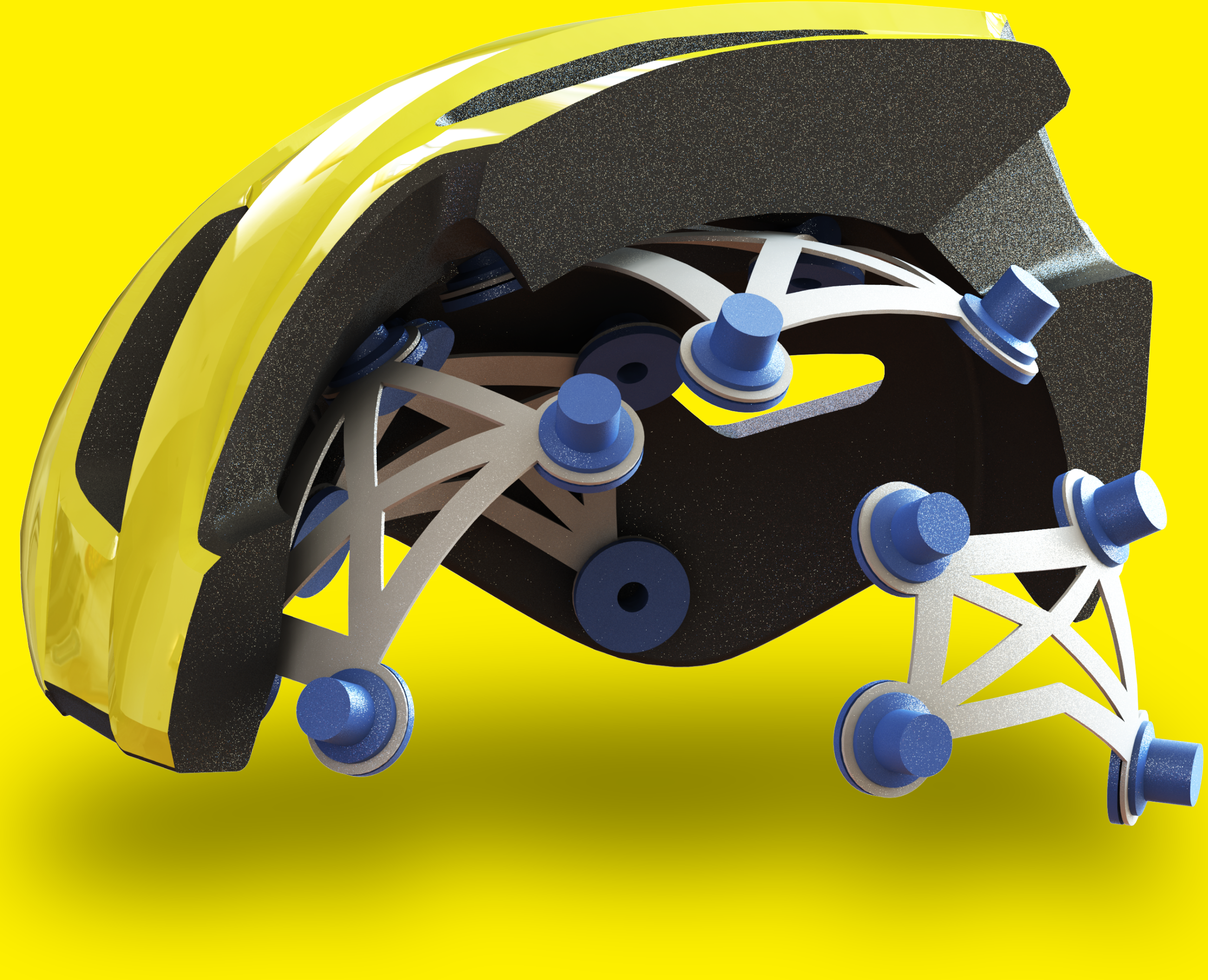
INCREASING THE SAFETY OF THE MODERN BICYCLE HELMET:
DESIGN OF AN ADDITIONAL IMPACT PROTECTION MECHANISM



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SUMMARY

Orientation

In 2016, BBB Cycling provided an assignment to seven Integrated Product Design master students at the TU Delft, for the Advanced Embodiment Design (AED) course (of which the author of this project was part). The assignment asked for a safer helmet design regarding impact protection as well as covering a larger part of the head. The goal was to create a helmet which not only offered high speed impact protection, but also protected the user against the consequences of oblique and low speed impacts. Currently helmets only protect against high speed impacts, due to their EPS liner design. In 2018 the author of this project was asked to continue the efforts of BBB in creating a safer helmet, by taking the AED project as a starting point.

Analysis

Bicycle helmets reduce the chance of certain injuries such as skull fractures according to various research. However, they are not designed to prevent other injuries such as concussions or traumatic brain injury. Helmets have to pass EN1078 to be sold in Europe, which comes down to requiring accelerations to be below 250g after a straight drop at high speed (5.42 m/s for a flat anvil). Current helmets are optimized to pass this test and therefore offer the same basic level of protection. EPS liner helmets are the standard because they are affordable, lightweight and offer high form freedom.

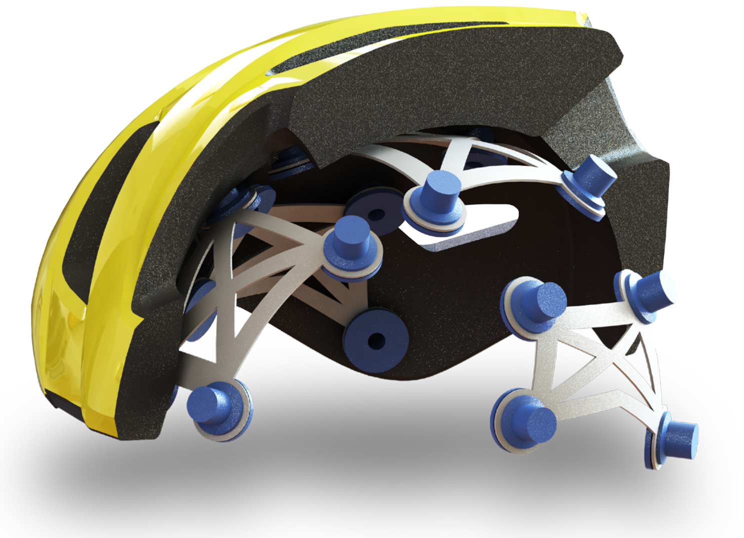
Since roughly two decades, research has shown the consequences of other types of injuries, such as DAI and SDH. These injuries can occur as a result of oblique impacts, which occurs almost in every case. An oblique impact is an impact that occurs under an angle, instead of the straight drop as simulated by the EN1078 norm. Besides oblique impacts, low speed impact are also not accounted for, since the EN1078 norm only tests for high speed.

Over the years, some helmet manufacturers have started to look into the unaccounted types of impacts. Of the concepts that have reached the shelves, MIPS is the most well known. MIPS is a system that can be implemented in existing helmets to reduce angular accelerations that occur as a result of oblique impacts. Manufacturers are able to utilize MIPS in their helmets, but this comes at a cost and does not differentiate them from others doing the same. Furthermore MIPS is not designed to reduce linear accelerations at low speeds.

BBB Cycling have also started the process of designing a safer helmet to compete with MIPS and others. The assignment proposed at the beginning of this project was as follows: design a bicycle helmet impact system that reduces the consequences of low speed and oblique impacts, to supplement the high speed impact protection of contemporary helmet design. The problem can be described as follows: making a safer bicycle helmet by adding protection for unaccounted impact types increases the chance of it becoming unattractive to consumers, due to the increased thickness, weight and price. Therefor the assignment is: design a safer bicycle helmet, while maintaining a competitive advantage over other helmet companies.

Synthesis

The aforementioned conclusions plus the AED project formed the start of the synthesis phase. The AED project adopted a material and shape centered approach, testing different materials and designs in an early stage of the project. The result was the Daedalus; an EPS liner helmet with an extra layer placed at the inside of the helmet. This extra layer consisted of roughly 100 EVA foam cylinders, connected through multiple separate hard shells. When tested, accelerations indicated that the extra layer was both able to reduce low speed accelerations by compression, as well as angular accelerations by shearing of the cylinders. Taking this concept into account and also taking a step back to look into different avenues, the synthesis phase of this project resulted in three different concepts. Based on the rating of each concept regarding six key factors, one concept was chosen. This concept was further developed into the initial final concept, shown on the right. It consists of four zones, which are able to compress (to reduce low speed accelerations) and shear (to reduce angular accelerations), due to four flexible energy absorbing units placed in the corners of each zone.



Simulation

To initially test the effectiveness of the design, early prototypes were made. Three form variations of the initial designs were made, as well as a change in wall thickness of one of the variations. The prototypes were made in a flat plane and involved one of the four zones. These were then used during the evaluation phase, to get an initial impression of the impact capabilities of the designs, and choose the most promising one. Afterwards a fully working prototype was made, by implementing it in an existing helmet.

Evaluation

To get an initial feel for the first designs, angular accelerations were quantified by measuring the amount of stretch when being pulled at with the force of 20N. This was then compared to the elastomers found in MIPS, to get an impression of the magnitude of scale. The low speed linear accelerations were quantified by compressing the zones with the force of 50N (similar to the average weight of a human head) and measuring the compression distance. After that a final prototype was made, that implemented the design in a full size helmet. Drop testing the working prototype showed a 8.3% reduction of the low speed linear accelerations and a reduction of 22.2% of the angular accelerations. Final oblique impact testing will have to involve a more accurate working prototype of the design, to test it according to the oblique impact test setup developed by MIPS AB. Low speed impact testing can be done using the regular straight drop impact setup, by lowering the drop height and therefore the speed at impact.

GLOSSARY

AIS
Abbreviated Injury Scale. An anatomical-based coding system created by the Association for the Advancement of Automotive Medicine to classify and describe the severity of injuries.

Angular kinematics
The motion of a rotating object described by angular displacement, angular velocity, and angular acceleration.

Angular acceleration
Acceleration on the head/helmet as a result of an oblique impact.

Attenuation
The reduction of the force, effect, or value of something.

Coronal rotation
Rotation around the axis ranging from the back of the head to the front (sideways).

DAI
Diffuse axonal injury. A type of brain injury in which damage in the form of extensive lesions in white matter tracts occurs over a widespread area.

EPS
Expanded polystyrene, the main protective layer of modern bicycle helmet. This foam material comes in a variety of densities, resulting in different mechanical properties.

EN 1078
European bicycle helmet impact standard.

HIC
Head injury criterion, a measurement of the likelihood of head injury arising from an impact.

High speed impact
Impact as a result of the speed at which helmets are currently tested according to (European) regulations. Helmets hit the anvil at 5.42 m/s on a flat anvil and 4.57 m/s on a kerbstone anvil.

Impact
The scenario of one object coming into contact with another at speed, in this case a bicycle helmet hitting the ground, a vehicle, or another object.

Linear accelerations
Accelerations on the head/helmet as a result of a straight drop a horizontal surface.

Low speed impact
Impact as a result of speeds lower than what helmets are currently tested at. Low speed in this project is considered as 3.0 m/s.

MAIS
Maximum Abbreviated Injury Scale (AIS).

Normal impact
Impact that occurs perpendicular to the helmet's surface/outer shell.

Oblique impact
Impact that occurs at an angle, contrary to a normal impact. A combination of a normal/radial impact and a tangible impact.

PC
Polycarbonate, the material that is used to create the outside hard shell of modern bicycle helmets.

Radial impact
Synonym of normal impact. Impact that occurs perpendicular to the helmet's surface/outer shell.

SDH
Subdural hematoma. A type of brain injury in which blood gathers between the inner layer of the dura mater and the arachnoid mater.

Tangential impact
Impact that occurs tangential to the surface of the helmet, causing the head/helmet to rotate.

TBI
Traumatic brain injury.


CAMP
Black Diamond CARBON FIBER PROBE 240
LA SPORTIVA
LA SPORTIVA

CONTENTS

INTRODUCTION

1.1. Project introduction

The essence of this project can be boiled down to 'designing a safer bicycle helmet'. Does this mean current helmets are not safe? Not exactly, but they are not as safe as one would think. Or at least, not as safe as they could or should be. Indeed, bicycle helmets aim to reduce injury in the event of a crash, but only up to a certain point. Virtually all helmets sold today are optimized to pass impact regulations set by law. These regulations however only test for one very specific scenario, resulting in companies designing helmets for this type of impact, and this type only.

In recent history, there have been several efforts to try and make bicycle helmets safer, with various levels of technical and commercial success. But with the lack of governmental regulation acting as a push for companies to innovate, only a handful of companies have tried their hand at this fairly unexplored and uncharted area. A disappointing observation for consumers perhaps who seek a safer helmet, but an interesting and potentially fruitful one for designers and engineers.

This project aims to find a way to increase the protection against two elements that current helmets do not account for, namely impacts low speed and oblique impacts. Summarized in one sentence, the goal of this project is: to design a bicycle helmet that besides high speed impact protection, also protects the user against the consequences of low speed and oblique impacts.

1.2. BBB Cycling

This project is commissioned by BBB Cycling, a Dutch cycling focused company based in Leiden, the Netherlands. BBB has stated the need for a safer helmet, a goal that was first introduced around two years ago.

part of your ride

Company

BBB Cycling (founded in 1998) produces bicycle components, clothing and accessories. It has a business-to-business strategy, thus not selling to customers directly but via dealers that carry the brand. Over the years they have developed a portfolio of over 1800 different products, ranging from brake pads to helmets to pumps, and many more.

Focus

Lately BBB have been focusing their design and innovation efforts on a couple of key product groups, mainly: helmets, saddles and (mini) tools. Especially their helmets have attracted more and more attention lately, with the Red Dot Design award winning Tithon, the Eurobike award winning Indra, and the recently IF Design award winning Kite.

Fig. 1.2.: A professional road cyclist wearing one of BBB's helmets.

ORIENTATION

Introduction

Before taking a look at the problem at hand, it is vital to first understand a couple key parts of this project. The two most important being the bicycle helmet itself and the AED helmet project that predated this one. The AED project had a similar goal and will serve as the starting point for this project. More on this in the ‘Synthesis’ chapter.

2.1. Starting point project

AED project

This project is a continuation of the Advanced Embodiment Design course (of early 2016) from the Integrated Product Design master at the TU in Delft. During this project, tasked by BBB Cycling, seven students (including the author of this report) made the first effort to try and tackle the problem at hand. This included (but was not limited to) finding solutions for the low speed and oblique impact problems, as well as looking at increased levels of head coverage, ventilation and overall design.

Fig. 2.1.: The visual prototype that marked the end of the AED project.

2.2. The bicycle helmet

Introduction

To better understand the need for a safer helmet, it is important to first understand what it is comprised of and how it works. The modern bicycle helmet is generally made out of four main elements: the thick EPS foam protective liner, the thin PC outer hard shell, the combined retention system, and the comfort padding.

BBB Icarus

As an example, the BBB Icarus (BBB's top range helmet) will be used:

Fig. 2.2.1.: One of BBB Cycling's most high end bicycle helmets: the Icarus.

Exploded view

An exploded view shows how the main elements relate to each other:

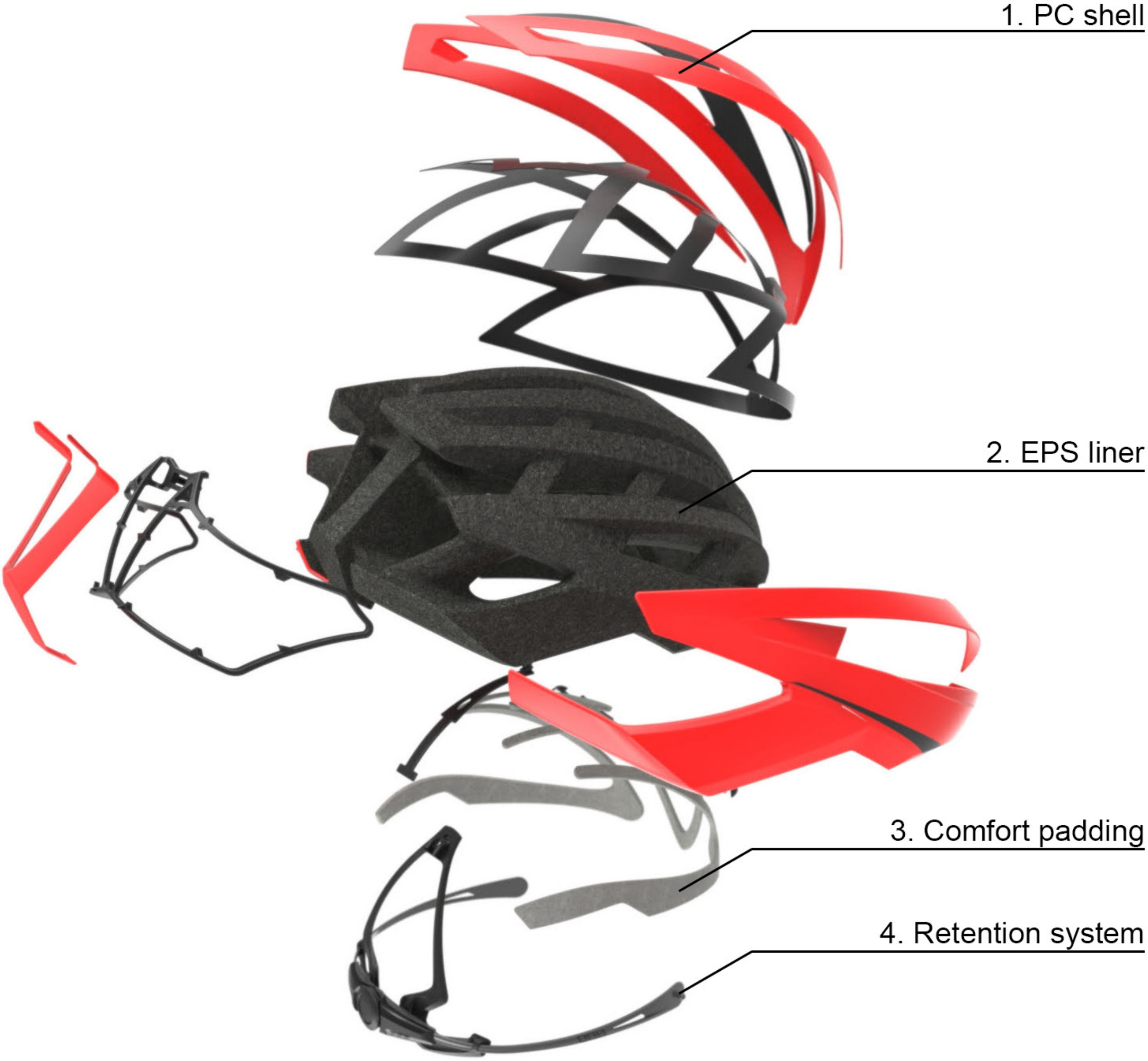


Fig. 2.2.2.: An exploded view of the BBB Icarus, showing the different parts and how they relate.

Cross section

The cross section of the helmet shows the thick EPS liner, with the thin PC shell wrapping around it:

Fig. 2.2.3.: A cross section of the BBB Kite, another popular BBB helmet.

Parts

Each of the different parts will now be briefly explained into more detail.

EPS liner
The EPS (expanded styrofoam) liner is the main protective element of the helmet. It acts as a sort of crumple zone layer, plastically deforming on impact. This can be seen when inspecting crashed helmets, which are noticeably thinner at the point of impact.

PC shell

The main function of the PC (polycarbonate) outer shell is twofold. First, it acts as a barrier to prevent sharp objects from piercing the relatively soft EPS and reaching the head. Second, it dissipates the impact forces over a larger area, transforming the high point force of a crash into a lower distributed load.

Retention system

To make sure the helmet stays in place on the rider's head, an adjustable retention system is placed in the helmet. It wraps around the head and under the chin, tightened by the ratchet system at the back of the head.

Comfort padding

As the name suggests, the function of the comfort padding is to make the placement on the head more pleasant, but also absorbs sweat. It is made of soft foam wrapped in fabric, made in shapes that follow the lines of the inside of the helmet.

