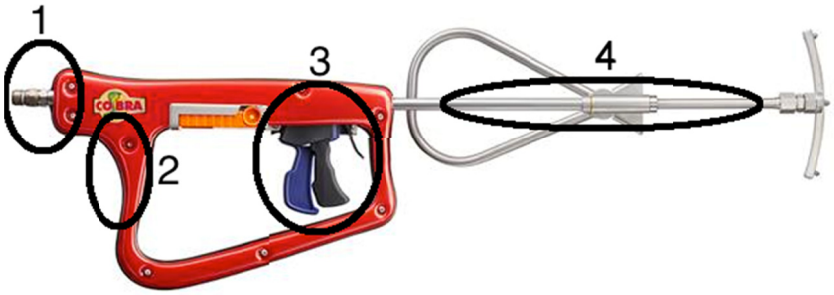


Figure 18 Subsystems 1-4.

The location of the other subsystems is shown in Figure 19:

5. Shell
6. Support handle
7. Cutting support/Splash protection

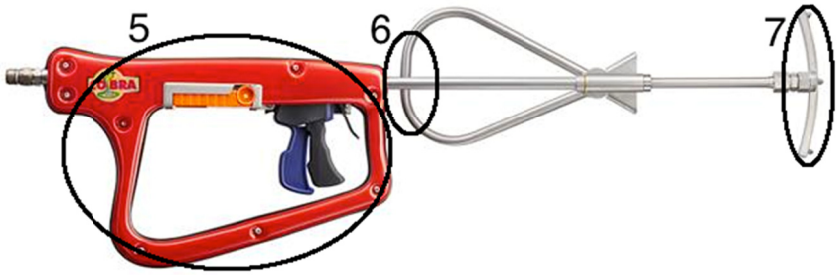


Figure 19 Subsystems 5-7.

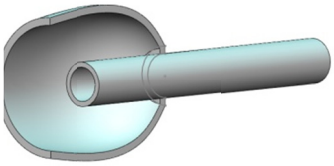
4.3 Solutions of subsystems

Sketches of the principal solutions for the different subsystems are shown below to show the principle of how to use the designed solution rather than what the detailed design looks like.

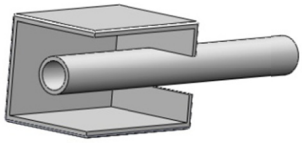
4.3.1 Coupling protection

The coupling protection is a security against accidents with small jets if cracks appear in the coupling. The coupling protection is an extra security if the operator does not use the protective hose sleeve correctly, which means that the operator has double security against small jets. This precaution may seem unnecessary, but because the outcome of an accident would be devastating, Cold Cut Systems believes this precaution is an important one. The protection needs to run over the whole hose coupling and covers, at the very least, the side against the operator.

The two alternatives shown in Figure 20 share the same fixed properties; both just cover the side closest to the operator. Alternative B is similar to A but has a rectangular shape instead.



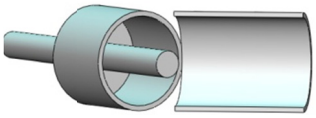
A



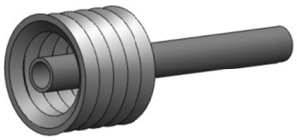
B

Figure 20 Fixed coupling protections.

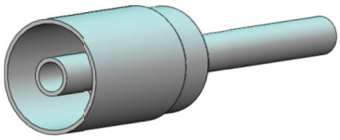
Three flexible solutions are shown in Figure 21. All of them are circular, but alternatives D and E are flexible along the branch while C has a foldable part that comes out from the branch.



C



D



E

Figure 21 Flexible coupling protections.

4.3.2 Trigger handle

The trigger mechanism contains the grip for the trigger hand and also controls the regulators for water, abrasive and foam. As shown in the pictures, different functions result in different color-coding of the buttons, shown in Table 1.

Table 1 Color-coding of trigger functions.

Color	Function
Blue	Water
Black	Abrasive
Grey	Foam
Yellow	Safety catch

The three alternatives of A, B and C, shown in Figure 22, are based upon the principle that uses the handle over the branch. The angle of the hand is the major difference between the alternatives in addition to the placement of the foam and abrasive buttons.

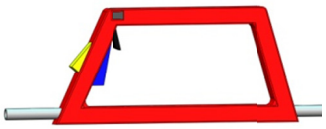
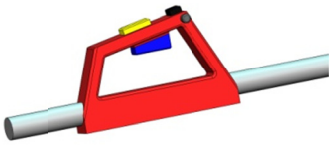
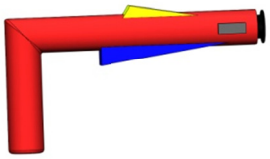
		
A	**B**	**C**

Figure 22 Trigger handle over the branch.

The three handles in Figure 23 are placed under the lance, and the grips look like a trigger handle on a gun. In alternatives D and F, the buttons are placed inside a frame as a protection, together with the safety catch, from accidental activation. Alternative E is a more compact and open solution with a thumb-controlled safety catch on the side. The idea of solution F is to enable the same grip all around the branch; the handle is pin-jointed both around the axis through the handle and the branch.

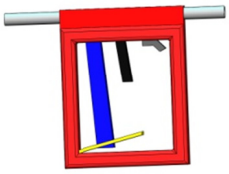
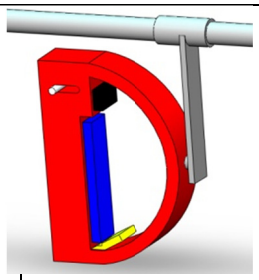
		
D	**E**	**F**

Figure 23 Trigger handle below the branch.

4.3.3 Cutting support/ Splash protection

The cutting support prevents the lance from coming loose from the position where it is used. This position could be against a flat surface as well as against an edge and at different angles. The purpose of this part is to give support to the user for maintaining extinguishing for a long period of time.

The three solutions shown in Figure 24 follow the basic idea of the four-point support used currently. The spikes are for stability and friction against the penetrated surface. The plate holds both the spikes and as a splashguard. In alternative A, the plate is partly transparent to make it possible to see the penetration hole. The plate is notched in alternative B due to the same reason. The feature of alternative C is to align the splash downward using a pitched plate.

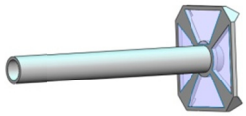
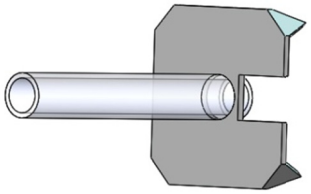
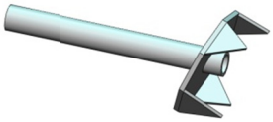
		
A	**B**	**C**

Figure 24 Plate-based cutting supports.

Figure 25 shows three solutions, or alternatives, that focus on stability. They all cover a greater surface area than the other subsolutions, thus providing more support to moment forces. In alternative D, the angle is adjustable in the same way as the current solution. In solution E, foldable supporting legs enable a smaller solution, but with an additional adjustment mechanism. Alternative F follows another principle; rather than stabilizing the COBRA using pressure against a wall, a nail grabs into a slanted hole and by a wire to unburden the recoil from the jet stream.

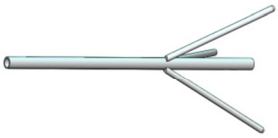
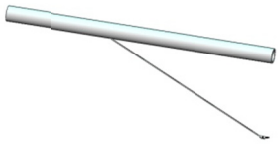
		
D	**E**	**F**

Figure 25 Cutting supports with focus on stability.

The three pictures in Figure 26 show different types of and ways of arranging the spikes. In G and H, the spikes are fixed in relation to the branch. However, in alternative I, the arrangement acts like a matrix where the branch can lead through for cutting purposes or relocating old holes.

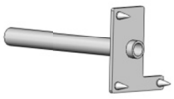
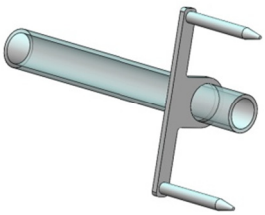
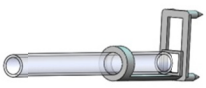
		
G	**H**	**I**

Figure 26 Cutting supports with spike-configurations.

The purpose of the alternatives shown in Figure 27 is to both stabilize and decrease the splash, which is achieved by a cup-formed solution that aligns the splash to pour down through a notch. In alternative K, the cup is cut to make it possible to see where the jet hits the surface.

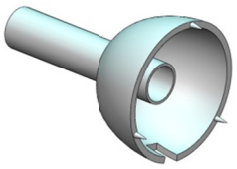
	
J	**K**

Figure 27 Cutting supports that focus on splash protection.

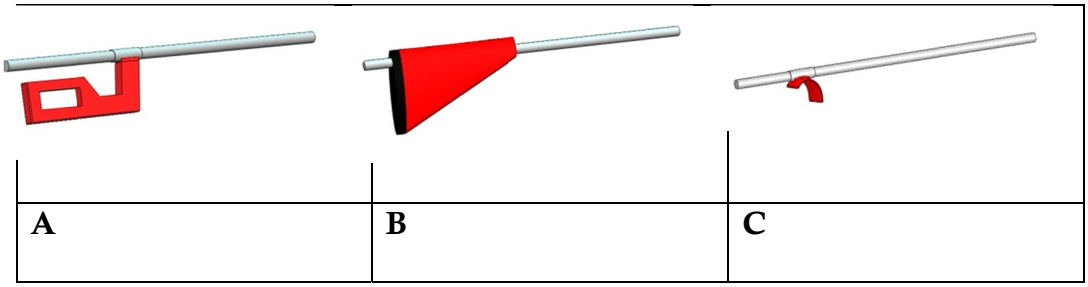
4.3.4 Body support

The body support solutions aim in supporting the force from the lance in the best possible way that relieves the loads for the user and enables a wide range of different application areas. The body support is treated independently from the shell but can still be a part of it. The solutions are divided into three categories: over the shoulder, under the arm and changeable supports.

Over the shoulder

The principle involving the placement of the branch over the shoulder is the one used today. Benefits of this posture are that the user can use the COBRA at several angles and will still reach a long distance from the spot where he or she stands.

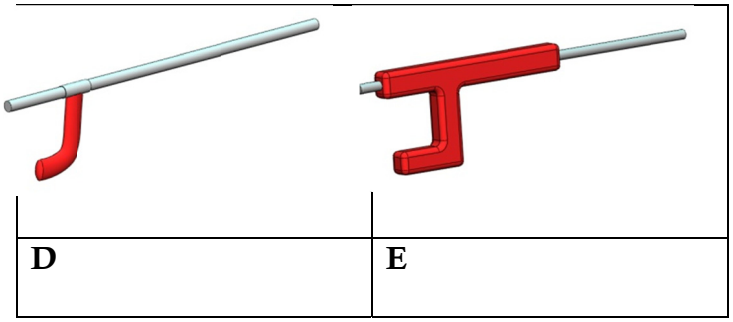
Figure 28 shows three concepts based on the same principal design as a rifle. In alternative A the shoulder support is connected with the trigger handle differently than the other two. Solution B is designed even more like a rifle with storage options for electronic components inside the rifle butt. Alternative C is more ergonomics-based; the support surrounds the shoulder to a higher degree and the user gets a wider area to absorb the force against chest and shoulder.



A	B	C

Figure 28 Shoulder supports for use over the shoulder.

The two solutions shown in Figure 29 are partly based on the same principle as those in Figure 28 but are supplemented with a side support under the arm. Both alternatives shown in Figure 29 have a part of the shoulder support that reaches under the arm that the user squeezes against the ribs when using the lance. The only difference between these two alternatives is that E is integrated in the shell that also separates the branch from the upper part of the shoulder.



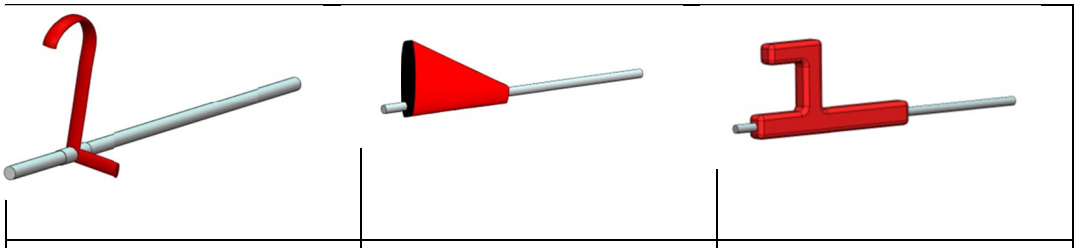
D	E

Figure 29 Shoulder supports for use around the shoulder.

Under the arm

The posture with the lance under the arm shortens the distance to some lower penetration objects, such as a floor. It also gives the user a shorter lever for supporting the recoil.

In the alternatives F and H shown in Figure 30, the weight of the lance is supported on the shoulder as well as the force from the recoil when shooting water. Alternative F has also a brace for the hip. Solution G is a more compact concept with regard to the support of the recoil force but has a greater area to use for squeezing the support between the arm and ribs.



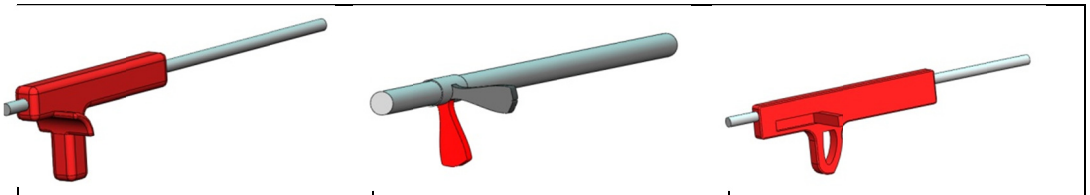
F	G	H

Figure 30 Shoulder supports for use under the arm.

Changeable support

The customers have voiced that it is important to them that the lance is able fit a variety of applications and work environments. A changeable support increases the flexibility of the lance when it comes to standing postures and disparities like left- and right-handed users.

Both alternatives J and K in Figure 31 have the opportunity to transform the support to fit the hip instead of the shoulder and vice versa. In alternative J, the brace is flexible around the branch. In alternative K, it is possible to unfold a brace when support against the hip is needed. In solution I, a sliding chest support is able to switch sides depending on which side the user holds the lance.



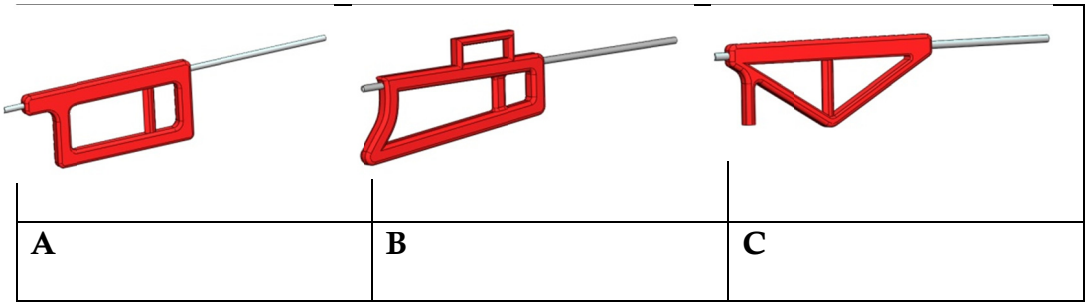
I	J	K

Figure 31 Changeable body supports.

4.3.5 Shell

The shell is the part of the COBRA that encloses the mechanical and electrical parts. It must be adapted to provide room for the trigger mechanism and the body support. The shell is also the part that contributes most to the overall design of the lance.

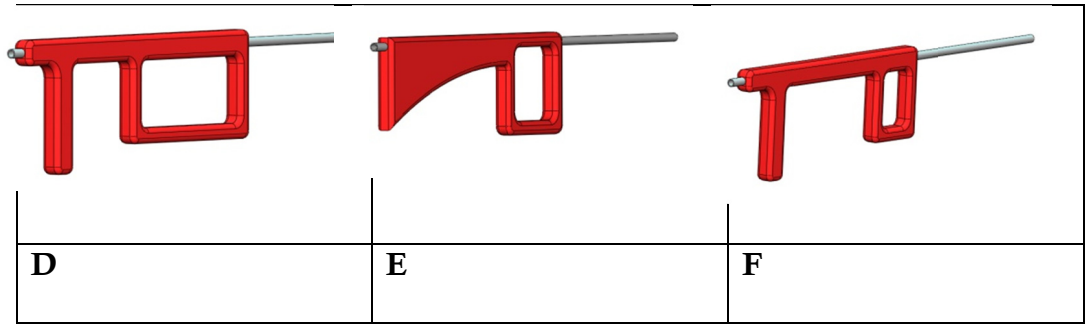
In alternatives A, B and C, shown in Figure 30, the shell consists of a frame that goes from the body support and surrounds the trigger. Solutions A and B are both similar to the present-day lance except for the fact that B has a handle on top. Solution C has much of the same function as A and B but is shaped like a triangle.



A	B	C

Figure 32 Shells with surrounding frames.

The alternatives shown in Figure 33 all have a separate body support and trigger as well as a loop around the trigger for protection. D and F are very similar, but D was constructed to also be a handle for the support hand. The alternative E is reminiscent of a gunstock, which will provide extra support for the arm and elbow.



D	E	F

Figure 33 Shells with separate body supports and triggers.

The two alternatives, G and H, in Figure 34 are reminiscent of many of the alternatives presented earlier, but are frameless alternatives. The last one, alternative I, makes it possible for two persons to push the lance at the same time. The shell is then held horizontal and the operators use their hips to push on each side of the lance.

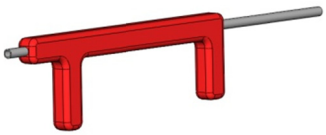
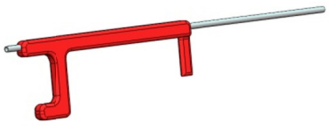
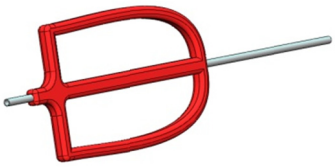
		
G	**H**	**I**

Figure 34 Frameless and two-person shell.

4.3.6 Support handle

This handle is intended for the hand that supports both the force straight backward against the user as well as the side force that can occur when the cutting support slides against the affected surface. This handle also plays a major role when the lance is used in irregular positions and when the lance is used without any support against a wall.

The present-day support handle is already very much appreciated and fulfills all the needs of the users. It is very simply and robustly constructed, which leads to the re-use of the current support handle.

4.3.7 Branch

The branch has several main functions: to transport water, abrasive and foam. The branch fulfills except for all these main functions also a function as a fixed point for all other equipment, such as the handles, shell, etc. The branch should be resistible against accidental bending loads that could occur when a firefighter steps on it. The main load is produced though the water pressure, which is 300 bars during normal use. There are no current problem areas in this subsystem and both the users and the company are satisfied with it today, which has resulted in no change in the current solution and has thereby cut the cost on the production of new components.

4.4 Evaluation of subsystems

The generated concepts for the different subsystems are discussed and evaluated during the early phase of the project to ensure that the concepts are reasonable and fulfill the requirements for the final solutions. The subsystems of the *Trigger handle*, *Body support* and *Shell* will be merged and further evaluated as one combined subsystem after this initial evaluation.

The other subsystems of *Coupling protection* and *Cutting support/Splash protection* will be evaluated through testing and discussion with the persons concerned. Under each sub-evaluation, the referred concept names are the ones used in Solutions of subsystems.

4.4.1 Trigger handle

Most users have expressed interest in a lance that is placed above the shoulder, removing the possibility of using alternatives A, B and C, which all require placement above or on the side of the branch. Thus, only alternatives D, E and F remain for further evaluation.

4.4.2 Body Support

Principles B and G are expurgated because the solutions are unnecessary ungainly without adding anything. Solution F is also eliminated because it cannot be used on a lance that is placed above the shoulder. Concepts I and K are expurgated because the movable parts reduce the sturdiness of the COBRA without adding enough value to the tool. The concepts that were further evaluated are A, C, D, E, H and J.

4.4.3 Shell

Concept B is expurgated because the handle on the top increases the size of the shell too much. However, the idea of an easy way to carry the lance is still relevant and was evaluated during the detailed design. Concept D is expurgated because a fixed support handle is unwanted. Concept E is eliminated because a solid solution does not add any value and would become ungainly. Solution I is also expurgated because it is adapted for two persons when the lance is almost always handled by a single operator. The following concepts that were then further evaluated are A, C, F, G and H.

4.4.4 Coupling protection

Concepts A, B and C were eliminated because they did not protect the whole area around the coupling. Because it is possible to use the lance from both the right and left sides, the protection must be turned differently for different operators, which is a time-consuming and complicated procedure. Concepts D and E underwent further investigation.

After discussion with Cold Cut Systems, concept D was selected for prototyping mainly because this solution was the most compact and there was already an existing supplier that produces the product in the manner Cold Cut Systems desires.

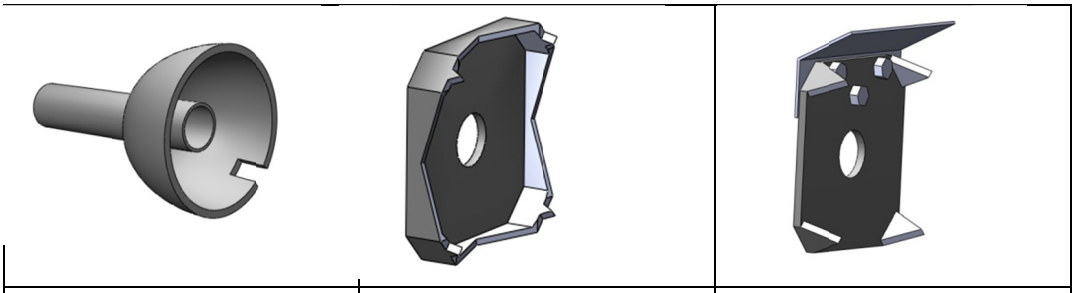
4.4.5 Cutting support/Splash protection

Concept A was eliminated because the transparent part would be covered with abrasive and dirt, which would remove the visibility and also the function of the concept. After discussions and product review, it became clear that a cutting support with an integrated splash protection was preferred. Thus, concepts D, E, F, G and I

were eliminated. The solution K is also expurgated because the idea with the bended edges is to stop the splash from bouncing toward the user; an opening would negate this purpose. Thus, concepts B, C, J and K remained.

