RESPIRE-F

COOLING VEST FOR THE FEMALE SOLDIER

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Performance:
The term Human Performance relates to the physical, mental, cognitive and perceptual performance.

In the military context this relates to the physical and cognitive capabilities and limitations of soldiers and how operations are executed safely and effectively.

RESPIRE-F

COOLING VEST FOR THE FEMALE SOLDIER

Adapting the current design of the ReSpire cooling vest so that the vest has a good fit for the female soldier in combination with the existing personal equipment.

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MSc. Graduation Thesis
June, 2022

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NOTE ON CONFIDENTIALITY:

As this Thesis was part of the Project ReSpire at TNO in collaboration with INUTEQ, not all developments in the design were ready to be published. Hence, in the thesis some illustrations and parts of illustrations are blurred. For the supervisory team a confidential appendix was made containing the confidential illustrations that support the project.

PREFACE

When checking the project opportunities on the webpage of graduation support, I came across the proposal from TNO to work on the female version of the ReSpire cooling vest as an intern in Soesterberg.

This project required me to quickly delve into the science of physiological processes and anthropometry of the human body and to understand how to improve performance of a female soldier. Some of the activities requested a lot of dedication from me and the experience has enriched my personal development. Therefore I would like to thank the ReSpire team at TNO for the necessary explanations and consult. In particular, I would like to thank Milène Catoire for giving me this opportunity to work on this project and with this team.

For the supervision during this project, I would also like to thank Henk Kuipers for critically assessing my work and stimulating suggestions for elaborating the thesis. Toon, I would like to thank you for your support in inspiring and devising the methodologies, execution and elaboration of the research activities in this project. Also I would like to thank Erlynne Bakker from INUTEQ and Laura Ahsmann for the attention and advice they gave me. Thanks to your expertise and insight, I was able to progress in the development of this project and learn more about how I could develop myself.

Thanks again to TNO and its people for involving me in the organization and to participate in various activities. It was truly inspiring and I am grateful for meeting the admirable people that contribute to Innovation for life

ABSTRACT

This thesis is about the adaptation of the design of the ReSpire cooling vest for female soldiers for in a military operational context. For cooling, the principle of ventilation by air and evaporation of sweat was used to extract heat from the body. The objective of this project was to design a version of the cooling vest which would fit the female soldier and provide an effective level of cooling.

In the recent past, incidents have occurred in the Defense Department where soldiers have been affected by heat stress and have suffered severe consequences, even fatalities. As a result, research has been initiated to find a way to cool soldiers during the performance of their operational tasks. It was determined that by means of a cooling vest that can be worn under the ballistic protection, the soldier can be cooled effectively and appropriately within the requirements of the equipment.
With the Ministry of Defense's intention to recruit more women into the various branches of the military, the need has come to make the cooling vest suitable for use by female military personnel.

Due to physiological differences between men and women, the design had to be changed to ensure that airflow would be effectively directed across the body. This was primarily due to the difference in regional sweat distribution, as evaporation of liquid sweat is necessary to achieve the required cooling capacity.

To create an appropriate fit for the shells, the physical differences between men and women were examined, as well as the body shape variation among women. Also, what and how in previous research has been determined what causes discomfort with equipment in female military personnel. In addition, a virtual anthropometric model was developed. In addition, a virtual anthropometric model was developed to determine the appropriate dimensions and shape for the shells.

From these findings, a design vision has been dictated with a schedule of requirements for how the final design could fit, but also provide sufficient and effective ventilation.

In the ideation phase, inspiration was drawn from the sports apparel industry how to design for shape variation and what appropriate principles would be for the ReSpire-F design. For various aspects of the shells, it has been identified what possible adjustments could be made and how these could be merged into workable solutions. These are clustered and formed into concepts, which are then weighed. Physical prototypes were made of the selected ideas, which could be tested for airflow distribution and wearing comfort. To assess wearing comfort, tests were performed on mobility and perceived discomfort, which was determined by means of the Locally Perceived Discomfort scale.

From the observations and results of this test, a chest shell design has been selected that should be suitable for different female military personnel, because it takes into account the deformation of the body under pressure and encloses the shape in the circumferential direction.

For further development, the design allows for optimisation of the configuration of the airducts, in order to improve the effective distribution. It was determined that minor changes in the positioning and orientation of the partition walls would not be noticeable by the user, so widening of the openings of the ducts or narrowing at the middle can be done to improve the ventilation.

