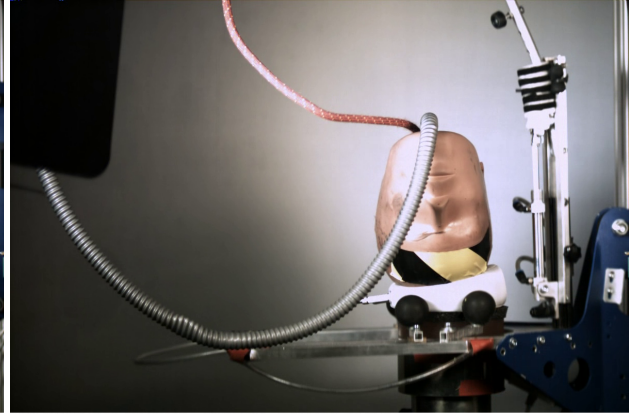
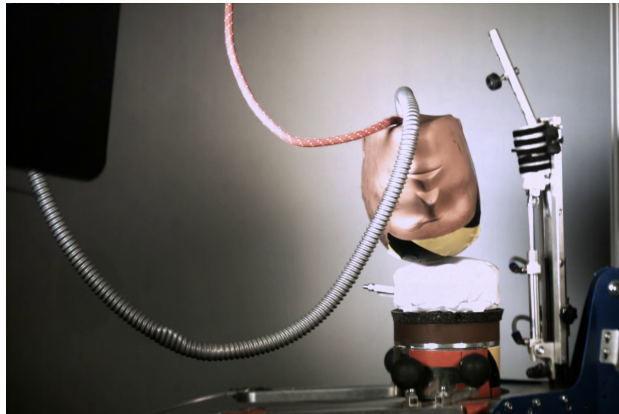


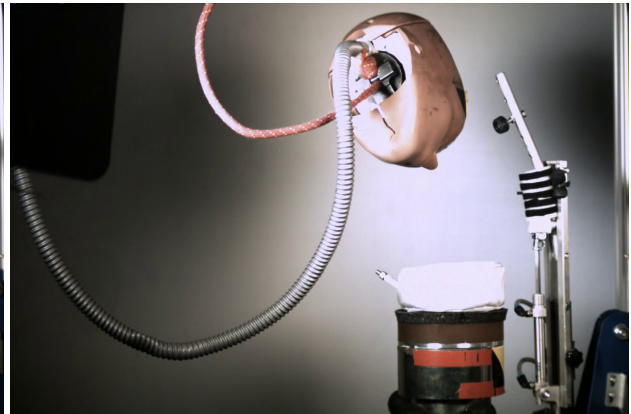
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# Investigating an airbag enhanced head protection solution

Using air to reduce rotational forces to the brain

M.Sc. Thesis in Industrial Design Engineering

**ELIN CARLSSON**

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M.SC. THESIS REPORT 2024

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**CHALMERS**  
UNIVERSITY OF TECHNOLOGY

Department of Industrial and Materials Science,  
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Investigating an airbag enhanced head protection solution  
Using air to reduce rotational forces to the brain  
ELIN CARLSSON

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statements in this thesis, reflect the author's own views.*

Cover: Testing an "air puck" prototype by dropping a test dummy head onto it.

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## Abstract

Traditional, foam-based helmets do a sufficient job protecting against linear impacts, but are not designed for angled ones. In other words, if you were to crash with your bicycle, as long as you wore a helmet you most likely avoided skull fracture - the injury type most related to linear impacts. You could however very well have suffered a concussion, which is the most common type of injury linked to angled impacts.

Angled impacts bring on rotational acceleration to the brain, causing its structures to shear and stretch. This is something that it does not cope with well. The brain has an in-built protection against some levels of rotational violence, but it has not evolved to cope with the speeds and forces related to e.g. skiing or cycling. As a reaction to this, Mips AB developed their 'Multi-directional Impact Protection System' - the MIPS layer. It is the most successful solution to address rotational violence in helmets today.

The company has filed a patent on a helmet concept that uses air filled elements - or "airbags" - to achieve the same function as the MIPS layer. The project has started from the patent idea and investigated whether the idea is feasible, predominantly through prototyping and testing in Mips' test lab in Täby.

**Keywords:** *mountain biking, MIPS, concussion, brain injury, rotational violence, helmet, head protection, airbag, Hövding*



## **Preface**

This report is based on a master's thesis carried out at the Department of Industrial and Materials Science, Division of Design & Human Factors at Chalmers University of Technology. The project started in November 2016 and was presented in June 2017. The project's scope was 30 ECTS and was done in collaboration with the company Mips AB.

Final work was made to the report during spring 2024.



## Acknowledgements

I would like to thank everyone at Mips for making me feel so at home at the office in Täby, and letting me be a part of meetings, trips, and parties. A special thanks to Sara Dybäck for always lending a helping hand. I could not have done this without you. Thanks to Marcus Arnesen for letting me talk you into doing a finite element analysis for my project, despite having your own thesis to attend to! Thank you Peter Halldin for supervising the project and thank you Yogen Patel at Autoliv for being available for meetings that gave me another point of view on the project.

Thanks to Örjan Söderberg for reminding me of what designers do during the project, and to Lars-Ola Bligård for help with the report during the final weeks. Lovisa and Mariell, thank you for encouragement and comments on my report, and for being great ski company!

I would like to thank Louise, Sofie, Christoffer, Maria, Johanna and Lily for support and also stepping in for peer review from time to time during the project.

After completing the bulk of the thesis and presenting, many years passed until I finally got to it and finalized the work - and that is something I'm very happy about today.

Till min familj!

Elin Carlsson, Gothenburg, May 2024



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# CHAPTER ONE

# INTRODUCTION

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The first chapter gives background to the project alongside details regarding its scope and limitations.

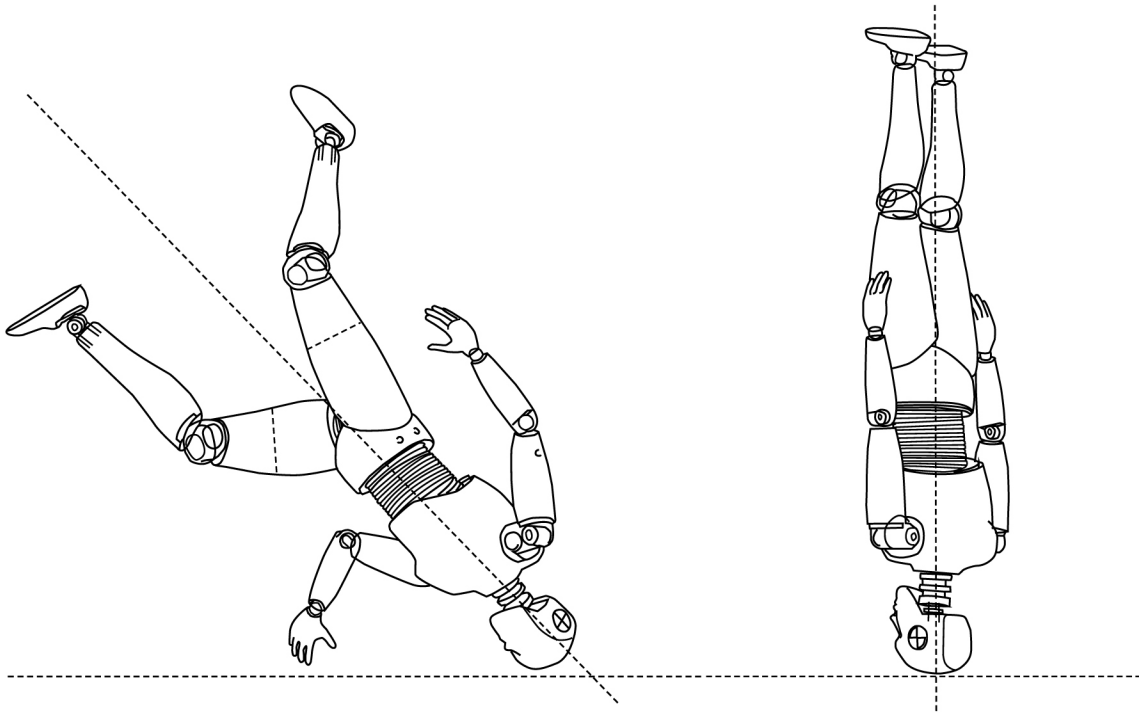
## 1.1 Project initiator and problem

Mips AB is the manufacturer of the ‘Multi-directional Impact Protection System’ layer, a helmet safety product developed to protect the brain against rotational violence. The company was formally founded in 2001 and is the outcome of a scientific research collaboration between the Karolinska Institute and The Royal Institute of Technology (‘Kungliga Tekniska Högskolan’, KTH) in Stockholm, Sweden.

Rotational violence to the brain often comes as a result of an angled impact to the head. This could e.g. be from falling off your bike and hitting the ground - it is rare that this does not happen at an angle (see figure 1.1). At the moment of impact the brain is given a spinning motion inside the skull. This leads to shearing and stretching of the structures inside the brain - something that it is not well equipped to handle. Among other injuries, concussion is a common consequence of this type of influence on the brain.

Traditional helmets do a sufficient job protecting against linear impacts but are not designed to manage angled impacts and their consequences. The MIPS layer is a thin sheet of low-friction plastic fitted to the inside of the helmet. In short, it allows the protective layers of the helmet to slide slightly relative to the head. This mimics the way the brain is allowed by the cerebrospinal fluid to rotate slightly inside the skull. This is the brain’s own protection against rotational violence. A more detailed description on how the system works, along with various injury types associated with rotational violence, can be found in chapter 2 Theoretical background.

With its introduction, the MIPS layer brought an innovative edge to the market considering that helmets have been constructed according to the same basic principle for a long time: to absorb linear force. This is also reflected in the fact that when evaluating helmets towards existing safety standards they are only tested for linear impact.



**Figure 1.1:** An angled fall compared to a straight one, image courtesy of Mips

Part of Mips AB's daily work is therefore to also push knowledge regarding testing, and develop test standards to evaluate how well helmets protect against rotational violence. The company has over two decades of scientific research and testing in its history.

Mips AB will hereon be referred to as 'Mips'.

## 1.2 Problem scope and aim

Mips is now looking for new product opportunities to investigate and develop alongside their low-friction layer. The company has filed a patent regarding a type of airbag fitted to a helmet structure - this makes up the project's starting point and overall focus. More detailed information regarding the patent can be found in section 5.1.

The project scope is: *to make use of air in an intelligent way in a head protection solution.* The main objective for the airbag would be - like the MIPS layer - to reduce rotational forces on the brain caused by angled impacts to the head. This will increase the safety of the wearer as well as bring a unique selling point to Mips. The project aims to determine whether the idea is feasible by evaluation through prototyping and real-world testing at Mips' facilities in Täby, just outside of Stockholm.

## 1.3 Delimitations

Although Mips is present in several segments, this project will focus on the mountain biking context to narrow the scope. More can be read in section 4.1 Mips' current business model and context.

## **1.4 Deliverables**

The project will evaluate the viability of the patent idea mentioned above, predominantly through the making and testing of physical prototypes. The resulting test data is a key deliverable, as well as the basis of the development of final concepts.

## **1.5 Report outline**

The report explains the implementation of the project. It is described in a mostly chronological manner, with a few exceptions such as e.g. the re-testing of concepts.

Chapter one and two sets the frame for the project, with chapter two providing more in-depth information and theory for the interested reader.

Chapter three describes the general procedure of the project, also giving brief explanations to the methods used.

Chapter four is the result of a research phase, and contains analysis regarding Mips' business model and the commercial setting of the project. It also gives the results of a user survey.

Chapter five to eight account for the iterative part of the project, where prototyping and testing have been performed to evaluate and form a basis for concept development.

The results and the project as a whole are discussed in chapter nine.

Chapter ten concludes the project.



## CHAPTER TWO

# THEORETICAL BACKGROUND

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This chapter highlights the mountain biking context of the project, goes deeper into helmets as they are today and compares it to what Mips offers.

### 2.1 The brain and how it responds to impact

The brain sits inside the skull surrounded by cerebrospinal fluid. The fluid acts as a natural cushion, and gives the brain an in-built protection against rotational violence by allowing it to rotate slightly within the skull. However, this in-built protection has evolved to cope with forces that are a result of walking and running. It is not designed for the speeds and forces that can be the result of e.g. skiing or biking.

The brain weighs around one to one and a half kilograms, and its consistency has been described by surgeons as that of Jell-O or uncooked tofu (Lawrence et al., 2007). Its bulk modulus, i.e. how resistant a substance is to compression, is five to six times larger than the shear modulus. In other words, the brain tends to deform predominantly in shear rather than compression, and is therefore more sensitive to rotational loading than linear loading (Kleiven, 2013). This can be illustrated with a scenario from boxing, where an athlete can receive several straight punches to the face but instantly drops to the floor when hit by an uppercut. The straight punches cause the brain to alternately compress and decompress, something that it can handle relatively well. When the uppercut hits, instead the structures of the brain get stretched and shear in relation to each other - causing the boxer to lose consciousness. The information in the above paragraph is, where no source is given, taken from internal presentations at Mips.

Head injuries can be divided into ‘contact injuries’ and ‘inertial injuries’ according to Gennarelli, a renowned clinician and researcher in the field of traumatic head injuries. Contact injuries are the result of a direct impact to the head, e.g. contusions, skull fractures, and epidural hemorrhage; where a bleeding causes a buildup of blood between the skull and the brain’s outermost membrane. This buildup then puts acute pressure on the brain. For contact injuries, the head does not have to be set in motion (Bosch, van den, 2006).

Inertial injuries are caused by sudden acceleration or deceleration of the head and does not have to involve direct contact. Examples of inertial injuries are concussion, diffuse axonal

## 2. THEORETICAL BACKGROUND

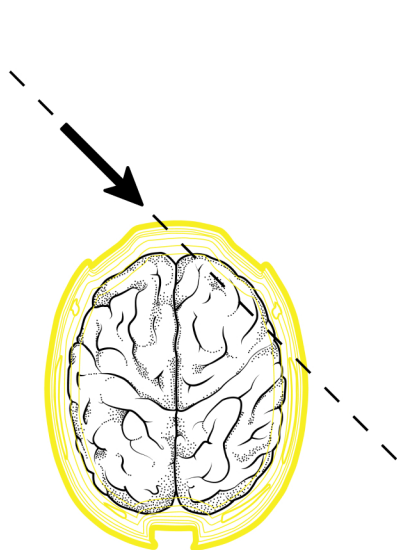
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injury and intracerebral hemorrhage; a type of hemorrhage that occurs within the brain tissue. Concussion is not an exact medical state. Very often, it is not possible to identify any structural damage to the brain tissue (Black et al., 2015). According to the medical definition, concussion is a clinical syndrome characterized by immediate but temporary and fully reversible loss in brain function as a result of mechanical force or trauma to the brain (American Association of Neurological Surgeons, 2017). In a typical cerebral concussion the person loses consciousness as an immediate response to the impact loading. It is the most common head injury, accounting for around 70 percent of admissions to hospital (Kleiven, 2013).

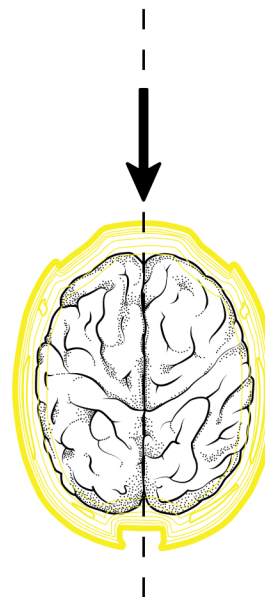
Symptoms can include memory problems, headache, nausea, confusion and slowed reaction to stimuli (Healthline, 2017). More than 99 percent of patients leave the hospital within two weeks (Kleiven, 2013). Diffuse axonal injury (DAI) is a result of shearing on the brain that tears and stretches the axons, the brain's nerve fibers. Severe DAI results in the person becoming unconscious immediately after the injury and remaining in a coma or vegetative state. The most common cause of DAI is vehicle accidents, but it can also be the result of child abuse such as in 'shaken baby syndrome' (Brainline.org, 2017).

### Impact direction

When forces are oblique, i.e. affecting the head at an angle, they bring on tangential forces to the head (see figure 2.1). Rotational forces and their corresponding acceleration on the brain are more connected to the inertial injuries mentioned above. Linear impacts (see figure 2.2) are the result of direct, "straight on" forces to the head, i.e. forces with direction along a radius line from the center of the head, and can be associated to contact injuries to the brain.



**Figure 2.1:** An angled, or oblique, direction of force



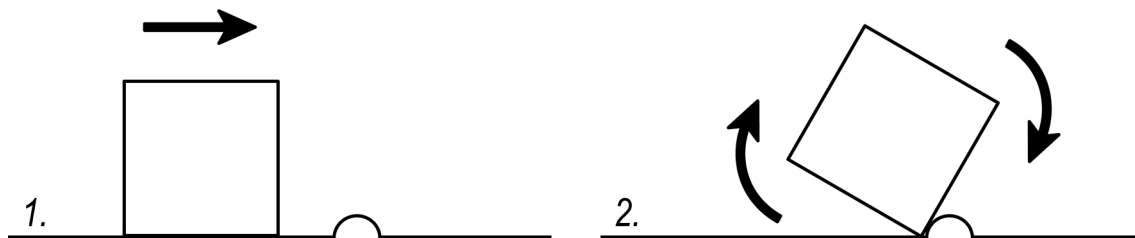
**Figure 2.2:** A linear direction of force

## 2.2 Helmet design

Helmets have different looks and functions depending on which activity they are made for, though the common principle for any helmet is to protect the head by dispersing and absorbing the energy of impacts directed towards it. The most common way of achieving this in bicycle helmets is to use some kind of plastic foam as the energy absorbing layer. The foam technology that most helmets currently use is over 40 years old (Lamb, 2008).

When a severe enough impact affects the helmet, the foam material compresses and deforms plastically. The energy from the impact is transformed into heat as the foam crushes. The crushing lengthens the head's stopping time, hence reducing the peak acceleration the brain experiences as a result of the impact (Bicycle Helmet Safety Institute, 2016b). A majority of helmets also have a hard outer shell. It diffuses the energy from an impact over a larger area of the foam, provides a barrier against sharp objects that could penetrate the foam, and keeps the foam from breaking up.

It also serves a purpose in making the helmet slide better against the ground in a crash. If the head gets caught in an obstacle, the abrupt stop is likely to expose the brain to higher forces including increased rotational force (Arai, 2017).



**Figure 2.3:** Wrenching as a result of an object, e.g. a helmet, getting stuck in an obstacle

Most bicycle helmets have some kind of comfort padding that sits in between the protective layers and the head. There is often a system that allows for some fit adjustments to the helmet, e.g. through tightening of a wire that pulls a plastic frame closer to the head. Helmets have air inlets to provide the wearer with sufficient ventilation. Helmets for mountain biking are more or less aerodynamically shaped, depending on how speed-focused the mountain biking is. They can look fairly similar to helmets for urban bicycling or road race bicycling if the intended use is cross country racing (read more about different types of mountain biking in section 2.5). However, mountain bike helmets often have a visor and extend to cover more of the back of the head. The visor protects the face from minor branches hitting the face and eliminates some sunlight to the eyes. For the downhill discipline of mountain biking riders usually wear full-face helmets, i.e. helmets that are designed with chin guard to protect the face.

In bicycle helmets, ventilation is achieved through holes in the helmet that puts the head in direct contact with the surrounding air. They are also shaped to facilitate the flow of air. In e.g. motorcycle helmets, there are none or very few holes that connect the head to the outside. Instead, ventilation is achieved through channels running underneath the shell, with inlets that face the wind. This type of ventilation is not as effective. However, due to

## 2. THEORETICAL BACKGROUND

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higher speed (generating wind) and a more static body position, the need for ventilation is not as great in motorcycling as in mountain biking - except for when temperatures are very high. The amount of ventilation affects the look of the helmet, as does the mountain bike discipline it is designed for.



**Figure 2.4:** Helmets for downhill, trail and cross country racing (or road biking)

Size and stiffness are two variables that affect helmet design regarding how well the helmet can absorb energy. (If there were no practical limitations on size, helmets would be made as big as possible in a soft material.) A softer material can dampen light blows effectively, but have the risk of bottoming out when subjected to greater force. Increasing the thickness can prevent bottoming-out, however to keep helmets at reasonable sizes, stiffer materials are used instead. This will prevent bottoming-out in severe accidents, but at lower forces the material will not deform as much, resulting in higher forces on the head (Kurt et al., 2016).

It is preferable that the helmet is not wider than the shoulder width of the person wearing it, the reason for this being that it is better to have your shoulder hit the ground first than your head (Kurt et al., 2016). Also, if the helmet is very thick it will wrench the head more should it get stuck against an obstacle in the ground. This will contribute to greater strain on the neck and possibly also rotational forces to the brain (Arai, 2017). Helmets that are too big in circumference will also fail on consumer acceptance (Bicycle Helmet Safety Institute, 2016b).

When a helmet has received many impacts the foam has compressed and deformed plastically underneath the outer shell, i.e. it has deformed in a way where it will not go back to its original state. This reduces the shock-handling properties of the foam (Mills, 2007). The foam is compressed from two sides, since whenever the foam is subject to force coming from the outside, the head inside the helmet exerts the same force on the foam from the inside. The great majority of helmets are not explicitly designed to manage angled impacts, but can actually still provide some protection against rotational violence. This is due to the helmet being able to move around on the head to some extent, and the foam liner can also shear elastically (Bosch, van den, 2006).

### **Materials used in bicycle helmets**

The plastic foam can be either expanded polystyrene (EPS) or expanded polypropylene (EPP). EPS is more likely to be permanently compressed after it has absorbed an impact.

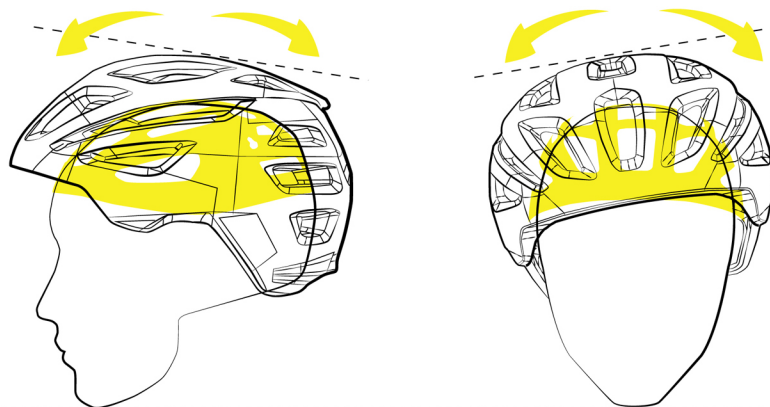
Even at small forces, like pushing your thumb into the material, it can show a permanent dent. EPP will also be permanently compressed at high enough forces, but at a moderate force the material will flex back. This means that in applications where helmets are more likely to suffer repeated, smaller impacts, EPP is used. This is true for e.g. skateboarding helmets. EPS, being crushable rather than flexing back, is more “single use”. It is used to a greater extent for applications where you want to protect against one, fatal crash, like in a bicycle accident. This often leaves the EPS helmet in pieces, by design. Common materials in the outer shell is polycarbonate or ABS, or in some cases composite materials like fiberglass (Bicycle Helmet Safety Institute, 2016c).

Some examples of more innovative materials implemented in helmets are D3O, Poron and VPD. D3O is a polyurethane material saturated with a non-Newtonian fluid, i.e. a fluid whose viscosity increases with the rate of shear strain. In its relaxed state the compound is soft and flexible, but it stiffens upon impact to dissipate energy (D3O, 2017). Poron is a brand name for a polyurethane foam that can be used in different configurations. It can be used for energy absorbing purposes in body gear and shoe insoles. It can also have memory foam-like properties, making it contour to the shape of your head to improve fit in helmets (Rogers Corporation, 2017). VPD is developed by POC, and is therefore found exclusively in POC’s own helmets and body armor. It stands for Viscoelastic-Polymer Dough, and similar to D3O it stiffens at impact. In its relaxed state, protection is flexible and adapts to the body (POC, 2016).

‘Koroyd’ is a material made out of plastic tubular structures, resembling drinking straws, welded together. It is often put into helmets together with a layer of expanded plastic foam. When the helmet is impacted, the tubes are crushed and that is where the kinetic energy is absorbed. Benefits of Koroyd compared to expanded plastic is low weight and that the tubes increase airflow compared to a solid foam. According to the company, it is said to reduce energy transmission to the head with 30 percent (Koroyd, 2016).

### 2.3 The MIPS low friction layer and its challengers

The ‘Multi-directional Impact Protection System’ is based on offering a relative motion between the outer layers of the helmet and the head. This is achieved by installing a less



**Figure 2.5:** The helmet’s sliding movement with the MIPS layer, image courtesy of Mips

## 2. THEORETICAL BACKGROUND

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than one millimeter thin low-friction layer between the head and the expanded foam liner of the helmet. The layer is made out of a sheet of thermoformed polycarbonate and is - in the most common configuration - anchored with rubber straps that keep it in place, but allow it to move slightly in all directions. Information in this section is gathered from Mips employees where no other source is given.

When an angled impact hits the outside of the helmet, the head is pressed against the low friction layer and the outer layers will slide 10 to 15 millimeters in relation to the head and the low-friction layer. This means that the head continues to a greater extent in the direction it was originally travelling in. Some of the rotational forces that would have been transferred to the brain are redirected into that movement. The sliding movement takes place during just 3 to 10 milliseconds (Mips employee, 2017).



**Figure 2.6:**  
Mips' logo as the recognisable yellow dot at the back of the helmet

Every low-friction layer is brand-, model- and size-specific, so Mips works closely with each helmet manufacturer to arrive at the final design. The layer is modeled to fit the shape of the helmet and custom cut to match ventilation outlets. It is important not to change the appearance of the helmet, but helmets being equipped with Mips have the yellow Mips logo dot printed in the back.