After the decision that a four-point support should be used, concept generation for the optimization of the splash protection was performed. This step leads to three new generated concepts.

The alternative L is almost the same as J with the difference that the spikes are gone. The idea is that all the water will bounce back into the cutting support. Concept M has flanges on all sides with the purpose of preventing the water from coming out from the sides of the cutting support. Solution N is similar to M, but it only has a flange on one side. Thus, the edge is in contact with the surface at all times and stops the bounce back of water in the most critical direction.



L	M	N

Figure 35 Cutting support with focus on splash protection

To determine which splash protection works best, prototypes were used to execute tests. The testing procedure and the result of the tests are described in Appendix E.

Not one of the concepts of C, J and M functioned correctly; the water mist slipped under the flanges and reached the operator. The pressure from the water jet made it impossible to keep solution L in the right position and the water became a sliding bearing.

The only concept that worked as expected was concept N, which was very effective. To improve alternative N even further, the flange could be expanded outside the edges of the cutting support, providing a bigger surface protected against water that bounces back. Because it is important that the flange is in contact with the surface all the time, one more improvement is to build in springs that always push the flange against the surface. The test also shows that a notch, as in alternative B, increased the visibility without increasing the bounce back of the water. The optimized solution was therefore an improvement of concept N combined with concept B. The final solution, O, is shown in Figure 36.

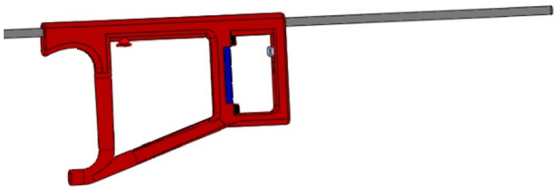
O

Figure 36 The final cutting support

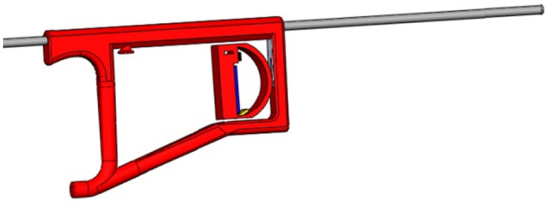
4.5 Combined subsystem

It is not possible to make a complete evaluation of each subsystem because three of them are coupled. The shell, body support and trigger handle are dependent on each other. An evaluation of the combined subsolutions are therefor performed.

The two figures in Figure 37 show the main principle of squeezing the body support of the COBRA under the arm. They also show the robust frame of the shell and two different possibilities for handles for use in various directions.



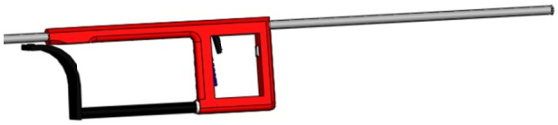
A



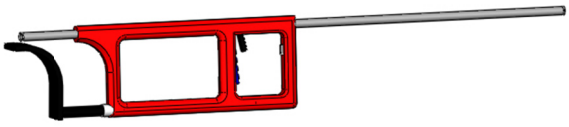
B

Figure 37 Two combined subsystems with rigid bowed shells.

Figure 38 presents two very similar concepts. The handle and the function of an adjustable body support is the same; the difference between C and D lies in the smaller shell of alternative C.



C

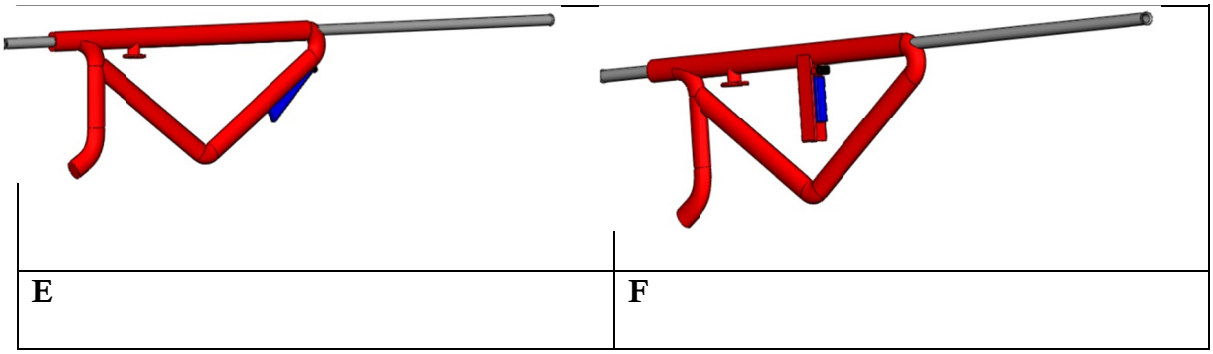


D

Figure 38 Two combined subsystems with adjustable body supports.

The two concepts shown in Figure 39 share the same body support as those in Figure 37, however, they are very different when lot with its protruding shell design.

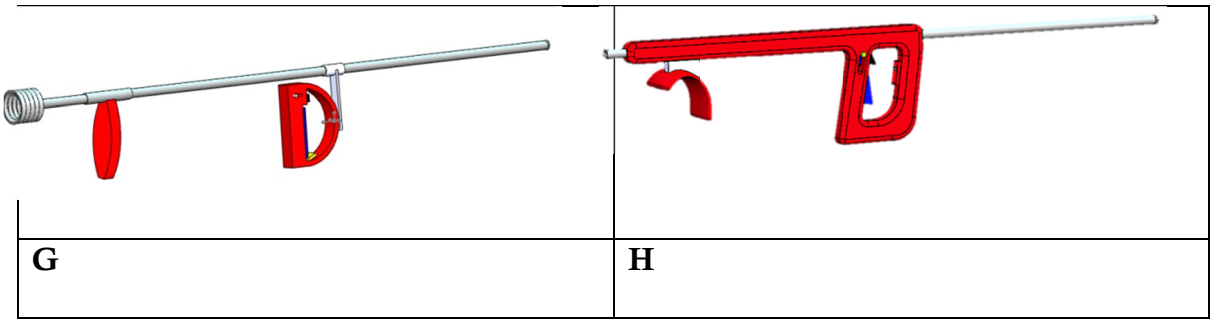
Between the alternatives E and F, a different placement and design of the trigger mechanism can be seen.



E	F

Figure 39 Two combined subsystems with V-formed shells.

Another kind of design and modular thinking is shown in the two alternatives in Figure 40. In alternative G, the functions are more separated and specialized to solve the individual subsystems in various ways; both the handle and the body support are completely adjustable around the branch. The other concept focuses more on the use of the lance positioned over the shoulder and has therefore a more rounded body support that is only adjustable lengthwise.



G	H

Figure 40 Two combined subsystems using modular thinking.

4.6 Evaluation of combined subsystem

A weighting procedure for related parts of the requirement specification provides a good view of how well the alternatives fulfill the users' wishes and demands. Please consult Appendix D for a full detailed overview of this weighting result.

In addition to the users' demands, the technology itself has demands for what alternative is actually feasible for further use. These demands could be stated in the requirements specification, but the combination of subsystems may also cause new prerequisites.

The weighting procedure shows that the most promising alternatives are A and B. Together with C and F, they have the highest rank from the users' perspective. The result from this procedure together with discussion and comparison of technology and compatibility issues is that alternatives A, B, F and G passed the evaluations. These alternatives are shown in Figure 41.

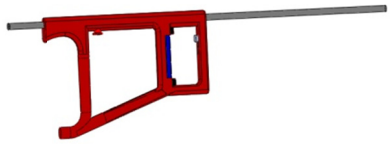
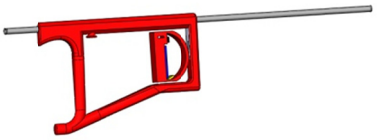
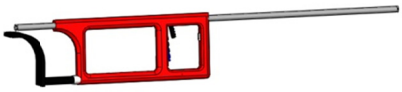
	
A	**B**
	
F	**G**

Figure 41 Alternatives of combined subsytems presented for Cold Cut Systems

After presentation and discussion with those responsible for product development, the sales and workshop teams decide to continue with alternative A. The main argument for alternative A is that it seems to be most robust alternative, both in handling tough use as well as how it would technically function and be manufactured. It will also provide good stability upon squeezing the body support under the arm. Another advantage is its symmetry, which provides the possibility of using the lance under the arm while still being able to reach the triggers.

4.7 Detailed design

This detailed design chapter explains the final solution with a walkthrough of all sub-functions and parts. All functions are described with pictures, the motivation for the various features and a description of how the functions work. See Appendix F for a complete set of drawings of all parts that not are standard components.

4.7.1 Shell

The most important part for ergonomics is the shell. Much time is spent on finding the right dimensions that makes it possible for people of different sizes to use the lance. The user will also be able to wear different equipment without causing any problems. The most important measurements are the distance between the shoulder and trigger handle and the grip size of the trigger handle. To determine these measurements, anthropometric data was studied and prototypes were tested on persons with varying body measurements. The measurement of the grip was 77 mm, which is within the recommended interval (Bohgard, M et al, 2009). The measurement of the distance between the shoulder and the trigger handle was compared with data describing the functional reach of the large proportion of the population of Swedish adults (Bohgard, M et al, 2009). The measure between the upper and lower part of the body support was adapted to fit a large user wearing fire-

protective equipment. The length of the lower part located under the armpit is set to give support even when the operator is leaning his or her torso forward in a sharp angle. A full picture of the shell is shown in Figure 42.

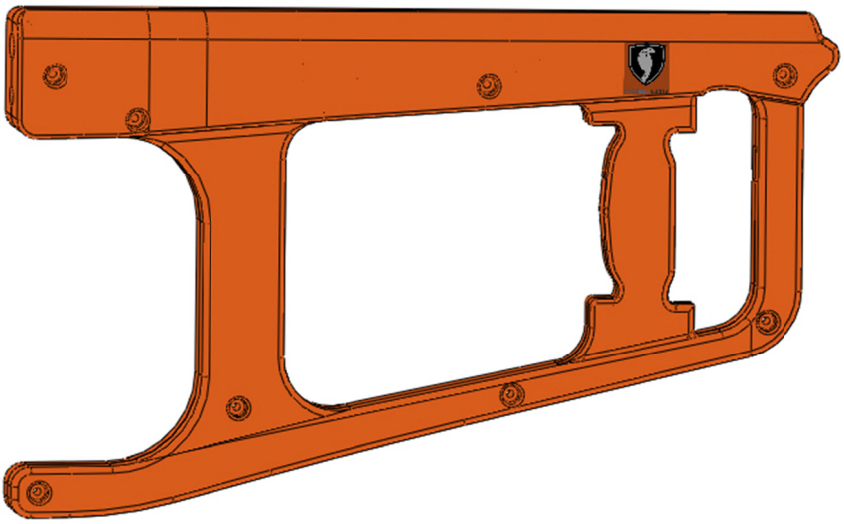


Figure 42 The shell.

Protection of the trigger hand in the front of the shell is shown in Figure 43. This part of the frame is to protect both the user's hand and the buttons from being pinched or hit by something.

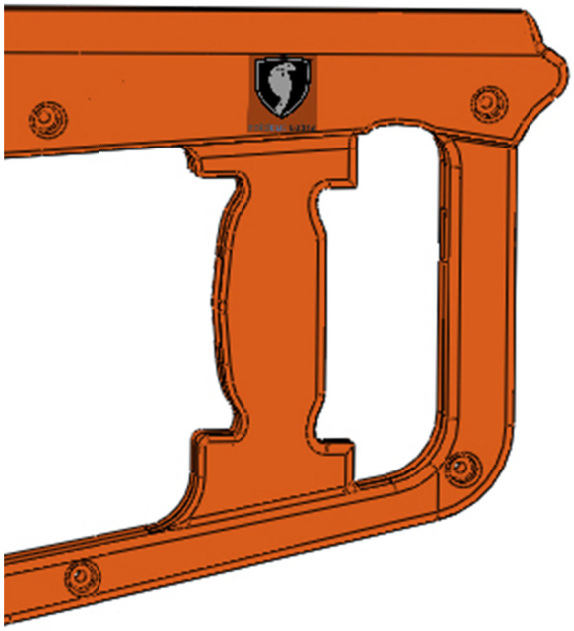


Figure 43 Protection of the trigger hand.

The shape of the shell is design to look smooth, without any sharp corners that could get stuck into on something. The shell is also narrower in the aiming direction to

mediate the feeling of an arrow in which way the water goes and the lance should be used.

It is very important that the user gets a robust feeling of the shell and that it does not get bent or twisted. To increase the stability of the shell, the lower frame runs all the way from the protection of the trigger hand back to the body support, which increases the stability and is also a design feature that gives the lance a cleaner, smoother appearance.

The width of the shell is varies throughout the frame. For example, the upper part is wider than the rest of the shell because it contains many different components and simultaneously functioning as a good support against the shoulder. The width of the lower part of the body support was adapted to give a comfortable and ergonomic grip for the arm when squeezing against it. The part of the frame that combines the upper and the lower body support must be able to fit a radio transmitter. The width of the lower frame and the protection for the trigger hand were made to fit well with the lower part of the body support. The trigger handle itself is a bit thinner than the lower frame to be more ergonomic for the trigger hand (Bohgard, M et al, 2009).

4.7.2 Adjustment function

To meet the users' need to adapt the distance from the shoulder to the penetration target, the lance was equipped with an adjustment function. It is too time-consuming to disassemble the whole shell and fixations every time a shorter or longer branch is needed. Because emergency situations change quite fast after penetration through floors, roofs and walls, the need for shorter and longer lances must be fulfilled by the equipment available.

The need for different distances is not only an ergonomic issue, it is also very important for safety. If the distance from the shoulder to the pitched roof is too long, the user is forced stand in a more upright position in which it is harder to withstand the recoil from the water jet than in the suggested position.

For changing the distance more flexibly and efficiently, the shell was designed to be adjustable along the branch. The branch is the same length all the time, but the important distance from the nozzle to the shoulder is adjustable. There are three fixed positions along the branch; these can be fastened and loosened by two hasps that lock and unlock a notched bar. A bar and a hasp are shown in Figure 44.

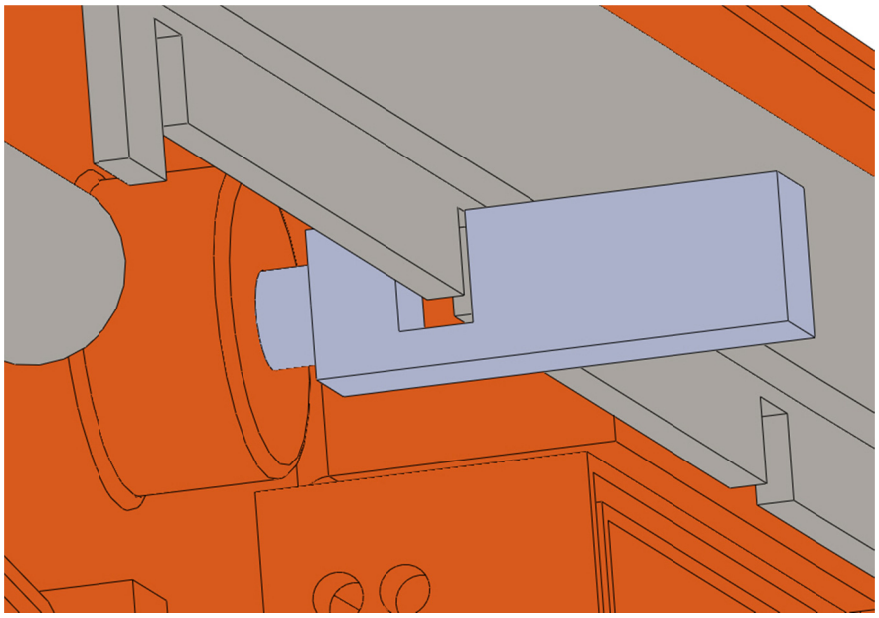


Figure 44 Hasp and notched bar for adjustment function.

The hasps are fixed in the branch's direction in the other shell and are allowed to glide in the perpendicular direction, which means that the adjustment function is unlocked when hasps' buttons are pushed outside the left shell. The buttons and how they are pressed are shown in Figure 45. The buttons are placed at such a distance that the user has to put down the lance and use the both hands to press the buttons. This step was implemented to avoid possible accidents that could occur if the shell was adjustable while in use.

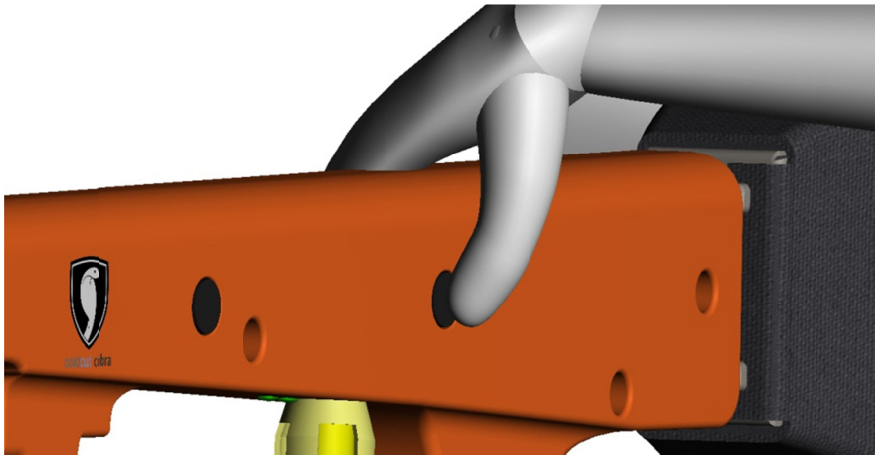


Figure 45 The two buttons for the adjustment function.

The buttons are sprung to return to locked position whenever a button is released. The spring between the inner side of the button and the shell are shown in Figure 46.

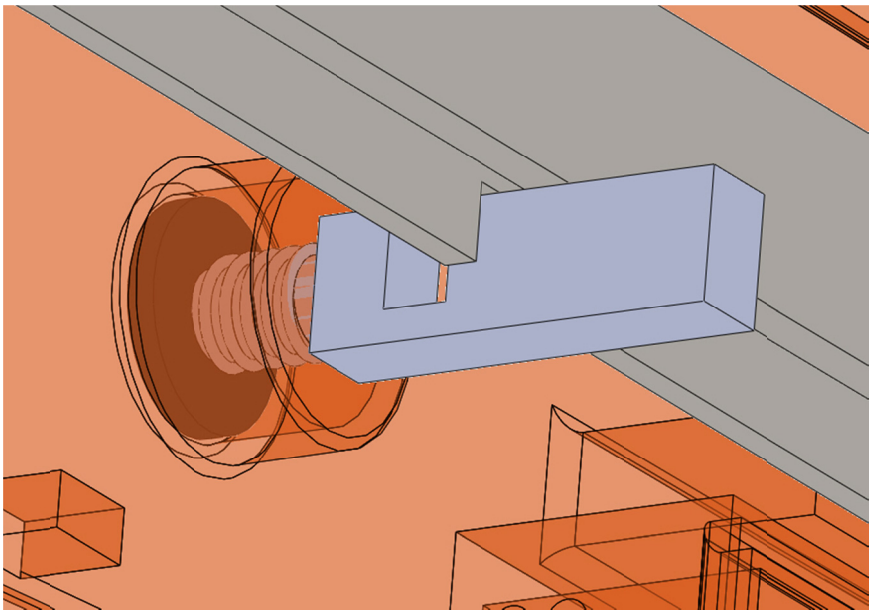


Figure 46 Spring for locking the adjustment.

4.7.3 Electrical system

When referring to the electrical system, all functions of the electronic characteristics are included. Figure 47 shows a picture of the shell half when all electronic components are mounted. The picture shows the first priority system with wire-controlled functions.

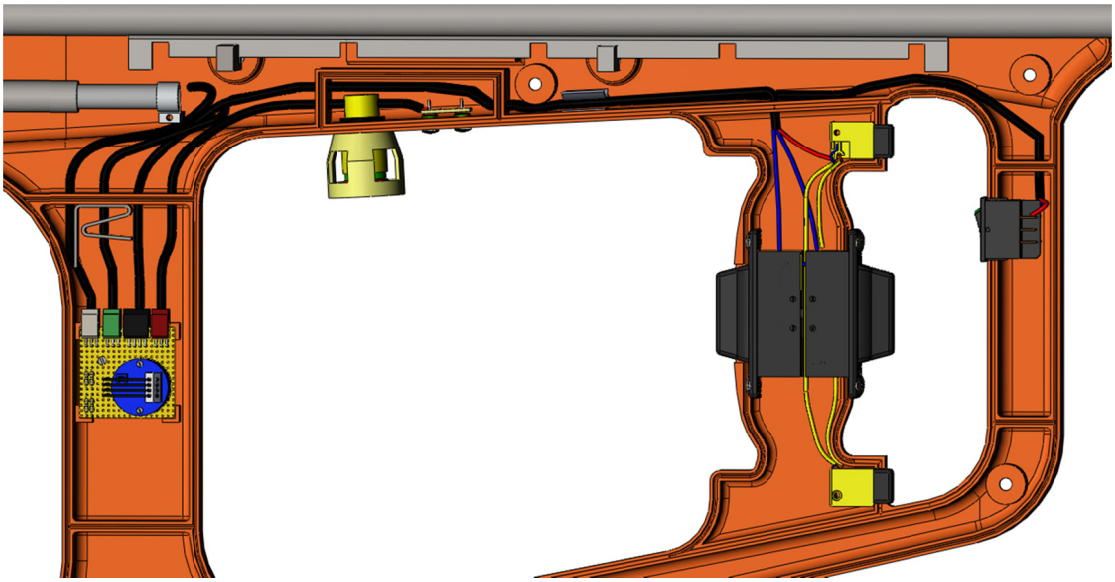


Figure 47 Overview of the electrical system.

The present-day lance was built from many small mechanical solutions for the trigger mechanism. With the new lance, Cold Cut Systems hopes to introduce a wire-controlled trigger system. Resultantly, an electrical system with two alternatives of information transfer, either by wire or by radio, was developed.

