

Further Development of a Rescue Helmet

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Abstract

The aim of this master's thesis was to further develop a helmet for search and rescue personnel, on request from *AUK Protection*, formerly known as *Baering*. This thesis succeeds the KTH MF2061 higher course project *Baering Y1 - Product development of a new search and rescue helmet in collaboration with Baering* in 2013.

AUK Protection had identified a need for a purposely designed helmet through contact with members of Swedish *Search and Rescue*(SAR) and *Swedish Sea Rescue Society*(SSRS). There are approximately 2000 active SAR and SSRS members who use helmets designed for recreational activities, such as rafting and mountain climbing, for lack of a better alternative. The helmets are consequently modified to accommodate their specific needs. Essential rescue equipment, such as position lights and communication systems, are retrofit using fasteners, tape, straps and Velcro. User studies conducted in the MF2061 project indicated safety concerns with the aforementioned attachment methods. The retrofit components protrude from the helmet and often interfere with other rescue equipment, with the risk of entangling the user.

The *Y1* helmet concept produced in the MF2061 project was evaluated together members from SAR and SSRS, with focus on form and functionality. Different materials and manufacturing methods were researched and the manufacturability of the *Y1* was analysed. It was ultimately decided to discontinue the development of the *Y1* due to the feedback received. New concepts were generated with focus on anthropometric data, manufacturability, helmet safety standards and the ability to mount additional components. Different material combinations were investigated and evaluated using physical testing. Further development of the concepts involved clay sculpting and 3D CAD modelling. The final concept was chosen based on input from the users, AUK Protection and HOWL Design Studio.

The *R1 -Rescue One* helmet is the result and supersedes currently available solutions for rescue applications. The essence of the *R1* helmet is a modular mounting system that can be customized for use with third-party components. Prototypes were manufactured in the correct materials for further evaluation. Drop tests were performed according to PAS 028 standard validate the mechanical properties of the helmet.



KTH Industriell teknik
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Sammanfattning

Syftet med denna magisteruppsats var att vidareutveckla en hjälm för livräddningspersonal, som gjordes på begäran från *AUK Protection*, tidigare känd som *Baering*. Denna avhandling efterföljer MF2061 högre kurs-projektet *Baering Y1 - Product development of a new search and rescue helmet in collaboration with Baering* som genomfördes i KTH år 2013.

AUK Protection hade identifierat ett behov av en speciellt utformad hjälm genom kontakt med medlemmar i svenska *Search and Rescue(SAR)* samt *Sjöräddningssällskapet(SSRS)*. Det finns omkring 2000 aktiva SAR och SSRS medlemmar som använder hjälmar avsedda för fritidsaktiviteter, såsom forsränning och bergsklättring, i brist på ett bättre alternativ. Hjälmarna modifieras följaktligen för att tillgodose deras specifika behov. Nödvändig räddningsutrustning, exempelvis positionsljus och kommunikationssystem, monteras på hjälmen med hjälp av skruvar, tejp och kardborreband. Användarstudier i MF2061-projektet indikerade att dessa monteringsmetoder medför säkerhetsrisker. Enligt SAR Norrtälje hakar utstickande komponenter som är monterade på hjälmen ofta fast i övrig räddningsutrustning, med risk för att trassla in användaren.

Y1 hjälmkonceptet, som produceras i MF2061-projektet, utvärderades med avseende på form och funktion tillsammans med medlemmar från SAR och SSRS. Olika material och tillverkningsmetoder undersöktes och producerbarheten av *Y1* analyserades. Det beslutades slutligen att avbryta vidareutvecklingen av *Y1* baserat på feedbacken som erhöles. Nya koncept genererades med fokus på antropometrisk data, producerbarhet, säkerhetsstandarder för hjälmar och förmågan att montera ytterligare komponenter. Olika materialkombinationer undersöktes och jämfördes med hjälp av fysiska tester. Vidareutvecklingen av konceptet involverade skulptering i lera och 3D CAD modellering. Det slutliga konceptet valdes utifrån input från användarna, AUK Protection och HOWL Design Studio.

Resultatet, hjälmen *R1 - Rescue One*, ersätter tillgängliga lösningar för räddningsapplikationer. Det som utmärker *R1*-hjelmen är ett modulärt monteringsystem som kan anpassas för användning av tredjepartskomponenter. Prototyper av *R1* tillverkades i korrekta material för vidare utvärdering. Falltester utfördes i enlighet med PAS 028 standarden för att validera de mekaniska egenskaperna hos hjälmen.

FOREWORD

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Artur Adson & Timu Matin

Stockholm, November 2014

NOMENCLATURE

The notations, abbreviations and software used in this master's thesis are listed and described here.

Notations

Symbol	Description
E	Young's modulus (Pa)
E_p	Potential energy
E_K	Kinetic energy
r	Radius(m)
t	Thickness (m)
h	Height (m)
m	Mass (kg)
g	Gravitational constant, 9,81 (m/s ²)
psi	Pound force per square inch (lbf/in ²)

Abbreviations

<i>CAD</i>	Computer Aided Design
<i>CAE</i>	Computer Aided Engineering
<i>CAM</i>	Computer Aided Manufacturing
<i>CNC</i>	Computer Numerical Control
<i>PLM</i>	Product Lifecycle Management
<i>DFM</i>	Design For Manufacturing
<i>SAR</i>	Search and Rescue (Swedish)
<i>SSRS</i>	Swedish Sea Rescue Society / Sjöräddningssällskapet
<i>ABS</i>	Acrylate butadiene styrene
<i>PC</i>	Polycarbonate
<i>LD Foam</i>	Low Density polyurethane foam
<i>EPP</i>	Expanded Polypropylene
<i>EPS</i>	Expanded Polystyrene

Software used

Adobe Illustrator CS6

Adobe Photoshop CS6

Microsoft Word 2010

Microsoft Excel 2010

CES EduPack

SolidWorks 2013

Autodesk Inventor Professional 2015

Autodesk Simulation Moldflow

Keyshot 5

SRP Player

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1 INTRODUCTION

The project background, purpose and delimitations are presented in this chapter.

1.1 Background

Search and rescue personnel lack head protection that is purposely designed for their profession and needs. The rescue personnel are mainly working at sea, operating from boats, ships and helicopters. There are approximately 2000 active search and rescue workers in Sweden.

Helmets designed for outdoor sports, such as rafting and mountain climbing, are used as substitutes. Required functions such as position lights and communication systems have to be retrofit, often with make-shift solutions using cable ties, tape or Velcro. A common helmet is the Predator helmet, a rafting helmet, used by Search and Rescue, SAR, in Norrtälje. These helmets lack desired properties and functions to meet their standards.

User studies conducted in MF2061 project, year 2013, indicated problems with these custom mounting solutions. The retrofit components protrude from the helmet and can interfere with ropes, wires and other rescue equipment. This is a safety concern especially among rescue workers that operate from helicopters.

A concept of a search and rescue helmet, named the *Y1*, was developed in collaboration with *Baering* as part of a higher course project in 2013. The result was a full-scale model of the helmet, purposely designed for rescue personnel, see Figure 1.



Figure 1. Y1 rescue helmet concept.

1.2 Purpose

In this thesis project, the Y1 concept is evaluated and further developed with the aim of presenting a production ready helmet, the R1, Rescue One.

The project will begin with an evaluation of the Y1 concept in conjunction with Baering and *Howl Design Studio*. User interviews will be carried out to identify areas of further development. Research will be conducted on materials, manufacturing methods, safety standards and external components. The manufacturing methods will be benchmarked based on cost and efficiency. The materials will be physically tested according to the existing safety standards.

1.2.1 Deliverables:

- A user-friendly design according to anthropometric data and ergonomic guidelines.
- Highly detailed CAD models, with accurate dimensions and materials, designed for manufacturing
- A prototype with high degree of functionality and correct materials

1.2.2 Delimitations

- Integrated electronic components
- Prototype helmets in different sizes will not be considered due to time limitations.
- Field testing of helmets and practical evaluation of mounted components will not be performed.

2 METHODS

This chapter explains the methods used throughout the project, from acquisition of data to concept development and evaluation.

2.1 Iterative design process

Iterative design process is a design methodology, a cyclic process of prototyping, analysing, testing and refining. The method involves the users in several stages of the design process, to avoid problems and to correct them as soon as they emerge. Designs and prototypes are presented and the feedback given is used to further develop the design/prototype. This is mostly beneficial when it starts as early as possible in the design process to avoid unnecessary costs and too many irrelevant prototypes. (Schneider, J., & Stickdorn, M. (Eds.), 2011, ss. 124- 135)

- Stage one of the process is to create a better understanding of the user and product.
- Second stage is about creating concepts, prototypes.
- Third stage evaluation, testing and analysing
- Last stage is to implement the feedback and information gathered from stage three and refines the concepts or prototypes.

2.2 Project planning methods

A well-planned project is essential for achieving a good result. A project plan is created to provide an overview and clarify the important aspects of the project. A time plan is created and visualized with a Gantt-chart.

2.2.1 Project plan

The project plan is to clearly communicate the structure in the project through categorizing and describing each task. The project plan is divided into main and sub-categories.

2.2.2 GANTT-chart

Gantt-chart is used to structure the project plan and plan each task for a larger time limited project. The chart is divided into a horizontal timeline on one axis and a vertical axis with a list of chronological ordered tasks. Each task illustrated with a bar that represents the duration of time.(Johannesson, H., Persson, J-G., & Pettersson, D., 2004)

2.3 Information retrieval

Information is gathered to gain insight in areas of interest and background. The information is gathered through different methods, such as statistics, literature, articles, internet forums, websites etc.

2.4 Competitor analysis

A competitor analysis is conducted to analyse the market with focus on trends, key success factors in order to further understand the product and identify opportunities for improvement(Bergman, B. and Klefsjö, B., 2010). The analysis includes research regarding material, construction, standards and ergonomics of the product.

2.5 Material analysis

A material analysis performed together with the competitor analysis, concerning impact properties and shock absorption effectiveness to analyse which material that is of interest for the R1 helmet. To further analyse and benchmark the materials, the software CES EduPack is used to obtain comparable data.

2.6 Semi-structured interviews

An interview is a qualitative method for obtaining information. It is as structured conversation between the person conducting the interview and the interviewee. The objective is to uncover the interviewee's personal view and opinion on a certain subject by asking predetermined questions. A semi-structured interview differs from a regular interview by being more open for discussion and allowing both the interviewer and interviewee to elaborate on thoughts and ideas(Gill, Stewart, Treasure, & Chadwick, 2008).

2.7 Ideation workshop

An ideation workshop is a method where the participants discuss a certain subject and collaborate to produce ideas. The method allows the participants to express themselves more freely by playing out scenarios and list problems by exploring the gap between existing and future products. The workshop method in this project has been used in a way to explore the existing solution and implement scenarios for further development(Sharples, Giasemi, Vavoula, & Mike, December 2007).

2.8 Focus group

Focus groups are a group of people selected to represent the targeted demographic. A focus group is used to determine the customers' needs and find the problems with current solutions. The goal with this method is to both help the developers generate new ideas and evaluate alternatives (Ullman, 2010, p. 152).

2.9 Ideation

Ideation is the process of generating different solutions and designs. Different methods were used in the different stages of the development process.

2.9.1 Brainstorming

Brainstorming is a method used for generating new ideas. It is typically a group activity, but can be performed individually as well. Brainstorming is often focused on a specific theme or

function, with the purpose of generating as many ideas as possible within a certain time frame(Ullman, 2010, p. 190).

The brainstorming activity is usually divided in multiple sessions for each subject. In a group setting, the individual members generate ideas separately and share their work with the rest of the group at the end of a session. The purpose of sharing ideas is to trigger new ideas from other group members. In order not to limit creativity, placing judgment and negative criticism is not allowed during the sharing process. When all ideas have been presented, the entire process is then repeated.

According to Ullman, the four rules for brainstorming are:

1. Record all the ideas generated. Appoint someone as secretary at the beginning; this person should also be a contributor
2. Generate as many ideas as possible, and then verbalize these ideas
3. Think wild. Silly, impossible ideas sometimes lead to useful ideas.
4. Do not allow evaluation of the ideas; just the generation of them. This is very important. Ignore any evaluation, judgment, or other comments on the value of an idea and chastise the source.

2.9.2 Moodboard

A moodboard is a collection of images on a board that is put together to illustrate a certain mood where the purpose is to inspire the designers and communicate the direction of the product.

2.9.3 Speed sketching

Speed sketching is a method used to help produce large quantities of sketches in a brief limited time. Underlays can be used as templates during the sketching process to help the designer preserve the correct proportions, while maintaining the sketching speed(Sjölen, K., & Macdonald, A, 2011).

2.9.4 Exploratory sketching

Exploratory sketching is a method for both generating and exploring ideas and solutions. The sketches are quick and simple with focus on function. The aim is to generate as many ideas as possible(Sjölen, 2005).

2.10 Evaluation

Evaluation methods are used to benchmark and analyse different solutions, such as concepts and competitors.

2.10.1 Pugh-matrix

The Pugh-matrix is a method used for weighing different concepts, ideas or products against each other based on pre-defined performance criteria's. Often a reference concept or product is used with a neutral score. The items for comparison attain a relative score to the reference

product. The Pugh-matrix provides a visual overview of which concept that meets the stated criteria best(Ullman, 2010, pp. 221-229).

2.10.2 SWOT-analysis

SWOT analysis is a structured method used to evaluate the strengths, weaknesses, opportunities and threats in a project. The objective of the project is specified and the internal and external factors are identified as positive or negative depending on how they can potentially influence the result(Ullman, 2010, pp. 101-102).

2.10.3 Clay model

Clay models are used for translating 2D sketches and digital designs into physical 3D volumes. InDeClay and SuperClay are two types of clay purposely developed by Kolb Technologies for industrial designers and form exploration. The properties of the clay allow the designer to process the clay manually and make immediate adjustments by adding and removing material(Clay).

2.10.4 CAD

Computer Aided Design is used for producing digital prototypes of designs and generating drawings for manufacturing. The dimensions can be precisely controlled in a CAD environment.

2.10.5 Physical prototype

Physical prototypes are created to test and evaluate the product and or manufacturing method. The prototypes can be created to evaluate the concept, product, process or production(Ullman, 2010, p. 118). The aim with these physical prototypes in this project is to evaluate the concept together with the users. The secondary aim is to evaluate the manufacturing and production process if possible.

3 FRAME OF REFERENCE

The reference frame is a summary of the existing knowledge and former performed research on the subject and new findings.

3.1 Project plan

The project plan was divided into five phases and each phase is divided into main and sub branches.

1. Phase one emphasizes on planning the project and evaluating the previous Y1 concept.
2. Phase two includes research and analysis of the market today
3. Phase three is about concept development and benchmarking
4. Phase four is refinement, prototyping and testing
5. Phase five is presentation

See Appendix A for complete project plan. The project plan translated into a Gantt-chart, illustrating each task duration related to time, see Appendix B.

3.2 User groups

The information gathered through observations and interviews during the higher course project MF2061, led to two main user groups SAR and SSRS.

3.2.1 SAR

The Swedish Search and Rescue, SAR, governed by the Swedish Maritime Administration is responsible for sea rescue, including coastal areas around the lakes Vättern and Vänern. SAR operates from 15 bases in Sweden with helicopters. They have crew on stand-by, ready to dispatch within 15 minutes (Sjö- och flygräddning, 2014).

A helicopter rescue crew typically consists of four people; two pilots, a winch operator and a rescue swimmer. In a rescue situation, the rescue swimmer is lowered and raised from the helicopter using a wire rope and winch, see Figure 2. The rescue swimmer's objective is to reach the distressed as quickly as possible and bring them back to safety in the helicopter.



Figure 2. SAR Rescue helicopter with winch.[1]

The rescue swimmer must be able to communicate with the helicopter crew at all times and does so using a top mounted position light and a two way radio communication system. Furthermore, the rescue swimmer also relies on additional lights pointing in the field of view in low light situations.

SAR currently uses helmets on which external components are attached to accommodate these functions. A commonly used helmet is the Predator Full Cut, as seen in Figure 3. The Predator helmet is not purposely designed for the rescue swimmer's needs and has to be physically modified to enable mounting of components.



Figure 3. Predator helmet with mounted position and spotlights.

Interviews and workshops conducted in the MF2061 project revealed that the lights and other components mounted on the helmet risk getting in the way of the wire rope, resulting either in entangling the rescue swimmer or breaking loose from the helmet. The height inside the helicopter when seated is also limited for top mounted components.

SAR requested a more compact helmet design that minimizes the interference with the wire rope while still maintaining the same functionality.

3.2.2 SSRS

The Swedish Sea Rescue Society, SSRS, is a non-profit association with the objective of saving lives at sea. SSRS consists of 2000 volunteer members who operate from 67 stations along the Swedish coastline. Each year they receive over 7000 distress calls and are ready to respond within 15 minutes (Vi räddar liv till sjöss, 2014).

SSRS typically operate in less favourable and demanding weather conditions, with strong winds and high seas. The rescue personnel are heavily dependent on their rescue equipment and demand the highest level of quality and reliability. SSRS have 103 ships to their disposal; ranging from large cruisers to small boats, 15 hovercrafts and 45 rescue runners. The rescuerunner, as seen in Figure 4, is a purposely designed jet ski that can reach speeds up to 34 knots, or 63 km/h (Våra båtar, 2014).



Figure 4. SSRS Rescuerunner in action.[2]

During a rescue operation, safety and communication is essential to quickly locate the distressed and bring them to safety. User studies conducted in the MF2061 project course revealed that the helmet is a key piece of equipment for personal safety and for providing visual and radio communication.

Helmets such as the aforementioned Predator Full Cut and the Gecko Open Face are retrofit with radio speakers, lights and reflective tape. Visors are used in addition to prevent water from splashing directly in the eyes, especially under windy conditions and when travelling at high speeds over water.

SSRS found the current solution inadequate in terms of ability of attaching third party components, safety and ergonomics. The components are typically mounted using Velcro and cable ties. In some instances, the hard outer shell of the helmet needs to be modified and holes are made. This may compromise the structural integrity of the helmet and the safety of the user as a result. SSRS also experienced that there is a lack of helmets that take extra large head sizes and different head shapes in consideration.

3.3 Ergonomics

One of the important and unsolved matters according to SSRS personnel was the ergonomics in the helmets today. Head sizing and relative aspects for a comfortable helmet is presented below.

3.3.1 Head sizes

Different head sizes and shapes were taken in consideration when designing the R1 helmet. Most of today's helmet manufacturers offer different sizes for the purpose of providing better fit. In contrast, helmets that only come in one size, such as the Predator Full Cut, compensate for different sizes by using additional padding, resulting in the user having to carry more weight.

Helmet size is measured in head circumference, in the transverse plane over the temple, as seen in Figure 5. The dimensions are derived from the EN 960:1995 standard, as referred to in the PAS 028 standard.

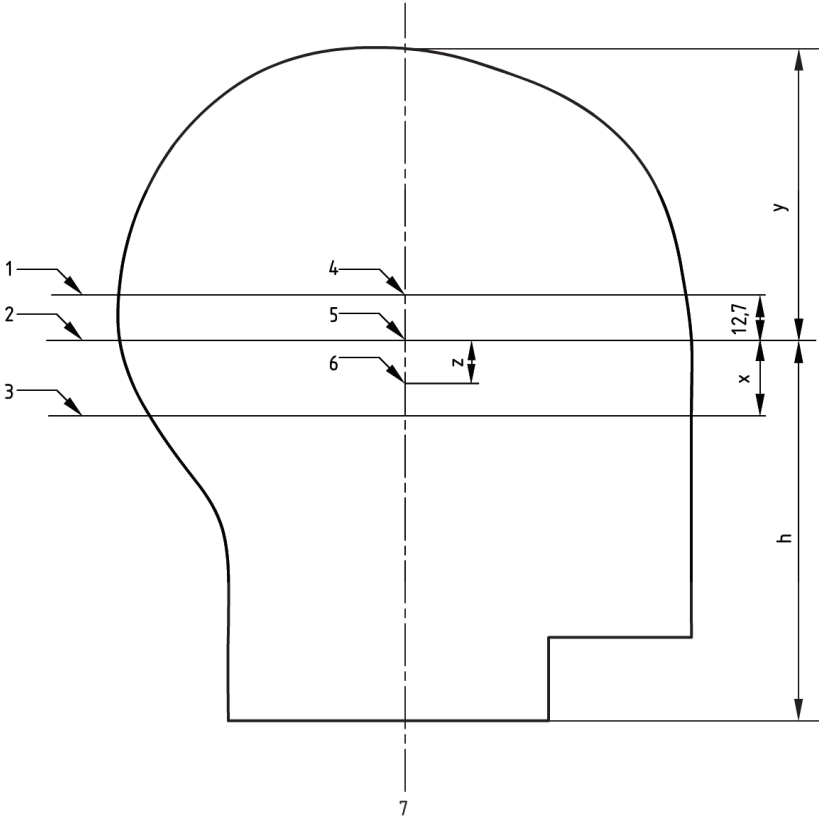


Figure 5. Section of vertical longitudinal plane. Circumference measured in plane marked with 2. [3]

The EN960 standard describes the standardized head mannequins used in testing of protective helmets. The dimensions are based on anthropometric data and translated into 15 nominal sizes, spanning from the 5th percentile female to 95th percentile male. Five common head mannequin sizes are presented in Table 1 below(Ball, 2011).

Table 1: Head form sizes with circumference.

Size	Delta Y [mm]	Delta X [mm]	Mass [grams]	Circumference [mm]
A	89,5	24	1525 +- 35	500
E	96	26	2050 +- 35	540
J	102,5	27,5	2885 +- 35	570
M	107	29	2950 +- 35	600
O	110	30	3285 +- 35	620

3.3.2 MIPS

The Multi Impact Protection System, MIPS, is a patented technology developed by MIPS AB, with the aim of reducing rotational forces on the brain caused by angled impacts on the head. MIPS achieved this by mimicking the brain, which is naturally protected by a low friction fluid layer. MIPS introduces a low friction layer in the helmet that allows the helmet to slightly rotate relative to the head at impact (MIPS Helmet, 2014).

The results from simulations of a human brain in the event of an impact with and without MIPS can be seen in Figure 6.

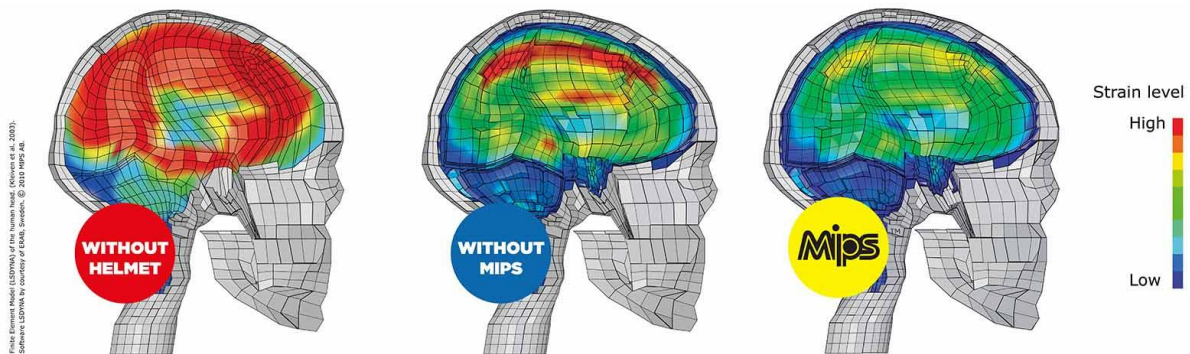


Figure 6. A comparison of the forces affecting the brain in the event of an impact, with and without MIPS. [4]

Stigson, H et al conducted a study for Folksam where they tested thirteen ski helmets. They performed three tests, one drop test on the crown of the helmet, one angled impact on the side and one on the top. The angled impacts were conducted to measure the rotational and translational forces subjected to the head. This is accomplished by letting the helmet and head form assembly accelerate vertically towards the ground while a steel plate accelerates horizontally along the ground. The system is adjusted so that the plate hits the helmet at a specific velocity (Stigson, Åman, Krafft, Kullgren, & Rizzi, 2014).

The helmets were dropped from 0,7 m, vertical velocity of 3.8 m/s, and the steel plate had a velocity of 6.3 m/s which results in a total velocity of 7.4 m/s. The study showed that only three helmets passed all three tests. The limit for translational acceleration that a head can be subjected to was 100g, see Appendix C for the helmets tested and their value (Stigson, Åman, Krafft, Kullgren, & Rizzi, 2014).

3.4 Essential helmet components

A helmet consists of essential components with different functions and properties. A brief description about each component, their main functions and common features are presented in the following chapter.

3.4.1 Outer shell

This part is generally created with composite materials such as fibreglass, carbon or aramid fibre hybrid or thermoplastics ABS, PC (Pierce, 2011). An in-mould outer shell is constructed by moulding the outer shell together with the foam. The result is a helmet that is lighter, better ventilated with larger degree of design freedom. Another method is to create a hard-shell construction, where the outer-shell and inner liner is created separately and glued together.

The hard shell construction is more robust, cheaper but heavier compared to an in-mould(Ambuske, Logan, & McManigal, 2012).

"The main purpose of the outer shell is to protect the users head from objects penetrating and distribute the impact over the inner liner/foam. Composite materials are generally better when it comes to penetration protection due to its higher stiffness than thermoplastics. Because of composite material properties the shell can be constructed thinner therefore, an overall lighter helmet compared to thermoplastics."(Adson, Larsson, Matin, & Svensson, 2013)The cons with using composite materials is the high material cost and labour intensive manufacturing method(Granta Design Limited, 2014).

The benefit of having a thermoplastic helmet except the low production price is that the shell becomes more durable and elastic which distributes the lower impacts better than composite materials(Mills & Gilchrist, 1991).

3.4.2 Inner liner

The inner liner is generally made from expanded polystyrene (EPS). The primary function of this component is to absorb the remaining force of the impact and distribute the load and decelerate the users head during impact. There are two types of inner liners that either offer protection from high single impacts or low multiple impacts (Shuaeib F. , Hamouda, Wong, Umar, & Ahmed, 2007).

3.4.3 Comfort liner

The comfort liners provides both comfort and secures the fit for the user. The secondary function for comfort padding is to help against vibrations and smaller impacts. The comfort liner is usually made of a firm synthetic foam pad such as EVA or Low-density polyurethane, covered with a skin friendly fabric(SHOEI CO., LTD).

3.4.4 Chinstrap

The chinstrap is the part that secures the fit of the helmet and fulfils the strict strength requirements according to the standard set. The chinstrap can vary in width and colour depending on the standard. The chinstrap is usually made in a synthetic material and covered with foam for comfort.

3.4.5 Retention system

Retention systems are used to provide a better or to fit several head sizes. The retention system is usually constructed with a knob or belt system for adjusting the size. The system can be designed in various ways depending on how the fit should be adjusted, some helmets can be adjusted all around and others only at the back. The retention system is attached to the helmet with metal rivets or screws.

3.5 External components

These components are not mentioned in the standards but requested by the user groups.

3.5.1 Communication

Communication is an important component that rescue personnel need for effective fieldwork, especially in airborne rescue, where the communication between the ground people and air crew is essential.

Prior to radio communication, rescue personnel used hand signals. This was a time consuming and non-effective method, according to Per-Magnus from SAR. Per-Magnus also stated that although there are several communication systems available in the market, only few meet their specific demands.

Baering AB thinks that an integrated or semi-integrated communication system can add product value.

3.5.2 Eye protection

According to Thore Hagman and other SSRS personnel, some type of eye protection is needed because of cold air at high speed and water floods. They also mentioned that some prefer goggles instead of visor due to better fit and a wider range of options to choose from. The visor is commonly made of polycarbonate because of its strength and good transparency. In addition, the visor can be treated with water- and scratch-proof coating (Schadvoy, 1997).

The visor can be integrated with the helmet or as an external part that is attached to the helmet. The visor is available in different sizes; long visors to protect a bigger area of the face and smaller ones which are easier to manoeuvre and have lower weight.

3.5.3 Camera

“The camera's main function is to record the rescue crew out on the field, for further evaluation and feedback. The main demands are that the quality should be watchable and waterproof with an existing housing or without. In addition to the demands SAR personnel also desires camera functions that can enhance their effectiveness out on the field, like Wi-Fi streaming. Today the GoPro camera is commonly used in this line of work, due to its price related to functions and the robust build. When using the water case the locations of the buttons are easy to find due to their elevated positions. The downside of the GoPro camera is that it is big and bulging outwards from the helmet. The most common position they attach the camera is on the top of the helmet which is due to the standard mounts and need for the GoPro to be horizontal.” (Adson, Larsson, Matin, & Svensson, 2013)

3.5.4 Snorkel

The snorkel is a tool commonly used by water rescue personnel. The snorkel needs to be able to move freely due to branches and wires that easily come between the snorkel and the helmet. SAR Norrtälje team prefers and promotes the aqua lung. Aqua lung Military is a snorkel well suited for SAR personnel, the snorkel is made out of a rubber neoprene material. The snorkel is shaped as a J-tube or a flex tube. A mask strap is connected to the snorkel for easily mounting the snorkel to any kind of underwater mask (Aqua Lung Military Snorkel).

3.6 Standards

Safety standards are looked into and compared to find suitable standards for the R1 helmet. Test methods and criteria's that need to be taken into account when developing the helmet are evaluated.

3.6.1 Helmet standards

The main function of a helmet is to protect the wearer from impacts by preventing penetration and absorbing force generated at impact. The helmet should be positioned correctly on the head to avoid unnecessary risks. The weight should be as low as possible to prevent strain in muscles over long term usage(SP, Technical Research Institute of Sweden).

Standards are created to verify and insure the user that the helmet follows the main functions. The standards also provide design guidelines for the developers and describe how the helmet should be tested with the corresponding failure thresholds(Ball, 2011, s. 307).

There are different standards due to different impact scenarios and severity of accidents. Additional tests that a standard may specify are water immersion, UV, retention system effectiveness. The differences between standards can be seen in Appendix D, where new and old standards are listed(CCID/Safety Unit, 2013).

There are some helmets today that follow a temporary standard, PAS 028, such as the Manta SAR and the Gecko helmet. PAS 028 is an interim standard because no British or European governing body have specified the performance criteria for rescue work. PAS 028 focuses on lifeboat rescue, therefore other standard certifications are added to fit the specific usage situation such as helicopter rescue, where airborne standard is needed(CCID/Safety Unit, 2013).

Some other standards that are common among search and rescue helmets are:

- BSI EN12492 – Mountaineering
- BSI EN1385–White water sports
- BSI EN 966 – Airborne sports

3.6.1.1 PAS 028

PAS 028 is the standard used for helmets in maritime applications such as water rescue(PAS 028:2002, 2002). The standard states both design restrictions and testing methods. The requirements that affect the design are taken into account at this stage.

- The materials of the helmet should not deteriorate from Ageing, exposure to sun, extreme temperatures and exposure to salt/fresh water.
- Metal parts on the helmet should be resistant to corrosion on exposure to salt water.
- The parts on the helmet that comes in contact with the skin should not undergo alterations from the effect of sweat and toiletries.
- The shell should not extend more than 10 mm from the inner liner.
- The helmet should protect the wearer at least to the FF'' plane see Figure 7.
- All edges should be smooth and rounded.
- Rigid projections on the inside of the helmet are not allowed.
- External projections shall not exceed 5 mm.

- The retention system should always be fixed on the helmet together with a chin strap
- The chin strap shall not be less than 18 mm wide.
- The mass of the helmet shall not be more than 700 grams.
- A peak is not allowed to be integrated with the helmet.