Additional recommendation were made for development of the carrier vest and the sizing system

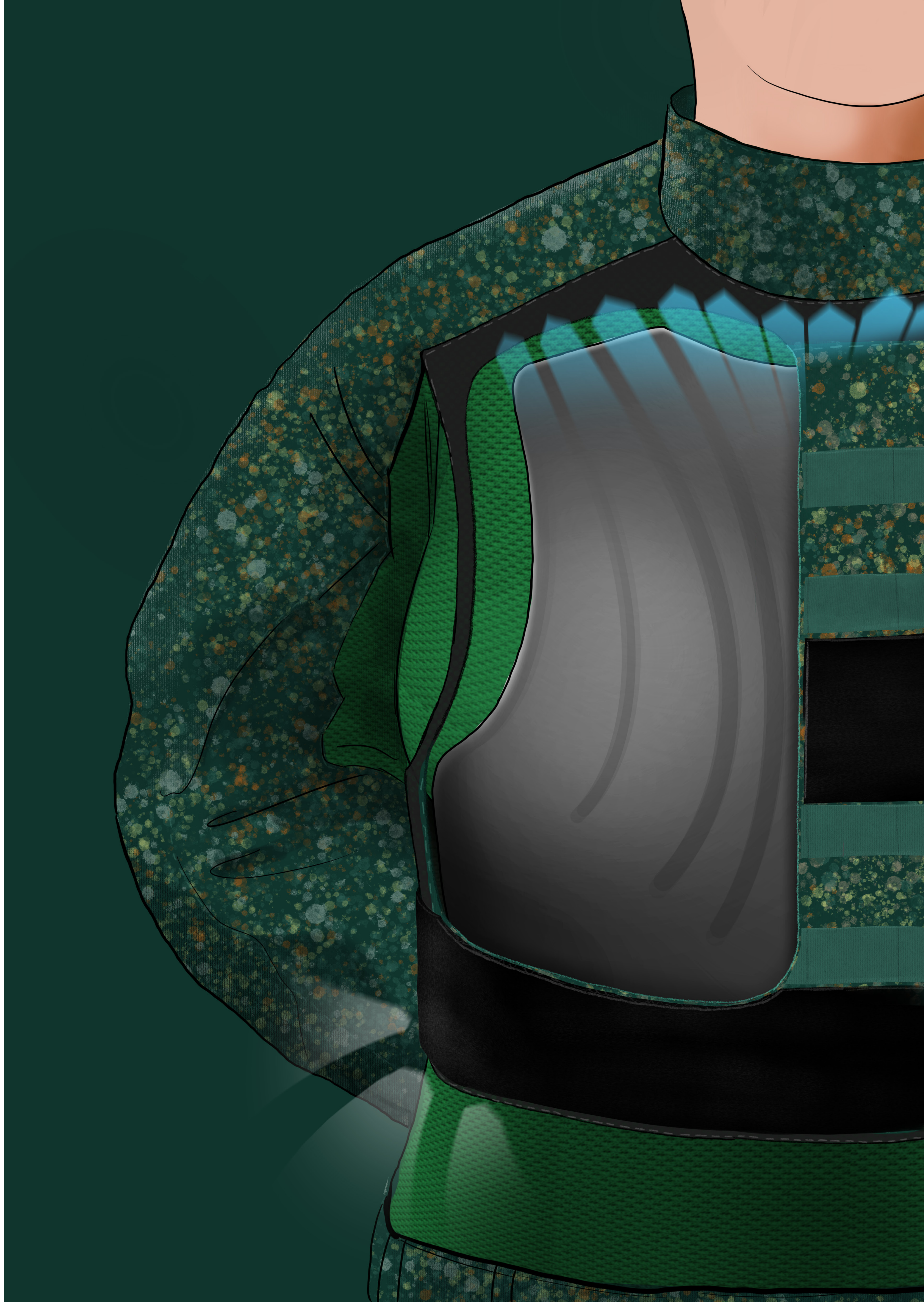


TABLE OF CONTENTS

PROJECT RESPIRE

Regarding the deployment of Dutch military personnel in conditions of high temperature, the question of better equipping soldiers for this purpose has arisen. The fact that the earth's temperature will rise as a result of climate change and the expected locations of deployment of military personnel have been taken into account in the decision-making process. Several climate reports describe the course of the rise in average temperature since 1880 (0.08 degrees Celsius per decade) and with a doubling of that rate since 1981 (0.18 degrees per decade) according to the NOAA National Centers for Environmental Information (2021). In the most favourable scenario, where carbon dioxide emissions in particular are reduced to such an extent, the average temperature is expected to continue rising until 2050 (Dahlman, 2021).