The helmet brand Giro, a part of the same owner constellation as Mips, has helmets with 'Mips Spherical': an alternative Mips design that is exclusive to Giro. Instead of the standard plastic layer against the head, the foam liner is divided in two layers. Acting like a ball and socket, the helmet

shell and outer foam liner are allowed to move independently around the head during an angled impact. The surfaces are treated to give as little friction as possible. An added value of the Mips Spherical is that the part of the liner that sits closest to the head can be custom shaped to fit the wearer's head (Giro, 2016).

### Challengers to the Mips system

There are brands with their own solutions to deal with rotational violence. During the ISPO 2017 fair in Munich, brands POC and Briko presented their approach to rotational violence. ISPO is the world's biggest trade fair for sporting goods and sportswear (ISPO Munich, 2016). POC's system 'Spin', an abbreviation of 'Shearing Pad INside', uses silicon pads that are placed in precise locations inside the helmet. The pads sit between the protective layers of the helmet and the head, allowing the helmet to move relative to the head. Briko's system is called 'Fluid'. It is a foam disk placed in a soft, plastic pod together with a low-shear fluid. Like POC's system, the pods are placed around the head in "strategic" places. When an impact happens the foam disk compresses, giving some additional linear protection. At the same time, the low-shear fluid is dispersed throughout the pod making it a slip plane that allows a motion of the helmet relative to the head.

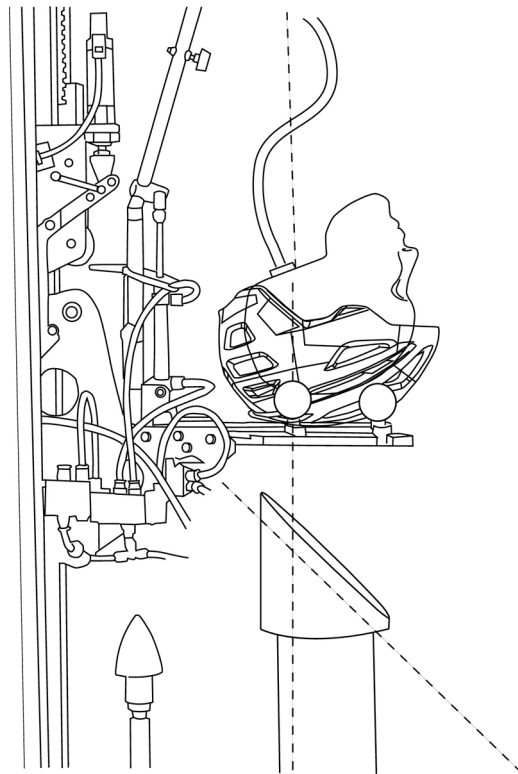
Since before the ISPO 2017 brands Leatt, Kali, 6D and Shred Optics have presented solutions to manage rotational violence. Kali and 6D's solutions are based on the shearing of a material, similar to POC's suggestion. Leatt's '360° Turbine' system consists of small discs that can be compressed in any direction. The 'Infinite RAA' from Shred Optics also consists of a matrix of smaller elements placed throughout the helmet. They use discs that are covered with fabric and attached to the inside of the helmet. The attachment point is able to slide on the surface of the disc, thanks to the fabric being elastic.

From a strategic point of view, Mips has embraced the competition since it brings more awareness to the cause. It helps to prove that rotational forces is a relevant issue and should be addressed in protection. It is also not clear whether Mips will have any head-on competitors since it is dependent upon what type of business model brands will go for, i.e. the ingredient product approach or just implementing the systems in their own helmets. When testing whether a helmet meets the requirements defined in the standard it is dropped onto an anvil with a test head inside it.

### 2.4 Standards and helmet testing compared to Mips' testing method

When testing whether a helmet meets the requirements defined in the standard it is dropped onto an anvil with a dummy test head inside it. The anvil used in helmet testing can be flat or hemispheric, or have a more narrow or pointy shape to resemble a curbstone or a traffic signpost (Bicycle Helmet Safety Institute, 2016a).

Drop height vary with standard as well as helmet type. The CE standard for bicycle helmets require the acceleration to the head to be below 250 g (Folksam, 2012). All standards have in common that they represent a "straight-on", linear impact. This corresponds to a crash where the person falls in a precise way vertically and lands on their head (figure 1.1 illustrates this). Mips' daily work is built around their proposed new way of testing that is dropping the helmet onto an angled anvil (see figure 2.7). Although the anvil is static and the actual drop is linear, it represents an accident scenario where you hit the ground at an angle.



**Figure 2.7:** The angled testing anvil proposed by Mips, image courtesy of Mips

This will be more similar to the course of events taking place in a real-life crash. The dummy head inside the helmet is equipped with sensors measuring the acceleration around

## 2. THEORETICAL BACKGROUND

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X-, Y- and Z-axis. Linear acceleration is measured, as well as the rotational accelerations around each axis (Mips employee, 2017).

### 2.5 Mountain biking

Mountain biking is the activity of biking off-road. Mountain bike terrain ranges from relatively wide gravel roads, to smooth and flowing forest trails, to steep, rocky runs. Roots, holes and drops are obstacles that make riding technically demanding, as well as the width of the trail. Narrow trails are called ‘singletrack’ and can be just wide enough to fit the width of the bike. ‘doubletrack’ is a wider trail, getting its name from that it is wide enough for two bikers abreast, which is about the width to fit a four-wheeled off-road vehicle (We Are Cycling UK, 2016).

The most characteristic trait of the mountain bike is the suspension that allows the bike to be ridden over rougher terrain. A mountain bike can be either fully suspended - meaning that it has both a suspended front fork and suspension in the rear-end of the frame - or it could have front fork suspension only. The rest of the frame is in this case stiff, those bikes being referred to as ‘hardtail’.

Travel is the maximum distance that the suspension can be compressed. The larger travel value, the greater wheel movement is the suspension able to dampen. How much the wheel moves is connected to how rough the terrain is. There are trade-offs with suspended bikes; pedaling a fully suspended bike on a smooth road (where no dampening is needed) will not just make the ride feel “spongy”, the suspension will also consume energy that would otherwise have helped the cyclist move forward. This makes pedaling uphill strenuous. Fully suspended bikes are also heavier and more expensive, both in purchase and maintenance. Short-travel suspension allows for going uphill but limits riding to relatively smooth terrain. Bicycles with longer travel distance will be able to handle rougher terrain and high-speed descents. The longer the front travel, the stronger the emphasis is toward descending as opposed to pedaling uphill (Higgins, 2016).

There are different styles of mountain biking and each discipline is reflected in the way the bicycle is designed. Travel length, weight and geometry are some of the traits that differ between bicycles. ‘Cross Country’, or XC, can be divided into two styles: racing and trail. XC race bikes are lightweight and suspension distances are ‘short-travel’, i.e. between 100 and 120 millimeters, making them suitable for long-distance runs or mountain ascents. It is common to ride on gravel roads. If XC race puts emphasis on distance and time-keeping, XC trail is more about recreation. Bikes are 120 to 140 millimeters in travel, and runs are more technically challenging. In Sweden, the race category is often simply referred to as XC and the trail category as trail or singletrack. Bikes for both XC disciplines can be either fully suspended or hardtail, and like in all mountain bike disciplines there is some overlap between bike types.

Bikes for ‘All Mountain’ or ‘Enduro’ are more adapted to handle rough terrain going downhill, at the same time keeping the ability to pedal uphill, though the bike will be heavier than a XC bike. Travel length is between 120 and 160 millimeters (Higgins, 2016). Many bicycles have adjustable suspension that can be set to a shorter travel length or locked to eliminate dampening completely.

‘Downhill’ is, as the name suggests, a discipline of mountain biking focused on the descent. Downhill bikes are built extra sturdy and are fully suspended, with front suspension travel distance between 160 and 180 millimeters (Higgins, 2016). This makes them heavy, and their weight precludes from any pedaling to the top. Instead, access to the mountain is gained with shuttle bus or lifts. Many ski resorts open their premises for biking during summer season.

## *2. THEORETICAL BACKGROUND*

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CHAPTER THREE

# GENERAL DESCRIPTION OF PROCEDURE

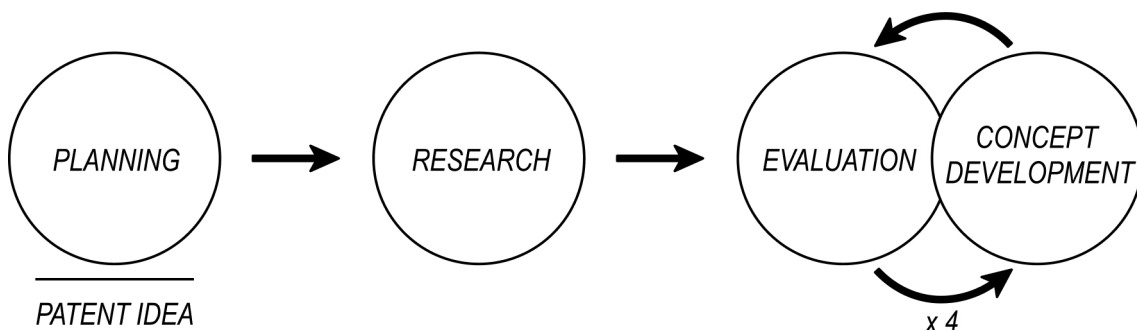
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The following chapter outlines the activities that have made up the project.

## 3.1 Overview

The process is visualized below. It is sparse compared to how the design process might often be depicted: containing also a phase where a problem is defined, or framed, and an ideation phase. The former is normally based on research, and the latter starts from the defined problem.

In this project, the problem was rotational violence to the brain, which is also the core of Mips' business. The starting point for the project was a patent idea that was yet to be validated at the start of the project. Therefore, the research phase was directly followed by evaluation. Evaluation has been heavy on prototyping and testing, partly because that is the way Mips operates but also since the idea was novel and little support could be found for it in e.g. existing products. The insights from testing have been used for further concept development.



**Figure 3.1:** Project workflow scheme

## 3.2 Planning

The project was initiated with the writing of a planning report. In the planning report, the project is defined in terms of content and aim, which serves a purpose for all parties involved; school, company and thesis worker. A Gantt chart was created to understand how time should be distributed among the planned activities. The project was scheduled to run for 20 weeks.

Because of the project's focus on prototyping and testing, it was crucial to have access to Mips' facilities in Täby since they include a test lab and various workshops. Being in close proximity to people with knowledge in relevant fields, e.g. biomechanics, innovation strategy, and engineering, was also thought to be beneficial for the project outcome.

## 3.3 Research

The research activities were conducted to form a basis for concept development and evaluation. The findings were summarized and incorporated in product development guidelines. In addition to the methods below, much information has been gathered from Mips, through asking questions and attending internal presentations. The test methods used at Mips are developed by the company, and therefore little information can be found about it that is not published by the company itself.

### Literature study

Literature studies are performed to give an idea of the current level of knowledge within a field. By incorporating one at the start of the project, it was made sure that there were no significant gaps in knowledge and it provided for a better understanding of both what rotational violence to the brain is, i.e. the problem, and the setting of the project in terms of the mountain bike context but also the commercial context.

Relevant literature was found through recommendation from the company supervisor as well as the Chalmers library database that provides a good tool for finding scholarly publications. It was thought to be of importance that the literature held a certain level of scientific quality since what you find in e.g. media is often simplified to be more easily digested, and therefore can not give any in-depth understanding.

Examples of typed in search keywords are *airbags*, *rotational violence*, *brain trauma*, *concussion*, *mountain biking* and *helmet use*.

The result of the literature study can be found in chapter 2 Theoretical background.

### Business model and context analysis

The 'Business Model Canvas' is a tool for understanding and creating business models for a company or a product. It has nine components that describe the relationship the company has with customers and partners, how the product gets out and money gets in, and what activities and resources are needed to deliver the offering - or the value proposition - that the company has (Strategyzer, 2016). In the project, the canvas was used to highlight Mips' 'ingredient product' business model, and the types of relationships it implies with

end users and partner brands. This brought an understanding for the type of constraints that the final concepts would be affected by, e.g. sales channels and manufacturing.

The context analysis aimed to identify the actors involved, and more specifically what requirements could be connected to each actor. It was based on the relationships identified in the business model analysis. The context analysis can be found in section 4.1. The results were used to define the design guidelines, found in section 4.6.

The business model is also mentioned in relation to the final concept, in section 8.2.

## **Benchmarking**

To understand if Mips has any competitors related to the aim and scope of the project a study on current products was conducted. The most relevant question would be whether anyone else has a product incorporating air that aims to reduce rotational violence to the brain. Since that was not found, the search was widened to head protection solutions that use air, as well as protection gear that use air. The products were included regardless of their context, e.g. skiing or motorcycling. Therefore it became rather a technology study on what is feasible, in the context of personal protection. Products were found through web searches and through a visit at the annual ISPO exhibition in Munich (see the second half of section 2.3), as well as through tips from Mips employees. One product, an inflatable liner for an American football helmet, was the subject of another thesis work at Mips.

The result of the study - regarding applications of air in these types of products - can be found in section 4.2. There's also an inventory of competitors to Mips within the scope of their existing product offering, i.e. protection against rotational violence, at the end of section 2.3.

## **User survey**

Being a part of the research phase, the survey had questions aimed towards getting a broader understanding for the user group and the mountain biking context. The questions were combined to get both quantitative and qualitative data, some being multiple-choice questions and some open-ended questions. Since Hövding had been identified in the benchmarking as the product that lies closest to the project scope, a question was asked specifically about Hövding to elicit attitudes regarding it. It was thought to be interesting how it would compare to a regular foam based helmet and if there would be any difference in attitude between the urban context and the mountain biking one.

- How old are you?
- What gender do you identify with?
- What type of mountain biking do you mostly do?
- How often do you use a helmet while mountain biking?
- Are you happy with the helmet(s) you have today? Why/Why not?
- Is there anything you think is missing in the market today regarding head protection (or other types of protection for mountain biking?)
- Which ones of the injury types have you sustained from mountain biking?

### 3. GENERAL DESCRIPTION OF PROCEDURE

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- Are you familiar with the ‘Hövding’ airbag head protection? What are your thoughts on it?
- Have you been involved in a crash affecting the head or neck while mountain biking? Could you describe what happened?
- What other protection and gear do you use while mountain biking?

The survey had the 10 questions listed above and collected 353 answers. It was online for 72 hours. It was initially posted on the online forum happyride.se, the largest bike forum in Scandinavia according to the forum’s own Facebook page. After a few hours, the number of respondents had reached over a hundred, but 96 percent of the respondents were male. To engage a more diverse group the survey was also posted in the closed Facebook group ‘Mtbtjejer Swe’ (translation ‘Mountain Bike Girls Sweden’). The final ratio between men and women were 112 women to 238 men, corresponding to 32 and 67 percent. Two people preferred not to answer the question about gender and one stated ‘Other’. Asking about gender was done because of the uneven distribution of men and women in the sport; it was thought to be interesting whether data could point to any differences in attitudes or satisfaction with gear. Data was clustered into categories in the software NVivo, a program that through e.g. color-coding tools simplifies the sometimes cumbersome process of dealing with qualitative data.

The results of the survey can be found in section 4.5.

#### **Interviews with expert at Autoliv**

Autoliv AB is the world’s largest automotive safety supplier (Autoliv, 2024). Unstructured interviews were held on three occasions with an expert in automotive airbags, with title Global Development Manager at Autoliv. One meeting was held via phone, the other two at Autoliv’s facilities in Vårgårda. Although the company might not be focused on rotational violence, it does work with biomechanical principles connected to safety. It also has expertise in airbags, even though airbags are traditionally used for more blunt, linear impact dampening. Discussion topics included the technology behind airbags, how they are constructed, and the holistic philosophy that Autoliv has when developing their safety products. Other technology was also discussed such as the use of torsion bars to fine tune energy absorption in cars, or electric glue that loses its adhesion at a certain voltage. The scope of the project was also discussed and evaluated to some extent.

The outcome of these interactions can be found in section 4.3.

### **3.4 Making of prototypes**

The project had four prototyping phases, described below.

#### **Phase 1 - Initial validation**

The first prototyping phase, described in section 5.2, was a direct validation of the original patent idea. Time-wise, it followed directly on the research phase, but it was not connected to it in the sense that none of the research findings actually affected it.

The plan was to construct something as close as possible to the way the head protection is

described in the patent. One rationalization was made: to leave out the inner structure of the airbag. Partly because it was not described in a detailed way in the patent, and partly because it was considered too complex in regards to the time frame.

Airbags are constructed from fabric and sewed together; therefore sewing was a first choice for prototyping. There was also an idea to heat weld sheets of plastic together. There was a sewing machine available but no tools for heat welding, which affected the decision. Since it was the first attempt at constructing prototypes, it was also expected that the prototyping phase would become explorative in its nature, and serve as a learning phase regarding possible techniques.

#### **Selection**

Selection was based on how well the airbag allowed for movement, i.e. how supple the structure was. For some sewing methods, the way the seams were laid on the fabric made the structure more rigid, or folds increased the thickness and made the fabric less flexible. In some cases it also affected the fit on the metal head form that was used as a template: the seams “stole” too much fabric in addition to the seam allowance and made the fit too small.

#### **Evaluation meeting with Mips employees**

During prototyping, a thought emerged that the project had arrived too fast into prototyping a close-to-reality helmet. Although that might be positive from a patent-validation perspective, there was a feeling that there could be other insights to gain through less complex prototyping, that would require less time before it could provide insights. Those insights could support or disprove the patent idea but to a lesser cost in terms of resources. A meeting was held with the R&D team at Mips. It was agreed that in the early stage of the project, it was reasonable to investigate other aspects that are relevant for the final solution e.g. durability through sewing techniques and different sizes and pressure values.

The activity is described in section 5.3 Intermediate evaluation.

#### **Summary**

The phase was an introduction to constructing prototypes, and although it was cancelled after the evaluation meeting it brought an understanding for construction methods and material that were useful in further prototyping activities.

#### **Phase 2 - "Back-to-basics"**

Following the evaluation meeting, the second prototyping phase (see section 5.4) was going to move away from the explorative nature of the first phase. The prototypes would be simpler, and focus on providing more incremental insights. The most basic insight would be if these round “air puck” prototypes were durable enough to withstand an impact in the test rig.

Second to durability, the prototypes were designed to test thickness and pressure. Thickness would be one of the features affecting the design of a helmet the most, especially in terms of looks, and pressure value has influence on the behavior of an air filled product. The two parameters also have a connection: to avoid bottoming out, you could either

### 3. GENERAL DESCRIPTION OF PROCEDURE

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increase thickness while keeping the pressure, or the other way around. A similar relationship between size and stiffness influences traditional, foam based helmet design.

The prototypes were constructed in four different thicknesses with valves for pressure monitoring. In this prototyping phase, as opposed to the first, research was used to better understand how the prototypes should be designed.

#### **Testing the "air puck" prototypes**

At first, the plan was to test the prototypes on the angled anvil to see whether the "shearing movement" would be evident. Discussion with the company supervisor resulted in the advice that it was better to start the testing at a flat surface, to make sure that the prototypes would meet the basic linear requirements (the only requirements that exist from a helmet safety standard perspective). The first test session was therefore made on a flat anvil.

Since the prototypes held up well, testing could proceed on the angled anvil. Each test is recorded with a high-speed camera during the time of impact and a few milliseconds before and after. The idea was to, rather than looking at numerical test results, inspect the slow motion footage and judge whether any of the "shearing movement" between the fabric layers could be seen in the prototype. Results were regarded of interest as a comparison between concepts, but not in terms of values since they would not correspond to a finished helmet solution (due to drop height and the design of the test). Choosing between the 30 and the 45-degree anvil, the 30-degree anvil was favored since it would be a compromise between an angled and a linear impact and hence give some insights about both.

The testing is described in section 6.1.

#### **Summary**

The second phase gave the insight that an air filled element will dampen linear impacts. Compared to the foam reference, the "air pucks" did better in both reducing translational and rotational acceleration. They did however show a rolling phenomenon.

#### **Phase 3 - A "more complete" helmet**

The previous testing had focused on a limited aspect of a head protection solution, a detached "air puck". It is not representative for a helmet concept, neither is the test procedure of dropping a test head onto the air-filled prototype lying on the anvil. The head got a spinning motion on its way up from the prototype after impact, and there was also a rolling phenomenon that would not be present in a helmet concept.

Due to the above reasons the third phase again focused on prototyping a more complete helmet solution with air elements incorporated, fitted to the test head. It was also clear that from Mips and the company supervisor's side, the goal was to test a complete helmet solution.

The third prototyping phase is described in section 7.1.

#### **Ideation areas workshop**

The workshop was planned as a brainstorming session for concept development. Leading up to the workshop it was clear that the project was not in a stage where such ideation

would be useful. The project had a defined problem and a defined idea. Since prototyping and testing had not shown whether the idea would be a solution to the problem, ideation would have to be based on the *assumption* that it would work.

The workshop instead focused on identifying areas of interest for the development of a head protection solution. Areas identified were material and technology, the shape and size of the air elements, where they would be placed in relation to the other structures of the helmet, and how the user would interact with the solution. A second group of areas was also identified, but deemed to be of interest mostly at a later stage of product development. These were comfort, customization, foldability, and ways to achieve ventilation.

#### **Early concept development**

In order to not end up in the same situation as in the first prototyping phase, the above areas and the research findings were used to as far as possible define the helmet concept before starting the prototyping.

#### **Testing the helmet concepts**

Since the prototypes in this testing phase were “complete” helmet solutions, and they both had a layer of foam in them, it was concluded that they could be tested in the same way bicycle helmets are tested without risking damage to the head, i.e. at a higher drop height than previous testing. This would make the test results more relevant for comparison.

See results of the testing in section 7.2.

#### **Ideation**

It was not known whether an air element should be pressurized or “just air filled” (meaning filled with air at atmospheric pressure, i.e. same pressure as outside of the element’s walls). Therefore ideation took place with both scenarios seen as possible.

The activity is described in section 8.1.

#### **Evaluation using FEM modeling**

The finite element method (FEM) is a numerical method to solve complex technical problems in engineering and mathematical physics. It is often used for analysing fluid flow, heat transfer and structural analysis. FEM is integrated in modern CAD software, allowing engineers to realistically check the durability of parts that before manufacturing only exist in the computer environment (Comsol, 2015).

There are aspects of experimental testing, i.e. testing in a real-life environment, that can make it difficult to draw clear conclusions from test results. There was another thesis project at Mips at the time of the project: it regarded the development of a FEM model of an American football helmet. In that project, experimental testing of foam pieces gave data on the foam’s properties in e.g. compression and shearing. That data would then be the basis for the FEM model.

Since the purpose of finite element analysis is to complement or reduce the amount of prototypes and experimental testing needed when developing, or optimizing, an opportunity was identified to investigate some of the fundamental parameters of the air-filled

### 3. GENERAL DESCRIPTION OF PROCEDURE

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elements. In the FEM environment, this could be done without the disturbance of e.g. the rolling phenomenon, the prototypes being too unrefined, or other physical limitations. One of the two thesis workers in the American Football helmet project made the FEM analysis.

The FEM analysis is presented in section 8.3.

#### **Summary**

The helmet prototypes did not perform better than a MIPS equipped helmet. Being on a prototype level still, there was however room for improvement regarding the construction. Therefore, it was not ruled out that a helmet solution using air could work. The FEM modeling gave some indications for further product development, like what a change in material elasticity would do and whether the air elements should be pressurized or not.

#### **Phase 4 - Modification and retesting**

Due to the exploring nature of both testing and prototyping, test results from the different phases were not always comprehensive enough to draw certain conclusions. A test session could e.g. consist of four tests of two concepts, where each concept had been tested with and without tape. With few test runs for each configuration it's not clear whether the results are reliable, though they could be a guidance for further prototyping.

To make it possible to draw more certain conclusions more repetition was needed. Also, there had been phenomena during testing that made it difficult to trust test results. Therefore, the retesting was preceded by a modification session. There were two problems to adjust for:

#### **Pucks rolling**

The "shear-like" movement described in the patent was still an interesting idea to evaluate. When the "air puck" prototypes were tested on the angled anvil, they had showed a rolling movement. To prevent that, the pucks were modified so that they could be better attached to the surface beneath. Again, the footage from the high-speed cameras was of greater interest than test results, to see how the layers of the pucks moved at impact. Another reason for the modification was that if the air filled element were to be enclosed between rigid layers of the helmet, the rolling movement would be obstructed anyway.

#### **Air leaking**

When the helmet concepts were tested the first time, the weight of the test head seemed to push air out of the prototypes inside the helmet shell before the concept had hit the anvil. For the retesting, prototypes were improved with pieces of EPP foam in between the air elements. The foam pieces would carry the weight of the head instead of the air filled elements, but hopefully not interfere with the movement too much.

The result of the modification and retesting is integrated at the end of chapter 6.

*CHAPTER FOUR*

# **INITIAL RESEARCH AND USER SURVEY**

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The chapter will both touch upon products that specifically use air for head protection, and various applications of airbags. It will describe Mips' company profile and present the results of an online user survey.

## **4.1 Mips' current business model and context**

The information in this section is loosely based on the 'Business Model Canvas' framework, described in section 3.3. Mips' core value is to offer protection against rotational violence, something that is reflected in the company slogans and social media hash-tags, #saynotorotationalviolence and #MIPSinside.

Mips does not manufacture any helmets of their own. Their current business model is to sell their low friction layer as an 'ingredient product' to brands, meaning that they adapt each low friction layer to fit the model brands choose to equip with the MIPS system, keeping the features and branding of the original design. Today the Mips low friction layer is the most successful solution to address rotational violence in head protection, and is incorporated in world leading brand's helmets including POC, Sweet Protection, Giro, Fox and Troy Lee Designs.