The parallel project, the development of wire controlling, is still running. To make it possible to still have two opportunities, the two alternatives share the same layout. As shown in Figure 48, the only components that differ are, from the wire control's point of view, the radio unit, radio socket and a spring to fasten the radio. For the radio unit, a cutout of the shell needs to be performed, on the opposite side from the shoulder, to be able to disconnect the radio unit from the lance. The picture shown on the right in Figure 48 is the principal view of how the radio unit will fit into the shell. In this view, the radio unit is drawn using the largest allowed measures that the radio manufacturer can use.

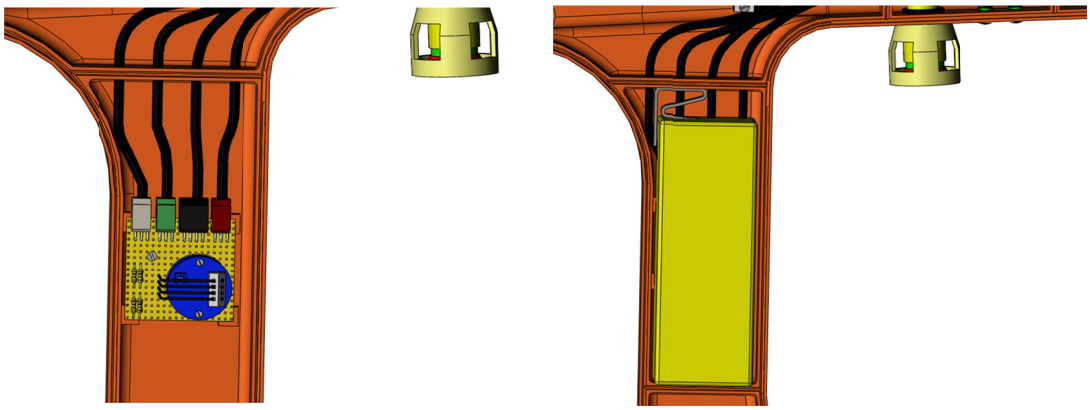


Figure 48 Wire-controlled system on the left, radio-controlled system on the right.

The height limitation of space for the circuit board or radio unit is due to the inner walls that encapsulate the electronic devices. The lance must follow the IP65 classification requirements, which means that it should be dust-tight and water jet protected (SP Sveriges Tekniska Forskningsinstitut, 2011).

To ensure IP65 requirements are met around the electronic devices, the enclosure area is kept as small as possible. With a small area and with screws positioned close to the walls, the risk of dislocation and leakage is minimized. The enclosure consists of one shell half with a grooved edge and one with a flange. In the groove, a rubber strip is placed to make the enclosure robust and dense. An example of the encapsulation of the emergency button and the LEDs is shown in Figure 49.

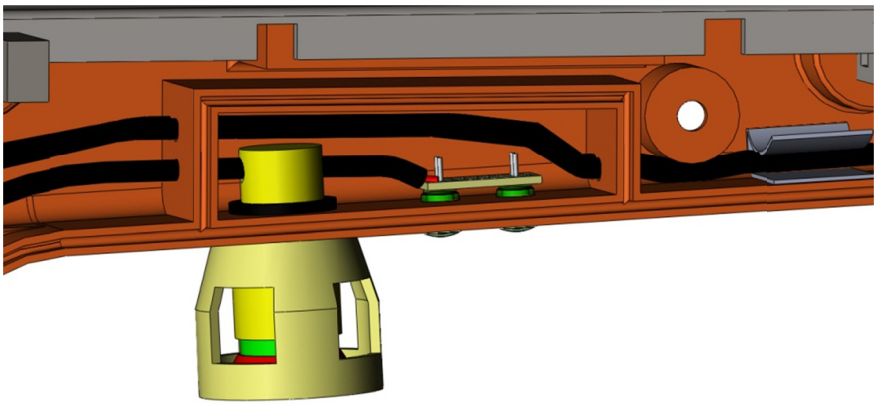


Figure 49 Enclosure of the emergency button and LEDs

To assure sufficient maintenance and to minimize the use of different parts, different design strategies have been used (Eppinger & Ulrich, 2008). Examples of design approaches for the minimization of material consumption are listed below:

- The same cable was used for all devices, even if all the conductors were not in use.
- The cable length was minimized by using the circuit board for a lot of connections between the buttons.

Approaches to simplify maintenance of the electrical system are listed below:

- Sockets to connect the cables to the circuit board were used.
- Different colors on the sockets were used to simplify the correct connection.
- One single screw was used to fasten the circuit board when aligned into its frame.

Trigger buttons

The buttons were placed to maximize safety and comfort, thus making it easy to handle all functions when using the lance in a normal posture. All the launch buttons, as shown in Figure 50, can be activated with one hand without changing the posture with the rest of the body. The buttons are of the hold-and-run type for the safety catch, water and abrasive buttons and are bi-stable for the foam button. The foam button has a colored side, which is visible when the button is activated. The placement of the buttons is shown and explained in Figure 50.

1. Safety catch
2. Water
3. Abrasive
4. Foam

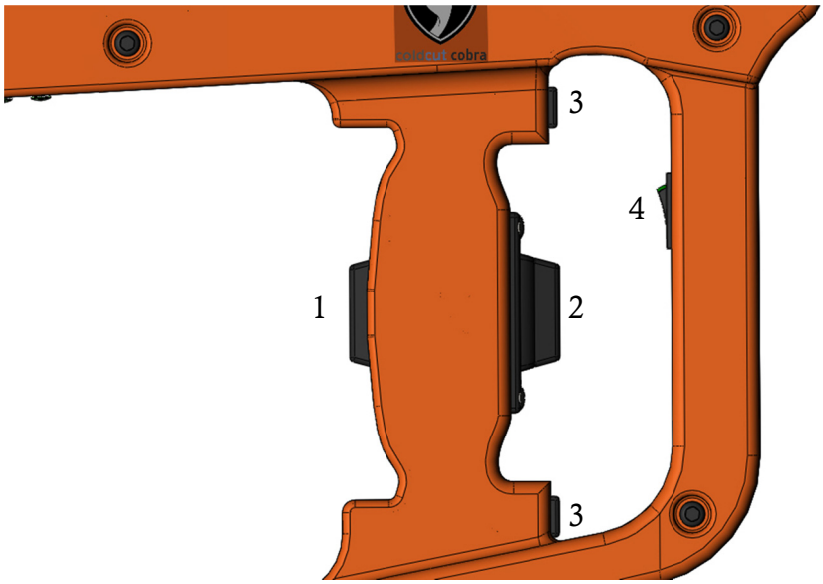


Figure 50 Trigger handle with buttons numbered.

The safety catch is serially connected with the water button and the user has to thereby squeeze the trigger handle to activate both buttons. The abrasive and foam must be delivered with the water and are therefore connected in serial with the water. This electronic safety makes it possible to carry the lance in a safer way than the present-day lance.

The trigger handle is designed to be symmetric, which allows the user to use the same grip when the lance is used upside down. The shape of the handle is of the same type as the drilling machine with an indentation at the back of the handle, which makes the grip more comfortable when pushing the abrasive button. The indentation, as shown in Figure 51, shortens the distance from the thumb web to the abrasive button and holds the hand in the correct position for reaching both the water and abrasive buttons simultaneously.

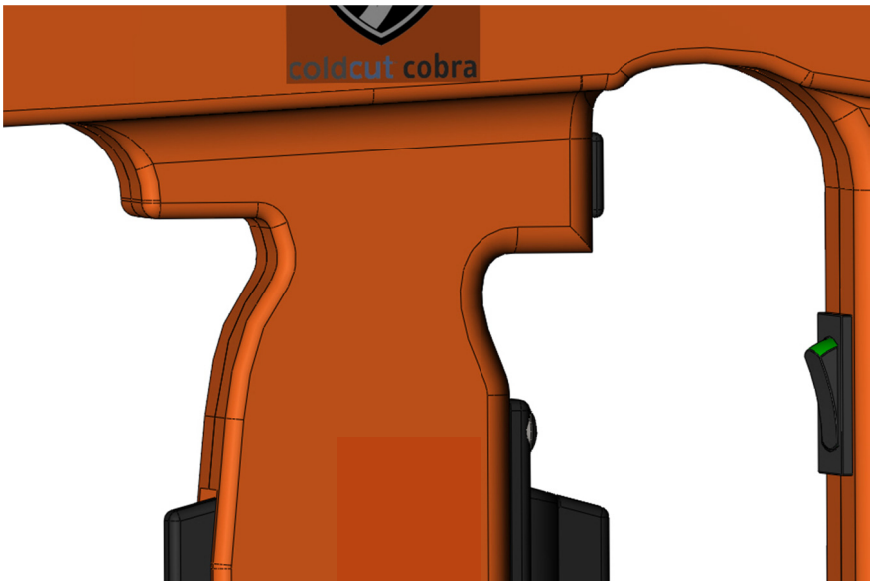


Figure 51 Trigger handle with indentation for the thumb web.

The handle is big enough to make room for a large hand even with fire gloves on. A large hand should be able to push only the water button without touching any of the abrasive buttons.

Hose connection

Cold Cut Systems is, as mentioned earlier, running a parallel project to develop wire control of the trigger functions, which implies that the parameters of the circuit board are not finished yet. However, the development of this new lance enables the implementation of the new technique to be very soon. A connection from the hose to the circuit board must be robust and flexible. The pneumatic coupling shown in Figure 52 is easy to connect and disconnect; it is resistant to wear and tough use while securing the electrical transmissions.

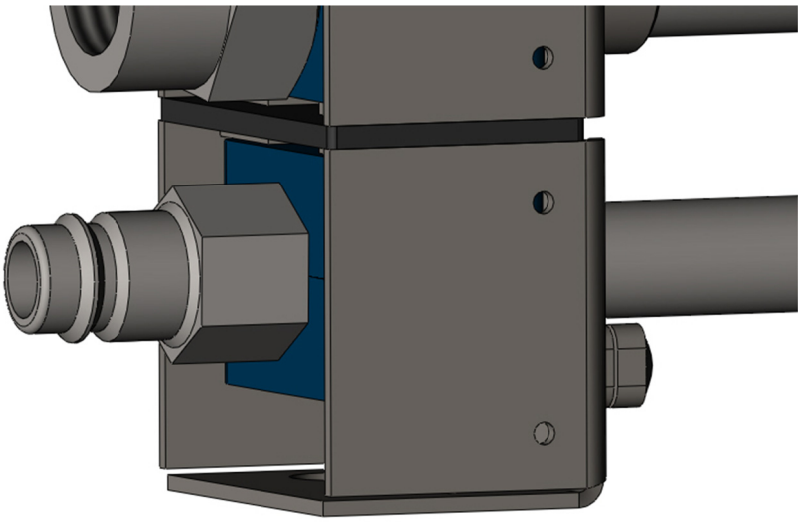


Figure 52 Pneumatic coupling for electricity transfer.

A spiral cord, shown in Figure 53, goes through the whole pipe and allows the lance to be adjusted throughout the branch without having to snatch off the cable to the hose. The spiral cord is soldered to a ring stuck between the nipple and the pipe, which makes the whole pipe and nipple into a conductor.

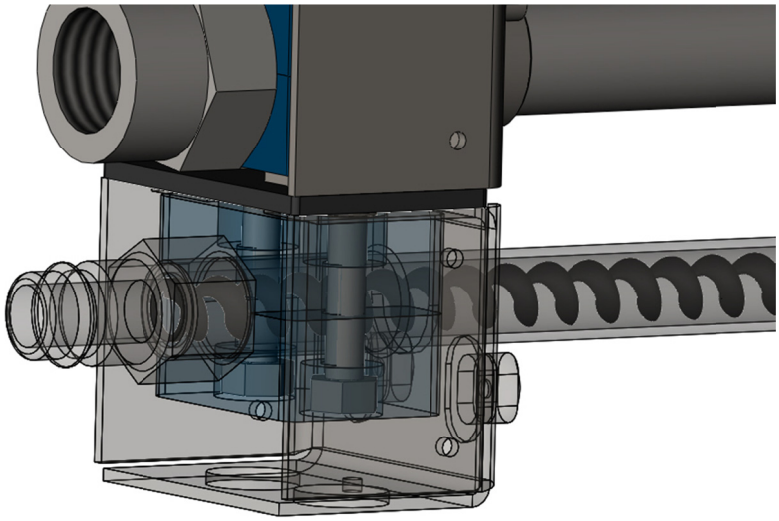


Figure 53 Spiral cord with connection to the nipple.

Emergency button and LEDs

To be able to stop the water jet in an emergency, an emergency button was placed inside the frame of the shell, as shown in Figure 54, which makes it easy to reach for both right- and left-handed users when it is placed inside the frame to also prevent accidental use. To extend this preventive measure, the button was surrounded by a frame, which obstructs the button from being activated when it is gripped by a hand or hit by an arm. To press the button, the user must use the finger to get inside the frame.

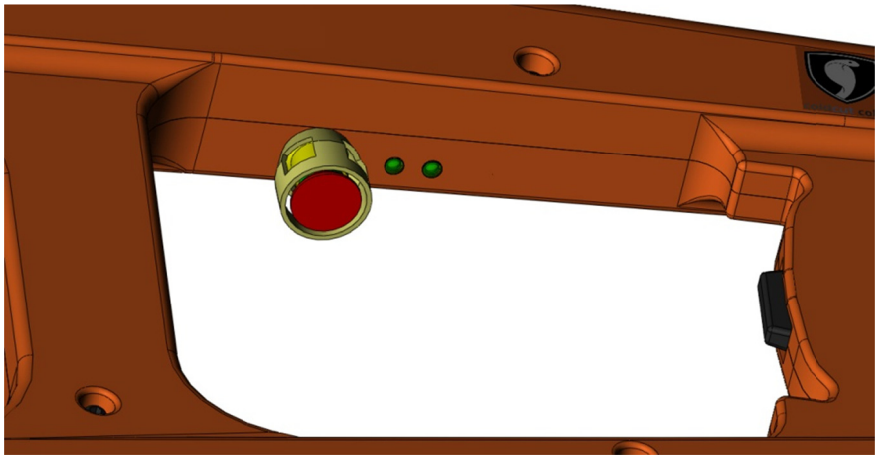


Figure 54 Emergency button and LEDs.

The emergency button stops the whole system including the pumps and engines from pumping water. The system must then be restarted from the pump unit and the emergency button must be pulled out again to enable use of the lance again.

To determine whether the system is on, two LEDs are placed beside the emergency button. The LEDs are serially connected to the trigger buttons and connected to each other in parallel. The parallel connection is to secure the trigger function in the case if one of the LEDs is broken.

4.7.4 Coupling protection

The coupling protection is, unlike the protective hose sleeve, not possible to remove from the lance, which gives the operator no other choice than using it. It covers the whole coupling and has the shape of a bellow. The flexibility of the bellow makes it possible to push it in and attach or remove the coupling. It is designed using a Kevlar-like material, which has the possibility to withstand a small jet. A natural attachment point for the bellow would be on the shell, but because the shell will be adjustable along the branch, a brace placed on the branch just behind the coupling is used instead. The bellow is attached to the brace with rivets, which makes it easy to mount and difficult to remove. In Figure 55, it is possible to see the bellow and the brace from behind and from the front.

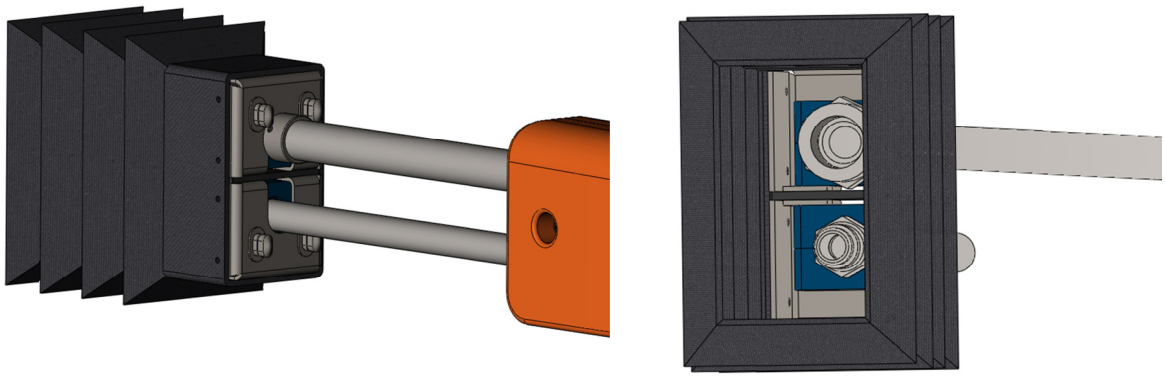


Figure 55 The bellow and the brace, from the front in the left picture and from behind in the right picture.

The brace also serves as an attachment point for the electric coupling and wire pipe. It is attached to the branch and the wire pipe with standardized pipe couplers already manufactured for Cold Cut Systems. Except for the pipe couplers, the braces are built using two pieces of 2-mm bended stainless steel plates, which are attached to the bellow. The bended plate goes around the pipe couplers as shown in the lower unexploded part of Figure 56.

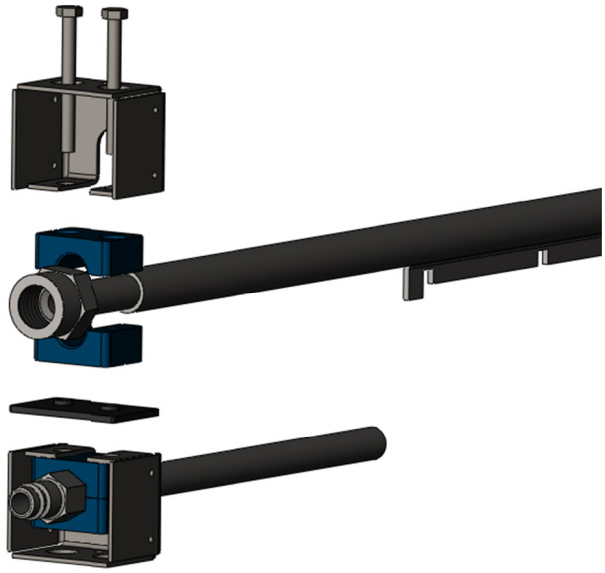


Figure 56 Exploded view of the brace.

Between the bended plates, there is a plastic gasket that will give the pipe couplers the correct distance. The distance between the branch and the wire pipe was adapted to the space in the shell. The plastic gasket, shown in Figure 57, also serves as an isolator. It isolates the bended plates from the M6 bolts holding the brace together. An exploded view of the brace is shown in the upper part of Figure 56.

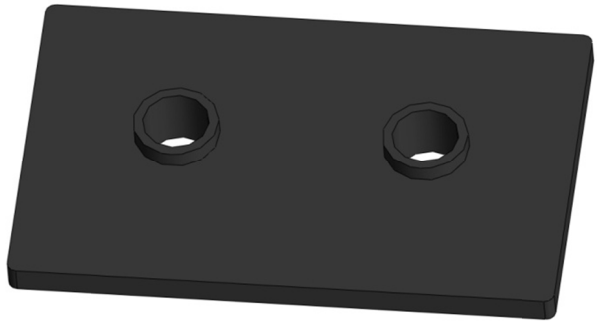


Figure 57 Plastic gasket that isolate the bolts from the bend plate.

The bended plates are constructed with DFA in mind. Because the hole for the branch is large and oval, it makes it possible to mount the brace on the branch after the coupling is in place. Holes in the top also make it possible to reach the bolts with a screwdriver. Figure 58 shows a closer view of a bended plate. The figure also shows the small holes for the rivets.

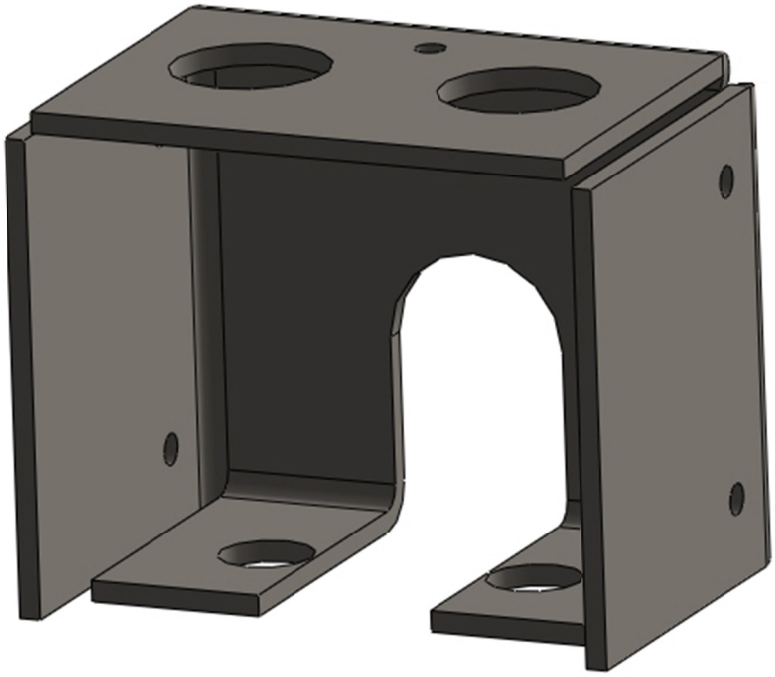


Figure 58 Close-up view of a bended plate.

The hose sleeve protection was redesigned to fit the new lance. The new sleeve must be wider to fit around the bellow. The old hose sleeve was attached to the shell, which is no longer possible due to the varying distance between the shell and the brace. It will instead be attached to the same brace as the barrow. The hose sleeve was attached in a similar way as a canopy, with a twisted sprint. The locking of the hose sleeve is shown in Figure 59.