In recent years, there have been a number of incidents in which military personnel have suffered heat injuries (ZEMBLA, 2019) and the Ministry of Defence has published a handbook on heat illness (Van der Made, 2020). The consequences of heat illness are, in addition to reduced deployability, for example, reduced ability to cover long distances and reduced decision-making capacity due to loss of concentration (INUTEQ, 2022) (van der Made, 2021). For the work and conditions in which military personnel are deployed, a loss of performance can make the difference between carrying out an operation successfully or failing with serious consequences.

Therefore TNO is developing a cooling vest for military personnel operating independently of a vehicle or other platform and is designed in a way that the vest integrates with the outfit and gear of the soldier. This project is called the ReSpire project and is performed in cooperation with INUTEQ. The project is carried out on behalf of the Dutch ministery of Defense.

The current design for the cooling vest is developed for male soldiers and are not suitable for female soldiers, as its affects the performance of the female soldier and does not provide enough increase in performance. During the tests, it was found that the fit was too big and wide for the female participant, causing dislocation of the shells in combination with the other pieces of equipment through movement.

This is mainly due to the differences in the shape of the upper body in women compared to men, but to make a suitable vest for women it is necessary to take into account the variability in shape. In addition, physiological differences in women with respect to men need to be assessed, in order to ensure effective cooling capacity.

GLOSSARY

Defence Operational Clothing System (DOKS)	Project by the Ministery of Defence to implement a modern combat clothing.
Improved Operational Soldier System (VOSS)	Modern combat equipment system for the individual soldiers in the Dutch Defence.
Clothing and Personal Equipment Company (KPU-bedrijf)	The KPU-company provides the soldiers their uniform, camouflage suit and shoes, as well as other personal equipment, for instance their sleeping bag, flask, etc.
INUTEQ	The involved commercial partner of the ReSpire project and a producer of personal cooling equipment.
Anthropometry	The science on physical properties of the human body, mostly dimensional descriptors of body size and shape.
Computational Fluid Dynamics (CFD)	The analysis of fluid flows by means of numerical solution methods, mainly as simulations done in computer models.
Computer Aided Design (CAD)	The use of computers to assist in the design of constructions or devices.

PROBLEM STATEMENT & RESEARCH QUESTION

The current design for the cooling vest is developed for male soldiers and is not suitable for female soldiers, as it affects the performance of the female soldier and does not provide enough effective cooling.

During operational user tests with the prototype and military personel, it was found that the fit was too big and wide for the female participant, so it crept up (Linssen et al., 2020). When assuming different positions, for instance in lying position, little cooling was sensed.

In the event that more pressure is exerted on the vest, for example by carrying a backpack with a pack, it was found that the channels provide less airflow, as the body fills them from the inside. This can be a bigger problem for women when carrying lighter loads, assuming the skin is so different to men.

Additional problems with the prototype arose when increasing the carrying load by means of a backpack. Upon further investigation revealed that the airflow was reduced in the channels due to the user's skin entering the channels.

One of the factors in this problem is how supple the skin is and thus how it folds, which is related to properties such as subcutaneous fat, which is present in different degrees between men and women.

RESEARCH QUESTION

HOW CAN THE DESIGN OF THE COOLING VEST BE ADAPTED FOR FEMALE SOLDIERS?

How is the physique of a female soldier different from male soldiers?

How do female soldiers perspire differently than male soldiers?

How are female soldiers different in physique (shape and size) and anatomy (underlying tissue) compared to male soldiers?

How is the cooling vest currently designed?

What is the context in which it will be used?

What are problems with the current design with both males and females?

Which problem specific to females need to be solved?

How does the clothing industry adapt for the female physique?

How does the clothing industry create adjustability?

How does the clothing industry adapt for mobility and comfort?

What does the sports industry adapt gear for the female physique?

How can the design be adapted for female soldiers?

How does the vest need to be shaped to fit female soldiers, in terms of body shape characteristics and composition?

How can effective cooling be ensured?

How can the vest be changed to prevent undesired limitations or nuisance?

PROJECT APPROACH

Prior to starting re-design, the current design will need to be assessed, by examining the prototype and the supporting documentation.