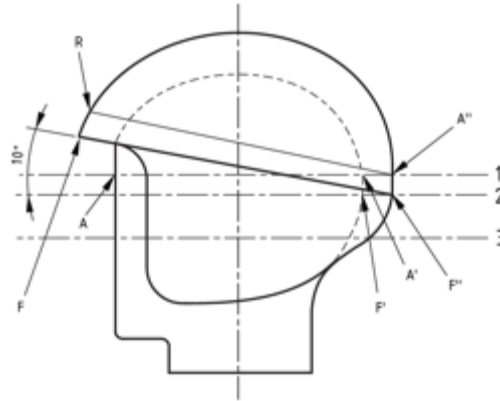


Figure 7. Extent of protection and wearing position. [5]

3.6.1.2 Testing according to PAS 028

Different tests are carried out to test the construction and design of the developed helmet. The test methods and thresholds are designed to imitate the working conditions of the helmet, see Table 2. The drop height and striker weight have a direct correlations with the head form used. The drop height shall be set to give a nominal impact energy, the height can be calculated with Eq.(1) and (2).

$$E_p = m \cdot g \cdot h \quad (1)$$

$$h = \frac{E_p}{m \cdot g} \quad (2)$$

The rigid mode method is performed to measure the force transmitted to rigidly mounted head form on which a helmet is fitted, where the force transmitted to the head form shall not exceed 12,5kN. A weight is dropped from a specific height on to the rigidly mounted helmet. The falling head-form test is performed by placing the helmet on a head form, according to EN 960, equipped with accelerometers, which in turn is placed upside down and dropped from a measured distance on to an anvil. The anvil can be flat, round or other shapes such as curb stone. The deceleration shall not exceed 250g at any time and the total time when the deceleration exceeds 150g shall not be longer than 5ms.

The penetration test is performed in the same way as the rigid mode method but differs in head form and the striker used. The point of the striker shall not get in contact with the head form. See

Table 2 for test methods.

Table 2: The different tests and their specific threshold according to PAS 028.

Striker weight	Drop weight	Impact energy	Failure threshold
----------------	-------------	---------------	-------------------

Falling head form method (Crown impact)	The weight of the head form (4,7 kg for head form J)	0,33 m	15 J	250g
Rigid mode (Crown impact)	5,0 kg	2,0 m	100 J	12,5 kN
Rigid mode method (Off-crown impact)	5,0 kg	0,5 m	25 J	12,5 kN
Resistance to penetration (crown impact)	1,5 kg	2,0 m		No contact with head form
Resistance to penetration (Off-crown impact)	3,0 kg	0,5 m		No contact with head form

See Appendix E for full description of each test method(PAS 028:2002, 2002).

3.6.2 Component standards

The working conditions for a rescue member are different depending on what type of field work they specify in. SAR and SSRS are known to work in wet and water conditions, which restricts them a bit when buying a component. A classification, IPXX, is used to rate an electronic equipment environmental protection. IP stands for ingress protection, where the IP number stands for how good the electronic equipment is enclosed. The first number represents the protection extent from solid objects and materials, see Table 3. The second number lists the protection against liquids criteria's see Table 4. For working conditions like search and rescue the components would need at least a IPX7 standard which allows the component to be underwater up to 1 m for 30 min. The standard aims to give the user a better understanding than the vague marketing terms, such as waterproof.

Table 3: First number designation in IP standard.

0	- No protection (Sometimes X)
1	- Protected against solid objects up to 50mm ³
2	- Protected against solid objects up to 12mm ³
3	- Protected against solid objects up to 2.5mm ³
4	- Protected against solid objects up to 1mm ³
5	- Protected against dust, limited ingress (no harmful deposit)
6	- Totally protected against dust

Table 4: Second number designation in IP standard.

0	- No protection (Sometimes X)
---	-------------------------------

1	- Protection against vertically falling drops of water (e.g. condensation)
2	- Protection against direct sprays of water up to 15 degrees from vertical
3	- Protection against direct sprays of water up to 60 degrees from vertical
4	- Protection against water sprayed from all directions - limited ingress permitted
5	- Protected against low pressure jets of water from all directions - limited ingress permitted
6	- Protected against low pressure jets of water, limited ingress permitted (e.g. ship deck)
7	- Protected against the effect of immersion between 15cm and 1m
8	- Protected against long periods of immersion under pressure

3.7 Competitor analysis

Rescue helmets are relatively new to the market and no official standard has been created. A helmet market research was conducted to further understand the essentials of a helmet, construction, modularity and features the helmet developers value when designing a helmet. The research consists mainly of helmets developed for rescue work but also other helmets that can be used due to their standards or functionality. See Appendix F for the complete helmet market research.

3.7.1 Main competitors

The most common helmets that are used by rescue members today according to SSRS and SAR members, some of the helmets are developed specifically to meet the rescue members needs while some have low weight and or easily modifiable.

3.7.1.1 Predator

“The most well-known helmet that Search and Rescue personnel at Norrtälje use is the Predator helmet, see Figure 8. The predator helmet follows the standard EN1385 helmets for canoeing. Used by the search and rescue members because of its low price and weight. They also liked that the helmet has a snug look.”(Adson, Larsson, Matin, & Svensson, 2013)

The Predator helmet was purchased for further investigation, the thickness and fit was evaluated. The Predator helmet uses a 3mm thick ABS plastic as its outer shell glued together with a 15 mm inner liner, made of closed EVA foam. The button/belt retention system requires two hands and for the helmet to be removed for adjusting, according to SAR at Norrtälje(Predator helmet, 2010).



Figure 8. Predator Full Cut helmet. [6]

3.7.1.2 Gecko

“The Gecko helmet is one of the first helmets that were designed for search and rescue personnel, see Figure 9. The Gecko has built in attachment points for visor and camera mounts, bought separately. The overall weight is around 720 grams without exterior components as cameras and or visor. The inner liner of the helmet is constructed in EPS. The helmet has an inflatable liner, which gives the user better control over the helmet fit. A specific intercom can be placed inside the helmet. The outer shell is constructed in Kevlar fibreglass. The helmet is BSI approved to PAS 028: 2002 MSHS(Gecko Headgear Ltd, 2014).“(Adson, Larsson, Matin, & Svensson, 2013)



Figure 9. Gecko Marine Safety Helmet. [7]

3.7.1.3 Manta Hi-Viz SAR Multi-Role Helmet

The Manta SAR helmet is designed for a wide range of safety standards including PAS 028. The helmet has built in visor and attachment points for external visors and ear protectors, see Figure 10. The helmet has a knob controlled retention system, easily adjusted with one hand(Pbi Height Safety Limited, 2014).

The helmet follows seven standards that are:
EN14052:2005 High performance safety helmet
PAS 028:2002 Marine safety helmet
FS/1 Quad & ATV helmet
EN1384 Equestrian helmet
EN352-3:1997 Hearing protection
EN166:2002 Industrial eye protection
EN12492 Working at height / Mountaineering



Figure 10. Manta SAR Multi-purpose helmet. [8]

The Manta SAR Helmet uses a 3-6 mm thick high impact ABS shell combined with an 18-22 mm thick inner liner, giving a total weight of 550 grams. (Pbi Height Safety Limited, 2014)

3.7.1.4 OPS-core FAST

A newly developed helmet designed according to the well-used military helmet OPS-Core see Figure 11. The use of ACH-ARC rail system gives the user possibilities to mount all sorts of components that the military uses today with no need of screws or other means that could degenerate the helmet.



Figure 11. OPS Core Fast helmet. [9]

The base jump model, the cheapest one, is made of polycarbonate with a NVG mount moulded together with the shell. The inner liner consists of EPP combined with LDV, low density vinyl, a closed cell foam for comfort. The liner is divided into smaller parts placed strategically around the helmet. The helmet has a retention system with a knob at the back for easy adjustments. The system is constructed in a way that tightens all around the helmet by turning the knob(Ops-Core, Inc)

3.8 Materials

In this section materials are presented and how they act in the context.

3.8.1 Outer shell

The material of the outer shell depends on what type of demands there are and the degree of protection that the helmet should follow.

3.8.1.1 Composite shell

Less material is needed to achieve the desired amount of protection compared to a thermoplastic helmet, because of the materials high stiffness and strength, resulting in a lighter helmet. A composite shell can be very beneficial, for instance when designing a MC-helmet where the weight, single high impact and penetration protection are key features. On impact, the composite shell crumples, cracks and delaminates which reduces the impact force transferred to the helmet liner (Mills & Gilchrist, 1991). The composite shells are usually constructed in multiple layers of fibres inside a mould, by adding resin and heat, the material hardens(Granta Design Limited, 2014).

3.8.1.2 ABS

As for a search and rescue helmet where multiple impacts are common a more flexible material is beneficial, for instance ABS plastic. These kinds of shells can upon impact flex and therefore distribute the impact force better on to the inner liner. ABS, also called acrylonitrile-butadiene styrene, has good impact properties and cost-effective manufacturing processes (Caswell, Gould, & Wiggins, 2007, pp. 95-99). The cons of using ABS is that it degrades with time when exposed to UV. The UV properties is improved by adding UV stabilizers in the moulding process or adding a UV protective coating afterwards (Granta Design Limited, 2014). ABS has lower stiffness than composite material and therefore a thicker shell is needed to pass the penetration impacts, which also makes the shell heavier than composite shell.

3.8.1.3 PC

Polycarbonate, PC, has the advantage of withstanding higher temperatures than ABS which makes it possible to create in moulded helmets due to the high moulding temperature of EPS/EPP. ABS provides good impact strength, but when a material with higher impact strength and better engineering properties are needed, polycarbonate is recommended. The disadvantages with using polycarbonate are the material's bad chemical resistance and notch resistance (Caswell, Gould, & Wiggins, 2007).

3.8.2 Inner liner

Very few materials are known to be used as an inner liner. Lately some new materials have been tested and evaluated, such as Koroyd, but can be expensive due to high material and manufacturing cost. Baering stated that a less expensive material should be used, as a result from the previous project.

3.8.2.1 EPS

EPS is the most commonly used liner due to its good shock absorbing properties, low cost and ease of manufacture. The liner is compressed and permanently deformed when absorbing even a low impact. The EPP and helmet is therefore disposed of after the impact (Caswell, Gould, & Wiggins, 2007). A lower density EPS has the properties to be softer and lighter but does not protect against high impacts. While a higher density has higher weight, it can protect against bigger impacts with a thinner liner. Some helmets today has a combined EPS density line, which means that they have one high density EPS together with one lower density EPS to create a helmet that can protect the wearer against a wider variety of impacts.

3.8.2.2 EPP

Almost the same as EPS foams, the big difference is that the EPP does not deform permanently in smaller impacts, which makes it possible for the helmet to withstand multiple impacts. The EPP is also a bit more expensive than the EPS (Granta Design Limited, 2014). In a low impact, the EPP material will compress to absorb the impact but returns to its original shape. In a high impact, the EPP will act more as EPS and deform a bit and almost return to its original shape. These kinds of liners are typically used in hockey helmets, due to repetitive impacts. Because the EPP does not crush during impact, less impact force can be absorbed and a higher density or thicker liner is needed for a higher demanding standard (Shuaeib F., Hamouda, Wong, Umar, & Ahmed, 2007).

3.8.2.3 EVA

EVA foam liner is also known as a soft foam liner. These kinds of liners usually does not meet the specific requirements for a typical helmet according to Nina Faile's research for Creative Commons (Faile, 2011). This foam is usually combined with a hard plastic outer shell and thus a comfortable helmet with bearable protection against smaller impacts.

3.8.3 Inner liner and shell combination

According to the design requirements, a multi impact liner is preferred. The material choice was therefore EPP. EPP is a bit harder to calculate compared to a standard EPS density calculations, due to that EPP stress-strain behaviour can be divided into three regions, linear elasticity, non-linear elasticity and densification. In a research paper conducted by F.M Shuaeib et al. (2007), a finite element simulations of drop tests was performed, with different EPP densities together with different thickness and varying ABS plastic thicknesses. According to Shuaeib, the optimal helmet design would be EPP 55 kg/m³ with 15mm foam thickness and a 5mm ABS shell thickness. Table 5 shows different densities combined with different shell thickness, foam thickness and the resulting peak-acceleration(Shuaeib F. , Hamouda, Wong, Umar, & Ahmed, 2007).

Table 5: Peak acceleration as a function of shell and liner properties.

Densities	Foam thickness	Shell thickness	Peak-acceleration
55	20	4	235
65	25	4	540
45	20	5	223
45	25	4	204
65	15	4	296
55	20	4	235
55	25	3	221
65	20	3	245
55	15	3	282
55	15	5	266
45	20	3	220
55	25	5	224
45	15	4	280
55	20	4	235
65	20	5	254

One important factor that SSRS personnel have been repeating is the weight, which is mainly determined by the outer shell. Shuaib mentioned in the paper that the thickness of the shell has a small effect on the peak acceleration. The thickness is mainly decided from the penetration resistance requirements (Shuaeib F. , Hamouda, Wong, Umar, & Ahmed, 2007). The shell should therefore be as thin as possible without compromising the penetration resistance requirement.

3.9 Manufacturing

The methods presented are those more relevant when developing a helmet. The method, pros and cons of each method and design recommendations are described.

3.9.1 Injection moulding

- High tooling cost
- Low unit cost
- Suitable for high volume mass production
- High surface finish
- Highly repeatable process
- Cycle time 30-60 sec
- Almost all thermoplastic materials
-

The injection moulding process requires an injection moulding machine, raw plastic material and mould/moulds. Injection moulding according to CES EduPack is most beneficial when the annual quantity is at least 10 000 units per year.

The raw plastic material is melted in the injection forming machine and then injected into the mould, where the raw plastic material cools down and solidifies into the final product. See Figure 12, which illustrates the process in more detail. (Granta Design Limited, 2014)

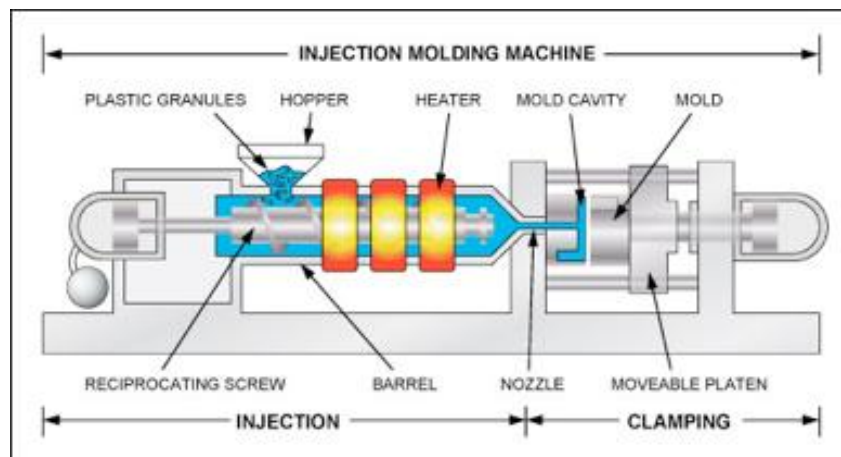


Figure 12. Process of injection moulding. [10]

General tips when designing for injection moulding, a uniform wall thickness throughout the part can minimize the sinking, warping, residual stresses and cycle times. Another tip is to use generous radius at all corners, provide draft on the part for easy removal and ease of closing and opening the moulds. The use of ribs, improves part stiffness in bending, this to avoid thick sections to achieve the same. This also saves weight, material costs and cycle time costs of the part (Custompart.Net, 2009).

3.9.2 Thermoforming

- Low tooling costs
- Moderate unit costs
- Good surface finish
- Good for prototype making and low volume productions
- Tolerance of 0,4 %
- Good with ABS, PS

A manufacturing method where a plastic sheet is heated and then formed into a specific mould(Granta Design Limited, 2014). Thus only controlling the side that touches the mould surface.

There are two main thermoforming methods used, the first and cheaper method is vacuum forming and the second method is high pressure-forming. The key advantages of using thermoforming is that it is cost-effective, low tooling cost, short lead time and the ability to create large parts(Lesko, 2008). Cost effective in a production with an annual quantity of 250-3000units (Productive Plastics, Inc, 2014). One of the biggest disadvantages is that the thickness of the part is hard to control.

The cost is mostly dependent on what type of mould used and if the process is automated or not. There are positive and negative moulds where the positive mould is used for a better surface finish on the inside while the negative mould is used for a better finish on the outside surface.

3.9.2.1 Vacuum forming

Vacuum forming is the cheap and simplified version of thermoforming. The extruded plastic sheet is heated until the plastic is softened, then pressed against a 3D mould by vacuuming out the air between the plastic sheet and mould. Once the desired shape is achieved, the plastic is cooled and finally released from the mould. See Figure 13for an illustration of the vacuum moulding process(Lesko, 2008).

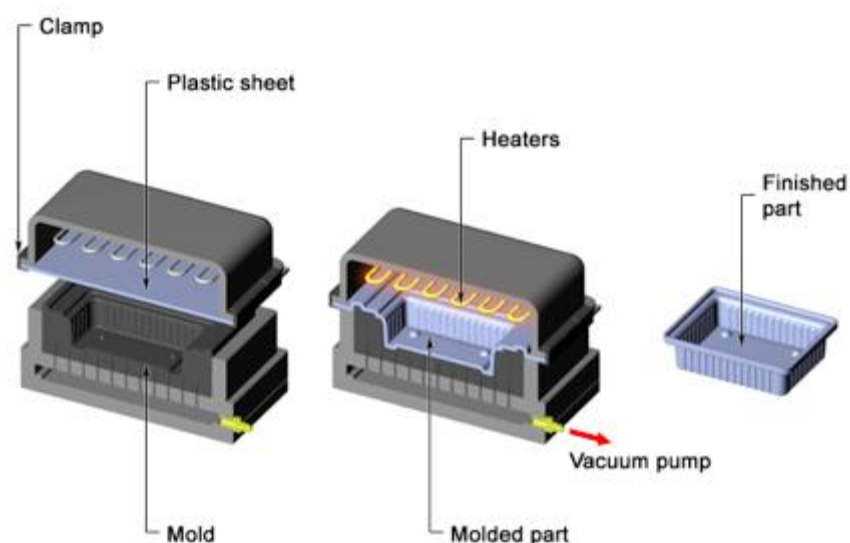


Figure 13. Process of vacuum forming. [11]

3.9.2.2 Pressure forming

Air pressure is used on the back side of the heated plastic sheet to assist the vacuum process to force it to the mould. See Figure 14 for an illustration of the pressure forming process. The air pressure is usually between 50 psi up to 100 psi. The additional force makes it possible to form thicker sheets and achieve finer detail, textures, and sharp corners, on the surface facing the mould. The final product quality is very similar to an injection moulded part. Thus making pressure forming an alternative to injection moulding when the annual production quantities are under 10 000 units (Productive Plastics, Inc, 2014).

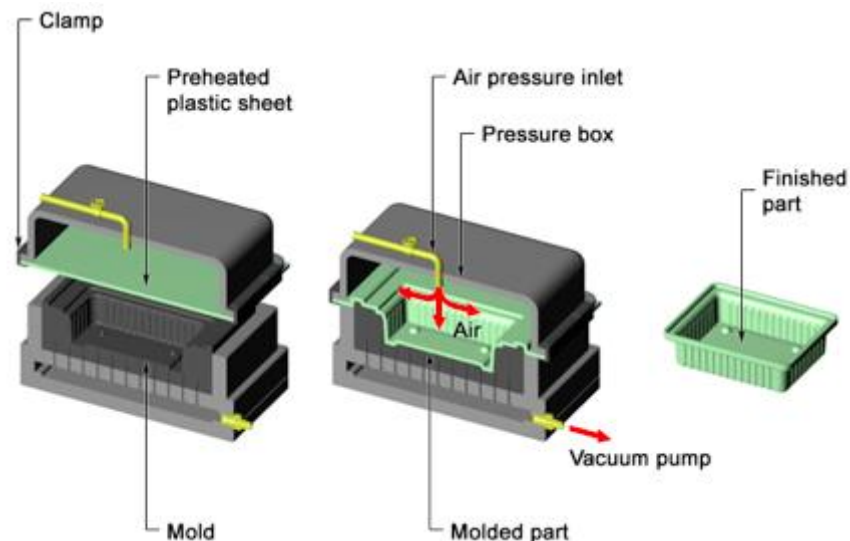


Figure 14. Process of pressure forming. [12]

3.9.2.3 Design recommendations

Peter Ljungberg from WETA-plast and Michael Gryvik from Arla-plast were contacted for a short phone interview regarding thermoforming recommendations. Questions regarding design that can facilitate a good thermoformed result were asked. Michael Gryvik mentioned a PDF document, *A Vacuum Forming Guide*, (Formech International Ltd, 2010), where it states several thermoforming recommendations and tips on moulding. An extract of the recommendations and tips are listed below:

- Hygroscopic materials, ABS or PC, needs to be pre-dried. The material placed in a dryer and heated to the specific temperature during a specific time. Time and temperature depends on material choice.
- The wall thickness can differ. To accommodate this, the sheet can be pre-stretched right before the vacuum is turned on.
- A more expensive but more efficient way to control the thickness is to use a plug assist. A female and assisted male mould is used in combination, to cool the areas where most stretching would occur.
- Undercuts are possible, but increases the tooling cost.
- Big draft angles on the moulds edges for ease of release.
- Labour-intensive process, the mould needs good surface finish.

3.9.3 Expanded foam moulding

EPS and EPP are very similar materials when manufacturing. EPS and EPP foams are currently dominating the market, due to its good performance and lightweight properties. The manufacturing cost is low for large production quantities. The EPP and EPS consist of plastic cells that are bonded together in the desired shape. Foam helmets are generally made by expanded foam moulding.

There are two stages in the moulding process. It starts with solid polymer granules that are first softened and expanded by steam-heating under a small pressure. The softened granules are then transferred to an aluminium mould where the particles are steam heated at a higher pressure, making the particles expand to 20 or more times their original volume, fusing the particles and reshaping to the moulds design, Figure 15 shows an example of the process(Granta Design Limited, 2014). A typical mould for an EPP helmet liner has a core and cavity and the gap between them defines the shape of the helmet. The core is generally hemispherical in shape and configured to roughly match the shape of a human head.

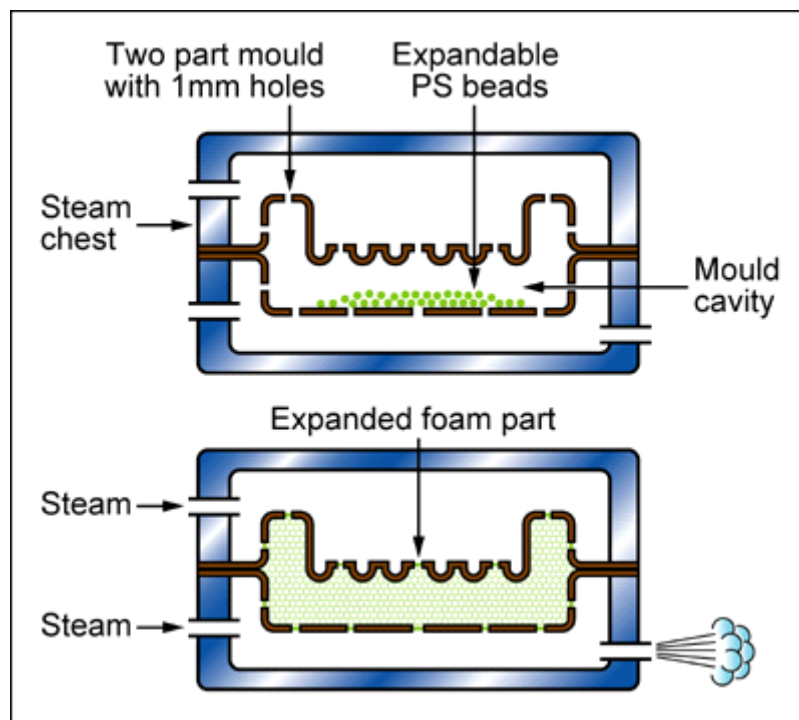


Figure 15. Expanded foam moulding process. [13]

A problem encountered in manufacturing of EPP helmets is how to include complex shapes such as cut outs and holes for fasteners and ventilation in the moulding process. A method that is used for forming holes in EPP helmets is to cut the holes after moulding process with a hot knife or wire. The principal disadvantage to this procedure is that it can be extremely messy due to the EPP accumulating on the knife and around the workstation where the cutting is performed.

Another attempt made to efficiently mould holes into EPP helmets is to employ “sliding” core in which there are movable projection in the core, which correspond in size to the holes to be formed in the helmet. When moulding the helmet the projections are inserted into the void between the core and cavity before the beads are introduced into the mould. After the part

cools, the projections are retracted into the core before the core and the cavity are separated(Kask Helmets, 2013).

3.10 Assembly methods

Creating a hard-shell helmet, the outer shell and inner liner are manufactured separately and assembled together after the manufacturing process with a bonding agent. The outer shell and inner liner is bonded with adhesives or tape which depends on the construction and material choice. Jens Grunwald from ARPRO was contacted and consulted regarding bonding of EPP, in return he sent us a list of adhesives, see Appendix G. Peter Andersson from Industrisupport was contacted to further understand which type of bonding method best suited for each application. Andersson mentioned three main types: spray adhesive, double-sided adhesive and two-component glue.

3.10.1 Spray Adhesive

Peter Andersson talked about spray adhesives such as Spray 77 from 3M, when bonding light foams and fabrics. Even though Jens Grunwald from never mentioned spray adhesives, Peter thought that bonding fabrics was best done by spraying, due to its ease of applying and low weight without damaging the foam.

3.10.1.1 Double-sided adhesive

Peter also mentioned VHB tape, a double-sided adhesive, for a more flexible bond and good enough strength for a helmet. Peter thought that the VHB tape would be very efficient due to its small thickness and very good flexibility. The VHB tape does not affect the material properties and creates a bond that makes the outer shell and inner liner work as one when flexing.

3.10.1.2 Two component glue

For a stronger bond than VHB tape but still flexible, Peter thought that the rubber modified two component epoxy, DP-8010, could be an option. This bonding method also had a high chance of melting the surface of the foam, increasing the stiffness. The two component epoxy was also the most expensive choice with the smallest area treated per cost.

3.10.2 Fasteners

Screws and nuts are a way to mount retention systems, chinstrap and other external components, with the needed of stability and strength for the fastening. There are several ways to mount but the most common way is to have metal inserts placed on the helmet. The metal inserts can be moulded in place directly during the manufacturing process or inserted by using ultrasonic welding. The easiest ways are by forcing the inserts to place and or gluing them after the manufacturing process.

The materials of both the screw and insert can be made of aluminium, steel, titanium or some cases plastic.

3.10.3 External components

There are several different external helmet products, cameras, lights and other performance enhancing products. Every brand usually has its own mounting solution, some use adhesives, straps or other means. There are military helmets such as Ops-core that has the option of using

a multi-functional mount, which can attach a wide variety of external mounts. Figure 16 shows different configurations of the OPS-Core with an ACH-ARC rail.



Figure 16. OPS Core helmet in different configurations. [14]

3.10.3.1 ACH-ARC rail

The ACH-ARC rail is a mount solution for the standard issue Advanced Combat Helmet (ACH). The rail uses the existing chinstrap mounting holes for securely fitting it to the shell. The ACH-ARC rail uses external mounts to mount a wide variety of mission specific accessories to their helmet, such as lights, cameras, O2 masks and other performance equipment. The ACH-ARC rail is a sliding rail with integrated locking positions. Two component adapters are needed to connect to external mounts. The first main component is the Picatinny adapter that also works as a sliding rail with locking positions. The second main component is a Wing-Loc adapter with three screw holes, which gives the user the option of screwing on any component. Figure 17 shows the ACH-ARC rail and the two main components (OPS-Core Inc, 2014).



Figure 17. ACH-ARC rail. [15]

A big issue with the ACH-ARC rail is that the rail itself protrudes from the helmet and needs a Picatinny or a Wing-Loc to mount components which makes the component protrude even more from the surface of the helmet, according to Per-Magnus Grönlund and Marcus Johnson from SAR Norrtälje.

3.10.3.2 Picatinny Mount

Another helmet used in the military market is the Pro-Tec A-bravo helmet, that has a mounting area for a picatinny mount, see Figure 18.



Figure 18. PT Bravo helmet with Picatinny mount. [16]

The Picatinny rail is a standard mounting platform for accessories and attachments. The picatinny rail was first designed to fit scopes but since its popularity, several other accessories have been designed with the same interface such as, lights, cameras and other attachments(Military & Rescue supply). Figure 19 shows the picatinny rail.



Figure 19. Picatinny rail. [17]

The picatinny rail is constructed with a T-shaped cross section with a combination of flat areas. Accessories are mounted by either sliding them on from one end and then locked with bolts, levers or thumbscrews onto the slots between the raised sections.

3.10.3.3 Commercial mounts

The mounting possibilities depends on the component and its mounting accessory. Common methods are adhesives and straps. The GoPro camera can be mounted using adhesives widely used by both SAR and SSRS, see Figure 20. The mount uses industrial strength, waterproof adhesives. The adhesive is easily attached on a cleaned surface on the helmet. The mount is available in two profiles, curved and flat.



Figure 20. Different mounts for GoPro cameras. [18]

Another method used is straps. The mount is connected with a strap that goes around the helmet vent holes to secure the system, see Figure 21. This method can be somewhat unstable if the design promotes the use of straps or not.



Figure 21. Bicycle helmet with strap-mounted lights. [19]

Velcro straps is an alternative mounting option used in military applications as well as SAR and SSRS.

4 IMPLEMENTATION

This chapter describes the execution phase of the project and how the methods and conclusions from the pre-study were implemented.

4.1 Evaluation of Y1

The Y1 concept was evaluated together with rescue workers from SAR and SSRS.

4.1.1 Workshop with SAR

The workshop was held at Brinellvägen 85, Stockholm, KTH on 18 February. The workshop started with a quick summary about the Y1 helmet and the project goal for the thesis work. Both users had the chance to try and further inspect the Y1 helmet and during that time discuss anything that came to mind. Some of the key feedback that was received throughout the workshop was:

- Possible to fit different types of goggles
- Customizable
- Create a flush camera mount (Prevent the winch from attaching to the camera)
- A camera mount that can fit all
- Easy to push on and off with thick gloves
- Possible to integrate the snorkel
- A semi-integrated position light, with changeable cover for different light colours
- a bit long at the back, ends to close to the neck.
- Be sure to have the gravitational point on the centre of the helmet

See Appendix H for complete Y1 evaluation/ feedback.

4.1.2 Workshop with SSRS

An interview was carried out with SSRS members Mats Ryde, Thore Hagman and Fredrik Falkman, who had been involved in developing, selecting and evaluating safety equipment for SSRS. The purpose of the interview was to get a better understanding of the work involved in rescue operations and what they demand of their equipment, focusing on head protection. The interview took place on 6 March at SSRS headquarters on Talattagatan 24, Västra Frölunda, Gothenburg.



Figure 22. At SSRS headquarters with Fredrik Falkman and Mats Ryde, to the right.

The Y1 concept developed in the MF2061 project was presented and used as reference for the interview and discussions. The interview led to the following insights regarding head protection and their expectations:

- The weight is the most important performance criteria. The base helmet must weigh no more than 400-600 grams.
- Durable and designed for multiple impacts rather than singular high impact scenarios. The outer shell should be made of a material that would allow making holes for mounting components.
- SSRS prefers modular design over integrated features - loose one function and you need to dispose of the helmet. Mounts needed for position light, communication, and visor. The position light must be mounted on the top so that it is visible from all sides. Would like to have a visor that can be mounted in mid position, acting as a sun screen. It is exhausting for the eyes to constantly have to re-focus when looking through a visor covered in water droplets.
- User friendliness is of essence when performing volunteer work. It should take no longer than two hours to clean the helmet after each mission from saltwater and dirt. No special training should be required to use the helmet to its fullest potential. All functions, buttons etc., need to be self explanatory and accessible even with thick neoprene gloves.
- Larger sizes needed. 62cm in circumference is often the largest available size. Since the head never stops growing it would be great with a 63-64cm size.

SSRS also presented a communication system that they had co-developed with Peltor, named the Rescue kit, as seen in Figure 23. The system is fully submersible in saltwater, according to IP-68 standard, and features two helmet mounted speakers and a microphone. The transmitter is separately mounted on the chest of the user to minimize the total weight of the helmet.



Figure 23. Peltor Rescue-kit, speaker and microphone.