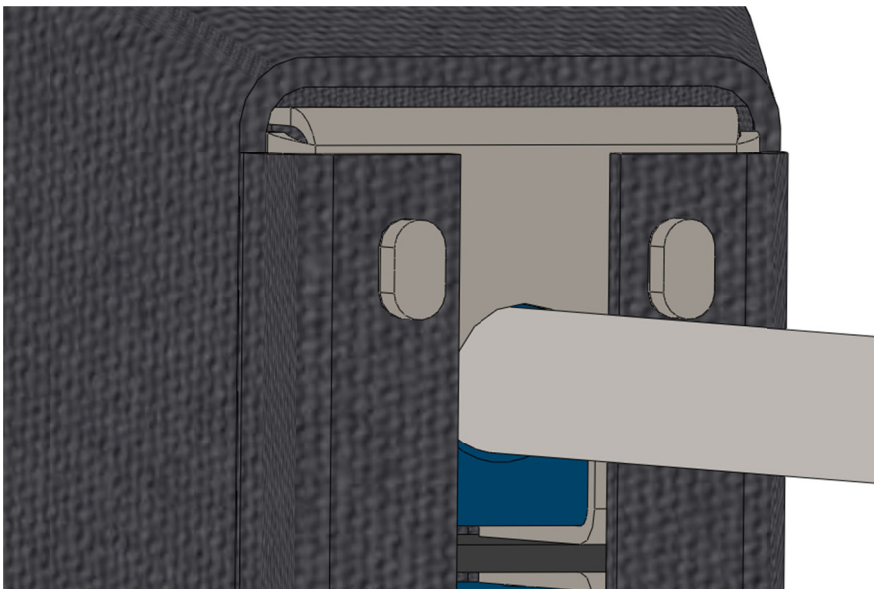


Figure 59 Close-up view of the locking for the hose sleeve protection.

An illustration with the hose sleeve mounted on the brace is shown in Figure 60. The hose sleeve will, just like the bellow, be constructed using a Kevlar-like material.

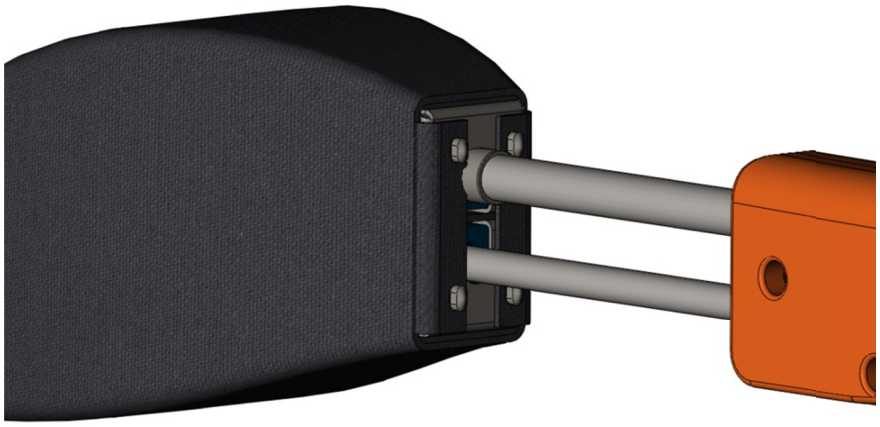


Figure 60 Mounted hose sleeve.

4.7.5 Cutting support

The cutting support has two main tasks: to provide a good grip on the surface during cutting and extinguishing and to prevent water that bounces back that may reach the operator. The present four-point support has been re-used as the basis for the new cutting support. The users feel that the present four-point support provides good support if the distance of the spikes is maintained. The presence of the four spikes provides good stability by having at least two spikes in contact with the cutting surfaces. The spikes are polished on the inner edges to give as good of a grip as possible, even at sharp angles. The spike lengths were adapted to provide an ideal cutting distance between the nozzle and the surface. The best cutting result was obtained when the distance between the nozzle and cutting surfaces was 15-20 mm (Lundmark, 2011). Figure 61 shows the cutting support from a side view.

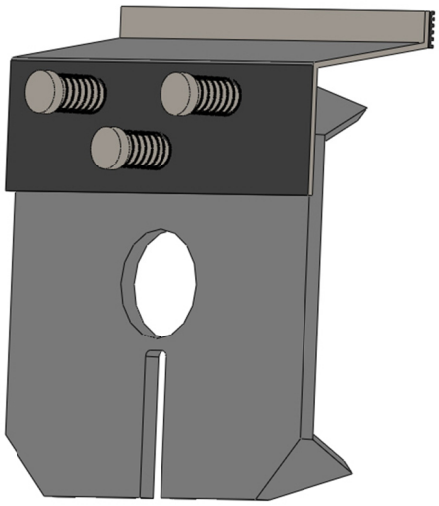


Figure 61 Cutting support and flange.

The size of the sight notch is a compromise; the notch is as big as possible without letting too much water that bounces back toward the user pass through it. The notch is as close to the center of the cutting support as possible to decrease the blind surface between the nozzle and the notch when the operator is looking for an old penetration hole. Figure 62 shows the size and location of the notch.

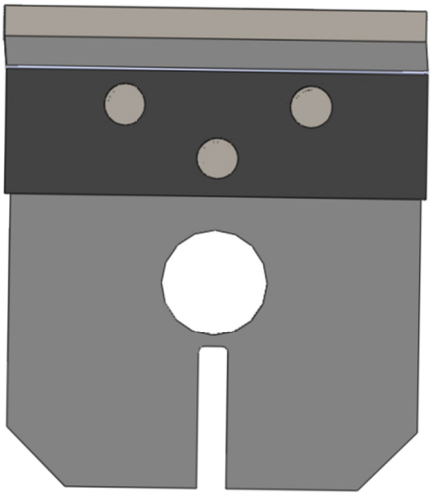


Figure 62 Location of the notch and the bolts.

The flange that prevents the water from bouncing back was placed as close to the cutting support as possible to simultaneously provide a compact solution while increasing the angle from the nozzle protected from the water that bounces back. This design is illustrated in Figure 63, in which the ring represents the nozzle, the blue line illustrates the water and the thick grey line represents the flange on the cutting support.

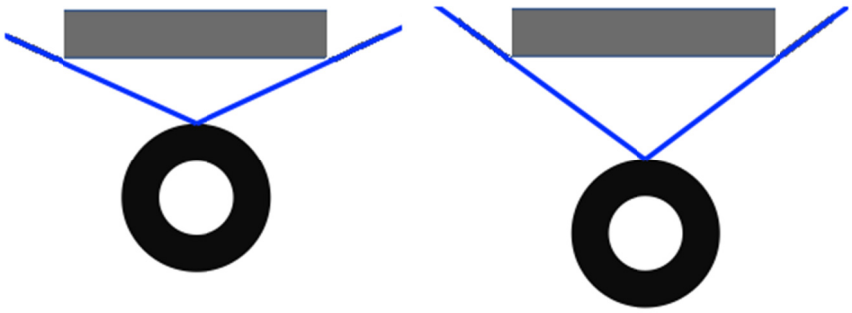


Figure 63 Illustration of how the distance between the nozzle and flange affect the angle that is protected.

To give the flange a better contact area, a rubber strip was added to the edge, which can be seen in Figure 64. The rubber strip will smooth uneven surfaces on, for example, brick walls. It is important that the rubber is soft enough to be able to smooth the surfaces and simultaneously resist the water and abrasive to prevent the need of service.

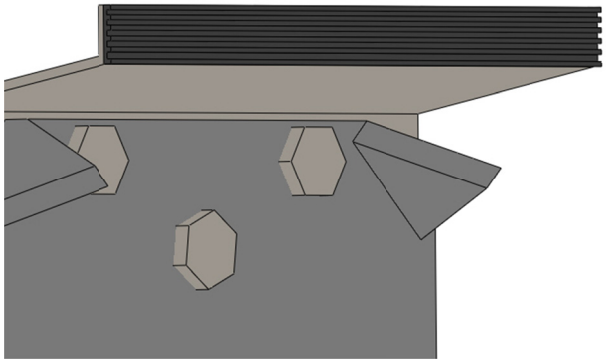


Figure 64 Rubber strip to smooth uneven surfaces.

The flange is mounted on the cutting support with three M6 bolts. The bolts pass through the cutting support in drilled holes and are attached with nuts, making it easy to remove the flange and increase the modularity, which is important if some user prefers to work without it. The location of the bolts is shown in Figure 62.

Because the flange always needs to be in contact with the surface, there are three springs that press it down. Three is the lowest number of springs needed to keep the flange in balance. The height of the springs is adapted to give the flange the flexibility of having contact with the surface during the most common cutting angles, i.e., 90-110°. The springs are located around the bolts that combine the flange and the cutting support, as shown in Figure 65.

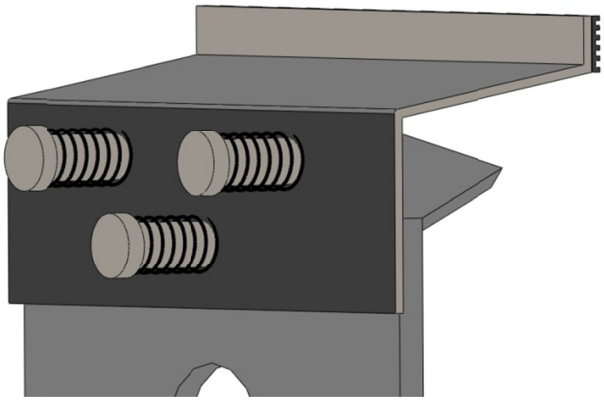


Figure 65 The springs that press the flange against the surface of the penetration object.

The cutting support will be attached to the branch in the same way as the present-day solution, by being squeezed between the nozzle and the fixation nut. Figure 66 shows the attachment of the present four-point support. The new cutting support allows the branch to turn around in a certain direction when the cutting support is pressed against a wall, but the resistance is enough to maintain it in the right position when the cutting support is not pressed against a wall.

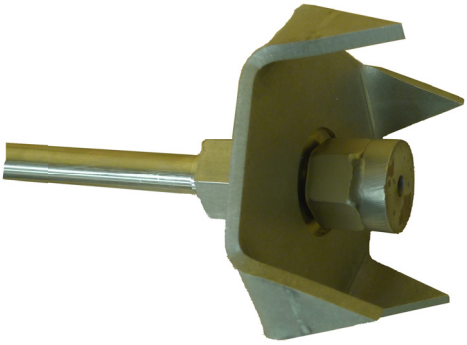


Figure 66 Attachment of present four-point support.

There are no severe strength requirements on the materials being used for the cutting support. The applied forces are only those that arise when the user pushes the cutting support against the wall, which makes it possible to use a material with a low ductility, if desired. It is more important that the material have a hardness that makes it durable and gives it the ability to withstand the constant abrasion of the water and abrasive.

4.7.6 Final solution

All the subsolutions together contribute to the final solution. When all subsolutions are combined, the lance appears like the one depicted in Figure 67.

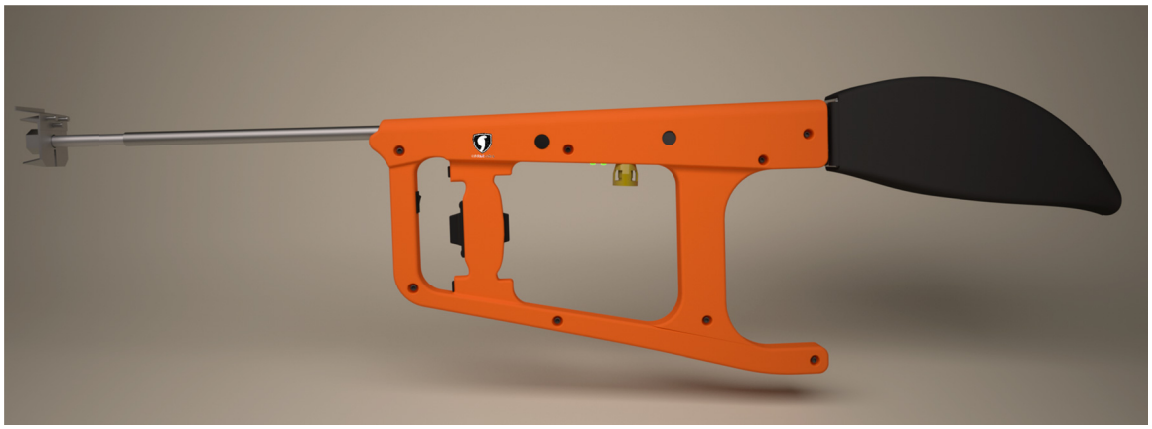


Figure 67 Rendered picture of the final solution.

4.8 The new lance in use

The new lance has a new design with several new features. It has been adapted to fit the users' different prerequisites and needs. It was designed to be easy to handle, robust and safe. This chapter describes how the new lance could be held and used.

The new lance is better supported using a part of the shell under the arm and against the ribs, which makes it possible for the user to squeeze the lance and hold it more stable than in the present-day lance. An upright position can be seen in Figure 68, which also shows the case in which the lance is adjusted to its back position.

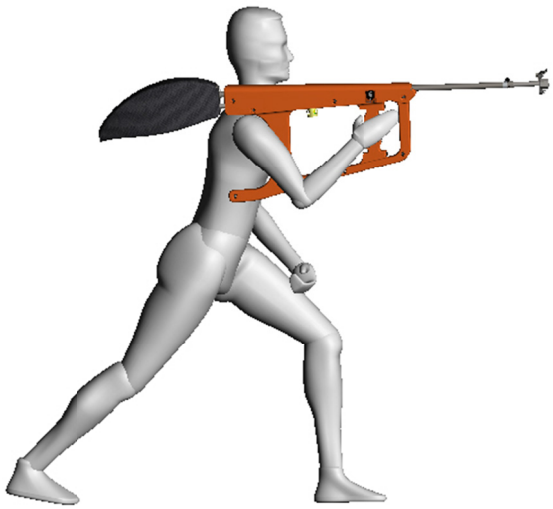


Figure 68 Manikin standing upright with the new lance in its back position along the branch.

Figure 69 shows a manikin with the lance in its adjusted front position; this position is more often used on roofs and ladders when the user needs to come close to the wall or roof.

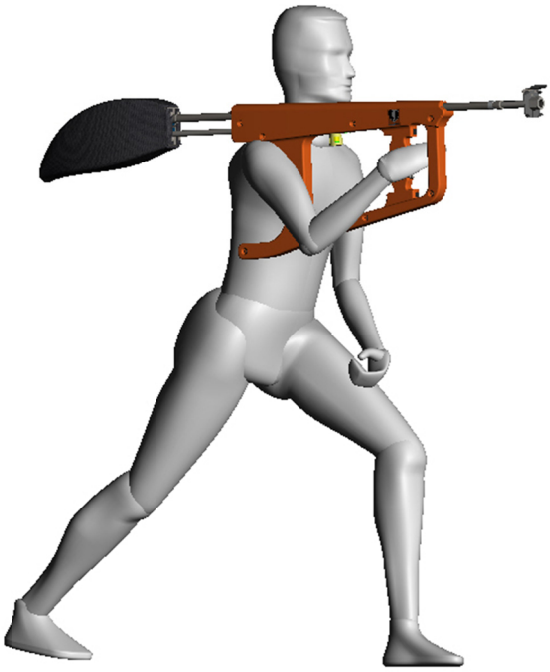


Figure 69 Manikin standing upright with the lance in its front position.

Another feature of the new lance is the possibility to use it upside down, e.g., for when the user needs to reach under the roofing tile or into a house foundation. The upside down configuration is shown in Figure 70.

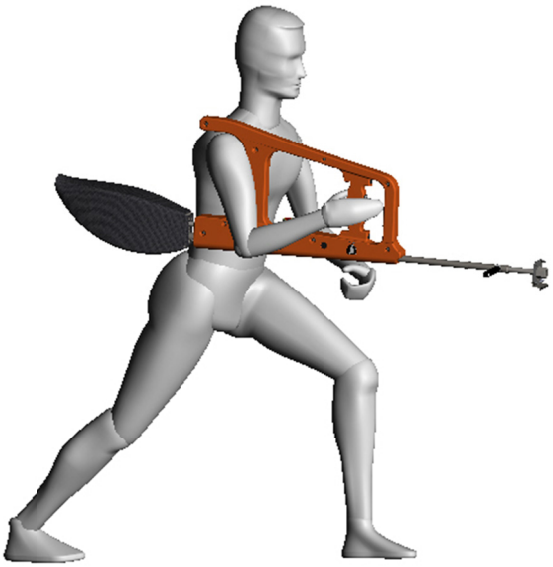


Figure 70 Manikin holding the new lance upside down.

The photomontage in Figure 71 shows how using the lance will appear when the lance is used in a real firefighting operation.

Figure 71 The lance in a real firefighting operation. (Photomontage)

5 Discussion

This project has met its goal; a basis for production of a prototype of the whole lance was made. Much must still be done before the lance could be put into serial production. Further tests and evaluations must be performed, and Cold Cut Systems, CCS, must make some investment decisions before a serial production can be developed. At the end of this project, CCS has taken part of the material to make the first prototype. The responses from CCS have been very positive, and CCS is looking forward to ordering a prototype of the whole lance and beginning related tests.

The fact that CCS is satisfied with the outcome is a result of a very tight and well working collaboration throughout the whole project. The prerequisites have been very good from the beginning. Factors including an office close to the other engineers' offices and their workshop have played a major role when it comes to close communication with the involved persons. The most important factor has been the willingness of the CCS personnel to help with the project. They have provided a lot of support for us, both when it comes to knowledge and feedback on the working process. The fact that the development work was based on a deep customer survey has also played a major role in the positive outcome of the project.

The project has been a great learning experience. To be accepted into a new industry with all its new terms and knowledge has caused many new situations that have put our creativity to the test. Having an office located at CCS has also contributed to the feeling of having a real project and has allowed us to gain a lot of experience from everyday office life. It has also been a great experience to see how a product development process really refines a lot of good ideas into a more complex solution. It has been very instructive to determine how this product development process makes it possible to find solutions that would have been impossible to find in one step. This insight becomes extremely significant when looking back to the beginning of the project. There were a lot of brainstorming ideas of how to solve problems when CCS presented the present-day lance. This brainstorming was even before the collection of user responses and many of the thoughts and ideas at that stage in the process were quite far from the users' needs. The brainstorming procedure was repeated once again when many of the new ideas and concepts after the need collection went through the testing procedures. This time the ideas were much closer to the users' needs.

Another piece of knowledge we have gained throughout these events and processes is the importance of validation. It is very important to validate all solutions brought forward in the process not only against the requirements specification but also with responsible persons from the company. Without support from the company, it would be a waste of time to refine the solution.

6 Conclusions and recommendations

The project has met its goals, a basis for a prototype production is delivered to CCS and the lance has been improved on several areas. The benefits with the new lance will be:

- A more stable support against the shoulder.
- Possible to use upside down.
- Adjustable shell.
- Prepared for wire control.
- Secure against water jets during coupling failure.
- Center of mass is closer to the user.
- Decreased bound back of liquid against the operator.

With a lot of parallel projects running in small subsystem areas, CCS is always taking small steps forward and increasing the technical level on the product as a whole. What is really important, in the case of a product with a user interface, is that the user understands the effort the company puts into all improvements. This project focuses on improving the user interface and the involvement of other technical improvements to ensure the users believe that it is the next generation cutting extinguisher they hold in their hands.

The new lance demonstrates the next step in ergonomics, a human-machine interface and safety with its new features. The hope is that this upgrade will soon be standard and new groundwork has been laid to find new ways to further the whole concept of cutting extinguishing.

Henceforth, testing and optimizations need to be performed to apply this project's outcome from a prototype to a production project. Different materials must be evaluated, especially for the shell where the plastic must withstand forces rough handling and be able to work at a wide temperature range. It is also recommended to perform tests to find an optimal size of the four-point cutting support, where a lesser size and a higher performance are balanced against each other.

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Appendix A User investigation

Summary of customer survey

Question	Answer	Comments
1) Does the shape of the lance fit well into the shoulder?	No ☐ 10% Yes ☑ 90%	**If no, how would you want to have it?** Think it could have better ergonomic fit. Better support as like an AK-5.
2) Does it happen that the lance slips of the shoulder during use?	No ☑ 70% Yes ☐ 30%	**Comment.** Want higher friction against shoulder. It is slippery and not ergonomic.
3) Does it happen that you hold the lance in another position than the usual (against the shoulder with the hose above the shoulder)?	No ☑ 63% The hip ☐ 27% Under the arm ☐ 10%	**Another way?** Sitting. Hook around an edge to get support.
4) Is it difficult to hold the lance in the right position during penetrating?	No ☐ 10% Yes ☐ 30% Some-time ☑ 60%	**If No/ sometime, when?** For prolonged use. When working from ladder. When directing through a floor into a compartment above. In concrete, often because of to low pressure. Against hard and slippery surfaces.

5) Does it happen that the water jet slips out of the penetrated hole?	No ☐ 10% Yes ☑ 90%	**If Yes, what are the most common reasons?** Because of to low pressure on the wall. When change the grip. When getting a bad grip against the wall with the cutting support. Lack of concentration. Due to the surfaces e.g. slippery
6) What is the most common working position?	 180° 0° ☐ (180°) ☑ (135°) 50% ☐ (90°) 40% ☐ (45°)	
7) Which functions do you want to be able to control with the "trigger hand"? Ok to choose more than one option.	Water ☑ 100% Abrasive ☑ 100% Foam ☐ 15%	**Other wishes/ comments.** Foam should be bi-stable since it's not used so much.
8) Is it any part/ function on the lance that is hard to manage/ maneuver with fire equipment on?	No ☐ 45% Yes ☑ 55%	**If Yes, what?** The on/ off button on the transmitter. The coupling between hose and lance.

9) Is it possible that at some point by mistake activates a trigger?	No ☑ 70% Yes ☐ 30%	**If yes, which and when?** When not using the safety catch. The on/ off button. When carrying/ resting with the lance pointing downwards.
10) Is there any way to facilitate the carrying of the lance?	No ☐ 37% Yes ☑ 63%	**If Yes, how?** Not an issue unless climbing a ladder. With a harness for unloading. With a handle above the lance. A harness, but it would probably be in the way. A case to hang around the shoulder or neck
11) Are there times when you would prefer a different length of the lance?	No ☐ 22% Yes ☑ 78%	**If yes, when?** Longer when reaching into a window. Shorter in confined spaces. Shorter when working off a ladder.
12) Is it a problem with liquid that bounds back during use?	No ☐ 30% Yes ☑ 60% Some-time ☐ 10%	**If Yes or Sometime, in which way does it complicate the extinguishing?** Impairs sight. Can be reduced by altering angle to building and using a splashguard. During penetration in other materials then wood. When it is cold you get covered by ice. Water on visor can complicate

13) Is it something on the lance that sometime has been broken?	No ☐ 22% Yes ☑ 78%	**If Yes, what?** Button to transmitter. Linkage from trigger to operating lugs. The lance get bend between a wall and a sky lift. The pivots that controls the radio. The nozzle.
14) Has it happen that the lance has lost radio contact with the water pump?	No ☐ 40% Yes ☑ 60%	**If Yes, when does it happen?** During a extinguishing in an industrial premises. Due to bad battery. Linkage failure from trigger to operating lugs.