Besides providing an understanding of the methodology of the company TNO, it provides insight in possible challenges and limitations of the design.

An analysis will be made of the physique of the female soldier, about the relative differences to the male soldier and how alteration might me made, which could be implemented in the design phase.

For adaptation solutions and inspiration, how the clothing industry adapts for female physique and mobility issues is something that will be investigated. This includes looking into for instance how modularity is created or mobility is ensured.

Solutions for the various sub-problems will be combined in design concepts that are to be evaluated based on criteria related to the research done in first phases as well as the requirements set for the cooling vest to be implemented. These concepts will subsequently be prototyped and assessed in mechanical performance as well as human research test, to acquire insight in how different designs are experienced.

The objective is to work out different designs based on theory to improve the physiological process of cooling and how this can be implemented in a manner that also ergonomically suits the female subject better.

From evaluating these a final design can be constructed in a closely developed prototype and tested more thoroughly. Recommendations will be made on how to further test, evaluate and develop the design.

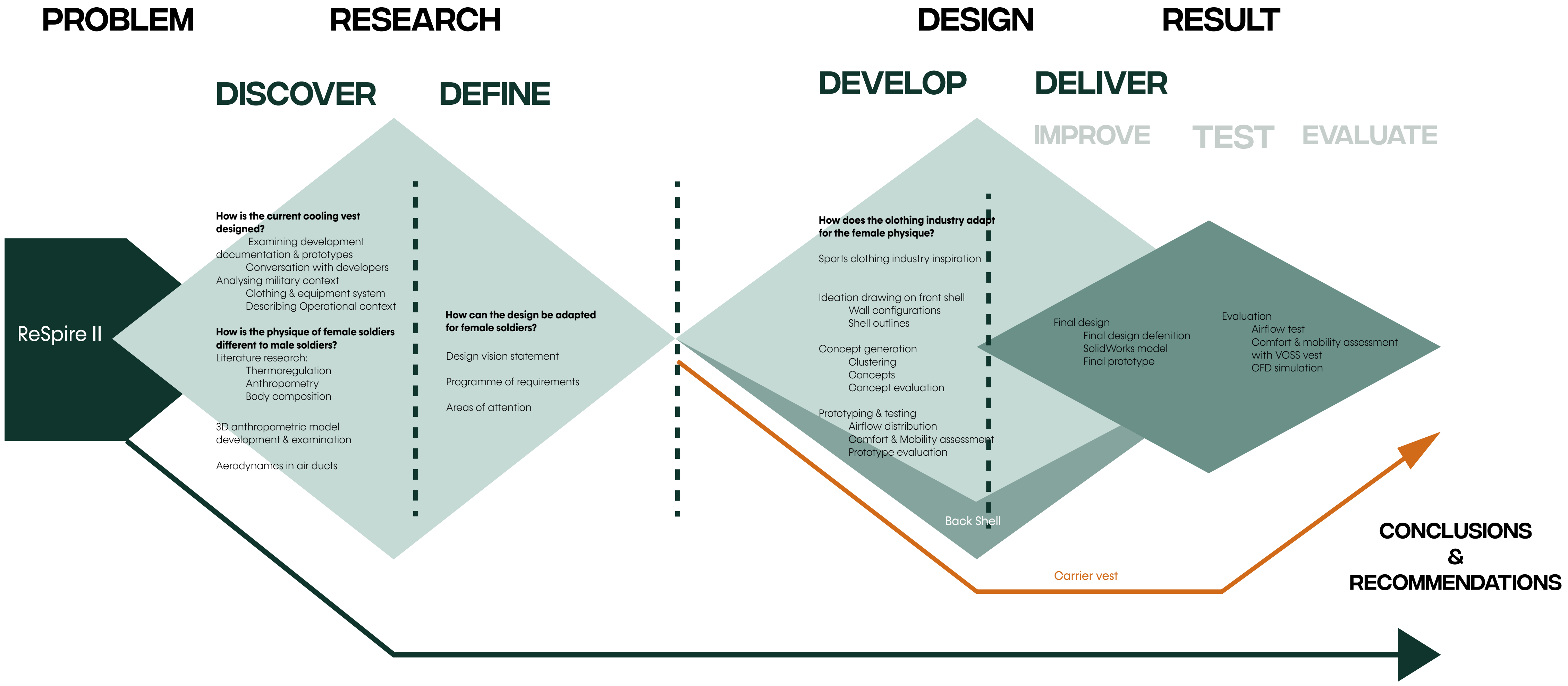


Fig. 1: Project process

EMPLOYMENT AS GRADUATION INTERN AT TNO

One of my motivations for doing this project was to be able to work as an intern at TNO and gain experience. I also wanted to work a lot on location in Soesterberg, to get to know the organisation and its employees.