4.1.3 SWOT-analysis of Y1

Every strength, weakness, opportunity and threat of the Y1 helmet was added into a S.W.O.T. chart, for further development of the new R1 helmet. See Table 6.

Table 6: SWOT-analysis of Y1 concept.

Strength	Weakness
<ul style="list-style-type: none"> • Removable ear section • Integrated position light • Low weight, composite shell • Easy to wear, adjustable size • Possibility to integrate communication • Possible to attach rail mounts • Flush mounts 	<ul style="list-style-type: none"> • Weak area where the retention system fastens • Critical area where the rail mounts attaches • Hard to manufacture with standard methods • Hard to integrate lights with right IP standards • Not enough protection at the ear section • Sizing does not follow EN 960 standard • Specific mounts needed
Opportunity	Threat
<ul style="list-style-type: none"> • Can be used in other markets such as military/ coast guard, forest work, rafting and airborne sports • Possibility to manufacture mounts to meet the users´ needs • Partnership with a communication firm to fully integrate it with the helmet 	<ul style="list-style-type: none"> • The inner liner is too thin to meet the requirements • Too expensive to manufacture due to small market and expensive material • Competitors can sell cheaper with a wider range of components possibilities

4.2 Design requirements

Before the ideation process could start, a design requirement list was created of needs, demands and X-factor. An X-factor is referred to as an innovative feature that would place the product ahead of the competition. The design requirement list was carried over from the previous project MF2061, the PAS 028 guidelines and the Y1 evaluation conducted in this thesis project. For the complete design requirement list, see Appendix I. The bullet list below is an extract from the complete design requirement list:

- Lightweight
- Balanced weight
- Ergonomic fit, suitable for people with bigger head sizes

- Prevent wires from interfering with components on the helmet
- Possible to fit desired components, such as lights, camera, eye protection and intercom-system
- Being able to interchange components
- Withstand multiple impacts
- Optimized for marine application
- There must be room on the front of the helmet for resting goggles or folding up a visor.
- The placement of the ventilation holes that are used for mounting components need to be carefully considered.
- Components such as cameras and working lights need to be positioned in a similar angle as the field of view.
- The position light needs to be placed making it visible 360 degrees and from above
- PAS-028 standard states that the helmet must not have sharp edges or shapes extruding more than 5mm.
- The mounting points should look indistinguishable when no components are attached.

Additional required and desired functions for eye protection:

- Protect the user from harsh wind and water
- See clearer during bad weather
- Misdirect water and debris from head
- Good optics quality material
- Piecewise adjustment (step by step)
- Possible for the user to take it off easily or remove it from the eye of sight
- One-third visor, beneficial against sunlight
- Easy to clip on to the helmet
- Low weight
- Short so that it does not get in the way of snorkel or mouth protection

4.2.1 Interview with Mikael Swarén

Baering had started a relationship with Peak Innovation, a firm that helps new business with company relations. One of the new contacts was with Mid Sweden University. The test facility at Mid Sweden University specializes in testing special fabrics. A test rig for repeated impacts with slalom poles for POC. Björn Berggren and Linus Wikström, from Baering, arranged a meeting with Mikael Swarén, from Mid Sweden University to talk about the rescue helmet project. Preparations was made before the interview with Swarén, some guideline questions where created. The key finding from the interview:

- SP, Technical research institute of Sweden, can perform testing according to PAS 028.
- Helmet impact scenarios should be analyzed to know if a stiff or more flexible material is needed. Consider how low and high impacts affect the shell.
- One-third visor would be beneficial against sunlight.
- A cut out near the ears so that water can run out during high water pressure, to prevent ear pressure from the water.

The complete questionnaire and Swaréns answers can be seen in Appendix J.

4.2.2 Inner liner thickness

To determine the thickness of the inner liner a simplified calculations was made. According to research papers the shell absorbs up to 30% of the total impact energy. There are also some papers that say that this value can differ up to 8,8% to 13,7 %, depending on shell construction.

The shell properties are excluded in this calculation to find the worst-case scenario for the foam. The impact velocity, given by PAS 028 is used to calculate the thickness. During an impact, the foam has a limit of how much energy it can absorb to prevent the foam to, “bottom out”, reach densification stage during impact. This means that the foam cannot be compressed more than 80% of its thickness(Shuaeib F. , Hamouda, Hamdan, Radin Umar, & M.S.J, 2002). According to PAS 028 the nominal impact energy for rigid mode method is 100J, the force on the helmeted head form shall not exceed 12,5kN. The equation according to Shuaeib research paper to calculate X_{min} , the stopping distance of the impact force,

$$\frac{1}{2}F \times X_{min} = E_k \quad (3)$$

where the kinetic energy is the nominal impact energy, 100 J, putting the rest of the numerical values presented above in Eq. (3), will give $X_{min}=16\text{mm}$, representing 80% of the liner thickness. This gives a nominal thickness of 19,2 mm.

4.3 Material analysis

The results from the competitor analysis was analysed regarding what type of materials used for the outer shell. The more popular materials were further researched, the composite materials were excluded as a single outer shell material due to the need of withstanding multiple impacts. CES EduPack was used as a tool to analyse each material. A material benchmark was conducted from the aspects of cost and shock absorption properties. A separate benchmark was conducted on composite material as a secondary material for added stiffness. See Appendix K for the materials chosen and relevant properties.

The thickness of the shell material is assumed to be 3-4 mm, similar to Manta SAR, Predator Full Cut and conducted research, this is still determined by performing penetration tests.

4.3.1 Material requirements

According to PAS 028, SAR and SSRS a requirement list for the outer shell could be created.

- Low material cost
- Low density
- Flexible shell material, to disperse impact force over a wider area without permanent deformation. High Yield strength and low enough young's modulus and high elongation.
- Stiff enough to withstand penetration impacts. High young's modulus and high hardness - Vickers value.
- High fracture toughness
- High fatigue strength
- High energy absorption property, impact strength.
- Low water absorption properties.

- Good UV properties
- Withstand extreme temperatures
- Good water resistance to salt/fresh water.

The requirements for inner liner are listed below:

- A liner high compressive strength
- Withstand multiple smaller impacts
- Not too rigid foam, soft touch against head

4.3.2 Benchmarking

The evaluation method, Pugh's matrix, was used for choosing the most suited materials for further testing. The materials properties were gathered from CES EduPack and the mean value was calculated for each property to ease the comparison. The criteria's for each grading can be done by using one alternative as a reference, the normality value. The reference alternative will have the total score of zero. In this case, ABS plastic was chosen as the reference, due to the majority of helmets researched uses ABS. Due to ABS plastics poor UV protection and low hardness-Vickers value, a negative score was given on those categories. The ABS plastic also has good water properties and low material cost and therefore given a positive score in those categories. The material properties were graded better, worse or equal to the reference material. A positive score (+) was given when the material was better, neutral score (0) when equal and a negative score (-) when worse than the reference material. The manufacturing cost was assumed to be for 1000 helmets and therefore making injection moulding a high cost per unit. The rest of the thermoplastic materials were assumed to be manufactured through thermoforming. The upper limit for highest young's modulus was set to 12 GPa and elongation at 100%.

According to the Pugh's matrix, the thermoplastics with best scores were Polycarbonate, PC, with a total of 4 and PC/ABS at the second place with the score of 3. See Appendix L for complete material benchmark.

4.3.3 Material sample droptest

To further benchmark the chosen materials as base for selecting the appropriate density, a simple drop test was constructed to test different material combinations for the outer shell and liner, suggested by Mikael Swaren. The test was also performed to better understand the compression behaviour of the liner material, EPP, together with a hard shell.

If the density is too low, the densification zone is reached and a very high force is obtained before the energy has been displaced. But if the density is too high the force exceeds the critical value before energy has been absorbed. Therefore when conducting the sample tests, both the acceleration and the duration of the impact is analysed and evaluated. Eq. (1) is used with Eq.(3) to calculate the failure threshold for the drop test when the drop height is 1 meter and the weight is 1 kg together assuming that the kinetic energy is equal to the potential energy gives us Eq. (4) and (5).

$$E_k = E_p \quad (4)$$

$$F = \frac{m \times g \times h \times 2}{X_{min}} \quad (5)$$

With a maximum compression of 16 mm, X_{min} , will give a failure threshold of 1,22 kN.

Two shell materials and three EPP densities were tested, resulting in 6 test samples in total. The Table 7 defines each material. ABS was excluded from the testing due to enough data already available from the research conducted. The inner liner densities and densities were chosen based on the inner liner calculations and research gathered.

Table 7: Material samples used.

EPP densities	Outer shell material
EPP 40 g	3 mm PC/ABS
EPP 55 g	3 mm PC
EPP 60 g	

4.3.3.1 Droptest

A simple test mechanism was constructed, see Figure 24.



Figure 24. Drop test construction.

The load cell is placed under the materials and the weight is fixed to a wire that guides the fall. The weight falls on to the material where the load cell measures the acceleration. See Figure 25 for the test fixture. A material fixture was created to hold the material sample in place but also guide the force perpendicular to the measuring surface of the load cell to prevent shearing forces. The shearing forces can affect the result that the load cell registers which can result in a higher peak force.

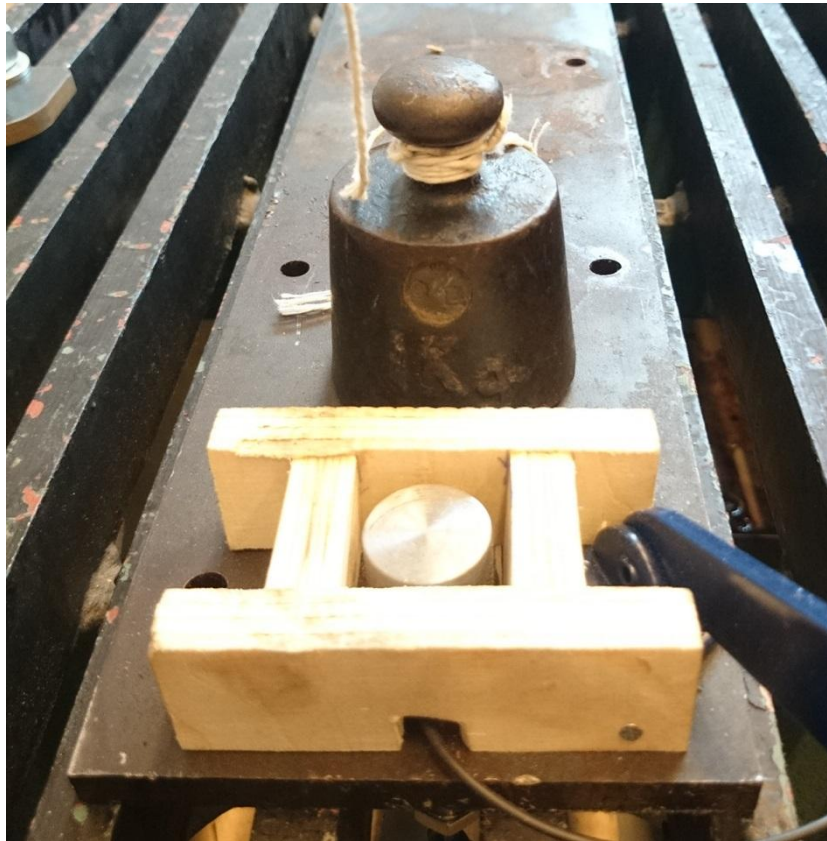


Figure 25. Drop test fixture.

The results for the drop tests for each material sample combination is presented in Table 8.

Table 8: Material drop test results

Material sample	F_{max}
40g + PC	1747
40g + ABS/PC	1197
55g + PC	1344
55g + ABS/PC	1535
60g + PC	1154
60g + ABS/PC	1382

4.4 Concept generation

4.4.1 Brainstorming

A brainstorming was conducted to generate ideas for carrying different systems that are compatible with the several components. The brainstorming session started with a focus on different components and then branched out to solutions. Figure 26 shows a part of the brainstorming result.



Figure 26. Results from brainstorming around component mountings.

4.4.2 Moodboards

In addition to brainstorming a moodboard was conducted. A collection of images was put together to convey a certain mood. Pinterest, Behance Network and other inspirational sites was used to find relevant images. The purpose of the moodboard is to communicate a desired direction for the project, regarding design and function. See Figure 27.

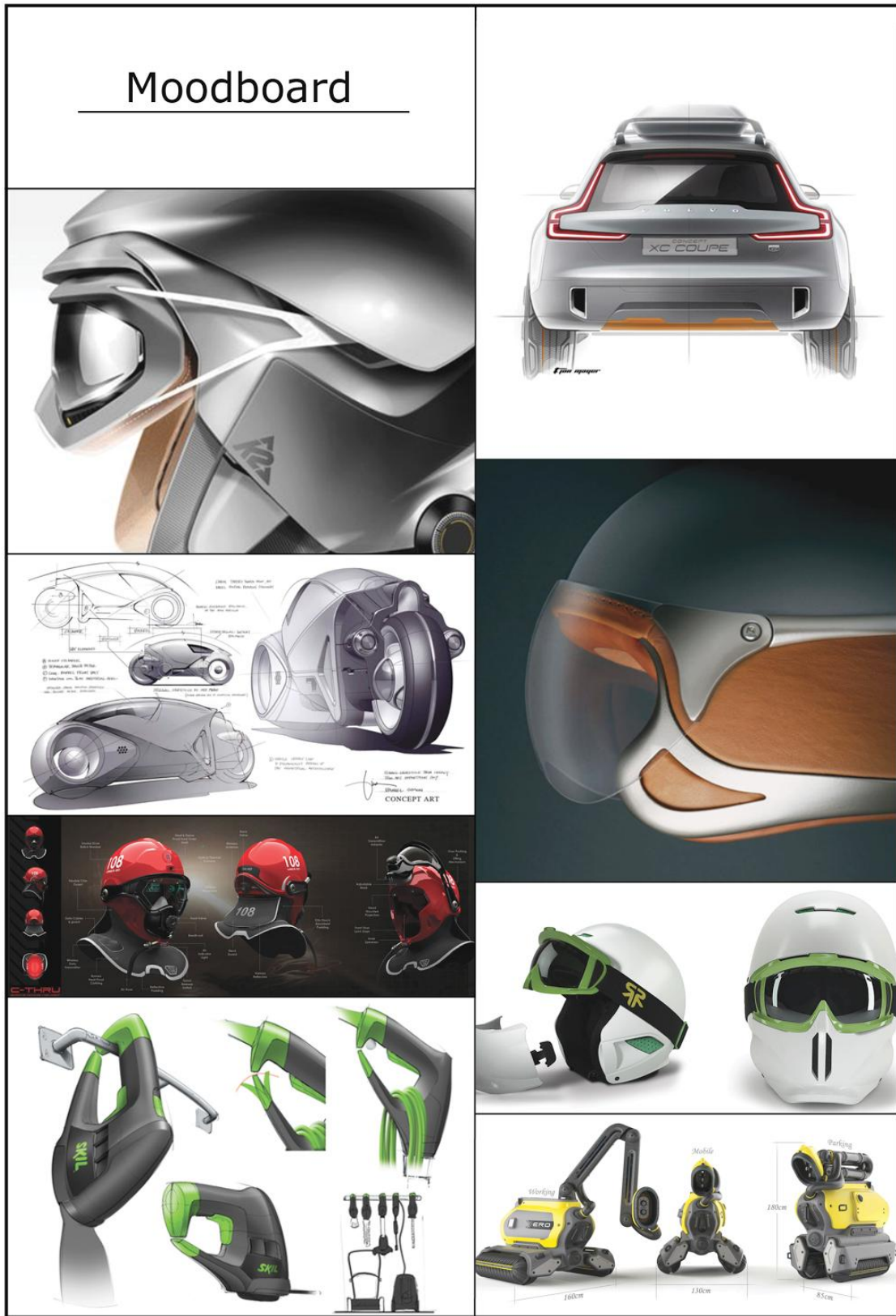


Figure 27. Moodboard for form development. [20]

4.4.3 Speed sketching

Thumbnail sketches of front and side view were created. Highlights and shadows were added to express volume and accent colours were used to mark key components and functions. An underlay of an anthropometric head form with a 20mm liner was used for correct proportions, See Appendix M. The resulting sketches were placed side by side for comparison and scrutiny. The sketches were grouped based on type of solution and form language, see Figure 28.



Figure 28. Speed sketching.

4.4.4 Exploratory sketching

Explorative sketching on top of the main sketches was used to test various solutions and investigate the details of the sketches. See Figure 29.

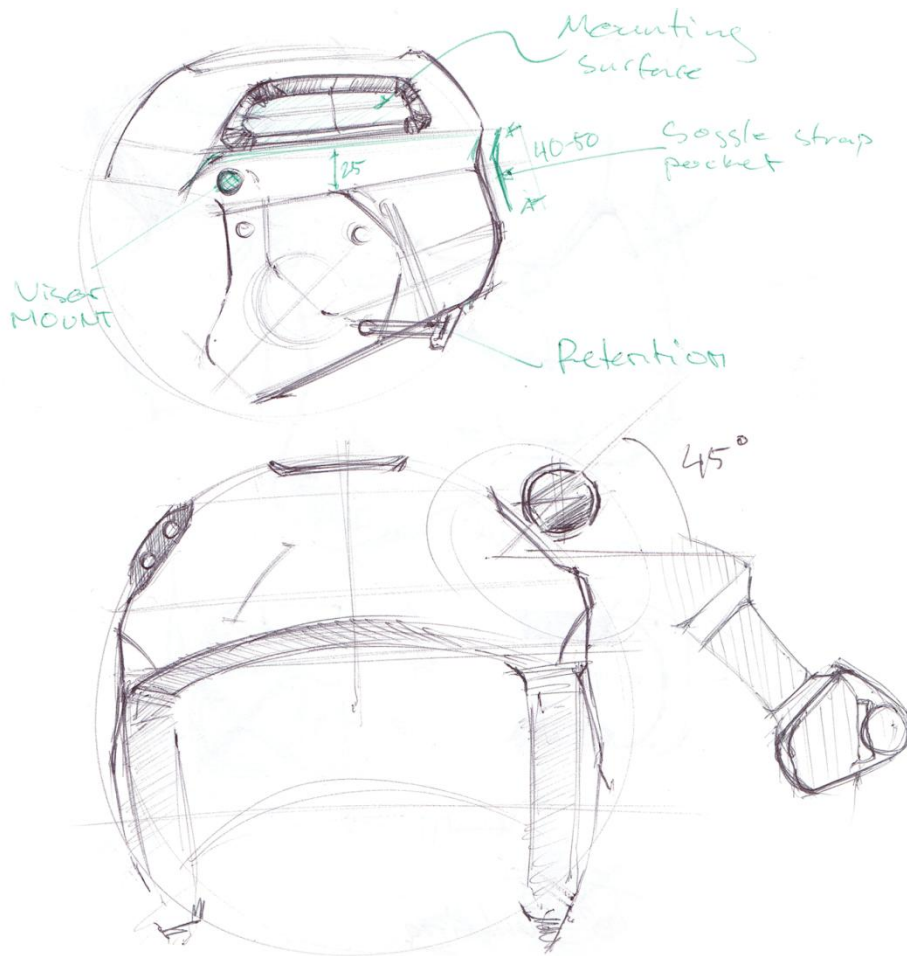


Figure 29. Exploratory sketching focused on function.

4.4.5 Feedback from HOWL design studio

Before the meeting with HOWL design studio, some preparations were conducted for a more detailed guideline over the meeting. The preparations included a guideline over the meeting, step for step on how the meeting should be carried out, sketches were selected for the presentation and questions on topics that needed further understanding were created.

The sketches and concepts were presented at HOWL Studio and feedback was received. The main function of the helmet was established as "the ultimate bearer of components". Furthermore, it was recommended to work with geometric shapes and defined edges to communicate that the helmet is intended for professional use. Considering that the typical working environment for the user being helicopters and high speed boats, it was also suggested that the overall form should express a sense of forward moving motion. See Appendix N for full feedback from the meeting with HOWL design studio.

4.5 Further development

4.5.1 Refined sketching

Three concepts were chosen and further developed based on the feedback given by HOWL. Larger sketches and renderings were created order to explore form and function in detail. More time was invested in defining transitions between different surfaces and materials, Figure 30.

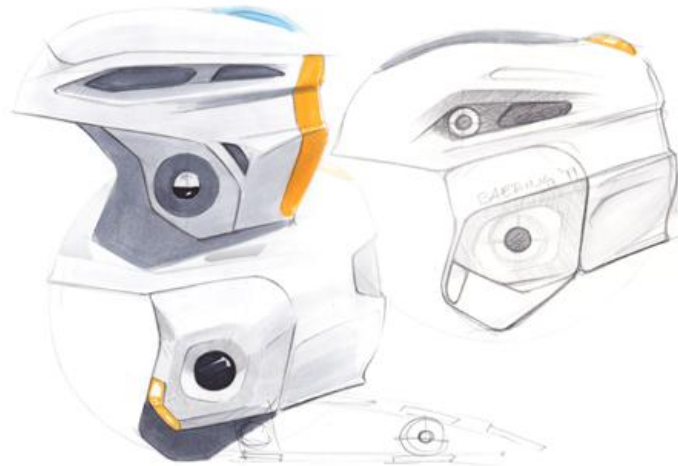


Figure 30. Refined sketches of helmet proportions.

The positioning of different components was further explored at this stage and possible mounting solutions were generated in the periphery, see Figure 31

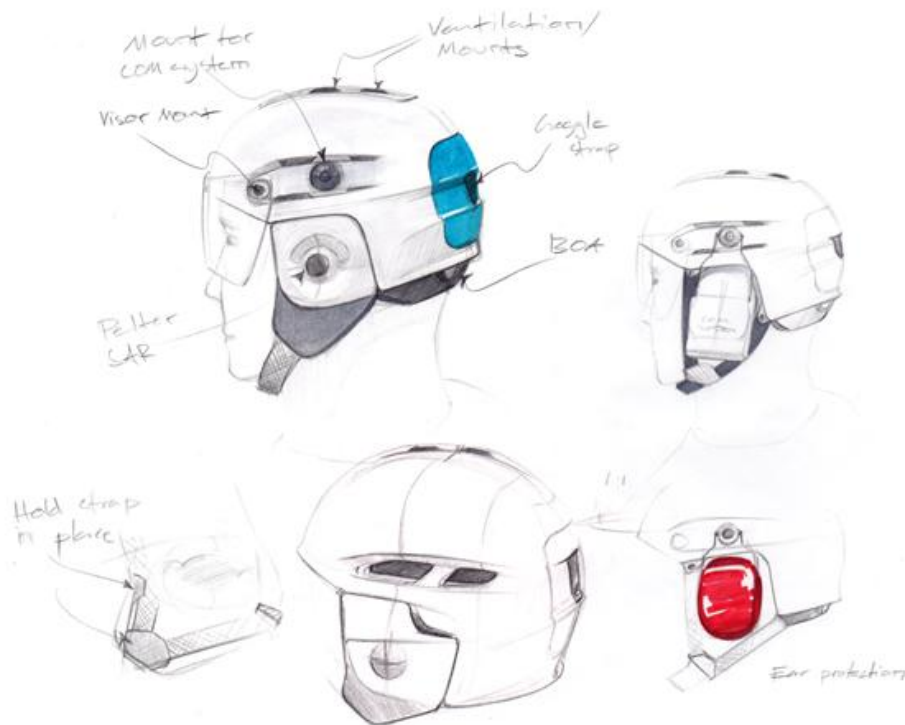


Figure 31. Refined sketches with placement of components.

4.5.2 Mount concepts

It is important that the mount concept for fastening components to the helmet surpasses anything previously known, since it is such a central aspect of the helmet concept.

Current best solution for mounting according to SAR personnel in Norrtälje is the ACH-ARC rail system. ACH-ARC is easily attached to the helmet and has a wide variety of external attachments. The biggest problem with the ACH-ARC rail system is that it protrudes too much from the helmet itself.

The main requirements for the concept generations is:

- Possibility to mount:
Position light, working light, Headlamp, Snorkel, Camera, Goggles/visor, Ear protection, Communication system (Peltor)
- Low weight
- Easy to use
- Rail system so it slides of during high force impact
- Fully customizable
- Few components
- Flush to helmet surface
- Prevent from wires and branches getting stuck
- No screws on to the helmet
- Sturdy construction
- No Adhesives, due to weather conditions and preferences from user group.

Figure 32 shows a part of all the mount sketch.

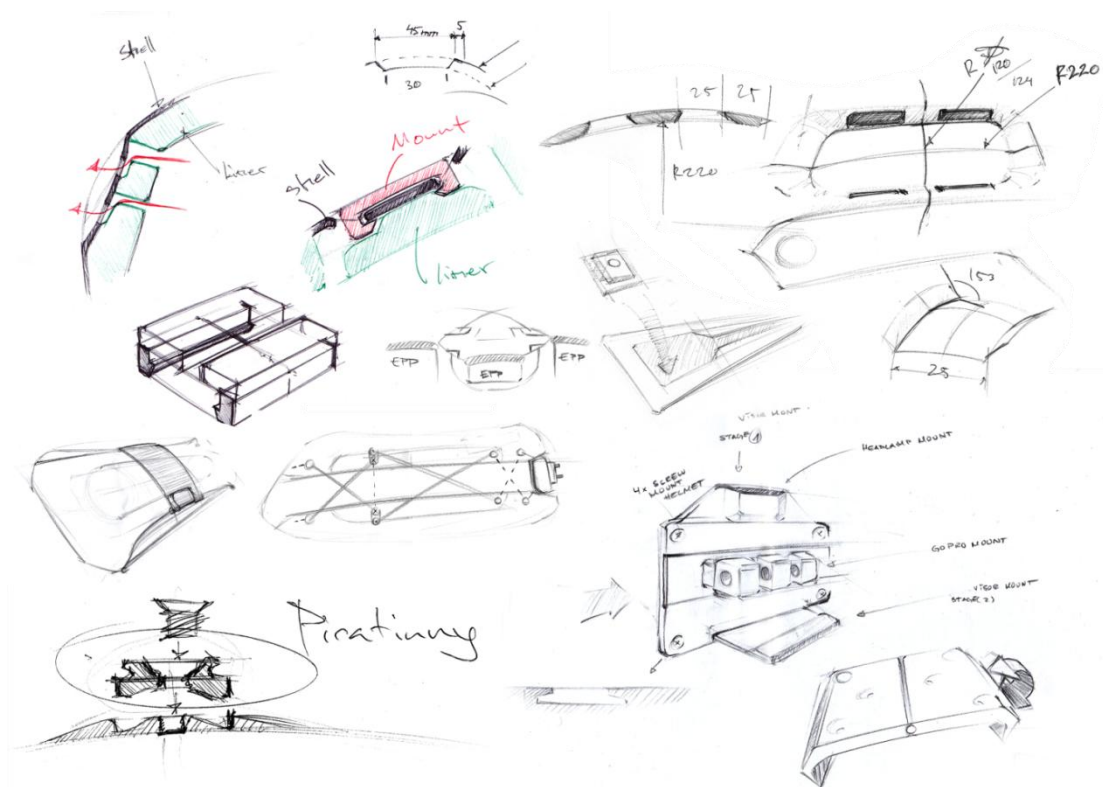


Figure 32. Mount concepts.

4.6 Prototyping

4.6.1 Clay models

In order to further explore form and get a better understanding of volume, 2D sketches were translated into two full size clay models, see Figure 33. CAD models of headforms were created according to EN 960:1995 standard and CNC milled in MDF. The headforms were used as a base on which InDeClay was applied, layer by layer. The headforms had a 15mm offset, representing the inner liner of the helmet. This was done to reduce the amount of clay needed along with sculpting time. The thickness of the clay was controlled in critical area with measuring needles.

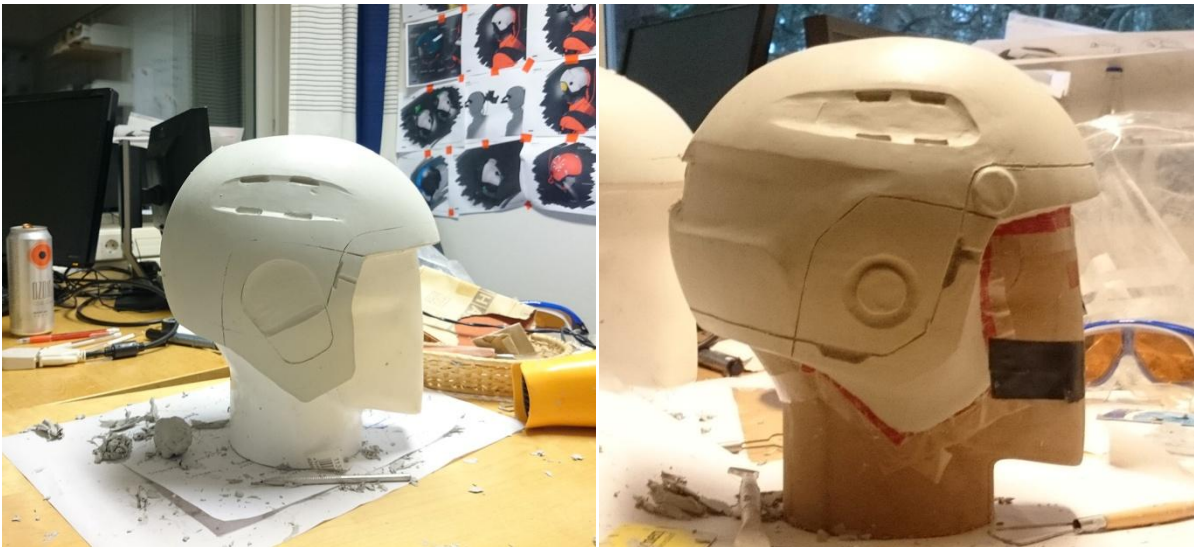


Figure 33. Clay models of two concepts.

4.6.2 Digital prototypes

Two CAD models were created using the same procedure as for the clay models, using them as inspiration. The focus was on ergonomic fit, an EN960:1995 head manikin size J was used as a starting point for adding components, see Figure 34.



Figure 34. CAD model of EN960:1995 head form, size J.

Firstly the comfort pads were added, secondly the inner liner and lastly the outer shell. Once the foundation for the helmet was laid out, the different material combinations were tweaked and features were added.

Modelling the helmets involved advanced surface modelling in Autodesk Inventor and Solidworks, as seen in Figure 35.

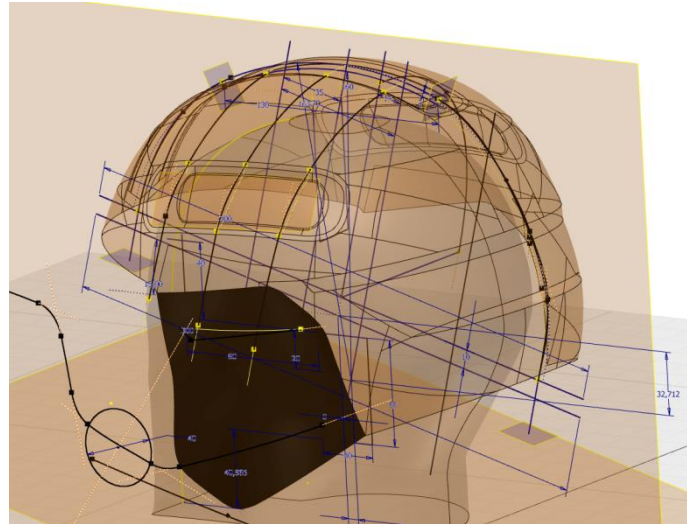


Figure 35. CAD, surface modelling.

The two concepts fulfil the same needs. The main differences between the two are in form language and technical solutions, as is presented below.

4.6.2.1 Form

The essence of Concept 1 is simplicity and low weight. The rounded outer shell of Concept 1, as shown in Figure 36, closely resembles the shape of the head, with the exception of functional areas that are clearly defined with intersecting surfaces and chamfers. According to HOWL, defined function would communicate that the helmet is intended for professional use.



Figure 36. Three quarter front and rear view of Concept1.

The form language of Concept 2 is more dynamic compared to Concept 1, without losing its professional appeal. It features continuous, distinct lines flowing from one side to the other. This gives Concept 2 a sense of movement and forward direction, as seen in Figure 37.