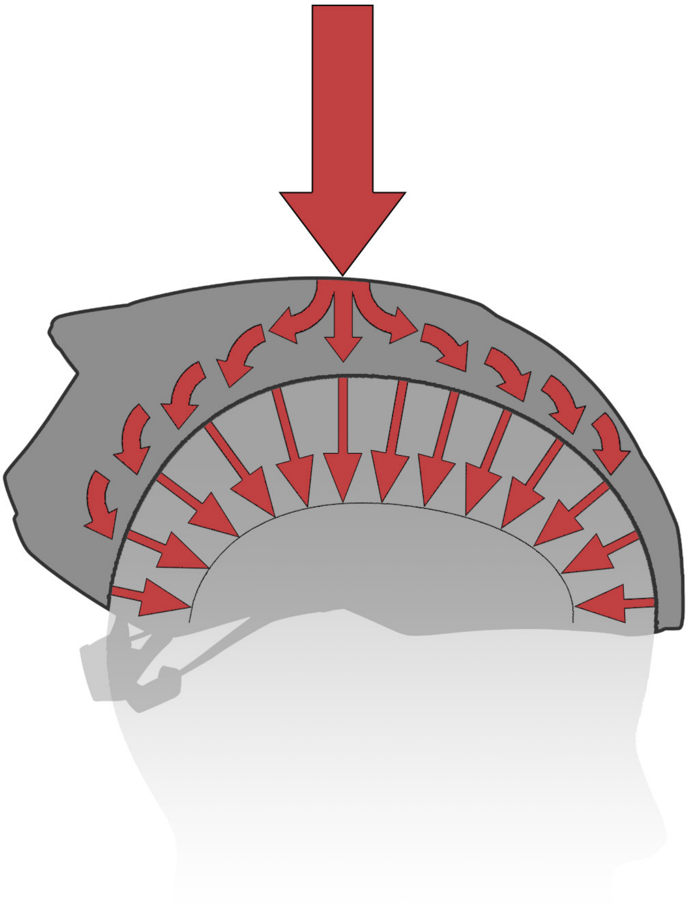
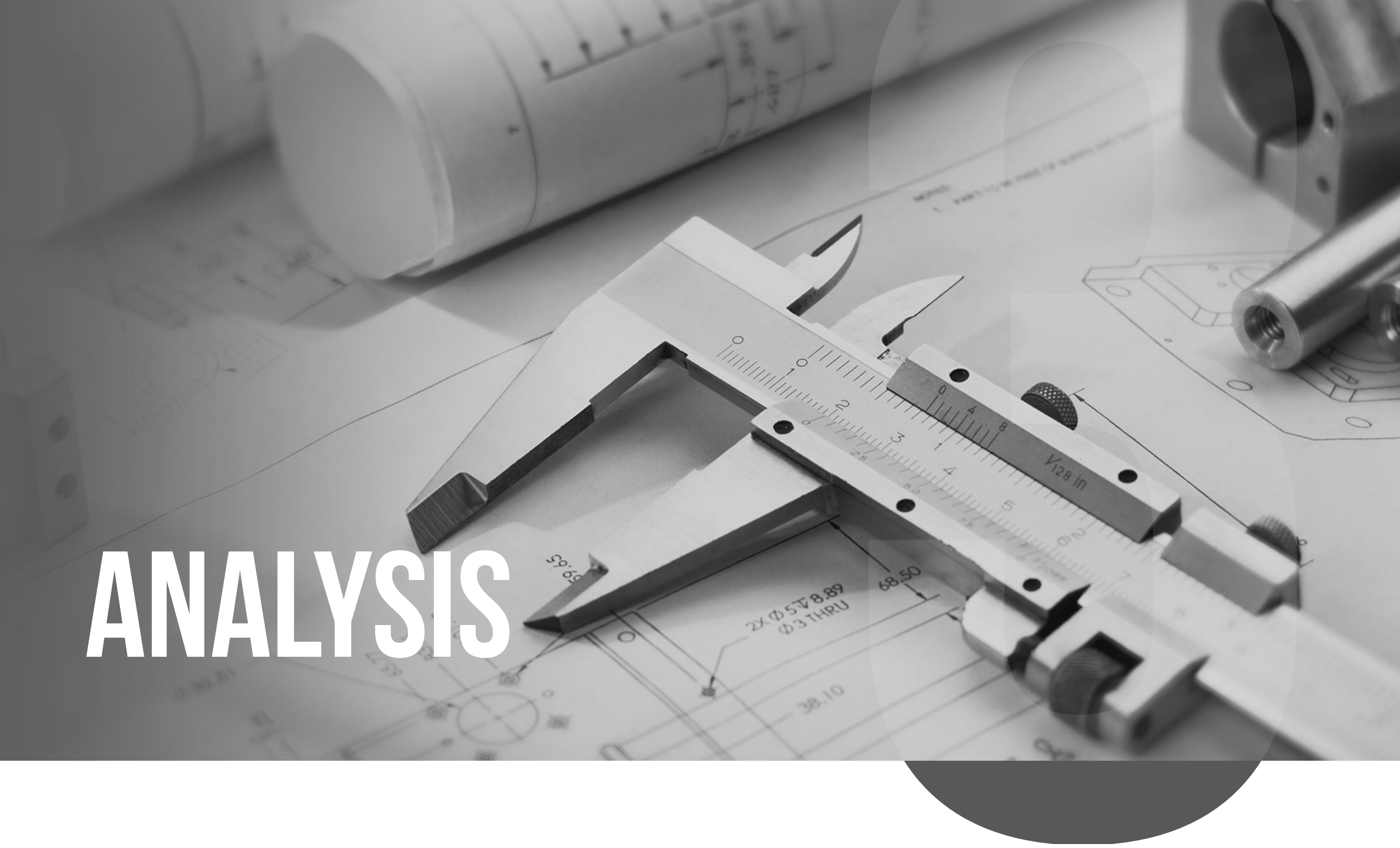


Fig 2.2.5.: The way the PC shell dissipates the point force.

Conclusions

Virtually all helmets sold today are constructed in the same way and are using the same parts and materials. The main impact absorbing part of the helmet is the EPS liner, which is only able to absorb high speed impacts. The outside of the EPS liner is covered in a thin PC layer, which prevents penetration of sharp objects and spreads the point force of an impact over a larger surface.



ANALYSIS

Introduction

When it comes to safety, generally all bicycle helmets sold today are optimized to pass the regulations specific to the country in which they are being sold. These regulations only test the helmets with regard to high speed, linear impacts. BBB Cycling wants to bring to market a helmet that is able to better protect the user against the consequences of low speed and oblique impacts, two scenarios current helmets fail to address. In this chapter the original design brief will be introduced first, which lead to the formulation of the problem definition. After having a good understanding of the problem at hand, the main research question and sub-questions will be presented. Each sub-question will subsequently be answered in the form of the conclusions of the main research done during this project. In the end, this all leads to a reformulated design brief, including a list of requirements.

3.1. Assignment

Original design brief

The main protective layer of bicycle helmets sold today is made out of the dense foam EPS, which is generally only able to protect the user against the consequences of high speed impacts. Due to the mechanical properties of the material, EPS is unable to deal with the two other mentioned types of impacts (low speed and oblique).
Testing the same helmets at lower speeds can still lead to dangerously high levels of accelerations, though not quite as high compared to high speeds. Furthermore angular accelerations of the head as a result of oblique impacts are not accounted for at all by current EPS liner helmets. These accelerations cause the brain to shift and rotate, after which it impacts the inside of the skull and compresses (causing bleeding and other trauma). The initial design brief in its entirety can be found in appendix 3.1.

3.2. Problem definition

Problem

To also account for low speed and oblique of impacts, an additional layer is proposed to be added to the existing type of bicycle helmet. Adding another layer to a bicycle helmet potentially adds volume and weight. This creates a helmet that is larger, heavier, and more expensive than the competition. These are all elements that have a negative influence on the consumer's acceptance of the helmet. Therefore, the problem can be described as follows: making a safer bicycle helmet by adding protection for unaccounted impact types increases the chance of it becoming unattractive to consumers. The question is: how to design a safer helmet, while maintaining a competitive advantage over other helmet companies.

Main research question

The totality of this project tries to answer one question in regards to designing a safer helmet, which is:

- How can you design a system that is both able to reduce the consequences of low speed impacts as well as oblique impacts, while remaining attractive for consumers in terms of size, weight and price?

To answer this question, it will be divided in three main sub-questions:

- How are helmets currently tested and how does this affect their design?
- What are the current developments in the market when it comes to safer helmets?
- Against what type of impact do current helmets protect the user and what kind of unaccounted types of impacts are out there?

Each of these questions will now be answered, in their own respect chapters.

3.3. Impact testing

Linear impact testing

To understand why current helmets are the way they are (and only protect against a specific type of impact), one has to look at the way helmets are certified prior to being sold. As explained previously, one of the biggest reasons why helmets do not account for other types of impacts, is because they are not tested for this (and thus companies are not legally required to provide this level of protection). For this project, the efforts will be focused on Europe. Therefore the European norm (EN 1078) will now be discussed.

EN 1078

The EN 1078 norm, or European standard, states in short that accelerations of the head cannot exceed 250g, when dropped straight down and hitting a flat and kerbstone anvil at a speed of 4.57 and 5.42m s-1 respectively:

- Test anvils: Flat and kerbstone;
- Drop apparatus: Guided free fall;
- Impact velocity, energy or drop height flat anvil: 5.42 m/s;
- Impact velocity, energy or drop height kerbstone anvil: 4.57 m/s;

Impact energy criteria: <250g.

Testing can be done by accredited institutes. For example, BBB's helmets are tested in an institute in China that is allowed to give out EN 1078 certificates, which then allows BBB to sell the helmets in Europe (once they pass the test).

On the right a traditional helmet drop test setup can be seen, with the kerbstone anvil in place:

Fig. 3.3.1.: A standard straight drop helmet impact setup.

Oblique impact testing

As stated above, currently only straight drop impact tests are required, testing linear accelerations. With the rise of innovations to combat the effects of oblique impacts, ways of quantifying the effectiveness of these products also had to be invented. The most well known of these being the one developed by the equally well known company: MIPS.

MIPS

When it comes to testing angular acceleration as a result of oblique impact, at the moment there are four ways of doing it, the benchmark being the way MIPS test their product. A steel head form with a silicon layer is fitted with a helmet and dropped vertically on a 45 degree surface, covered with sand paper.

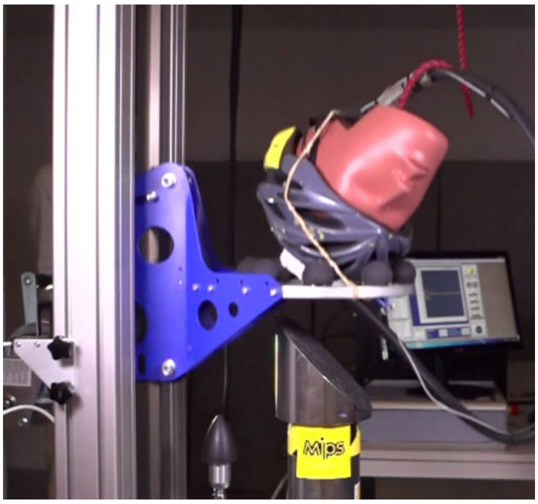


Fig. 3.3.2.: The oblique impact test setup developed by MIPS AB, to measure angular accelerations.

The angle of the anvil simulates a situation that involves both linear accelerations, as well as angular accelerations. More information on the other ways of testing oblique impacts can be found in appendix 3.2.

3.4. Competitors

To put the different competitors in perspective, a two axis matrix is made. On the one axis, the low speed impact features are displayed. On the other, the angular acceleration features. The values range from - (feature not present/weak feature) to + (feature present/strong feature).

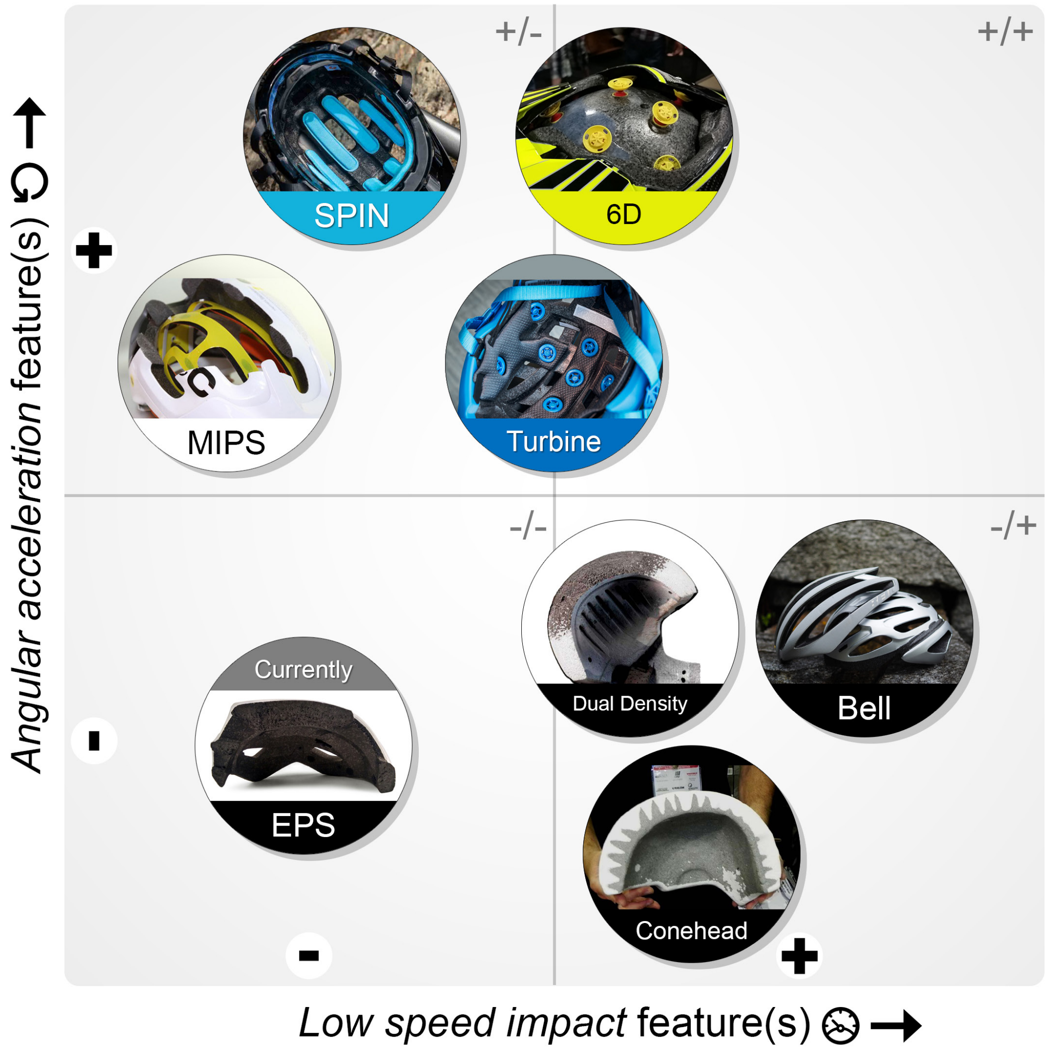


Fig. 3.4.1.: A matrix displaying the competition in terms of low speed impact and angular acceleration features.

This project aims to fill the gap in the +/+ quadrant, meaning the goal is to design an impact system that has both strong low speed impact features, as well as angular acceleration features. As can be seen, there currently is little competition that has both these features. Most companies focus on either one of the two, with the most realized concepts emphasizing on the reduction of angular accelerations.

3.5. Impact

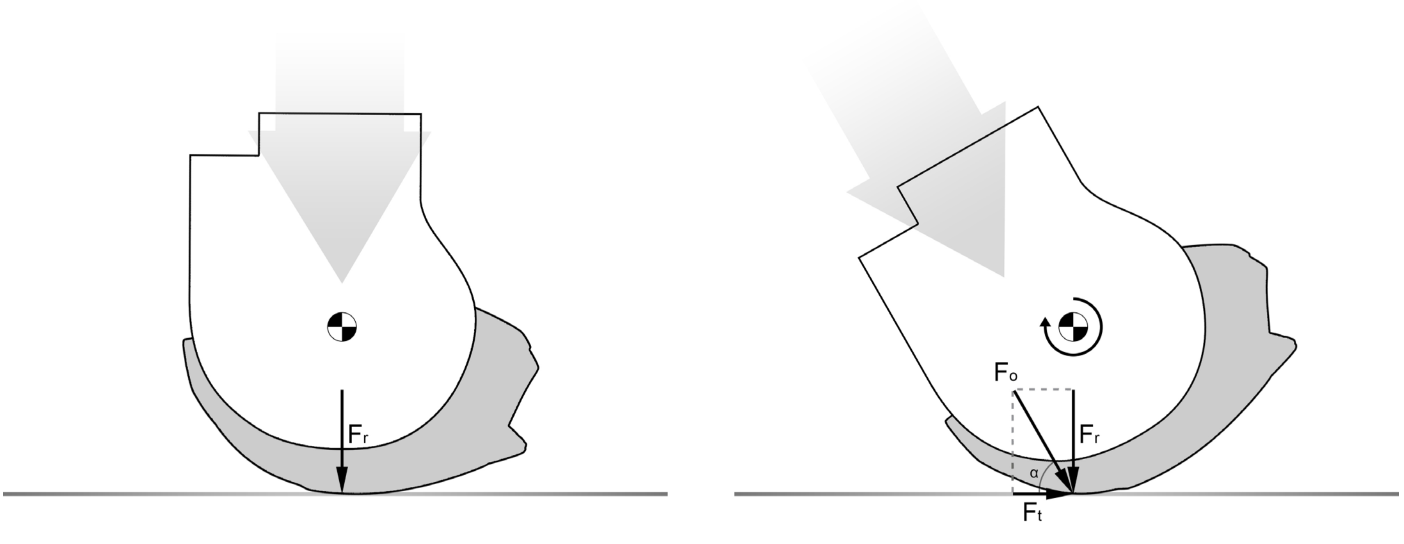
Introduction

The bulk of the research in this project revolves around the unaccounted impact protection of today's helmets. First it will be explained in more detail against which kind of impacts current helmets do and do not protect. Then effects of these impacts will be explained, namely the occurring accelerations of the head that cause injury. Facts and figures will be presented to get a sense of scale of these accelerations, to which the final design can be compared later on in the project. Finally more practical issues that will affect the design will be addressed, such as the physical room for an extra impact absorption system inside the helmet, as well as which areas of the helmet suffer the most impacts.

Additional impact protection

Modern bicycle helmets are designed to protect the user against the consequences of linear accelerations. Linear accelerations only occur when the impact direction is in the radial direction (perpendicular to the helmet surface), pointing to the center of mass of the head and helmet. In reality, oblique impacts occur under almost all circumstances. This means that the impact direction is under an angle, resulting in linear accelerations but also angular accelerations (see fig. 3.5.1.).

Fig. 3.5.1.: Left: radial forces during a perfectly straight impact. Right: radial and tangential forces during an oblique impact.

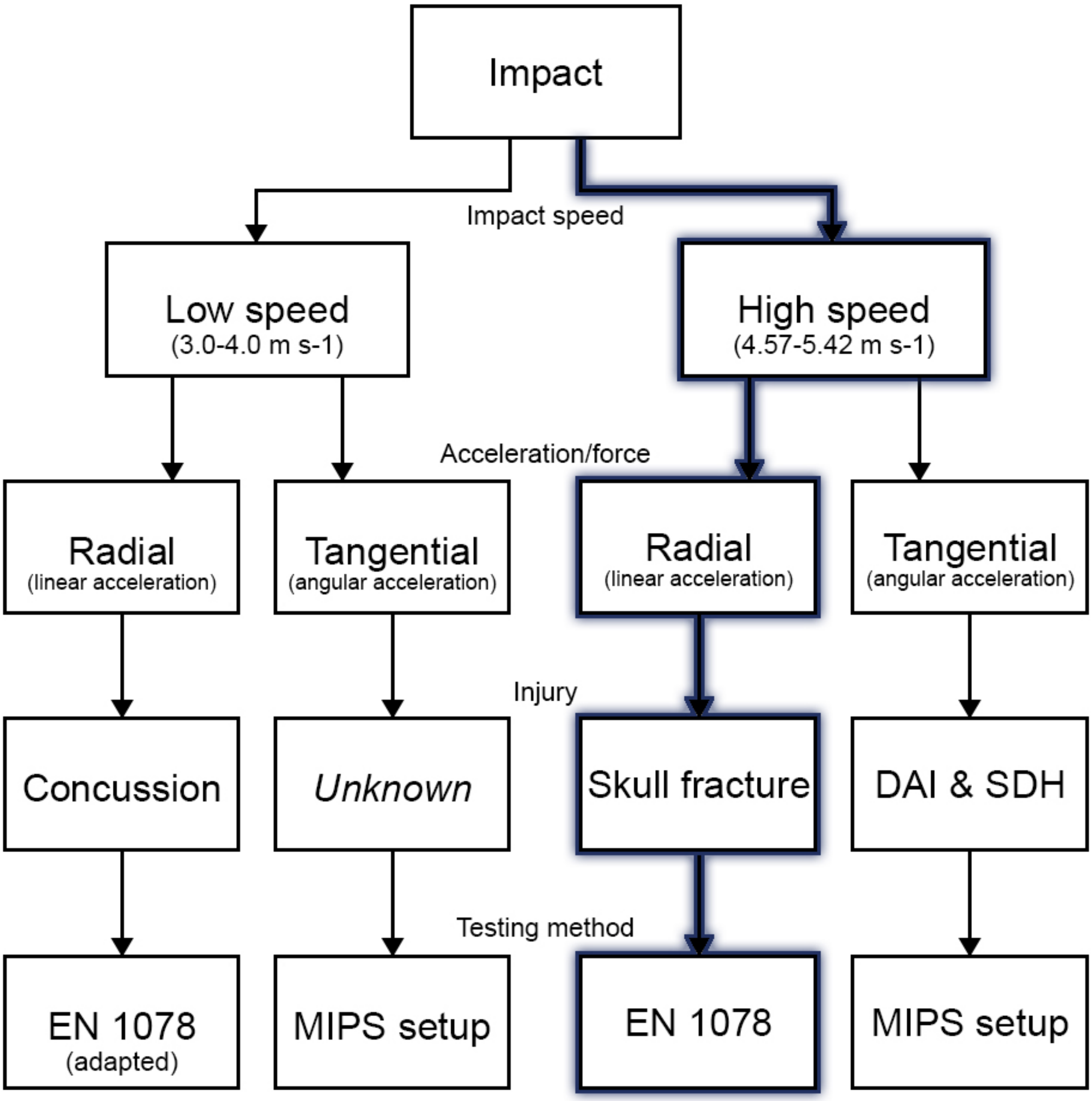


Furthermore helmets are optimized to offer protection against high speed impacts, for example when crashing at speed. The mechanical properties of the protective liner do not provide the same impact absorption qualities at low(er) speeds, for example when tipping over while standing still.

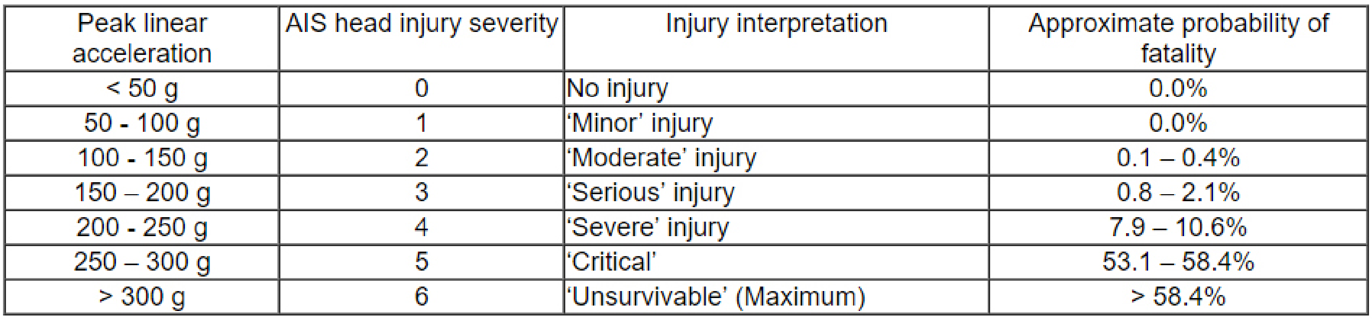
Low speed linear accelerations can cause concussions and other brain trauma. Angular accelerations of the head can lead to DAI (diffuse axonal injury, the stretching and shearing of nerves) and SDH (subdural hematoma, the collection of blood outside the brain). In order to minimize this as much as possible, helmets should evolve to provide additional protection on top of the current high speed impact protection.

To get a better overview of the different impact types and consequences, see the chart below (fig. 3.5.2.):

Fig. 3.5.2.: A more comprehensive overview of the occurring impacts, their consequences and how they can be tested. The blue outlined trajectory shows current helmets and their limited part of the whole story.



Linear accelerations for speeds below 3.0m s-1 pose such a low risk, that this is considered the cutoff point when it comes to impact speed. Figure 3.5.3. shows the low amount of risk for impacts around 50g of linear accelerations, with figure 3.5.5. showing linear accelerations around 50g equate to impact speeds around 3.0m s-1.