In 2014 Mips entered into a strategic partnership with BRG Sports, the world's biggest helmet manufacturer that at the time owned Riddell, Giro and Bell, opening up for wider implementation of the Mips technology. Since then, Mips has established test labs and offices with workforces also in the American and Chinese markets.

In March 2017 Mips was listed on Nasdaq Stockholm. In the attention following the listing, some analysis touched upon the fact that Mips was a "one product brand". It is true that the products that Mips sell are all providing the same core value, and development is largely focused on different ways of achieving the same thing; the movement of the outer parts of the helmet in relation to the head. (The thesis project also fits into this category.) There is however a strategic product matrix that holds a number of variations on the low friction layer, e.g. regarding manufacturing methods, technology to achieve low friction

#### 4. INITIAL RESEARCH AND USER SURVEY

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or just adapted to different types of helmets, e.g. a low friction layer especially suited for motorcycling helmets. One of the most unique examples is the Giro Spherical (see section 2.3). The products are licensed to partner brands.

A strength of being an ingredient brand is that Mips can stay outside competition between brands and take advantage of the widespread safety trend (Sprinchorn, 2017). They can get their products to the market no matter what company is currently the strongest, both in terms of volumes sold and brands that are important from a strategic perspective. A brand with good reputation within its field can lead way for others to adopt the MIPS system. Coming from the company itself, “Mips wants to be everywhere there is a risk to head injury from rotational motion. That’s why Mips is an ingredient brand” (Thiel, 2017).

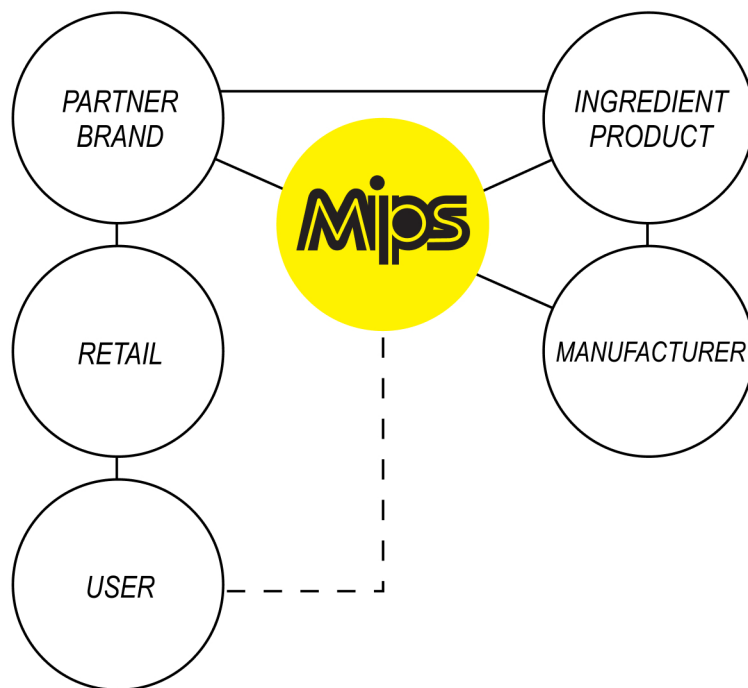
Technically, Mips sells business to business, but it is essential that the end user accepts the technology. If there is a request from people, that will transfer to the helmet manufacturers that will be wanting to work with Mips. A key activity is therefore to spread knowledge about the system, how it works and why it is needed. Since helmet standards today are based on requirements for linear impacts only, one major area is also to develop test standards that acknowledge rotational violence based on numerical simulation of head and neck injuries. One of Mips’ key resources is its patents, and being an intellectual property company it is important to keep the connection with science and research (Thiel, 2017). The company is founded with the Karolinska Institute and The Royal Institute of Technology as its stepping-stones. One of its key resources are therefore the over 20 years of scientific experience held within the company.

### **Context analysis**

The below graphic shows the actors involved in Mips business today. Manufacturer, user and retail will be valid also for the project outcome. Today, all products are sold as ingredient products. It is therefore likely that the solution using air will be launched within the same business model, as an ingredient product too.

Today, partner brands manufacture helmets. They decide on branding and function of the helmet. Mips will receive CAD models of the helmet and construct a MIPS layer specifically for it, adapted to its shape and features. The MIPS layer will reduce size of the helmet with about half a size. The brand’s requirement is that the MIPS layer will not interfere too much, both in physical terms and branding terms. There can also be other features of a helmet, such as manufacturer’s own safety system or new materials, that need to be able to co-exist with the MIPS system.

User requirements are presented as the results of a survey in section 4.5. In a sense, retail shares many requirements with the users since they have to cater to the needs of the users. Looking at the sports industry there might be a predisposition in favor for “systems” - more or less gimmicky. Examples could be ski manufacturer Völkl’s ‘UVO’ that stands for “Ultimate Vibration Object”, a device that is attached to your skis and promises to reduce vibration (Völkl, 2017). This can be categorized as a need for a unique selling point, something that catches the attention of the customer. Very often there is no scientific backing or test results behind the products. This is far from Mips’ own requirements, having put a lot of emphasis on experience and connection to research and science in their



**Figure 4.1:** Illustration of the business context

public image.

## 4.2 Applications of air in commercial products

The analysis has some resemblance with a benchmarking or competitive landscape analysis. However, since there are currently no products with the function described in the project scope, the analysis has been made with a wider focus. The ‘Hövding’ solution is given a lot of attention since it is the only head protection solution on the market that uses air as a sole protective element, and therefore gives an understanding for many of the aspects that could be relevant in the project, from technology to marketing.

### Most relevant for project scope:

#### Hövding

Hövding is the first airbag bicycle helmet and was launched in November 2011 in Malmö, Sweden. Its inventors are Swedish Anna Haupt and Terese Alstin who came up with the idea in 2005, during their final degree project studying Industrial Design at Lund University. In an interview with the British magazine ‘Cycling Weekly’, Hövding’s CEO Fredrik Carling compares the Hövding to a traditional foam-based helmet (Cycling Weekly, 2015):

*“It is a cushion that offers much better shock absorption, as well as the rotational violence that your head could be exposed to in a crash: that is also significantly less due to the construction of Hövding”*

Looking into the marketing of the Hövding, it is clear that its target is people biking in an

#### 4. INITIAL RESEARCH AND USER SURVEY

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urban context. Advertising campaigns have almost a sense of avant-garde fashion to them, and it is often referred to as the helmet that does not give you “helmet hair”. To further stress the feeling of ‘city chic’, there are textile covers to buy to customize the appearance of the Hövding.



**Figure 4.2:** The “high fashion” vibe of Hövding’s marketing, image source: Hövding, photographer Jonas Ingerstedt

#### Function

The airbag is folded into a collar and in its normal state Hövding is worn around the neck. Sensors monitor the movements of the person wearing the collar. When an unnatural movement is detected, the airbag deploys. It turns into a hood that covers most part of the head, except for the face, leaving a free field of vision. The solution can be seen in its two states in figure 4.2. The deploy-or-not algorithm is based on data gathered from reenactments of bicycling accidents, and test cyclists wearing Hövding during everyday cycling. Hövding also has a ‘black box’ that records ten seconds of data during an accident. Inflation is achieved with a cold gas generator that uses helium. The pressure remains constant for several seconds, making it able to withstand multiple head impacts during the same accident scenario. After that the airbag slowly starts to deflate.

A possible advantage of the Hövding could be that it protects your neck, the below quote coming from Kathryn Sentance, stunt performer (Cycling Weekly, 2015):

*“It’s great, it completely immobilises your neck and head. I’m used to crashing quite a lot in, say, a full face helmet where you can still get quite a lot of neck movement. But with this - zero movement”*

Hövding is not supposed to go off during ‘normal cycling’ - defined by the company as all urban cycling and cycling on main roads, including getting on and off your bike. After you have put on the Hövding and closed the zipper, you activate it by attaching a snap fastener that works as an on-/off button. This should be done at the same time you get

on your bike, and when getting off you should detach the snap fastener. This is to avoid Hövding going off when it is not supposed to.

Due to the nature of the sensors, Hövding will not react to impacts that happen without any unnatural movement preceding it, e.g. if the cyclist rides into a low hanging obstacle such as a traffic sign or a branch. This also includes falling objects hitting the cyclist's head (Hövding, 2016). There are reports of the Hövding deploying in situations where its protection is not needed. Hövding's CEO Fredrik Carling replies:

*“If you consider the ‘family of movements’ that we have defined to be accidental movements - we’ve then put a little bit of a safety margin on top of that. So, you could be in something where you think ‘Well, I didn’t really hit my head but it still inflated’ - well, we like that, we like to have that as a safety margin both for us and for you as a cyclist.”*

Carling also says that a Hövding should have 5-7 years of life for most cyclists. It is a one-time use product, but you can get a new one at a lower price if your Hövding has deployed. All of the major insurance companies in Sweden will replace a Hövding within the home insurance, provided that you pay the insurance excess fee (Hövding, 2014).

### Reviews

The Swedish insurance company Folksam tested thirteen of the most popular bicycle helmets in Sweden in 2012. In linear testing, at a height corresponding to the helmet reaching 25 kilometres per hour at the time of impact, Hövding got by far the best result with 65 G (gravitational units), three times better than all other helmets in the test (Folksam, 2012). As a comparison, legal requirements for linear drop tests are 250 G to avoid skull fracture (Folksam, 2015).

The Hövding airbag was tested at Stanford University, USA and the results published in a study named ‘Modeling and Optimization of Airbag Helmets for Preventing Head Injuries in Bicycling’. Hövding's name is undisclosed, but the company refers to the study in their marketing. Hövding was tested pre-inflated, at five drop heights ranging from 0.6 to 1.8 meters with pressure levels at 35, 42.5 and 50 kilopascal. The linear impact testing of Hövding showed that it could achieve up to an eightfold reduction in the risk for concussion compared to the standard EPS helmet. The study concluded that conventional foam technology in helmets suffers from the limitation of a maximum wearable size, something that the airbag helmet can bypass.

The French consumer awareness magazine Que Choisir, a part of the same international organization of testing as the Swedish counterpart Råd & Rön, tested Hövding and concluded that a fully inflated Hövding did not absorb enough energy when dropped against a 130 millimeter steel anvil. It performed significantly worse than traditional bicycle helmets. This type of testing is meant to represent an accident where the cyclist hits a curbstone or a road signpost, i.e. a narrow obstacle. The French lab also showed that the Hövding inflates in 382 milliseconds, which was thought to be slow compared to the legal requirements for motorcycle airbags that have to deploy in less than 200 milliseconds (Engstedt, 2014). As a comparison, the car airbag type designed to protect your head, neck and shoulders is inflated in around 30 milliseconds, according to the expert at Autoliv that has been involved in the project. The inflation technology used for airbags in car applications is

however different.

Hövdning dismissed all test results as irrelevant and claimed that no current standards could be applied to such an innovative solution. The company sent out an aggressive email to all European consumer awareness magazines threatening with legal actions should they publish the results. The email is published on the website of Råd & Rön.

## Relevant

### Football helmet with inflatable liner

Riddell produces American Football helmets. The comfort liner of their ‘Speed’ models can be inflated to improve fit. Better fit improves comfort, but also reduces how much the helmet can move on the head - making it protect better. The less helmet movement the better from a protection viewpoint. The inflation system is reached from the outer shell, where a number of vents are placed (Riddell, 2017).

### Airbag vests

There are several examples of vests with built-in airbags aimed towards motorcycling, some brands include Hit-Air, Helite, Alpinestars, Bering and Dainese. There are also similar vests aimed towards horseback riding. The simplest vests are operated with a tether strap attached to the motorcycle. When the rider is separated from the bike, the strap pulls a safety pin from a gas release system and gas starts to flow. Inflation takes around 200 milliseconds for the Helite airbag (Helite, 2017). In the higher end segment, vests are wirelessly connected to sensors placed on the bike. The Dainese ‘Air-D’ suit has a pair of three-axis accelerometers mounted on the legs of the front fork and a “skid sensor” mounted under the seat (Dainese, 2017).

Vests typically inflate over the whole upper body to protect the thorax and the ribs. Extra volume is often inflated around the neck area. This limits movement of the head both front-back and sideways, protecting against whiplash injuries. It is also often designed to protect the back, from lower head to tailbone - depending on how far it extends.

### Avalanche airbag backpacks and vests

An avalanche backpack is designed to increase your chances of not getting buried beneath the moving snow in the event of an avalanche. It is used by skiers, snowmobile drivers and anyone spending time in terrain where the risk of avalanches is present. Manufacturers include ‘ABS’, ‘Mammut’, ‘Backcountry Access’ and ‘Black Diamond’. The airbag is folded into the back of the backpack, or in some models in the shoulder straps.

In an avalanche, larger objects rise to the surface while smaller sink towards the ground. The idea is to increase your overall volume and therefore keeping you on the surface of the avalanche. As soon as you become aware of an avalanche, you pull a trigger handle and the airbag starts to inflate. The first avalanche backpacks used a gas canister to achieve inflation, either with compressed nitrogen or air. A 150 liter bag takes around 3 seconds to inflate (Mammut, 2014). Trauma is one of the biggest causes of death in avalanche accidents, and accounts for between a quarter and a third of deaths according to the Canadian Avalanche Centre (Weiss, 2013). Therefore, some models are designed to protect your neck by having the airbag cover the back of the rider’s head.

Black Diamond's backpack is called 'JetForce' and uses an electric fan for inflation (Black Diamond, 2017). While gas canisters need refilling before the backpack can be used again, the fan provides for unlimited activations of the airbag as long as the fan has enough battery power. Airbags that are inflated by the limited supply of gas provided by a canister need to be more airtight, letting as little gas as possible out. A fan operated airbag can be made lighter since air supply is unlimited, and a more permeable - and therefore lighter - fabric can be used.

### **4.3 Information about automotive airbags from company Autoliv**

In this section, the outcomes from conversations at three occasions with an expert at Autoliv will be gathered.

Airbags are good at distributing a load, not absorbing it. Airbags are in most of their current applications used for spreading a force load. When they are used in cars, they need to be inflated fast but deflated at almost the same speed. If the airbag has not started to release their gas and thereby lowering the pressure inside, any person thrown at the airbag would simply bounce back due to the compression of air.

Airbags are not suited for long-term inflation, but are made to perform during milliseconds. In cars, most inflation is achieved with packs of chemicals that, when mixed, generate hot gas. Hot gas takes less time to generate, but a downside is that as soon as it comes in contact with the surrounding air, it cools and the bag decreases in volume. In applications where you want the pressure to be constant, you use cold gas instead. This is the technology used in most wearable airbag applications, including the Hövding.

According to one of the fundamentals of physics, energy cannot be created or destroyed, but only be transformed into another form. This is the principle that Autoliv works according to, and more specifically: to create heat. As an example, the airbag situated in the front of the driver is inflated to spread the load on the face, and does generate some heat as the air compresses. But to really achieve energy absorption (or transformation of kinetic energy to heat) you would be better off having a structure that is made to deform inside of the steering wheel hub.

### **4.4 Helmets and sustainability**

In the manufacturing process of helmets, the foam layer is often fused together with the outer shell, making recycling of the different materials difficult. There are no commercially spread methods for recycling helmets. Instead, they are sorted as combustible waste (IL Recycling, 2017).

The fact that the materials' energy management capabilities deteriorate with age gives helmets a built-in best before date: it is recommended to replace your helmet within five years. If the helmet has received many impacts, the foam is likely to have compressed and therefore the helmet should be replaced before those five years have passed.

### 4.5 User survey

The survey was conducted to gather information about the context, satisfaction with current gear and attitudes towards an inflatable protection solution. The purpose was to get a general understanding for the project setting and identify any attitudes or facts that could influence the concept development.

#### Data analysis

Out of cross country race, trail, enduro and downhill, trail was the most common discipline with 55 percent stating that it was the type of mountain biking they mostly did. It is likely that the ratio is significant for the Swedish mountain biking scene, due to the terrain available. Data showed that helmet use is a natural and well established part of the sport, with 99 percent wearing a helmet at all times riding. While a solution like Hövding is marketed towards people that for some reason have chosen not to wear a helmet, it can be concluded that the selling point of “getting the protection of a helmet without wearing one” would not be as attractive for mountain bikers.

Of the respondents, 76 percent were happy with their helmets. There was no major difference when looking specifically at the male group and the female group respectively - they showed no difference towards the whole. The most mentioned characteristic connected to being satisfied with your helmet was comfort. It was mentioned both in a general sense (in Swedish: 'bekväm', 'bra komfort', 'skön') and in more specific ways as fit (referred to in 30 percent of the answers), weight (13 percent) and ventilation (10 percent). Fit included both the shape of the helmet and the size. Perhaps naturally, the most common reason to be unhappy with your helmet in some way was poor fit. This was true for both men (33 percent) and women (30 percent). Women complained that helmets were not made in small enough sizes, this was compensated with e.g. browsing the children's section or using a helmet designed for a different discipline. Men were less specific in their answers, referring more to the general shape of the helmet.

The second biggest complaint among men that were not satisfied with their helmets was bad aesthetics and that helmets looked and felt cheap, at 25 percent. This percentage among women was 15. For women, bad aesthetics shared a second place with problems with the straps and buckles of the helmet, at 15 percent (men 6 percent).

- *“The function is OK, but it looks like a mushroom”*
- *“It is OK but the buckle loses tension fast”*

#### Various insights emerging from the study

In this section, data does not necessarily correspond to a significant percentage of the respondents, but could still be useful in the creation of requirements or as inspiration for idea generation. Both negative and positive aspects are included.

Looking at the whole group, 6 percent stated that they had a helmet with the MIPS system. However, since it was not an explicit question the percentage might be higher. Among women that number was 8 percent, and 3 percent wanted to upgrade to a helmet with MIPS. In the male group, 3 percent had MIPS and 2 percent wants to upgrade. Two people had

negative opinions about MIPS connected to it being expensive. The feeling of safety in helmets were connected to how well the helmet covers the head, in particular the back of the head.

Helmets sometimes have to go well together with other gear. The compatibility between helmet and glasses could be better according to two people. Some helmets have integrated mounts for lamps, and better lamp integration was mentioned by two people. In Sweden, biking with lamps can extend the season with a few months when days start to get shorter in autumn. Many ride with two lamps, one attached on the handlebars of the bike and one worn on the helmet. Seven people judged the helmet by how it works together with a helmet cap, mostly that it should be easy to adjust the size to fit a helmet cap. It is not recommended to wear anything underneath the helmet, such as a beanie or a headband, since it makes the helmet sit higher on your head, and might leave parts of your head unprotected (Gargulinski, 2015). However, in cold temperatures a well-ventilated helmet can make some extra insulation for the head and the ears necessary. There are therefore helmet caps that are made as thin as possible not to jeopardize the safety of the helmet too much. Two persons wanted a helmet that they could wear with their hair in a ponytail. One person complained that the rubber attachment straps for the MIPS system snagged her hair.

- *“Well, it has the MIPS system and my hair gets stuck in the yellow straps. Not very pleasant...”*

57 percent of men did not miss anything in terms of protective gear on the market. Among women the number was 41 percent. Two women mentioned more gender neutral designs. Three women requested smaller sized helmets, and six wanted body protection, such as knee pads, adapted to women. One person wanted bigger sized women’s clothing. Bigger sizes on helmets was requested by two men. Eight men mentioned that they wanted cheaper gear, compared to none of the women.

A specific category was created with request like helmets being more lightweight, with better ventilation, and thinner, more flexible gear. Eleven men and eight women requested improvements like these. These aspects of product function can be described as ‘performance requirements’, requirements that have less to do with individual preference - they are objective rather than subjective. They are also somewhat self-evident (very few people would say that they have a preference for a hot, heavy and bulky piece of gear).

Two men had opinions regarding maintenance:

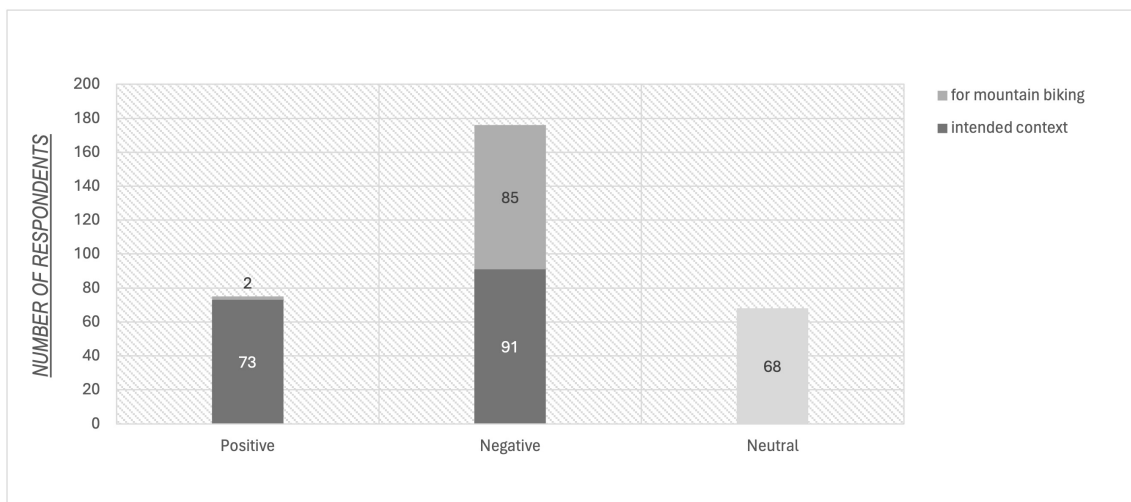
- *“I think many helmets today lack the possibility of washing the insides of the helmet in a handy way”*
- *“Pads and straps that are easy to remove and wash [...] Summer and winter pads so that the same helmet can be used with a cap underneath”*

It can be concluded that differences between women and men lay mostly in size and fit. This is more or less expected considering the sizes of the two populations in general - regarding sizes the biggest people are generally men, and the smallest are women. However, some bigger women had problems with the women specific gear.

### Attitudes towards the 'Hövding' airbag head protection

Two people did not answer the question, 351 people did. Out of the ones that did, 18 percent were not familiar with the Hövding head protection. No one specified that they owned a Hövding or had tested one themselves.

The question was not phrased as whether Hövding would be good or not for mountain biking, but many answered the question in that way. Therefore, the following rough division was made, where answers are separated depending on which context the respondent had in mind.



**Figure 4.3:** Attitudes towards the 'Hövding' solution

68 answers were neutral towards Hövding, or did not express a specific opinion. There were answers containing both positive and negative aspects, such as “Safe. Expensive.” or “Seems practical but looks very big around the neck”. Some expressed both a positive opinion about Hövding for commuting, and a negative opinion for it in mountain biking - meaning that those replies will be counted twice in the above division. (This is a consequence of attempting to quantify qualitative data.) Some answers were discarded in the above record for failing to answer the question.

Roughly 73 people were positive in their statements about Hövding regarding use in its intended context. However, many answers were of the type “good for others”, which could imply that the respondents own attitude towards the solution is different. There was also the attitude that it is worse than a traditional helmet, but better than nothing - which can be said to be fairly in line with Hövding's marketing.

- *“Yes. I think it's more suited for city biking than race-/mountain biking. Uncomfortable, bulky and hot to have a collar round your neck in the woods”*

Below are some of the comments from the ones that imagined Hövding in a mountain bike context and were negative. The most common concerns were that it would deploy when it is not practical, as well as fail to deploy when needed, e.g. when hitting low hanging branches. Also, it was regarded as hot, heavy and bulky and respondents did not trust

whether it would protect against a fall onto a sharp object like a pointy rock, i.e. if it would bottom out. Others were concerned about the risk of the airbag puncturing.

- *“MTB, no-no. At least the way it looks today. The protection needs to be smaller or perhaps integrated in the helmet”*

Two respondents were positive towards and expressed some interest in Hövding for mountain biking activities, but also correctly pointed out that it is not suited for that as it is designed today, neither does it target the mountain bike market.

- *“I would buy it if it was suited for mountain biking activities. The risk is too big that it deploys when jumping and in a normal, light crash.”*
- *“It’s a good idea but seems like it mostly works for falls in certain directions. Also not an ideal product for mountain biking where you tend to fall quite a lot without hitting your head, because of that you can’t have it deploying all the time.”*

15 people commented on the benefits of a normal helmet. Protection against smaller branches was mentioned, i.e. the discomfort of getting small branches in the eyes while biking through woods. A helmet designed for mountain biking often has a visor that hits branches before they get in your face. Protection against the elements like rain and cold, as well as bugs was also mentioned.

Twelve percent think that Hövding is expensive; both considering its purchasing price and that it is a cost to replace after it has been deployed.

Four responses regarded battery-powered protection and the fact that you have to keep Hövding charged. This was always seen as a negative.

- *“I wouldn’t feel safe with something that is based on use of batteries and electronics”*
- *“I’m sure it’s a good idea, but having to monitor whether the helmet is charged or turned on seems very unnecessary when you can just put a helmet on and go”*

The feeling of trust and the fact that Hövding needs to react before it offers protection was something touched upon in nine answers. Two people thought it was good that it protects the neck.

- *“I feel safe wearing a helmet that is always there. I wouldn’t want an airbag helmet in the forest.”*
- *“I’ve seen it. I don’t dare to believe that it works, though I’ve understood that it should.”*
- *“I don’t think a regular helmet is that ugly that I’m willing to take the risk I associate with that helmet. No matter what all tests say it is a helmet that needs to deploy in order for the protection to come in place. With a regular helmet that protection is already there.”*

As many other sports, mountain biking has its own dress code. The resistance towards helmet wear is lower than in urban bicycling (which is clearly shown in the survey).