Do you have any other comments, thoughts or wishes/ improvements on a future lance?

Attachment point on trigger guard for strap.
More robust on/ off switch.
Better way to stop battery falling out on operation.
Dummy box to replace transmitter with hard wire extension cable back to control unit on fire truck- used for no signal operation.
Protect the battery against water and freezing.
Better on/ off button.
A safety catch that shuts down the system.
Dead mans handle.
Rubber against the body support.
A handle that helps to keep the lance stably against the foundation.
A smother lance.
A changeable cutting support for different applications.
A fast removable splash protection.
A pin-jointed splash protection.
Better grip with the cutting support.

Thank you for your time!

Appendix B Need specification

Need No.	Need	Convert to requirement	Comment	Reference
1.	Possible to use against the hip.	Yes		Danny Moore, Questionnaire (27%), Lundmark, Palmqvist
2.	Possible to use under the arm.	Yes		Questionnaire (10%), Palmqvist
3.	Possible to use on a ladder	Yes		Danny Moore, Leif,
4.	Adjustable length of the branch	Yes		Danny Moore, Einar, Leif, Questionnaire (78%)
5.	More robust trigger mechanism	Yes	The mechanism is replaced with electronic equipment.	Danny Moore, Einar, Leif, Questionnaire
6.	More robust on/off switch	Yes		Danny Moore, Norway,
7.	Secure fastening of battery	Yes		Danny Moore,

8.	Comfortable posture with the lance over the shoulder.	Yes		Einar, Leif, Jan, Questionnaire (63%), Lundmark, Palmqvist
9.	Prevent the lance from slipping of the shoulder.	Yes		Questionnaire (30%)
10.	Device for hanging the lance close to the body when not in use.	No	Additional feature, possible to add in the future.	Einar
11.	Splash protection that prevents water and abrasive to hit the face.	Yes		Einar, Leif, Norway, Questionnaire (60%), Palmqvist
12.	Bi-stable foam function.	Yes		Einar, Palmqvist
13.	Lighter lance than the present.	Yes		Leif, Palmqvist
14.	More friction against a wall with the cutting support.	Yes		Leif, Questionnaire, Lundmark, FMV
15.	Easy to know when a function is activated.	Yes		Leif, Palmqvist
16.	Longer range radio communications.	Yes		Norway

17.	Easy to carry without activating any button accidently.	Yes		Questionnaire, Palmqvist
18.	Control water and abrasive with one hand.	Yes		Danny Moore, Leif, Einar, Questionnaire (100%), FMV
19.	Control foam with the same hand as for water and abrasive.	Yes		Leif, Questionnaire (15%)
20.	No foam-button on the trigger hand, it could confuse the operator.	No	Conflict with other stronger needs.	Lundmark
21.	Support recoil by hooking into something.	Yes		Leif, Questionnaire, Palmqvist
22.	All buttons should be easy to handle with gloves on.	Yes		Danny Moore, Norway, Einar, Leif, Questionnaire (55%), Palmqvist, FMV
23.	Possible to switch to another branch for other purposes.	No	Outside the scope of the project.	Einar
24.	Able to control water and abrasive with dead-man's grip on with one hand.	Yes		Danny Moore, Einar, Patrik

25.	Higher friction against the wall when used in sharp angles.	Yes		Questionnaire, Lundmark, Palmqvist, FMV
26.	Easy and fast way to change battery.	Yes		Questionnaire (60%), Palmqvist
27.	Protect battery from water.	Yes		Questionnaire
28.	A removable splash protection.	No	Additional feature, possible for CCS to add.	Questionnaire
29.	Always keep the distance between nozzle and wall about 5-10 mm.	Yes	At least when the penetration angle is 90 degrees.	Lundmark
30.	Best possible rest-position for the hand when the trigger is activated.	Yes		Lundmark
31.	A way to clean the nozzle from the plugs of abrasive that can appear.	Yes		Lundmark
32.	A small and compact lance.	Yes		Lundmark, Leif
33.	A mass-center closer to the operator.	Yes		Palmqvist

34.	Possible for the user to see the point of attack.	No	Conflict with more important properties like splash protection.	Palmqvist
35.	Fixation of the cutting support when penetrating.	Yes		Palmqvist
36.	Two persons should be able to operate the lance at the same time.	No	Conflict with a lot of other needs. Almost all users use it alone.	Palmqvist
37.	A handle for the support-hand that enables a longer support perpendicular out from the branch.	Yes		Palmqvist
38.	An additional branch to connect to the existing one to get a longer range.	Yes		Palmqvist
39.	Could be carried with one hand.	Yes		Palmqvist
40.	Extra protection against leakage in the coupling.	Yes		Palmqvist, Patrik
41.	The lance should not be wider than the present one.	Yes		Palmqvist
42.	Have a free space for a logotype	Yes		Patrik

43.	Possible to use on the thigh	Yes		Torvald
44.	Possible to use against the biceps	Yes		Mauri
45.	It should be comfortable to squeeze the trigger handle.	Yes		Lundmark
46.	The lance should be adapted for both right-and left handed users.	Yes		Patrik
47.	Possible to adjust the support handle along the branch	Yes		Einar, Jan, Palmqvist
48.	Should be construct of recyclable materials	Yes		FMV
49.	Proper function at -10°C to +55°C	Yes		Kockums/ FMV
50.	Be stored in air-temperature at -40°C to +55°C	Yes		Kockums/ FMV
51.	Must be able operate at a temperature of 150°C during 10 min	Yes		Kockums
52.	Should be able to operate at a temperature of 200°C during 5 min	Yes		Kockums

53.	Must not contain prohibited materials, chemicals according to international, Swedish our EU-regulations	No	Such materials do not exist in this project's interest.	FMV
54.	Should as much as possible be manufactured by non-magnetic materials.	Yes		FMV
55.	Branch shorter than 750 mm may only be used when a longer branch isn't possible.	Yes		AFS 1994:54
56.	Be able to use the same handle-trigger to other compatible tools.	Yes	If using radio communication.	Patrik
57.	No consumables of important parts. If some parts after all need to be change, it must be easy done.	Yes		Patrik
58.	Electronic components should be water and dust resistant according to IP 65, SS EN 60529	Yes		FMV, Patrik
59.	Use standard components as long as possible	Yes		Patrik
60.	If radio steering, an interchangeable handle needs to contain all electronic equipment.	Yes		Patrik

61.	If radio steering: Use the same trigger handle to control water for other applications.	Yes		Patrik
62.	Possible to change cutting support.	Yes		Patrik, Palmqvist
63.	Flexible wires and connector between lance and hose.	Yes		Patrik
64.	Branch should fulfill hydraulic standards, be acid-proof and stainless.	Yes		Parik
65.	It should be obvious how the lance should be used and maintained.	Yes		Hasse
66.	Rotate the cutting support around the branch.	Yes		Lundmark, Palmqvist
67.	Attachment for hose sleeve	Yes		Patrik

Einar – Annelund
Jan, Leif – Frölunda
Danny Moore – North Hamptonshire
Palmqvist, Mauri – SÄRF
Hasse, Patrik, Torvald – Cold Cut Systems
Norway – Norwegian fire fighters

Appendix C Requirement specifications

Redesign of the lance on a cutting extinguisher

Metric No.	Need No.	Metric	Importance	Units	Ideal value	Marginal value
		Body support				
1.	9	The body support should have a surface that prevents it from slipping off the shoulder.	4	Validate	-	-
	The lance should be able to, while using it in both standing, sitting and laying position, be supported against the:					
2.	1	Hip	3	Validate	-	-
3.	2	Armpit	3	Validate	-	-
4.	44	Biceps	2	Validate	-	-
5.	8	Shoulder	5	Validate	-	-
6.	43	Thigh	2	Validate	-	-
7.	25	The lance should be able to use in all pointing directions.	5	Validate	-	-

		Shell				
8.	42	The shell should have a logotype.	5	Validate	-	-
9.	27,58	The shell should capsulate the electronic equipment.	5	Standard	IP65	-
10.	4	Possible to with easy fastening loose the shell and adjust the fixating point on the branch.	2	Validate	-	-
11.	57	If the hose coupling breaks, a replacement of the shell would not be forced.	4	Validate	-	-
12.	57	Possible to replace damaged shell.	5	Validate	-	-
13.	36	Possible for a coworker to push on the lance.	2	Validate	-	-
		Grip and handle				
14.	6	There should be an obvious on/off button impossible to misinterpret.	5	Validate	-	-
15.	15	Clear feedback from all functions.	4	Validate	-	-
16.	30,45	Best possible rest-position for the hand when the trigger is activated.	3	Validate	-	-
17.	12	Activation button for foam should be bi-stable.	5	Validate	-	-

18.	6	More robust on/off switch.	5	Validate	-	-
19.	46	Activation button for foam should be suited for both left- and right-handed users.	3	Validate	-	-
20.	22	The lance should be easy to handle with gloves and other fire equipment on.	5	Validate	-	-
21.	17,24	When releasing the dead-man's handle the trigger shall automatically be blocked.	5	Validate	-	-
22.	17,18, 24	Dead-man's handle for the functions water and abrasive.	5	Validate	-	-
23.	18	The two functions; water and abrasive should be able to handle with one hand. As well as the safeties catch.	5	Validate	-	-
24.	19	The foam function should be able to handle with the same hand as for the water and abrasive.	2	Validate	-	-
25.	37,47	Adjustable support for the support hand. Both along the branch and perpendicular out from the branch.	4	Validate	-	-
26.	17	No button should be able to be activated accidently.	5	Validate	-	-
27.	45	Ergonomically designed handles and triggers.	3	Validate	-	-

28.	59	Strive after standard handles and as small modifications as possible.	4	Validate	-	-
29.	4	Easy fastening of the trigger handle to make it possible to move along the branch.	2	Validate	-	-
		Radio control, general				
30.	16	Longer range on radio signal.	3	Validate	-	-
31.	26	Fast and simple to change battery.	4	Validate	-	-
32.	7	Not possible for the battery to fall out	5	Validate	-	-
Alt. 1		**Radio steering, interchangeable handle**				
33.	60	The handle should contain transmitters, switches, battery and circuit board.	5	Validate	-	-
34.	61	Be able to use the same trigger handle to other compatible tools.	5	Validate	-	-
35.	61	Abrasive- and foam buttons should be placed on the lance and not on the interchangeable handle.	5	Validate	-	-
Alt. 2		**Radio steering, fixed handle**				
36.	5	The handle should contain switches.	5	Validate	-	-

37.	56	The radio transmitter should be moveable to be connected to another device.	5	Validate	-	-
Alt. 3		**Wire controlled handle**				
38.	5	The handle should contain switches.	4	Validate	-	-
39.	63	The lance's electronics should be possible to connect with a flexible connector from the hose.	5	Validate	-	-
		Branch				
40.	55	Distance from shoulder to the outlet trough the nozzle.	5	mm	750	+400
41.	4	Adjustable length of the branch.	2	Validate	-	-
42.	64	The branch should fulfill hydraulic-standards, be acid-proof and stainless.	5	Validate	-	-
43.	65	It should be impossible to mount the nozzle in a wrong way.	3	Validate	-	-
44.	38	An extra attachment branch to make the lance longer.	2	Validate	-	-
		Cutting support		Validate	-	-
45.	14	The grip surface between cutting support and wall must not slip easily.	4	Validate	-	-

46.	25	The cutting support should have a stable contact surface in all use-angles.	3	Validate	-	-
47.	21	Possible to hook the cutting support around an edge.	4	Validate	-	-
48.	22,32, 33,41, 65	The cutting support should be compact and easy to handle.	3	Validate	-	-
49.	13	The cutting support should have a low weight.	4	Validate	-	-
50.	62	The cutting support should quickly be interchangeable.	2	Validate	-	-
51.	35	No rotation or slack of the cutting support during penetration.	4	Validate	-	-
52.	66	Possible to rotate the cutting support around the branch.	3	Validate		
53.	29	Have an adequate distance between the nozzle and the surface.	4	mm	7,5	± 2,5
		Splash protection				
54.	11	Prevent the water jet to bounce back in operator's face.	4	Validate	-	-
55.	11	Align the splash in one direction.	1	Validate	-	-
		Coupling protection			-	-
56.	40	Protect operator from leakage from coupling.	5	Validate	-	-

57.	40	The hose coupling protection covers the whole risk area.	5	Validate	-	-
58.	40	The hose coupling protection should not be an obstacle when using the hose coupling.	4	Validate	-	-
59.	67	Attachment for hose sleeve.	5	Validate	-	-
		Carrying				
60.	3	A way to carry the lance without using hands.	1	Validate	-	-
61.	3,39	Possible to carry the lance with one hand.	5	Validate	-	-
62.	17	Impossible to activating any button accidently while carrying the lance.	5	Validate	-	-
63.	3	Be able to attach the lance to a belt while climbing in ladder.	2	Validate	-	-
64.	3,21	Enable fixation of the lance to the surrounding when using the lance on a ladder, sky lift etc.	4	Validate	-	-
		Maintaining			-	-
65.	57	No consumables of important parts except the nozzle.	4	Validate	-	-
66.	57	Easy to change/repair broken parts.	4	Validate	-	-
67.	57	No special tools needed for disassembling.	4	Validate	-	-

68.	14,25	Maintain sharpness or friction on the cutting support.	4	Validate	-	-
69.	31,57	Easy way to clear/change the nozzle.	3			
		Environmental			-	-
70.	48	Should be constructed of recyclable materials.	4	Validate	-	-
71.	49	Possible to use in a wide temperature range.	4	Celsius	-10 to +55	-
72.	50	Be stored in a wide temperature range.	4	Celsius	-40 to +55	
73.	51	Possible to operate a temperature of 150°C for a time.	4	Min	10	Or longer
74.	52	Possible to operate a temperature of 200°C for a time.	4	Min	5	Or longer
		General			-	-
75.	54	Be manufactured by non-magnetic materials.	4	Validate	-	-
76.	13	Lighter then previous lance.	5	Validate	-	-
77.	32	As small and compact as possible.	3	Validate	-	-
78.	41	Not be wider then present solution.	4	Validate	-	-

Importance scale

1. The requirement is not important; it should only be fulfilled if it could be so without any trade-offs whatsoever.

2. The requirement is not important; it should only be fulfilled if it could be so without any trade-offs of other functions.

3. The requirement would be good to fulfill, but is not necessary.

4. The requirement is important, but it could exist a solution without it.

5. The requirement is critical and it could not exist a solution without it.

Appendix D Kesselring matrix of combined sub-solutions

Metric No.	Metric	Combined subsystem							
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Body support									
1.	The body brace should have a surface that prevents it from slipping off the shoulder.	3	3	2	3	3	2	1	2
2.	The body brace design should distribute the force equally over the shoulder.	2	2	2	2	2	2	1	3
	The lance should be able to, while using it in both standing, sitting and laying position, be supported against the:								
3.	Hip	2	2	2	2	2	2	3	1
4.	Armpit	3	3	3	1	2	3	3	1
5.	Biceps	2	3	3	2	1	2	3	3
6.	Shoulder	3	3	2	3	3	2	2	2
7.	Thigh	2	2	2	1	2	2	2	1

8.	The lance should be able to use in all pointing directions.	3	3	3	3	3	3	3	3
Grip and handle									
9.	The lance should be easy to handle with gloves and other fire equipment on.	2	2	3	2	2	3	2	3
Carrying									
10.	Enable fixation of the lance to the surrounding when using the lance on a ladder, sky lift etc.	2	2	1	2	2	2	1	1
Total		**24**	**25**	**23**	**21**	**22**	**23**	**21**	**20**

Appendix E Test protocols

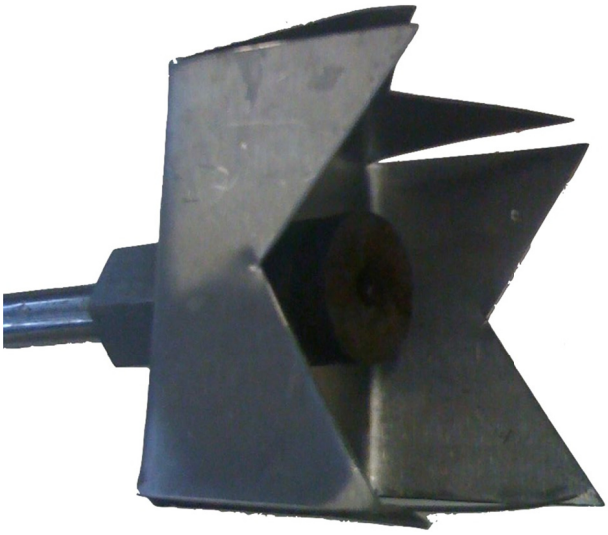
Test Protocol 1

Product tested:	Cutting support/ Splash protection. Four-point support with aiming flange.
Execution of test:	Shouting against a sheet of steel at Cold Cut Systems backyard. The purpose of penetrating a sheet of steel is to maximize the bound back.
Purpose with test:	To see if an aiming flange increases the possibility to find back to an old penetrated hole. Also to see if the flange influences the bound back.
Outcome of test:	The aiming flange makes it easier to find back to an old penetrated hole without influencing the bound back.
Further investigation:	Yes

Close-up picture over splash protection:	**Picture when using the splash protection:**
	 The distribution of the water shows that the aiming flange does not have any impact.

Test Protocol 2

Product tested:	Cutting support/ Splash protection. Four point support with box.
Execution of test:	Shouting against a sheet of steel at Cold Cut Systems backyard. The purpose of penetrating a sheet of steel is to maximize the bound back.
Purpose with test:	To see if the splash protection prevents the water to hit the operator's upper part of the body and face. The idea is that the water jet is stopped and gathered by in the box.
Outcome of test:	The edges of the box did not gather the water; instead the water jet slips out under the edges. The result is almost the same as when using a regular four-point support.
Further investigation:	No

Close-up picture over splash protection:	**Picture when using the splash protection:**
	

Test Protocol 3

Product tested:	Cutting support/ Splash protection. Four point support with angled surface.
Execution of test:	Shouting against a sheet of steel at Cold Cut Systems backyard. The purpose of penetrating a sheet of steel is to maximize the bound back.
Purpose with test:	To see if the splash protection prevents the water to hit the operator's upper part of the body and face. The idea is that the angled surface will draw the water into one certain direction.
Outcome of test:	The water was spread out to the sides before it hit the angled surface. The result is almost the same as when using a regular four-point support.
Further investigation:	Yes

Close-up picture over splash protection:	**Picture when using the splash protection:**
	

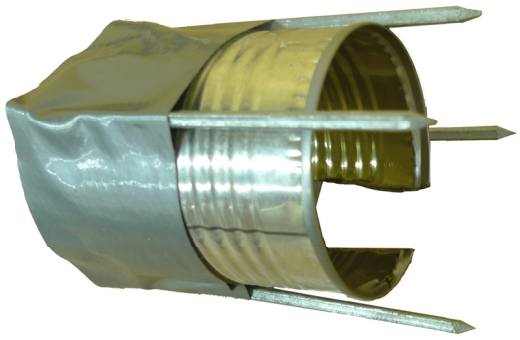
Test Protocol 4

Execution of test:	Shouting against a sheet of steel at Cold Cut Systems backyard. The purpose of penetrating a sheet of steel is to maximize the bound back.
Purpose with test:	To see if the splash protection prevents the water to hit the operator's upper part of the body and face. The idea is that the cylinder should enclose the water jet and prevent the jet from be spread.
Outcome of test:	The pressure made it impossible to keep the cylinder tight against the surface. When it become a gap the water slipped out and formed a sliding bearing which made it difficult to keep the cylinder in the right position.
Further investigation:	No

Close-up picture over splash protection:	**Picture when using the splash protection:**
	

Test Protocol 5

Product tested:	Cutting support/ Splash protection. Cylinder with spikes.
Execution of test:	Shouting against a sheet of steel at Cold Cut Systems backyard. The purpose of penetrating a sheet of steel is to maximize the bound back.
Purpose with test:	To see if the splash protection prevents the water to hit the operator's upper part of the body and face. The idea is that the water should gather in the cylinder and prevent the jet from being spread.
Outcome of test:	The water was spread out to the sides before it hit the cylinder. The result is almost the same as when using a regular four-point support.
Further investigation:	No