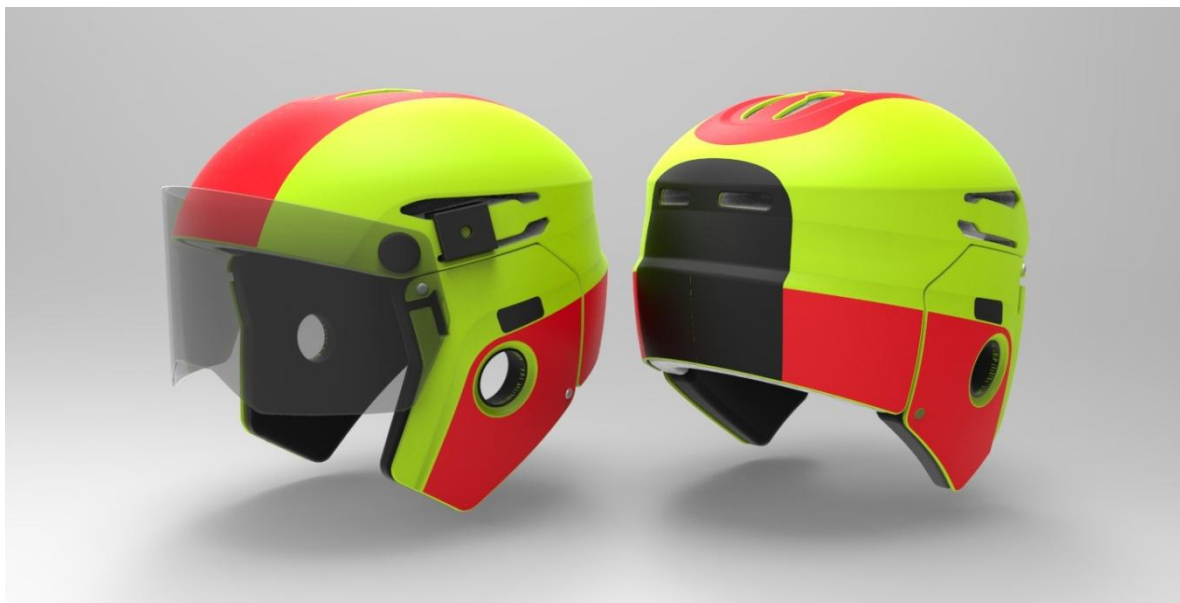


Figure 37. Three quarter front and rear view of Concept 2.

The helmets were rendered in two different high contrast colour combinations; in white, red and black, and yellow red and black. The combinations represent the colours used by SAR and SSRS, respectively.

4.6.2.2 Function - carrier of systems

Both concepts have the same modular approach to additional components, such as work lights and cameras. Based on previously received feedback, it was decided not to integrate any

components that would render the helmet useless if the components fail. The interviews performed during the pre-study also revealed that the same user might have slightly different needs depending on the type of operation. A modular interface enables the user to select components depending on the situation, i.e. add extra light sources if the operation is carried out at night.

Form wise it was desired that the mounting points would look indistinguishable when no components are attached. This was solved by using the same holes for both ventilation and mounting. The difference between the concepts in this aspect is the placement of the mounting surfaces and the connecting interface. The mounts designed for Concept 1 are attached with snap-fits while Concept 2 has mounting rails, as seen in Figure 38.

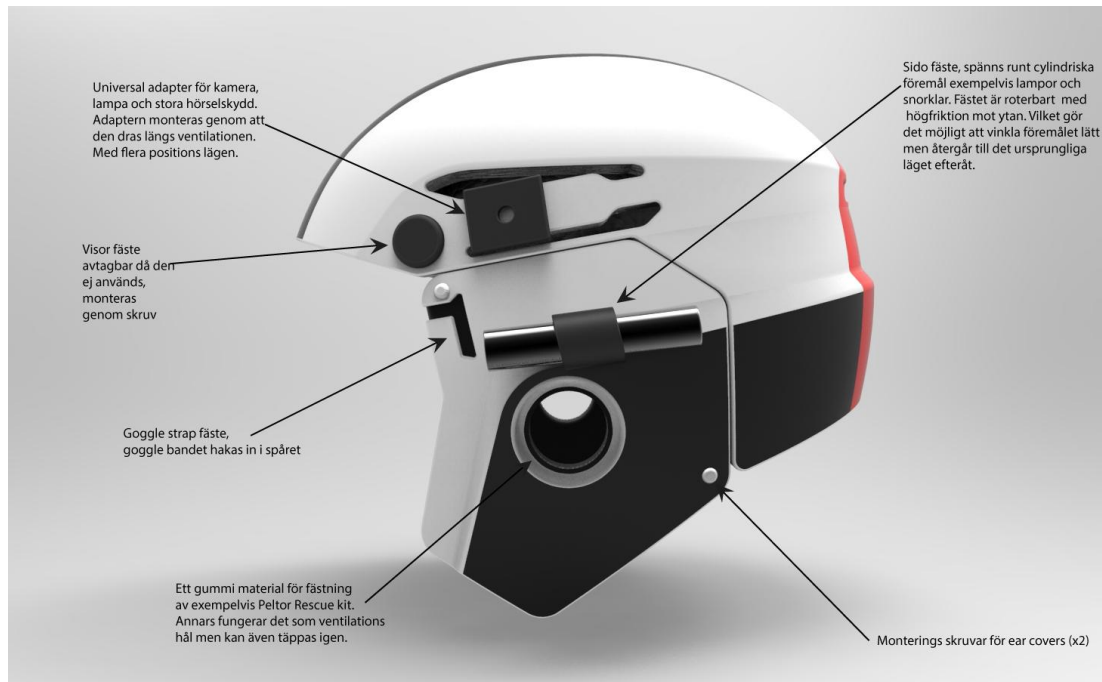


Figure 38. Side view of Concept 2.

Concept 1 attempts to minimize the overall envelope by having lowered surfaces for side ventilation and mounting holes in a 45 degree angle to the vertical. The mounting surfaces on Concept 2 face directly to the sides. This results in a slightly larger envelope but lower centre of gravity when considering the mounted components.

Both concepts feature removable ear covers with attachment points for communication systems, as seen in Figure 39. Goggle straps are also a common feature to prevent the goggles from sliding off the helmet when placed on the front upper part of the helmet.

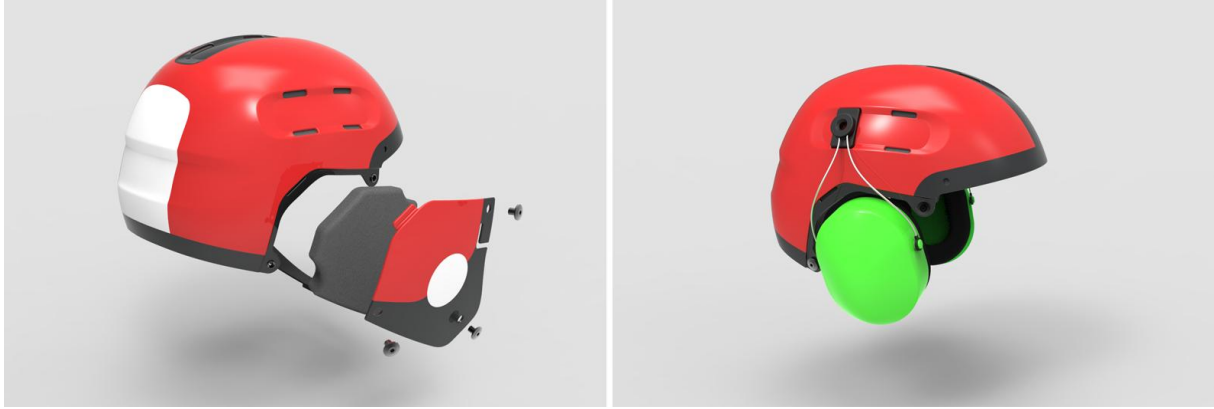


Figure 39. Removable ear covers and mounted third-party hearing protection, to the right.

4.6.2.3 Materials and manufacturing

The intended materials and manufacturing methods are the same for both concepts. PC-ABS is used for the outer shell and EPP as liner material. The estimated weight of the helmets, excluding additional components, are 350g and 450g for Concept 1 and 2, respectively.

4.7 Concept evaluation

SAR, SSRS and HOWL were consulted for feedback on form and features. The concepts were rendered in different views that focuses on features and form language.

4.7.1 SAR

The concepts were presented to Per-Magnus Grönlund and Markus Johnson through mail. Their first impression was that it looked good but was hard to evaluate through pictures, because they mainly wanted to see how the helmet plays along with their chosen added components. Some of the key feedbacks received:

- Concept 2 most aesthetically pleasing
- They prefer a standardized mounting solution, to use existing attachments, similar to ACH-ARC rail.
- They liked the idea of lowered mounting surfaces like the Concept 1, to mount components for a more flush mounting solution
- The goggle cut on the ear section, can be problematic when moving the goggles to the forehead section. They liked the idea of having a goggle clip on the back of the helmet instead
- Good idea to have detachable visor

The complete feedback can be seen in Appendix O.

4.7.2 SSRS

Concept 1 and Concept 2 were presented to Thore Hagman, Mats Ryde and Jens Samuelsson at SSRS. The general direction of mounting accessories on the helmet using universal mounts rather than having them integrated was well received. The importance of minimizing the weight of the helmet with the necessary components, along with having adjustability for different head shapes, was also emphasized. The full feedback that was received is listed below.

- SSRS liked the idea of having removable ear covers and being able to use third party hearing protection. It is important to note that hearing protection cannot rest on the top of the helmet as the height is typically limited inside the helicopter.
- The lowered surface designed to keep the goggle strap in place is a good feature. They would like to complement this with a loop on the back of the helmet that can be snapped over the strap.
- They would greatly prefer a visor over goggles when travelling by boat, as the visor does not fog as easily. The visor does not need to come down lower than regular goggles or glasses. Gath helmets were suggested for inspiration.
- The helmet should not only fit different head sizes, but shapes as well. SSRS have evaluated the OPS Core Fast and PT Bravo helmets. The OPS Core Fast helmet was preferred because of its retention system, making the length and width adjustable.
- Using red reflex tape, or any other colour that differs from the common white and yellow, was recommended to make the rescue workers stand out.
- Jens Samuelsson also informed that there is a need for a rescue helmet in the Icelandic coastguard and the Italian navy. Samuelsson also had access to forum for rescue workers where the concepts could be presented for feedback and discussion.

4.7.3 HOWL

The evaluation occurred through mail conversations. A short technical summary over the findings, regarding material, manufacturing and ideation for each concept together with rendered photos, was sent to Oscar Karlsson at HOWL

As a result of the mail conversation, HOWL decided to give a more extensive feedback. They were impressed and thought that both concepts were good. See Figure 40 for an extract from the feedback.



Figure 40. Feedback from Howl, suggesting reducing the rear overhang.

Concept 2 was the concept closest to Baering's brand expression. They liked the colour contrast, forward moving lines along the sides. The Concept 1 received good feedback on the ear cover section, big rounds and short. The full feedback can be seen in Appendix P.

4.7.4 Baering

The concepts were also presented to Baering, for further feedback. The meeting was kept short and the full feedback is listed below:

- They suggested that a semi-integrated top light, with a Baering logo, would be beneficial.
- The goggle strap hook placed on the ear covers can be problematic, debris can easily interfere.
- A larger market demand is fulfilled with the option of using detachable Ear protection/communication system.
- Short visor is preferred due to its ease of handling.

4.7.5 Concept evaluation

A Pugh's matrix was conducted to benchmark the two concepts with the requirement list as criteria's, to determine which concept to further work on. See

Table 9: Concept evaluation. The Y1 concept, the concept from the higher course project, was chosen as reference. The concepts were given a score depending, if it was better, worse or equal to the reference.

Table 9: Concept evaluation

Properties	Y1	R1 concept 1	R1 Concept 2
Ergonomic fit	0	+	+
Light weight	0	+	+
Balanced weight	0	+	+
Head protection from impact and sliding	0	+	0
No sharp edges, wires to get stuck in	0	+	0
Ventilation (Air and trapped water)	0	+	0
Construction design (stability)	0	+	+
Mounting position light	+	-	-
Mounting work light	0	+	+
Mounting GoPro (most common in their industry)	0	+	+
Mounting Goggles	0	0	0
Mounting Visor	0	+	+
Mounting external ear protectors	0	0	0
Mounting Snorkel	0	0	+
Mount flushness	0	+	-
Customizable	0	+	0
Aesthetics	0	0	+
Number of Equals (0)	17	4	6
Number of Positive score (+)	1	12	9
Number of Negative score (-)	0	1	2
TOTAL	1	11	7

4.8 Further refinement

Based on the feedback received on the two concepts, with benefits to both designs, it was decided to select the most well received features from the two and combine them into one final design.

It was noted that the form language of Concept 2 was preferred and the key elements that gave it a dynamic appearance were carried over.

The mounting solution from Concept 1 was chosen for further development based on the initial feedback from SAR and the risk of components getting entangled in the wire rope. The

shape of the functional surfaces needed refinement to match the shape of the rest of the helmet.

The changes to design were implemented directly in CAD and most of the helmet had to be re-modelled.

4.8.1 Mount concept

Three main ideas that emerged during the exploratory sketching process. Where one is a further development of the ACH-ARC rail system and the second one is a combination of the Y1 mount concept and Picatinny rail system, the last concept is a simplified mount concept.

4.8.1.1 Flush ACH-ARC rail

This mount concept emerged from a conversation with the SAR personnel. The idea is a slimmed and modified ACH-ARC rail that suits the R1 helmet. The concept follows the principles of the ACH-ARC rail but instead of building outwards from the helmet, it uses the existing lowered surfaces on the helmet creating a more flushed profile. The concept is also kept shorter than a standard ACH-ARC rail, due to less components needed. The rail is rotated slightly downwards, following the field of view. Figure 41 shows the flush ACH-ARC rail mounted on the helmet.



Figure 41. ACH-ARC rail concept.

On the back side of the mount four extrusions with cut outs were made, where straps with Velcro are connected, see Figure 42, straps are then wrapped around the inner liner to fully attach the mount to the helmet.



Figure 42. Backside of ACH-ARC rail.

4.8.1.2 Picatinny snap mount

This concept uses the principles of the Y1 Concept, see Figure 43, combined with a picatinny rail.

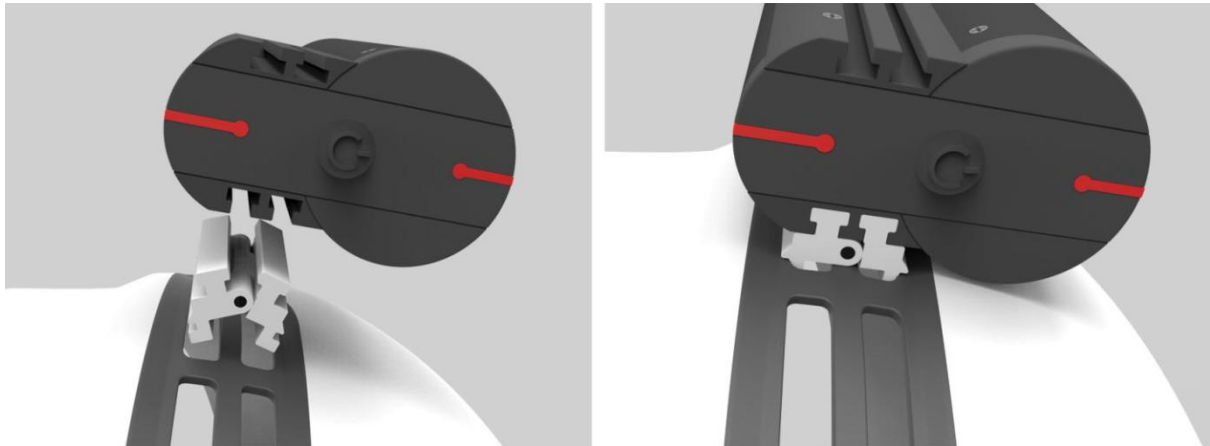


Figure 43. Y1 picatinny mount concept.

The research on mounts showed that the picatinny is widely used. It was noticed that the ACH-ARC rail system was not needed to fulfil the user requirements. The main use of ACH-ARC rail is when using several components together, but the rescue personnel only needs a few. By excluding the ACH-ARC rail from the mount equation the whole system would protrude much less. See Figure 44, a CAD rendering of the Picatinny snap mount.

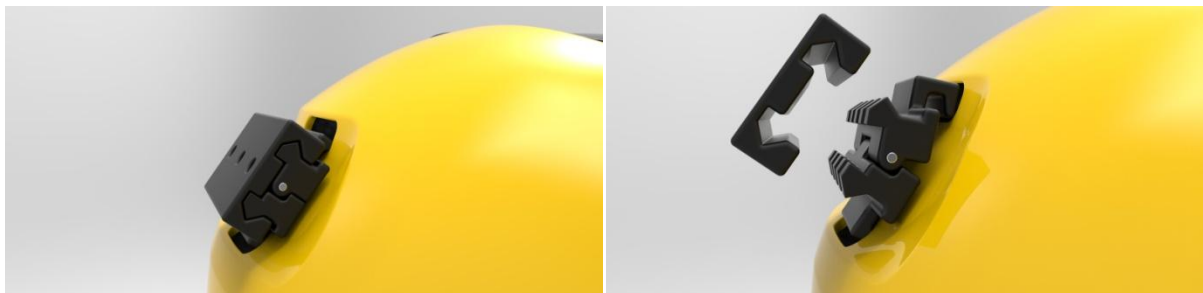


Figure 44. ACH-ARC rail inspired snap mount.

The use of the ventilation holes, like the Y1 Concept, makes the mount use existing helmet features instead of adding additional components such as screws or straps. The adapter consists of parts connected with a hinge in the centre, allowing the feet of the adapter to pass through the ventilation channels. The mount locks, once the components' mount is added by sliding over the rail, and securely attaching the whole system to the outer shell.

4.8.1.3 Flexi snap mount

Same as the picatinny mount, the Flexi snap mount uses existing ventilation holes for attachment. The mount snaps into place by flexing the arms, on to the ventilation holes. The mount has three screw inserts for attaching external components. This results in a component with feet that are constructed as snaps. The snaps are constructed short, detaching from the helmet instead of taking the helmet with it during an impact or interference. The mount relies on the material choice of the construction, the mount should be able to flex enough so that it can mount on the intended position, but not deform after some usage. Figure 45 shows a CAD of the Flexi snap mount.

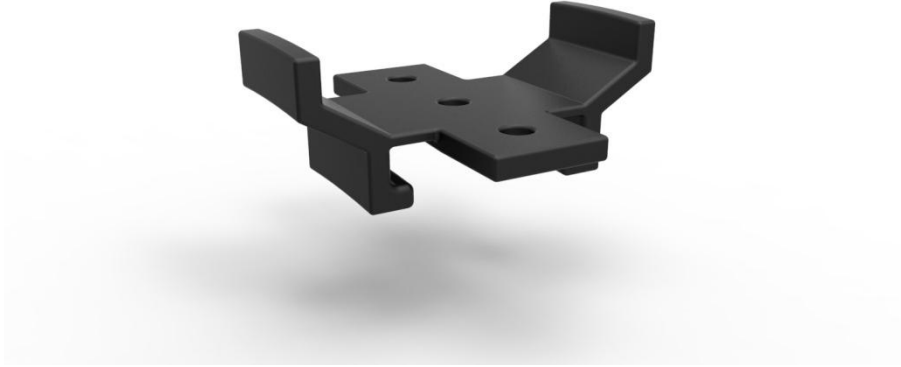


Figure 45. Flexi snap mount.

4.8.1.4 Mount Evaluation

Pugh evaluation method was used to quickly evaluate the different concepts and ACH-ARC rail system was used as the reference alternative. The results are listed in Table 10.

Table 10: Mount evaluation.

Properties	ACH-ARC rail system by OPS-CORE	Flush ACH ARC R1 Helmet	Picatinny Hook mount	Snap Fit Mount
Ergonomic	0	+	+	-
Component stability	0	+	+	+
Weight	0	+	+	+
During Impact	0	+	+	+
Component slides of during impact	0	+	+	-
No sharp edges, wires to get stuck in	0	0	0	-
Mount stability	0	-	+	-
Components mounted at the same time	0	+	-	-
Mounting position light	0	0	+	-
Mounting work light	0	0	0	+
Mounting Camera	0	0	0	+
Mounting external ear protectors	0	-	-	-
Mounting Snorkel	0	0	0	-
Helmet flushness	0	+	-	+
customizable	0	0	-	-
Follows form-language of the helmet	0	0	0	-
Number of Equals (0)	16	7	5	0
Number of Positive score (+)	0	7	7	6
Number of Negative score (-)	0	2	4	10
TOTAL	0	5	3	-4

4.9 MIPS

The initial contact with Peter Halldin, from MIPS was during the previous project, MF2061, where they introduced the system. Howl and Baering thought that MIPS would be beneficial for the R1 helmet, which led to a second meeting during this project.

Some short questions were prepared regarding the production of MIPS, costs and implementation. A secondary goal with the meeting was the hope of setting a date to perform drop tests with the working prototype.

The meeting was held together with Kim Lindblom, technical engineer at MIPS. Lindblom described how the MIPS could be implemented and provided material for creating MIPS prototypes, see Figure 46, that could be cut into the desired shape. No details were revealed about manufacturing costs.

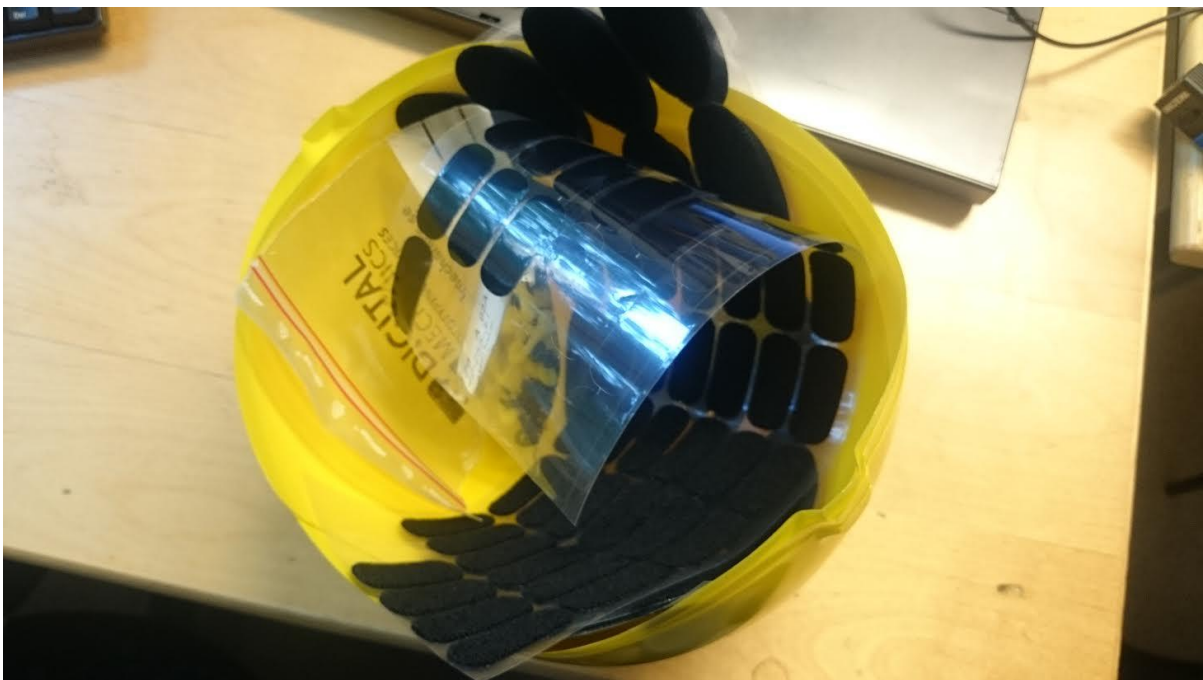


Figure 46. Material for making MIPS prototype.

The MIPS prototypes received are for medium sized helmet. MIPS is made of a low friction polycarbonate with a thickness of 0,7 mm, and is attached to the helmet's liner with small plastic screws, see Figure 47. The screws protrudes 3mm when inserted. This needs to be considered in the design of the inner liner in order to achieve a flush fit.



Figure 47. MIPS silicone attachment plugs.

4.10 Production R1 helmet

A general manufacturing procedure utilized in the industry.

1. Shaping process, the manufacturing of the different components.
2. Finishing process, this process involves removing of excessive material and removing material for the mounting holes, visor and trimming the lower edge for a smooth finish.
3. Painting process, this process also includes material improvements such as protective coatings.
4. Assembly and inspection, during this process the visor, screws, retention system, inner liner and comfort padding are assembled.

The outer shell production is of main focus in the production plan. The manufacturing method and cost for producing the inner liner is assumed as a constant. The method chosen and proven the efficient, cost and production wise, is expanded foam moulding.

The main goal with a production is to achieve an effective and low cost per part production. The materials with the highest score in the material benchmark were PC and PC/ABS. The material choice was therefore chosen to be a 4 mm thick when thermoformed, or 3 mm when injection molded.

As a final evaluation of the product for each manufacturing methods and material choice, a thermoforming production company and an injection moulding company were contacted, to help create a cost analysis of the concept and evaluate the feasibility of the product regarding production. The 3D model together with material choice, thickness, colour and estimated annual quantity was sent to each company.

The two companies were questioned regarding these subjects:

- Design manufacturability
- Mould Cost
- Production Cost / Labour
- Recommendations regarding finishing process and assembly

General feedback

The first thing that the manufacturers pointed out was that the use of PC restricts the use of lacquer and has bad salt-water properties. This would add cost in the production process, due to the need of a more costly coating process, to add chemical and water resistance. The use of PC will also increase the production time due to longer pre-drying time.

They suggested that it would be beneficial to use high impact ABS with UV stabilizers instead. This will be determined by performing penetration tests on the ABS shell. If a better penetration resistant shell is needed an ABS helmet combined with a layer of composite material could be sufficient enough. This would also result in a much lighter helmet with better penetration resistance protection.

4.10.1.1 Manufacturing process

The cost can vary depending on type of manufacturing method and annual quantities. A thumb rule is that bigger quantities lower the cost per component. With SAR, SSRS as customers and Norway as potential customers, it is easy to assume that an annual quantity of 1000 is reasonable.

4.10.1.2 Injection moulding

Anders Gustafsson from AQ Plast did a quick estimation on how much it would cost for an injection moulding production of the shell. Gustafsson spoke with the mould makers at AQ Plast and created a production cost analysis:

Material cost: Low - medium (colour choice)

Manual labour: Low (Granta Design Limited, 2014)

Mouldcost : 140 000 SEK

Hot runner and needle sealer : 30 000 SEK

Testing, transportation, measurements and a 10 % safety margin: 40 000 SEK

This results in a total starting cost of 210 000 SEK. Table 11 shows how much it would cost to produce helmets at different quantities.

Table 11: Selling price per part related to annual quantity

Project number	Annual quantity	Selling price incl. shipping
Helmet 1000	1000	21.4156 SEK
Helmet 10 000	10 000	19.6768 SEK
Helmet 50 000	50 000	17.9095 SEK
Helmet 100 000	100 000	17.2026 SEK
Helmet 200 000	200 000	17.2026 SEK

The cost is calculated according to AQ commission template, which includes material, machine and staff cost assuming that the material cost is 40 SEK/kg.

4.10.1.3 Thermoforming

Ola Listerud, project leader from Formplast was contacted, where they perform both vacuum forming and pressure forming. Listerud suggested that pressure forming or a plug assisted vacuum forming would be better in this type of application. The mould cost for pressure forming was somewhat higher than vacuum forming. The plug assisted thermoforming method is the most expensive method, but also the method that creates a more uniform wall thickness. Listerud performed a production analysis for the pressure forming method and the findings are listed below:

Material cost: Medium to high, extruded plastic

Manual labour: Medium-high (Granta Design Limited, 2014)

Mould cost: 34 000 SEK

CNC fixture: 7500 SEK

Cost per part in a 1000 annual quantity production: 200 SEK

Thermoforming is a more reasonable manufacturing method when the annual quantities are low. The lead cost is lower than injection moulding but much higher cost per finished part. Assuming that the testing, transportation and a 10% safety margin costs 40 000 SEK for thermoforming, same as injection moulding, would results in a total starting cost of 81 500 SEK.

5 RESULTS

The results and final helmet design are presented in this chapter.

5.1 R1 - Rescue One Helmet

The R1 helmet is designed to be the best carrier of systems for rescue workers operating at sea and from air. The R1 features a universal modular mounting system that can carry many different types of accessories, to meet the individual needs of users. The mounting system is designed to have a discreet appearance and blend in naturally with the rest of the helmet. The secondary function of the mounting points is to provide ventilation and allow for trapped water to escape, see Figure 48.



Figure 48. R1 helmet.

5.1.1 Ergonomics

Based on the pre-study and feedback received from both SAR and SSRS, it was decided to have helmets in different sizes, offering great fit, as opposed to one helmet that would provide decent fit across the range.

Four helmet sizes are offered, this is achieved by having two outer shells with different dimensions and two inner liners with adjusted thicknesses per shell size. The sizes range from 52 – 64, where 64 is the size requested by SSRS personnel. The different helmet sizes and head circumference dimensions are listed below. The medium sized helmet weighs 450 grams without external components.

Small - XSmall: 52 - 54cm

Medium: 55 - 57cm

Large: 58 - 60cm

XLarge: 61-64cm

Comfort liner

The comfort liner is created in two different thicknesses. One is thinner with a thickness of 3 mm with the ability to compress to 1-2 mm without any strain against the head. The thicker one has a thickness of 6mm, which can be compressed to 4-5 mm. The thicker comfort liner is used mainly by people that are in-between sizes or wants the added comfort. Comfort pads will also be available for the sides of the helmet. The side comfort pads are attached with Velcro to the retention system.

The material chosen for the comfort liner is flexible LD foam. The foam is covered in CoolMax fabric. Figure 49 shows the comfort pads located on the helmet.



Figure 49. Position of the comfort pad in the helmet

5.1.2 Standards

Based on research on standard and interviews with both SAR and SSRS, it was decided that the R1 helmet should follow the standards listed below:

- PAS 028 - (Marine safety helmet)
- EN 12492: 2012 Helmets for mountaineers
- EN 1385:2012 Helmets for canoeing

Then there are standards that are desirable but tougher to fulfil:

- EN 966: 1996 helmets for airborne sports

Helmets need to be tested according to the desirable helmets standards and compared with the test results performed according to the required standards.

5.2 Helmet components

Each component in the R1 rescue helmet is described and presented. The construction of each part and material choice and some manufacturing possibilities are presented. Figure 50 shows a cross section view of the helmet.