#### 4. INITIAL RESEARCH AND USER SURVEY

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- *“Would feel super strange though, riding around in the forest without a helmet - I mean difficult from a style perspective. But if I was to find out that it protects better than a normal helmet I would consider it.”*
- *“I’m a bit skeptical. I don’t trust that it works, and it does seem a bit stupid (superficial). Besides that I’ve understood that it is very expensive (I don’t know what it costs though).”*

Ten people had what can be categorised as an ideological concern regarding Hövding, that the need for it is constructed and that it is working against the development that they would prefer to see in society.

- *“I think it’s a constructed need”*
- *“In my opinion an unnecessary product that aims to hide away and make the protection invisible. I’d rather see as many as possible with a normal helmet so that wearing a helmet becomes the norm.”*
- *“I don’t think it’s very useful and i don’t like that it depicts biking as a dangerous activity”*

#### **Accident scenarios**

Abrasions and contusions were the most common injuries people had gotten from mountain biking, with 97 and 95 percent of respondents. For injuries regarding the head, it can be noted that 13 percent of the respondents had gotten a concussion while biking, but just 0.3 percent had suffered a skull fracture. Previous answers show that helmet use is well implemented. This underlines the relevance of systems like the MIPS system, that helmets today protect well against linear impact and the new challenge is to reduce injuries connected to rotational violence.

A question about whether the respondents had ever been involved in a crash affecting the head or neck was asked, and whether they could describe what happened. That gave insight in the events leading up to a crash. Number of responses were 352, out of these 40 percent had been involved in a crash where the head or neck was affected.

The most common reason for crashes is tricky or unpredictable terrain. Examples from the survey include getting a branch stuck in between the spokes of the wheel, biking into a ditch or a water puddle that was deeper than expected, or hitting a rock with the front wheel. Another common reason for crashing in mountain biking is “rider mistakes”. That can be hesitation before a jump or before riding downhill. When you get scared or perhaps change your mind in the middle of an attempt, you tend to hit the brakes. When the wheels are prevented from rolling, what often happens is that they lose grip and slip. Roots and wooden bridges also get slippery when wet.

40 percent of accidents were described as ‘over the bars’, commonly abbreviated as OTB. It is when the bike comes to an abrupt stop, most often due to getting stuck in terrain, but the rider keep their momentum forward and end up traveling over the handlebars of the bike.

- *"Hit the brakes hard and suddenly while in a steep downhill and went over the bars. Stiff neck, concussion, bruises and a dead leg (in Swedish: 'lårkaka')."*
- *"I rotated forward in a crash downhill and landed on my face, my helmet broke in eight pieces, I broke my neck and got fractures in two vertebrae."*

31 people crashed in a way that injured their face. 23 persons describe a crash scenario where a narrow object such as a branch or a stone hits the helmet. In some cases, the person has hit the ground first with the bike coming after to hit them in the head. 28 people mention complications to the neck after a crash.

- *"Skidded on a slippery footbridge. Rode straight into a tree, head first. Injured my chin, got lacerations and an aching neck. The helmet saved my forehead but broke at impact."*
- *"Crashed and the bike rolled over me. The pedal cut open my eyebrow."*

Below, some special answers are collected describing various crash scenarios. Thirteen people had crashed due to another cyclist, animal or car.

- *"Collided with an unleashed dog. Crashed. My shoulder took the worst impact but the helmet was spent. I saw that later. The dog was OK."*
- *"A branch got wedged into one of the helmet's ventilation holes and tore the styro-foam. Scalp got abrasions."*
- *"Handlebars got stuck making me fly over and I land on my head. Got a decent laceration coming from one of the straps of my helmet."*
- *"Have hit my helmet quite some times, but never got anything as bad as a concussion. Mostly in downhill or faster crashes when other parts of the body took the main impact while the head was sort of more 'bouncing around'."*

### **Survey insights summary**

Helmet use is very well implemented within the mountain bike discipline. There is a mountain bike dress code that is different from the one for urban bicycling, being more positive aesthetics-wise towards helmet wear and protection in general. However, aesthetics is still an important feature in helmets. From a user perspective, the most sought after characteristics in a helmet were good comfort, fit and the helmet being lightweight - all which can be categorized into the previously mentioned 'performance aspects'. Helmets were perceived as safe when they provided good coverage, especially covering the back and sides of the head. People were aware of the risk of hitting a narrow object, and regarding an airbag solution there were concerns regarding the solution bottoming-out, getting stuck or being punctured, not reacting at all, or reacting when not wanted.

A helmet that need maintenance or user surveillance, e.g. checking batteries, felt less safe than a traditional helmet. There are benefits of normal helmets that e.g. Hövding does not have, like providing warmth and protecting the eyes. According to crash scenarios, a helmet should protect against narrow objects like trees and bike frames. Riders heads get impacted in a variety of locations, at the back and side of the helmet, but also front. If you do not wear a full face helmet, those front impacts will lead to abrasions and lacerations

to the face.

## 4.6 Guidelines for product development

The research resulted in the following implications on the helmet solution. They are presented together with requirements coming from the project scope and company, as well as from the theoretical background research.

### Company

From Mips' perspective, the solution must incorporate air as a protective element and be worn on the head. It should always provide a sufficient, baseline level of protection that meets helmet regulations in terms of legal standards. It should also meet Mips' own proposed safety standards regarding oblique, i.e. "not straight", impacts. The solution should comply with Mips' brand image of scientific credibility.

### Context

It should protect against impacts towards the head that are not the result of a crash, e.g. hitting an overhead branch. The air elements, no matter how they will be designed, need to be durable enough not to be punctured by sharp objects, e.g. rocks or branches. It should withstand the elements, essentially meaning that it needs to be resistant to UV radiation and water, and function in the temperatures mountain biking is performed in. If the mountain bike rider crashes and would like to continue riding, the solution needs to be dependable for the rest of the mountain bike activity. It should not adversely affect the performance of other personal protection used in mountain biking, such as e.g. neck braces and back protectors.

### Users

The solution should be aesthetically pleasing enough not to deter use of it. It must provide sufficient ventilation, and be lightweight and comfortable. It should be possible to clean the helmet, e.g. sweaty inner parts. To give a feeling of safety, it should provide good coverage.

### Sustainability

It should not worsen the impact on the environment compared to the traditional EPS-based helmet.

## CHAPTER FIVE

# FIRST PROTOTYPING PHASE

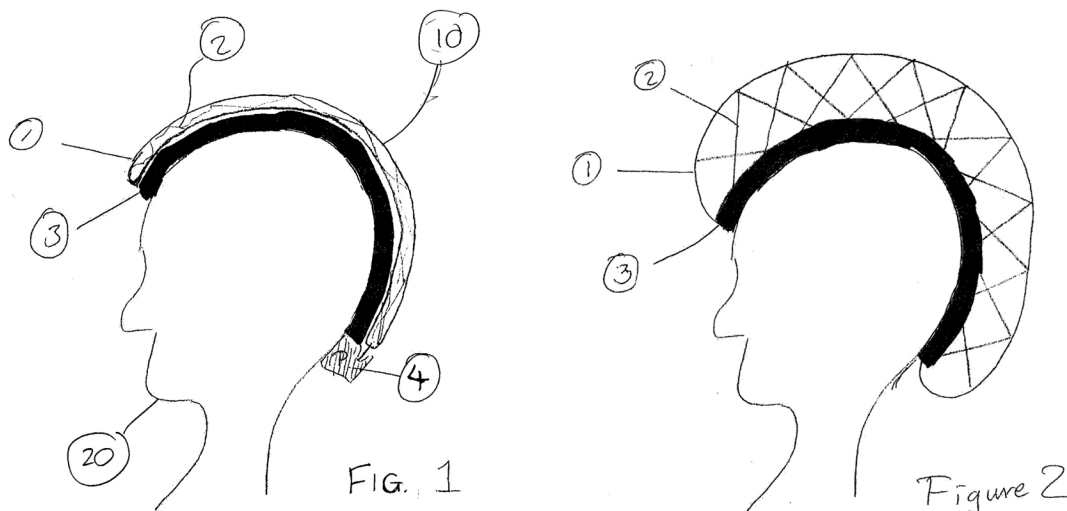
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The chapter begins with a presentation of the patent that is the starting point of the project. It is followed by a description of the prototyping process that lead up to the first testing.

### 5.1 The patent

The basis for the project is Mips' patent N405306GB. The patent consists of an airbag-equipped helmet designed to provide protection against angled impacts. The term 'airbag' is related to the type of cushions used in the automotive industry to protect a person in the event of an impact, and can be thought of as both pre-inflated and inflatable (see figure 5.1).

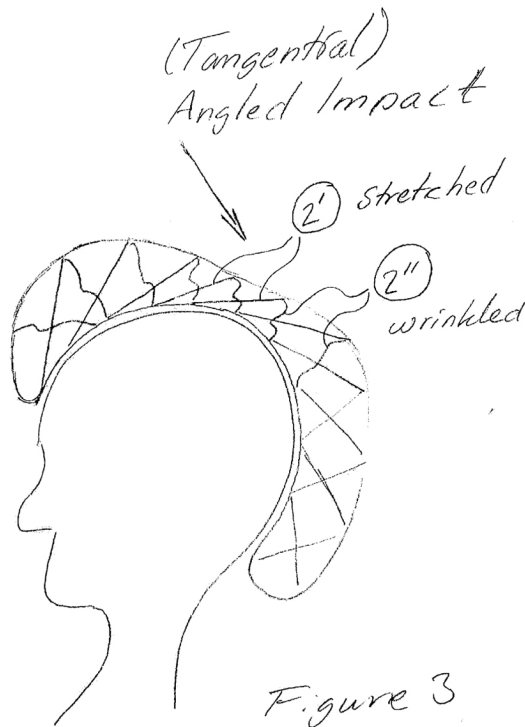
Illustrations in this section are taken from the patent, courtesy of Mips.



**Figure 5.1:** An airbag element fitted to a helmet structure, in deflated and inflated state

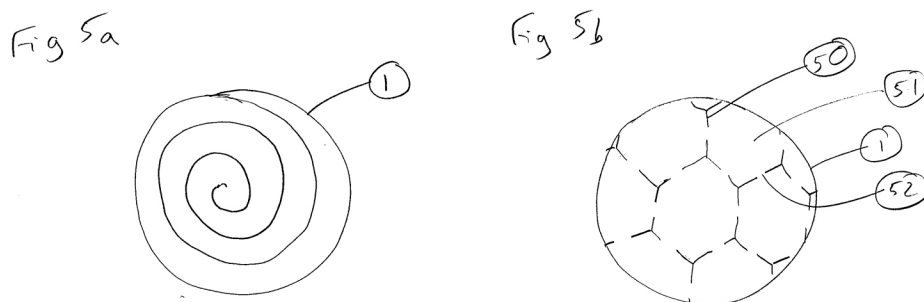
## 5. FIRST PROTOTYPING PHASE

There are already patents regarding air-filled elements in head protection. They are however meant to deal with linear impacts. This patent presents a way of achieving the same core function as the MIPS layer: provide increased protection when the helmet undergoes angled impact, i.e. protecting the brain against rotational violence.



**Figure 5.2:** An inner structure modifies the movement of the airbag

The idea is that when the airbag is affected by an oblique impact the airbag structure is deformed in a way that reduces the rotational forces that would otherwise be transmitted to the head (see figure 5.2). The outer layer moves relative to the inner layer in what can be described as a “shearing motion” (although technically the layers do not touch). The airbag has internal reinforcements that can further optimize this movement. The internal structure is meant to control the way the surface of the airbag deforms, so that it takes a shape that encourages the motion of the head to be translational rather than rotational upon impact. Reinforcements could be a network of threads, membranes, beams or tubes within the airbag cavity (see figure 5.3). There may be a single compartment airbag, or a structure formed by several compartments. It could also be a single compartment that is arranged in a folded or contorted manner. Materials can be any, e.g. nylon fabric.



**Figure 5.3:** Concepts for the inner structure of an airbag

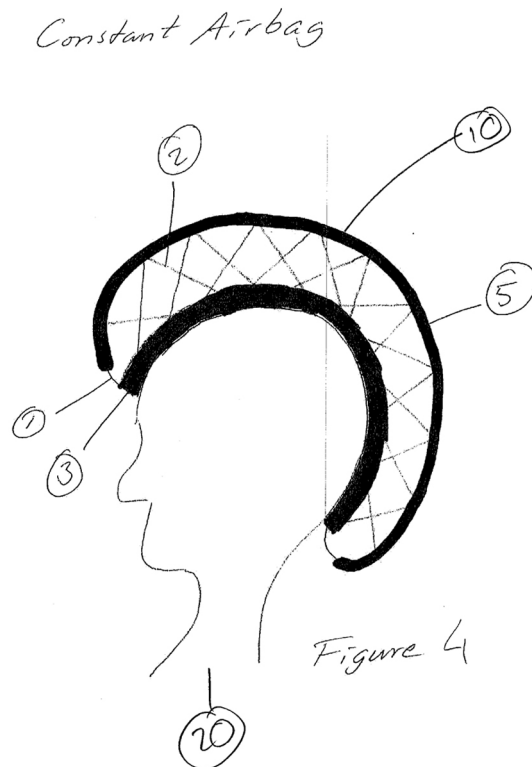
It can be filled with any gas (or liquid). It is also suggested that the airbag could be a ‘dynamic’ one, that deploys into its ‘active’ state (i.e. the state ready for shock absorbing) in the event of an impact. The head protection solution would then require an inflating device, such as e.g. a compressed cold gas cylinder like used in the Hövding, and sensors to detect when to inflate. Or, the airbag can be ‘constant’ - it is pre-filled and remains

inflated whether or not the user is involved in an impact.

The helmet can have the airbag as its only protective element, or combined with EPS, EPP or polyurethane materials, e.g. PORON or D3O. The solution could also be equipped with a sliding facilitator such as the MIPS low friction layer. It could or could not have a stiff outer shell (see figure 5.4).

## 5.2 Making of prototypes: Validation of the patent

The notion that two layers of an air filled element would show the relative, “shearing” motion described in the patent was not validated. No products using air based on that principle had been found during the benchmarking activity. Therefore, the first goal after the initial research was to test whether it would work or not. The section will explain the circumstances, decisions and difficulties influencing the prototyping phase.



**Figure 5.4:** A stiff outer shell in addition to a constant airbag

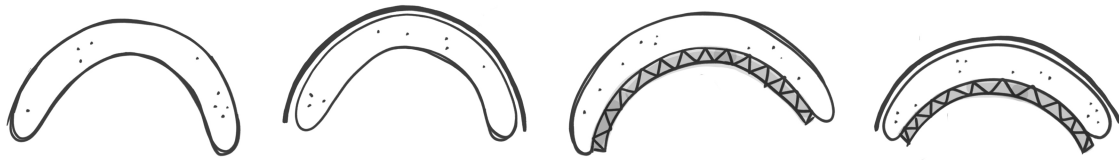
### Prototyping plan

The plan was to construct a prototype based on a simplified version of the patent, leaving out the internal structure and constructing a one cell airbag fitted to the test head Mips uses for testing. The prototype would be evaluated both in terms of its protection against linear impact and protection against angular impacts. In this early stage, there were many questions regarding the design variables of the solution. The main question was however whether the airbag would show the tendencies for reducing rotational motion that are described in the patent.

### Idea

The thickness of the protective layers of most bicycle helmets is somewhere around 30 millimeters, based on measuring the thickness of helmets at Mips’ office (comfort padding and MIPS layers not included). For the prototyping, four configurations were decided on (see figure 5.5):

1. 30 millimeters of airbag, no outer shell
2. 30 millimeters of airbag, with an outer shell
3. 8 millimeters of EPP and a 22 millimeter airbag, no outer shell
4. 8 millimeters of EPP and a 22 millimeter airbag, with an outer shell



**Figure 5.5:** Quick sketches planning the prototyping, configurations 1-4 from left to right

The concepts with airbags as sole protective elements (1 and 2) would allow for evaluating the airbag without any interference of other structures. If the airbag was to show a characteristic movement, it might be more exaggerated the thicker it is. Adding an outer shell could facilitate, or amplify, the movement. The concepts that had a layer of EPP (3 and 4) would provide a “baseline level” of protection, should the airbag bottom out.



**Figure 5.6:** The liner available

moment of impact, i.e. it would be inflated no matter if it was like that always, or having reacted to its surroundings.

The reason for choosing an 8 millimeter EPP liner was that ready-made liners with that thickness were available for the project (see figure 5.6). There was also the option of milling a liner to custom, but in this stage of the project 8 millimeters seemed as good as any thickness in the region of a centimeter. Having the “traditional material” make up less than a third of the total thickness seemed appropriate considering that the air filled element was the most novel and interesting to evaluate, thus making up a majority of the thickness.

At this time, no attention was given to whether the airbag would be of the dynamic or static variety. In any case - if pre-inflated or inflated when needed - the airbag would have roughly the same properties at the

### Process

Material was sourced from a website for kite builders. Two types of coated fabrics were purchased, one nylon and one polyester. Coating is done to lower air permeability and improve water resistance. The choice of nylon was based on the literature study of airbag applications. The fabric was called ‘Mirai Ripstop Nylon’ and the description read “lightweight nylon with some elasticity to it” (Textalk, 2016b). Since weight is an essential aspect of a helmet, a lightweight variety seemed appropriate. The weight was 48 grams per square meter with reinforcements in 1 x 1 centimetre squares. It is the reinforcement method that gives the name ‘Ripstop’, making fabrics resistant to ripping and tearing. Mirai was coated on one side with a soft polyurethane coating.

The other fabric, the polyester ‘Icarex Ripstop’, had a polycarbonate coating. It weighs 31 grams per square meter and has 1 x 1 centimetre reinforcement squares. The description said that polyester fabrics are more lightweight than the same thickness of nylon, as well as less elastic (Textalk, 2016a). Having one more and one less elastic fabric seemed appropriate from a testing perspective. However, when the fabrics arrived the elasticity was negligible. The way you would think of - and feel - an elastic fabric was not noticeable in the two varieties - both fabrics were thin and paperlike. Compared to Mirai, Icarex felt more so, almost resembling the kind of tissue paper used for crafts. Therefore, Icarex was dismissed in the prototyping. A cheap cotton fabric was also purchased to be used for pattern construction before applying it to the main fabrics. The prototyping had to be done with the testing in mind. Prototypes needed to fit the dummy test head in size M. An aluminum head form with the same size was used for fitting.

For all attempts, the intention was to construct one outer layer and one inner layer, joint with a fabric “rim” that gave the airbag a thickness of 22 millimeters between its two layers, where the inner layer was fitted to the test head. The prototyping process quickly assumed an exploratory nature, both because there was no blueprint for how the prototypes were best constructed, and also to learn and familiarize with different sewing techniques.

### Attempt 1

A helmet liner from a ski helmet in size M was disassembled to provide a sewing pattern for the inner layer (see figure 5.7). The parts were placed on the cotton fabric and since the helmet liner was sewn with overlapping seams, some seam allowance was added.



**Figure 5.7:** The liner before and after deconstruction

## 5. FIRST PROTOTYPING PHASE

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**Figure 5.8:** The template foam liner



**Figure 5.9:** Pinning the pattern to fit



**Figure 5.10:** Side and back view of the first attempt

For the outer layer, an EPS layer from a skate helmet found in the lab was used as a template, roughly two centimeters thick (see figure 5.8). Measuring the distance front-to-back and side-to-side gave some guidance in how much the pattern for the inner layer should be scaled up. The result after sewing the bigger pattern pieces together was that the shape did not quite follow the template and the fabric was folded and pinned to improve fit (see figure 5.9). A new pattern was created from the pinned adjustment.

Since the helmet liner used for the inner layer pattern had an uneven shape, and the skate helmet foam liner had not, the result was not great when joining the parts but as a first attempt it seemed promising (see figure 5.10).

### Attempt 2

Using the inner pattern derived from the comfort layer also for the outer layer was not good enough. To avoid the folding and pinning, a pattern was created using the skate helmet as a template. Cotton fabric was draped over the foam liner, roughly following the same principle how the comfort liner was constructed: one strip of fabric stretching from the front to the back and one along the circumference. The gap in between, with a shape that perhaps can be described as a "pointed oval", got as many pieces of fabric that was needed to reduce the wrinkles created (see figure 5.12). The technique is similar to modeling surfaces in a CAD software.

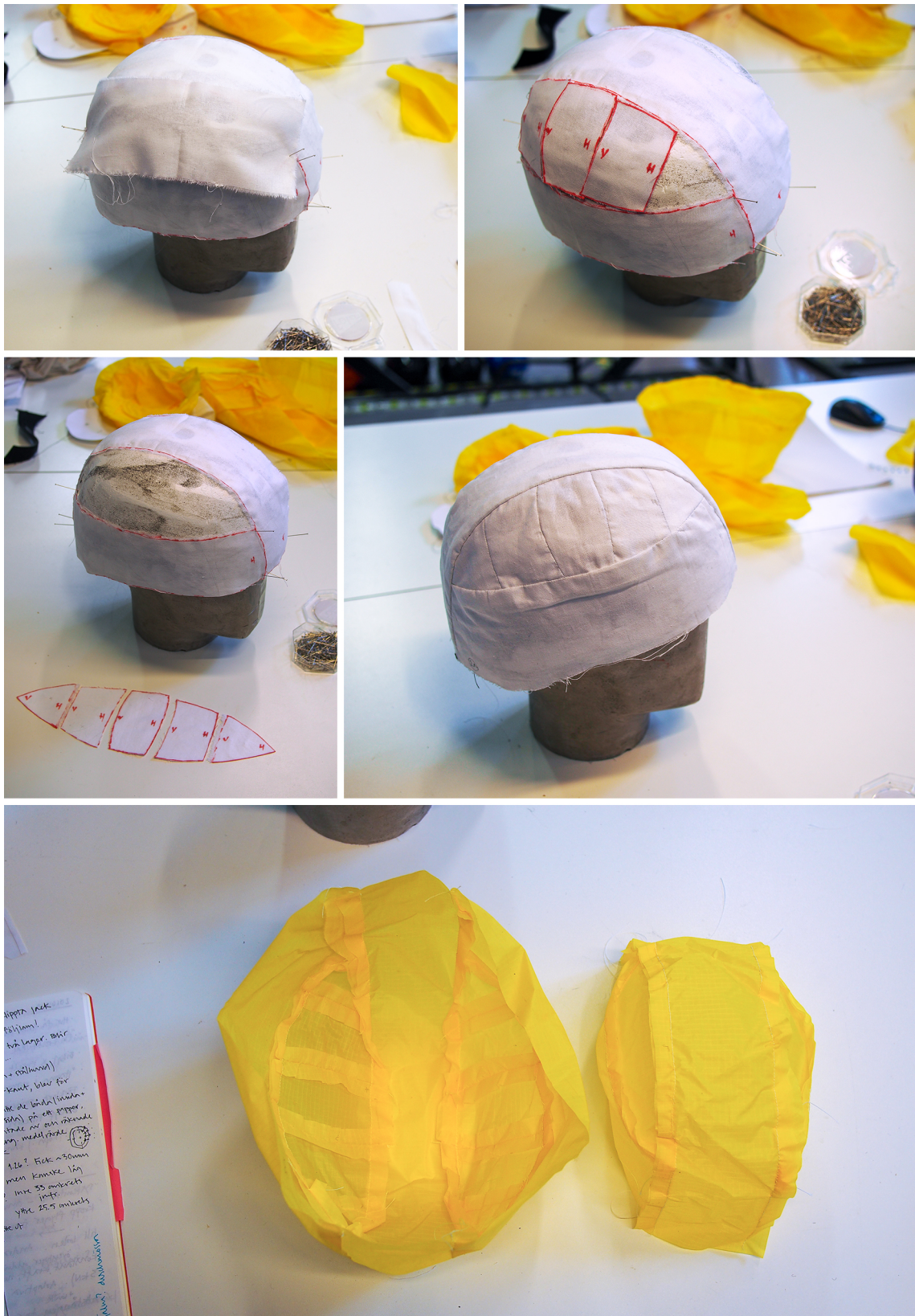
### Attempt 3

Inspired from the way airbags in cars are folded into their compartments; in this attempt fabric was hung over the aluminum head form and then folded and pinned to follow the shape snugly. Folds were kept straight not to complicate the construction too much and allow for easier scaling (see figure 5.11).



**Figure 5.11:** Attempt 3, draping the fabric

## 5. FIRST PROTOTYPING PHASE



**Figure 5.12:** Outer layer from attempt 2 together with inner layer from attempt 1

### Attempt 4

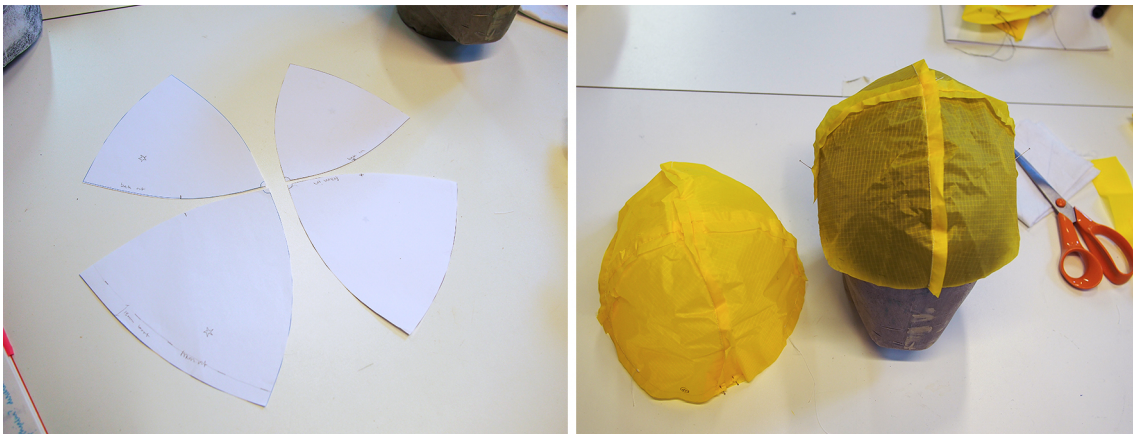
As a spin-off on the draped concept, a similar way of constructing was tried, with cut triangles (similar to what in sewing is called darts). This reduced the thickness of the fabric layer, making it more flexible and thus accommodating for movement. A downside with this way of constructing was that there was a small hole at the top of every triangular cut. To seal it you could sew or glue a small patch over it (see figure 5.13).