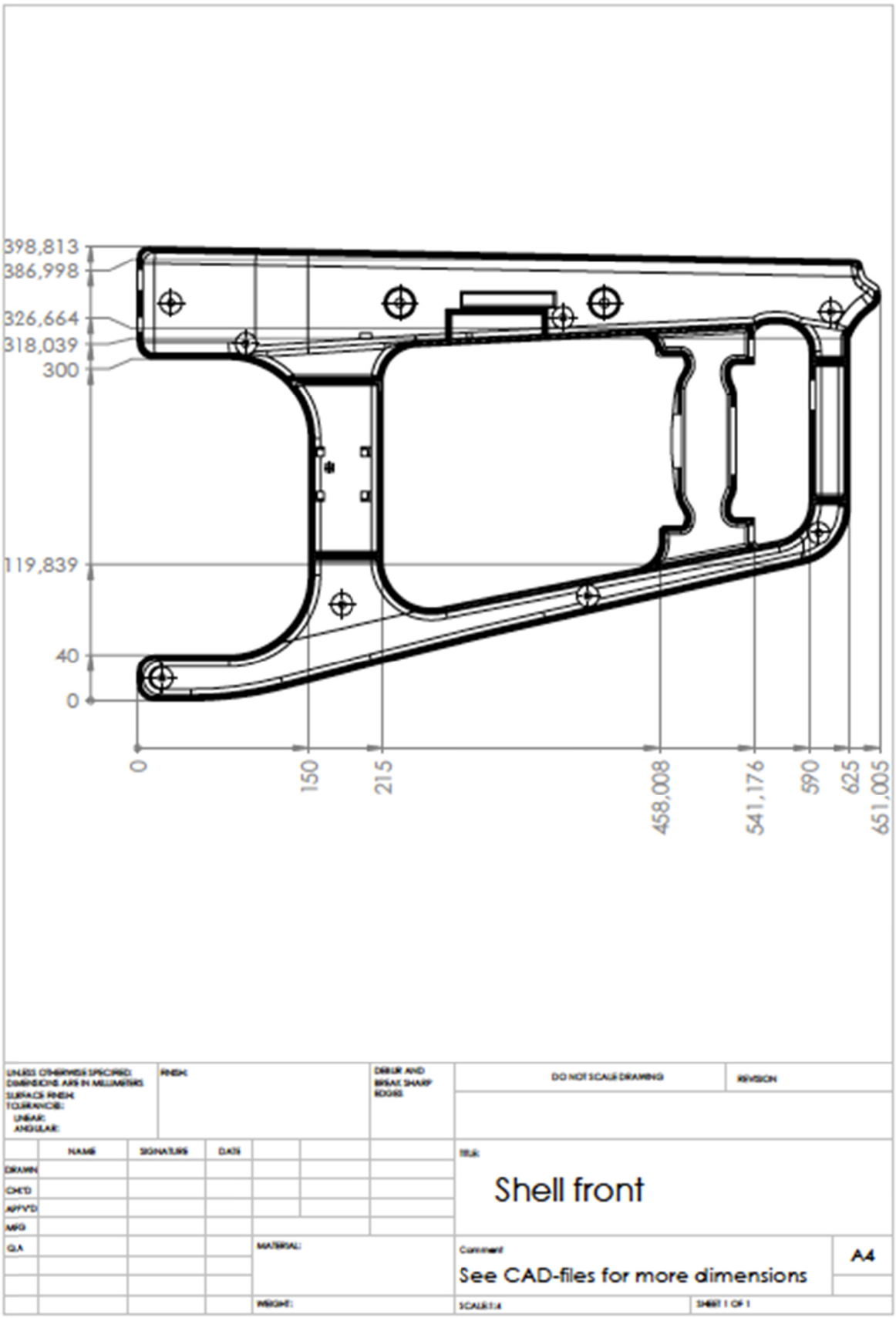
Close-up picture over splash protection:	**Picture when using the splash protection:**
	

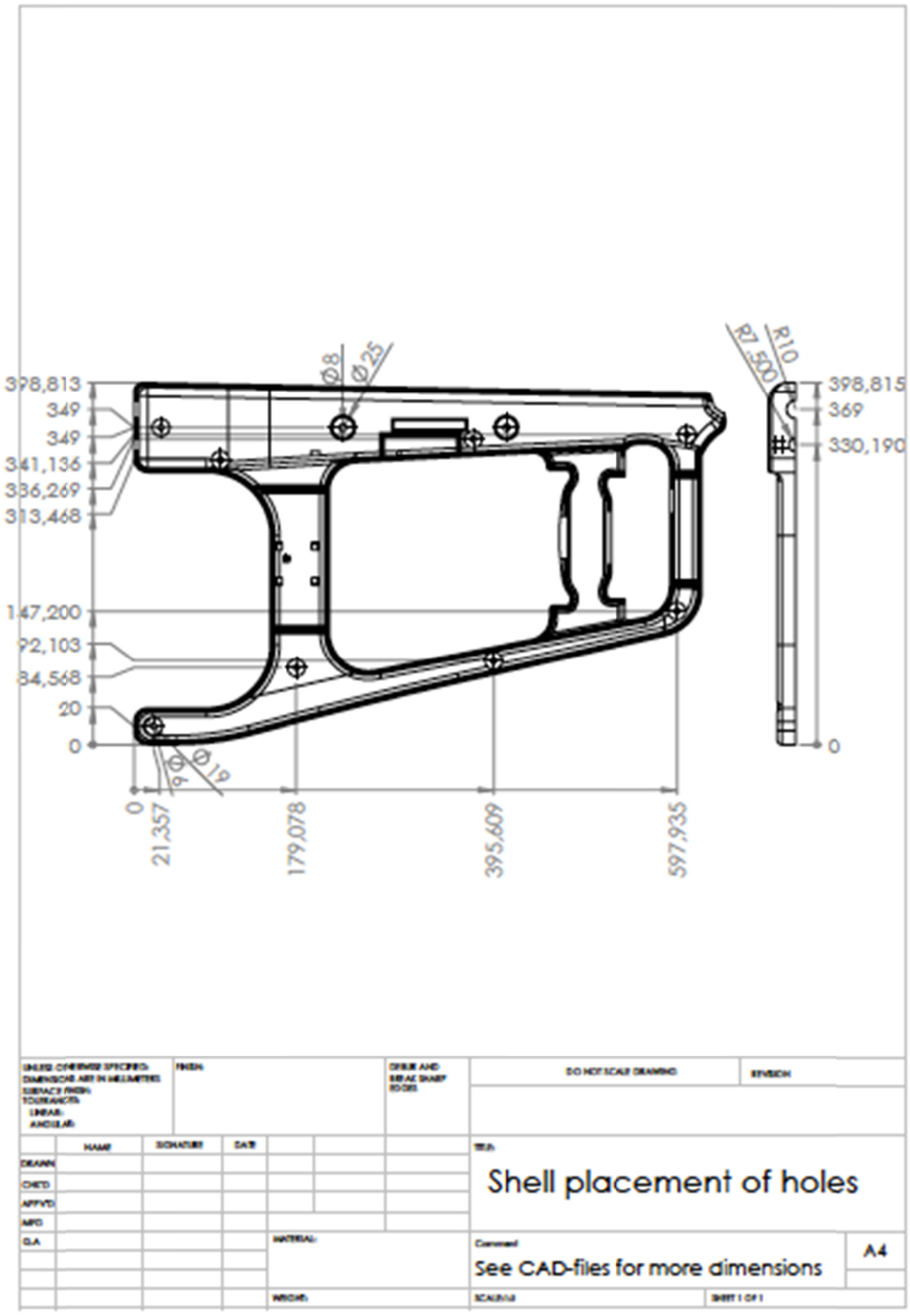
Test Protocol 6

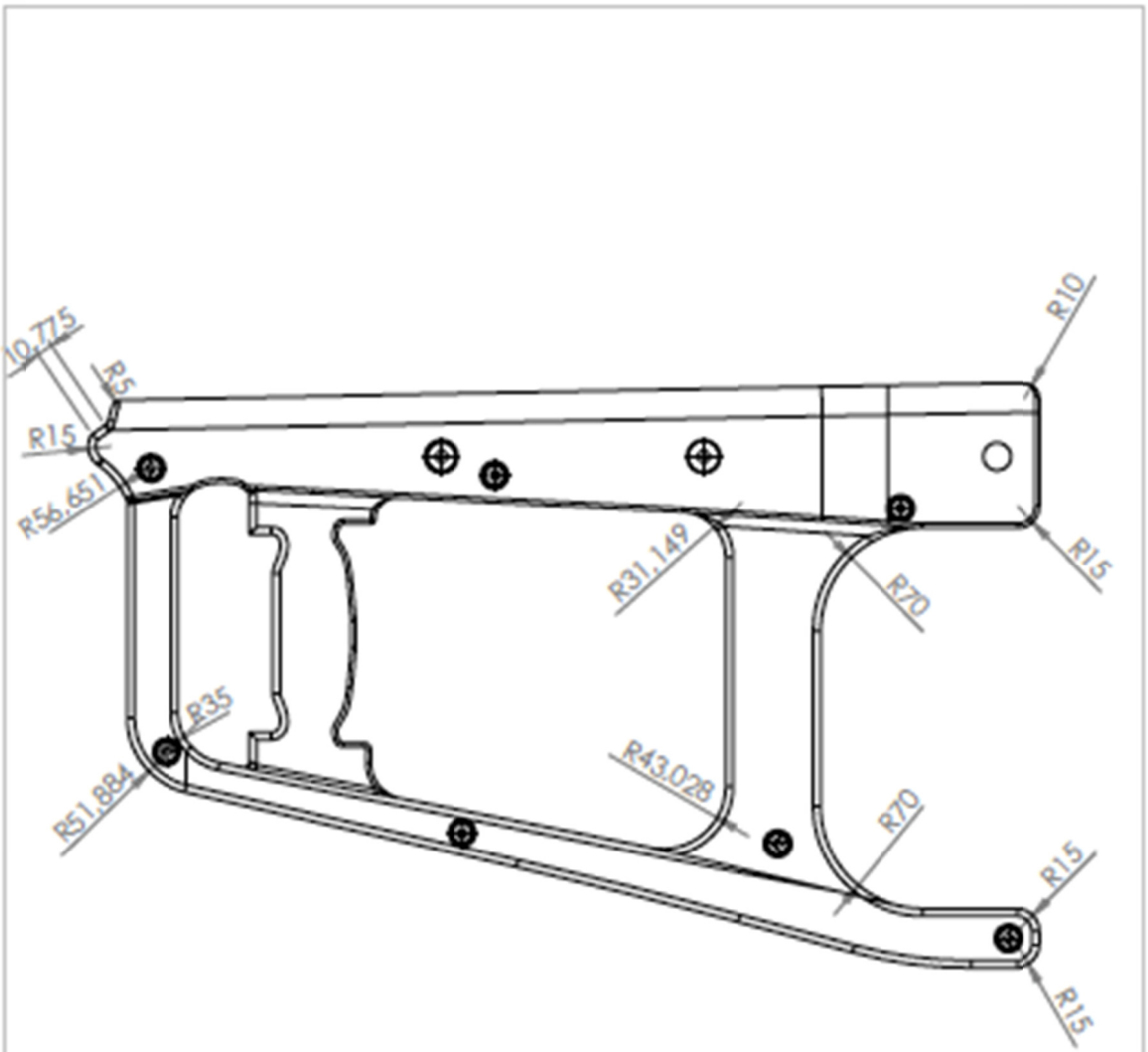
Product tested:	Cutting support/ Splash protection. Four point support with edge.
Execution of test:	Shouting against a sheet of steel at Cold Cut Systems backyard. The purpose of penetrating a sheet of steel is to maximize the bound back.
Purpose with test:	To see if the splash protection prevents the water to hit the operator's upper part of the body and face. The idea is that the edge will stop the water jet from going to one certain direction.
Outcome of test:	The edge stopped the water jet in one direction, which reduced the water that hit the upper body and face on the operator.
Further investigation:	Yes

Close-up picture over splash protection:	**Picture when using the splash protection:**
	 The distribution of the water shows that the flange control the water jet.

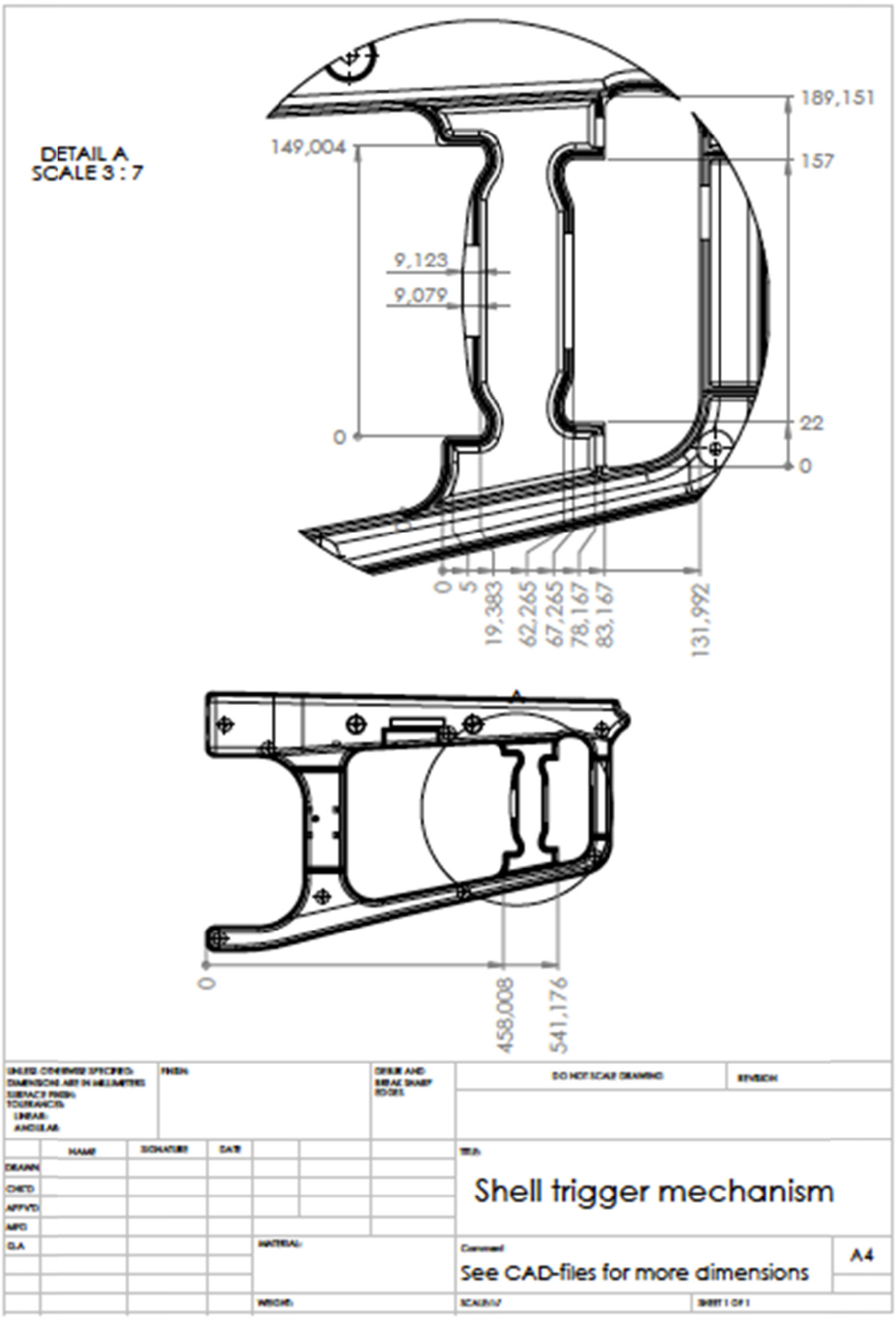
Appendix F Drawings




398,813
349
349
341,136
336,269
313,468
147,200
92,103
84,568
20
0
Ø8
Ø25
Ø9
Ø19
0
21,357
179,078
395,609
597,935
R7,500
R10
398,815
369
330,190
0
Shell placement of holes
See CAD-files for more dimensions
A4



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETRES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:				FINISH:			DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE				TITLE: Shell radius	
DRAWN								
CHK'D								
APPV'D								
MFG								
Q.A				MATERIAL:			Comment: See CAD-files for more dimensions	A4
				WEIGHT:			SCALE:1:4	SHEET 1 OF 1


DETAIL A
SCALE 3 : 7
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157
149,004
9,123
9,079
22
0
0
0
5
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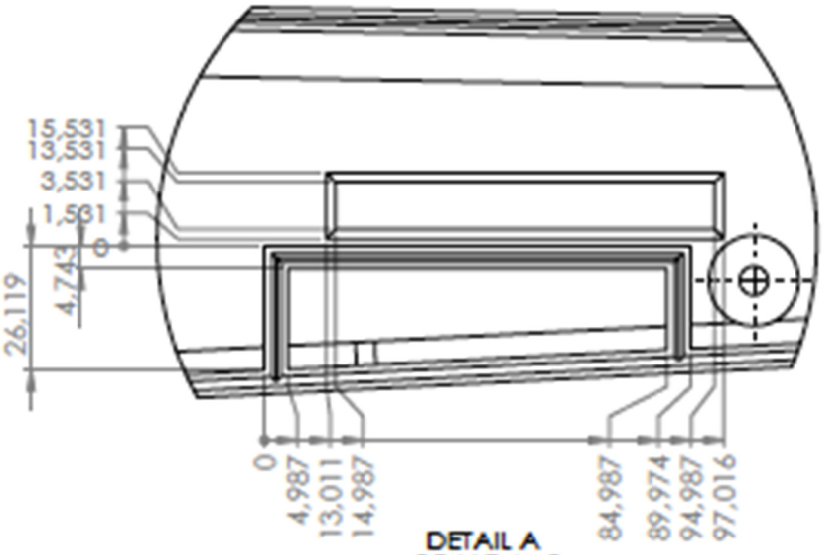
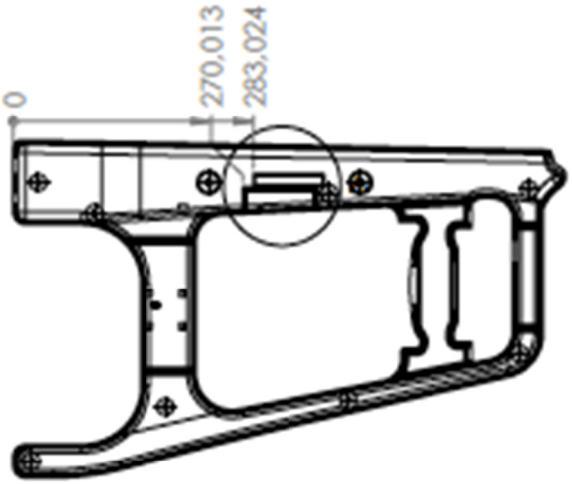
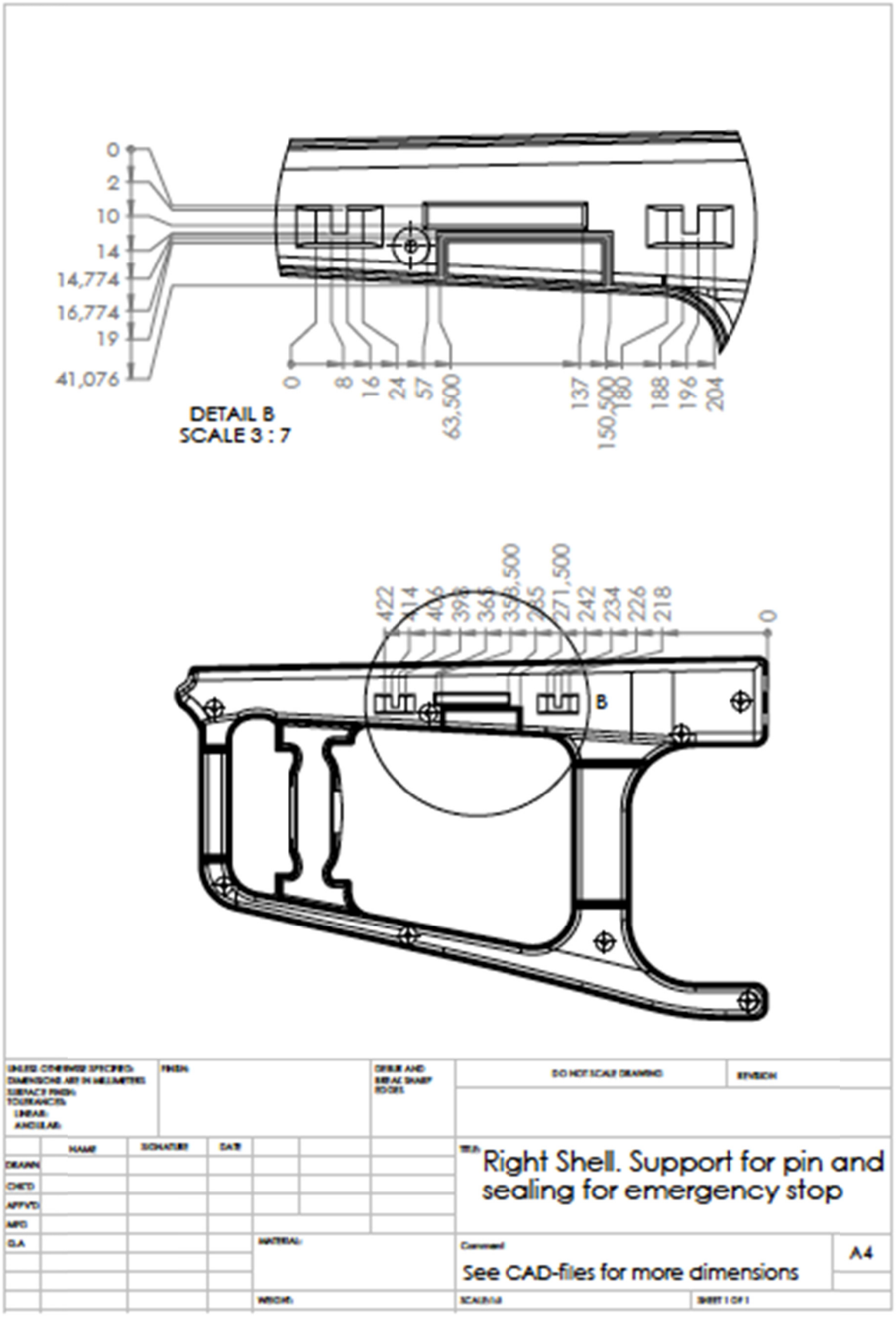
67,265
78,167
83,167
131,992
0
458,008
541,176
Shell trigger mechanism
See CAD-files for more dimensions
A4