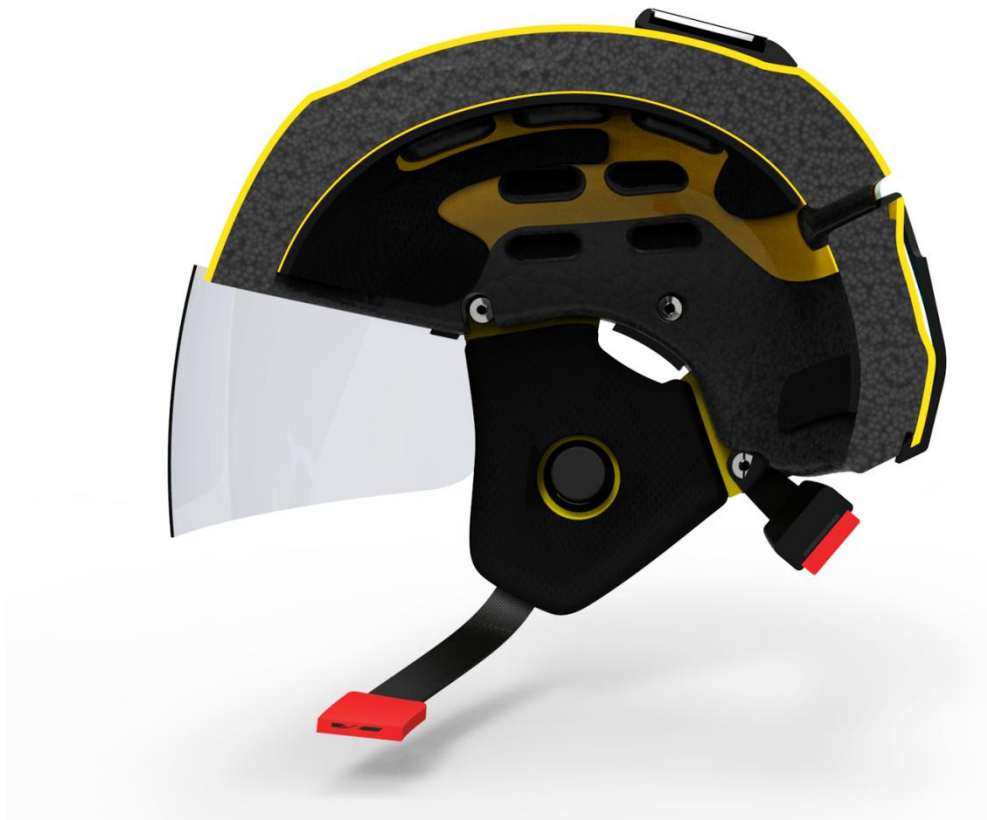


Figure 50. Cross section view of R1 helmet.

5.2.1 Outer shell

The outer shell is one of the essential components in the helmet, it is the first component people see and the first barrier in an impact. Figure 51 shows the outer shell.



Figure 51. Isolated outer shell.

There are three main surfaces for mounting located on the top centre as well as one on either side. The side surfaces are lowered for the intention of bringing the components closer to the body of the helmet and user, reducing the risk of entangling the components in wires, ropes and terrain. The top surface is mainly intended for the required position light as well as forward facing cameras and working lights. The surface is suited for using adhesive or strap mounts. Figure 52 shows a top view of the helmet.



Figure 52. Top view of the helmet.

The side surfaces feature ACH-ARC rail inspired mounts. The rails are dimensioned to allow for mounting two components on either side, such as additional lights or cameras.

Material

The research and benchmark showed that PC/ABS and PC was the most suited for this application. In the further investigation performed together with the manufacturers, it was decided to disregard the choice of using PC due to additional steps required in the manufacturing process, resulting in a relatively cost inefficient solution. This led to two outer shell material options:

The first hand choice is to use a 3 mm ABS with added UV stabilizer, ATECH 3003, see Appendix Q for full material specification. The ABS layer is then combined with a 0,5 mm thin layer of aramid, Kevlar 49 for added penetration resistance. The Kevlar layer wraps around the helmet from crown to the brim of the helmet. To add the extra layer an additional manufacturing process is needed. This solution and production method is more costly than for a PC outer shell, but more cost efficient considering the gains in weight reduction and mechanical properties.

The second material choice, the cheapest option, is a 4 mm PC/ABS with added UV stabilizer, ATECH 5103, see Appendix R for material specifications. The end result will be a thermoformed part with a varying thickness between 3 to 4 mm. The coextruded PC/ABS, consists of a top layer pure ABS and a 50/50 PC/ABS layer.

Considering the manufacturers feedback a 4 mm ATECH 3003 should be tested before choosing this material choices, to see if it passes which would be beneficial. The use of only ABS will lower the cost and weight compared to PC/ABS.

For an annual quantity of 1000 helmet per year, pressure forming was chosen. The preferable option is to use a plug assist or combine with a female mould, for a good uniform wall thickness. The lead production cost is calculated to:

Mould cost: 34 000 SEK

CNC-fixture: 7500 SEK

Material cost, ATECH 51003, PC/ABS, 400x400, 3 mm thick: 43,50 SEK.

The material sheet is pre dried and then vacuum formed. The vacuum formed part is then milled in a 5-axis milling machine to remove the excess material and ventilation holes, this option is optimal to drag down the manual labour hours.

The price per formed part: 200 SEK

A coating layer is added on the bottom side of the extruded sheet, where PC is located. The coating layer is for salt water and scratch resistance. A coated layer is also added on the top side for aesthetic purposes.

5.2.2 Inner liner

The liner is made in expanded polypropylene (EPP) with a density of 45 g/dm³ and 20 g/dm³, for the main liner and ear covers respectively. The research showed that a 19 to 20 mm thick EPP would withstand the requirements according to the standards. The inner liner for R1 follows the minimum thickness of 20 mm and goes up to 25 mm in certain areas.

The outside of the inner liner is designed after the inside of the outer shell with a 0,1 mm offset from the shell, creating space for glue or tape. The ventilation holes are slightly larger than the holes on the outer shell, with a margin of 2 mm, creating space for the mount holders. A 2,5 mm offset inwards on the area where the ear cover is supposedly placed. The cutout is 0,5 mm thinner than the thickness of the ear covers, creating a tight fit. A similar cutout is placed where the goggle strap is connected and near the visor hook. Figure 53 shows the outside of the inner liner.



Figure 53. Outside of the inner liner.

The inside is modelled according to the EN 960 standard. Drop shaped indents are placed on the inside for MIPS connection plugs. Larger cutouts where screws are placed for the retention system placeholders. Figure 54 shows the inside of the inner liner.



Figure 54. The inside of the inner liner.

The EPP is manufactured by expanded foam moulding. The mould is divided into two parts, one for the outside surface and one for the inside of the liner. The ventilation holes are created by hand or machine afterwards by using heat threads to shape after the proposed design. The ultimate solution would be to use a 4-parted mould to include the cutouts and ventilation holes in the moulding process.

5.2.3 Ear covers and chin strap

The final concept features ear covers that provide additional side protection and support. The helmet and ear covers provide a tight fit, even when the chin strap isn't tightly fastened. The centre of the ear cover features a chamfered circular hole designed for mounting the Peltor Rescue kit-system. The foam attached to ear covers is in EPP 20 g/dm³ covered with a thin layer of LD foam and Coolmax fabric for soft touch against the skin.

The top rear edge of the ear cover is trimmed to allow for trapped water to escape and prevent extreme pressure build-up when jumping in the water with feet first.

The ear covers are attached by sliding them in between the liner and shell and then fastened with three screws. Figure 55 shows an exploded view of the liner and ear cover.



Figure 55. Exploded view of the liner and ear cover.

The ear covers can be easily removed in favour of third party hearing protection or communication systems, such as the Peltor Optime, see Figure 56.



Figure 56. Peltor Optime communication system. [21]

The helmet is designed to work as a half cut when the ear covers are removed and the 4-point chinstrap is connected. When adding third party hearing protection or communication system, the user attaches the ear protection mount, see Figure 57.



Figure 57. Ear protector mount.

The ear covers are manufactured in the same materials and manufacturing methods as the outer shell.

The chin strap was constructed simple with standard components. The buckle is designed in a red plastic, ABS, with a minimum thickness of 18 mm. The straps are made in Polyethylene, a widely used material for the straps. A comfort pad is added for additional comfort and stability. There will be two chin strap options, one that is used in combination with ear covers, 2-point chin strap, and one without, 4-point chin strap. The 2-point chinstrap used with ear covers are connected at the lower part of the ear covers, see Figure 58.



Figure 58. Exploded view of ear covers.

The second chin strap is a 4-point construction, that is connected to the two holes placed on the retention system.

5.2.4 Communication system

The Peltor Rescue-kit was chosen as the recommended communication system for the R1 helmet. The rescue kit is currently used by SSRS and was co-developed with SSRS and Peltor. It is tailored to the needs of the rescue personnel operating at sea. The Peltor Rescue-kit is a two way communication system that features two speakers with rubber housings and a microphone that is mounted to a flexible arm. The entire system is approved for tough wet conditions and is IP68 certified. Figure 59 shows the Peltor Rescue-kit.



Figure 59. Peltor Rescue-kit.

5.2.5 Retention system

The retention system is inspired by the OPS-core retention design, and similar functions were implemented. It is an all-around retention system that goes from the temple area down to the neck following the contour of the helmet. Figure 60 shows the OPS-core retention system.



Figure 60. OPS-core retention system.

The retention system consists of a padded plastic strap that forms a loop together with an adjustable dial. The loop can be tightened at the neck using the dial to accommodate different head sizes and shapes. The retention system shares the mounting points and fasteners for the ear covers.

At the lower end of the retention, an inclined plastic extrusion is added which allows the user to change the position at the lower back. The retention is made of an elastic plastic material, TPE. Velcro is added where comfort pads can be attached.

The knob system was designed slightly larger than the OPS-core system, for easy adjustments with thick gloves. The knob was positioned high up on the neck to prevent interference with the neck or clothes at the back when moving the head around, see Figure 61.



Figure 61. Back view of the retention system attached to the helmet.

5.2.6 Mount concept

The mounts and adapters are manufactured in ABS plastic. The choice was motivated by the need for the mounts to handle less stresses than the shell, in order to preserve the shell in the event of an accident. Due to its complex construction, injection moulding is preferred. The mount is constructed to be used together with the ventilation holes.

5.2.7 Half integrated top light

A half integrated position light concept is developed. The position light is placed on the top part of the helmet. The half integrated light is protruding slightly from the helmets shell to be able to be seen from all sides and from above. The component is fastened by straps and follows the contour of the lowered top surface for a snug fit. The light consists of two components, the base is where the internal components are placed. The second component is the transparent plastic, that is available in different colours. The part has a silicone rim on the bottom face for a watertight fit. The two components are fitted with screws. Figure 62 shows an exploded view of the position light.



Figure 62. An exploded view of the position light.

5.2.8 Eye shield

The users liked the idea of having the possibility to chose between a visor or goggles. The quick solution for this was to add a goggle clip at the back which complements with the existing goggle track. The goggle clip is attached at the ventilation holes at the back, by firstly attaching to the top ventilation hole and then locked in to place by hooking to the lower back end of the helmet, see Figure 63.



Figure 63. Goggle clip concept.

5.2.9 Visor concept

The eye shield concept mainly focuses on the mounting construction and usability. The visor is decided to be short for easy handling and the material choice is Polycarbonate due to good optical qualities and high impact properties.

The concept is based on MC-helmet visor constructions, which are designed to withstand harsh winds. The visor can also be positioned in different angles, piecewise. The concept uses the same construction idea as MC-helmets but downsized to exude a more minimalistic and discrete design. Figure 64 shows an exploded view of the mount.

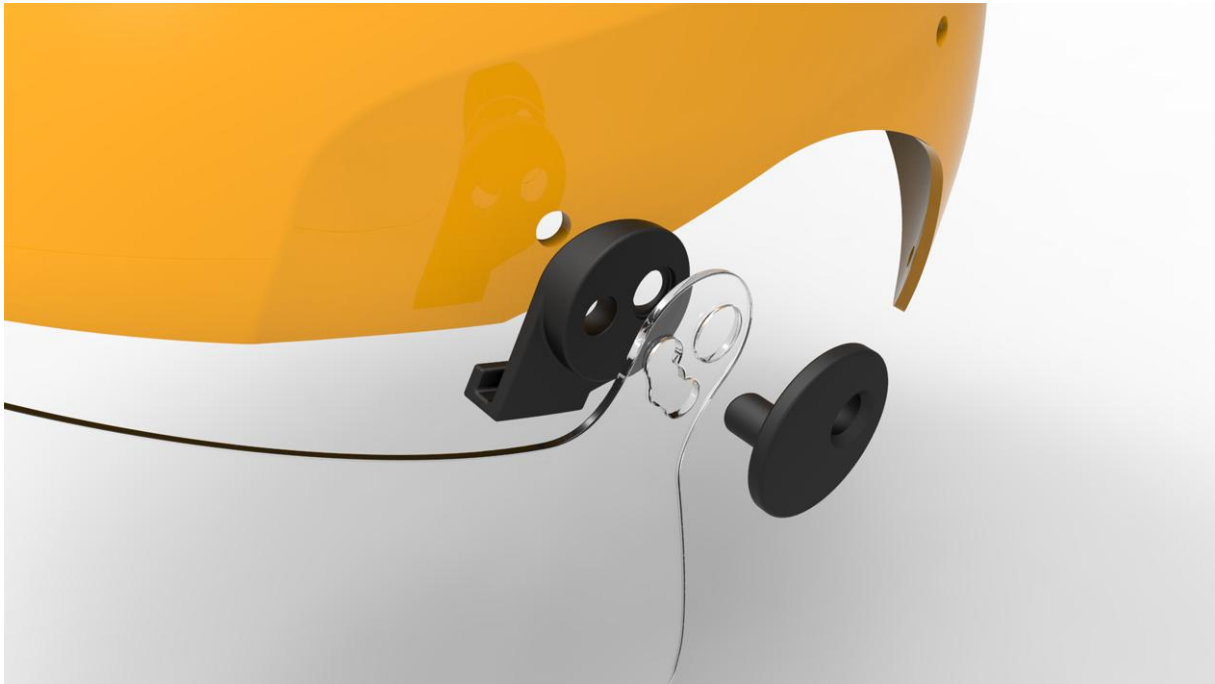


Figure 64. Exploded view of the visor concept.

The mount is constructed as sandwich structure, with the visor in the middle. The top plate has an extruded pivot point, which the visor rotates around. The two halves are fixed with a screw through the pivot point. A second extrusion is placed parallel to the pivot point, which goes from the top plate down to the bottom plate.

The visor itself has a hole that fits into the extruded pivot point, with a max 0,1 mm tolerance. The second cutout on the visor is three connected holes. Big rounds between each hole creating a track for the second extrusion. The distance in the track is slightly shorter than the extrusions diameter, to prevent the visor from moving uncontrollably.

The visor is created in 2 mm PC with added UV protection and abrasion resistance. The visor is designed as one third, covering half the face, slightly angled away from the face to prevent the visor from hitting the nose or coming in the way of things, see Figure 65.



Figure 65. Visor concept, in different positions.

5.3 Physical prototype

A description of the materials and manufacturing methods used to produce the physical prototypes.

5.3.1 Outer shell

The manufacturing of the outer shell was consulted with different vacuum forming companies in Sweden, to understand the process and to receive offers on how much it would cost to produce five to six outer shell. See Appendix Q for an overview of the different companies contacted and their offers. Baering thought that it was too costly this early in the development process. They suggested that the outer shell should be created as cheap as possible. It was therefore decided that the outer shell should be produced at KTH.

5.3.1.1 Milling

The outer shell 3D model was reconstructed to a male mould. The 3D model was angled 16 degrees from the reference plane, viewed from the side, to prevent negative release angles, see Figure 66. By choosing a male mould, a more even wall thickness can be achieved at the top of the mould, the testing area, where the heated plastic has its first contact, and better fit to the inner liner.

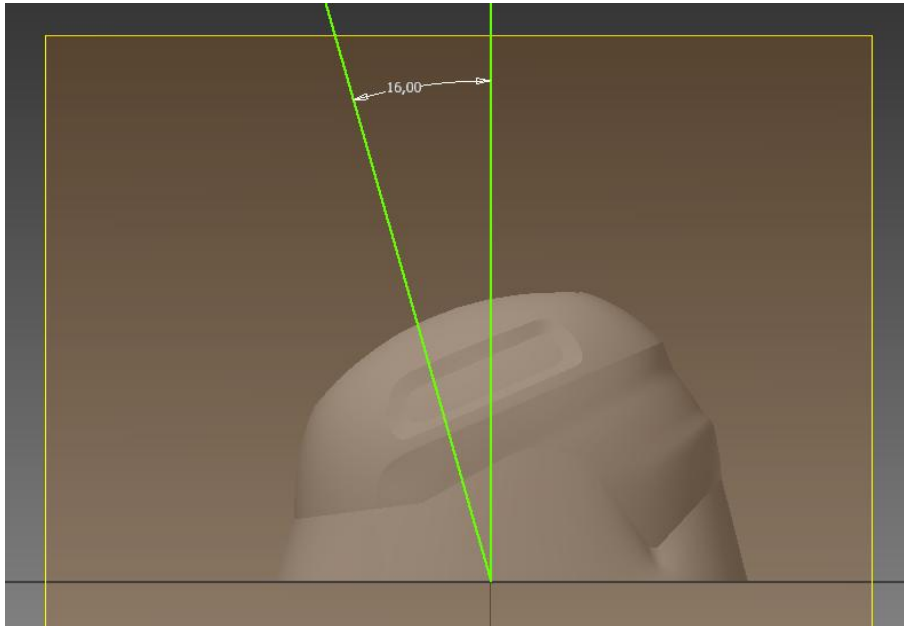


Figure 66. CAD model of outer shell mould, tilted 16 degrees forward.

The 3D model of the male mould was milled at KTH machine workshop, with Roland MDX-540, a 3-axis CNC machine. The 3D model was created in Inventor and exported in .stl-format, the format used by SRP player.

When constructing a 3D model for one sided milling one must take under consideration that the tool works perpendicular towards the base plane, and therefore a clearance between the tool and the part is needed. The finished mould is shown in Figure 67.



Figure 67. Mould used for vacuum forming the outer shell.

5.3.1.2 Vacuum forming

A 4 mm and a 3 mm PC/ABS was bought from Arla Plast. Mikael Gryvik from Arla Plast was consulted for a quick how to use PC/ABS when thermoforming. Gryvik mentioned that the most important part when thermoforming PC/ABS was pre-drying. If the material is not pre-dried, the trapped moisture inside the plastic sheet will expand during vacuum forming and result in an uneven thickness and poor surface finish. The pre-drying temperature was obtained from Arla Plasts' thermoforming guide, see Appendix R. It was decided that the PC/ABS should be dried for 10 hours at a temperature of 100 degrees Celsius. A hot air oven was used to raise the temperature evenly in the material to minimize deformation through and warping.

The Formech 508FS was used as the vacuum forming machine, the machine has built in heaters and pressure regulators. The plastic sheet was heated until it reached forming temperature, between 180- 200 Celsius. The plastic sheet becomes elastic when the ideal temperature is reached. The forming temperature can be verified through observation by feeling the plastic to see if it rebounds. When confirmed that the forming temperature had been reached, the mould was quickly pulled up while applying the vacuum. The heater was then pulled back and the formed part was left to cool. This process of heating and forming must be performed as fast as possible to minimize build-up of internal stresses in the material. See Figure 68 for finished formed part.



Figure 68. Vacuum formed outer shell.

The ear covers were made according to the same manufacturing method. Polyurethane moulds was created for use in vacuum forming, as seen in Figure 69. Four individual moulds were attached to a wooden base plate for the purpose of maintaining the appropriate distance between the mould pieces.

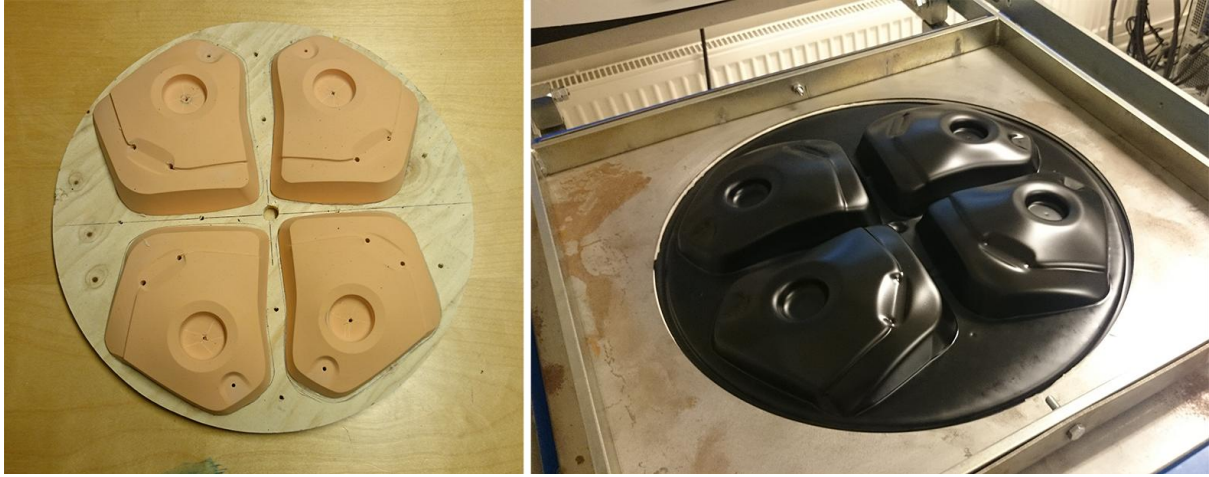


Figure 69. Vacuum formed ear covers.

5.3.2 Liners

As previously stated in the manufacturing chapter, an EPP helmet liner is typically made by expanded foam moulding in a closed aluminium mould. After having consulted prototype workshops, a more cost efficient method was suggested by CNC milling the liner. Using this method, the liner would not achieve the smooth water resistant surface, but the properties would be sufficient for validating the fit and to perform drop tests. It would also be possible to change the design of the liner without having to re-invest in new moulds.

The EPP inner liner was milled in two steps at KTH, using the same CNC machine as for the outer shell mould. Firstly, the outside of the liner, the surface in contact with the outer shell, was processed, see Figure 70. The limitations of the 3-axis CNC machine meant that the side ventilation holes could only be slightly processed, not extending all the way through.



Figure 70. Milled outer surface of inner liner.

The second step was to remove material from the inside. To properly secure the work piece in the CNC machine for the this step, a fixture was made. The fixture was designed as a negative of the inner liner outer surface, as seen in Figure 71. The fixture was manufactured from a polyurethane block according to the same method as the outer shell mould.

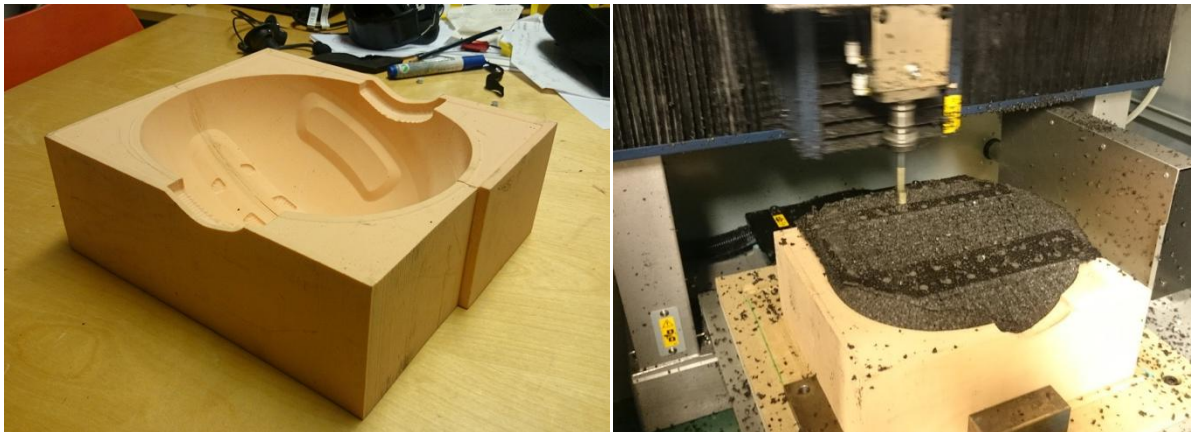


Figure 71. Fixture for inner liner, CNC machining.

The final step was to process the liner manually and make the side ventilation holes, and remove any other excess material. The final result is shown in Figure 72.



Figure 72. Finished prototype liner.

The process for making the ear cover liners was very similar; the EPP was processed from both sides using a fixture, as shown in Figure 73.



Figure 73. EPP liners for ear cover, with CNC fixture.

A layer of 5mm thick EVA-foam was added on the inside of the liner to provide comfort for the user. The EPP and EVA were covered with a layer of Coolmax fabric, attached using 3M Scotch-Weld 77 spray adhesive. The finished ear cover liner is shown in Figure 74.



Figure 74. Ear cover liner with EVA padding and CoolMax fabric.

5.3.3 Mounts

KTH have access to two Makerbot 3D printers that can print in ABS and PS. The first Makerbot is a Makerbot replica 2x, a double extruder which can use support material for the more complex shapes. While the second one, the Makerbot replica 5, only uses one extruder. Makerbot replica 2x with ABS together with support material, was mainly used due to the complex shapes of the printed components.

5.3.4 Assembly

The outer shell and ear covers were assembled using six pairs, three per side, of M4 screws and nut inserts. The nut inserts have a rectangular base to prevent them from rotating when tightening the screw, as seen in Figure 75.



Figure 75. M4 nut insert and screw.

After the ear covers had been attached, both the main liner and the ear cover liners were attached using double sided film adhesive. The chin strap system was attached to the ear covers with snap-fits. See Figure 76 for the assembled helmet prototype.



Figure 76. Fully assembled prototype helmet.

5.3.5 Estimated cost calculation

The EPP manufacturing is estimated and calculated from the experience of the prototyping phase. In the prototyping phase the EPP inner liner was CNC - milled from a block with the dimensions of 280x230x140 mm, which creates 8 helmets and some excess material. The cost is estimated to:

EPP, material cost/helmet: 151 SEK
CNC-milling fixture: 200 SEK
Manual labour, 30 minutes: 200SEK/hour
Cost per inner liner: 251 SEK

The last stage in this process is the assembly where the liner and shell are combined with VHB tape. Table 12 below lists all external expenses and total cost for one helmet.

Table 12: Total cost calculation.

Component:	Price per helmet:
Material, PC-ABS	43,50 SEK
Outer shell	200 SEK
EPP material and processing	251 SEK
Chinstrap (Peltor)	55 SEK
LD foam comfort (Kask super plasma)	99 SEK
Retention system	249 SEK
Total cost of one helmet:	897,50 SEK

5.4 Testing

5.4.1 Testing at MIPS

The MIPS prototypes were cut out to fit the helmet, a countersunk shaped as a drop with a depth of 3 mm, a radius of 3mm was cut out from the liner, and the silicone plugs were placed. For a lesser friction between the MIPS prototype and helmet several low friction pads were placed at critical areas on the liner. Figure 77 shows the inside of the liner, with the teardrop and additional MIPS components.



Figure 77. Liner inside with MIPS low friction pads.

Figure 78 shows the MIPS prototype mounted in the helmet, the pads placed on the MIPS are for additional comfort.



Figure 78. MIPS mounted in helmet.

A test plan was made, describing how to test and in which order to test to receive the best results as possible. Of the seven prototypes created, two were integrated with MIPS. The test plan can be seen in Appendix S.

5.4.1.1 Testing

Two tests were planned to be performed, one standard drop test and one angular impact drop test, a specific MIPS testing procedure. When arrived at MIPS, the prototypes were further inspected to see if the system had enough low friction against the helmet liner. Peter thought that the MIPS system was trimmed too far up at the sides which could prevent the MIPS from working during a side impact. It was decided that the angular drop tests would be performed at the top side of the helmet, with a drop height of 1,05m. Figure 79 shows the helmet positioned on MIPS testing rig for angular drop test.

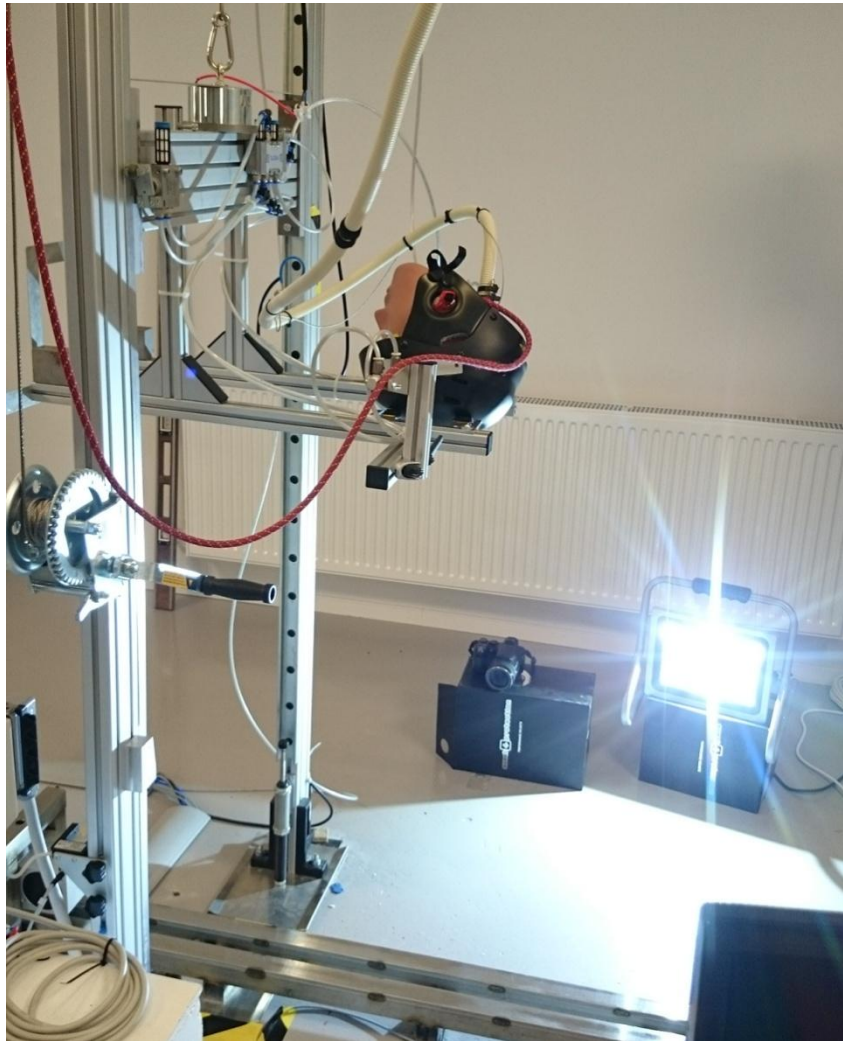


Figure 79. Angular drop test and position of helmet.

The helmet that received the best results from the angular drop test method was helmet 2, with MIPS and EPP 45, with a translational acceleration of 102g. Figure 80 shows the drop test result for helmet 2. For complete test results, see Appendix T.

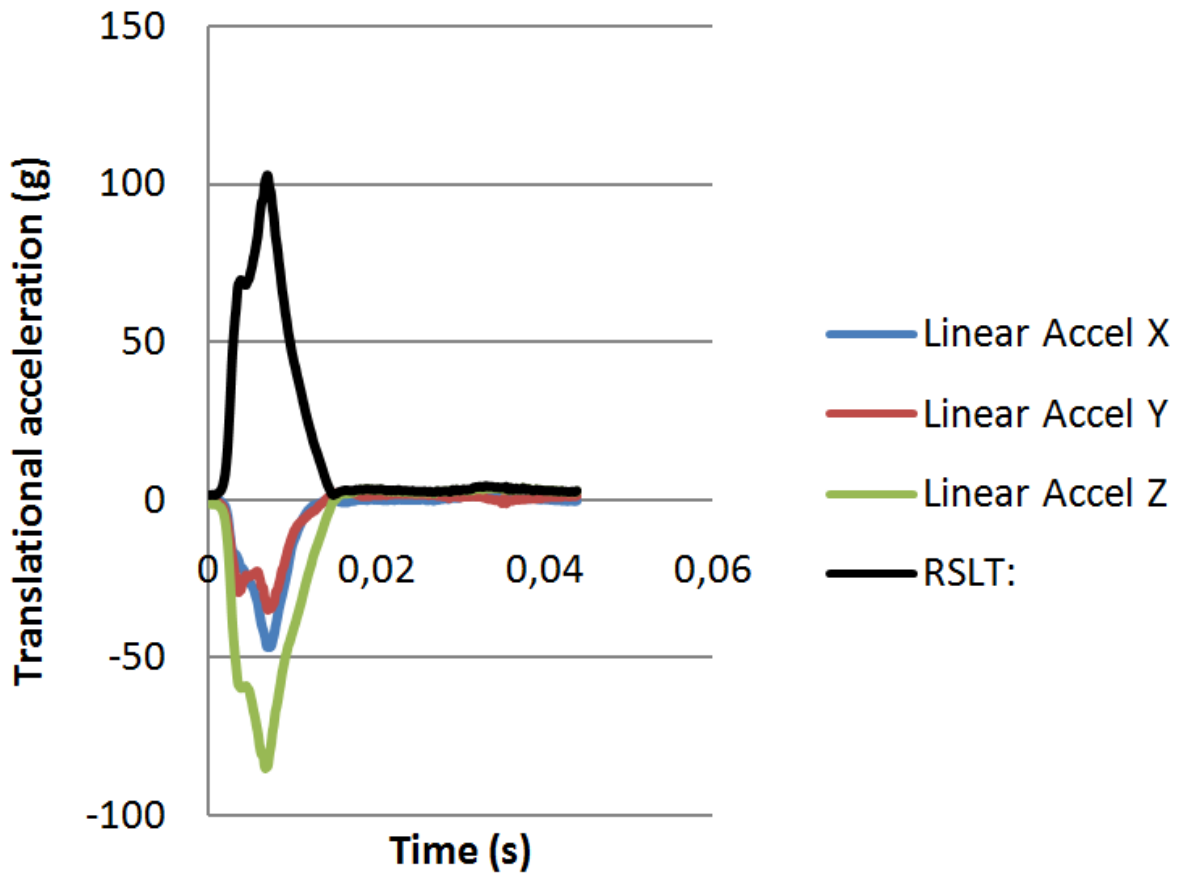


Figure 80. Angular drop test results of helmet 2.