**Figure 5.13:** Attempt 4, removing excess fabric

### Attempt 5

In between construction iterations, attempts were made to join inner and outer layer with the third surface, the curved fabric rim. The result was always that after the outer layer had gotten the rim sewn on, the circumference of the inner layer never seemed to match the remaining side of the rim that it should be attached to. This was thought to be simply an accuracy problem, and to counter it a CAD software was used to create a pattern with better precision.



**Figure 5.14:** Attempt 5, pattern making in CAD software

The software used was ‘Solid Works’. An existing MIPS layer was used as starting point for the inner layer of the airbag since it is fitted to the size of the head. A tool called ‘Flatten Surface’ was used to project the surfaces onto a plane. This tool is aimed towards fabric applications, e.g. creating patterns for car seats. The low-friction layer was divided into four triangular-like shapes. The CAD software could then be used to get the exact

## 5. FIRST PROTOTYPING PHASE

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arc length of the sides of the parts that would make up the circumference of the edge that goes towards the rim. The scale percentage that corresponded to a 22 millimeter rim was calculated, and the pattern pieces were scaled up to that percentage. The pattern for the inner- and outer layer were printed and placed on the fabric. A seam allowance of 1 centimeter was added and the parts sewn together. Due to the crossing seams the final result was stiffer than the other attempts. The pattern together with the result can be seen in figure 5.14.

### Selection

By this time, the iterations had lead to quite a few different approaches to construction. Placement of the seams and thickness were aspects influencing the suppleness of the layers. The attempt that turned out best in regards to allowing movement was the fourth attempt. It was chosen as the one to move forward with. Since the problem with joining accurately was still evident, it was decided that the pattern should be re-drawn in the CAD software.

Despite calculations on the sizes of the two layers and the fabric rim, the parts did not add up in assembly. It was concluded that the problem lay in the tolerances possible to achieve by the sewing machine, more specifically in keeping the specific measurements when sewing with seam allowance.



Figure 5.15: Selection

### 5.3 Intermediate evaluation

A thought had emerged that the project had moved too fast into prototyping the initial idea, a discrepancy with the nature of the design process. The latter is often described as a funnel or a diamond, where you “go wide” in idea generation *before* you evaluate to focus on fewer concepts.

To address this reflection, a meeting was asked for with technical engineers at Mips. The meeting did not come after the prototyping but rather as an interruption of it. Ways of simplifying the idea and aim with the prototyping was discussed. It was clear that the idea needed validation, and it was also agreed that the path was too focused on one single outcome. Instead of attempting to create close-to-reality prototypes, i.e. a complete helmet solution that could be worn on the head, perhaps there were other insights to be gained in making less finished prototypes - especially when so little was known regarding pressure and behavior of an airbag in an angled impact.

## 5.4 Making of prototypes: “Back-to-basics”

After the evaluation meeting, the new aim became to simplify the prototyping idea further, acknowledging that it could give basic insights regarding construction such as: What type of sewing is required to produce something with seams that would hold up at an impact? How airtight will a sewn airbag be? Will it have to be sealed, and if so with what?

### Idea

Even though the prototyping that had taken place so far was based on a simplified version of the original idea (leaving out the internal structure), it had not been basic enough. The outcome of the evaluation was to prototype a limited aspect of the final solution. The idea was to focus on a cross section of the fully-covering prototype; something that represented a layer of air in its simplest shape.

It was decided that the new prototype would be round, perhaps more accurately described as a short cylinder, or a “puck”. The reason was to show the same movement in any direction of impact. It had to be possible to surveil the pressure inside the “air puck”. Thicknesses 20, 30, 40 and 50 millimeters were to be tested. The measurements were derived from the fact that a helmet often is around 30 millimeters thick. That thickness for a single airbag would represent replacing all protective layers of the helmet with air. Should there be a layer of expanded foam in combination with the airbag, that airbag would be represented by the 20 millimeter prototype. The thicker prototypes were of interest to see what the result of scaling up would be, or could represent a dynamic solution, i.e. inflated when needed (since a constantly inflated airbag more than 30 millimeters thick would be at risk of failing on consumer acceptance).



**Figure 5.16:** Prototypes with Dunlop valves

### Process

Size was adapted to fit the smallest of the anvils, making the prototypes 12 centimeters in circumference. For each thickness, two round pieces with 1 centimeter seam allowance

## 5. FIRST PROTOTYPING PHASE

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was cut from the car airbag fabric. Instead of a curved rim like in the previous attempts, the side of the "air puck" would now be made out of a straight strip of fabric. Assembly still required a bit of concentration, but sewing together the curved edge with a straight piece of fabric was easier.

A seam allowance of 0.5 centimeters was also tested, but the fabric then started to fray in handling, e.g. when turning the "air puck" inside out after sewing. Seams were sealed with 'LiquiSeam', a substance used to make seams waterproof and mending tears in tents, outerwear and rubber boots. Valves of the type 'Dunlop', or 'Woods' (in Sweden mostly referred to as "common bike valve") were cut from bike tubes and attached to the prototypes. The valves would allow for filling of the prototypes, and also to monitor the pressure they were filled with since bicycle pumps often have integrated pressure monitors.



**Figure 5.17:** Sewing the pucks in the new fabric

During the prototyping phase contact with an employee at Autoliv AB had been initiated. After the second meeting, he arranged for airbag material to be sent to Mips' office. Prototyping had begun with the yellow nylon (see figure 5.16), but it was abandoned as soon as the airbag fabric arrived. The new fabric was thicker, but also softer and less paperlike in its behaviour, making sewing easier.



**Figure 5.18:** Latex sealing of prototypes

## 5. FIRST PROTOTYPING PHASE

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To make the prototypes more airtight a substance called 'latex milk' was purchased. The LiquiSole was good at sealing seams, but the texture did not allow for covering bigger surfaces. Liquid latex is used for creating custom molding casts for crafts. You take an object you would like to cast, cover it in several layers of latex and the result is a soft cast that can be filled with plaster or concrete. To keep the dried latex from sticking it is dusted with talcum powder.

The "air puck" prototypes were made in four thicknesses. When filled with air, they bulged and kept their shape, also overnight, indicating that they were fairly airtight.



**Figure 5.19:** Final result of the first prototyping phase

## *5. FIRST PROTOTYPING PHASE*

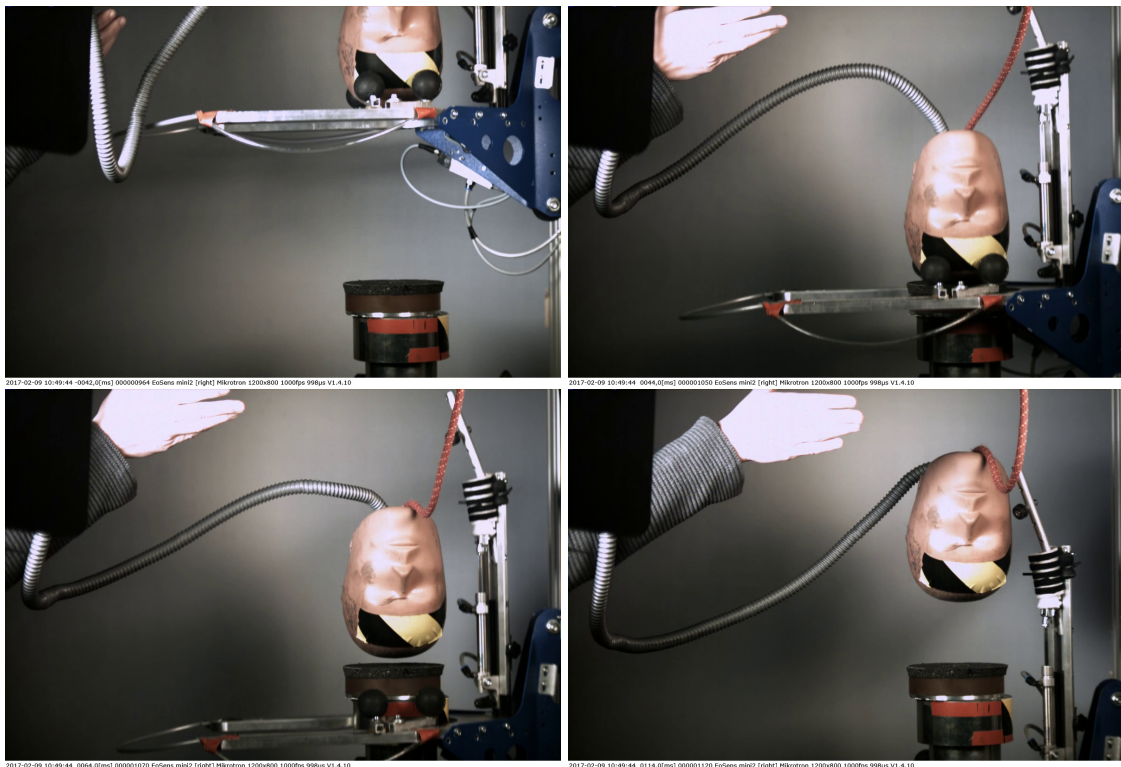
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## CHAPTER SIX

# EVALUATION AND EARLY CONCEPT DEVELOPMENT

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The chapter will explain how the basic prototypes were tested and how the resulting insights were used in further development.



**Figure 6.1:** Reference testing against a flat EPS foam disk, 3 m/s

## 6.1 Testing

The "air puck" prototypes were a representation of a detached airbag element, and hence the testing would have some discrepancy with reality. Instead of having the protective

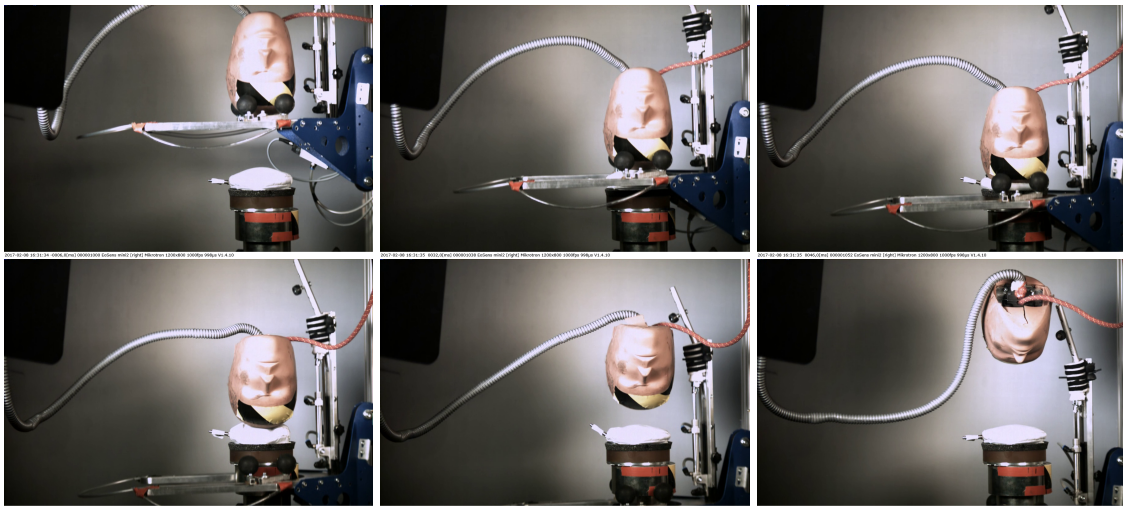
## 6. EVALUATION AND EARLY CONCEPT DEVELOPMENT

elements on the test head and dropping it against the anvil - similar to how helmets are tested - the head would have to be dropped against the air puck placed on the anvil.

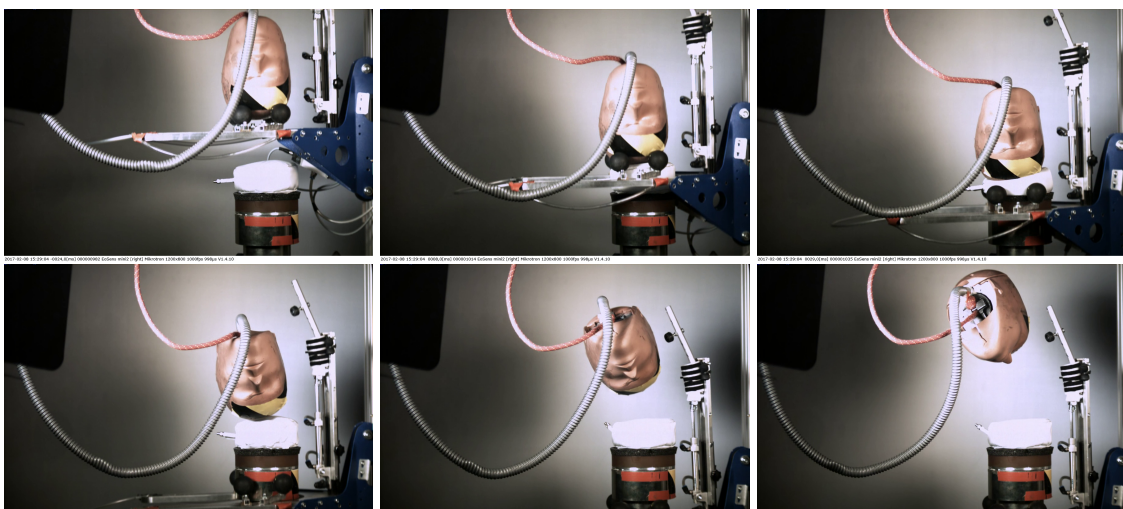
### 0 degrees - 3 m/s

In the first test, it was not known how durable the prototypes would be. Therefore, drop height was modest to avoid bottoming out and damaging the expensive sensors in the test head. Height was about 70 centimeters, which gave a speed at impact at around 3 meters per second.

When Mips tests the performance of their MIPS layers, the helmet model equipped with MIPS is always compared with that same model without MIPS. Similarly, the prototype testing needed a reference. The reference test was to drop the test head against a layer of EPS foam. Underneath the foam is a rubber disk to further protect the test head.



**Figure 6.2:** 2 centimeter “air puck” prototype, 3 m/s on flat anvil



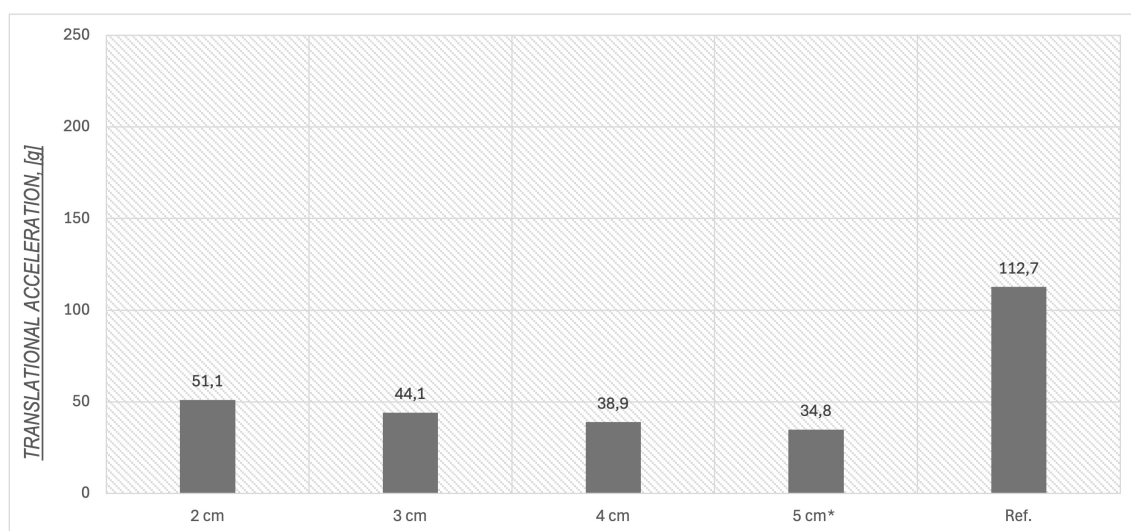
**Figure 6.3:** 5 centimeter “air puck” prototype, 3 m/s on flat anvil

All tests in Mips’ test rig are automatically recorded, and the movie frames show that the reference bounces back fairly straight upwards (see figure 6.1). After the EPS-only attempt, the airbags were tested at the same height and speed. For all thicknesses, the head is first pushed down into the airbag and then bounces back, but does not follow a straight path like in the reference. Instead, the head is given a rotational movement on the way up. This is thought to be because the head, seen from above, is more narrow towards the forehead. The narrow part sinks deeper into the airbag, and when the compressed air kicks back the head is sent off in an unbalanced way. Video frames from the test of the thinnest and thickest airbag - at 2 and 5 centimeters - can be found in figure 6.2 and 6.3. The thicker the airbag, the more pronounced the spinning is when the head leaves the airbag. It is allowed to sink deeper into the thicker airbag and the angle at the time it bounces back becomes greater.

**Table 6.1:** Testing of “air puck” prototypes, 3 m/s on flat anvil

Id	Translational acceleration	Rotational acceleration	Rotational velocity
2 cm	51.14	1.44	14.14
3 cm	44.15	1.17	13.63
4 cm	38.92	1.06	14.42
5 cm*	34.81	1.03	15.92
<i>Ref., EPS foam disk only</i>	<i>112.68</i>	<i>1.57</i>	<i>6.54</i>

\*value is the mean value of 3 test runs



**Figure 6.4:** Testing of “air puck” prototypes, 3 m/s on flat anvil - Translational acceleration

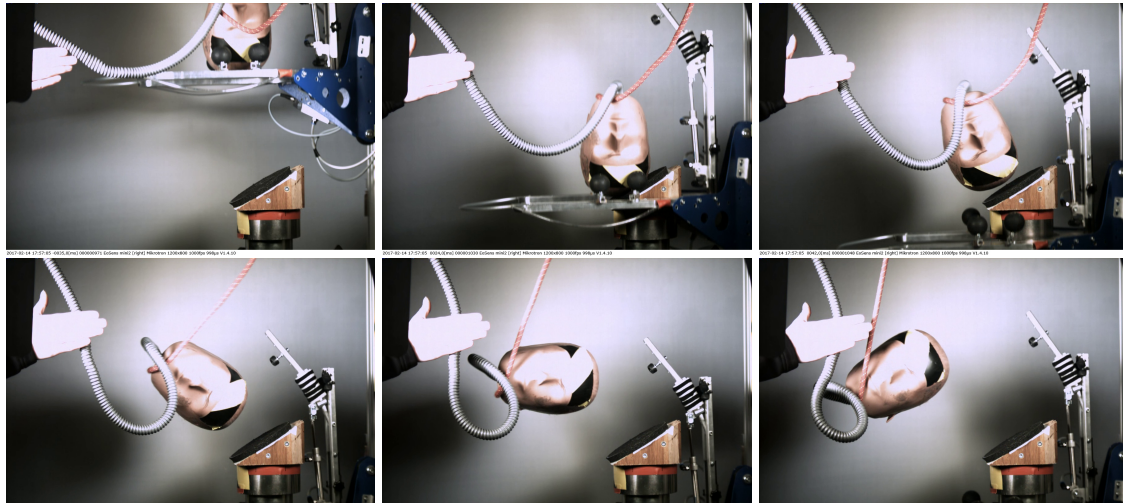
The 5 centimeter was tested three times as a safety measure, to understand the movement and make sure that the test head was not at risk for damage at impact. Since the test

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was conducted on a flat anvil, no conclusions have been drawn regarding the angular acceleration and velocity - this is why that part of table 6.1 is grayed out. The thicker the airbag the lower the translational acceleration transferred to the head, as seen in the graph in figure 6.4. Dropping the head against the EPS-clad anvil gave a value of 112.7 g. The thinnest airbag, at 20 millimeters, more than halved that value. The thickest airbag reduces - on average - the reference value with 70 percent. It can be noted that the reference test gets a very low rotational velocity compared to the airbag tests (see table 6.1). From the recorded movies it is clear that the head in that test bounces back in a straighter path, and the numbers show a significantly higher translational acceleration. That should explain where the energy has been distributed.

### 30 degrees - 4.5 m/s

Next testing procedure was against a 30-degree anvil, that Mips had custom made out of an old wooden cabinet. The reference had a fairly clean rotation around one axis. The airbags were taped with adhesive tape onto the EPS disc.



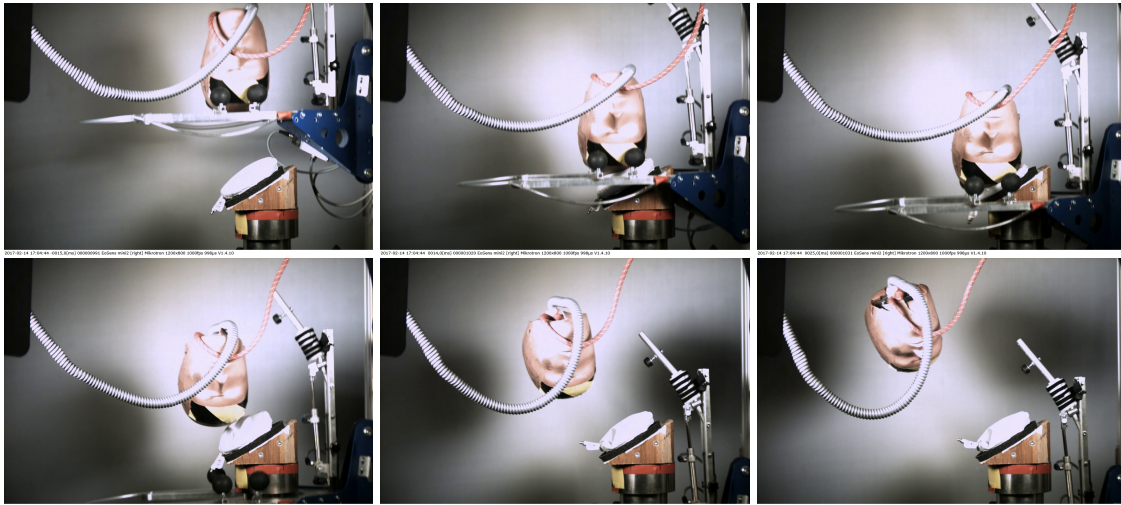
**Figure 6.5:** Reference testing against a 30-degree angled EPS foam disk, 4.5 m/s

For the airbag tests, the twirling of the head due to it sinking down into the airbag was still there, together with the rotation as a result of the angled anvil. The most remarkable phenomenon was that when the head struck the top layer of the airbag, it pulled the fabric in a way that made the airbag roll off the anvil. It became more distinct the thicker the airbag was, and it can best be seen in the last three movie frames of the 5 centimeter test in figure 6.7. Because of this, the wanted outcome - the layers of the airbag “shearing” in relation to each other - could not be seen.

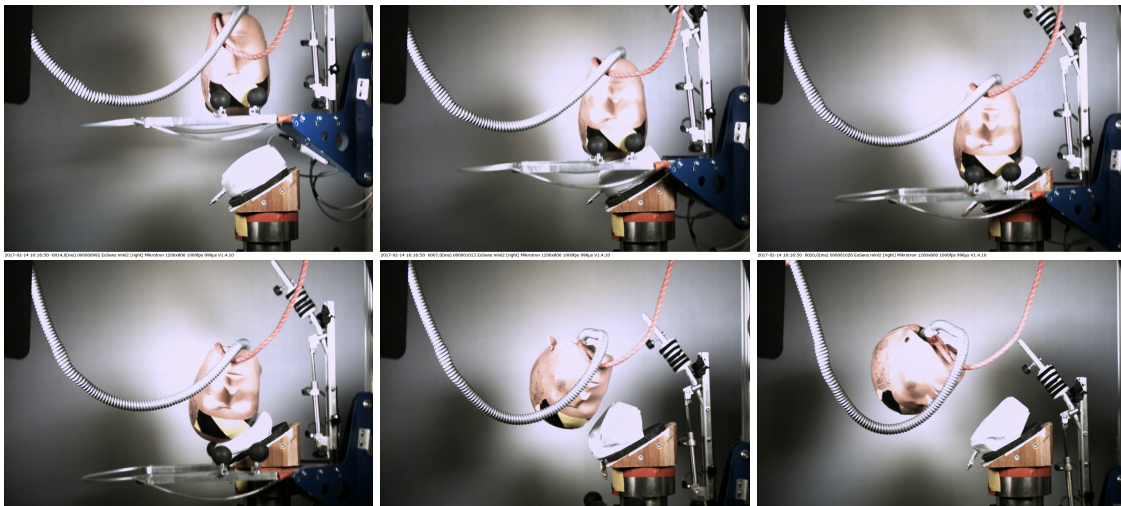
The reason the 2 centimeter prototype was tested twice was that the first value seemed to be out of trend, having increased more than the 3 centimeter did compared to 4, and the 4 centimeter compared to 5. However, it was concluded that it probably was within range. The pucks performed significantly better than just the EPS foam. Compared to the flat testing, the pucks did no longer perform better with increased thickness. Thicknesses 3 and 4 centimeters seem to perform the best in reducing rotational acceleration. The 5

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centimeter airbag is the best in reducing the translational acceleration, but performs the worst in the rotational case (see table 6.2).