DETAIL A
SCALE 4 : 5



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETRES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:				DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE				TITLE: Left Shell. Sealing emergency stop	
DRAWN								
CHK'D								
APP'D								
MFG								
Q.A				MATERIAL:			Comment: See CAD-files for more dimensions	A4
				WEIGHT:			SCALE:1:7	SHEET 1 OF 1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19
41,076
0
8
16
24
57
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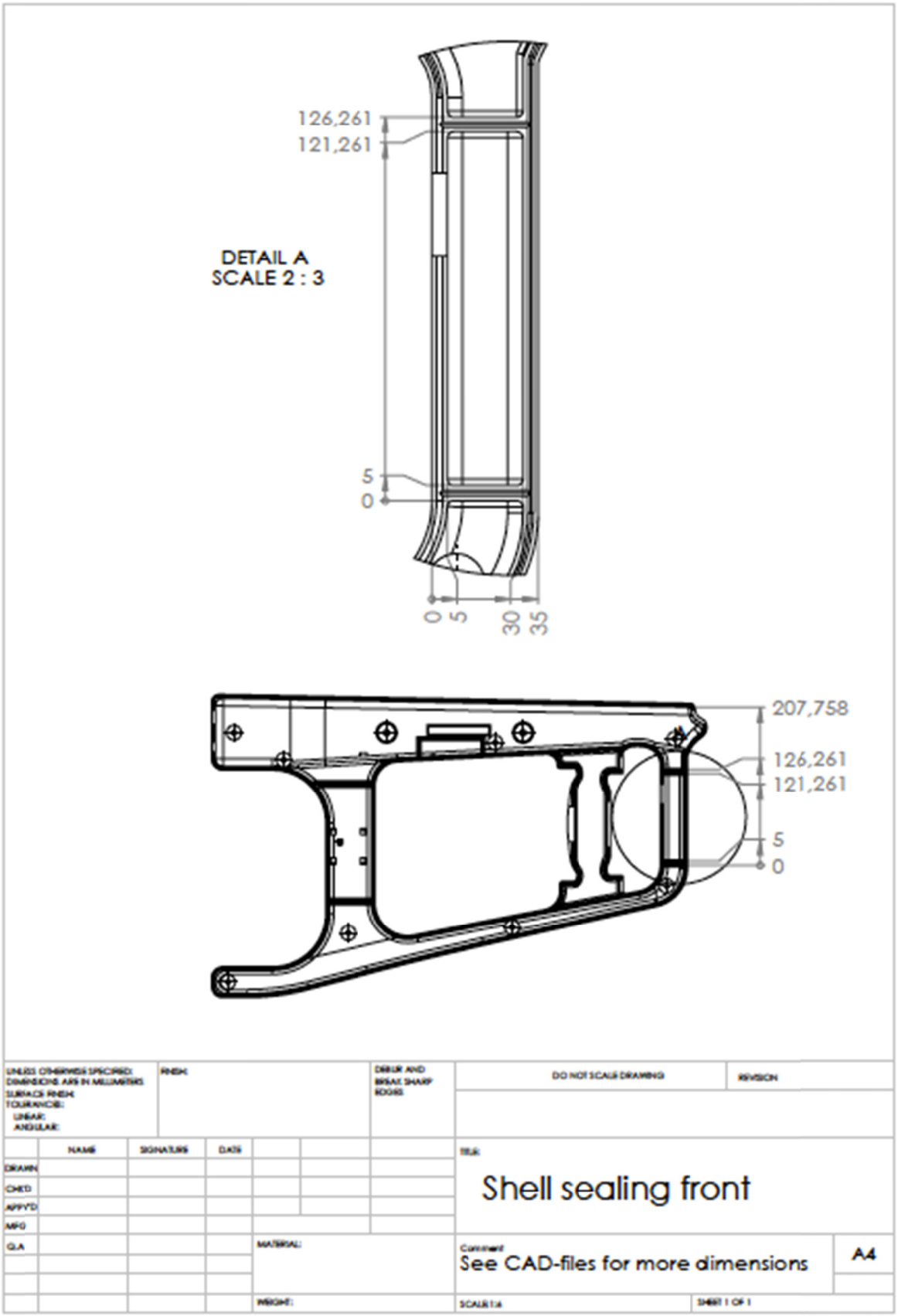
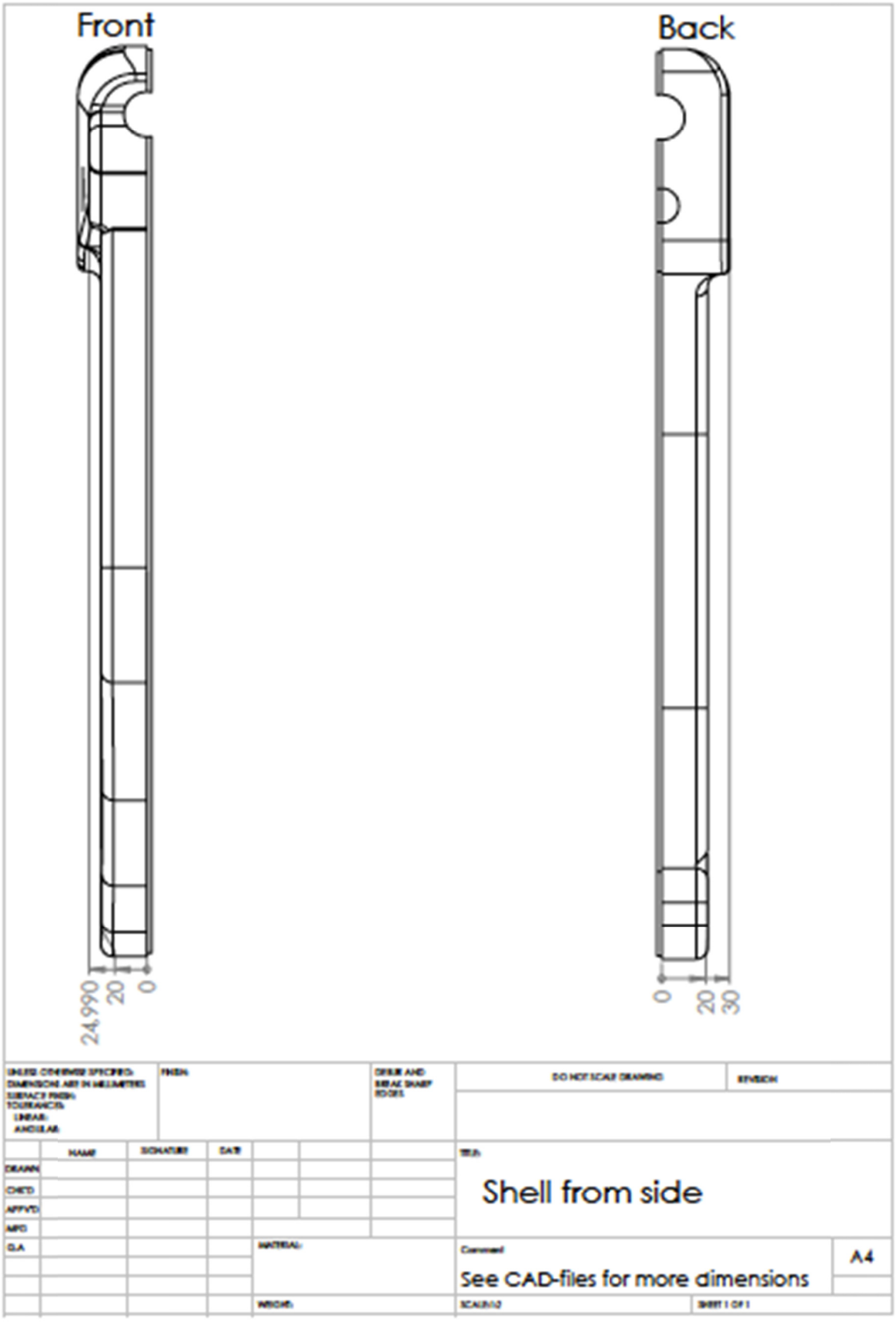
137
150,500
180
188
196
204
DETAIL B
SCALE 3 : 7
422
414
406
398
390
358,500
271,500
242
234
226
218
0
B
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHKD
APPVD
MFG
Q.A
MATERIAL
WEIGHT
Right Shell. Support for pin and sealing for emergency stop
See CAD-files for more dimensions
A4
SCALE 1:3
SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:		DEBUR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE			TITLE: Shell sealing front	
DRAWN							
CHK'D							
APP'VD							
MFG							
Q.A				MATERIAL:		Comment: See CAD-files for more dimensions	A4
				WEIGHT:		SCALE:1:6	SHEET 1 OF 1


Front
Back
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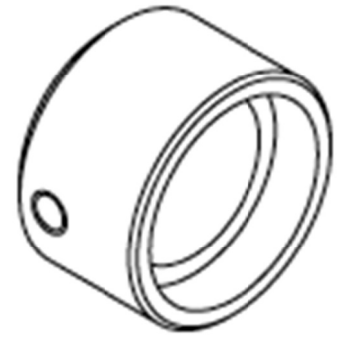
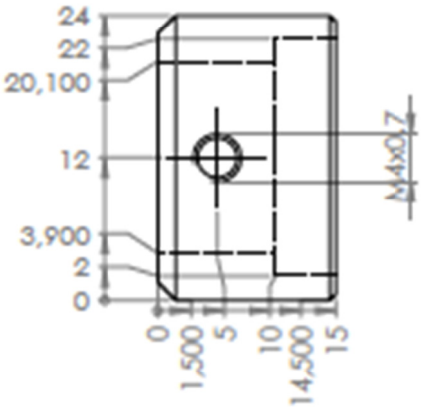
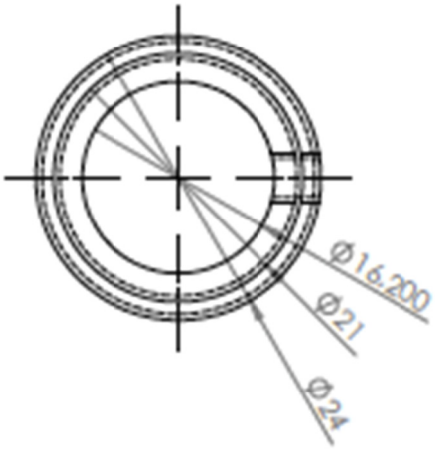
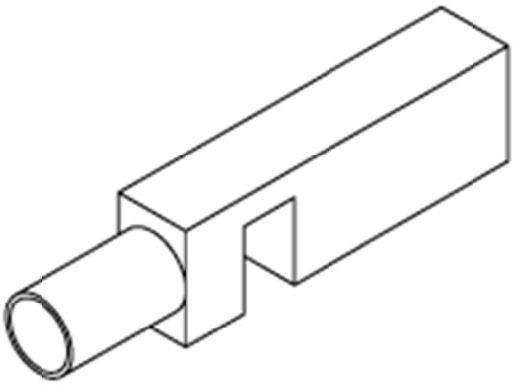
20
0
0
20
30
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APP'VD
MFG
Q.A
MATERIAL:
FINISH:
Shell from side
A4
See CAD-files for more dimensions
SCALE:1/2
SHEET 1 OF 1

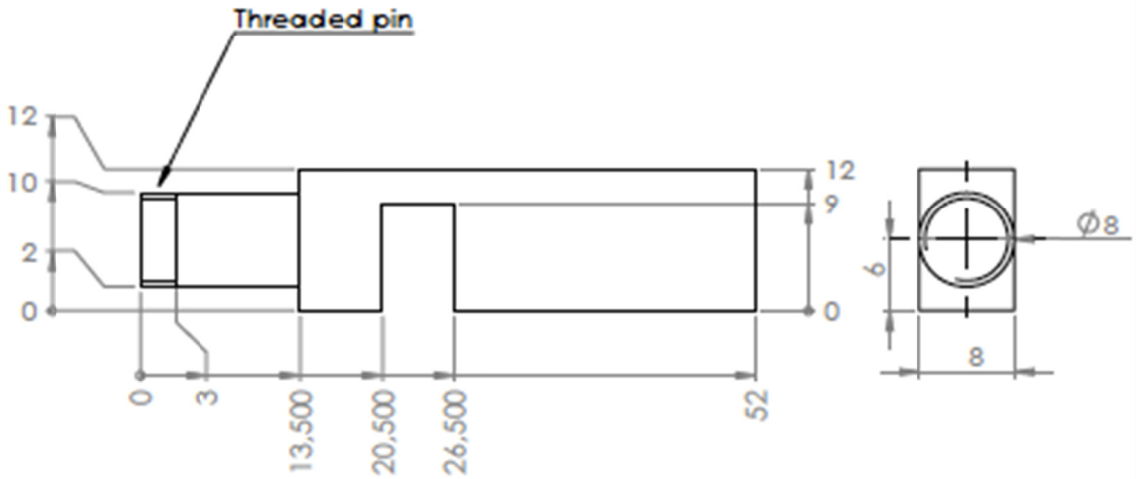




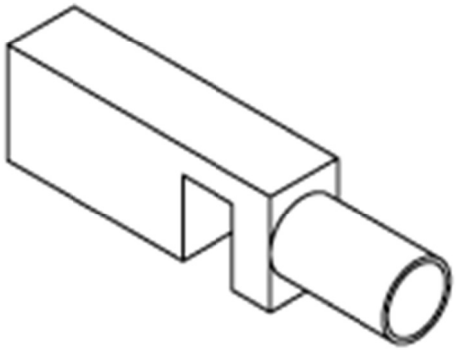


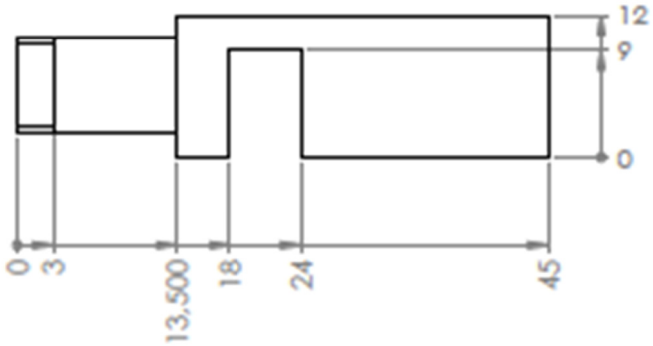
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETRES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBURR AND BREAK SHARP TO 0.3	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE			TITLE: Locking ring	
DRAWN							
CHK'D							
APP'D							
MFG							
Q.A				MATERIAL:		DWG NO.	A4
				WEIGHT:		SCALE:2:1	SHEET 1 OF 1

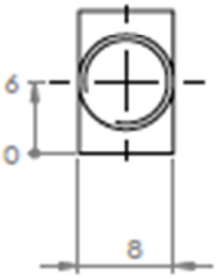




UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:			FINISH:			BREAK AND BREAK SHARP EDGES	DO NOT SCALE DRAWING
	NAME	SIGNATURE	DATE				
DRAWN							Lock pin back
CHK'D							
APP'VD							
MFG							
Q.A				MATERIAL:			DWG NO. A4
				WEIGHT:			SCALE:2:1 SHEET 1 OF 1







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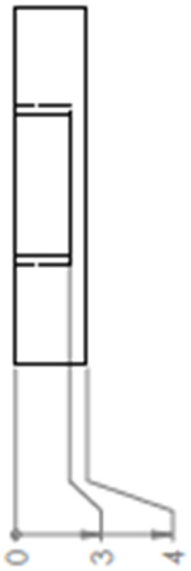
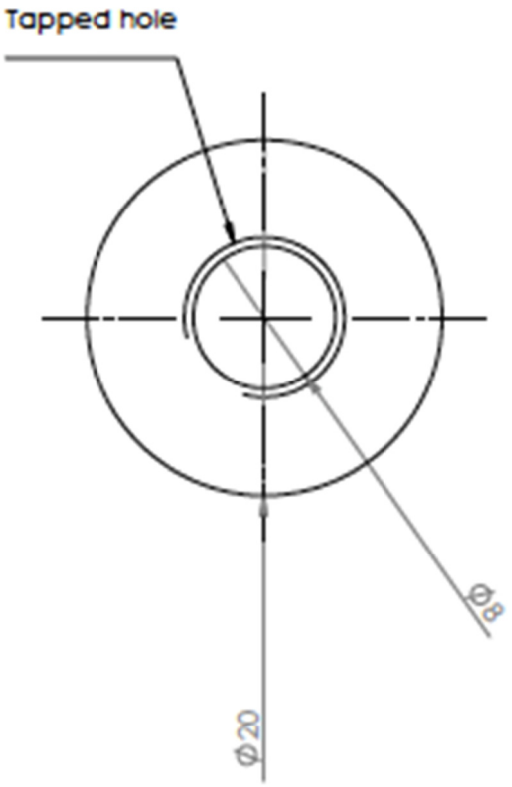
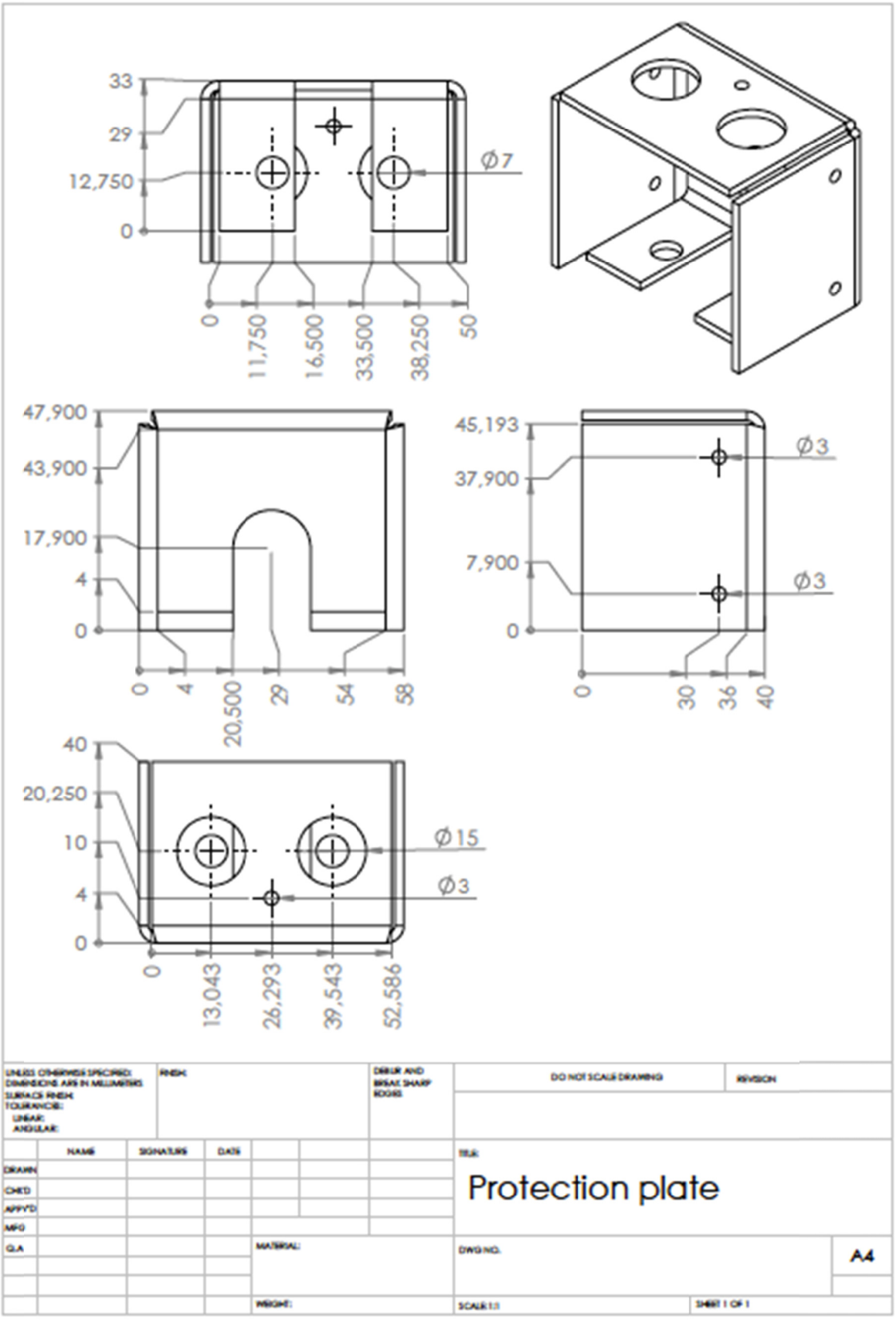
	NAME	SIGNATURE	DATE					TITLE: Lock pin front	
DRAWN									
CHK'D									
APPV'D									
MFG									
Q.A				MATERIAL:				DWG NO.	A4
				WEIGHT:				SCALE:2:1	SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETRES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:				FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION
	NAME	SIGNATURE	DATE				TITLE: Button head
DRAWN							
CHK'D							
APP'VD							
MFG							
Q.A				MATERIAL:			DWG NO. / A4
				WEIGHT:			SCALE/2:1 / SHEET 1 OF 1