Peak linear acceleration	AIS head injury severity	Injury interpretation	Approximate probability of fatality
< 50 g	0	No injury	0.0%
50 - 100 g	1	'Minor' injury	0.0%
100 - 150 g	2	'Moderate' injury	0.1 – 0.4%
150 – 200 g	3	'Serious' injury	0.8 – 2.1%
200 - 250 g	4	'Severe' injury	7.9 – 10.6%
250 – 300 g	5	'Critical'	53.1 – 58.4%
> 300 g	6	'Unsurvivable' (Maximum)	> 58.4%

Source: The Potential For Cycle Helmets To Prevent Injury - A Review Of The Evidence

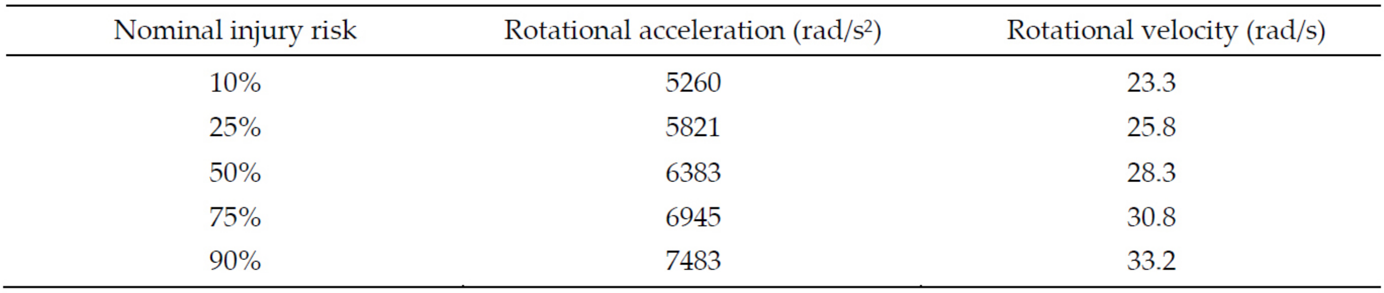
Fig. 3.5.3.: Different levels of linear accelerations vs the type of head injury.

Angular accelerations

A comprehensive helmet impact test performed by Swedish insurance company Folksam in 2017 showed that on average traditional EPS liner bicycle helmets cause angular accelerations between 7.6 and 9.1krad s-2, in some cases even reaching 10krad s-2. Angular accelerations of around 7.5krad s-2 (and higher) have a (>)90% probability of injury, meaning that current helmets offer virtually no protection in this regard.

Current systems and concepts that try to mitigate angular accelerations have shown that it is possible to reduce them to between at least 5.4 and 6.5krad s-2, significantly lowering the probability of injury to 15-50%.

Fig. 3.5.4.: Nominal injury risk vs angular acceleration.



Nominal injury risk	Rotational acceleration (rad/s^2)	Rotational velocity (rad/s)
10%	5260	23.3
25%	5821	25.8
50%	6383	28.3
75%	6945	30.8
90%	7483	33.2

Source: Rotational Head Kinematics in Football Impacts: An Injury Risk Function for Concussion

Low speed impact

Low speed impact testing done by the author of the BBB Tithon and BBB Kite helmets at TASS International suggests there is a linear relation between the impact speed of the helmet and the size of the accelerations. Figure 3.5.4. shows a graph extrapolated, downwards) of the results of the impact testing ranging from 3.0m s-1 to 5.42m s-1 (EN 1078 norm speed), with 0.5m s-1 intervals.

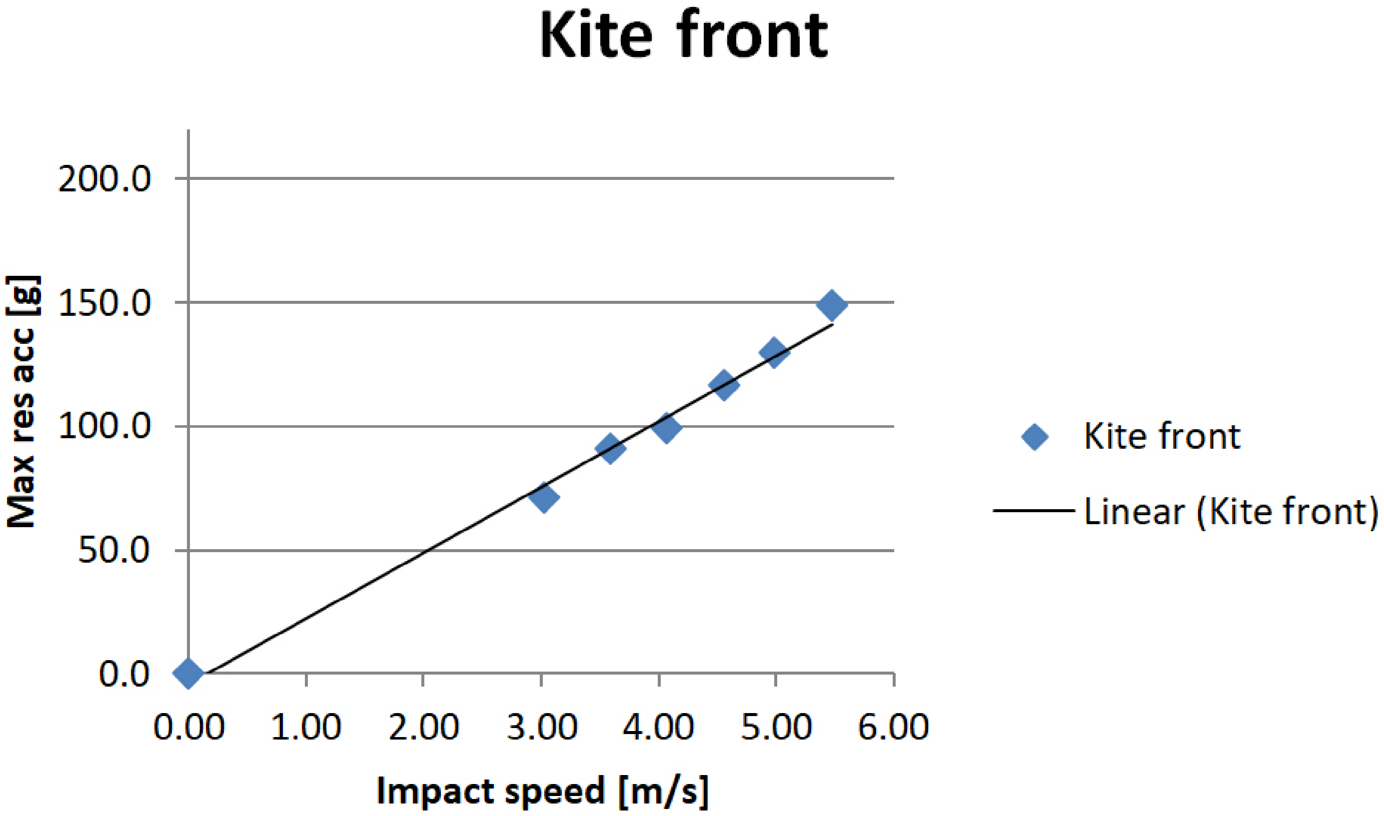


Fig. 3.5.5.: Impact speed vs maximum resultant acceleration of the BBB Kite helmet, impacted at the front.

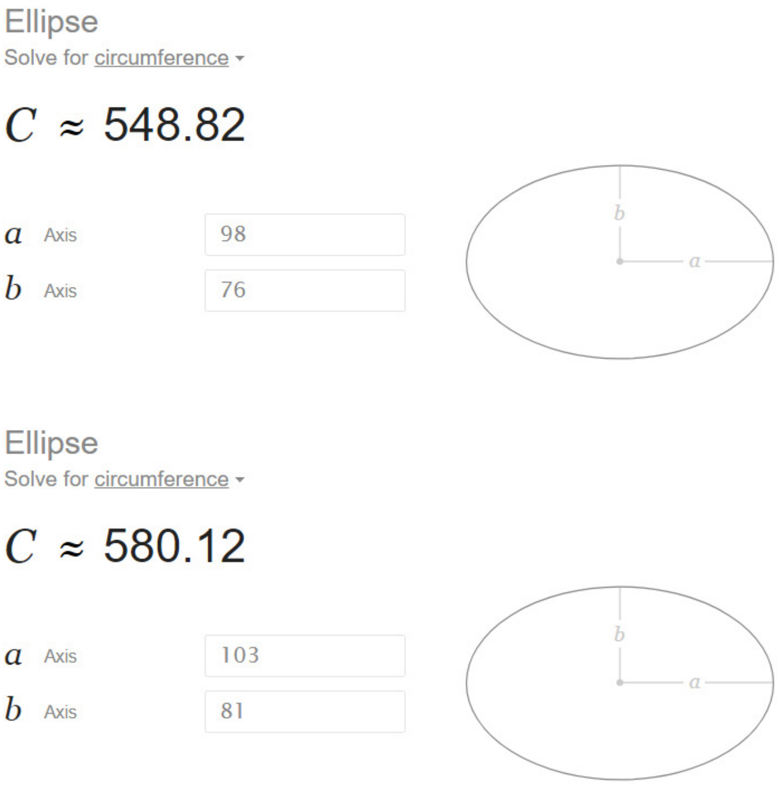
What the relation looks like for speeds lower than 3.0m s-1 is unknown after this testing at this point. However it stands to reason that the line will (slightly) curve towards and ending in the origin, as the maximum acceleration at the impact speed of 0m s-1 naturally is 0g.

These results go against the initial hypothesis formulated at the beginning of the project, stating that the EPS material (because of its mechanical properties) would yield proportionally higher accelerations at lower impact speed. In fact, the behavior of the material seems entirely linear and predictable, at least for impact speeds from 3.0m s-1 to 5.42m s-1.

Lastly, preliminary testing of low speed impact protection concepts (produced by BBB's manufacturer) at two impact locations, has shown that linear accelerations can realistically be reduced from 197 to 164g (front/middle), and from 134 to 119g (side/rear). A reduction of around 11% and 17% respectively.

Size and head form

Currently most of BBB's helmets are offered in sizes medium (M) and large (L), with head circumferences ranges of 55-58cm and 58-61cm respectively. When reducing the length and width of the elliptical head shape by only 10mm (or 5mm at each side), the circumference is approximately reduced from 58cm to 55cm (see fig. 3.5.6. below). This means that adding a relatively small amount of space for additional impact protection has a large effect on the sizing and fit of the helmet.


Ellipse
Solve for circumference

$C \approx 548.82$

a Axis 98

b Axis 76

Ellipse
Solve for circumference

$C \approx 580.12$

a Axis 103

b Axis 81

Fig. 3.5.6.: The effect of reducing the length and width of the head form by 5 mm at each side; a 3 cm circumference reduction.

Impact protection location

Almost half of the impacts (around 47%) occur at the front of the helmet, followed by almost a third on both sides combined (around 31%) (see fig. 3.5.7.). The top of the head as well as the rear are responsible for a minority of the impacts (around 14% and 23% respectively).
Low speeds impacts are believed to mainly occur at the sides of the helmet. Furthermore angular accelerations are higher around the x-axis of the head compared to the y-axis (9.1krad s-2 vs 7.6krad s-2).
To create a system that is both minimal in size and weight, as well as as effective as possible, additional impact protection should be implemented at the locations where they are needed most.

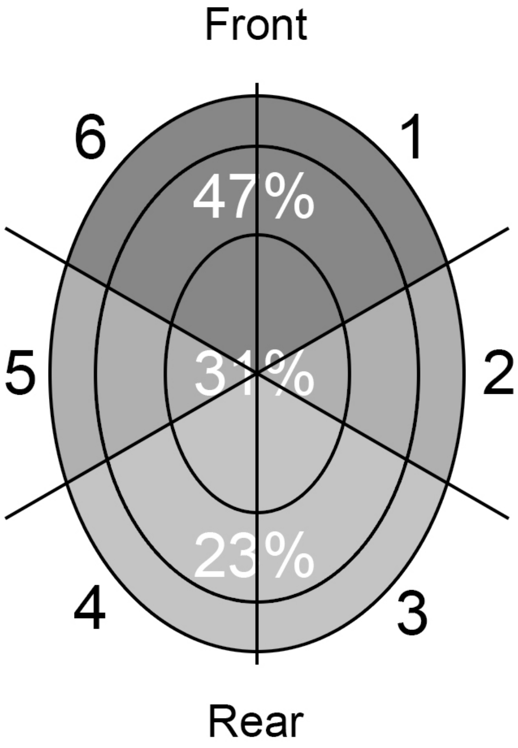


Fig. 3.5.7.: The distribution of impacts across the helmet.

3.6. List of requirements

The analysis chapter contains the conclusions of the analysis phase of the project. For a more detailed explanation of these findings, see appendix 3.6. The conclusions have led to a list of requirements, which is laid out below. The list is organized in five parts, which are regarded as the most important elements in designing a safer helmet: general helmet design, low speed linear accelerations, angular accelerations (oblique impacts), size and fit, and weight.

1. General helmet design

1. An additional impact protection system is to be added to current helmets;
- EPS is to be used as a material to absorb high speed linear accelerations;
- Inmold technique should be used for the fabrication of the high speed impact liner and outer hard shell (most likely PC);
2. The added system must be implementable in the current style of helmet manufacturing;
- No major adjustments to the molds can be made;
3. The helmet (including the system) must comply with the EN 1078 norm, meaning:
- Peak linear acceleration at 5.42m s-1 (flat anvil) and at 4.57m s-1 (kerbstone anvil) must be <250g;
- Peak linear acceleration with the added system must not be higher than without the system;
- Peak linear acceleration should ideally be <150g.

2. Low speed linear accelerations

1. Peak linear acceleration at 3.0-4.0m s-1 (flat anvil) must be lower than peak linear accelerations at 5.42m s-1 (flat anvil) and at 4.57m s-1 (kerbstone anvil);
- Peak linear acceleration at 3.0-4.0m s-1 (flat anvil) should aim to be 10% lower (or more). (Peak low speed linear accelerations of current helmets is estimated at around 100-150g);
2. Low impact speed protection should (mainly) focus on the sides of the helmet.

3. Angular accelerations (oblique impacts)

1. Peak angular acceleration must be 6.0krad s-2 or lower, in any direction;
- Peak angular accelerations should ideally be lower than competitor solutions, mainly MIPS which ranges from 5.7-7.0krad s-2.

4. Size and fit

1. The added system can take up a maximum of 5mm in all directions;
2. The added safety functionality should not create a helmet that is deemed ‘too big’ by the target group;
3. The added safety functionality should not negatively influence the fit and comfort of the helmet (e.g. make the inner diameter significantly smaller).

5. Weight

1. The weight of the helmet (size M) should be <330g;
- The weight should be around the same as other heavier helmets that can be explained. E.g. the speed pedelec BBB Indra weighing around 320g (size M) due to its increased high speed impact protection because of higher traveling speeds.

Conclusions

The way bicycle helmets are currently tested and therefore designed, offers little to no protection when it comes to low speed and oblique impacts. Todays helmets are made out of EPS which is almost entirely only able to absorb the consequences of high speed impacts. Research has shown oblique impacts occur in almost every impact scenario. Besides linear accelerations, they also cause angular accelerations of the head, leading to serious brain injuries. To counter this, there has been a trend in the bicycle helmet industry which focuses more and more on reducing angular accelerations. Low speed impact protection is still a low priority, but tests have shown that these impacts can have significant consequences as well. To reduce the effects of these impacts as much as possible, a system is to be designed that fits in current style helmets, without major modifications.

SYNTHESIS

Introduction

As stated at the beginning of this report, this project can be seen as a continuation of the AED project, which resulted in the BBB Daedalus. If anything, the project served as a welcome diving board to start the current project. While the AED project provided a head start on things like initial orientation and getting familiar with concepts like accelerations, it proved to be particularly useful when entering the synthesis phase. Unlike many projects, the idea generation did not start with a blank slate, requiring to start from scratch so to speak. Still, it was necessary to take a few steps back from the Daedalus concept, which will be outlined next. The synthesis phase ultimately resulted in three concepts, which were judged by six main criteria and of which one concept was chosen for further development.

4.1. Starting point synthesis

BBB Daedalus

The Daedalus was very much the starting point of this project. This did not however mean that the goal per se was to take the Daedalus and take it to the next level. Instead it was taken as a main inspiration and previously done research. The design of the Daedalus will now be briefly summarized, to understand how it served as a starting point for the synthesis phase of this project.

The Daedalus is an EPS liner helmet with an extra layer placed at the inside of the helmet. This extra layer consisted of roughly 100 EVA foam cylinders, connected through multiple separate hard shells. Accelerations test by the team indicated that the extra layer was both able to reduce low speed accelerations by compression, as well as angular accelerations by shearing of the cylinders.

The so-colled Wonder Liner has been succesfully tested. Shows promissing results, this technology makes the cycling industry closer to a safer road cycling helmet.

Fig. 4.1.: The result of the AED helmet project: the BBB Daedalus.

4.2. Concepts

The idea generation phase and the categorization of these ideas culminated in the forming of three concepts, which will now be further explained. After that, the concepts will be compared on six key fronts, after which a choice will be made. This final concept will be developed further into the final design.

Concept A

This concept makes use of a double EPS liner design, with a foam structure in between. The sandwich-like design resides along the ridges or beams of the helmet, going from the front to the back. The extra EPS beams are separated for two main reasons. First is to allow for independent and impact specific movement of the system.

Furthermore, because of the oval shape of the inside of the helmet and outside of the head, the relative sliding/rotating motion between them (as a result of angular accelerations) would increasingly cause more friction. This is less of a problem when you look at the movement from side to side, because the human head is more round in this direction (making rotations over this arc easier).

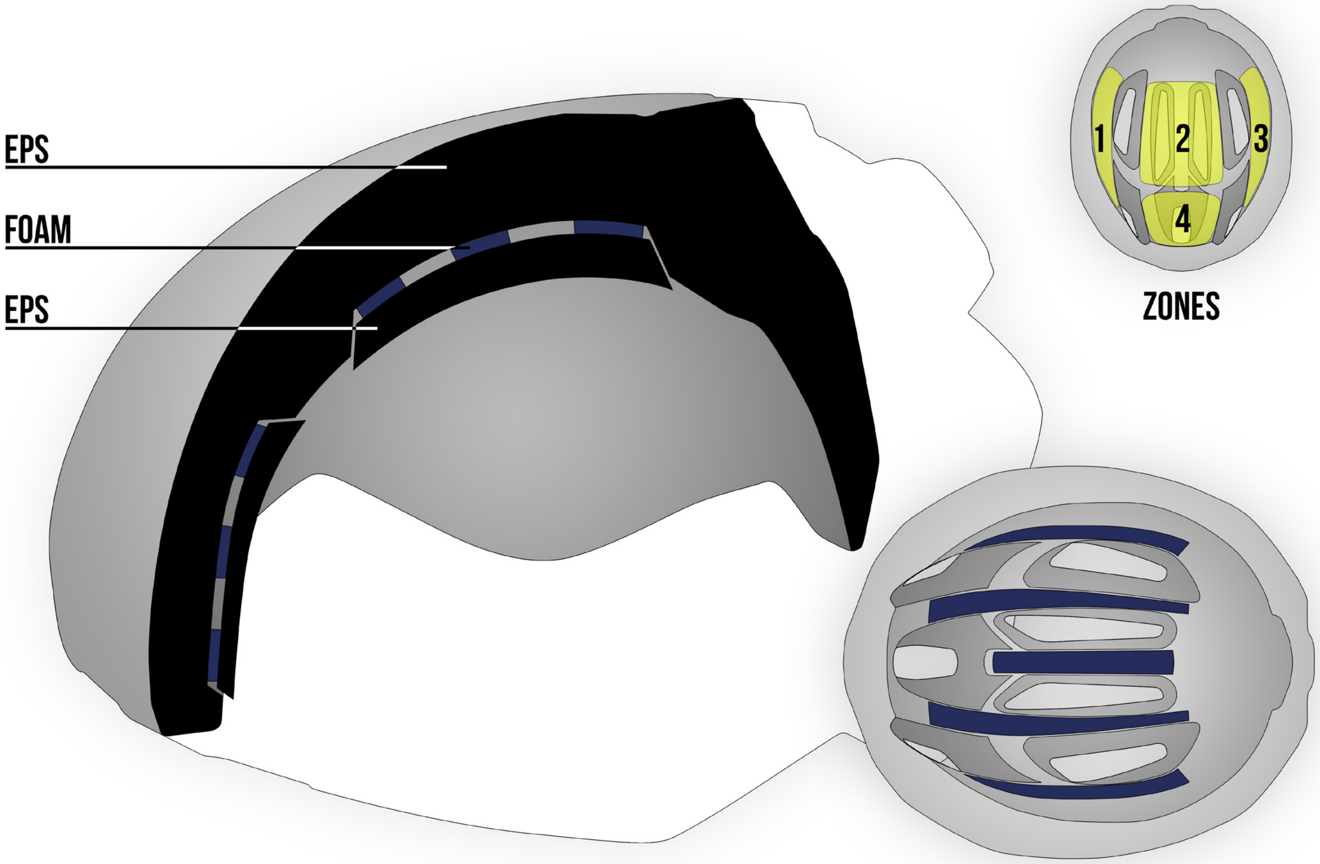


Fig. 4.2.1.: Concept A, showing the inner workings through a cross section in perspective.