**Figure 6.6:** 2 centimeter “air puck” prototype, 4.5 m/s on 30-degree angled anvil



**Figure 6.7:** 5 centimeter “air puck” prototype, 4.5 m/s on 30-degree angled anvil

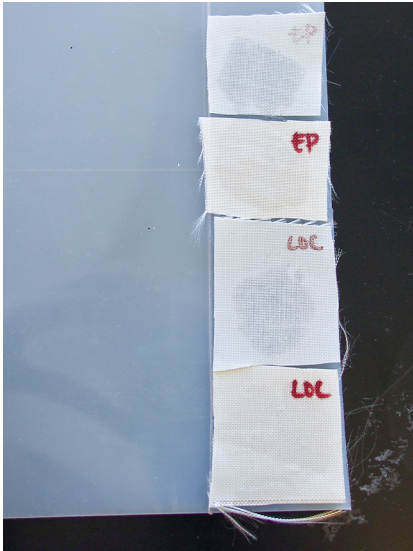
**Table 6.2:** Testing of “air puck” prototypes, 4.5 m/s on 30-degree angled anvil

Id	Translational acceleration	Rotational acceleration	Rotational velocity
2 cm*	93.65	1.75	13.28
3 cm	72.33	1.18	7.94
4 cm	61.91	1.64	13.56
5 cm	45.29	2.25	25.47
<i>Ref., EPS foam disk only</i>	<i>149.59</i>	<i>7.36</i>	<i>28.34</i>

\*value is the mean value of 2 test runs

### Additional testing

To address the fact that the prototypes rolled off the anvil a second testing session was held, with modified prototypes. The first idea was to attach the bottom layer of the airbag to a stiff layer such as a piece of plastic sheet. It was investigated whether the airbag could be glued onto the plastic, but the adhesion was not good enough. The glue types tested were a cyanoacrylate-based one (commonly referred to as ‘super glue’) and one epoxy glue. It was not clear what type of plastic the sheet consisted of.



**Figure 6.8:** Glue test



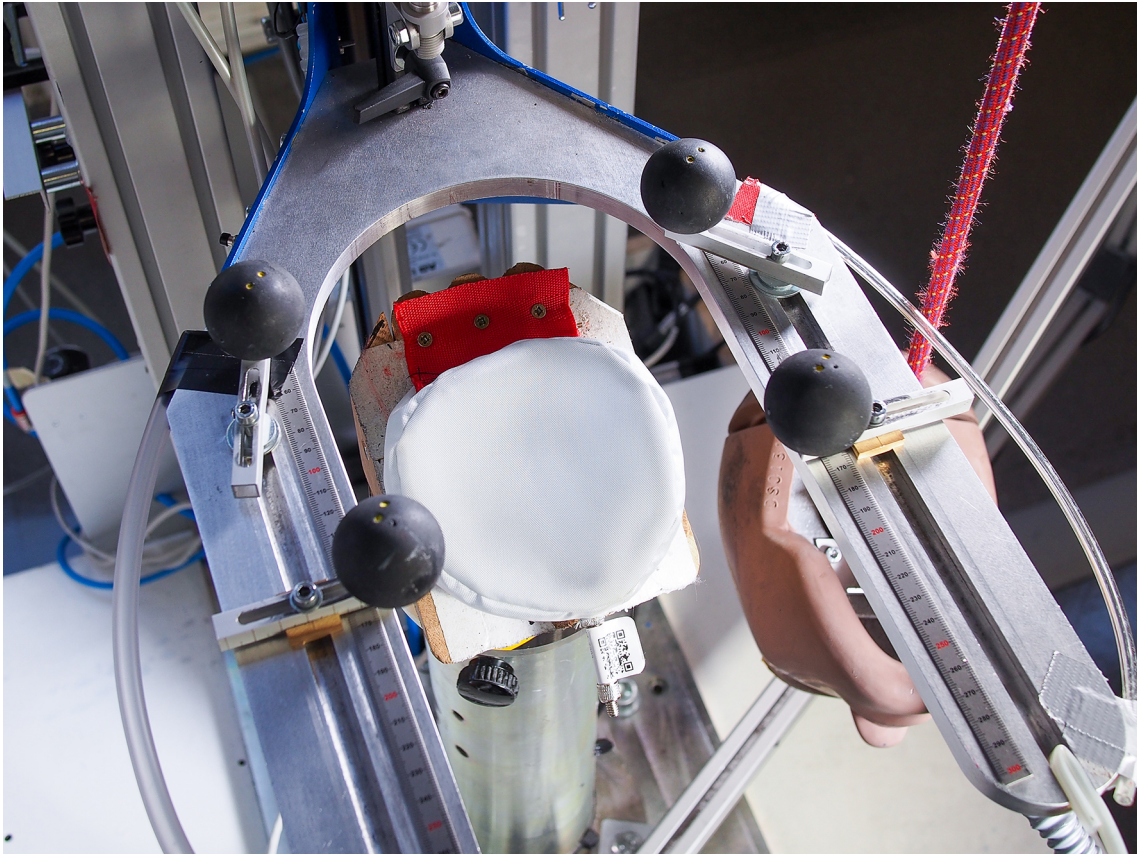
**Figure 6.9:** Lashing strap screwed into the anvil

Instead of gluing, a piece of lashing strap was sewn onto the prototypes. It could then be fastened with screws into the wooden 30-degree piece. The testing was then repeated, however since the fastening did not allow for a EPS puck underneath the airbag, the 2 centimeter prototype was excluded from testing due to fear of bottoming out.

### Results

The reason that the 3 and 4 centimeter prototypes have one extra testing each is that they both showed a third value that was higher than the two first runs. In retrospect, that was true also for the 5 centimeter prototype and it should have been tested an extra time.

Similar to the first test, the translational acceleration was lower the thicker the airbag was. However, in this test the reference performed better than the thinner prototypes (see figure 6.11). In general, the prototypes gave significantly higher values in respect to both linear and rotational management when fastened to the wood. That would imply that the rolling played a part in dampening or redistributing the energy from the impact.

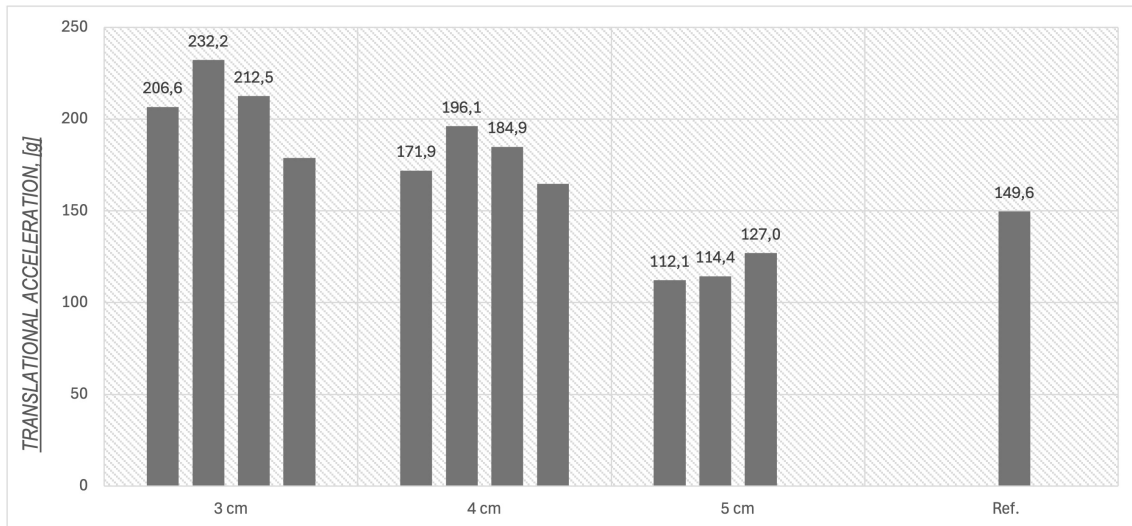


**Figure 6.10:** One of the modified prototypes attached to the wooden 30-degree wedge

**Table 6.3:** Re-testing of modified “air puck” prototypes, 4.5 m/s on 30-degree angled anvil

Id	Translational acceleration	Rotational acceleration	Rotational velocity
3 cm	206.60	7.20	15.70
3 cm	232.20	8.40	14.10
3 cm	212.50	7.90	16.80
3 cm	178.91	6.50	17.54
4 cm	171.89	6.84	20.01
4 cm	196.12	8.23	14.57
4 cm	184.86	6.78	13.92
4 cm	164.80	6.30	15.60
5 cm	112.11	4.04	24.96
5 cm	114.37	3.82	17.94
5 cm	127.00	4.10	17.30
<i>Ref., EPS foam disk only</i>	149.59	7.36	28.34

## 6. EVALUATION AND EARLY CONCEPT DEVELOPMENT



**Figure 6.11:** Testing of “air puck” prototypes, 4.5 m/s on 30-degree angled anvil  
- Translational acceleration

### Comment

The air pucks held up well in seams, none of the prototypes broke in any way during testing. The testing on the flat anvil put higher strain on the pucks than the testing on the angled surface, at least in the testing where the pucks were not fastened with screws.

The pucks were not completely airtight. When filled with the air compressor the indicator on the nozzle showed that pressure value got as high as 5 bar. This was at first falsely interpreted as the pucks holding pressure. However, when filling the pucks using the foot operated pump (for bicycle tubes) the indicator barely got up to half a bar. This meant that as long as you kept adding air at a high enough rate, the pucks seemed airtight. But when filled with the slower flow of air from the foot pump, the flow in was about the same as the flow out. Meaning that no pressure built up inside of the volume. However, since impact in testing happened quickly, the air inside the pucks did not have time to escape through the fabric and seams. But if you applied slow pressure, e.g. by pushing a finger to the surface and down, the puck deflated at the same rate.

Meeting the requirements for linear impacts with the 12 centimeter circumference pucks does not imply that a bigger volume, such as the initial idea with a single airbag fitted to the head, would do so too. It would probably bottom out, especially if it is not pressurized but just filled with air. Also, the 5 centimeter airbag that performed the best in translational acceleration is still 2 centimeters, or 30 percent, thicker than the thickness of most foam based helmets today. The scenario where the head is dropped against a flat surface does not correspond to a scenario where the airbags are placed against the head, and the head is dropped together with the airbags against a flat, angled surface. Also, if the airbags are enclosed between the stiffer layers of a helmet, the rolling movement would be obstructed.

### Conclusions

- The airbags do not have to be completely airtight to be able to dampen the energy of an impact. Another way of expressing this is that the airbags do not have to be pressurized. They just have to contain air at the moment of impact.
- The airbags “rolled”. This will probably not happen in a helmet solution where the airbags are contained within other protective layers.
- The situation of having a test head impact a detached airbag does not correspond to reality.

### 6.2 Concept development

The insights from the prototyping phase and the first testing were valuable, although not strong enough to determine whether the original idea would work or not. Before initiating a second testing phase, the solution needed to be better defined. Concept development in this stage focused mainly on features of the airbag element of the helmet. Evaluation is based on technical feasibility as well as insights from the initial research. Whenever possible, the concepts have been evaluated from a user perspective.

#### State and user involvement

Three possible scenarios were defined. The solution could:

- **Be always air filled with constant shape**

The helmet has the same dimensions and appearance at all times, from being stored at home to when it is in use. In theory, the helmet is always prepared for an accident. The user just have to put the helmet on, and otherwise takes no action in regards to it.

- **Be a two-state solution, prepared by user before activity**

During transport to the mountain biking terrain, e.g. biking through the city before getting to the trails, the helmet is in a state where it offers basic protection - enough to meet the legal requirements. When the rider is about to begin mountain biking, the helmet is activated, or put into ‘ride-mode’. Ride-mode means that extra protection is added through inflation of air elements. The incentive could be aesthetic concerns while biking through an urban context, aesthetics being less relevant when you are in the mountain biking terrain.

- **React to context and be activated when needed**

Similar to the way Hövding operates. When the solution detects what it believes to be a crash it deploys the air elements without the user having to be involved. This will always involve some kind of system, like sensors, to determine whether to activate or not. Similar to Hövding, the incentive would be that a reacting solution can be thicker (and therefore provide better protection) in the moment of impact than would ever be accepted by the rider while biking.

#### Comment and evaluation:

Even though the constant-shape solution is described as keeping the user passive, most things filled with (pressurized) air do require some maintenance over time. Bicycle tubes

have to be checked from time to time to make sure they have enough air in them. This is related to the permeability of the material, i.e. how much fluid it allows to pass through it. This is something to be aware of regarding the always air filled concept. However, the prototyping showed that airbags did not need to be neither pressurized nor completely airtight to dampen an impact.

For the two-state solution, making the rider responsible for preparing the helmet before the activity does come with the risk of forgetting to activate. This was also mentioned in answers to the survey, but in regards to Hövding. In similar situations, e.g. in a car where you have to put the seatbelt on, manufacturers have built in sound alerts to make it uncomfortable to drive without it. Hövding is meant to be activated at the same time the wearer closes the zipper, the routine providing some memory support to the user. But if you have biked through the city, you have already closed the buckle. Another routine would have to be found to aid the user in remembering. Also, making a helmet where you can increase the level of protection does raise the question whether it should not be prioritised to keep the helmet as safe as possible at all times. Finally, if the ride-mode makes the helmet bigger in circumference it could feel like it gets less aerodynamic.

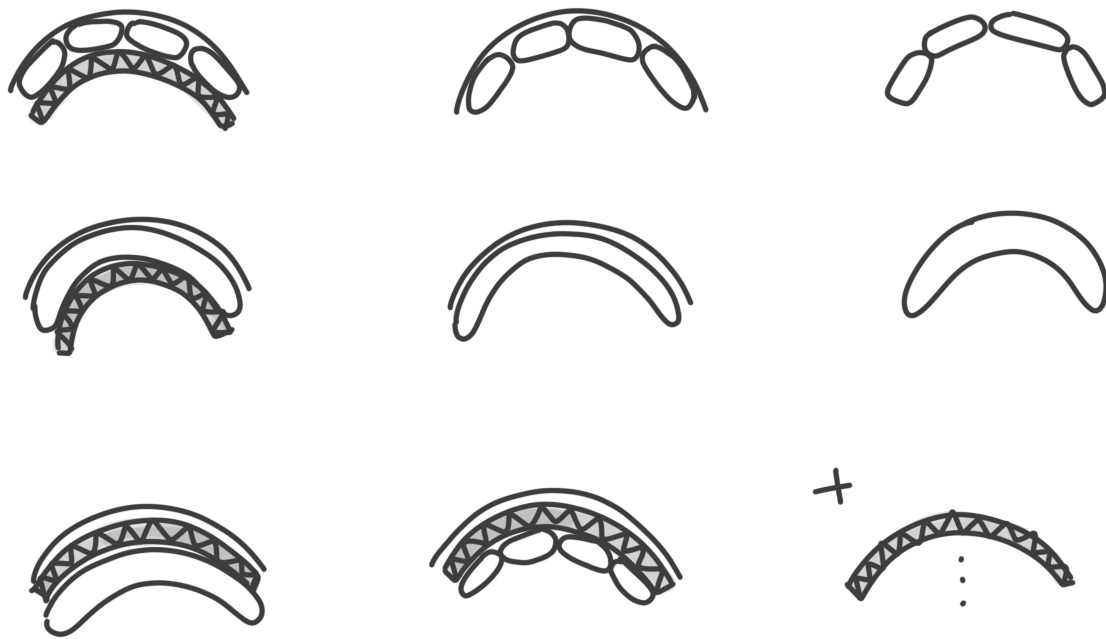
A reacting solution, that should sense a crash in order to deploy, would most likely operate similar to the Hövding whose algorithm is based on the gathering of data during everyday cycling. The user survey showed that one of the biggest concerns with Hövding was that it could go off in cases where you do not want it to. The company's CEO states that they would rather have it deploy one time too many than fail to deploy when it is needed. That type of safety margin would become unpractical in a mountain biking context due to the number of crashes that take place as an inherent part of the sport. Most of the time, a crash while mountain biking will not put an end to the activity, but the rider would get up on the bike again and continue riding. Therefore, having a solution that activates in a crash, unless it can be reset into its protective state, would not be useful. It is also very likely that the speed and loss in elevation that is a natural part of mountain biking would make it difficult to develop an algorithm that understands the difference between an accident and the activity executed the way you would expect it, especially regarding downhill biking where the descents are the fastest. And even if it is possible, it is not part of Mips' expertise today.

### **Conclusion**

- A helmet concept that senses when it should activate is disregarded due to the context of the project
- A two-mode helmet is disregarded in favor of a solution that provides the best protection it can give at all times
- The constant shape solution is chosen for further development

### **Architecture and number of cells**

The solution should be worn on the head and fitted to a helmet structure, these are requirements coming from the way the project is scoped. Ideation in this area was to build a matrix out of all combinations possible; with-without outer shell, putting the layers in different order, etc. Included in the matrix was also the number of cells. The number



**Figure 6.12:** Quick sketches forming a matrix of combinations

of cells can in theory range from a single one to an uncountable number, like the cells in a sponge, but are represented with a lower number in the graphic (see figure 6.12). A single-cell solution had been attempted during the first prototyping phase.

### Comment and evaluation:

#### Number of cells

Ventilation is one of the “performance aspects” of helmets, and one of the most mentioned aspects in the survey. Since ventilation for bicycle helmets is achieved with holes that run through all layers of the helmet, ventilation is the strongest reason against a single-cell solution.

To achieve the “shearing movement” of the air inside an air element, there has to be a distance to shear and too small cells would not provide that.

#### Architecture

The function of a hard, outer shell is to protect against sharp objects impacting the helmet, as well as dispersing the impact energy over a bigger area. Even though the nylon fabric that airbags are usually made of is very durable, a soft surface that adapts to a sharp object in a crash will in any case experience greater strain than a hard smooth surface, that to a greater extent will bounce off the object. The tendency to get caught in terrain would also put the brain at higher risk for injury (see section 2.2 Helmet design).

Having the airbag as the outermost layer could be a way of attracting attention with regards to marketing, but it is also possible that the helmet solution will become too extreme in relation to what is currently accepted in the minds of people. The more radical an innovation is, the more time it often takes for it to reach acceptance (Norman & Verganti,

2014). There can also be a psychological contradiction in having something soft and “empty” serve as protection, even though the opposite is far from ideal. A common response to the Hövding in the survey was questioning whether it would protect against sharp objects. Other than impact management, the outer layer in helmets today protect the foam against UV radiation and the smooth surface is easy to wipe clean. An airbag outer would probably be more difficult to clean. The material of the airbag would have to be resistant to UV and moisture. Nylon-66, that is used in most airbags today, is not UV resistant. Nylon in general is hygroscopic, meaning that it attracts and absorbs water from the surrounding environment. Over time, the material will swell and start to degrade (Craftechind, 2017). Stabilizers can however be added to the material to keep it from degrading in an outdoor environment (ACT Inc, 2017).

There are helmets made without the hard outer shell, with the foam making up the outermost layer. Although a function of the outer shell is to protect against UV, the foam can be formulated so that it is resistant to UV exposure (Materia, 2005). Reports from the survey showed that branches sometimes catch the ventilation holes of the helmet, tearing the foam. From a mountain bike context perspective, a helmet without an outer shell is therefore not ideal. Fusing of the outer shell and the foam layer in normal helmets do however prevent easy recycling, it would be positive from a sustainability perspective if the helmet design allowed for disassembly.

The layer closest to the head could be foam or airbag elements. Aspects affecting the choice are comfort and fit. The airbags could give a soft, cushioning feel against the head. Similar to the Riddell helmet with the inflatable liner, the airbags elements could be designed in a way that allowed for custom fitting of the helmet. But it is not evident that the parameters that are optimal for comfort are also optimal for energy management.

A layer of EPS or EPP would provide added protection should the airbag elements bottom out. Having foam closest to the head could also provide a practical way of attaching straps and fit systems, since that is how helmets currently look. It would make the touchpoint between user and helmet the same as in a traditional helmet, something that could be an advantage in the sense that a too radical solution could struggle to gain consumer acceptance, as mentioned in above paragraph.

### **Conclusion**

- Because of the mountain bike context the helmet will have an outer shell
- The helmet will have a layer of EPP or EPS
- The airbags will be made as big as possible without impeding airflow in the helmet
- The airbags can either be placed against the head or underneath the outer shell

### **6.3 Selection**

The most promising ideas in each ideation area were brought into two concepts. An evaluation meeting held with Mips employees supported selection. Due to the airbag as a concept still being unproven, discussion focused on further prototyping, and in particular what could be done following the same prototype track as the previous, i.e. with sewn airbags.

## 6.4 Early concepts

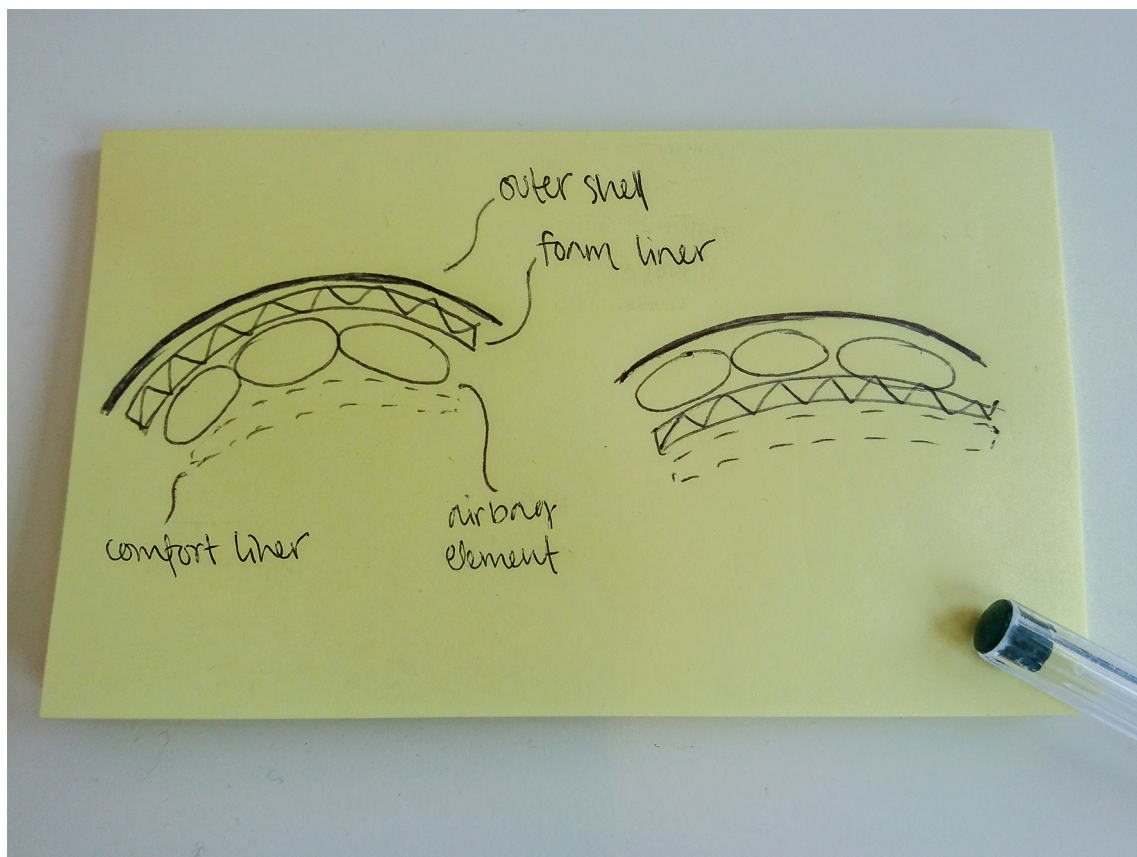
The evaluation resulted in two concepts:

### Concept 1

In the order they are mentioned counted from the head and out, the helmet consists of an EPS or EPP layer, airbag elements and a hard outer shell.

### Concept 2

The second concept has the same layers as the first, only the airbag elements and the foam layer have been switched, positioning the airbag elements against the head and the foam layer against the airbags and the outer shell.



**Figure 6.13:** The concepts, in order 2 and 1 from left to right



## CHAPTER SEVEN

# SECOND PROTOTYPING PHASE

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This chapter will present the process of making and testing prototypes to address questions not answered in the first prototyping phases.

## 7.1 Making of prototypes: A "more complete" helmet

The first prototyping had given insights in the energy management capabilities of a single airbag element, detached from the head and not connected to any other structural elements, like e.g. an outer shell. The aim of the second prototyping was to test a more complete, wearable helmet solution. Although the rolling movement shown by the "air pucks" seemed to be good for energy management, putting them inside the helmet structure would probably be more true to how a helmet solution would be in reality.

### Idea

The idea was to use the air puck prototypes more or less like they were in the first prototyping and testing, but placed inside a helmet structure. In one configuration they would be placed in between the outer shell and the foam liner, in the other against the head, followed by the foam liner and the outer shell. Four configurations were decided on:

- Concept 1
- Concept 1 + double adhesive tape between airbags and outer shell
- Concept 2
- Concept 2 + double adhesive tape between airbags and EPP shell

### Process

The 8 millimeter foam liner used in the first prototyping was used in the second prototyping as well (see figure 7.1). Since the liner was placed in different order in the two concepts, two different sizes were needed. One in size S/M and one in size XL were used. The smaller one had to fit on the test head, the bigger one had to fit within the outer shell.

## 7. SECOND PROTOTYPING PHASE

Regarding outer shells, there was not much to choose from. The biggest constraint was the fact that to evaluate the performance of the concepts a reference is needed (just like the performance of a MIPS equipped helmet is always determined by also conducting tests on the helmet model without MIPS).

The influencing parameters would be friction (of helmet inner against head and helmet outer against anvil) as well as thickness, and to some extent mass. Mass affects the moment of inertia the head experiences, and that influences the acceleration values.