33
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Ø7
0
11,750
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33,500
38,250
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47,900
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17,900
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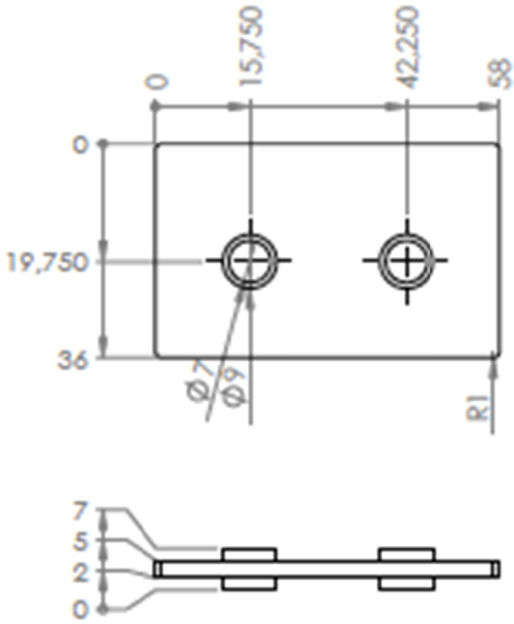
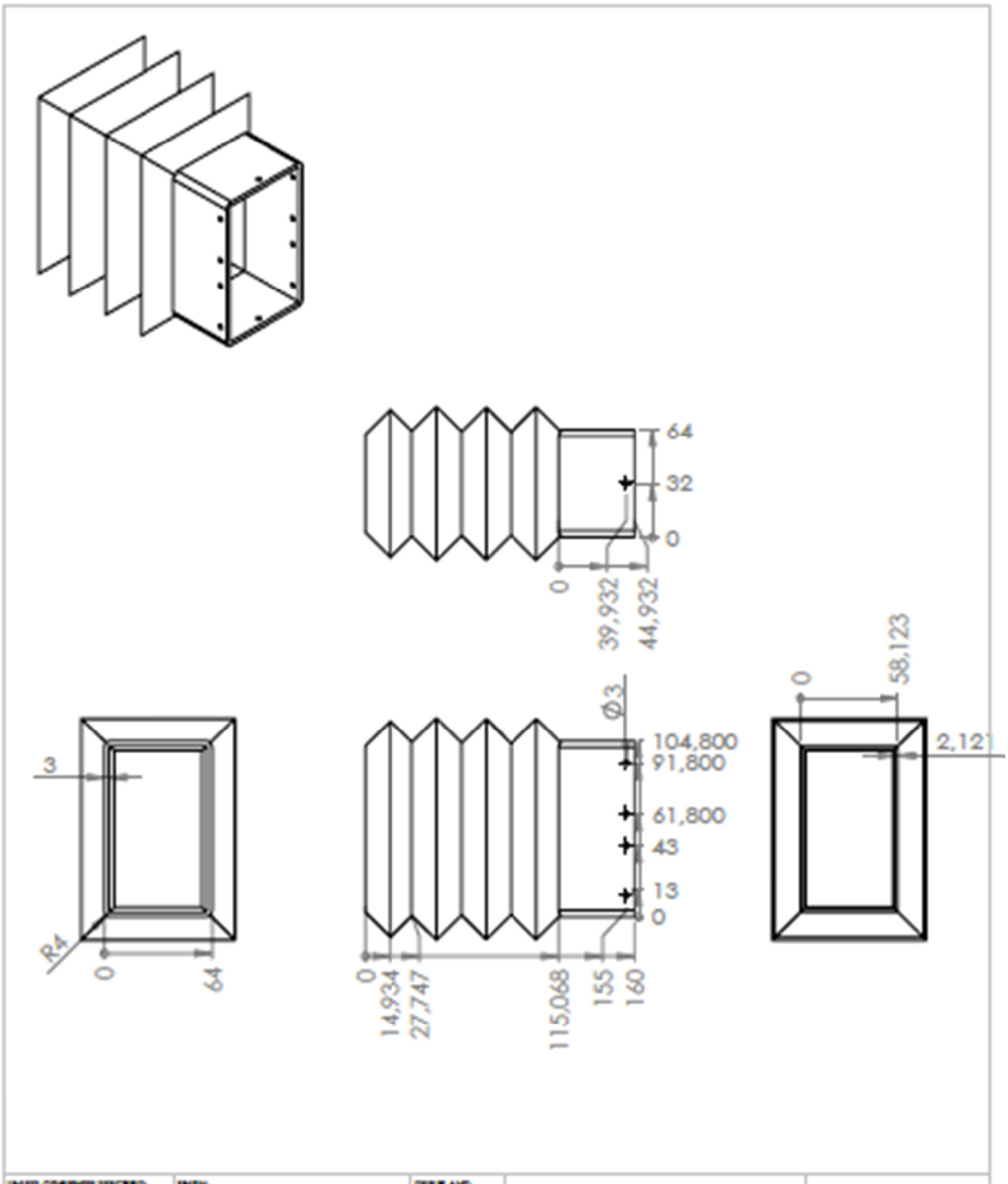
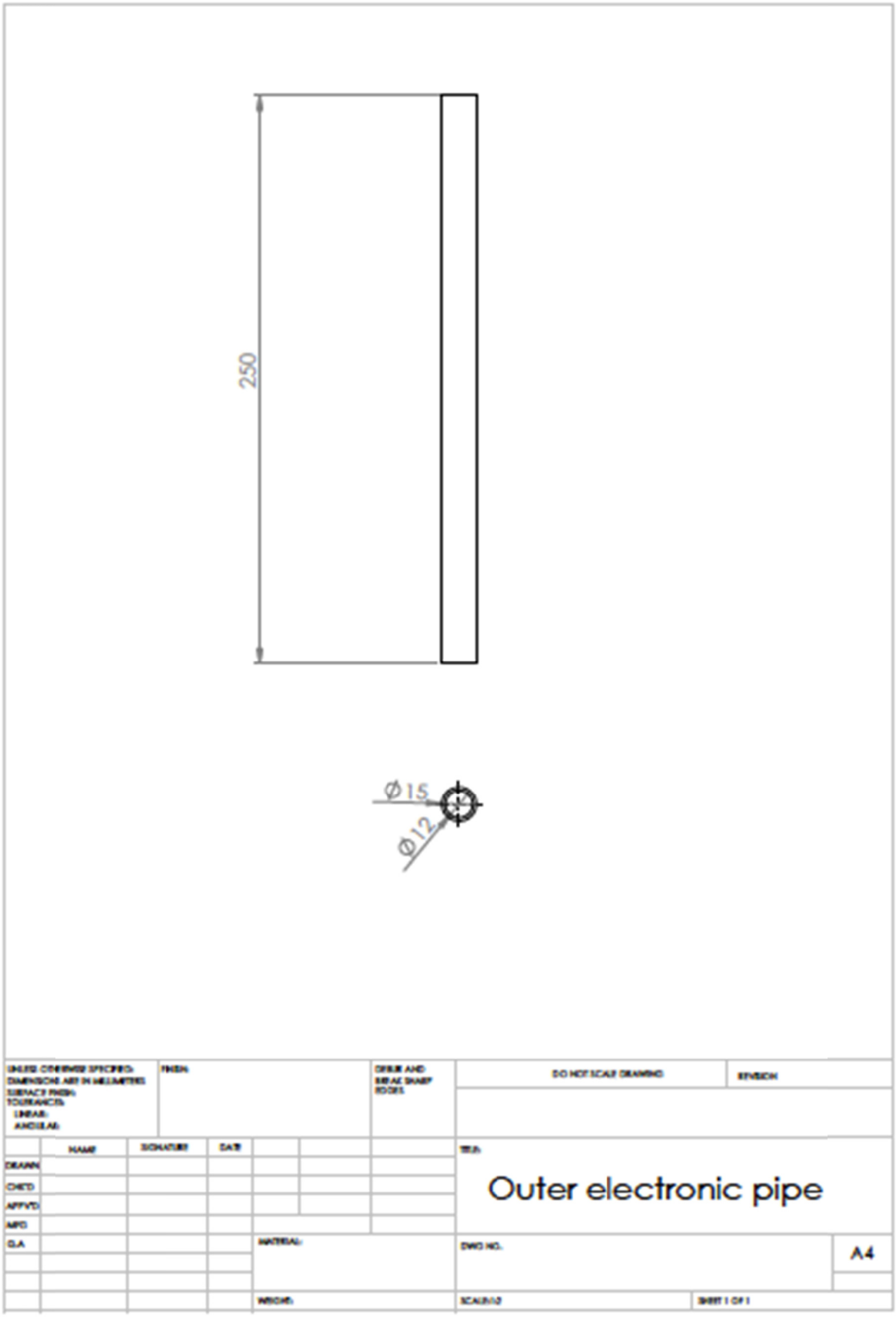
0
0
4
20,500
29
54
58
45,193
37,900
7,900
0
Ø3
Ø3
0
30
36
40
40
20,250
10
4
0
Ø15
Ø3
0
13,043
26,293
39,543
52,586
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHKD
APPVD
MFG
Q.A
MATERIAL:
WEIGHT:
Protection plate
DWG NO.
A4
SCALE:1:1
SHEET 1 OF 1

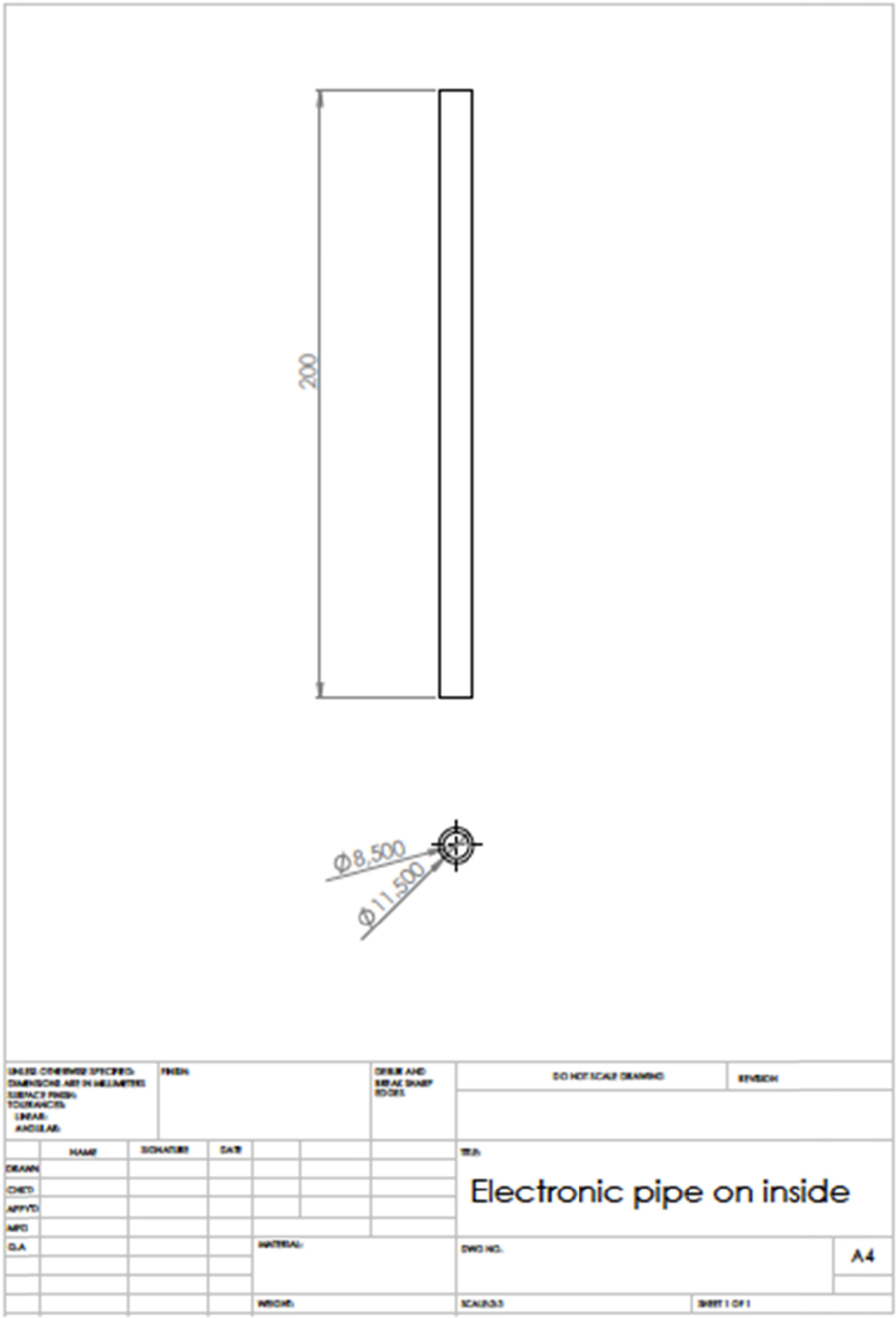


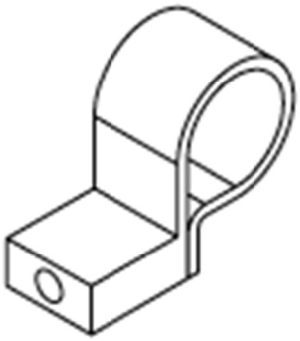
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE			TITLE: Plastic distance	
DRAWN							
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:		DWG NO.	A4
				WEIGHT:		SCALE:1:1	SHEET 1 OF 1

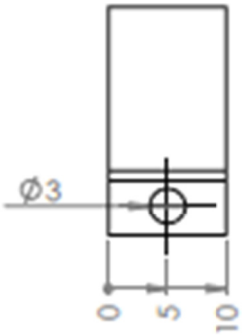


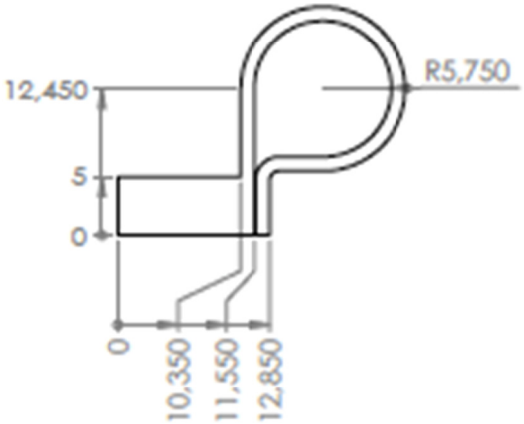
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES:	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE			TITLE: Protective bellow	
DRAWN							
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:		DWG NO.	A4
				WEIGHT:		SCALE:1:3	SHEET 1 OF 1


250
Ø15
Ø12
Outer electronic pipe
A4

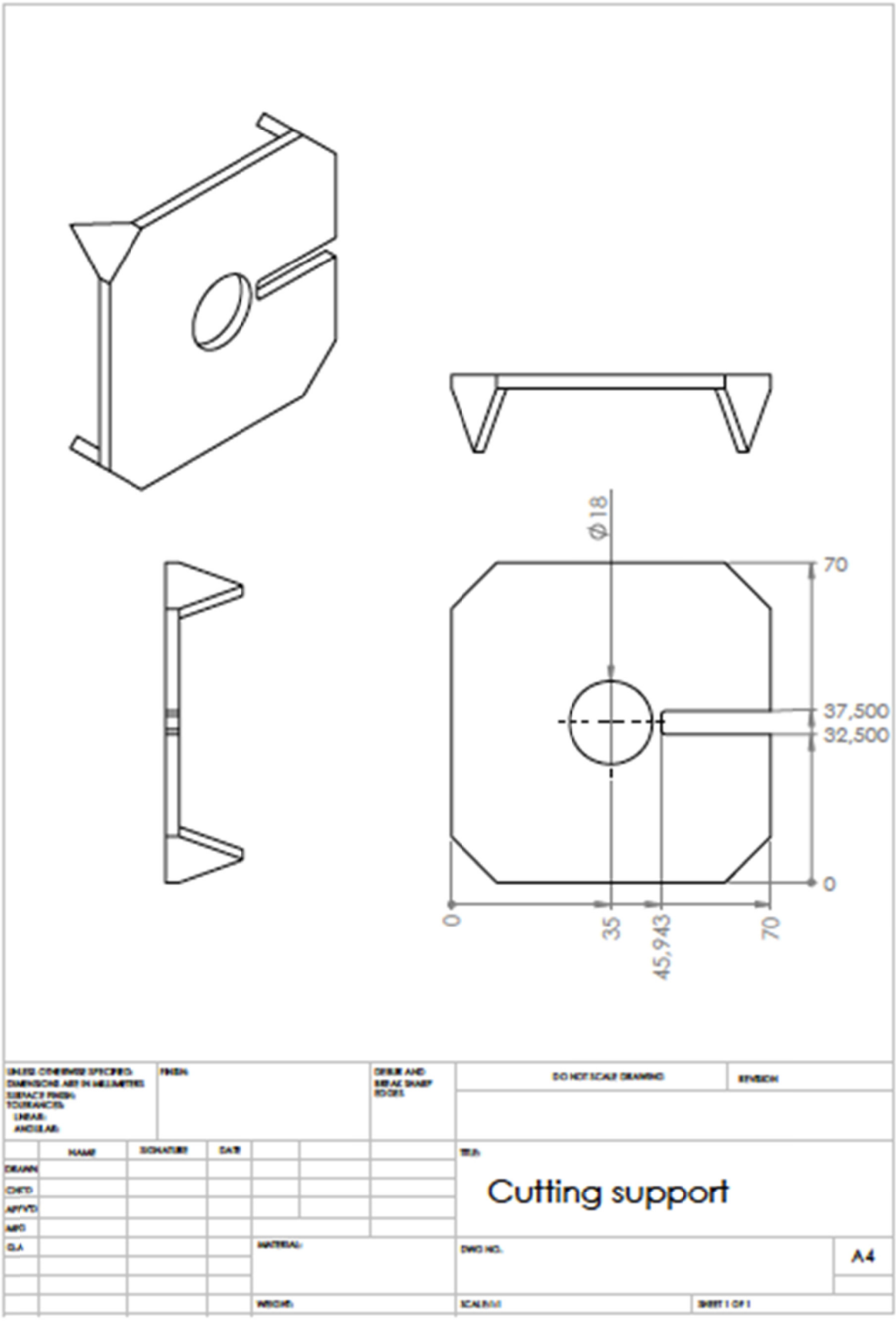

200
Ø8.500
Ø11.500
Electronic pipe on inside
A4







UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETRES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:			FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE				TITLE: Pipe clamp	
DRAWN								
CHK'D								
APP'VD								
MFG								
Q.A				MATERIAL:			DWG NO.	A4
				WEIGHT:			SCALE:1:1	SHEET 1 OF 1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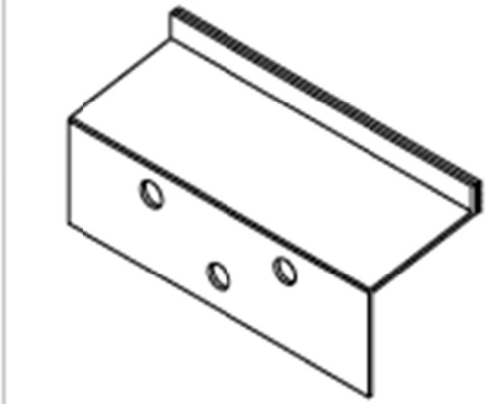
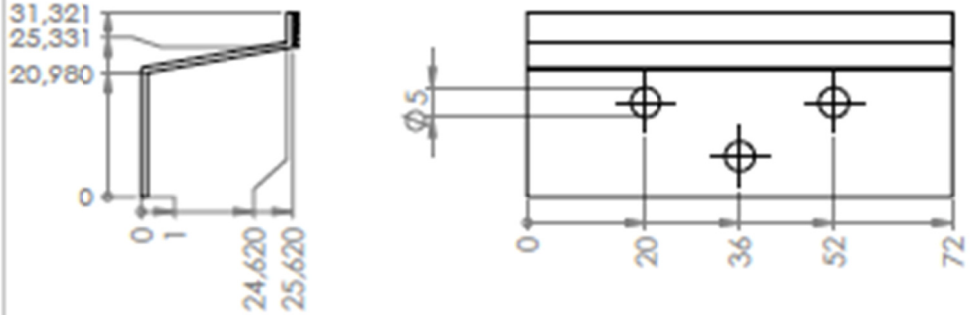
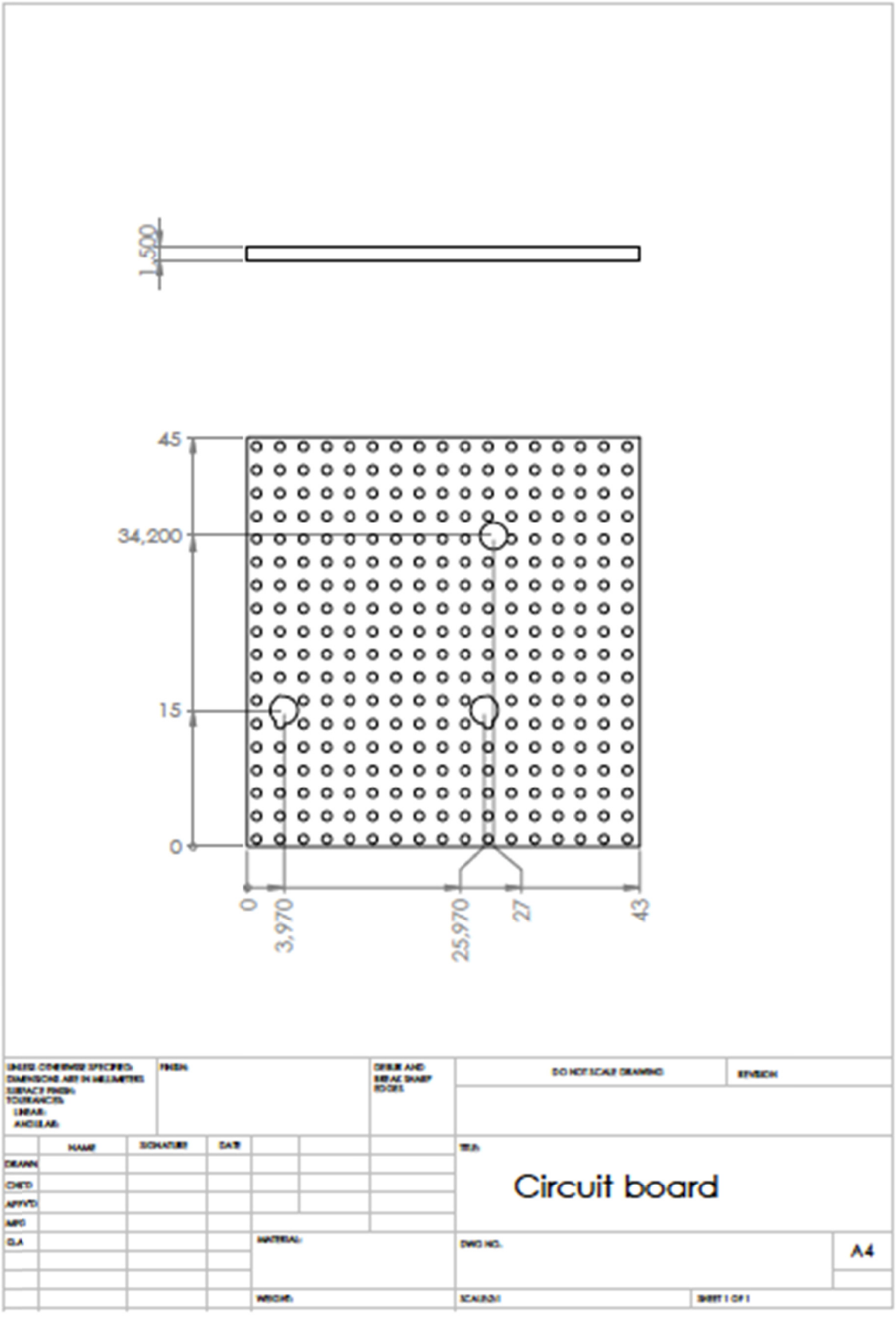
32,500
0
0
35
45,943
70
Cutting support
A4





UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:			FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING
	NAME	SIGNATURE	DATE				TITLE: Splash protection
DRAWN							
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:			DWG NO. A4
				WEIGHT:			SCALE:1:1 SHEET 1 OF 1


1,500
45
34,200
15
0
0
3,970
25,970
27
43
Circuit board
A4