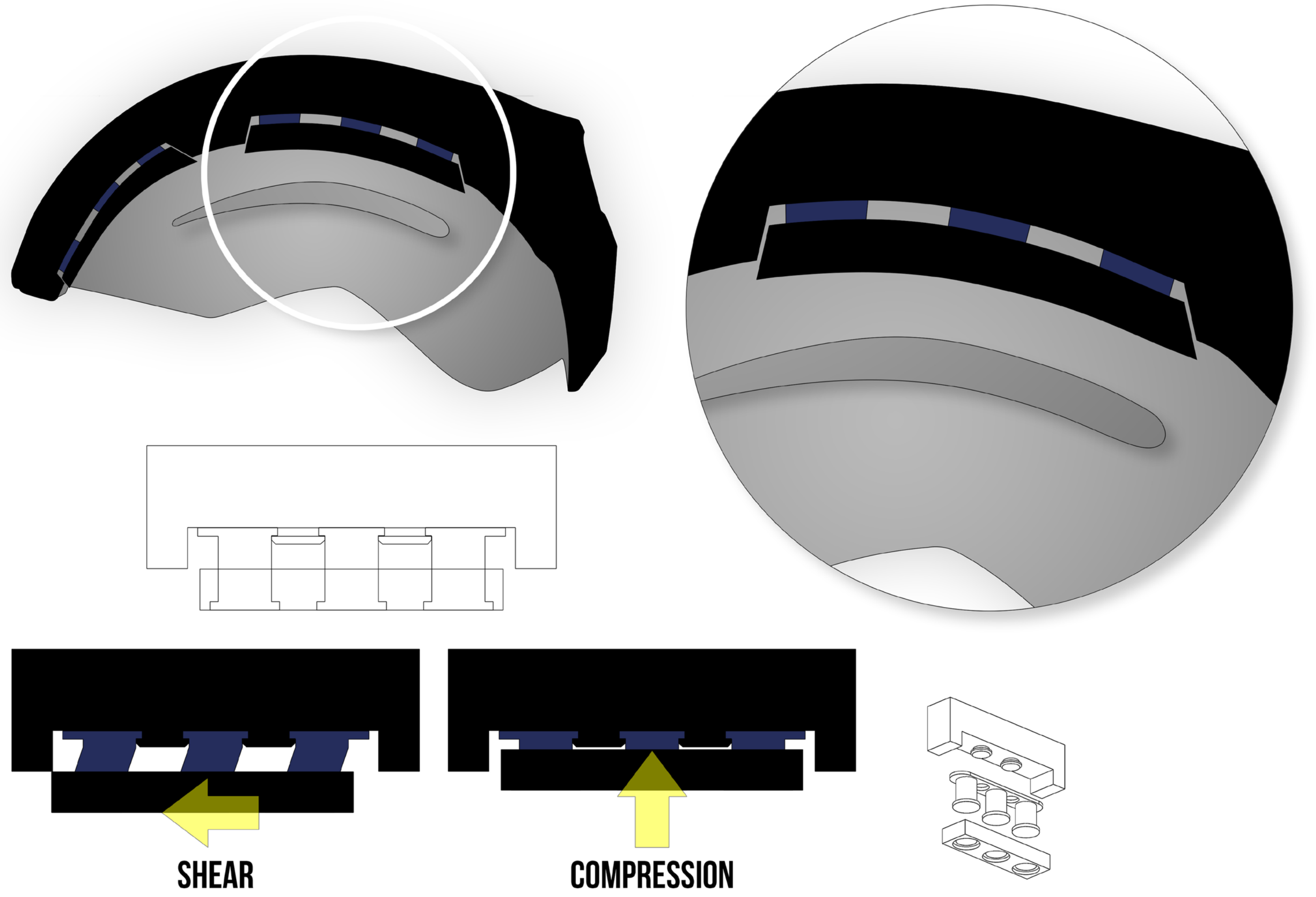


Fig. 4.2.2.: The cylindrical constructions (inspired by the AED concept) can both shear and compress.

Implementing this concept in current helmets will require large modification of the inner mold, taking into account the discharge angle of the sliders when they retract from the mold. Size wise this concept is adaptable, since the height of the impact layer in between the two liners of the EPS can be adjusted according to the desired impact protection by BBB. A thicker layer will result in more protection, but also a bigger helmet. The weight of the concept will mostly consist of the impact layer, because the second EPS layer will be 'cut out' of the main liner, not adding any extra material (and thus weight). Ventilation properties are somewhat similar to current helmets, since the inside will not be too different from the version without this system. This concept has a relatively large amount of parts and contact points, increasing the amount of effort and time to assemble. Manufacturability is also not favorable, since it makes use of a second layer of EPS, which has to fit not only the helmet, but also the head of the user.

Concept B

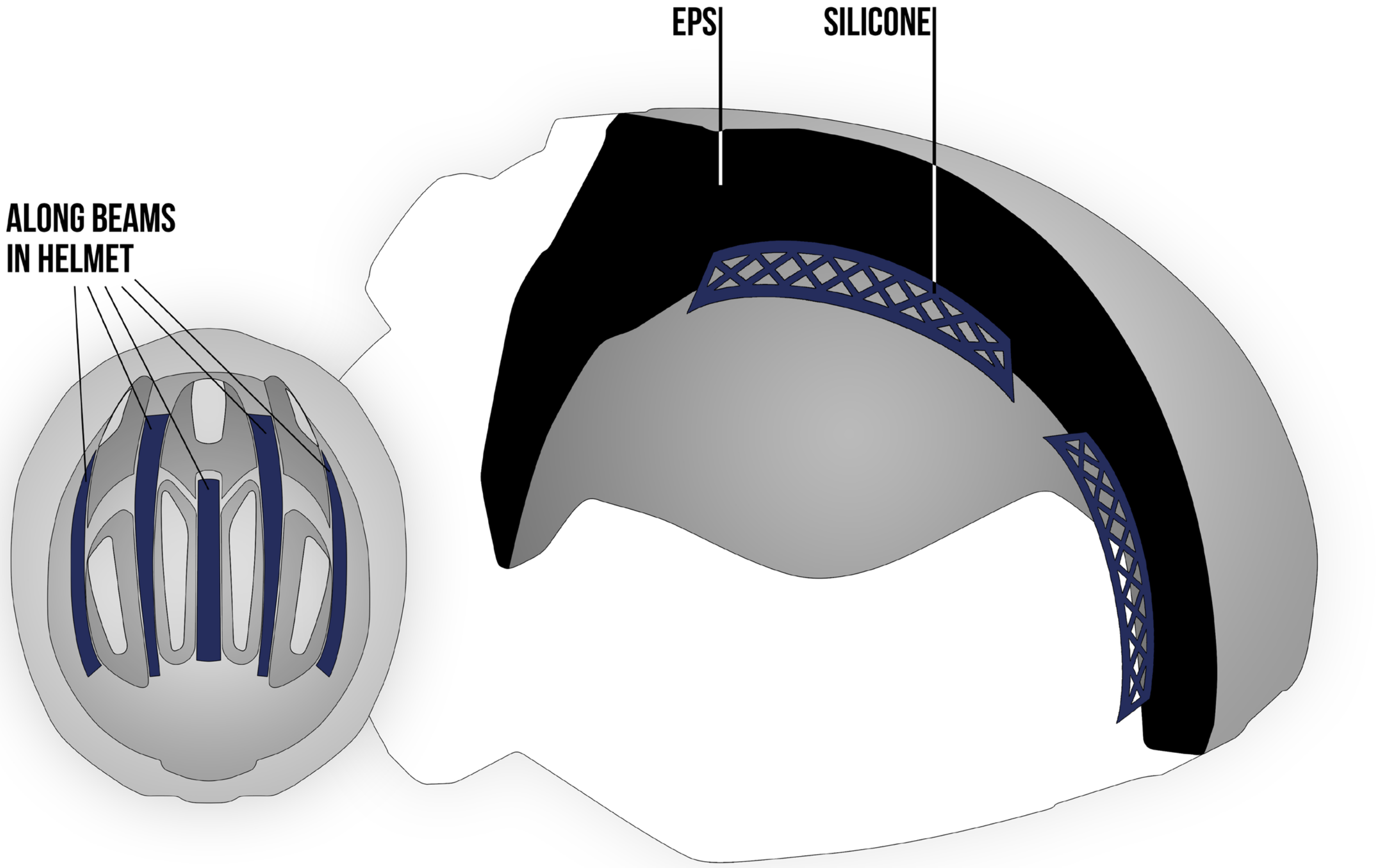


Fig. 4.2.3.: Concept B, taking a manufacturing based approach when designing.

This idea revolves around the ability to create a single 'strip' of silicone that can be formed out of a sheet of material. The strips are then put in recessed parts of the ridges of the helmet. Their relatively simple design and way of manufacturing enables great flexibility when it comes to implementing it in all kinds of different helmet designs (one of BBB's big wishes).

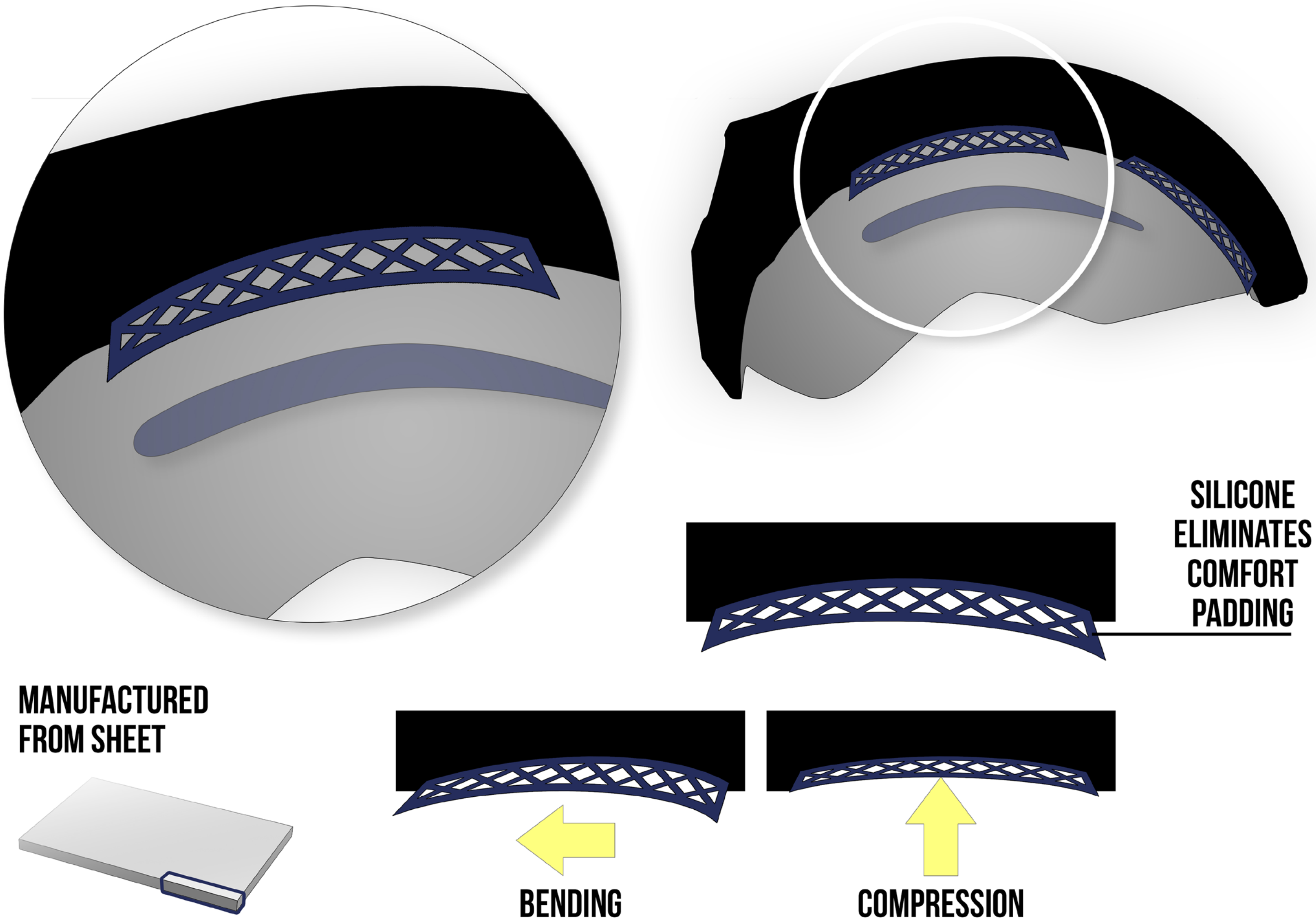


Fig. 4.2.4.: The beams are made out of sheet material, increasing customization and making manufacturing easier.

The current helmet readiness of this concept relies for a great deal on the use of ridges in the design. Because most of BBB's helmets offering use this design, implementing this concept in the current line up will not lead to any foreseeable problems. Recessing the beams will allow for a reduction in size as well as shed some of the EPS weight. The open structure of the beams not only provide the impact absorption capabilities, but will also allow for air to pass through, ensuring ventilation is not hindered. Because the impact strips have to be carefully aligned with the beams of the helmet, this concept is not the easiest to assemble. Manufacturing of the strips however does come out favorable in this concept, as they can be made from a foam sheet, simply by (e.g. laser) cutting them.

Concept C

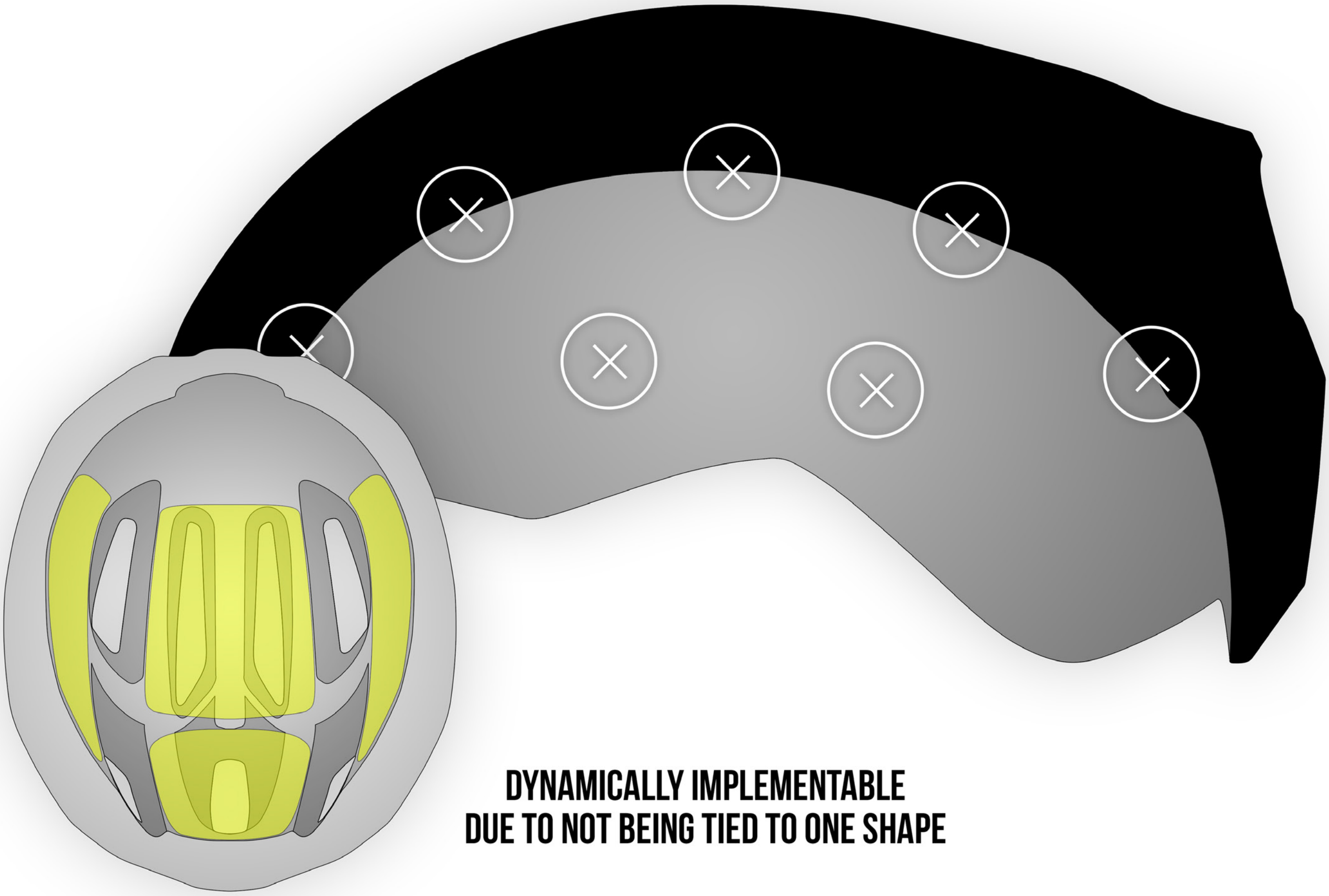


Fig. 4.2.5.: Concept C, employing the idea of having identical single units scattered across the helmet.

The final concept makes use of the principle of having a single ‘unit’, which can be placed anywhere in the helmet using an in mold anchor (similar to how currently the retention system is attached). It shares the same benefit of the previous concept, in the sense that the location of these units can be adapted to the design of the specific helmet in which they are placed.

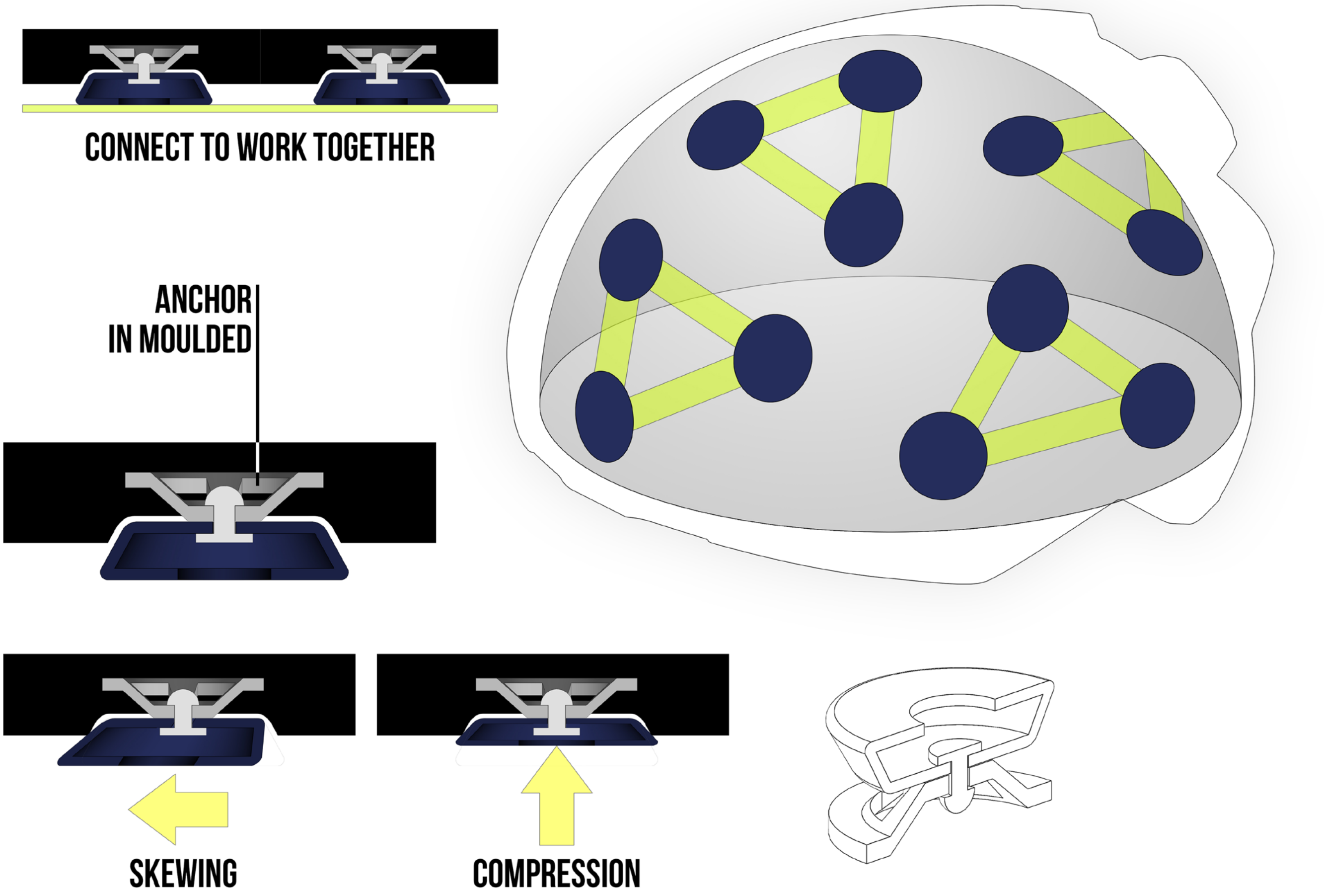


Fig. 4.2.6.: By connecting the units, the impact absorption is not limited to highly specific places on the helmet.

Since this concept makes use of the anchors that are already being used to for example attach the retention system, it is quite current helmet ready. Embedding the units inside the EPS reduces the size of the system, which is a plus. Because the embedding sheds some of the EPS weight, this will benefit the weight. Ventilation properties are relatively high compared to the other concepts, since it only adds single units, instead of entire beams of material. Ease of assembly is achieved by the anchors, which are simply pressed in place (like the retention system). Because this concept revolves around a single repeating unit, manufacturability is greatly helped. It can be implemented in every helmet, regardless of the shape, size or design.

4.3. Concept choice

Criteria

To assess the different concepts, a matrix is setup which addresses the six most important criteria based on the main requirements for this project. These are (in no specific order): current helmet readiness, size, weight, ventilation properties, ease of assembly, and manufacturability. Each of these criteria has a score ranging from 1 to 5, whereas 1 being the lowest (bad) and 5 being the highest (good). Each concept is scored on the above mentioned criteria, filling in the matrix shown on the side:

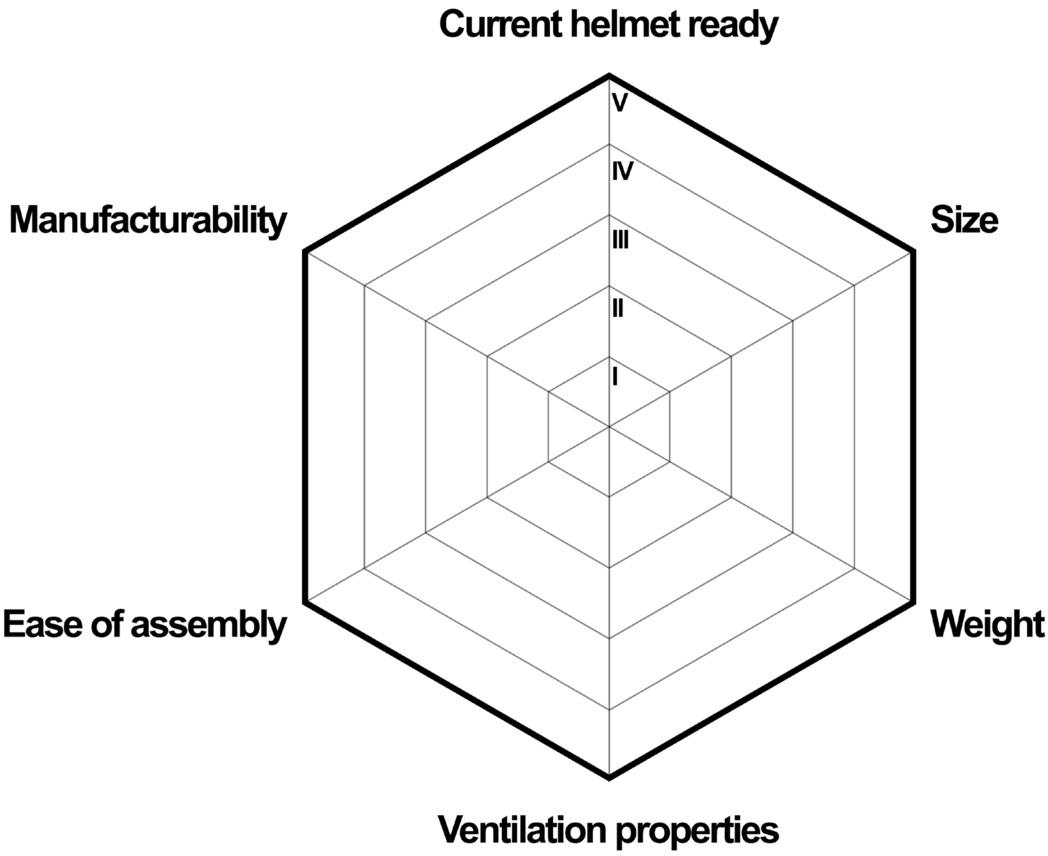


Fig. 4.3.1.: The matrix that was created to rate all concepts.