The two concepts therefore had to have the same outer shell as the reference. The differences between the each concept and the reference would as far as possible be narrowed down to the protective layers, i.e. the airbags together with the thin foam layer, and the foam layer-only reference.

Available outer shells were skate helmets in size L. Skate helmets are often ‘hard shell’ helmets, meaning that their outer shell is not fused together with the foam in manufacturing. Instead, both parts are made separately and attached to each other with glue placed in a few strategic places. This means that they can be disassembled. There were also thin plastic layers that seemed suitable. They were vacuum formed to be low friction layers inside motorcycle helmets, and being thinner was thought to give the airbags better conditions for showing that “shearing” movement. But, since there were no foam liner that fit them there was no reference available and they could not be used for prototyping.

The bicycle valves that were attached to the “air puck” prototypes were long and would probably obstruct the “shearing movement” (see figure 5.19). If the head is dropped and lands so that the valve’s metal cylinder is in the impact area sensors will pick up a high value. Therefore they needed to be replaced with something softer and less bulky. To get a rough idea of how to shape the airbags for coverage inside the concept, the metal headform was covered in the type of plastic foam wrap used for packing. It was stretched over the head and then taped to retain the shape. Using a marker, the tape-foam wrap layer was divided into five pieces (see figure 7.2).



**Figure 7.1:** The 8 mm foam liner



**Figure 7.2:** Working out the shape

## 7. SECOND PROTOTYPING PHASE

The shapes were transferred to a 25 millimeter thick open-cell foam and cut to get an idea of the volume that the airbags would occupy. These were placed inside the skate helmet shell and it was concluded that it was not big enough to accommodate the pieces. An XXL ski helmet from one of Mips' partner brands was sourced to make up both the reference and - in deconstructed state - provide an outer shell for the concept prototypes. Also, for the Concept 2 where the airbags were placed closest to the head, the foam liner was too small. The pieces were scaled down and transferred to pattern pieces, adding 1 centimeter of seam allowance.



**Figure 7.3:** From foam templates to airbags placed in the helmet shell

Valves were cut from arm floats, the kind of soft plastic pillows that children have on their arms for safety when swimming. These valves are soft compared to the metal valves, and after use they can be pushed into the inflated volume to take up less space. They were pushed through holes made in the edge strip of the airbag and sewn on. A layer of double adhesive tape was placed between the plastic and the fabric before sewing.

## 7. SECOND PROTOTYPING PHASE



**Figure 7.4:** The prototyping process from attaching valves to sealing the seams with latex, to the finished airbags

The airbags were coated two times with latex all over, and two times with the Liquisole used for the previous prototypes on seams from the outside. The airbag fabric was already coated on one side, none of the two substances would adhere well to that coating.

### 7.2 Testing

It was known from previous testing that the airbags held up well, and that it meant less strain on them to test against an angled anvil. Therefore, it was decided that the test should be done at the 45-degree anvil at 6.2 meters per second - which are the normal parameters when Mips test bicycle helmets for angled impacts. The speed corresponds to around 220 centimeters in drop height.

#### 45 degrees - 6.2 m/s

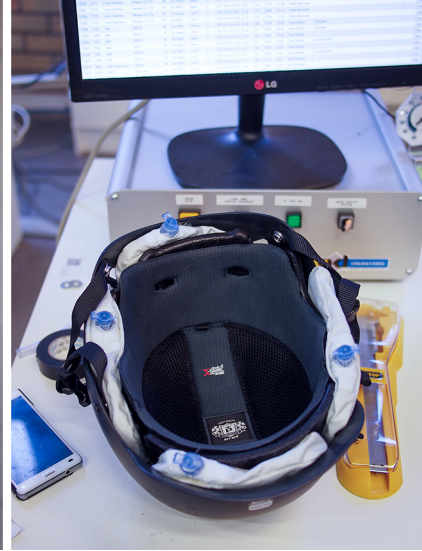
There were two references in the test. Both were the ski helmet model sourced from one of Mips' partner brands. One was equipped with the MIPS system, one was not. The material of the foam liner was EPS. In both concepts, the head had a comfort liner on to give the same friction between head and the concept. For both concepts, the airbags were prepared by inflation by mouth (see figure 7.10). They were placed inside the helmet and the head was put in place. The helmet then had to be adjusted to make sure that the head was placed straight in relation to the X and the Y axis (see figure 7.12). The test head has sensors inside specifically for surveiling that.

### Concept 1

The first concept had the airbags in between the outer shell and the foam liner. Open cell foam pieces were placed to provide distance between the airbags, spreading the airbags more evenly over the inside of the shell (see figure 7.5). The smaller sized foam liner was then placed in the helmet, with the comfort liner inside (see figure 7.6).



**Figure 7.5:** Foam pieces for distance between the airbags



**Figure 7.6:** Liner placed in the helmet

### Concept 2

The airbags are placed inside the EPP foam liner, in the helmet concept's outer shell (see figure 7.7). When the concept is placed in the rig, the head is first placed in the comfort liner before lowered in place into the helmet concept.



**Figure 7.7:** Airbags in the foam liner



**Figure 7.8:** Before lowering of head with comfort liner

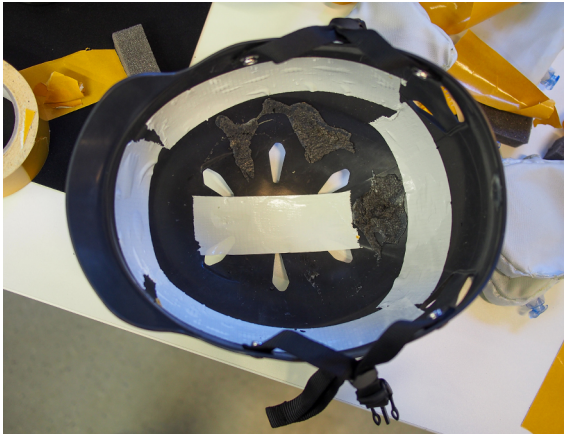
### Result

The untaped Concept 1 showed the best numbers in both translational and rotational acceleration. It can however not compete with the MIPS equipped reference in rotational velocity, having 25.22 g compared to 16.51 g for the MIPS helmet.

The Concept 2 with double adhesive tape performed similar to the MIPS equipped reference in translational acceleration measured by the test head at slightly above 130 g. The one without tape did slightly worse, at 148.8 g. In rotational acceleration, results for both taped and untaped Concept 2 matched the reference without MIPS at 7.60 and 8.50 g, the reference without MIPS scoring 7.67 g.

**Table 7.1:** Testing of helmet concepts, 6.2 m/s on 45-degree angled anvil

Id	Taped	Translational acceleration	Rotational acceleration	Rotational velocity
Concept 1	no	84.67	4.00	25.22
Concept 1	yes	126.16	5.67	27.02
Concept 2	no	148.80	8.50	33.40
Concept 2	yes	131.30	7.60	35.30
<i>Ref. with MIPS</i>	-	132.49	4.41	16.51
<i>Ref., MIPS removed</i>	-	130.91	7.67	28.25



**Figure 7.9:** Taped outer shell



**Figure 7.10:** Inflation by mouth

### Comment

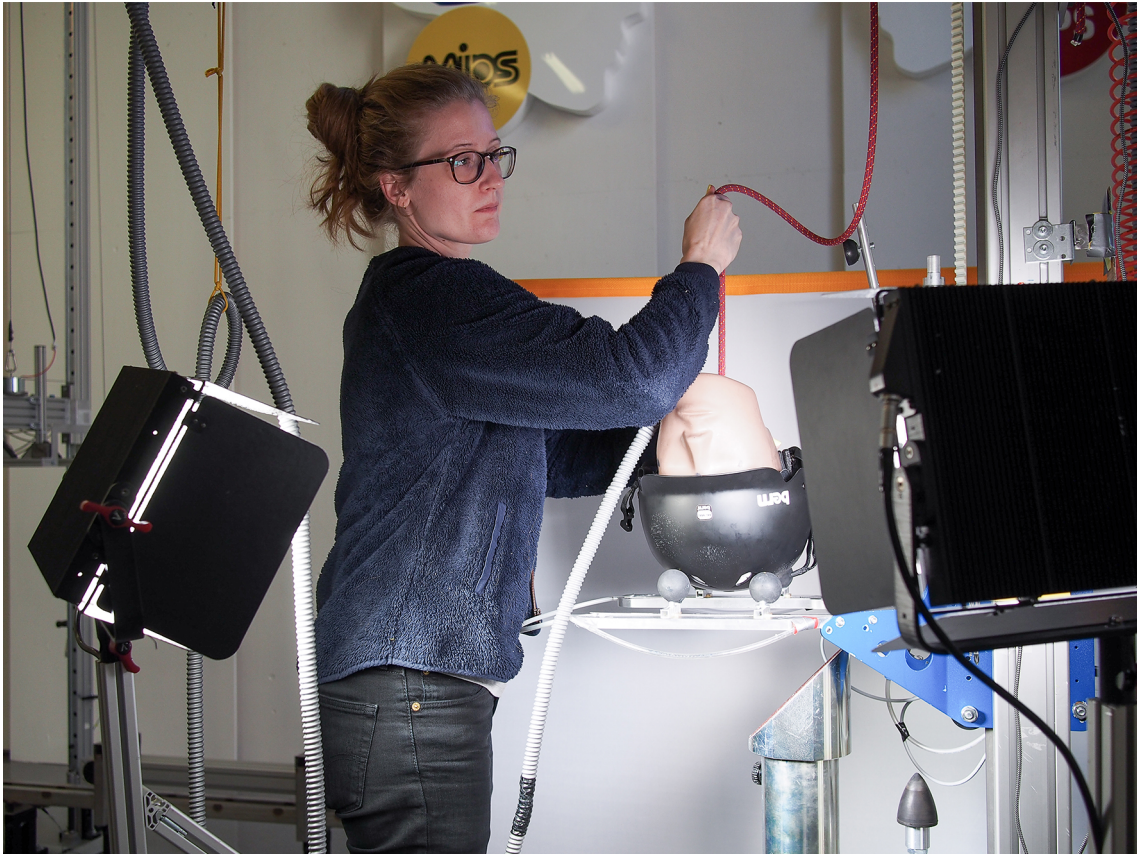
After impact, the whole helmet had rotated significantly on the head for both concepts (see figure 7.11). The whole inner liner (together with the head) had rotated in relation to the outer shell. Despite that “MIPS movement” the rotational acceleration for Concept 2 did not give a reduction of the rotational acceleration. The most promising results were the ones of Concept 1.



**Figure 7.11:** The concepts after impact: Concept 1 to the left, Concept 2 to the right

It was evident that while the helmet was adjusted to lie flat in X and Y direction, the head inside pressed against the airbags and slowly removed air inside. There were still air in the airbags after impact, but it is unclear how much.

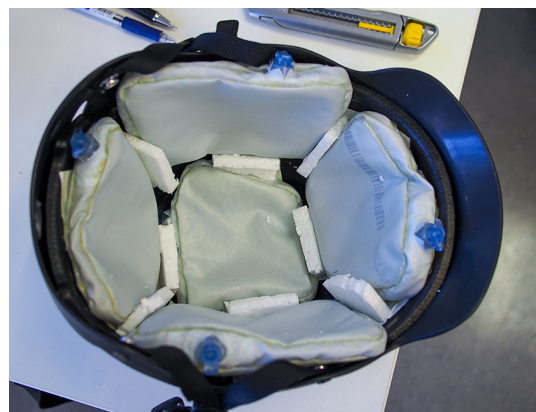
The concepts were tested twice each, but each concept was configured with and without tape for the two runs (figure 7.9 shows the taped outer shell of Concept 1). Further testing was needed to make the results more robust and for more certain conclusions to be drawn.



**Figure 7.12:** Manually adjusting the head in X and Y direction

### Second part of testing

To address the problem with the air leaking out while the head was being adjusted, concepts were reinforced with EPP pieces in between the airbags. These were meant to carry the weight of the test head while it was being adjusted to lie straight - a process that does take some time, requiring some going back and forth. In this test, airbags were taped to reduce the “rattling around” and to enhance the “shearing movement”.



**Figure 7.13:** Foam pieces in between the airbags

### Result

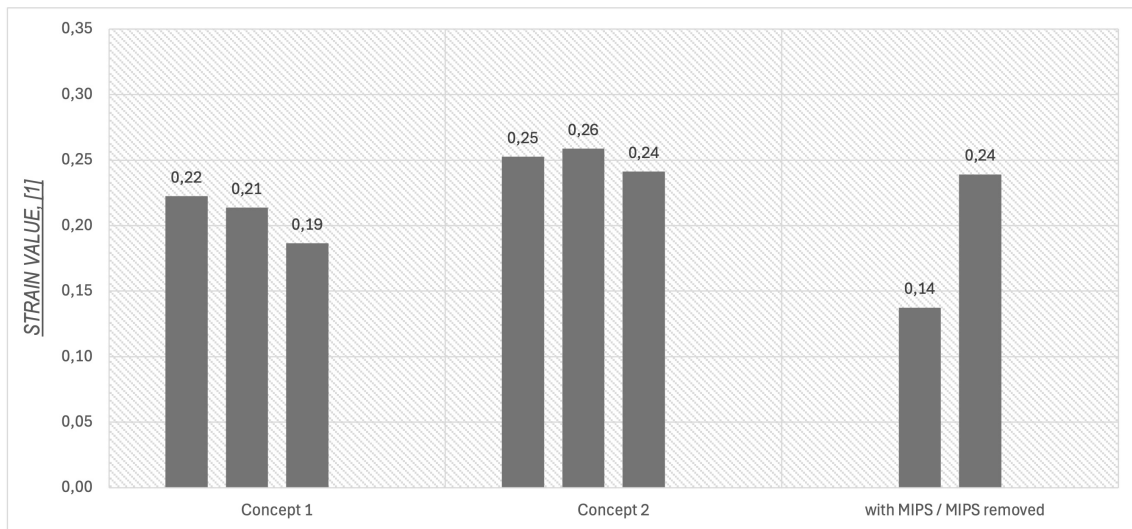
Out of all tested, Concept 1 did best in translational acceleration and about the same as the MIPS equipped helmet in rotational acceleration. Concept 2 was better than the two foam helmet references in translational acceleration, and better than the helmet without MIPS in rotational acceleration. The two concepts were about equally bad in rotational velocity where the MIPS low friction layer outperformed all others.

To know how the different values in translation acceleration, rotational acceleration and rotational velocity actually affect the brain, Mips performs computer-modeling analysis

using the data from the testing. This is where their FEM model of the brain is key. For a strain modeling on the results in table 7.2 it is clear that the MIPS equipped helmet gives the least strain on the brain, see the graph in figure 7.14.

**Table 7.2:** Testing of helmet concepts, 6.2 m/s on 45-degree angled anvil - All taped

Id	Translational acceleration	Rotational acceleration	Rotational velocity
Concept 1	81.40	4.90	32.90
Concept 1	68.90	3.80	33.70
Concept 1	75.50	3.70	30.10
Concept 2	81.60	5.60	32.90
Concept 2	88.10	5.80	33.30
Concept 2	92.00	5.30	33.30
<i>Ref. with MIPS</i>	<i>132.49</i>	<i>4.41</i>	<i>16.51</i>
<i>Ref., MIPS removed</i>	<i>130.91</i>	<i>7.67</i>	<i>28.25</i>



**Figure 7.14:** The test data translated into a strain simulation (the strain value is a unitless value)

## Conclusion

The two concepts did not perform better than the MIPS equipped helmet. Out of the two concepts, Concept 1, where the airbags were placed in between the foam liner and the outer shell, got better numbers in both translational acceleration and rotational acceleration. Due to the nature of the concepts - still being on a prototype level - it was not deemed impossible that there were room for improvement of the numbers through further improvement. Therefore, Concept 1 was brought into further development.

## 7. SECOND PROTOTYPING PHASE

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## CHAPTER EIGHT

# FINAL CONCEPTS

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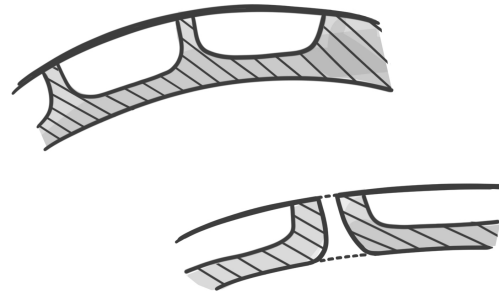
The chapter will present a few concept paths based on the insights from the activities making up the project.

### 8.1 Ideation

Some concepts below are a direct consequence of prototyping and testing, some emerged from individual brainstorming, or through discussion and collaboration with Mips employees. Some further research has been conducted to aid the creation of final proposals.

#### Protecting the airbag elements and ventilating the helmet

From the second testing, it was clear that should you put non-airtight airbag elements in the helmet they need to be protected from the effect of the head putting pressure on it. It is also possible that the airbags will experience strain from other situations - this could e.g. be being packed in a bag and affected by other gear putting pressure on the helmet. Therefore, it seemed suitable to have some built-in structure or mechanism to protect the airbags.



**Figure 8.1:** Cavities that can hold the air elements in the foam liner, and let air in

In the concept, the airbags are enclosed in cavities in the foam liner. The walls would be thin enough not to obstruct the movement of the airbags, similar to how the foam pieces were dimensioned in the second part of testing in the second prototyping phase (see figure 7.13). The foam walls would also enable an opening from the head out to the surrounding air, providing the helmet solution with ventilation (see figure 8.1).

#### Air filled or pressurized

The testing showed that an air-filled - not necessarily pressurized - concept could dampen an impact. At this stage, it was not known whether a pressurized solution would give better

or worse results. In the following section it is described how both areas were explored in ideation.

### **Air filled concept**

Even if the air elements were not airtight, as long as they had a shape that enclosed a volume of air inside, and small enough holes or general permeability, they could dampen an impact. This was envisioned in different ways. The airbag elements could be attached to the insides of the cavities, e.g. being glued. This would keep the shape of the air elements, making sure that they enclosed a volume of air.

In another concept, air elements were filled with an open-cell foam that maintains the volume inside the airbag by keeping it from collapsing. There are camping mats that self-inflate, no battery or power needed. In between the two main, outer, layers of the mat is an open-cell foam. When you roll the mat up, you compress the foam and the air that is inside is forced out through a vent. When you close the valve, the mat stays compressed due to no air being allowed in. When you open the vent, the open-celled foam is just sturdy enough to push the two layers of the mat apart. This creates a weak vacuum, causing air to rush in. The mat itself is airtight, and when the vent is closed the air stays inside the mat and creates a cushion.

The mat needs to be airtight in order to handle the body weight of the person lying on top of it. (A parallel can be drawn to the "air puck" prototypes that leaked air when you pushed a finger into them.) In the helmet concept, the air elements do not have to be airtight to dampen an impact. This puts less complexity into e.g. manufacturing. Also, should the airbags become worn with age with a few small holes in them, it will not affect their function too much.

Another concept is that the airbag elements are placed in the shell before the in-mold process. When the expanded plastic is pushed into the shell, the airbags would have to be either pressurized or sturdy - or both in order for them to not lose their shape. It is unclear whether a too rigid structure would restrict the "shearing movement" that would manage the angled impact.

### **Pressurized concept**

A pressurized concept has higher manufacturing requirements on it since it needs to be airtight. If the solution is pre-filled with constant shape, it would most likely also require some kind of maintenance. The system could either be self-monitoring, or the user could be made responsible for checking that air pressure is adequate, similar to how you treat your bicycle's tires or a football.

Inflation can be achieved with canisters filled with compressed gas, by mixing chemicals to produce gas or with a fan (as seen in avalanche airbags, see section 4.2). An external source can also be used, such as an air compressor. There is manual pressurization, like inflation by mouth or using a pump. There are many varieties of manual air pumps, from bicycle pumps that stand on the floor to small handheld rubber bulbs. Some technology, like the chemical mixture, is however more suited for a reacting concept rather than a constant one.

For the pressurized concept, inspiration is drawn from self-inflating tires. It is most common in military vehicles and heavy trucks and machinery, where it has involved a compressor or another type of air resource on the vehicle to supply air. A few examples have been found for a new type of self-inflating tires that draw air from its surroundings, 'SIT' is a system for cars and 'PumpTire' is a crowd funded project whose initiators expected to start selling in 2016 (Venturekick, 2014). The concepts use a type of pump called a peristaltic pump. It uses moving compression to pump a fluid or gas around an enclosed system, often a tube. It is common in medical applications, but the principle is present also in nature e.g. in the squeezing of muscles that push food down your throat. In tires, the compression is achieved naturally through the rolling of the wheel and the pressure that the mass of the vehicle - car or bicycle - puts on it. When the compressed part is released from pressure, it decompresses. That creates a vacuum that sucks in air (Glass, 2015). The systems have a tube chamber lined up close to the bead of the tire. A sensor picks up on whether the pressure has dropped inside, and opens a check valve to let air in. The opening of the valve could also be purely mechanical, and the valve opens more the lower the pressure is.

Since a helmet does not show the same movement dynamic, inflation would have to happen in another way - the concept uses a small fan. Users were skeptical towards a protection solution that requires a power source to work in an accident scenario. However, if the sensor is mechanical the solution would not need constant power. Since it is not involved in the accident scenario but just maintains the air levels the fan does not have to be that powerful.

### Material and manufacturing

In talks with the expert at Autoliv, it was concluded that airbags are not made for holding a pressure value or even holding air for a longer period of time. Partly because in most of the applications that are relevant at Autoliv it is essential that the airbag pressure is released shortly after inflation, but also since permeability is an inherent characteristic of fabric often being either woven or knitted. If not coated, there will be holes in the fabric between yarn threads that let air through.



**Figure 8.2:** Experimenting with welding

## 8. FINAL CONCEPTS

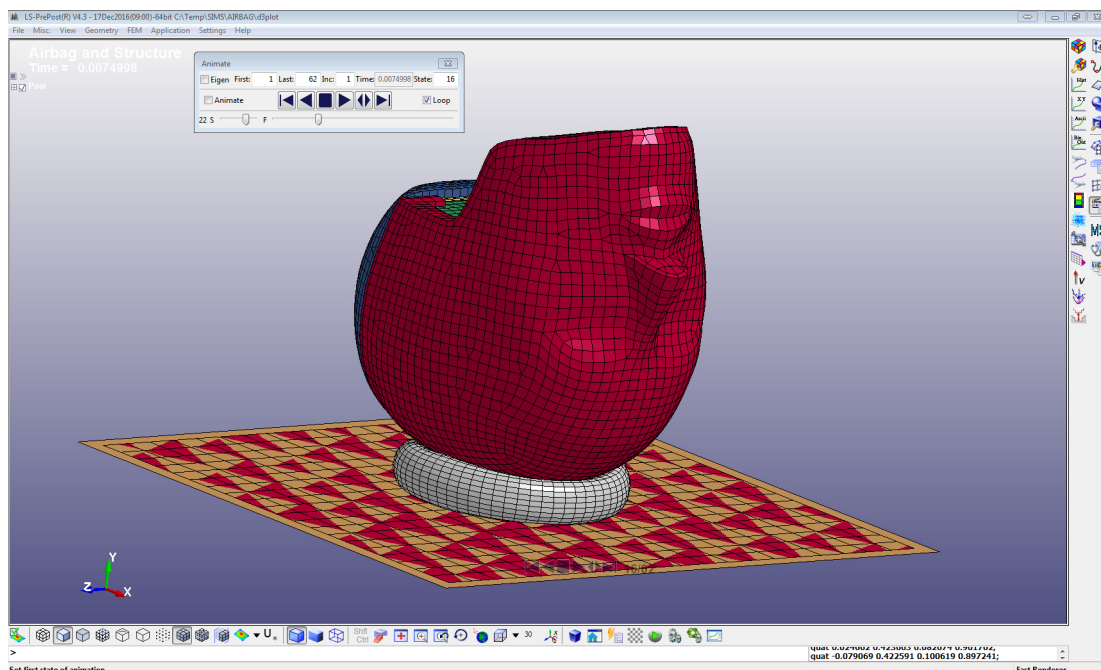
It was experimented with welding sheets of plastic together. The material provides for a more airtight structure. A major difference between the sewn airbags and the welded ones were that the latter ones became two-sided, while the sewn airbags were more “three dimensional” since they are separated by a fabric wall.

### 8.2 Business model

Mips is currently not a helmet manufacturing company. They are an ingredient brand, and to deviate from that business model would be a big change. Mips would no longer sell on license, but under their own name, and engage factories in making a new product. Selling helmets of their own would imply competing with their partner brands, something that is not good for keeping a good relationship and trust.

The business model is the same for both concepts. An airbag system would fit into Mips current product matrix, since it offers the same core function as the company’s other products. However, compared to the MIPS low friction layer that only needs a few recesses in the foam liner of the brand partner’s helmet, an airbag system would be a bigger interference to the helmet. It is therefore more likely that Mips would sell the airbag concept to one or a few chosen partners, similar Giro’s special spherical version of Mips (see section 2.3) and how it is marketed. Giro still has helmets with the common MIPS layer. It is likely that it would be a way to broaden the range of products, not eliminating the current MIPS low friction layer.

### 8.3 FEM evaluation



**Figure 8.3:** Screenshot from FEM software

Some of the most fundamental questions remaining were whether the airbag elements...

- ...should be pressurised or just air filled?
- ...should be made out of an elastic or a non elastic material?