There was also a plan to test the helmets with the standard drop test method, but it seemed that they did not have the right equipment, a flat anvil was needed which they did not have at that moment.

6 DISCUSSION and CONCLUSIONS

A discussion of the results and the conclusions that the authors have drawn during the Master of Science thesis are presented in this chapter. The conclusions are based from the analysis with the intention to answer the formulation of questions that is presented in Chapter 1.

6.1 Process

The initiation for this project is thanks to the company Baering, they were impressed with the results from the MF2061 project and wanted us to continue the work as a thesis project. They have been of great support in terms of supervision, feedback and help with information about company philosophies.

When developing a complex shaped product with big dimensions made it hard for us to work quickly due to the time it needed to remodel and implement certain inputs. Using the iterative design process showed to be effective at the early stages of the project, but when the mould and 3D models needed to be changed at later stage of the project showed to be very time consuming.

During the thesis work, we faced some challenges that proved to be extra time consuming. The biggest problem was that neither of us had further developed a helmet before, this made it hard to estimate the time for each task and in which order they should be conducted.

The extent of this project was also bigger than we initially thought for the timeframe we had. This led to compromises throughout the project, such as the mounting area and retention system.

6.2 Y1 evaluation

Our initial approach was to evaluate the Y1 helmet and further develop the design for manufacturing. It was however decided to do a completely new design based on the insights gained from users and manufacturers during the evaluation of Y1. The design of the outer shell was not suited for manufacturing with injection moulding or vacuum forming. Furthermore, the discovery of the Peltor communication system used by SSRS removed the need for integrated hearing protection.

6.3 User centred design

The core users were contacted early in the project for the purpose of identifying their working conditions and needs. We gained invaluable feedback and insights through our interviews and workshops. This gave the project a depth and insight within the area of rescue work and user-centred design. Addressing the needs of our different users proved to be challenging, and we eventually had to make compromises. Some of the needs were contradictory, others would increase the manufacturing costs significantly. Through our process we learned to be selective and find a balance different needs, design and manufacturing costs.

6.4 Material choice

The material choice of PC or PC/ABS showed to be problematic in the later stage of the project, where the Pugh method was used to compare materials based on their structural properties. It was difficult to identify the threshold values for the different properties based on the research. The material limits were estimated, rendering the result not 100% accurate. Therefore, a second benchmark was conducted by testing.

The initial drop test method with material samples proved to be harder to conduct than expected. It was hard to receive a straight drop with the weight. This resulted in inconclusive results, due to some angled impact. There were also too few test samples which made it hard to draw conclusions.

PC/ABS was initially chosen based on discussions with material distributors. Further discussions with manufacturers led to new insights and ABS combined with Kevlar was considered a more appropriate combination. The use of Kevlar may result in a higher production cost but overall a better protected helmet.

6.5 Manufacturing

The task that proved to be most time consuming was the prototype manufacturing, due to that both of us had limited experience working with plastics and the involved manufacturing process.

The choice for manufacturing method is pressure forming with a plug assist for a more uniform wall thickness. Pressure forming was chosen due to its better surface finish than vacuum forming. A plug assist can be added for a better uniform wall thickness, but some research regarding the design of the plug assist needs some consideration. This should be done together with the manufactures.

A few problems occurred during the prototype phase, one problem was that the extruded plastic was pre dried to few hours, which resulted in bubbles on the surface. Another problem was the uniform wall thickness, the extruded plastics that were bought had a thickness of 3 mm, which was too thin. This resulted in a finished part that had a 2 mm thickness near the sides. This can be prevented by adding 1-2 mm and pre stretch the plastic before vacuum forming, for a better wall thickness of 3 mm.

6.6 Physical testing

The design and material choices have been exclusively evaluated through physical testing. The results were tangible and accurate but required a lot of preparation work and could therefore only be performed in the late stages of the project.

Though more testing is required in the proper settings, the results from the tests conducted at MIPS indicate that the helmet construction and impact absorption abilities are within limits, when compared to the study performed by Folksam.

6.7 Final result

The results and final helmet design presented in this report is to be considered as work in progress. Further development and testing is required. The results have not yet been presented to users.

The choice of designing after a mount concept early in the project showed to be problematic later on, in the thesis work. The new mount concepts that were developed later in the thesis work were hard to implement, because the outer shell CAD was optimized for the first mount concept. This made it hard to receive a good result without remodelling the shell.

Overall, the product, R1, fulfils most of the design requirements set during the master thesis, with the exception of the mount construction.

7 RECOMMENDATIONS AND FUTURE WORK

The recommendations for future work is presented here.

7.1 Potential manufacturers

It is recommended that contact is established with potential manufacturers as early as possible in the process to discuss pricing and trial production.

7.2 Mount testing

The mount concept should be revised and tested in scenarios representing working conditions.

7.3 Initial evaluation

The current design is presented to users for initial evaluation of ergonomics and fitting of components.

7.4 Further testing

Further physical testing is required to assure that the helmet and material choices comply with the EN 966 and PAS 028 standard. The full series of tests require preconditioning and are more demanding than the drop tests performed at MIPS. These tests also require more prototype helmets to be made and it is recommended that these are made according to the chosen manufacturing method, in a small trial production run. The tests can be performed at SP Technical Research Institute of Sweden for a cost of 7000 SEK.

It is also during this phase that the material choices are optimized. By performing penetration resistance tests on different thicknesses and material choices, the outer shell can be improved.

7.5 Field testing

When the helmets have passed the tests, they are ready for field testing. These tests should be performed in collaboration with SAR and SSRS and be evaluated by professional rescue workers. The focus of these tests should be the overall ergonomics of the helmet, the mounting system and the overall durability of the helmet.

7.6 Refine design

The results from the field testing needs to be processed and design changes may be required. If changes are made, a second trial production run is required for testing and approving the new design.

7.7 Final evaluation

The final design needs to be evaluated together with the core users before being greenlit for production.

7.8 Certification and manufacturing

Final step once the helmet design has been greenlit is to perform the standardization tests for certification. The production can begin once the helmets have passed said tests.

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Figure 5. Section of vertical longitudinal plane. Circumference measured in plane marked with 2. [3]

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Figure 14. Process of pressure forming. [12]

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Figure 15. Expanded foam moulding process. [13]

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Figure 17. ACH-ARC rail. [15]
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Figure 18. PT Bravo helmet with Picatinny mount. [16]
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Figure 19. Picatinny rail. [17]
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Figure 20. Different mounts for GoPro cameras. [18]
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Figure 21. Bicycle helmet with strap-mounted lights. [19]
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Appendix A - Project plan

Phase 1 - Planning & Evaluation

The objective of this phase is to organize the project. The Y1 concept developed in HK2 will be evaluated with the aim to identify areas that need to be further developed and refined.

Project description and seminar presentation

The Project description is a document that describes the background, choice of methods and goals of the project.

Project plan

The deliverables of the project, each phase is described and arranged in chronological order.

Evaluate Y1 concept (feedback from Howl & Frankly)

Evaluate the existing concept Y1 regarding form, functionality and materials. A discussion will be held to form a work plan together with Howl.

Design brief, deliverables, time plan

After the evaluation, a new design brief can be created, where it states the terms the helmet should meet before production. It will also conclude of deliverables explaining what the company can expect at the end of the project. A project time plan will be presented to provide stakeholders an overview of the project.

Risk analysis

A risk analysis will be carried out to identify any potential risks that may result in failing to meet any of the deliverables.

Background study

Evaluate the report on the development of the Y1 concept.

Phase 2 – Research

Research will be conducted in the following areas:

Marketing opportunities - standards (defines test method)

Analyze the market, competitor helmets and identify what the market wants, to find out which standards Y1 should follow and how big the production volume should be. Get in contact with MIPS and relevant faculties to test the helmet.

Investigate alternative markets for marina applications, such as FMV, extreme sports and search and rescue in snow environment.

A SWOT analysis will be performed on the existing Y1 concept to position it in the current market.

Research communication systems

Look into different communication systems and how to implement them. Do a user-study to identify which type of communication is most wanted. If needed, develop a new solution or integrate an already existing concept. Benchmark cost and manufacturing.

Light and IP standards

Research will be conducted on rescue lights as well as IP classifications for dust and water resistance to determine appropriate standards.

Materials (with Howl & Frankly):

Research materials used in competitor helmets, discuss with Howl and Frankly regarding materials used in H1 helmet. More specifically, look into material options for:

Outer shell

Find suitable materials and benchmark their properties and manufacturing cost. Research how the materials act during impact and how the helmet should be constructed. Compare hard and soft shells.

Inner liner

Find suitable materials and benchmark their properties, such as shock absorption, and manufacturing cost. Research the materials function during impact and how the helmet should be constructed. Compare collapsing liner with elastic liners. Investigate alternative materials.

Comfort liner

Investigate the costs and need of a pre manufactured comfort liner/pads or in-house developed comfort liner/pads. What does the user want and what are the manufacturing costs? Does the comfort liner have any other functions other than to provide comfort? Find suitable distributors of pre manufactured comfort liners or develop a new comfort liner. Determine the type of fabric that is best suited in the users' conditions.

Manufacturing

Look into the different stages of the development process, from raw material to assembled product. Compare different manufacturing methods based on cost and efficiency. Investigate different manufacturers.

Compare manufacturing methods

What type of manufacturing method is available? Conduct a benchmark comparing different manufacturing methods with quality, cost and efficiency in mind for each material.

Production design

Create a production plan that is best suited for this product.

Price calculation, estimate tooling cost

Done in collaboration with Frankly. Present the conclusions and discuss price and need for tools and moulds.

Find prototype manufacturers

Find manufacturers that can deliver prototypes with the materials in mind. Test a small production with 3-4 prototypes. Order materials for impact testing, to strengthen the connection with manufactures and oversee the production process.

Phase 3 - Concept development

In this phase the research and feedback will be implemented and the concept refined.

Impact testing

Material samples will be produced to perform impact tests. The results from these tests will determine materials for the outer shell and inner liner, as well as the thickness for these layers.

Refine CAD design

Create a refined CAD according to chosen manufacturing method. Evaluate several concepts together with Howl and the target group.

User interface

Develop different user interface designs based on user feedback.

Communication system

Implement different communication systems in the CAD for evaluation. Alternatively develop a new communication system.

Feedback from Howl

Discuss the form language and functionality with Howl.

User group feedback

Present concepts to SAR and SSRS for feedback.

Design for manufacturability

Make the CAD manufacturing ready.

Frankly, feedback on manufacturability

Discuss material choices and manufacturability with Frankly.

Phase 4 - Prototype & Testing

Produce a prototype with full functionality for field testing.

Function testing

Test the communication system and lights under working, including wet, conditions.

Production test

Production test and assess quality to find the best manufacturer.

Prototype for user testing (ergonomic evaluation in the field)

Produce a fully functional prototype for performing user field studies with SAR and SSRS.

Fatigue testing of the helmets components

Perform repeated stress tests on the helmet in expected working conditions.

Certify helmet

Send prototype helmet and perform tests for BSI approval according to chosen standards.

Phase 5 - Final product

Process the results from the prototype tests and implement necessary design changes.

Final CAD

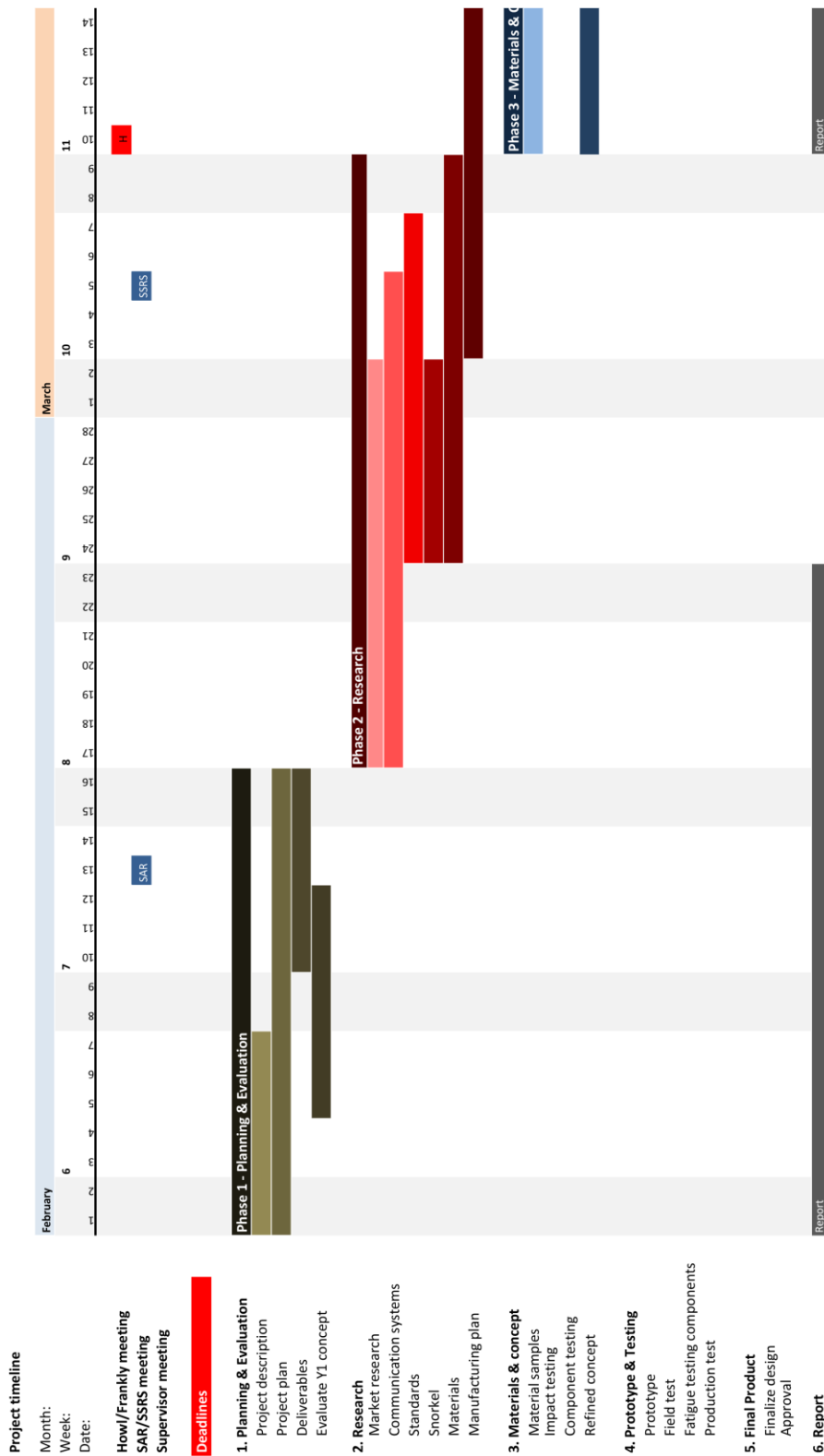
Make adjustments if needed and finalize the design.

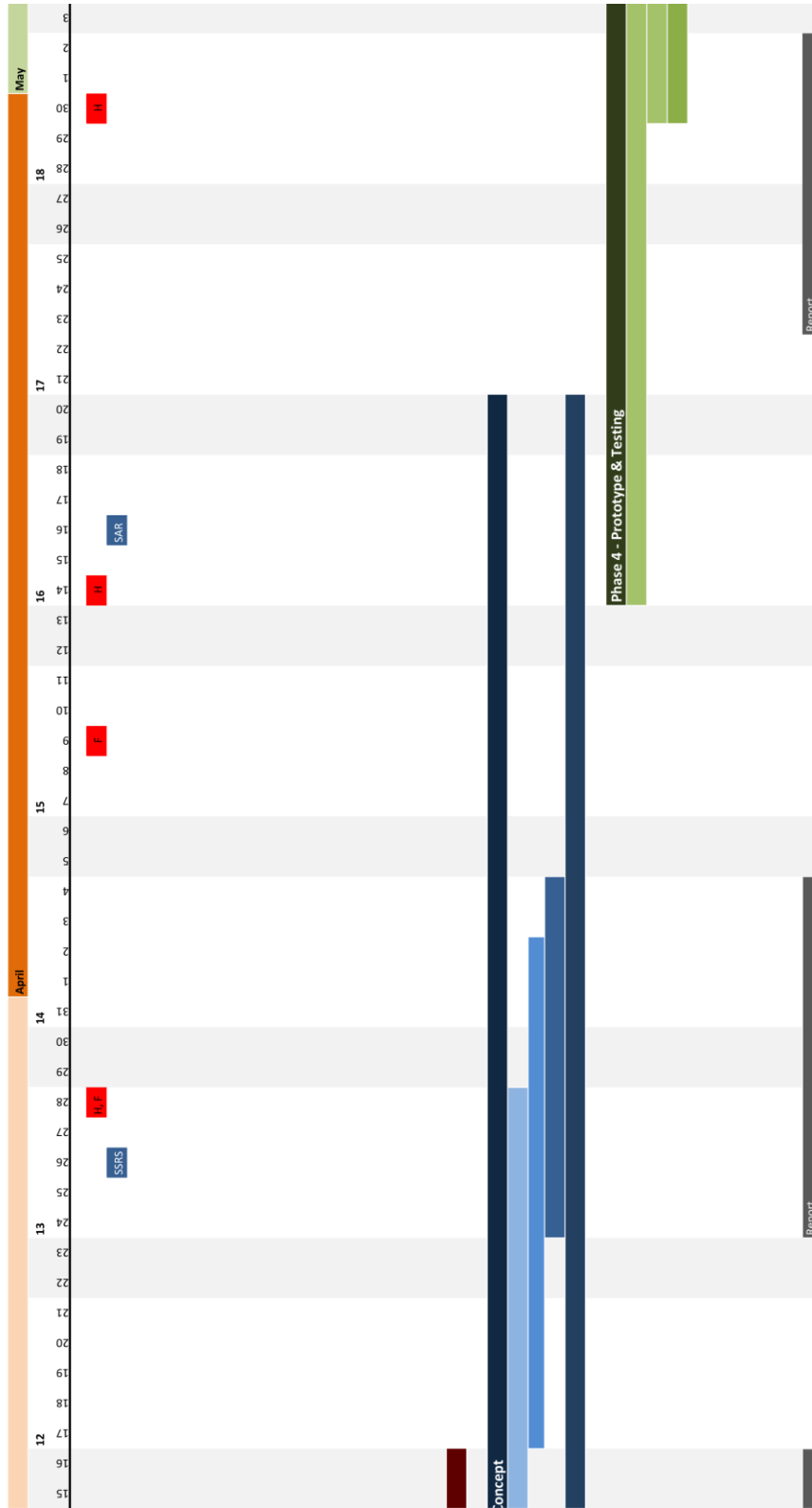
Final approval

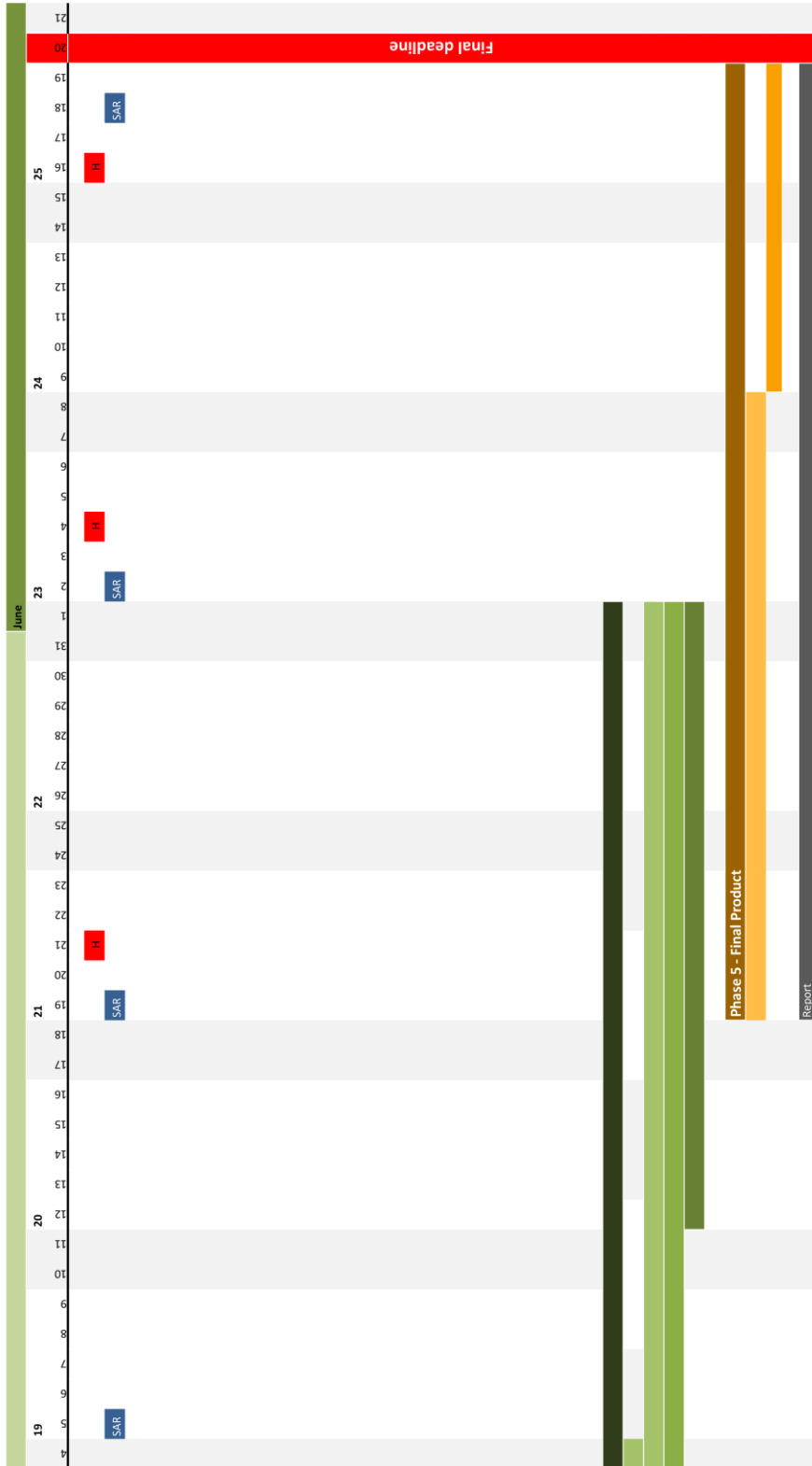
Present the final design to stakeholders.

Appendix B - Gantt-scheme

A Gantt chart is made to illustrate an overview of the project plan.







Appendix C - Folksam Helmet test results

Following Appendix presents the results from the study conducted by Folksam.

Helmet	Translations- acceleration (g)	Rotations- acceleration (rad/s ²)	Rotations- velocity (rad/s)	Strain (%)
AnonRaider	105,7	7481	39,0	41%
Biltemaskidhjäl äl	136,4	9617	38,4	44%
EverestUEXT MIPS HLM	119,3	5303	34,1	34%
EverestU AllMountainF 12	130,2	9628	38,3	44%
GiroG10	109,1	8364	35,9	42%
GiroCombyn	96,6	6523	38,0	42%
Head Pro	119,6	6935	36,9	39%
POCReceptor Backcountry MIPS	119,7	7321	38,8	40%
POCReceptor Bug	137,1	9445	38,0	44%
SalomonBrig ade	120,8	9764	37,1	43%
ScottChaseMI PS	131,7	5746	30,8	33%
SmithVantage	132,1	8594	36,6	43%
SweetProtecti onIgniter MIPS	138,3	4519	26,1	26%

Appendix D - Standard Evaluation

Name	Application	Region	Number of tests	Number of helmets	Test conditions	Drop height on flat	Drop height on	Drop height on	Failure threshold, max g
EN 1365: 2012	Helmet for canoeing	Europe	7, 4 impact tests under different conditions and 3 additional to test retention system strength and buoyancy	4	1.High temperature 2.Low temperature 3.Artificial ageing 4.Water immersion	Dependant on helmet size: A 495mm helm: 0.49m E 535mm helm: 0.37m J 575mm helm: 0.33m M 605mm helm: 0.27m O 625mm helm: 0.25m	1,5 - 2,1 m	1,5 - 2,1 m	250 g
EN 966: 1996	Helmet for airborne sports	Europe	11		1.High temperature 2.Low temperature 3.Artificial ageing Falling mass onto a fixed headform, additional impacts are required at the front, side and rear of the helmet. Headform tilted 60 degrees from the base. 1.High temperature 2.Low temperature 3.Artificial ageing 4.Water immersion	1,5 - 2,1 m	1,5 - 2,1 m	250 g (2453 m/s ²)	
EN 12492: 2012	Helmet for mountaineers	Europe			Falling mass onto a fixed headform, additional impacts are required at the front, side and rear of the helmet. Headform tilted 60 degrees from the base. 1.High temperature 2.Low temperature 3.Artificial ageing 4.Water immersion	Front, rear and sides using the flat striker dropped from a height of 500 mm	Hemispherical striker: 2 m	10	
EN 397:2012	Industrial helmets	Europe			Fixed headform, with a falling mass striker. 1.High temperature 2.Low temperature 3.Artificial ageing 4.Water immersion	1 m	1 m	5	
EN 1077: 2007	Ski helmet	Europe	Helmet are impacted twice at two points at least 100mm apart.		1.High temperature 2.Low temperature 3.Artificial ageing 4.Water immersion	1,5 m		250 g (2453 m/s ²)	
EN 1078: 2012	Cycle helmet	Europe		Four helmets must be submitted for each head-form size specified	1.High temperature 2.Low temperature 3.Artificial ageing	1,5 m	1,064 m	250 g	
EN 14052: 2012	High performance industrial helmets	Europe			1.High temperature 2.Low temperature 3.Artificial ageing 4.Water immersion	Striker onto the helmet Height: 2.04m	Striker onto the helmet Height: 2.04m	5	
EN 1384: 2012	Equestrian helmets	Europe			1.High temperature 2.Low temperature 3.Artificial ageing	1,5 m	1,5 m	250 g	

Energy absorption	Headform/ Striker	Penetration test	Retention system strength	Comment	Link
15 J	A: 3.1kg E: 4.1kg J: 4.7kg M: 5.6kg O: 6.1kg	Mass: 3 kg conical striker onto the helmet. Height: 0.5 m	Minimum width of 15 mm Tensile Force: 20 N/min Shall be no less than 150 N and no more than 250 N		
89 J	5 - 6 kg	Mass: 3 kg Drop Height : 1 m Max: 5 mm	drop from a height of (200 ± 5) mm	This is an old version, there is a 2012 EN 966 standard version, but cost money to see	http://www.satrappeguide.com/EN966.php https://www.youtube.com/watch?v=Oq0BrXVgjEM
	5 kg	Mass: 3 kg conical striker onto the helmet. Height: 1 m	Dynamic Extension: Max 35 mm Residual Extension: Max 25 mm Effectivness: Mass 10 kg at a 45 degree angle		http://www.satrappeguide.com/EN12492.php
89 J	5 kg	Mass: 3 kg conical striker onto the helmet. Height: 1 m	Minimum width of 10 mm Tensile Force: 20 N/min Shall be no less than 150 N and no more than 250 N	Optional tests: very high and very low temperatures, splashes of molten metal, electrical voltages up to 440 V, and lateral deformation	https://www.satra.co.uk/spotlight/article_view.php?id=429 http://www.satrappeguide.com/EN1077.php
89 J 62 J		Mass 3 kg Height: 0.75 or 0.37 m Depending on the class of the helmet	drop from a height of (200 ± 5) mm Dynamic Extension: Max 35 mm Residual Extension: Max 25 mm		https://www.satra.co.uk/spotlight/article_view.php?id=291
100 J 50 J (front, side and rear)	5kg	Flat blade striker a smaller, sharper striker. 5kN for crown impacts, 15kN for off-crown impacts		Optional tests: very high and very low temperatures, splashes of molten metal, electrical voltages up to 440 V, and lateral deformation	https://www.satra.co.uk/spotlight/article_view.php?id=396
89 J		Mass: 3 kg, conical shape Height: 0.5 m			

Appendix E – Test method description

Testing according to the standard PAS 028.

Pre-test conditioning

Artificial ageing (UV Exposure)

The outer surface of each helmet shall be exposed to ultraviolet radiation from a 125 W xenon filled quartz lamp at a distance of (250 ± 10) mm from the nearest point on the helmet, for (48 ± 2) h.

Water immersion

After artificial ageing, the helmets shall be totally immersed in salt water (containing 35 g/l of sodium chloride) at (20 ± 5) °C for between 4 h and 24 h. The helmets shall be anchored to the bottom of the container. At the end of the immersion period each helmet shall be released from its anchorage and whether or not it floats to the surface shall be recorded.

Low temperature conditioning

The helmets shall be maintained at a temperature of (-20 ± 2) °C for between 4 h and 24 h.

High Temperature conditioning

The helmets shall be maintained at an ambient temperature of (20 ± 5) °C for between 4 h and 24 h.

Rigid mode method

Shock absorption of the helmet is assessed by the direct measurement of the force transmitted to a rigidly mounted headform on which the helmet is fitted, when a striker is allowed to fall onto the helmet. The headform used should be according to the standard EN 960. The striker should have a total mass of 5.0 Kg and flat, circular impact face (130 mm in diameter). The striker should be positioned above the headform so that it can be dropped in guided fall. Low inertia force transducer, firmly attached to the base and connected to the headform, to measure the impact force transmitted to the headform. The transducer shall be positioned so that its axis is co-axial with the path of the striker. The transducer shall be able to withstand forces up to 40 kN without damage. The measuring system, including the headform and its mounting, shall have a frequency response.

Crown Impact

The striker shall be allowed to fall onto the centre of the crown of the helmet from a height of $(2\ 000 \pm 5)$ mm measured from the point of impact on the helmet to the impact face of the striker.

Off-Crown impact

The striker shall be allowed to fall onto the helmet from a height of (500 ± 5) mm measured from the point of impact on the helmet to the impact face of the striker. The test shall then be repeated to impact the rear and each side of the helmet.

Falling head form method

The shock absorption characteristics of the helmet are determined from the deceleration it undergoes when fitted to a headform (5- 6 kg) and dropped in guided free fall onto a fixed steel anvil. The fixed anvil should be, rigidly fixed to the base, with a flat and a circular

impact face of (130 ± 5) mm diameter. Headform fitted with a tri-axial accelerometer mounted near to the centre of gravity of the headform. Tri-axial accelerometer, with a mass of less than 50 g, that can measure and record decelerations of up to 2 000g.

Crown impact

The helmet fitted on to a headform shall drop from a height between 1.5 – 2.1 m, the drop height shall be set to give an impact energy of 89 J.