Rating and choice

Next step is to rate each concept on the six different categories, starting with concept A:

Concept A while initially looking promising, turned out to have some unexpected weak spots. Especially manufacturing will make this concept quite expensive and difficult. Furthermore, it cannot be guaranteed that the two separate EPS layers provide the same absorption capabilities as one equally thick single layer.

Concept B is quite balanced when looking at the shape of the matrix. However, concept C scores slightly higher in a couple of regards:

Looking at the scores, concept B and C both rate relatively high, with concept A being scored significantly lower. One of the major downsides of concept B is caused by its main strength: the fact that it is manufactured from a sheet. This (in its current form) mainly allows to design in 2D, reducing the impact reduction properties in the side to side direction of the helmet. Furthermore, concept C allows for so much customization, it can be implemented in virtually every helmet design. For these reasons it was opted to further develop concept C, while looking at the other concepts to harvest potentially useful features that would be otherwise left out.

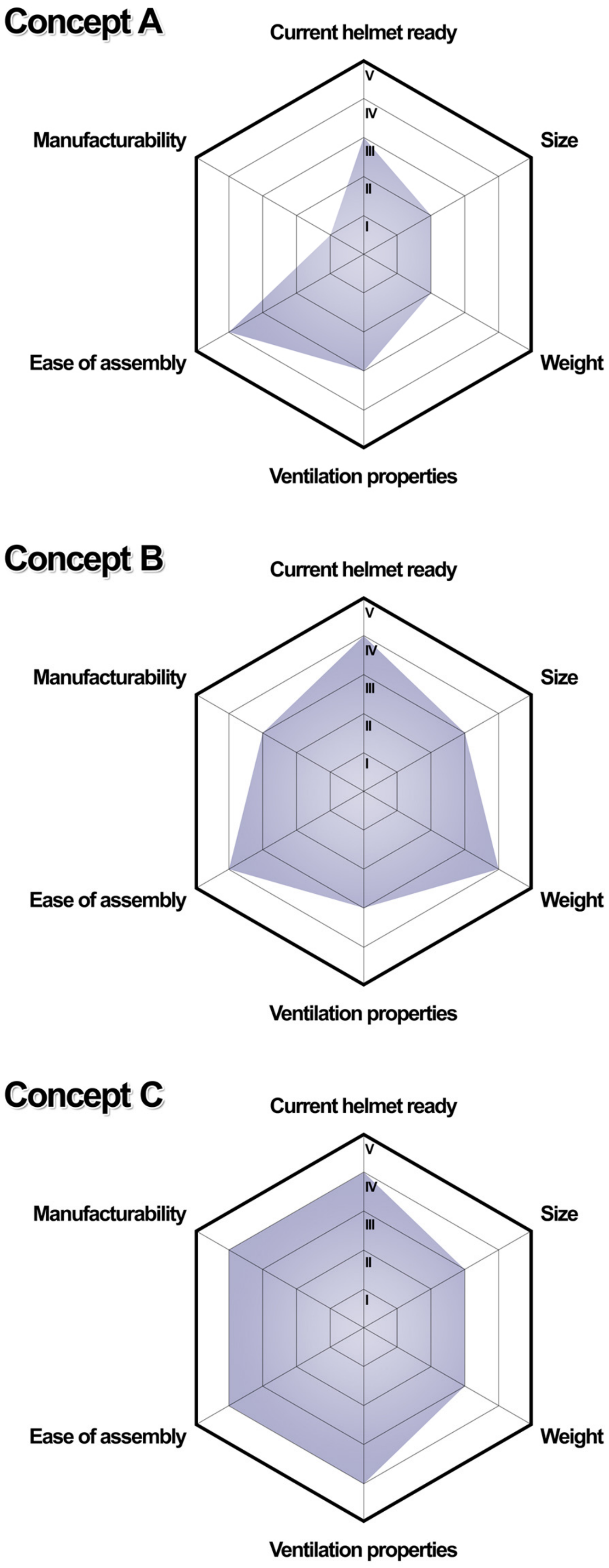


Fig. 4.3.2.: The rating of concept A, B and C.

4.4. Final design

Introduction

Now that a choice out of the concepts has been made, it is time to take it one step further. This chapter will explain the most important parts that were deeper developed, starting with the identification of four 'zones' inside the helmet, which will house the impact absorbing parts of the system. Then the focus will shift to the actual parts that will absorb the impact, why they have the shape that they have, and how they aim to counteract the different types of accelerations. Finally more practical parts of the design shall be addressed, such as how the system is assembled and is connected to the helmet, as well as features to try and keep the added thickness to a minimum.

Zones

Even though it was decided to 'choose' one concepts over the other, nothing stands in the way of using different elements of the other concepts. One of these is the division of the helmet in four (or possible more) areas, called zones. While originally the third concept was based on the idea of individual units that could be placed along the entire helmet, this automatically is also its Achilles heel.
Instead, dividing the helmet into distinct areas will allow to strategically provide protection where it is needed. Furthermore, using zones instead of points will increase the effectiveness of the impact protection. Instead of relying on the impact to occur on one of the single points, a wider area makes sure no impact 'slips through'.
Lastly, the use of the zones falls in line with the conclusion of the impact location protection (see Analysis chapter). This said that the protection of the head is not to be uniform, but should cater to the protection needed at each location.

The following four zones are therefore formed: the two sides (left and right), the top and the front:

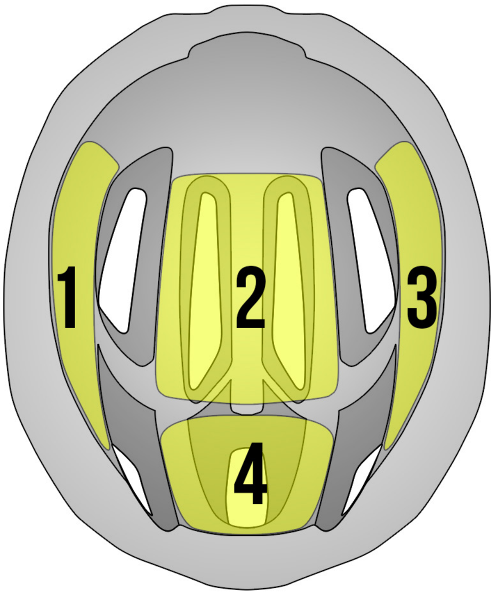


Fig. 4.4.1.: The identification of different zones, on the left done digitally, on the right applied in real life.

Another reason for not using one shell to cover the entire area of the head (like for example MIPS does), is because this can work against itself in certain situations. Pulling at one side results in movement at the other, where it is attached and impedes on any further motion.

Beams

Because the system has to be implemented in current helmet style design, the next part will take a look at the ‘playing field’ so to say; the area and possibilities (but also limitations) that modern helmets dictate.

Fig. 4.4.2.: A variety of helmets showing the similar ‘beam’ design.

The majority of traditional (non-aerodynamic) road cycling helmets are constructed from a multitude of connected EPS ‘beams’, that run from the front to the back. This creates helmets with long and narrow ventilation holes, which allows air to enter the helmet for effective ventilation of the head.

Most of BBB helmets deploy a similar overall design. At the inside of the helmet, the flat surfaces of the beams are the areas that make contact with the head.

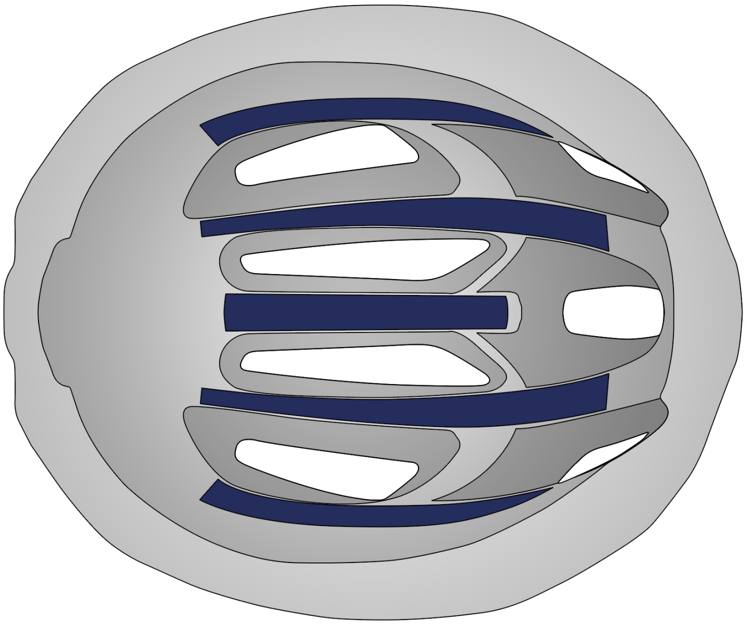


Fig. 4.4.3.: The beams offer the area that can be utilized to attach parts directly to the helmet.

Design

After having identified the different zones and the ridges that play a central role in the implementation of the solution, the concept was further worked out.

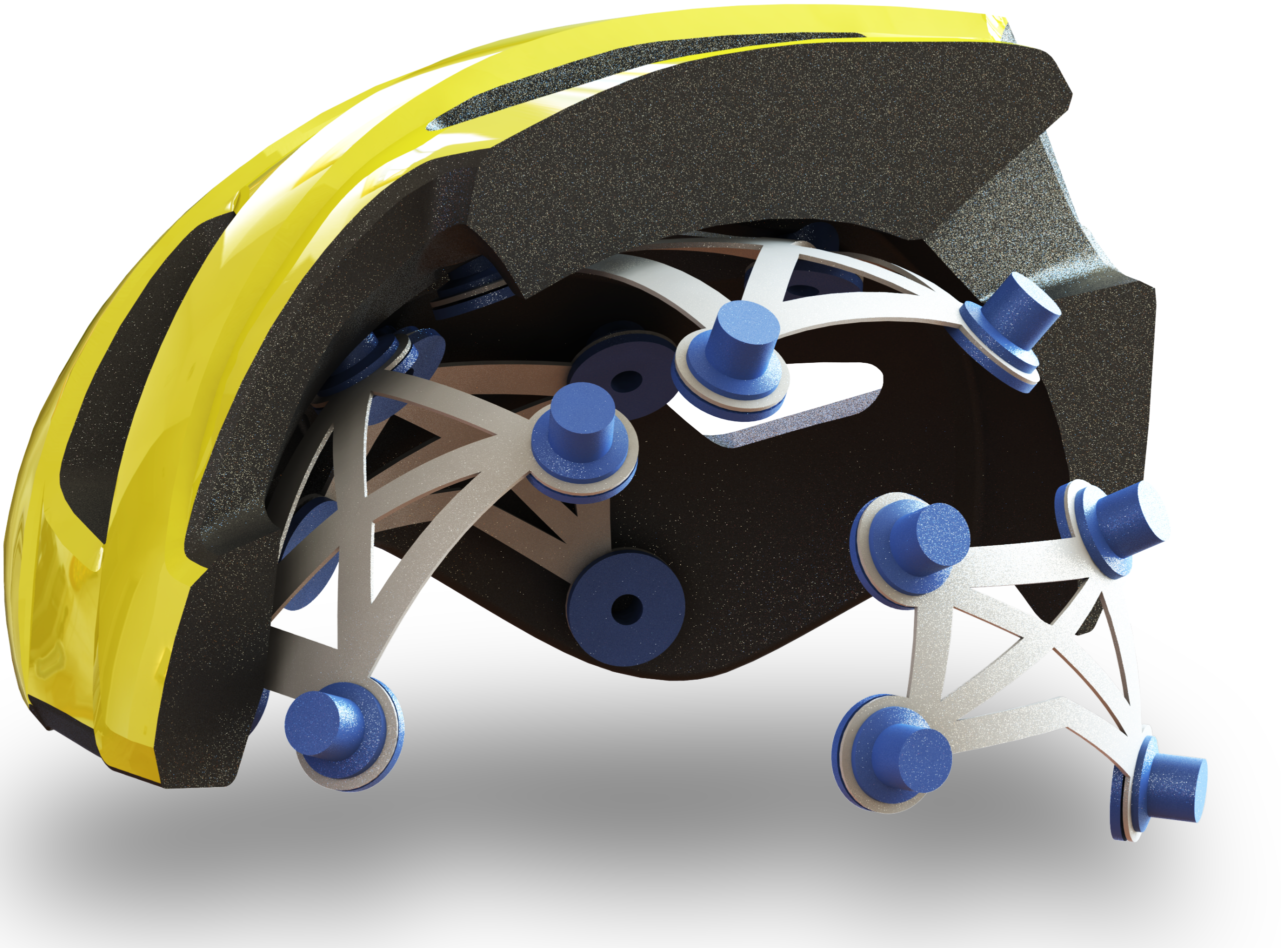
Round impact units

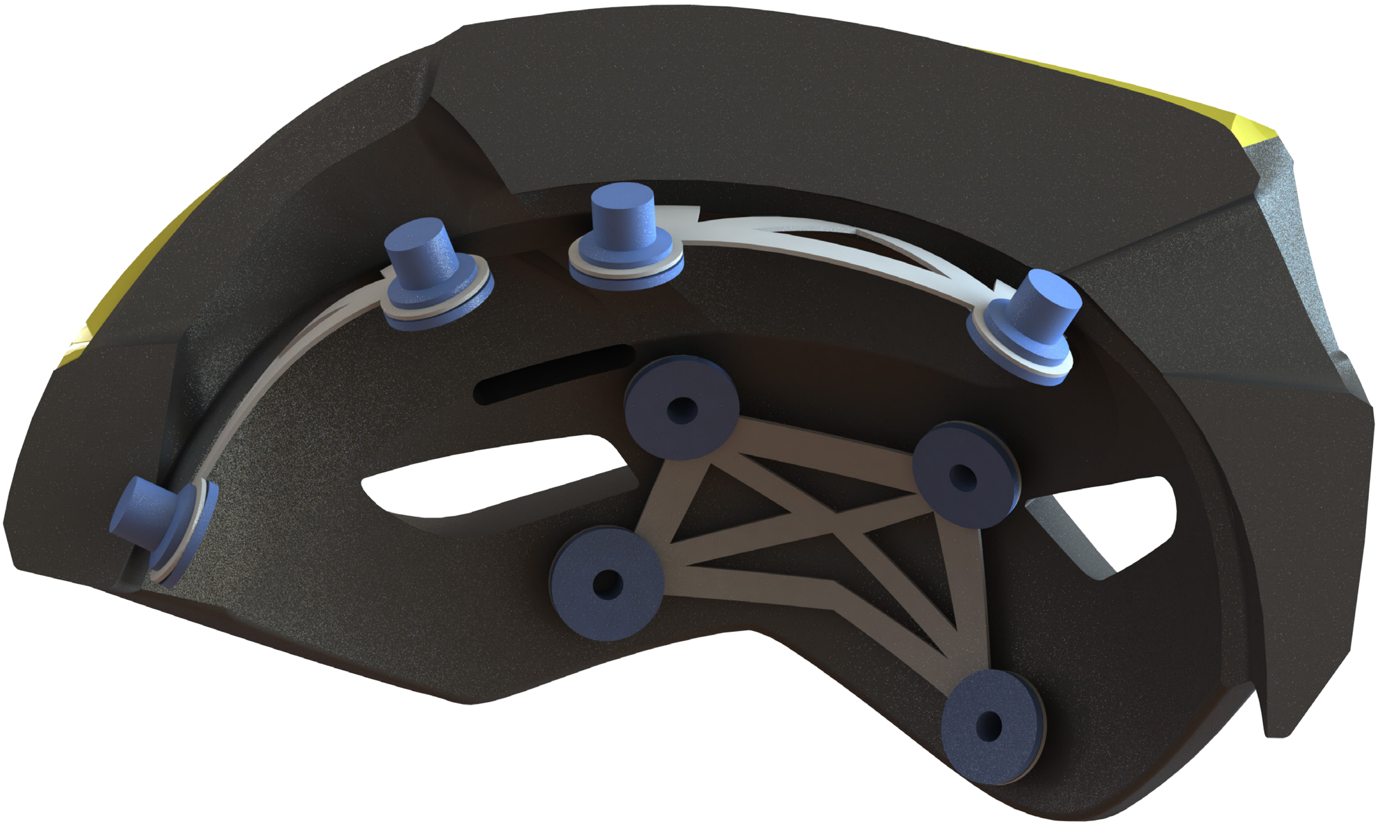
One of the features important in the ability of the system to reduce angular accelerations in all tangential directions to the head, is the possibility of so called 'float'. The best way to describe this is the ability of the system to move freely in 360 degrees. To ensure movement in all directions was possible, development of the impact units was quickly guided towards round shapes.

In helmet

An overview of the concept placed in the helmet, before a more detailed explanation of the parts and their function is provided:

Fig. 4.4.4.: A look at how the four elements are placed in the helmet.





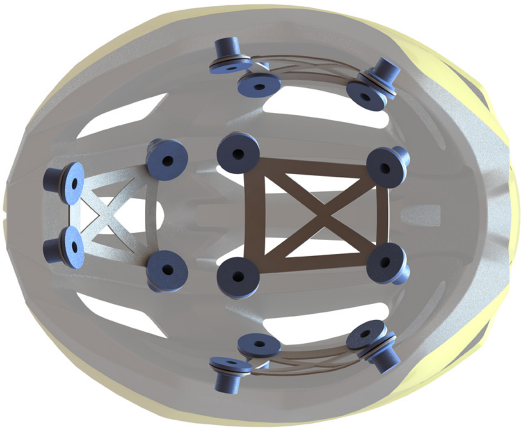


Fig. 4.4.5.: A cross section view and top down view of the system show the orientation of the system.

Impact properties

Low speed impact
The system provides low speed impact protection, by being able to compress at low speeds. No matter where the helmet is impacted, all four cylinders will (depending on where the impact takes place) compress in various degrees.

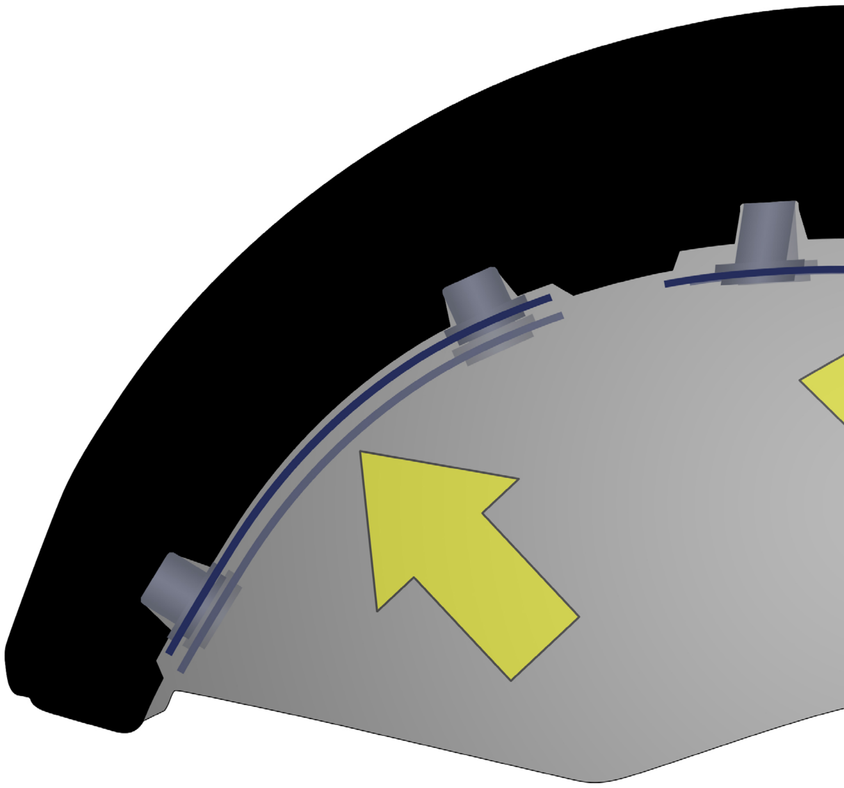


Fig. 4.4.6.: Compression of the cylinders, allowing the absorption of low speed impact accelerations.

Angular accelerations
As well as being able to handle linear accelerations due to compressing, shearing of the cylinders will allow the shell parts to rotate relative to the position of the helmet, thus reducing angular accelerations.

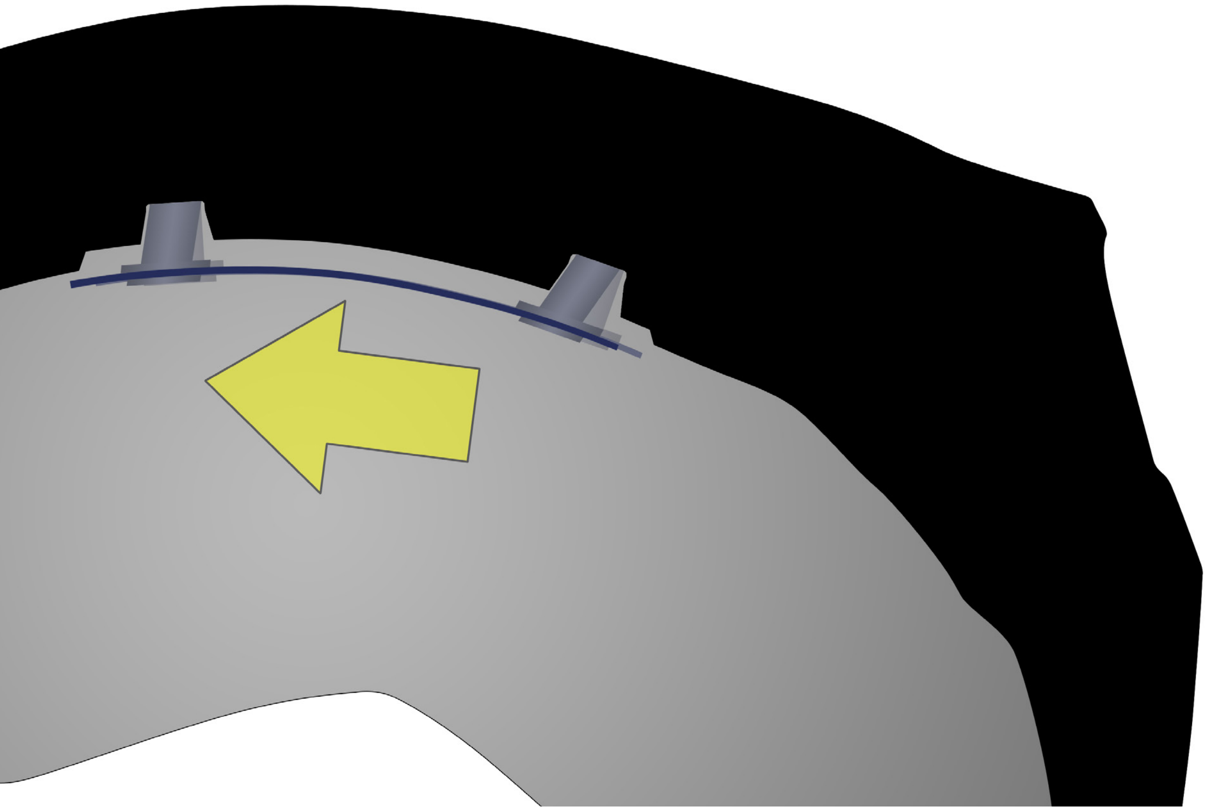


Fig. 4.4.7.: Shearing of the cylinders, allowing the absorption of angular accelerations as a result of oblique impact.