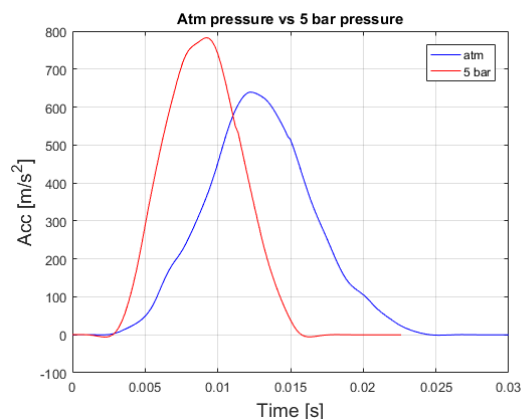
The making and testing of physical prototypes did not seem to be able to answer those questions, at least not in their most theoretical sense. Therefore, a FEM modeling was conducted. An "air puck" with 12 centimeter circumference was modeled, mimicking the prototypes from the first testing. The head model that Mips uses was then set to impact the air puck at a speed of 4.5 meters per second. Those parameters were chosen because they had been used in the physical testing, and constructing a computer model benefits from having real-world values as reference.

From testing, it has been difficult to evaluate whether air is pushed out of the airbag in an impact, and if that affects how well it dampens the energy. From interviews at Autoliv, one of the most essential requirements is that the airbag releases its gas at the moment of impact. This does however depend on the airbags' application, and the side curtain airbag happens to be designed to keep its inflation for the whole duration of the accident. In the modelling, the air puck was tuned to release about ten percent of its fill mass in impact. (The FEM model available for airbags does not consider a flow of molecules, but rather a decrease of the mass inside the volume.)

## Pressure

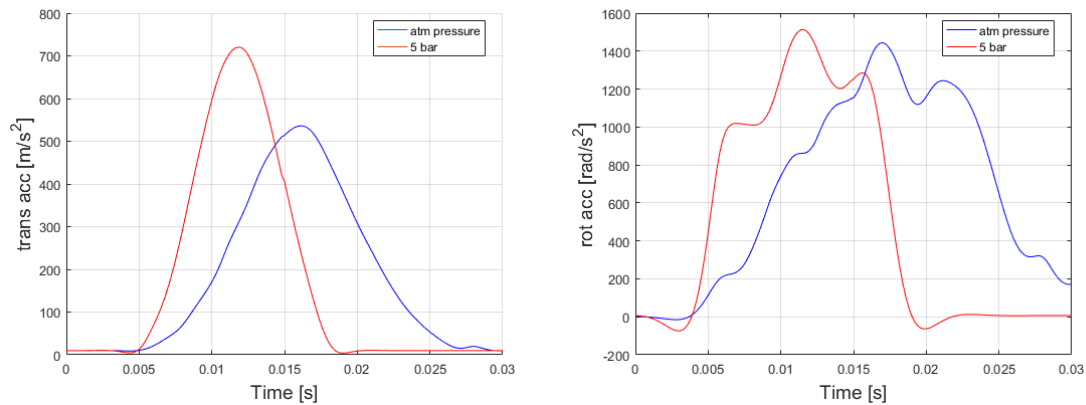
The graph in figure 8.4 shows the difference in translational acceleration between an air-filled (atmospheric pressure) air puck, and an air puck modeled with 5 bar pressure, when dropped onto a flat anvil. The speed at impact is 4.5 meters per second.

The pressurized element has a higher peak value, but a shorter time frame, whereas the element with atmospheric pressure has a lower peak but a longer time frame. The area underneath each graph is about the same, meaning that the total energy affecting the head is the same.



**Figure 8.4:** A (just) air filled "air puck" vs a pressurized one, 4.5 m/s on flat anvil

## 8. FINAL CONCEPTS



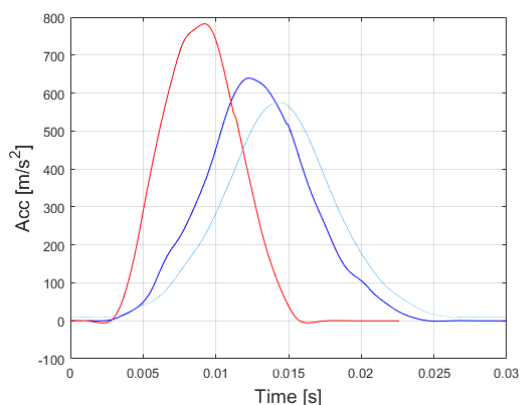
**Figure 8.5:** A (just) air filled “air puck” vs a pressurized one, 4.5 m/s on 30-degree angled anvil - Translational acceleration and rotational acceleration

In figure 8.5, the same test is performed but at a 30-degree angle towards the impact surface. The graphs depict the translational acceleration and the rotational acceleration.

In the first graph, it is not given which scenario is the better one. In Mips’ work with defining test standards, the relationship between peak value and duration is at the time of writing one of the key questions being discussed.

### Flexible material

In the graph shown in figure 8.6, the additional curve compared to figure 8.4 represents an air puck modeled in a flexible material. Its Young’s modulus was made a hundred times lower - the same force applied to a string of the material would deform length-wise a hundred times more. Having a flexible material lengthened the duration and lowered the peak (the curve for the flexible material is the one with the lowest peak).



**Figure 8.6:** The addition of a curve depicting the ”air puck” modeled in a flexible material

## CHAPTER NINE

# DISCUSSION

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In the following chapter it is discussed what became of the project, the methods used and the circumstances that have influenced the result.

### 9.1 Aim fulfillment

The scope was to make use of air in an intelligent way in a head protection solution. With the formulation of the scope, and the nature of Mips as a company, the term ‘intelligent’ refers to using air as a medium to manage angled impacts. The project has investigated the feasibility of using air as a means to reduce rotational violence on the brain. The process has been heavy on prototyping and testing, which is in line with how Mips operates and test results were also an expected deliverable.

The best performing concept, Concept 1, still performed worse than the Mips equipped reference in strain value, although the two results were similar. If the airbag solution would be further developed and brought into a working state but still perform worse than the Mips layer, the Mips layer should be premiered.

### Testing and prototyping

Being able to relate a test result to a specific phenomenon, e.g. something that can be seen on the captured video from the test runs, requires experience. Due to the nature of experimental testing, it was often not clear what caused a specific test value.

The testing and prototyping nature of the project was part of the expectations for how the project would be realised. However, testing and prototyping can have its limitations. Often, methods for constructing by hand produce less refined prototypes than if they were to be produced in an industrial setting. There are different types of prototypes. The ‘quick and dirty’ way of creating prototypes is common in a design process, and is chosen to get insights fast without spending extensive time and resources. Mips process is based on thoroughness and science, and it is important that you have control over the test procedure and know what parameters influence it.

The problem with the prototypes rolling off the anvil is one example. When conducting the FEM study, that phenomenon was addressed and sorted out in the computational

environment by simply adding a constraint that the bottom layer could not separate from the surface below it. That option - to refine and control what is is that you are actually testing - is not offered by experimental, real-world, testing. It is sometimes hard to narrow down what features in the prototypes have influenced the test results, i.e. has there been an actual “shearing movement” in the airbags or could it be a more general “rattling around” of the airbags inside that gave a positive result?

### **9.2 The technology driven process vs the design driven process**

Where the design process starts from a need - or a lot of the times with conducting research to find that need - the project started with an existing idea. The options were then to pursue that idea, or frankly to question the project as a whole. Mips has a precise value offering; not just about personal protection, but personal protection against rotational violence. Looking at their product portfolio, they are in a sense an one-product company (products offer the same function, although have some different configurations to them).

Filing patents is one approach to innovation in companies, and the patents that Mips has on their low friction layers ensures that they can stay a competitive actor in the market. The patent that was the basis of the project was filed since the company saw an opening in the market there. There are several other patents regarding air elements in helmets, so most likely the opportunity spotted was to connect airbags to the rotational acceleration. When the project was initiated, no investigations had been made from the company’s side to validate the idea.

There has been a constant balancing act between validating the initial idea at the same time wanting to “break free” from that constraint and just start from scratch, in the design way - i.e. to start from the research and from users. But there was a defined scope, and the scope was indeed very interesting. Also, Mips did not want a number of concepts but something that was as finished as possible at the end of the project. However, if the design methodology would have dictated the project, the process had been a different one.

Something the project has not had is that widening of the solution space that is a characteristic of the design process; the creative generation of ideas where “no idea is a bad idea”. The concept was already defined. This also meant that there was no clear connection between the research conducted and the following parts in the process, something that was questioned early in the project and many times thereafter. The need that Mips works to fulfill is the need for safety, to reduce rotational violence to the brain. Asking the question “In what other ways can this problem be solved” became somewhat irrelevant.

#### **User focus**

Empathy and a connection to the end user is an inherent part of design as an activity, although there are different theories regarding how much users should be (actively) involved in the process. In the case of the project, the user study was a part of the initial research. The aim was to broaden the general knowledge about the context and people’s relationships with their protective gear. Therefore, some of the insights are fairly self-evident and just “scratch the surface” of user attitudes. There can be different motives

behind conducting a user study, e.g. evaluating a concept or eliciting more in-depth attitudes regarding a chosen area. A way of doing this is asking “Why?”, something that the study in the project did not do. In the project scope, or in Mips’ business as a whole, there was no support for finding a need that would turn into a new product.

The project has largely been focused on validating whether airbags can be used to manage rotational violence. The following ideas, coming from a user centered design perspective, are more in line with the design methodology. They would however probably render the patent irrelevant.

- Weight is an important parameter of helmets, as confirmed by the user study. Air filled elements could be incorporated in the helmet to reduce weight while maintaining (or improving) its energy absorbing capabilities. Rotational violence to the head could be addressed with Mips’ usual low friction layer.
- A neck protection solution is interesting both in regards to how many reported having injured the neck, and it that would fit Mips’ science-based company profile. There was also a connection between coverage, especially regarding the back of the head, and the perceived level of safety in a helmet.
- The traditional foam material in helmets suffer irreversible deformation at certain impact levels. When the foam has deformed plastically, its capability to handle another impact is lowered. Using air in a helmet solution could be a way to bypass that limitation. Similar to how companies are using e.g. Poron and VPD foam to handle repeated, smaller impacts before the underlying EPS is activated.
- The most mentioned reason among survey respondents to be unhappy with their helmet was poor fit. The airbags could be incorporated into the helmet with the purpose of improving comfort, e.g. by reducing pressure points, or improving fit as an alternative to the fit adjustment system that is often placed in helmets today. In this use, it is not certain that the airbags would be used for angled impact management, as is stated in the patent.

### 9.3 Ethics

Whenever you attempt a project involving or affecting others, it’s important to evaluate your activities from an ethics perspective. Some important principles to consider are beneficence, non-maleficence, autonomy, and integrity. The first two can be explained with the simple “to help and do no harm”, tracing back to Hippocrates and ancient Greece (Varkey, 2021). Autonomy is related to each person’s right to make informed choices about their own lives - this could be about their body or e.g. about personal data. Integrity is to act in line with the ethical principles, transparently and consistently, also if no one is around to see it.

For this project, some comments could be made:

- In broad strokes, the scope and ambition of the project aligns with the ethical principle of “to help and do not harm”, since it’s meant to enhance the head protection and hence the safety of the wearer. In a typical user-centered design project, and perhaps

especially an academic one, decisions are made with the users best interest in mind. As a business, there's inevitably (and rightfully) other factors that will influence projects. These include maintaining a viable business model, i.e. being able to make money, and staying competitive. An unethical behavior would be to develop a product for e.g. marketing value, in a way that at the same time compromises on user value - in this case protection. The new product would potentially enter the 'gimmicky' realm mentioned in section 4.1 Mips' current business model and context. Thankfully, the marketing value for a product of a company like Mips is closely linked to the user value, and the company's reputation is closely associated with the principle of integrity.

- The project has been implemented in Mips' spirit, centered around lab testing with test results being an expected part of the delivery. Lab testing brings benefits regarding reproducibility and obtaining detailed test data. Opting instead for testing in a real-world mountain biking context would mean that users would test the safety of the concepts at the risk of sustaining head injury. Test results would then be obtained at the cost of the user. This would have been ethically questionable, hence making the lab testing the preferred way to go. However, one could question how well dropping the test dummy head onto the angled anvil corresponds to the real-world scenario. Mips has developed their testing method with the standardized way of testing as a starting point, and even though the angled anvil test rig is closer to reality, there's probably ways to come even closer while still not putting the user at risk.
- User data gathered in the survey did not contain any information making it possible to identify respondents, meaning that respondents' integrity was maintained.

### 9.4 Future work

If Mips want to continue work on a helmet incorporating air, like it is described in the patent, it is recommended that further work is put into the feasibility of the idea, i.e. whether air elements will show the rotational violence reducing movement when affected by an angled impact.

The company could either continue on the "basic track" and gain one insight at a time regarding e.g. pressure, thickness, size and what material properties would benefit the wanted function. FEM modeling could be suitable for this. However, building a FEM model that behaves exactly like reality risks consuming a lot of resources. Especially if Mips would be interested in whether the "shearing movement" would happen or not, since it is a phenomenon that is not purely a result of a "force-on-structure", but most likely a rather complex movement to model. That might be better tested with more refined physical prototypes. By engaging the factories Mips works with, or using the resources in their own lab, like milling of foam or vacuum forming, they could produce foam liners with the cavities mentioned in chapter 8 Final concepts or perhaps thinner and more supple airbags.

Instead of going at full speed trying to prototype something that is close-to-reality, ways can be found to define the concept as far as possible before spending resources in testing.

Design methodology is one approach, e.g. investigating if users would be interested in an air filled solution. Pitching the idea to sales and marketing is another, they might like the unique selling point or they would consider it gimmicky. Manufacturability can to some extent affect the development of a concept. In short, investigate what you should do (in terms of needs) and what you can do, and hopefully the scope will be narrowed down before starting investigating through testing. The big risk, seen from Mips' perspective is however that you deviate from the patent.



## CHAPTER TEN

# CONCLUSION

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This thesis has investigated the feasibility of a novel patent idea through the making and testing of physical prototypes. The patent describes a head protection solution incorporating air-filled elements, or "airbags", with the main objective of reducing rotational violence to the brain of the wearer.

- The first testing, where the test head was dropped onto simplified, "air puck" prototypes, showed that air can be used to dampen the energy of an impact. It also showed that the air elements do not have to be neither airtight nor pressurized to achieve this.
- In the second testing, with concepts closer to a wearable helmet, the best performing concept had air elements placed between the helmet's stiff outer shell and the expanded foam layer next to the users head. It performed close to, although not better than the MIPS equipped reference. Considering that the prototype was in early stages with lower refinement and finish, it had potential despite slightly worse test results.

With the best performing prototype as starting point, two final concept paths were defined:

- A (just) air-filled concept where the helmet contained air elements that were not airtight, but with just little enough permeability to keep the air inside at impact. To keep their shape, the layers of the air elements could be glued to the insides of the helmet structure, or be kept apart by an open-celled foam inside.
- A pressurized concept took inspiration from self-inflating tires and medical applications, and uses a sensor - electronic or mechanical - to detect a drop in pressure. It then activates a small fan to restore the pressure values. Since the fan is just used for maintenance and not involved in the accident, it can be of a weaker variety.

For both variants, airbags are enclosed in cavities in the foam, protecting them from pressure and allowing for ventilation through the helmet layers.

User research showed that the most important characteristics in a helmet from a user

## *10. CONCLUSION*

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perspective were comfort, fit and the helmet being lightweight. These characteristics are naturally aligned with the properties of air. Should Mips be willing to deviate from the patent, they could explore how air could be used to e.g. reduce weight of a helmet solution or use air elements that adapt to the shape of the head to improve fit.

# REFERENCES

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- ACT Inc. (2017). *MATERIAL CHARACTERISTICS*. <https://www.advancedcableties.com/material-characteristics/>. (Retrieved on 2017-05-29)
- American Association of Neurological Surgeons. (2017). *Neurosurgical Conditions and Treatments – Concussion*. <http://www.aans.org/en/Patients/Neurosurgical-Conditions-and-Treatments/Concussion>. (Retrieved on 2016-11-21)
- Arai. (2017). *How a Helmet Works*. <http://www.arai.bg/en/home/real-world-protection/how-helmet-functions/>. (Retrieved on 2017-01-11)
- Autoliv. (2024). *A global leader committed to Saving More Lives*. <https://www.autoliv.com/company>. (Retrieved on 2024-05-01)
- Bicycle Helmet Safety Institute. (2016a). *Bicycle Helmet Standards*. <http://www.bhsi.org/standard.htm>. (Retrieved on 2017-05-29)
- Bicycle Helmet Safety Institute. (2016b). *Helmets: How they work and what standards do*. <http://www.helmets.org/general.htm>. (Retrieved on 2016-11-30)
- Bicycle Helmet Safety Institute. (2016c). *How Bicycle Helmets are Made*. <http://www.bhsi.org/howmade.htm>. (Retrieved on 2016-11-23)
- Black, M., Gargollo, P., Lipson, A., & The Dana Foundation. (2015, February). *Brain trauma, Concussion, and Coma*. [http://www.brainline.org/content/2009/06/brain-trauma-concussion-and-coma\\_pageall.html](http://www.brainline.org/content/2009/06/brain-trauma-concussion-and-coma_pageall.html). (Retrieved on 2016-11-21)
- Black Diamond. (2017). *Halo 28 Jetforce*. [http://blackdiamondequipment.com/en/jetforce-airbag/halo-28-jetforce-BD681302\\_cfg.html#start=2](http://blackdiamondequipment.com/en/jetforce-airbag/halo-28-jetforce-BD681302_cfg.html#start=2). (Retrieved on 2017-05-29)
- Bosch, van den, H. (2006, January). Crash helmet testing and design specifications. *Journal of Educational Psychology*.
- Brainline.org. (2017). *Coma / Vegetative State*. [http://www.brainline.org/landing\\_pages/categories/coma.html](http://www.brainline.org/landing_pages/categories/coma.html). (Retrieved on 2016-11-21)
- Comsol. (2015, January). *FEA Software*. <https://www.comsol.com/multiphysics/fea-software>. (Retrieved on 2016-02-16)
- Craftechind. (2017). *6 Reasons NOT to Use Nylon Fasteners*. <http://www.craftechind.com/6-Reasons-NOT-to-Use-Nylon-Fasteners/>. (Retrieved on 2017-05-29)
- Cycling Weekly. (2015). *No helmet? No problem - The Hövding Airbag*. <https://www.youtube.com/watch?v=f3iK60eRwr4&index=13&t=2s&list=>

## REFERENCES

---

- PLVtsF4t0ktP2jppQSVgdMn1ZjolinGJm1x6. (Retrieved on 2016-02-14)
- D30. (2017). *D30 Smart Materials*. <https://www.d3o.com/>. (Retrieved on 2016-11-15)
- Dainese. (2017). *D-Air*. <https://www.dainese.com/d-air/>. (Retrieved on 2017-05-29)
- Engstedt, H. (2014, June 9). Uppblåsbara cykelhjälmarna klarar inte säkerhetsstandarderna. *Råd & Rön*. <http://www.radron.se/artiklar/Uppblasbara-cykelhjalmen-klarar-inte-sakerhetsstandarderna/>.
- Folksam. (2012, June 8). *Nytt test visar stora brister bland de populäraste cykelhjälmarna*. <https://media.folksam.se/sv/2012/06/08/nytt-test-visar-stora-brister-bland-de-popularaste-cykelhjalmarerna/>. (Retrieved on 2012-06-08)
- Folksam. (2015, 05). *Folksam's Bicycle Helmet Test 2015 - Helena Stigson*. doi: 10.13140/RG.2.1.2542.3849
- Gargulinski, R. (2015, July 8). *Can You Wear a Visor or Hat With Your Bicycle Helmet?* <http://www.livestrong.com/article/360820-can-you-wear-a-visor-or-hat-with-your-bicycle-helmet/>. (Retrieved on 2016-02-14.)
- Giro. (2016). *Giro Introduces Innovative Ski Racing Helmet With Reimagined MIPS Protection System*. [http://www.giro.com/eu\\_en/giro-introduces-innovative-ski-racing-helmet-with-reimagined-mips-protection-system/](http://www.giro.com/eu_en/giro-introduces-innovative-ski-racing-helmet-with-reimagined-mips-protection-system/). (Retrieved on 2016-11-17)
- Glass, A. (2015, December). *This self-inflating inner tube is 'making the impossible possible', apparently*. <https://www.bikeradar.com/news/this-self-inflating-inner-tube-is-making-the-impossible-possible-apparently>. (Retrieved on 2017-05-29)
- Healthline. (2017). *Concussion*. <http://www.healthline.com/health/concussion#overview1>. (Retrieved on 2017-05-21)
- Helite. (2017). *Airbag Application*. <http://www.helite.com/airbag-application.php?jacket=Motorcycle&lg=en>. (Retrieved on 2017-05-29)
- Higgins, J. (2016). *Bike Suspension Basics*. <https://www.rei.com/learn/expert-advice/suspension.html>. (Retrieved on 2016-11-30)
- Hövding. (2014, November). *Ny Hövding på Hemförsäkringen*. <http://www.mynewsdesk.com/se/hovding/pressreleases/ny-hoevding-paa-hemfoersaekringen-1079989>. (Retrieved on 2017-05-29)
- Hövding. (2016). *How hövding works*. <https://hovding.com/how-hovding-works/>. (Retrieved on 2016-02-16.)
- IL Recycling. (2017, May). *Hjälm sorterar som*. <http://atervinningsbar.se/grovsopor-brannbara/hjalm/>. (Retrieved on 2017-05-29)
- ISPO Munich. (2016). *A very warm welcome to ISPO Munich!* <http://munich.ispo.com/en/index.html>. (Retrieved on 2016-11-16)
- Kleiven, S. (2013). Why Most Traumatic Brain Injuries are Not Caused by Linear Acceleration but Skull Fractures are. *Frontiers in Bioengineering and Biotechnology, 1*. doi: 10.3389/fbioe.2013.00015
- Koroyd. (2016). *Smith Forefront Helmet Review Pinkbike*. <http://koroyd.com/smith-forefront-helmet-review/>. (Retrieved on 2016-11-15)
- Kurt, M., Laksari, K., Kuo, C., Grant, G., & Camarillo, D. (2016, September). Modeling

- and Optimization of Airbag Helmets for Preventing Head Injuries in Bicycling. *Annals of biomedical engineering*, 45. doi: 10.1007/s10439-016-1732-1
- Lamb, L. R. (2008). *Contribution of Air Flow to Impact Attenuation in Chamber Structures* (Unpublished doctoral dissertation). University of Ottawa, Canada.
- Lawrence, P. F., Bell, R. M., & Dayton, M. T. (2007). *Essentials of Surgical Specialties*. Lippincott Williams & Wilkins.
- Mammut. (2014, February). *EpicTV Gear Geek - Mammut Avalanche Airbags - ISPO 2017*. <https://www.youtube.com/watch?v=uhm1hRKprz8>. (Retrieved on 2016-11-23)
- Materia. (2005, August). *EXPANDED POLYPROPYLENE*. <https://materia.nl/material/expanded-polypropylene/>. (Retrieved on 2017-05-29)
- Mills, N. (2007). *Polymer Foams Handbook: Engineering and Biomechanics Applications and Design Guide*. Oxford: Butterworth-Heinemann. doi: 10.1016/B978-0-7506-8069-1.X5000-4
- Norman, D., & Verganti, R. (2014, January). Incremental and Radical Innovation: Design Research vs. Technology and Meaning Change. *Design Issues*, 30, 78-96. doi: 10.1162/DESI\_a\_00250
- POC. (2016). *POC Ski Helmet Concepts & Technologies – Snow*. <http://www.pocsports.com/eu/research-innovation/protective-concepts.html>. (Retrieved on 2016-11-15)
- Riddell. (2017). *Riddell Speed Helmet*. <http://www.riddell.com/riddell-speed-helmet.html>. (Retrieved on 2017-05-29)
- Rogers Corporation. (2017). *PORON XRD Extreme Impact Protection*. <http://www.xrd.tech/products/1/PORON-XRD-Extreme-Impact-Protection.aspx>. (Retrieved on 2016-11-15)
- Sprinchorn, E. (2017, March 21). *Hjälmbolaget Mips tar steget in på Stockholmsbörsen - Interview by Tomas Kvarnkullen*. <https://www.di.se/ditv/borsmorgon/hjalmbolaget-mips-tar-steget-in-pa-stockholmsborsen/>. (Retrieved on 2017-03-26)
- Strategyzer. (2016). *Business Model Canvas*. <https://strategyzer.com/canvas/business-model-canvas>. (Retrieved 2016-12-16)
- Textalk. (2016a). *Icarex Ripstop*. <http://shop.textalk.se/se/article.php?id=19971&art=6487003>. (Retrieved 2017-05-29)
- Textalk. (2016b). *Mirai Ripstop Nylon*. <http://shop.textalk.se/se/artgrp.php?id=19971&grp=689063>. (Retrieved 2016-05-29)
- Thiel, J. (2017, March 17). *MIPS: SKA VÄXA SNABBT OCH NÅ HÖG LÖNSAMHET - VD - Interview by Johan Lind*. <https://borsliv.svd.se/index.php/news/detail/86a6355a-01be-4ede-9406-4c093a56be3a>. (Retrieved on 2016-03-31)
- Varkey, B. (2021). Principles of Clinical Ethics and Their Application to Practice. *Medical Principles and Practice: International Journal of the Kuwait University, Health Science Centre*, 30(1), 17–28. doi: 10.1159/000509119
- Venturekick. (2014). *The next level for PumpTire*. <https://www.venturekick.ch/The-next-level-for-PumpTire>. (Retrieved on 2017-05-29)
- Völkl. (2017, May). *UVO – Ultimate Vibration Object*. <https://www.voelkl.com/skis/technology/technology/uvo.html>.

## REFERENCES

---

- We Are Cycling UK. (2016). *Terrain definitions for MTB courses*. <http://www.cyclinguk.org/courses-and-training/faq/terrain-definitions-for-mtb-courses>. (Retrieved on 2016-11-30)
- Weiss, C. (2013, May). *Ubak avalanche airbag harness protects your whole head*. <https://newatlas.com/ubak-avalanche-airbag-harness/26476/>. (Retrieved on 2016-11-23)

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