With this graduation project I was involved in the team active on the ReSpire project, with members from various academic backgrounds and work experiences. All activities during this project I had to execute on my own, however for advice and knowledge I was able to consult specialists in thermophysiology, human movement science and health sciences. Working in a team of members with different expertise is something I would need to have experience in as an industrial design engineer, so therefore this collaboration was valuable in my personal development.

During this period, I also became involved in other activities at TNO, particularly as a participant in other researchers' experiments and projects. Since TNO is a large research organisation, all these tests were very diverse, and I picked up experience in setting up and carrying out tests with human subjects.

Another way I got involved was assisting with the field tests on the Vlasakkers. For these tests, I learned what preparation was required, how the set-up was determined and how this was actually carried out with soldiers. Since TNO DSS has a long history of collaborating with the Ministry of Defence on research, this was an excellent opportunity for me to gain experience in the defence domain.

Simultaneously other interns were also working at TNO and we were urged to get to know each other's work and learn from shared experience to improve our own work. For me this was especially helpful as it helped reflecting on my experience as intern at TNO.

Fig. 2: Assisting during the field tests at the Vlasakkers

Fig. 3: **Activity as a pilot test subject with the ReSpire Vest**

1 INTRODUCTION TO RESPIRE

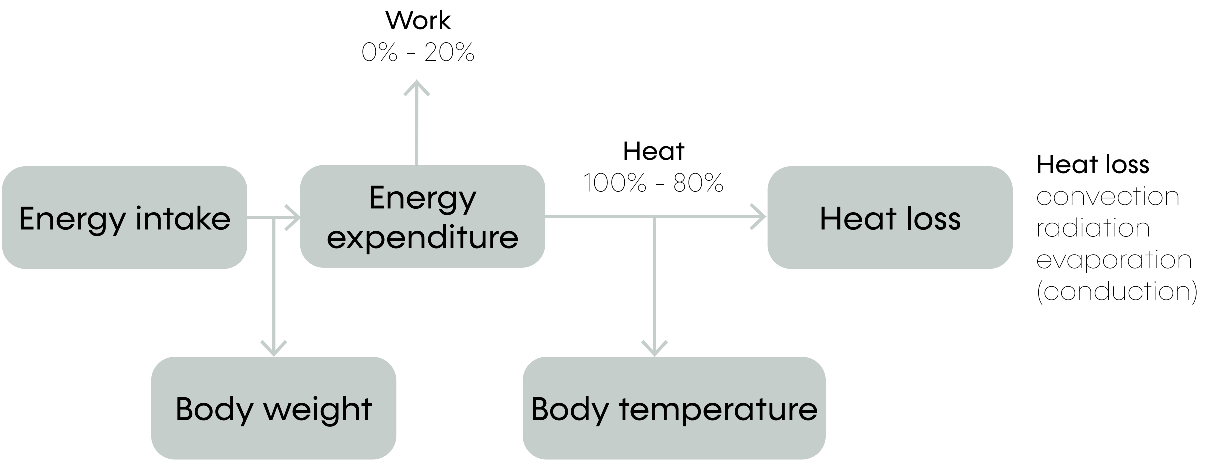
1.1 THERMOREGULATION & RESPIRE

The thermoregulatory response in humans is characterised by the mechanism to maintain body temperature at around 37 degrees Celsius (Osilla et al., 2021). This regulation is a form of homeostasis and in order to survive preserve an internal temperature. As humans are endotherms, meaning as a species, we use thermoregulation to keep a consistent body temperature despite shifting environmental circumstances. Ectotherms are animals that extract heat from their environment and are therefore mostly dependant on external heat sources.

The core temperature for humans is stabilized in a narrow range, typically between 36 to 37 degrees Celsius. Hyperthermia is attributed to the body overheating, whereas hypothermia is in case of the body cooling down too excessively. For both these states there can be damaging consequences to the body system, as it leads to ischemia, diminished blood supply to organs, and consecutively organ failure (Osilla et al., 2021).