Off-crown impact

Each helmet shall be subjected to one impact on each of four sites, the centres of which shall be least 75 mm from each other. The following sites shall be impacted at least once: an area in which there are ventilation holes (where applicable), a retention system fixing point (or directly above if the fixing point is outside the test area) and the temporal area. The drop height shall be set to give impact energy of 15 J

Penetration test

Test strikers are allowed to fall onto both the crown and off-crown areas of the helmet when it is fitted to a rigidly mounted hemispherical headblock, a different striker being used for the crown and off-crown tests. The headblock is then examined to determine whether the striker has made contact with it and whether the headblock has sustained visible damage. The head block is rigidly mounted on a metal base, the headblock shall be made of hardwood, with a soft metal insert to permit detection of any contact made by the striker. The insert shall be such that the surface can be restored to its original condition after any contact by the striker. Strikers made of steel, each with one conical end, with a mass of 1.5 kg for crown impact and 3 kg for off-crown impact.

Retention system strength

The helmet is mounted on a headform, with the retention system fastened, in the way in which it is intended to be worn. The retention system is subjected to a sudden downward force and its strength characteristics are determined from measurement of the dynamic and residual extension of the system. Loading apparatus, consisting of a chin strap loop with a round or square guide bar and an extension measuring device to measure the vertical displacement of the chin strap loop.

The chin strap loop shall consist of two parallel metal bars each with a diameter of (12.5 ± 0.5) mm fixed (76 ± 1) mm apart. The guide bar shall have a steel end stop and shall be fitted with a cylindrical drop weight having a mass of (4.0 ± 0.2) kg. The weight shall be free to move at least (600 ± 5) mm vertically on the guide bar. The mass of the loading apparatus excluding the drop weight shall be (5.0 ± 0.5) kg.

Retention system effectiveness

The helmet is mounted on a headform, with the retention system fastened, in the way in which it is intended to be worn. The helmet is subjected to a sudden upward force applied at the rear edge of the shell, rotating it forwards on the headform. The guidance system, shall have a total mass of (3.0 ± 0.1) kg enabling the drop weight (10 kg) to be dropped in guided free fall through a distance of at least 180 mm.

Appendix F - Competitor analysis

A competitor analysis is made to further understand the construction in a helmet.

Competitors

ID	Brand	Model	Source	Main market(s)	Standards	Components	Material, shell	Material, liner	MIPS	Year introduced	Weight (grams)	Size (circumference, cm)	Price
1	OPS-Core	FAST Base Jump	http://www.ops-core.com/FAST_Base_Jump_Sp http://helmet.2pac20.com	Extreme sports, base jumping etc. There's also a military version available.	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	FAST ARCs - 4 position accessory rail connectors for quick attachment of headborne accessories, including lights, cameras, goggles, COMMs, face protection etc. NVG mounts, Picatinny adapter and Velcro.	Polycarbonate	EPP & LDV	No	638-643	S/M/L, 53-61	\$203	
2	OPS-Core	FAST Carbon	http://www.ops-core.com/FAST_Carbon_Helme http://2pac20.com	Extreme sports, base jumping etc. There's also a military version available.	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	FAST ARCs - 4 position accessory rail connectors for quick attachment of headborne accessories, including lights, cameras, goggles, COMMs, face protection etc. NVG mounts, Picatinny adapter and Velcro.	Polycarbonate	EPP & LDV	No	638-643	S/M/L, 53-61	\$641	
2	Mainta	SAR	http://www.future-safety.com/mainta-multi-role-sar-helmet/	Working at heights / Urban climbing Maritime operations / Boat driver Confined space / CBRN Technical assistance / Rescue Snowmobile/ATV/quadbike	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Internal light shield, optional visor, light reflective surfaces, mounts for ear protection or communication, ventilation		No					
3	Gecko	Open Face Marine Safety Helmet MK11	http://www.gettheadgear.com/company/press/Gecko%26%203039%3BnewMK11-hbc-military-omegas-multi-roles-helmet/1432	Serious fibsters, professional operators, maritime services, military	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Visor, intercom, mount for cylindrical objects, acoustic liner, reflective straps, goggle strap	ABS	EPP, inflatable	No	700	56-63	£148	
4	Protec	A-Bravo	https://www.protechhelmet.com/products.asp?cat=14 http://tmv.com/shop/pro-tec-bravo-helmet/	Whitewater, rafting, kayak	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Internal light shield, optional visor, light reflective surfaces, mounts for ear protection or communication, ventilation		No					
5	Predator	Full cut	http://predatorhelmet.com/whitewater/helmets/	Whitewater, rafting, kayak	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Visor, intercom, mount for cylindrical objects, acoustic liner, reflective straps, goggle strap		No					
6	MSA POC	Receptor	http://www.pocsports.com/en/products.asp?cat=14 http://tmv.com/shop/pro-tec-bravo-helmet/	Alpine	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Removable ear covers, removable nec roll, compatible with communication neck roll and Beats audio, google strap	Aramid	EPP	No	600		2.000 kr	
7	POC	Receptor Backcountry MIPS	http://www.pocsports.com/en/product/1129/receptor-backcountry-mips	Alpine	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Removable ear covers, removable nec roll, compatible with communication neck roll and Beats audio, google strap	Aramid	EPP	Yes			2.500 kr	
8	POC	Crane Pure	http://www.pocsports.com/en/product/1866/crane-pure	Alpine	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Internal light shield, optional visor, light reflective surfaces, mounts for ear protection or communication, ventilation		No					
9	Prijon	Surf Full Cut	http://www.prijon.com/produts/wildwasser/sicherheit-wildwasser/wildwasserhelme.html	Kayak	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Internal light shield, optional visor, light reflective surfaces, mounts for ear protection or communication, ventilation		No					
10	Icaro	Scarab Helmet	http://www.icarozoo.com/produts/helmets/Scarab/Scarab.htm	Search and rescue	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Mounts for Visor and Peltor Optime 2	Fiberglass	Polystyrene	No	750 + 50	54-64	201 EUR	
11	Shred	Ready	http://shredreadyquivers.com	Whitewater, rafting, kayak	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	HOGZ.O Retention System	ABS	EPP	No				\$75
12	WRSI	Current pro	http://www.wrsisafety.com/helmets.asp	Whitewater, rafting, kayak	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Mounts for visor, removable ear protection, pinch face protection			No				\$97
13	WRSI	Rescue Pro	http://www.wrsisafety.com/rescue_helmets.asp	Water sports helmet	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Mounts for visor, optional ear protection pad, GoPro mount		No					\$149
14	GATH	Gedi	http://www.gathsports.com/product/single.php?id=107	Water sports helmet	EN14052:2005 PAS 028:2002 EN1384 EN1384 EN1384 EN1552-3:1997 EN166:2002 EN12492 BSI P.A.S.028:2002 CE Marked	Mounts for visor, optional ear protection pad, GoPro mount		No					\$149

15	Scott	Jervis	Alpine	CE EN 1077 Class B	Removable ear covers, google retainer, M-R.A.S Fit system, Ventilaton	Polycarbonate	EPS	Yes	Small, Medium, Large, 51,5-63,5	162 EUR
			http://www.scott-sports.com/global/en/product/s/2307953811009/helmet-scott-jervis-black-orange-matt-1/							
16	Scott	Chase	Alpine	CE EN 1077 Class B	Removable ear covers, google retainer, M-R.A.S Fit system, Ventilaton	Polycarbonate	EPS	Yes	Small, Medium, Large, 51,5-63,5	1 200 kr
			http://www.scott-sports.com/global/en/product/s/2242783813006							
17	Sweet	Trooper	Alpine	EN 1077 Class B		TLC, Thermoplastic Laminated Carbon Fibre	EPS	No	S,M,XL, 53-61 (medium)	2 200 kr
			http://www.sweetprotection.com/ski-and-snowboard/helmets-protection/?p=trooper&pid=520							
18	Sweet	Trooper MIPS	Alpine	EN 1077 Class B		TLC, Thermoplastic Laminated Carbon Fibre	EPS	Yes	S,M,XL, 53-61 (medium)	2 700 kr
			http://www.sweetprotection.com/ski-and-snowboard/helmets-protection/?p=trooper-mips&pid=571							
19	Sweet	Grimir	Alpine	EN 1077 Class B	Hidden inserts for GoPro and Contour camera, goggle strap	Carbon fibre	EPS	Yes	S,M,XL, 53-61 (medium)	2 999 kr
			http://www.sweetprotection.com/ski-and-snowboard/helmets-protection/?p=grimir-mips&pid=572							
20	Sweet	Rooster	Alpine	EN 1077 Class B		Carbon fibre, ABS	EPS	No	S,M,XL, 53-61 (medium)	1 800 kr
			http://www.sweetprotection.com/ski-and-snowboard/helmets-protection/?p=rooster&pid=573							
21	Leader	SAR All risk helmet	USAR, BACK Country SAR, Rope Rescue, EMS/Ambulance, Confined Space, Wildland Fire Fighting, CBRN Environments, Swift Water Rescue, Boat/Maritime Rescue Operations, Snowmobile & ATV Operations	NFPA 1951:2007 NFPA 1932:2010 ANSI Z89.1, Type 2, Class C EN 14052:2005 EN 397 EN 12492 PAS 028:2005 EN 1384 EN 166:2002 EN 352-3:1997 EN 1385:1997 EN 166 (Face shield)	Retractable clear eye shield Ratchet style size adjustment Photo luminescent vent covers SOLAS reflective taoe Forestry mesh visor Ear defender hearing protection	(3,6mm, 100 joules)	(18-22mm, 90 joules side/front/rear)	No		\$174, \$315 with full length marine visor, ear defender hearing protection, vent cover
			http://www.alliancefireandrescue.com/online-literature/AER-NewProductBrochure12.pdf							
22	Pacific	eXtractor Water Operations Helmet	Fire and Rescue helmets		Visor, google strap, ventilation	Fibretuff composite	-	No		-
			http://www.ruoc.com/content/13-hour-it-works							
23	Ruroc	RG-1	Alpine		Face mask, ventilation	High impact ABS	EPS	No	One size fits all, adjustable liner	\$290
			http://munkohelmets.com/us		Visor mounts, ventilation, BCCS compatible, Lumi-Safe International Orange, reflective markings			No		
24	Mango	USCG CEAN XT4	US Coast Guard, Search and rescue		Retractable goggles, possible to attach outer fire proof cover			No		£132,95
			http://www.kask.it/product.php?cat=2&product=474							
25	Cromwell	ER1	Emergency rescue		Visor mounts, communication system mount, lamp carrying system	ABS	HD Polystyrene	No	51-62	\$200
			http://www.kask.it/product.php?cat=2&product=474							
26	Kask	CMC Rescue helmet	Safety, emergency rescue	ANSI Z89.1-2009 CE EN 397				No		
			http://www.kask.it/product.php?cat=2&product=474							

Appendix G – Jens ARPRO, suggested Adhesives

Appendix G shows the adhesive list suggested by Jens Grunwald from ARPRO.

ARPRO®



ARPRO® Post processing of molded ARPRO®

Cutting ARPRO®

Method	Advantages	Cutting Tips	Comments
Band saw (horizontal or vertical)	<ul style="list-style-type: none"> All densities possible Standard equipment 	<ul style="list-style-type: none"> High cutting speed and wire cooling are recommended Cutting speed adjustment is needed with density 	<ul style="list-style-type: none"> Rough surface obtained
Hot wire	<ul style="list-style-type: none"> Portable equipment can be used 	<ul style="list-style-type: none"> Use a nickel-chromium wire, speed 0.5 to 2 cm/sec Wire temperature adjustment is required 	<ul style="list-style-type: none"> Thin parts more difficult

Assembling ARPRO®

Glue	Advantages	Processing	Tradename - Supplier (example)
Cyanoacrylate	<ul style="list-style-type: none"> Mono-component 	<ul style="list-style-type: none"> Need surface treatment or primer (e.g. Loctite® 770™) Curing time necessary 	<ul style="list-style-type: none"> Loctite® Hysol 3430™ - Henkel
Aminoacrylate	<ul style="list-style-type: none"> Only clean surface required 	<ul style="list-style-type: none"> Two component glue 	<ul style="list-style-type: none"> Scotch-Weld™ DP-8005 - 3M
Double face adhesive	<ul style="list-style-type: none"> Quick installation 	<ul style="list-style-type: none"> Surface treatment required For temporary applications only 	<ul style="list-style-type: none"> Gerband Klebeband 094500 - Gerlinger
Hot melt	<ul style="list-style-type: none"> Quick system Only clean surface required 	<ul style="list-style-type: none"> Glue gun needed Application to be studied depending on shapes 	<ul style="list-style-type: none"> Jet melt 3764Q – 3M Temperature 140-150°C

Recommended surface treatment: cleaning and degreasing with solvent (such as acetone or alcohols...). Treatment with sandpaper can also be used.

Welding	Advantages	Comments	Equipment used
Hot plate	<ul style="list-style-type: none"> Can be easily automated 	<ul style="list-style-type: none"> Medium investment Higher density of joint area 	<ul style="list-style-type: none"> Commercial welding system slightly modified
Hot air	<ul style="list-style-type: none"> Low investment 	<ul style="list-style-type: none"> Reproducibility questionable Higher density of joint area 	<ul style="list-style-type: none"> Industrial hot air blower

Screwing ARPRO® ARPRO® can also be screwed or assembled to mechanical parts with suitable devices:

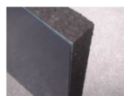


40 to 100 g/l



Further information can be found at www.ejot.com

Thermo-bonder tissue ARPRO® can be linked to other materials using adhesive tissues:



ARPRO® covered with ABS



Further information can be found at www.ab-tec.com

Bulletin: 606

Version: 004

This information is provided as a convenience to customers and reflects the results of internal tests conducted on ARPRO samples. While all reasonable care has been taken to ensure that this information is accurate as of the date of issue, JSP does not represent, warrant or otherwise guarantee, expressly or impliedly, the suitability, accuracy, reliability or completeness of the information.



Appendix H – Workshop SAR, Y1 evaluation

Appendix H presents the workshop results and the workshop procedure.

When and Where:

18th of February at, The Royal institute of technology, KTH, Stockholm

Purpose and aims of the workshop:

Evaluate Y1 concept prototype, the result from MF2061 project course.

Notes for the workshop holders

- One of the workshop holders takes notes while the other one asks the questions
- Let them guide the discussion to a certain degree.
- Keep the conversation light and constant
- “All ideas are good ideas”

Participants:

Per-Magnus Grönlund

per-magnus.gronlund@sjofartsverket.se

Marcus Johnson

marcus.johnson@sjofartsverket.se

Procedure

- Start with a quick summary of the results from the MF2061 course
- Discuss lightly, cost, materials and mounts
- Present the Y1 prototype concept
- Let them feel the prototype and talk aloud
- Discuss issues and improvements

Result

- Possible to fit different types of goggles
- Customizable
- Create a flush camera mount (Prevent the winch from attaching to the camera)
- If the camera falls of, a safety line is required to prevent the user to lose the camera
- A camera mount that can fit all
- Easy to push on and off with thick gloves
- Possible to integrate the snorkel
- The top of the snorkel sticks out which can interfere with wires and other rescue equipment.
- The snorkels nozzle can sometimes be in the way
- Position light , blinking or as constant light.
- A light that works well under NVG conditions
- Changeable concave cover for the position light in different colours, Green and Blue
- Possibility to use a 3,5 mm plug and a NATO plug (VHF) for the communication system
- A block solution to customize the ear area.
- An easy retainer system that is easy to operate with one hand using a thick glove.

- More robust retainer system
- Batteries to provide power to all the lights or batteries for each component
- Cut out reflexes or integrated reflexes
- No ear modules, better comfort. One solution for all with integrated communication that can be removed as pleased.
- Face mask to protect against harsh winds and cold environments.

Appendix I - Design Guideline

Guidelines and requirements and desirables gathered from the customers and research are listed below.

General

1. Protect user's head from impact and sliding, PAS 028 (Marine safety standard)
2. Tailored & ergonomic fit
3. Light weight
4. Balanced weight
5. No sharp edges to prevent wires/cables from getting stuck
6. Ventilation (air & water)
7. UV-light resistant
8. Highly visible, colour contrast to environment
9. Withstand multiple blows
10. Scratch and salt water resistant
11. Operate in temperatures specified in PAS 028 (Marine safety standard)
12. Similar price as the competitors
13. Interface suitable to be handled with thick gloves
14. Form languages as the H1 helmet
15. Metal parts on the helmet should be resistant to corrosion on exposure to salt water.
16. The parts on the helmet that comes in contact with the skin should not undergo alterations from the effect of sweat and toiletries.
17. The shell should not extend more than 10 mm from the inner liner.
18. The helmet should protect the wearer at least to the FF'' plane according to PAS 028.
19. All edges should be smooth and rounded.
20. Rigid projections on the inside of the helmet are not allowed.
21. External projections shall not exceed 5 mm.
22. The retention system should always be fixed on the helmet together with a chin strap
23. The chin strap shall not be less than 18 mm wide.
24. The mass of the helmet shall not be more than 700 grams.
25. A peak is not allowed to be integrated with the helmet.

Functions

26. Intercom-system
27. Work light
28. Position light
29. Camera
30. Optional mouth cover and snorkel
31. Eye protection from sun, wind, water and debris
32. Controls adjustable with gloves
33. Attachable visor
34. Mounts

Desirable

35. Detachable intercom-system (suggested Peltor or waterproof speakers)
36. Same intercom-system for both in & out of the helicopter
37. Intercom that allows the wearer to hear the outside sound
38. Integrated lights
39. Flush camera
40. Prevent wires to interfere with components on the helmet

41. Customizable
42. Mounts according to the users need
43. Retainer system that is easy to manoeuvre with thick gloves
44. Suitable for relevant markets (SSRS, Extreme sports, FMV)
45. Optimized for marine application
46. Certified (standards BSI and IP)
47. Easy to charge lights and intercom
48. Lifetime of 5 years
49. Scratch resistant light cover

X-factor

50. Live camera feed to helicopter
51. Integrated battery-pack for all components
52. Attractive design
53. Pre manufactured waterproof lights
54. Pre manufactured waterproof intercoms

Appendix J – Interview Mikael Swaren

An interview conducted with Mikael Swaren from Mittuniversitet. The questions and answers are presented below:

Meeting with Mikael Swarén Monday 31/3 2014

Har ni tillgång till dokumentation om olika standarder? Vi skulle behöva låna PAS 028

Hur mycket kostar det att certifiera enligt en standard?

Kolla med SP

Materialprovbitar vs. hela hjälmar för att utföra impact-tester. Eller finns det något lättare sätt att ta reda på vilken tjocklek linern ska ha?

Går att testa mindre bitar för att få ut någon form av materialkonstant. Förslag att placera en lastcell/trycksensor under provbiten och släppa en vikt. Borde finnas möjlighet att utföra liknande tester på KTH.

Vilka tester skulle du rekommendera? Vad bör vi tänka på när vi designar hjälmen?

Ring och hör med SP, Swerea, Sweco och POC.

Vilka tester skulle vi kunna utföra i er testverkstad?

Främst ett textil-lab där man kan utföra utmattningsprov. Finns även en automatisk rigg i Åre som gjordes för att testa POC-hjälmar mot upprepade smällar från slalomkäppar.

Vilka är de svåraste testerna?

Vad för tjocklek och material har POC hjälmar? Vilken POC hjälm har klarat de tuffaste testerna och vad för material hade den?

Osäker, bäst att höra med POC. Nummer till produktchef Oskar Huss är 073-2033141.

Vilka liner-material klarar bäst små repeated impact men även medelstora impacts?

UPD, EPP, Supracore.

Vilka egenskaper bör man titta på när man väljer liner och outer shell?

Vilken typ av smällar hjälmen utsätts för, stora/små, om de är upprepade osv., och var de kommer ifrån.

Vad är skillnaden mellan ett hårt skal och ett mjukt skal?

Hårda skal absorberar mer vid större smällar (spricker) men mindre relativt mjuka skal vid små smällar då de inte flexar lika lätt. Detta kan kompenseras för med en något mjukare liner.

Vilka material skulle du rekommendera för oss? Liner och outer shell?

En inner liner som har varierande densitet, ex hög densitet EPS ,där det finns risk för stora smällar, kombinerat med låg densitets EPS för mindre smällar. EPP då det främst finns risk för upprepade, mindre slag. Går att göra skalet något tunnare om man limmar ett lager aramid (kevlar) på insidan som skyddar mot penetration. Det funkar som ett bra säljargument, syns att man tänkt till.

**Vad för typer av material-kombinationer har du sett som du skulle kunna rekommendera oss?
(galna ideer)**

Memoryfoam för komfort liner (ex som i skidpjäxor). Tror inte så mkt på in-mould (outer shell och liner gjuts i ett), mer formfrihet vilket oftast leder till snyggare hjälmar, men är samtidigt ömtåligare. Möjligtvis en kärna i Supracore som är täckt med UPD eller liknande, för att förhindra att cellerna fylls med vatten.

Tillverkning - vakuumformning, formblåsning eller formsprutning? Vi ska tillverka en relativt liten serie och det lutar just nu därför åt vakuumformning. Vet du om det skulle påverka materialegenskaperna till skillnad från formsprutning?

Formar för formsprutning kostar ca 150 000 - 200 000kr att tillverka i Sverige. Gör formarna i Kina kostar det ca 30 000kr. Tips att kontakta Mälarplast, de har kontakter i Kina. Handelskammaren kan för övrigt ha koll på vilka företag i Kina som är säkra att göra med. Kolla även med ESSGE-plast i Östersund.

Hur skulle hjälmen påverkas vid en impact om linern är helt limmad med skalet eller om den är punktlimmad?

Svårt att säga, krävs tester för att avgöra.

Vad tycker du om "onesize fits all"? Hjälmar med skal bestående av flera rörliga delar ex. hockeyhjälm.

Viktigt att hjälmen håller ihop även efter en smäll som eventuellt spräcker skalet, eller om spännet under hakan släpper.

Övriga kommentarer:

- Ny standard för störtloppshjälm, hjälmarna måste nu max 230 g från ett fall på 6,8m.
- Störande om pannlampan eller kameran ändrar position om man träffats av en våg.
- En tredje dels visor bra i vatten mot solljus.
- Vid höga fall i vatten, eller om vatten tränger in under hjälmen under högt tryck är det viktigt att det finns utlopp så det inte trycker mot öronen.

Appendix K – Material properties

Materials gathered from the competitor analysis. The material data is extracted from CES EduPack, Granta design limited.

Material	Density [kg/m ³]	Material cost [Sek/kg]	Manufacturing cost, annual quantity of 1000	Young's modulus [GPa]	Yield Strength [MPa]	Tensile strength [MPa]	Elongation [%]
ABS (High impact)	1030	20.9	Medium	1.755	29.6	36.85	40
ABS (20% glass fibre, injection molded)	1200	25.9	High (Injection molding, low quantity)	5.585	64.8	81	2.5
PC/ABS	1110	29.95	Medium	2.515	37.55	45.5	87.5
ABS + PA (PA6 or PA66)	1080	31.5	Medium	1.325	32	42	74.25
ABS (20% carbon fibre, injection molded)	1135	61.45	High (Injection molding, low quantity)	13.1	85.2	106.5	1.5
PC (High viscosity, molding and extrusion)	1200	29	Medium	2.38	62.15	67.5	115
PC (10% Glass fiber)	1275	35.3	Medium	3.62	63.8	58.5	7
HDPE (high molecular weight)	951	12.45	Medium	0.938	23.1	23.5	485
PP (Copolymer, impact, low flow)	900	20.85	Medium	1.0365	12.65	23	441
Fiberglass	1650	39.25	High (labor instensive hours/unit)	20.7	151.5	189.5	1.25
Carbon fibre	1550	165.5	High (labor instensive hours/unit)	109.5	248.5	310.5	1.25

Material properties: CES EduPack

Material	Fatigue Strength [MPa]	Fracture toughness [MPa*m ^{0.5}]	Hardness - Vickers [HV]	Impact strength Notched 23°C [kJ/m ²]	Max Temperature [°C]	Min Temperature [°C]	Water resistance [Fresh, Salt]	UV Resistance
ABS (High impact)	14.75	2.375	8.9	35.3	70	-40	Excellent	Poor
ABS (20% glass fibre, injection molded)	32.65	3.1	19.45	5.755	77	-40	Excellent	Poor
PC/ABS	18.4	2.815	11.25	36	70	-35.5	Acceptable	Fair
ABS + PA (PA6 or PA66)	16.8	3.41	9.61	84.9	70	-57	Acceptable	Poor
ABS (20% carbon fibre, injection molded)	43	3.605	25.55	5.25	77	-40	Excellent	Poor
PC (High viscosity, molding and extrusion)	27.25	2.2	18.65	85.85	111.5	-42	Excellent	Fair
PC (10% Glass fiber)	23.45	4.07	20.8	12	116	-42	Excellent	Fair
HDPE (high molecular weight)	9.5	1.615	6.95	80.1	120	-77	Excellent	Fair
PP (Copolymer, impact, low flow)	9.085	1.475	7.66	17.9	100.6	-18.5	Excellent	Poor
Fiberglass	75.8	61.3	45.45	157.5	180	-98	Excellent	Fair
Carbon fibre	125.5	32.05	74.5	94.5	175	-98	Excellent	Good

Material properties: CES EduPack

Appendix L – Material Benchmark

A Pugh matrix was used to benchmark the materials gathered from the competitor analysis.

Material	The normality limit	ABS (High Impact)	ABS (20% glass fibre, injection molded)	PC/ABS (PA6 or PA66)	ABS (20% carbon fibre, injection molded)	PC (High viscosity)	PC (10% Glass fiber/injection molded)	HDPE (high molecular weight)	PP (Copolymer, impact)	Fiberglass (Epoxy SMC)	Carbon fibre (Epoxy SMC)
Density [kg/m ³]	930-1130 [kg/m ³]	0	-	0	-	-	-	+	+	-	-
Material cost [Sek/kg]	25-30 [Sek/kg]	+	0	-	-	0	-	+	+	-	-
Manufacturing cost (annual quantity of 1000)	Medium cost range	0	-	0	-	0	-	0	0	-	-
Young's modulus [GPa]	1-2 [GPa] Upper limit 12[Gpa]	0	+	+	-	+	+	-	0	-	-
Yield Strength [MPa]	25-35 [MPa]	0	+	+	+	+	+	-	-	+	+
Elongation [%]	30-50 [%] Upper limit 100%	0	-	+	-	0	-	0	0	-	-
Fatigue Strength [MPa]	10-30 [MPa]	0	+	0	+	0	0	-	-	+	+
Fracture toughness [MPa*m ^{0.5}]	2-4 [MPa*m ^{0.5}]	0	0	0	0	0	0	-	-	+	+
Hardness - Vickers [HV]	10-20 [HV]	-	0	0	-	0	+	-	-	+	+
Impact strength Notched 23°C [kJ/m ²]	20-50 [kJ/m ²]	0	-	0	-	+	-	+	-	+	+
Max Temperature [°C]	60-80 [°C]	0	0	0	0	+	+	+	+	+	+
Min Temperature [°C]	(-30)-(-50) [°C]	0	0	+	0	0	0	+	-	+	+
Water resistance (fresh, salt)	Excellent, Acceptable	+	+	0	+	+	+	+	+	+	+
UV Resistance	Fair	-	-	0	-	0	0	0	0	0	+
Number of Equals (0)		10	5	11	8	3	8	3	3	1	0
Number of Positive score (+)		2	4	3	3	4	5	6	4	8	9
Number of Negative score (-)		2	5	0	3	7	1	5	7	5	5
TOTAL		0	-1	3	0	-3	4	1	-3	3	4

Appendix M - Underlay

Underlays used for sketching.



Appendix N - HOWL meeting

Preparations including questions and a step by step guide and the feedback received.

Möte med HOWL Design

- 12: 30, leave from KTH.

Start with presenting the results since last meeting:

- Benchmark material
- Benchmark manufacturing methods (Contacted several manufacturers in Sweden and asked for quotas)
- Conducted a simple cost evaluation
- Investigated helmet standards
- A competitor and market analysis
- Analyzed mounts today and possibilities for attachments
- Examined the tests that needs to be performed and how to conduct them.
- Evaluated anthropometrical dimensions for a head and created a 3D model of a head according to EN960.

Present the sketches/ concepts

- Start with the favourite sketches
- Talk about the overall construction of the helmet.
- Mount concepts

Feedback:

- Looks very good, likes the defined lines and the goggle strap area.
- Try to avoid the sporty look, it should look more professional
- The mounts should play along with the rest of the components.
- The helmet should be geometrical but also dynamic.
- “A sense of moving forward”
- Ask yourselves what the helmet would look like without ear covers, the third-party ear protectors should be following the design of the helmet or vice versa.

Questions

1. Should we create our own mount concept or use standard components available?
 - Your own, but create space for today's solutions.
2. What type of comfort liner (material) do you use today, H1 Helmet? Distributor?
 - Not decided yet
3. The H1 helmet uses a NVG mount, correct? Any problems with patents?
 - Yes, the H1 helmet will have its own mount concept. Do the best you can, the best helmet and the patent problems and other problems can be solved later.
4. Ear covers or one complete helmet?
 - Ear covers would be good, bigger market and the ear covers makes the helmet look better, more proportionate.
5. Could we borrow a BOA retention system?
 - Those are Franklys, we have to talk to them first. It is otherwise the helmet manufacturer that designs them. Because they have developed helmets before, they will have the knowledge on how to implement them.

6. Where did you get the scanned headform? What templates do you use when designing the inside of the inner liner? The three inner liner dimensions per shell, do they vary in thickness or form?
 - We follow POC helmets, we have not decided completely on the templates.
 - The inner liner varies in thickness, but it is always the helmet manufacturers that decides which the different sizes. Depending on which helmets they create after.
7. Why 9 helmet sizes?
 - Because MSA has it
8. In that case, should we design our own or follow your template? (less cost when manufacturing mould)
 - You should preferably design your own, no need for 9 sizes. Maybe 3-4 because the user also has a neoprene headpiece under.

Appendix O – SAR Concept Evaluation

Appendix Q consists of the feedback from Per-Magnus Grönlund and Marcus Johnson, conducted by mail.

Feedback Y1, juni-14

Hej grabbar, ledsen för väldigt sen respons. Både jag och Per-Magnus har varit bortresta/upptagna senaste tiden.

Angående konceptbilderna ni skickade så ser de mycket bra ut, koncept 2 är den som ser bäst ut enligt oss.

Det är svårt att ge utförlig feedback baserad på bilderna, eftersom det är först när all utrustning vi behöver är monterad, som det är lättare att kunna se brister samt styrkor. Ni skrev att de integrerade lamporna samt snorkeln är tekniskt svåra att få till, och det förstår vi, men det innebär även att hjälmen i sin helhet är ganska lik andra hjälmar, och kanske därför främst kommer att konkurrera med hjälp av sitt utseende. Koncept2-hjälmen ser mkt bra ut och borde därför kunna slå sig in på marknaden. Angående fästsystem för de olika tillbehören tror vi att det skulle vara klokt att kunna göra det kompatibelt med befintliga system, syftar då på nato-skena (det system som finns på ops-core). Nackdelen med nato-fästena är att de bygger ut ganska mycket, men försänkningarna ni nämnde skulle ju kunna reducera utsticket något. Kanske går det att fästa era fästen på nato-fästet, eller tvärtom, för att få mer kommersiell kompatibilitet. Det är ju önskvärt för kund att en inköpt hjälm är någorlunda tidlös, så när kameror och lampor utvecklas med tiden så kan man ändå köpa dem och fästa på sin hjälm, då är ju en vanlig förekommande fästes-standard önskvärd.

Skåran för goggle-remmen är säkert bra för att hålla fast glasögon, men det kan även göra det svårt att sätta upp glasögonen i pannan, men då finns ju även utfasningen längs hjälmen sida, så man kan ju välja att inte använda skåran så funkar det nog bra ändå. Ett välintegrerat clip i bak på hjälmen skulle vara väldigt praktiskt för att inte riskera att tappa glasögonen.

Det runda hålet i hörselkåporna ser mkt bra ut, bra för ljudinsläpp om man vill det, det ger även hjälmen en helt egen och solid look.