Parts

The system is comprised of five different parts, assembled in the way as seen below:

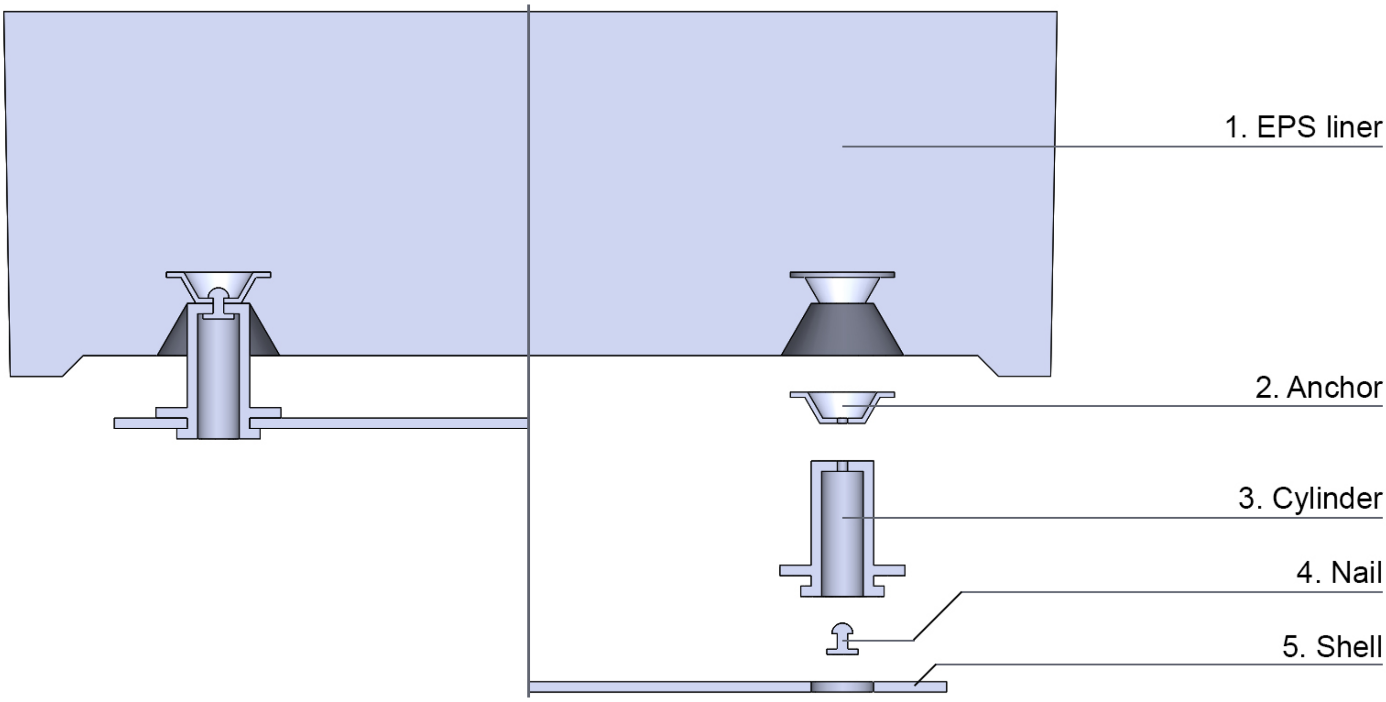


Fig. 4.4.8.: An exploded view showing the parts on the right and how they fit together on the left.

Embedding

The cylinders and shell parts are both recessed into the EPS liner. This enables them to compress and move under linear accelerations, reaching the inside contour of the EPS liner when 'bottoming out'.

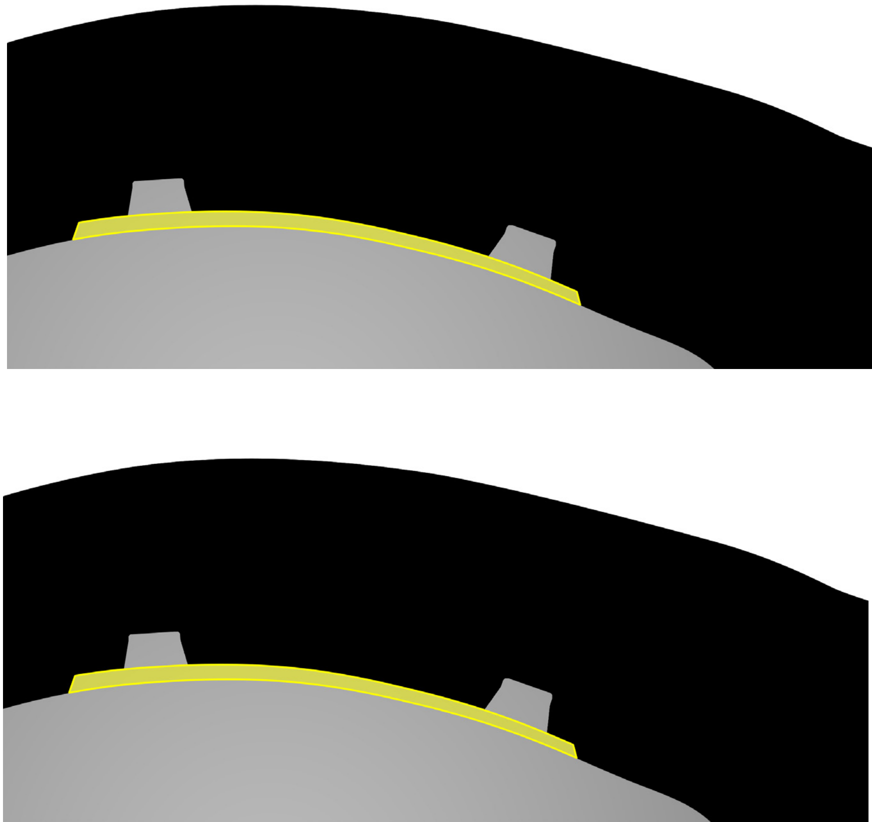


Fig. 4.4.9.: Recession of both the shell parts (top) as well as the cylinders (bottom).

Shell parts

The shell parts have cutouts in them to save weight, but also allow air to move through. This way the system does not negatively influence the ventilation properties of the helmet, one of the important aspects that cannot be compromised.

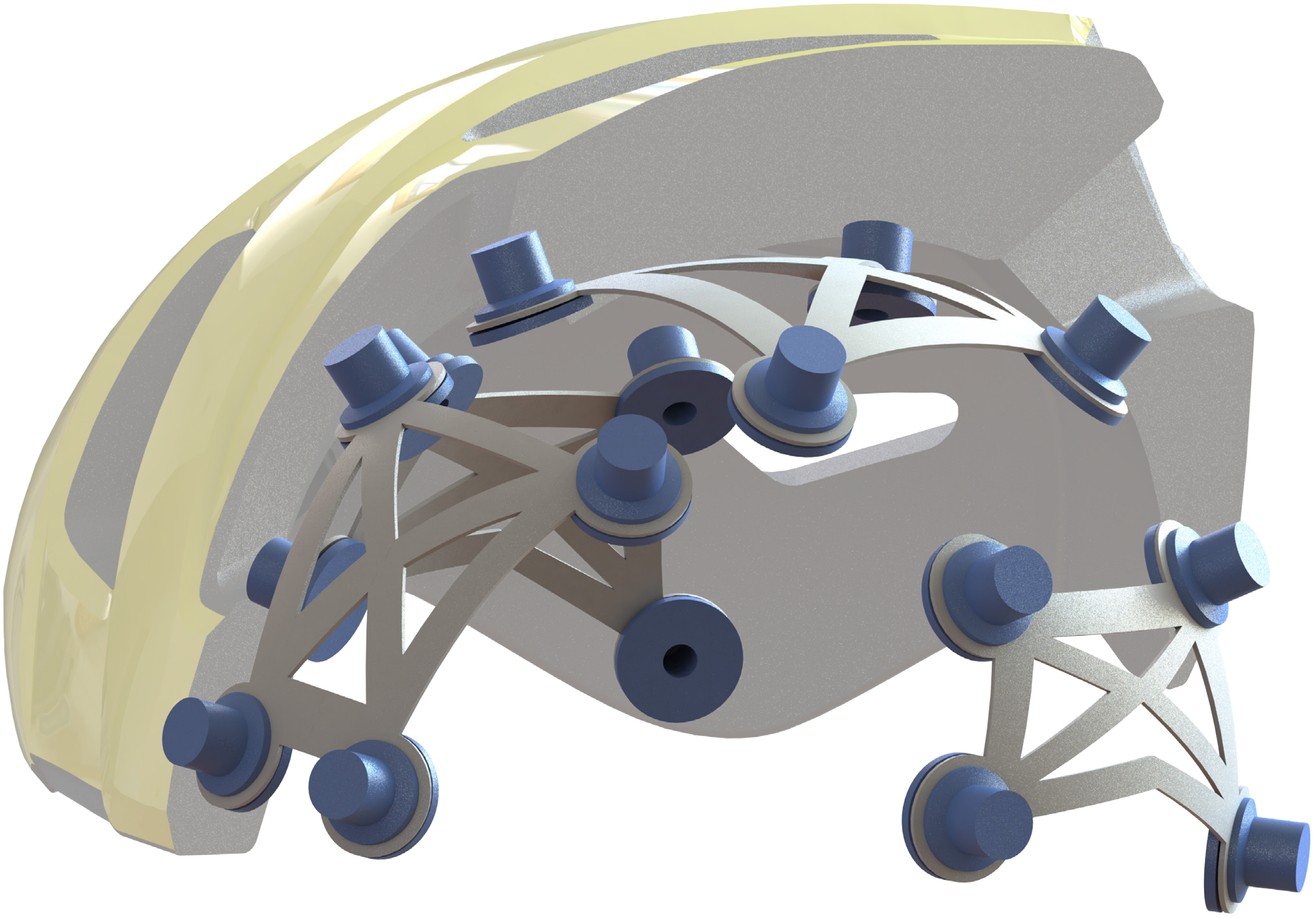


Fig. 4.4.10.: The four different shell parts aimed to absorb as much of the different locations as possible.

Anchors

Current BBB helmets make use of plastic ‘anchors’, which are embedded in the EPS liner using inmolding. At the moment they are being used to attach the retention system, but they can be applied to a variety of use cases.

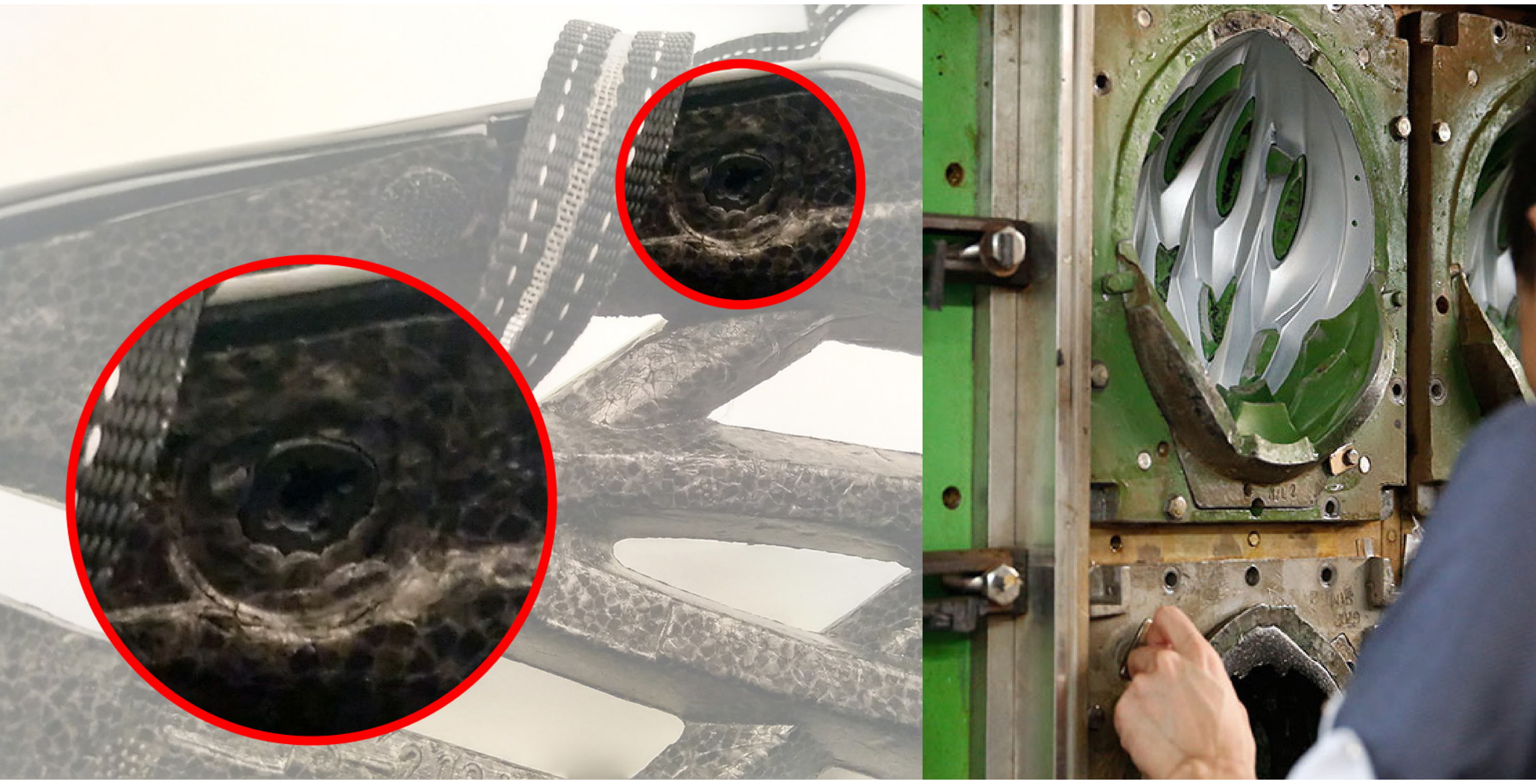
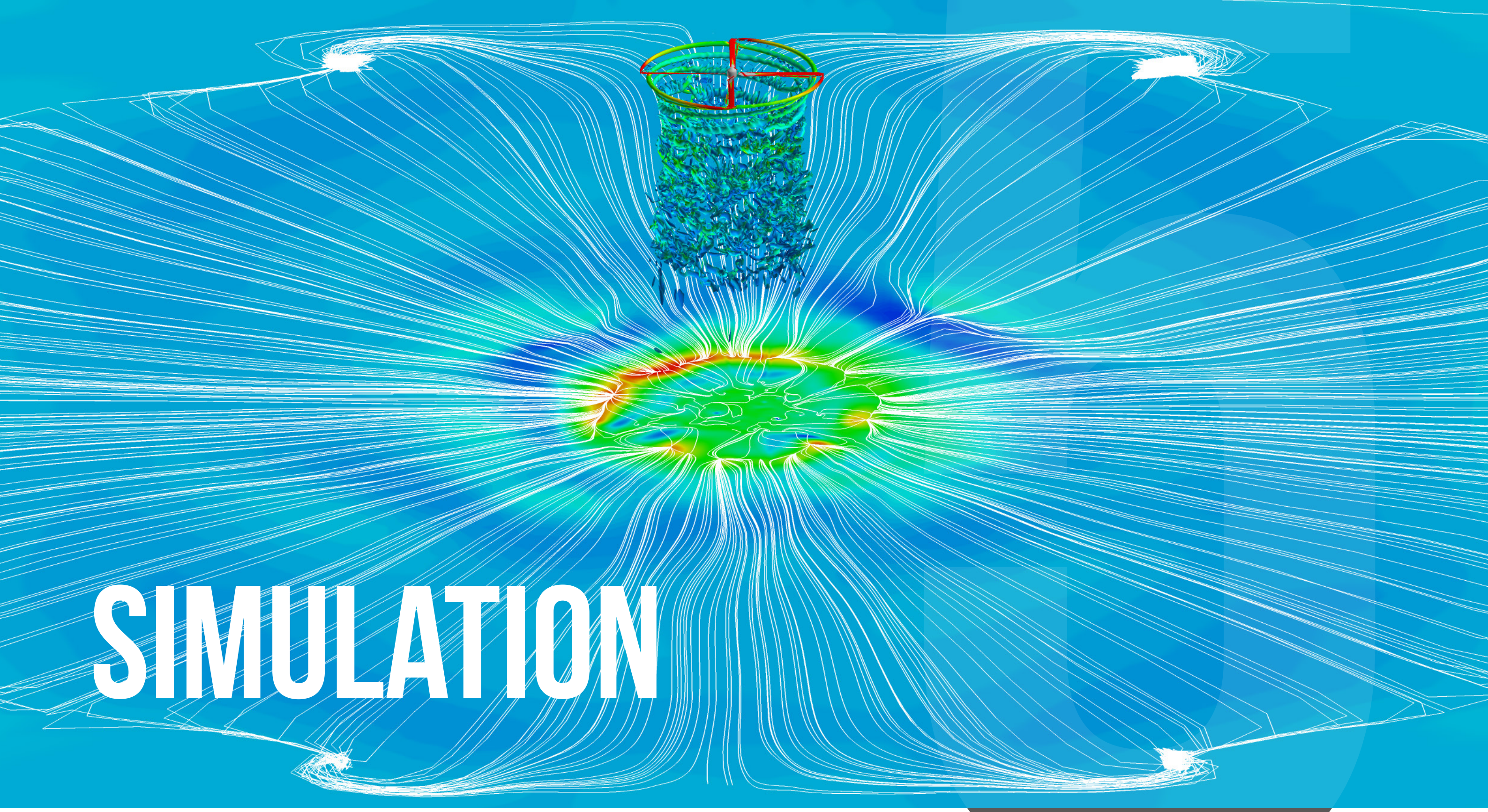


Fig. 4.4.11.: The anchors are inserted before the EPS is injected.

This same technique will be used to anchor the cylinders to the EPS liner. The little nail will be inserted via the cylinder, hence the open design at the end.

Conclusions

In the end a impact absorption system is proposed that can be implemented in current helmets, with only slight modifications to the inner EPS mold. The system consists of four separate shell parts, that have impact absorbing units at each of the corners. Low speed impact linear accelerations will be absorbed by compression of these units. Angular accelerations as a result of oblique impacts will be absorbed by shearing of the units. To get a first impression of the real world effectiveness of the design, rudimentary prototypes were made and tested. This will be covered in the next chapter, ‘Simulation’.



SIMULATION

Introduction

In order to evaluate the design, several prototypes were made. These prototypes were not fully fledged implementations of the system inside an existing helmet, but rather only the working parts placed in a flat orientation. Even though one design direction was chosen after completing the synthesis phase, several iterations of the impact absorbing units were designed and prototyped. To elaborate: three different designs or shapes were created and of one of those, one other version was made that differed in the wall thickness. The different shapes would give more information about the consequences of the design on the impact properties, while the change in thickness of one design would give insight in tweaking the specific properties of this design.

The prototypes were made by 3D printing three piece molds, which were then injected with silicone. The impact absorbing units were then placed in a PC shell part of around 2mm thick and then nailed to a piece of plywood.

5.1. Prototyping

Initial prototyping

Design A
The first design is the initial one, outlined in the synthesis phase. It can be best described by the shape of a hollow cylinder.

Design A was also altered by changing the wall thickness.

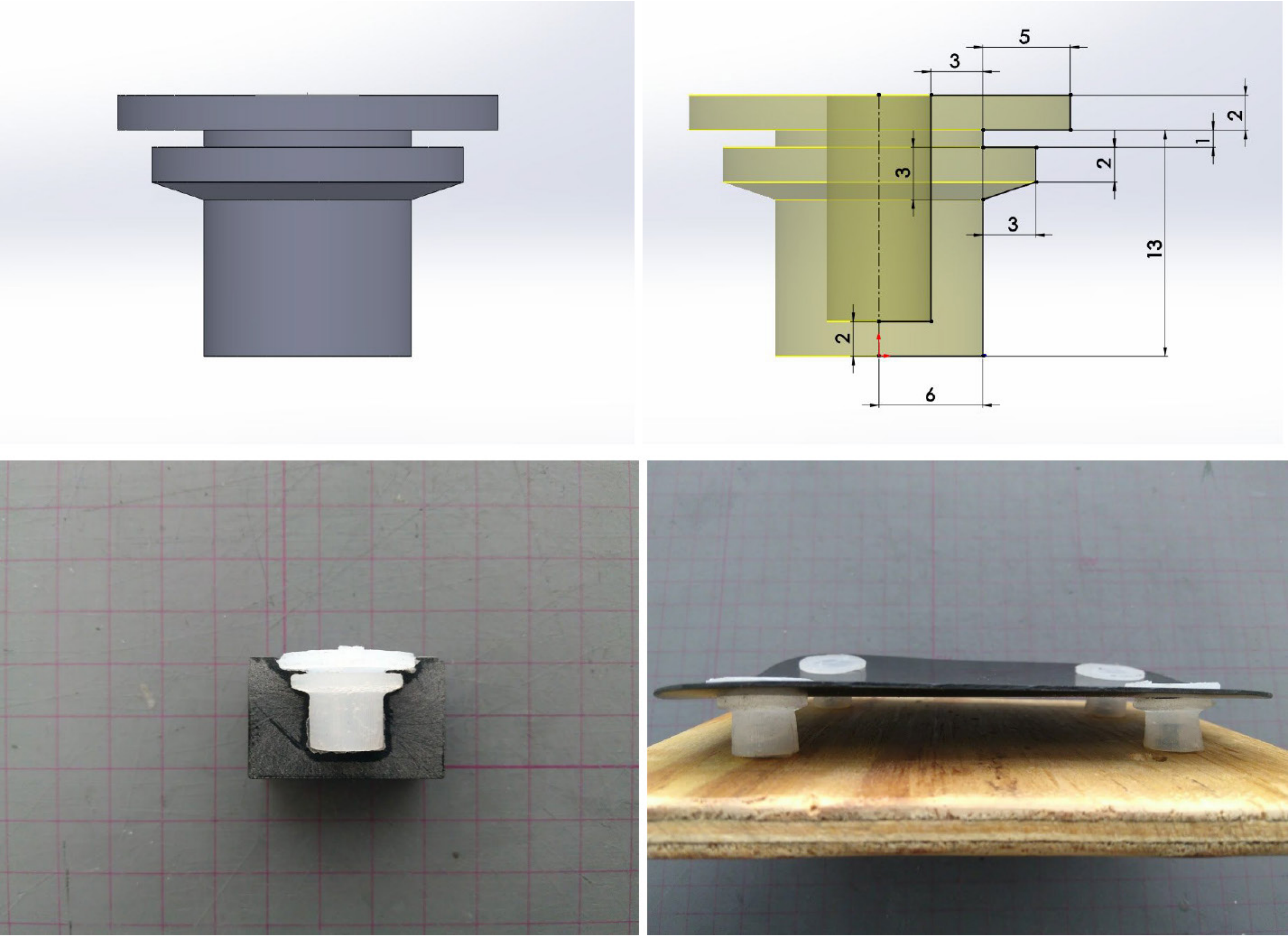


Fig. 5.1.1.: Prototype A, the design, dimensions, mold and assembly. Dimensions are in mm.

Design B
The second prototype revolved around the idea of more dome like shape.

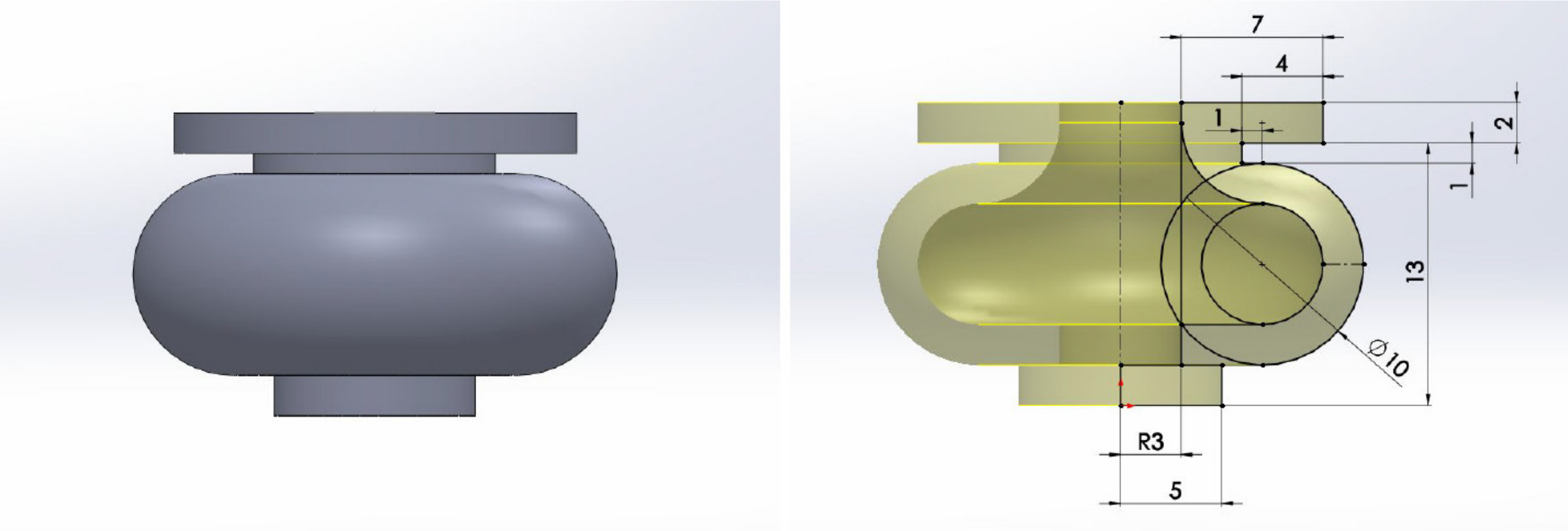


Fig. 5.1.2.: Prototype B, the design, dimensions, mold and assembly. Dimensions are in mm.

Design C
The third and final design could be described as kind of a combination between the previous two. It has a mushroom like shape, having both a cylindrical part as well as a dome shaped one.

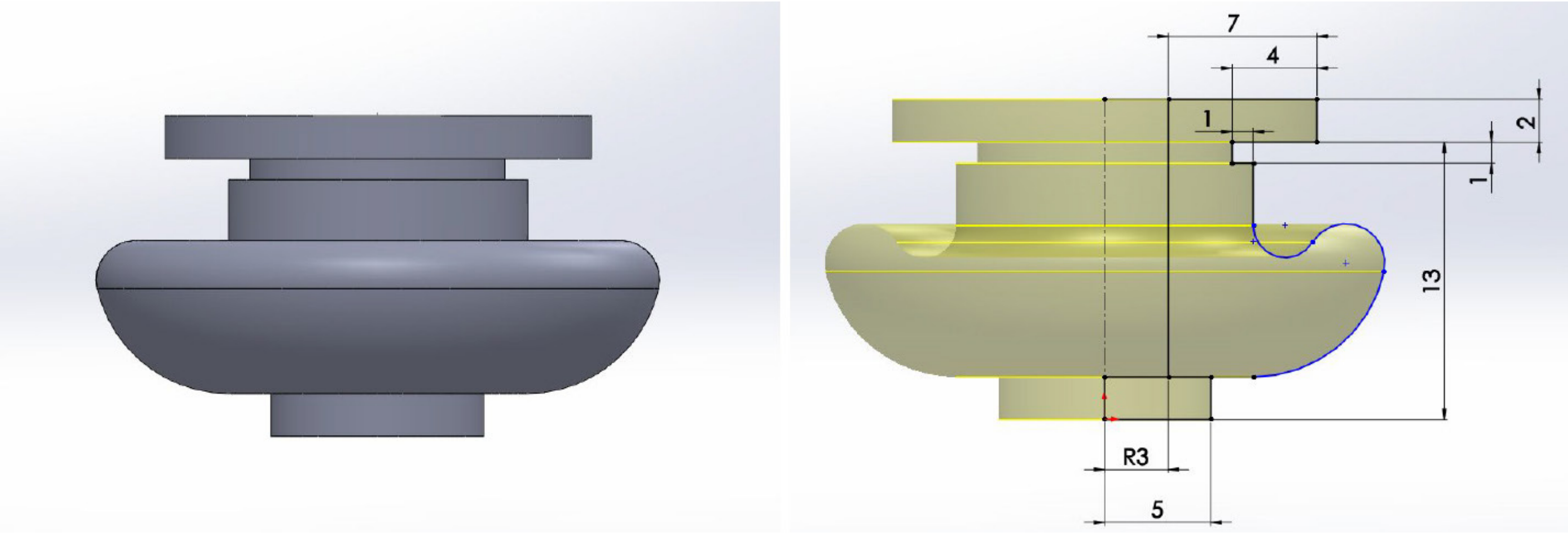


Fig. 5.1.3.: Prototype C, the design, dimensions, mold and assembly. Dimensions are in mm.

Final prototype testing

A prototype of the design was implemented in an actual helmet, which will be used to perform drop tests. More on this in the ‘Evaluation’ chapter.

Fig. 5.1.4.: Full size working prototype.

Conclusions

Variations of the chosen concept were made as a way to further develop and evaluate the concept. This included three different designs in terms of shape and one design with a different wall thickness. These different designs were then evaluated and compared to existing solution, which can be read in the next chapter, ‘Evaluation’. After choosing the most promising design based on initial testing, a fully working prototype was made. This will be used in drop tests to evaluate the actual effectiveness of the design.

6

EVALUATION

Introduction

To get an idea of the effectiveness of the design, it has to be evaluated. Evaluating the design ought to be done in three ways. To get a proper sense of the angular acceleration absorbing capabilities of the final design and in order to compare it to the competition such as MIPS, it has to be tested in a fully fledged helmet during an oblique impact test, the one popularized by MIPS AB. Then and only then, conclusions can be made on the scale of the angular accelerations and can these values be compared to for example the MIPS system. But this is the very final step, and before this can be done, more rudimentary tests of the initial design have to be made in order to check the order of magnitude and to give the design further direction. Hence the fabrication of the prototypes as shown in the previous ‘Simulation’ chapter.

On top of that, the low speed impact capabilities have to be tested. Since there currently are no commercial helmets that actively advertise their low speed protection, there is no system that can be used as a benchmark or to which the design can be compared. Further, unlike the oblique impact test setup developed by MIPS AB, there is a standard to quantify low speed impact accelerations. Regular linear impact test setups like the one used for the EN1078 norm can be used, albeit at a lower height (lowering the impact speed). This is what was done during the low speed impact testing of current helmets during this project (see chapter ‘Analysis’).

Secondly, a fully working prototype is made with accompanying drop test, based on the one used by TASS International. This will be the bridging step between the rudimentary testing and the professional type of testing, later down the road. The two types of testing shall now be further detailed.

6.1. Initial and final testing

Initial testing

To get a sense of scale regarding the current design when it comes to angular accelerations, it is opted to compare it to more established and quantified systems. In this case that is MIPS, the system that aims to reduce angular accelerations. The reason MIPS has been chosen as a benchmark is because they have been an established party in the oblique impact protection field, with years of constant development. This has consequently lead to a large amount of (independent) impact testing, making MIPS the most suited system to function as a comparison.

The elastomers in the MIPS system are set as the benchmark of the evaluation. MIPS uses four of these stretchable little bands, placed in a square like orientation.

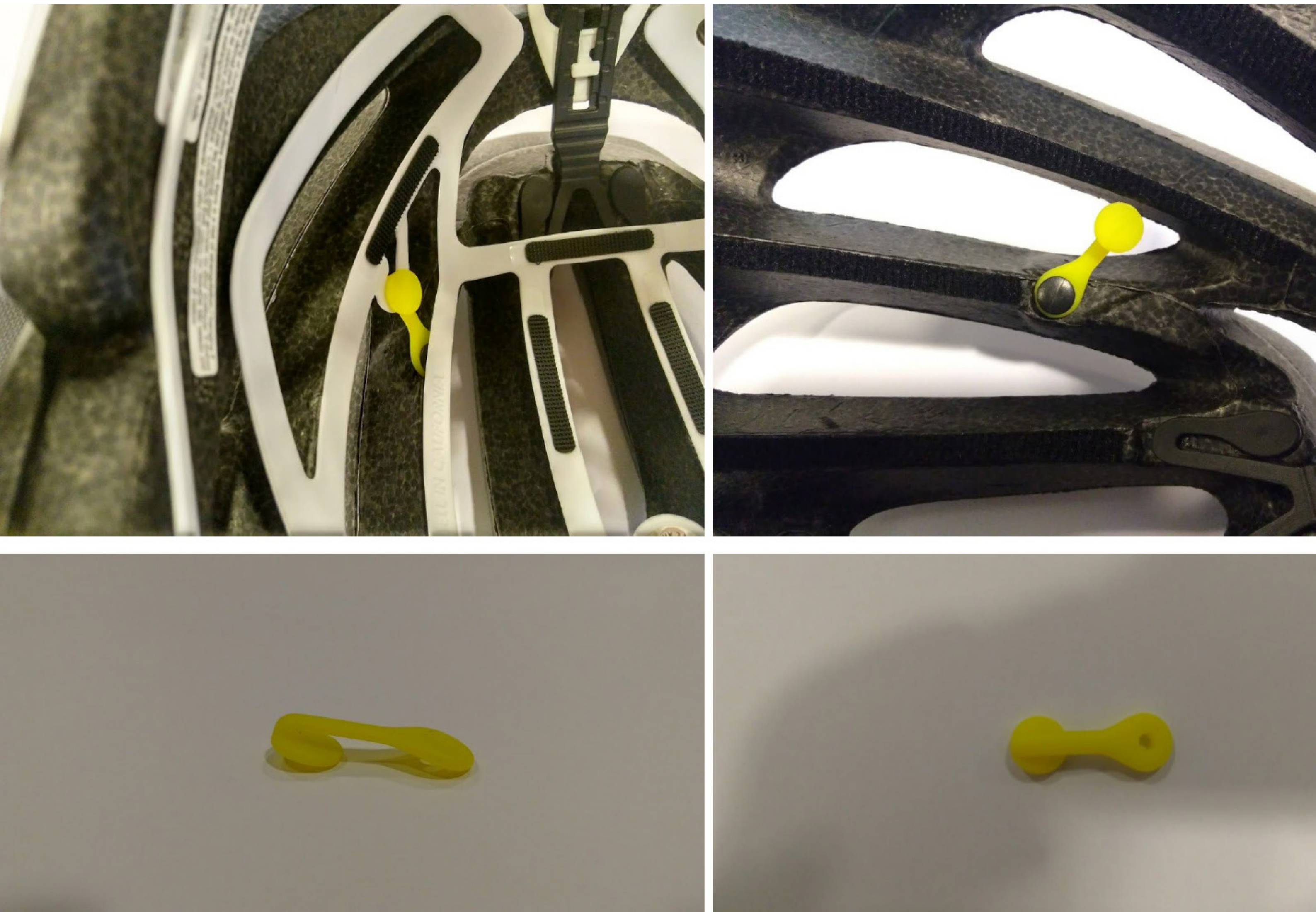


Fig. 6.1.1.: The energy absorbing part of MIPS: four elastomers orientated in a square.

When absorbing angular accelerations, two of the four elastomers are in use. This can be illustrated by the following image where MIPS is moving in the direction from down to up:

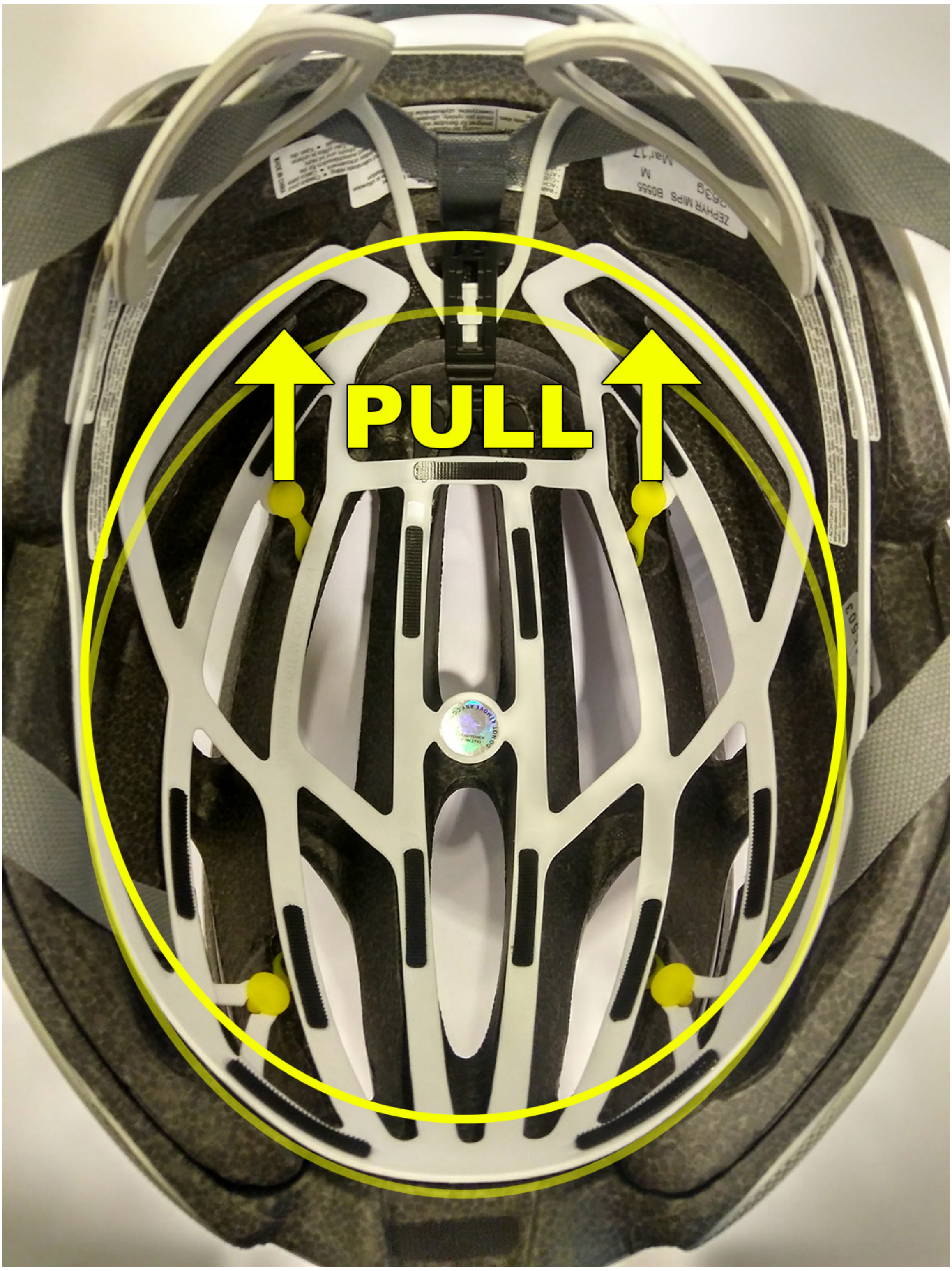


Fig. 6.1.2.: The MIPS system as it is moving during an oblique impact and pulls two of the four elastomers.

Quantifying

While it is true that this project revolves around occurring accelerations during impacts, quantifying these in an accurate and non-time consuming matter is unfortunately outside the scope of this project. Therefor, to get a first impression of the energy absorbing properties of the design and to make an effort to quantify this, force and stretch will be measured during this step of the evaluation.

MIPS elastomer
One MIPS elastomer is separated from the system and the stretch is measured while pulling at it with the force of 10N (using a force meter to measure).

As can be seen in the image above, the MIPS elastomer stretches around 14mm when pulled at with 10N. As explained earlier, when absorbing accelerations, two of the four elastomers are in use. This means that it takes twice the amount of force, or 20N, to move the MIPS system 14mm. Take note that in this testing, the friction between the MIPS shell part and the inside of the helmet is neglected. This justified by the fact that there is a ‘low friction layer’ in between, which provides a very smooth motion between the MIPS shell and the EPS.

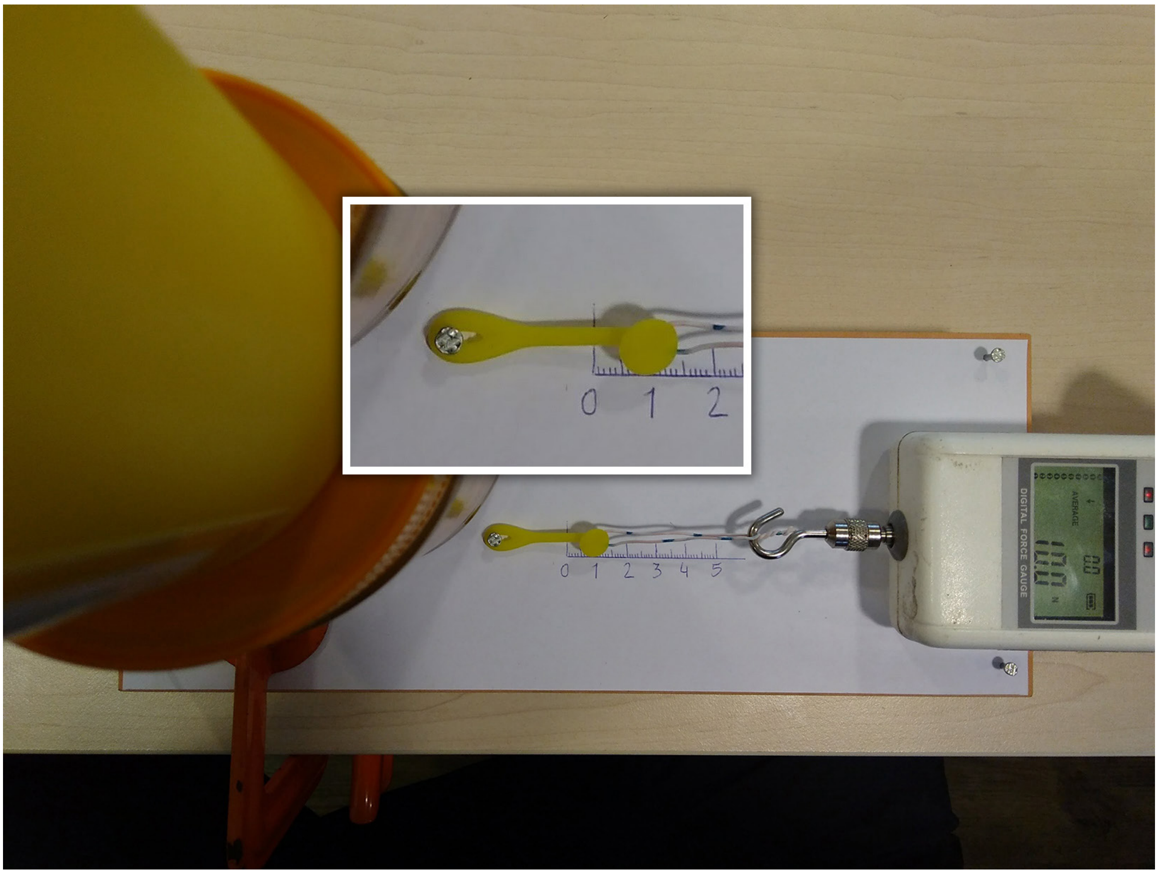


Fig. 6.1.3.: Measuring the amount of stretch of the MIPS elastomer while exercising 10N of force.

First prototype testing

Oblique impact

As the benchmark is now set, the prototypes can be tested. Given that the measured movement of the MIPS system is measured while using 20N of force, this same amount will be used when testing the prototypes.

Test setup

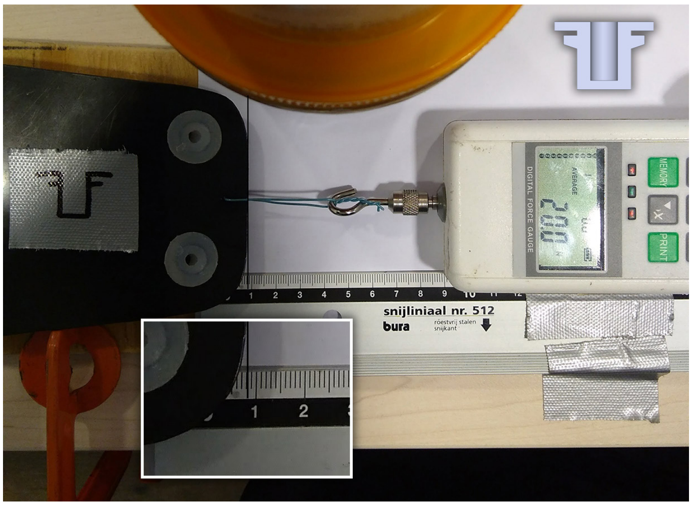


Fig. 6.1.4.: Measuring the amount of stretch of prototype A while exercising 20N of force.