De fjäderbelastade hörselkåporna som kunde fästas på koncept1 brukar av erfarenhet inte vara någon hit i vatten, men det finns säkert andra användare som ser nyttan med dem.

Att kunna välja om man vill ha visir eller inte är mycket bra. Vi påminner igen om att det är bra om man kan modifiera inredningen för att få en individuellt bra passform.

Vi tycker ni har jobbat på väldigt bra och det ska bli mycket kul att få se prototyperna när de är klara.

Hur ser er tidsplan ut, när ska x-jobbet presenteras, och vad har ni för resultatmål innan ni känner er färdiga med projektet?

Mvh

Marcus & Per-Magnus

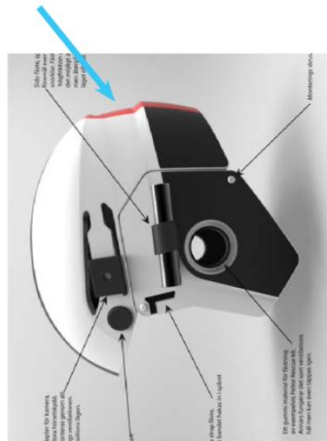
Appendix P – HOWL concept evaluation

The complete feedback received from HOWL design studio, including the rendered pictures.

Feedback

Jag vill börja med att säga att jag är grymt imponerad av det arbete ni har genomfört och de båda koncepten ni visar. Jag har full förståelse om tiden är knapp och ni har begränsad tid att göra eventuella justeringar men jag vill ändå ge så rättvis feedback som möjligt.

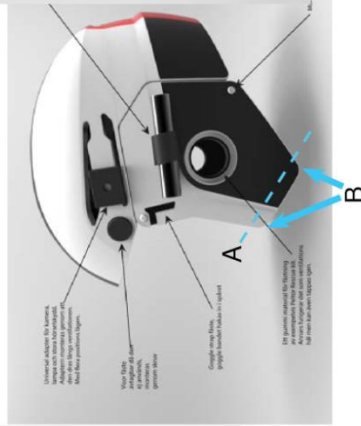
Funktion
Jag tror att det är nödvändigt att fästa googlas resorband bak på hjälmen. Tänker att när yrtårgåvan hoppar i vattnet så kommer vattnet vilja slita av googlarna från hjälmen. Det är bra att ni gjort ett spår på hjälmen där bandet skall löpa, vilket också adderar synvinkeln till plastskålet och karaktär till designen.



Funktion
EPP skummet skulle kunna få något större radier och med det bli mjukare mot den som bär hjälmen.



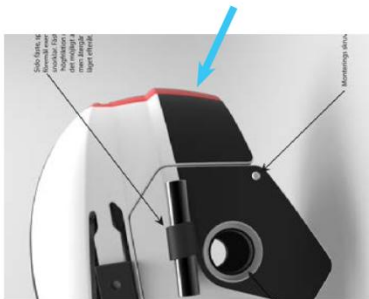
Funktion
Det skulle vara bra att få verifierat att sidkliporna på Konzept 2 inte sticker ner för långt, dvs om det finns risk för att den delen begränsar rörelsefriheten. Jämför jag Konzept 1 och 2 så ser Konzept 1 mer balanserad i detta avseende. Eventuellt handlar det om att korta av sidorna något (1). Jag tror också att Konzept 2 skulle må bra av lite större radier (mjukare) i nedre kant (2).



Funktion
Visieret skulle behöva slimmas. Detta med tanke på att vi vill undvika alltför mycket utstickande delar på hjälmen som kan lastna eller begränsa rörelsefriheten.



FormUttryck
 Koncept 1 skulle må bra av att tryckas in något i nacken, om det är möjligt ur ergonomihänsyn. Då skulle den yttersta punkten flyttas upp och hjälmen skulle få en finare kontur. Här är Koncept 2 bättre. v



FormUttryck
 Designelementet med infästning för kamera på Koncept 1. Skulle kunna lita lite bättre med övriga designelement. Hur hölls den sig till den svarta grafiska elementet (A) och behången (B)? Nu känns den lite som en "inlagd".



FormUttryck

Jag tycker det svarta fältet på Koncept 1 som ett grafiskt element (stickar eller lock) och inte separat del.

Jag tycker att det svarta fältet skulle må bra av rader (blå pil) för att lita bättre med genomgående formspråket på Koncept 1 hjälmen.



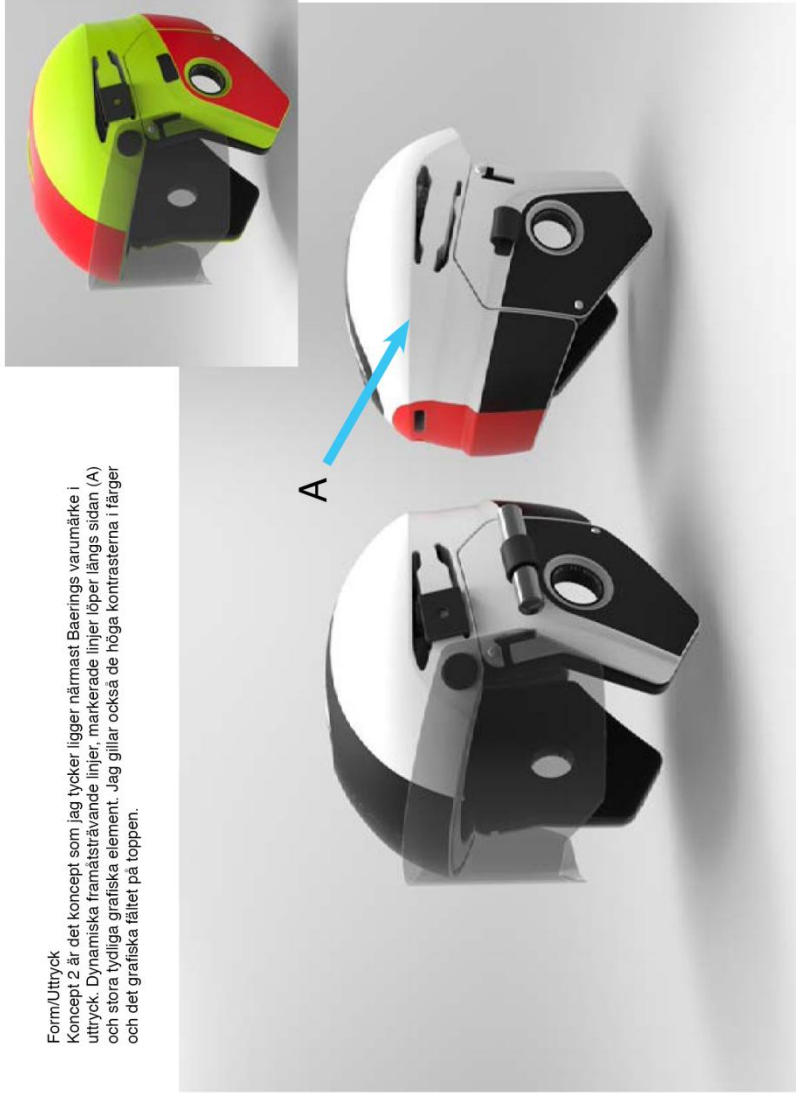
FormUttryck

Svajande linje. Antingen är det en synvilla eller så svajar den på linjen något (där blå pil pekar). Just markerade linjer som denna är det extra känsligt och avslöjande om de är ojämna.

Det vita fältet på toppen skulle kunna vara lite kortare för att göra det röda fältet bredare. Som det är nu så upplever jag att det svarta och vita fältet på toppen "brakar med varandra". v



Form/Uttryck
Koncept 2 är det koncept som jag tycker ligger närmast Baerings varumärke i uttryck. Dynamiska framåtrivande linjer, markerade linjer, löper längs sidan (A) och stora tydliga grafiska element. Jag gillar också de höga kontrasterna i färger och det grafiska fältet på toppen.



Appendix Q – Companies contacted

The list of companies contacted regarding prototype manufacturing are presented below

Potential companies for producing prototype

Company name	Manufacturing method	Materials	Contact	Contacted by	Last contact	Price for tooling	Price for helmet	Link
Modellservice	Vacuum forming	Thermoplastics	peter.holm@modellservice.com	Artur	3-18-2014	23000	1280	www.modellservice.se
Opido	Vacuum forming	Thermoplastics	robert.hovnell@opido.se	Timu	3-18-2014	8000-10000	1500	http://www.opido.se/Swedish/Samiad-kompetens
Fermprodukter	Vacuum forming		Website	Timu	3-18-2014	Don't have time	Don't have time	http://fermprodukter.se/
Special-Plast AB	Vacuum forming EPP		sales@special-plast.se	Timu	3-18-2014	Don't have time	Don't have time	http://www.special-plast.se/
Premould	Formsprutad Prototyp	Thermoplastics	info@premould.se	Timu	3-19-2014	150 000 - 200 000	Low	http://www.premould.se/
Prototal	Formsprutad Prototyp SLS Vacuum forming	A big variety of plastics	info@prototal.se	Timu	3-19-2014	15-25 000	7-900	http://www.prototal.se/
Modell & Prototyp	Formsprutad Prototyp SLS Vacuum forming	Polyurethane, Stark ABS, PS, PA	Website	Timu	3-19-2014	Does not have the right material	Does not have the right material	http://www.modellprototyp.se/
Weta plast	Vacuum forming prototype		peter@wetaplast.se	Artur	3-19-2014	10000-15000	150	http://wetaplast.se/sv
Stegoplast	Vacuum forming		goran.bjarle@stegoplast.se	Artur	3-19-2014	Don't have time	Don't have time	http://www.stegoplast.se/Vacuum/vacuum.asp
GT Prototyper	SLA, SLS prototyper	Polyamide	ingela@gtp.se	Timu	3-19-2014		6000	http://www.gtp.se/
AQ Plast	Injection moulding	A big variety of plastics	anders.gustafsson@aqg.se	Timu	7-19-2014	210 000	21,41 for a 1000 helmets annually	http://aqg.se/sv/plast/aq-plast
Formplast	Vacuum forming and pressure forming	Thermoplastics	Ola.Listerud@formplast.se	Timu	7-19-2014	Mold: 34000 CNC-fixture: 7500	200	http://www.formplast.se/

Appendix R – Thermoforming Guide

An extract from Arla Plast thermoforming guide, consists of the pre-drying temperature for PC and ABS.

THERMOFORMING

Thermoforming Processing Parameters

Mold And Set Temperature

The set temperature is the temperature which the thermoplastic sheet hardens and can be safely taken from the mold. This is generally defined as the Heat Distortion Temperature at [455kPa]. The closer the Mold Temperature is to The Temperature (without exceeding it), the less you will encounter internal stress problems in the part. For a more rapid cycle time, if post shrinkage is encountered, post cooling fixtures can be used so that parts may be pulled early.

Lower Processing Limit

This column shows the lowest possible temperature for the sheet before it is completely formed! Material formed at or below this limit will have severely increased internal stress. The least amount of internal stress is obtained by hot mold, hot sheet, and very rapid vacuum and/or compressed air.

Predrying times (based on 1 mm material)			*PC Sheet thickness Predrying time	
Material	Drying Temperature	Drying time per 1 mm	(mm)	125°C (h)
ABS	85°C - 90°C	1,5-2 h	1	1
			2	3
			3	4
			4	8
			5	16
PC	120°C - 125°C	See table*	6	24
			8	36

Normal Forming Temperature

This is the temperature which the sheet should reach for proper forming conditions under normal circumstances. The core (interior) of the sheet must be at this temperature! The normal forming temperature is determined by heating the highest temperature at which the sheet still has enough hot strenght to be handled, yet below the degrading temperature.

Upper Limit

The Upper limit is the temperature at which the thermoplastic sheet begins to degrade or decompose. It is crucial to ensure that the sheet temperature stays less than this limit. When using radiant heat the sheet surface temperature should be carefully monitored to avoid degradation while waiting for the "core" of the material to reach forming temperature. These limits can be exceeded, if only for a short time, with a minimum of impairment to the sheet properties.



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Appendix S – MIPS test plan

Helmet testing, a day at MIPS

The meeting is scheduled at 14:15 on 13/11

Leaving from Tekniska at 13:00

Agenda

- The meeting will start with a quick analyze of the helmet with the MIPS system, additional tweaks if needed.
- A total of seven helmets, where three of them are made with EPP 45 and four with EPP 55
- Two helmets are equipped with MIPS, one EPP 45 and one EPP 55.
- Four helmets tested with the rotational drop method. (Two EPP 45 and Two EPP 55)
- Four helmets tested with the standard falling headform method. (Two EPP 45 and Two EPP 55, where one of the EPP 45 from the rotational drop method is reused due to few helmets).

Rotational test method:

- EPP 45 original, helmet 4
- EPP 45 with MIPS, helmet 2
- EPP 55 original, helmet 3
- EPP 55 with MIPS, helmet 7

Fallingheadformmethod:

- EPP 45, drop height 1,8 m, helmet 4 (reused from previous test)
- EPP 45, drop height 2,0 m, if the previous helmet passed the failure threshold, helmet 6
- EPP 55, drop height 1,8 m or 2,0 m, helmet 1
- EPP 55, drop height 1, 8 m or 2,0 m, helmet 5

If possible reuse helmet 3 and helmet 6 for additional rotational testing together with MIPS

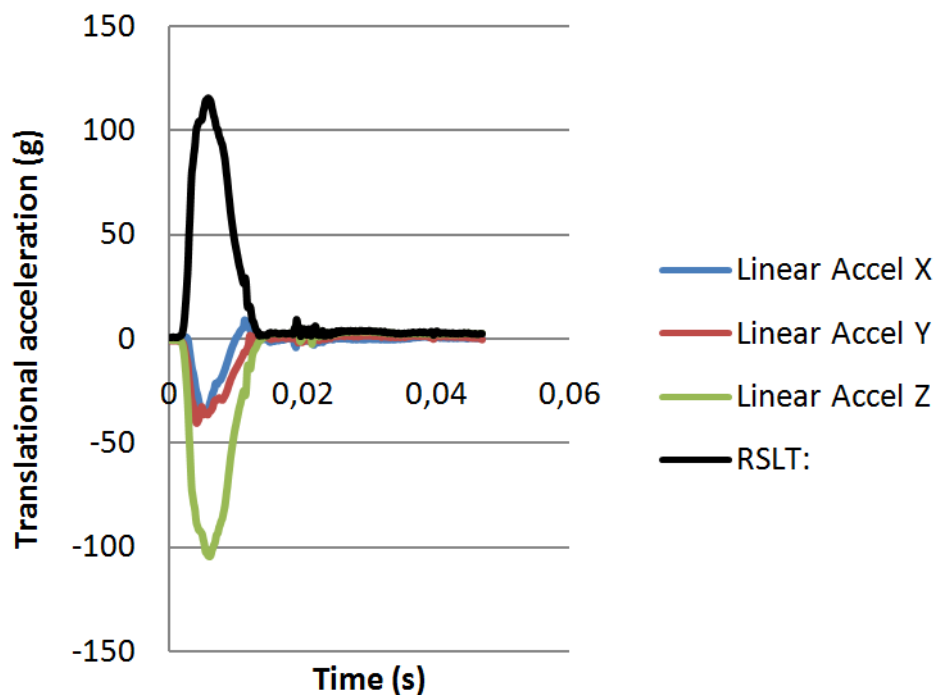
Appendix T - MIPS test Results

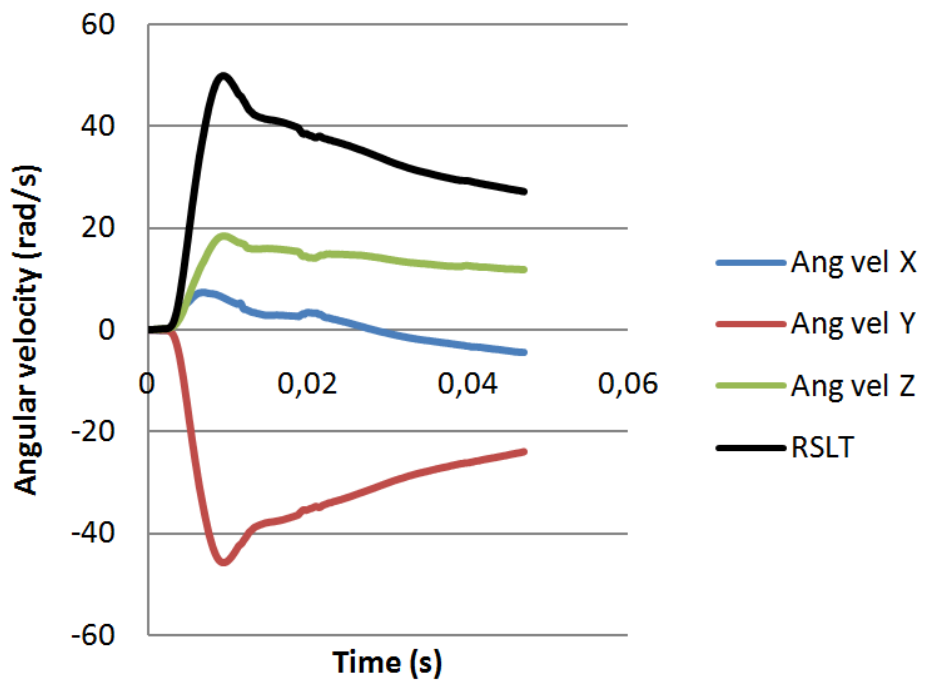
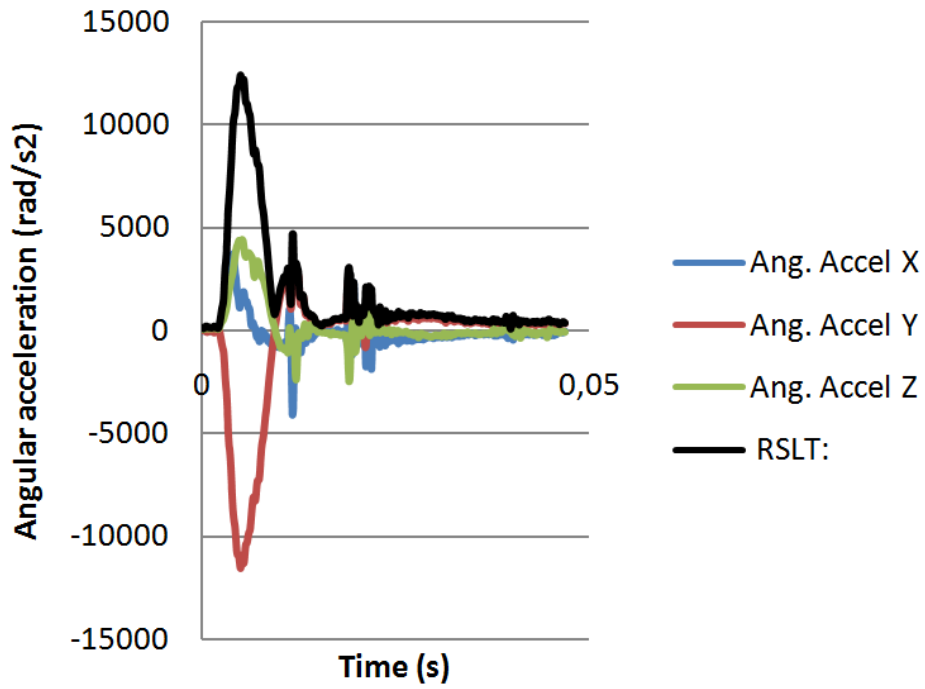
Appendix X presents the data and results from the drop tests performed at MIPS faculty. MIPS test results follows the procedure stated in the test plan, Appendix U.

Angular drop test method procedure:

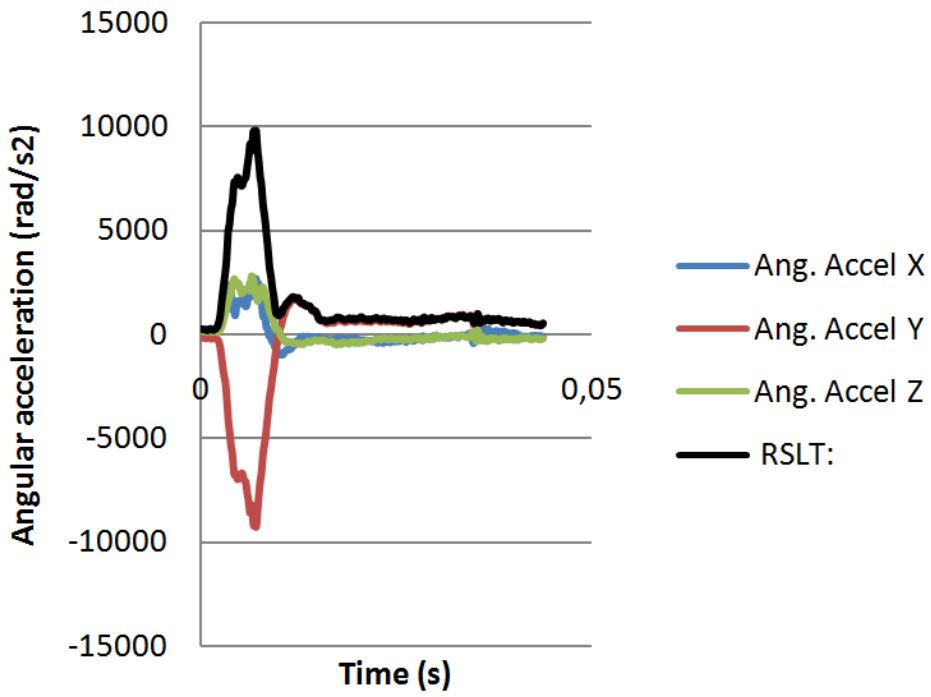
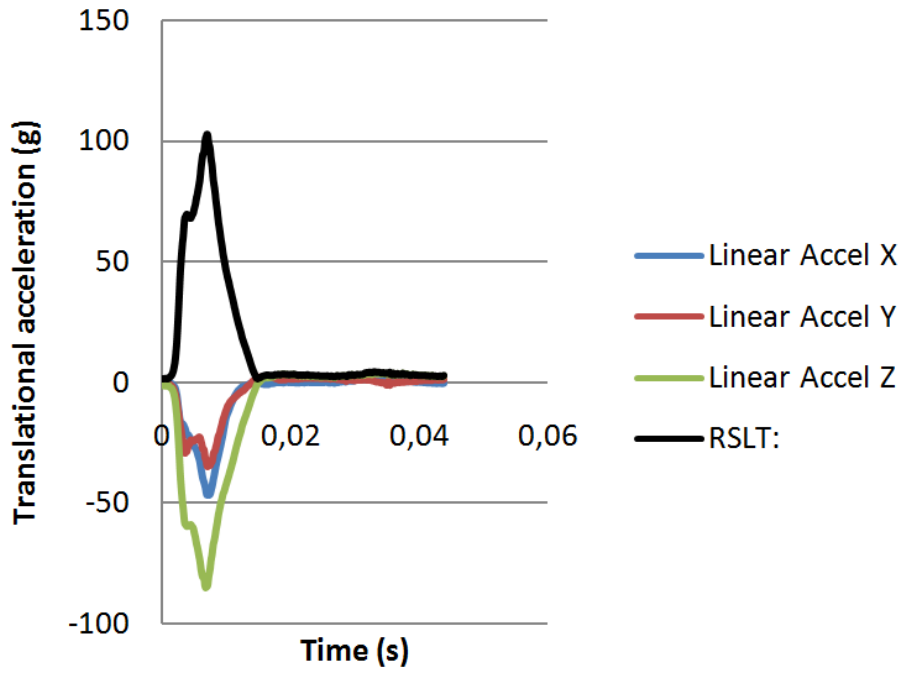
- A headform from a crash dummy (Hybrid III) with a head circumference of 58 is assembled with the helmet.
- The helmet and headform is dropped from 1,05m with a horizontal speed of XXX relative to the ground.
- The helmet is angled XX degrees.
- The failure threshold is 100g.

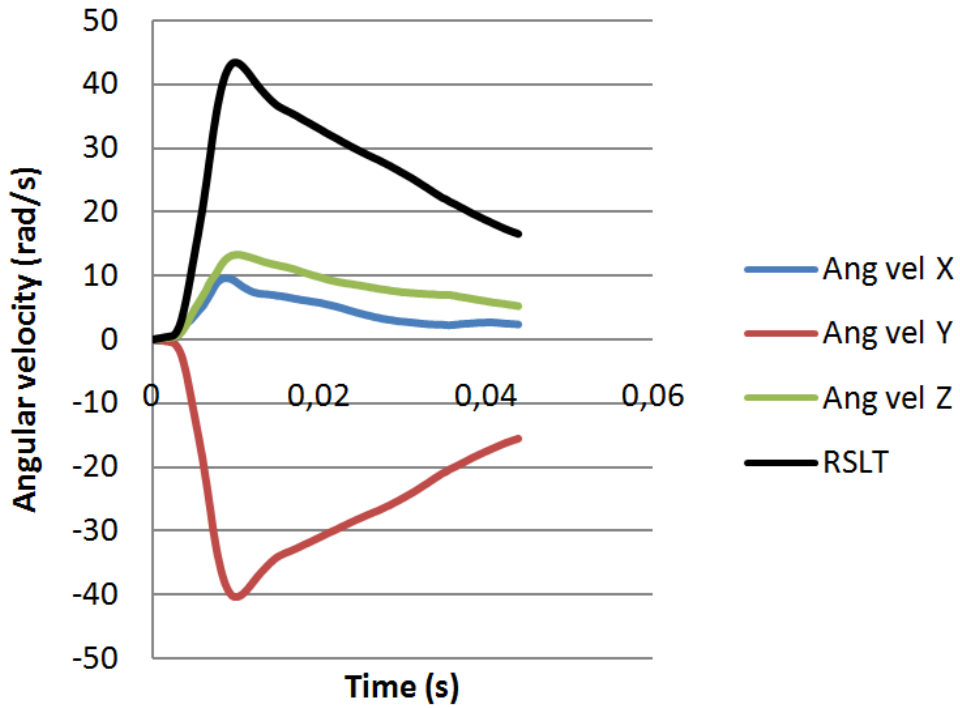
Helmet 4 with EPP45 without MIPS



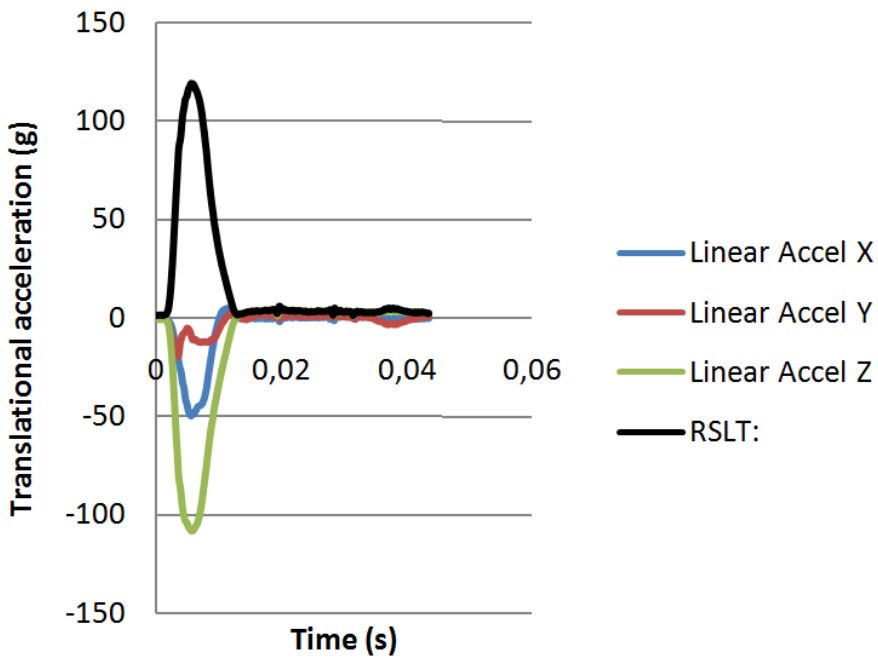


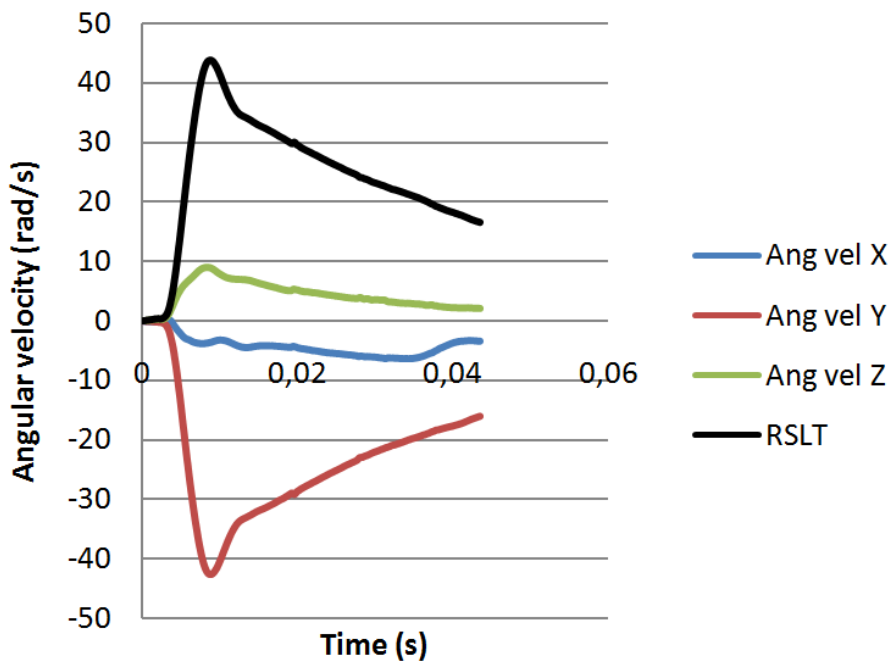
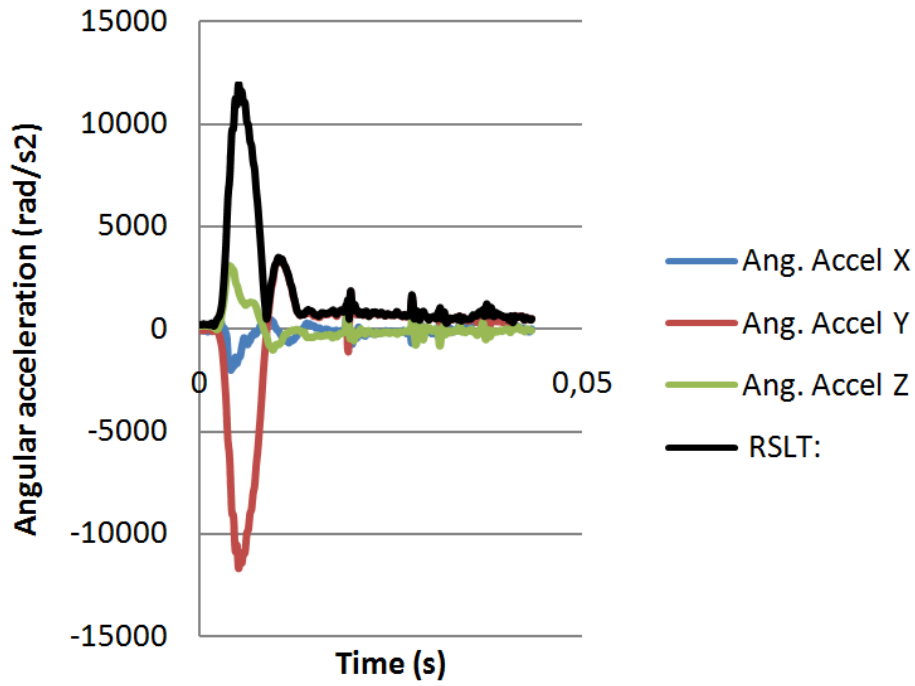
Helmet 2 with EPP45 with MIPS





Helmet 3 with EPP55 without MIPS





Helmet 7 with EPP55 without MIPS