Low speed impact

It was also attempted to quantify the low speed impact properties of the different concepts. As MIPS does not have any low speed impact absorption capabilities - it only claims to reduce angular accelerations - a direct comparison could not be made. A force of around 50N was used, based on the human head weighing around 5kg on average.

Test setup

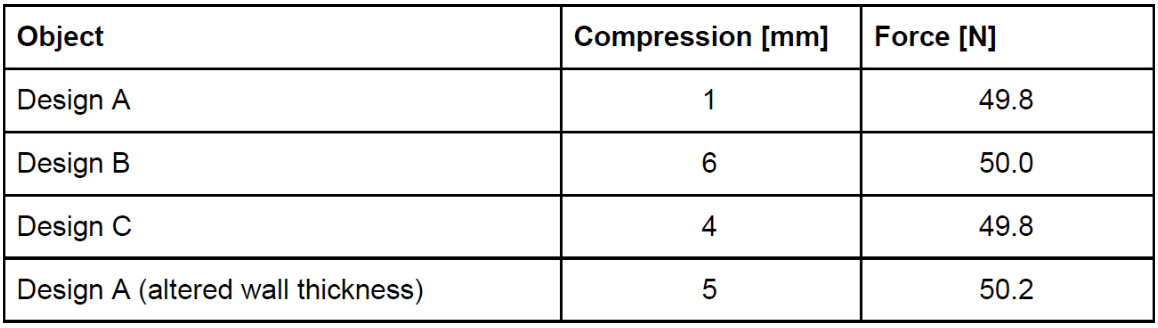
Fig. 6.1.6.: Measuring the amount of compression of prototype A while exercising 49.8N of force.

An overview of the different prototypes and how much they stretch when pulled at with a force of 20N:

Object	Stretch [mm]	Force [N]
MIPS elastomer	14	20
Design A	8	20
Design B	15	20
Design C	10	20
Design A (altered wall thickness)	12	20

Fig. 6.1.5.: A table showing all different prototypes and the amount of stretch when pulled at with 20N, including the MIPS elastomer.

An overview of the different prototypes and how much they stretch when pulled at with a force of around 50N:



Object	Compression [mm]	Force [N]
Design A	1	49.8
Design B	6	50.0
Design C	4	49.8
Design A (altered wall thickness)	5	50.2

Fig. 6.1.7.: A table showing all different prototypes and the amount of compression when pushed at with around 50N.

Next is an overall table of all the collected data:

Object	Stretch [mm]	Force [N]	Compression [mm]	Force [N]
MIPS elastomer	14	20	n/a	n/a
Design A	8	20	1	49.8
Design B	15	20	6	50.0
Design C	10	20	4	49.8
Design A (altered wall thickness)	12	20	5	50.2

Fig. 6.1.8.: A table showing the test results of all prototypes including the MIPS elastomer, on both stretch and compression.

Stretch compression relation

Although stretch and compression of the impact units were measured and evaluated separately, it has mentioned that these have a direct relation with each other. That is to say, the impact units have both stretching capabilities, as well as compression capabilities. These are linked however, meaning you naturally cannot pick the two most favorable numbers from the table above.

Final prototype testing

After the initial prototype testing, it is now time for the next step in the validation process. This time the aim is to come closer to the actual impact tests, done by certified institutes. Therefore a drop setup is made, in which a full size helmet with the final design implemented will be tested. The drop setup is heavily inspired by the one used at TASS International (used for the low speed impact tests).

Drop setup

The height of the drop is set so the helmet (with head form of 5kg) will hit the anvil with (what is considered in this project) low speed impact velocity, meaning 3.0m/s.
Both low speed and oblique impacts will be tested, both at low speed impact velocity. The angle of the anvil for the oblique impact is set to 45 degrees.
To evaluate the effectiveness of the design, the same tests will be done with the same model helmet (size L), the control, and the prototype.
The impacts will be recorded with a high speed camera, after which tracking software will be used to get data on position, velocity and acceleration.

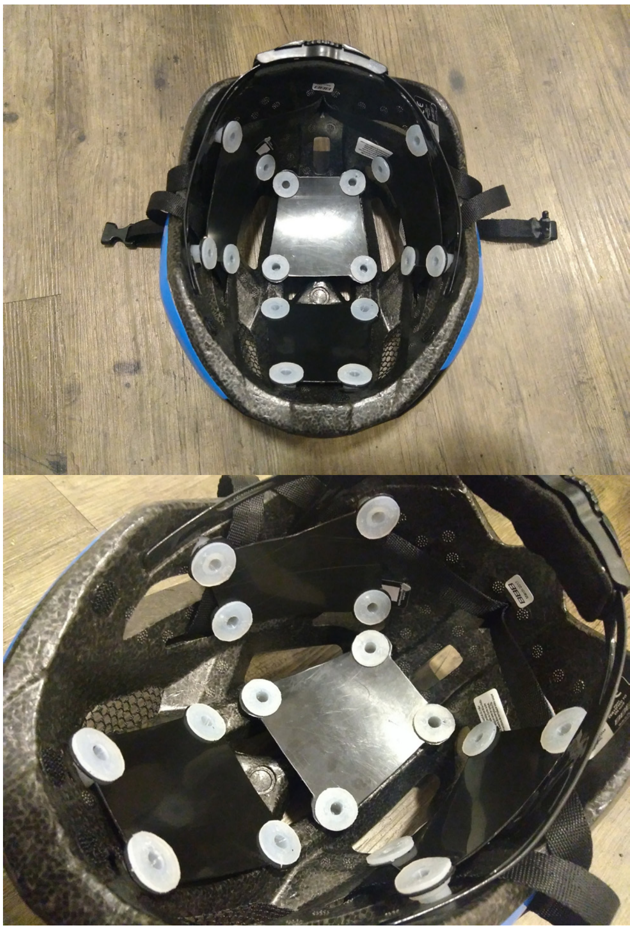


Fig. 6.1.9.: Full size working prototype.

Fig. 6.1.10.: Inspiration for the drop test; a professional drop test setup from TASS International.

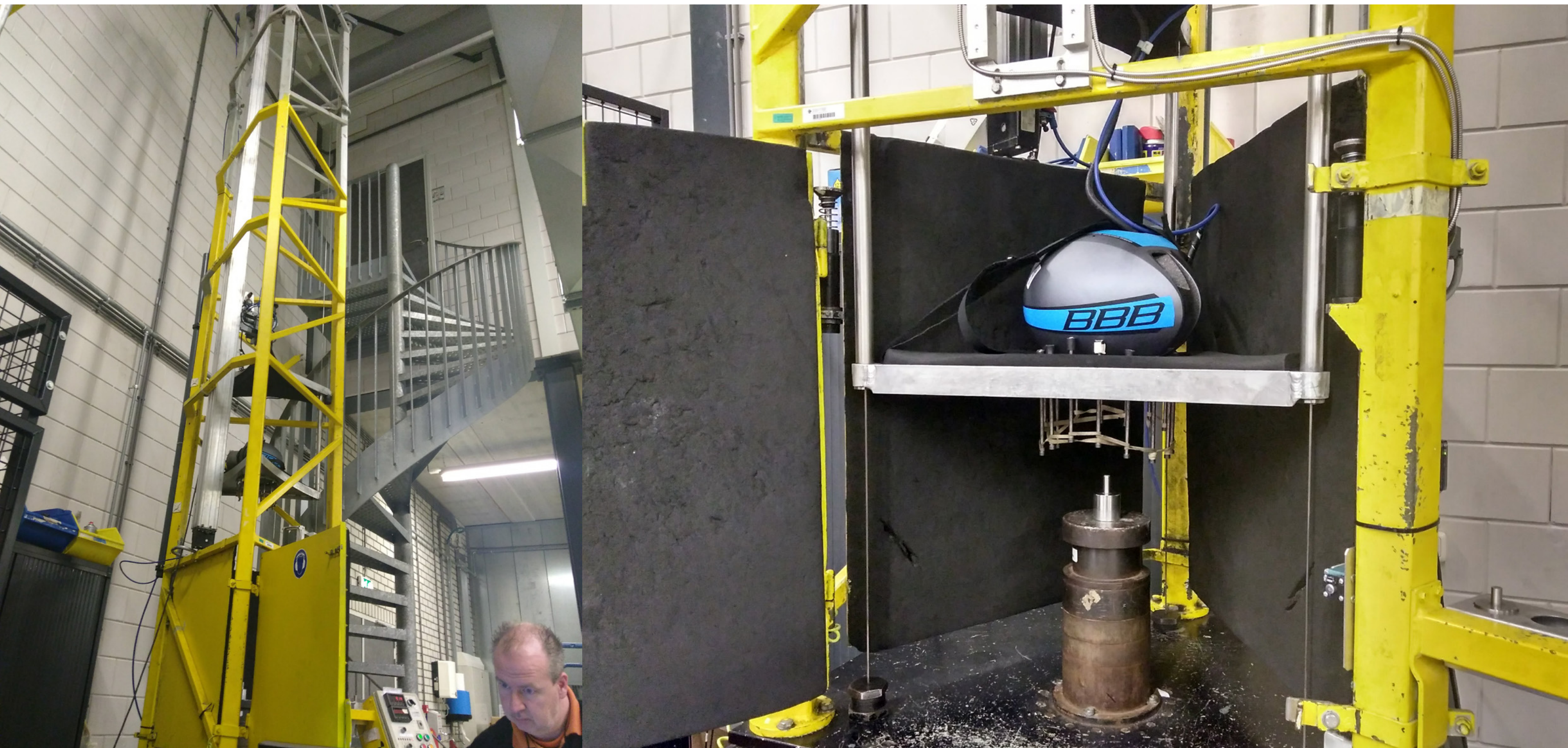


Fig. 6.1.11.: Fabricated drop setup with the 45 degrees anvil installed.

Results

Because the footage was captured with a high speed camera, the values given after tracking the helmet are off. The high speed camera captures video at 1000 fps, meaning everything slows down roughly 40 times (regular videos are mostly 25 fps). Therefore the absolute numbers should not take center stage; what is more important is the percentage difference (for example, a 20% lower number means 20% lower accelerations).

The results of the impact tests will be divided in two parts: drops on the flat anvil and drops on the 45 degree anvil. First the control helmet followed by the prototype helmet on the flat anvil will be shown.

Flat anvil

Control helmet on flat anvil:

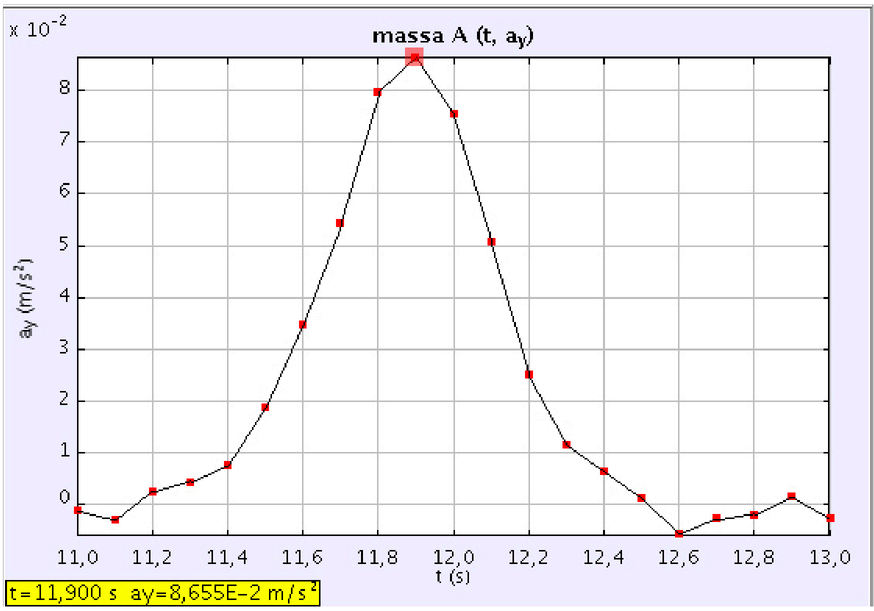


Fig. 6.1.12.: Results from the control helmet on the flat anvil.

Prototype helmet on flat anvil:

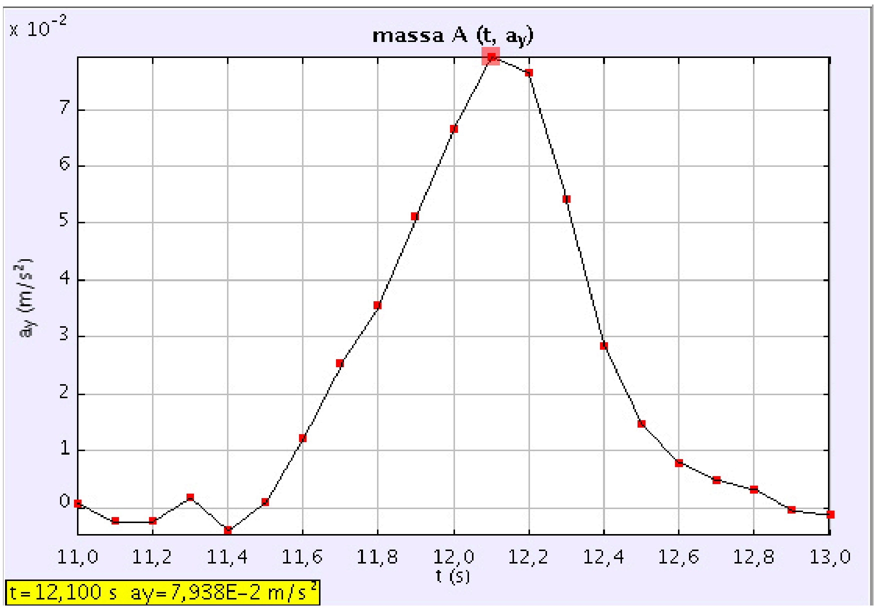


Fig. 6.1.13.: Results from the prototype helmet on the flat anvil.

45 degree anvil
Now the control helmet followed by the prototype helmet on the 45 degree angle.

Control helmet on 45 degree anvil:

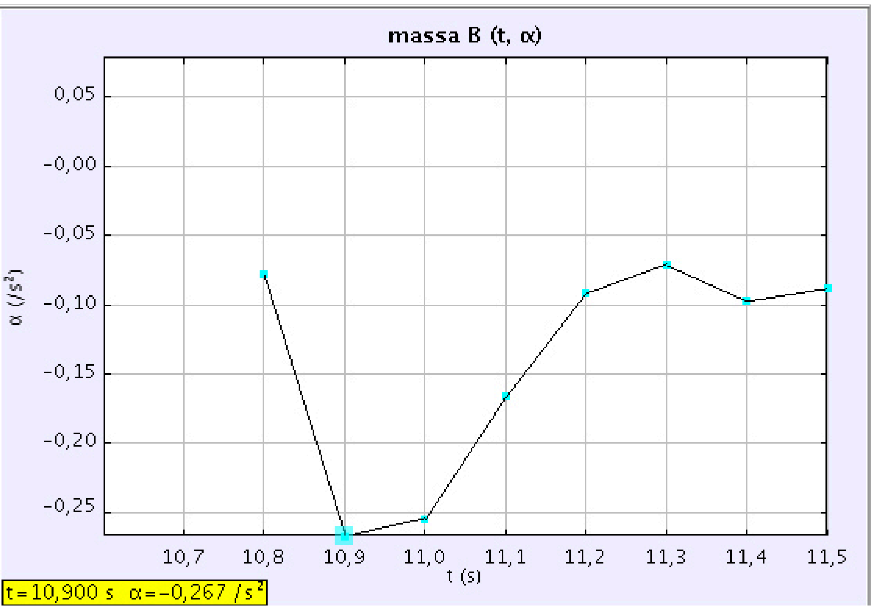


Fig. 6.1.14.: Results from the control helmet on the 45 degree anvil.

Prototype helmet on 45 degree anvil:

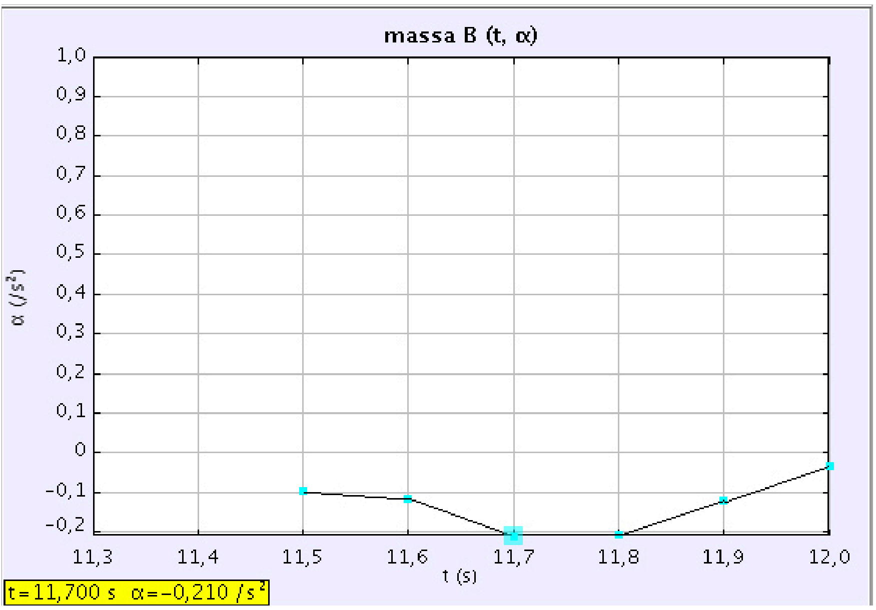


Fig. 6.1.15.: Results from the prototype helmet on the 45 degree anvil.

Conclusion testing

Initial testing
Looking at the results of the testing, design A (with the altered wall thickness) of the cylinders seems to resemble the stretching capabilities of the MIPS elastomers the most, leading to believe they will have similar oblique impact absorption capabilities. Because the units have both stretch as well as compression properties, this means the low speed impact absorption capabilities are also defined.

Final prototype testing
The control helmet shows a linear acceleration value of 8.66 versus that of the prototype of 7.94. This means the prototype shows a reduction of around 8.3%. When it comes to angular accelerations, the control helmet shows a value of 0.27 versus that of the prototype of 0.21. This means the prototype shows a reduction of around 22.2%.

6.2. Recommendations

Final testing
Because there are various testing methods and equipment used to test different sorts of impacts, it is important to choose one which will be used to validate the final concept. After all, the effectiveness of the design can only be compared to other products when they are measured in the same way, eliminating all other variables. The helmet impact testing standards have not yet caught up with the discovery of the implications of angular accelerations during an oblique impact. As a result there is currently no independent way of testing this, and validation therefore has to rely on the testing method developed by MIPS AB.
BBB's helmet manufacturer has recently invested in expanding their helmet testing capabilities. Besides the linear impact testing they already did to verify BBB's helmet design and their manufacturing,

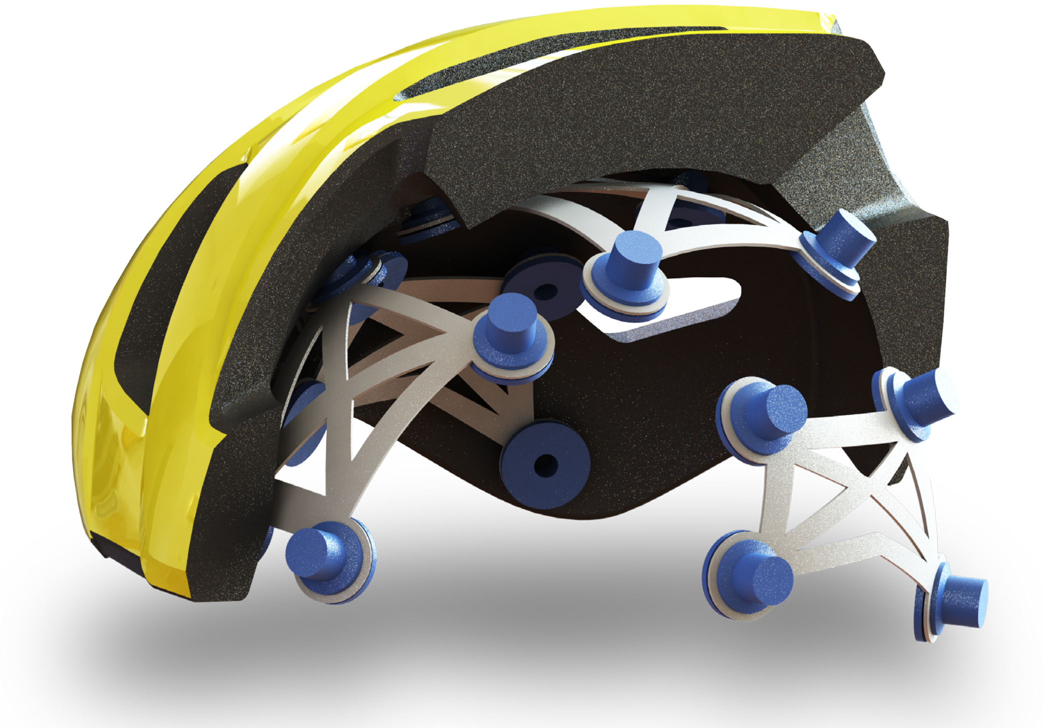
their latest addition is a setup to test angular accelerations. The way they test oblique impact is similar to how MIPS does it, by dropping the head form on an angled surface.
In the event of testing a full size EPS helmet with a prototype of the final design implemented, the MIPS AB oblique impact test setup should be used to evaluate the size of the angular accelerations.

Manufacturing
The final design recesses the cylinders by having round holes in the EPS, perpendicular to inside shape of the helmet. This makes manufacturing harder and more expensive, because the shape of the helmet is no longer a two part mold. A solution to this problem could be the use of sliders, as is done regularly with other helmet designs, but with sixteen cylinders, this could get costly very fast.

Prototype testing
The final prototype testing was done on a setup made from wood, with room for a lot of inaccuracies. Also because helmets can only be impacted once, the test data relies on few samples. This combined means the percentages in accelerations reductions should be taken as an estimates.

Final conclusions

In the end, a design has been made that can be implemented in regular helmets to reduce low speed linear accelerations and angular accelerations as a result of oblique impacts. The result is a continuation of the earlier AED project, which is a step forward in both design and testing. To really get confident in the design, a more accurate full prototype has to be made, tested in a professional oblique impact test setup. The regular linear test setup can be used to test low speed linear accelerations, albeit dropping the helmets from a lower height.
To really push the safety aspects of helmets further, regulations should be updated to include oblique impacts. This will also hopefully open up the door for wider consumer acceptance of bigger helmets (as was inescapable also in this project), as it becomes a more important aspect of helmet design. Hopefully the market will see more and more competition, by companies striving to create the safest bicycle helmet they can imagine.



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