To maintain core temperature, the body uses radiation, convection, conduction and vaporization and is severely dependant on intravascular volume and cardiovascular function. This functioning is to enable the body to transport the internal heat to the surface to dispense in the environment.

All heat that can not be lost to the environment is therefore stored in the body, leading to an increase in body temperature. In case of higher activity, when more energy and thus heat is created, for a similar heat loss the body temperature would rise (Osilla et al. 2021)(Kingma, 2021).



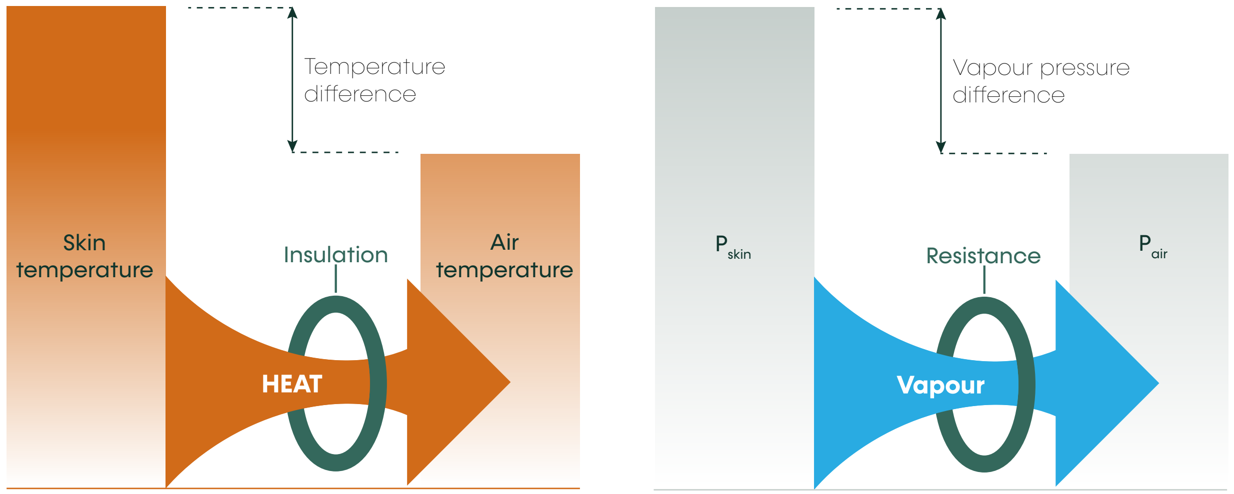


Fig. 4: Heat balance diagrams for temperature and vapour pressure difference (Kingma, 2021)

To control the transfer of heat through tissue, the human body can contract or dilate the blood vessels. With vasodilation, more blood is able to flow through the skin, which increases the heat transfer, which increases cooling. During vasoconstriction, the blood flow is decreased, restricting the transfer of heat and thus causing more insulation.

To cool the body during intense activity, when a large amount of heat is generated, sweat is excreted, which during evaporation into the air, extracts heat from the body. The evaporation is dependant on factors like the water vapour pressure in the air and on the skin and the relative humidity. In case of a small difference between the vapour pressures or with high relative humidity, evaporation of sweat into the air is limited. Relative humidity is expressed as the amount of vaporised water in the air as a percentage of the amount of vaporised water to reach saturation for the same temperature of the air.

This means that air is limited in the amount of vaporised water it is able to hold, meaning that in order to effectively evaporated sweat, humid air must be expelled for drier air (Kingma, 2021).

Fig. 5: Human Thermoregulation

THERMALLY CHALLENGING CONDITIONS:

Soldiers can be deployed in climatically extreme conditions, in terms of hot and dry environments or hot and humid environments. Performance is affected because the body will heat up through exertion and may rise to dangerous temperatures, with potentially life-threatening consequences. Physical effort irrevocably produces heat, with conversion to motion accounting for only 20% of the energy, the rest being released as heat.

The heat balance is the balance between the heat produced and the heat given off. If the body can dissipate enough, the core temperature will rise to a limited extent, which is called compensable heat load.

In certain circumstances, heat release can be insufficient, e.g. when humidity is too high, so that sweat no longer evaporates. Or when the ambient temperature is too high, the body cannot release the heat either.

During heavy exertion, the body can get into a situation of uncompensable heat stress, whereby the core temperature rises to such an extent that heat illness can develop, which defines itself as reduced deployability due to a rise in the core temperature.

FUNCTIONAL PRINCIPLE

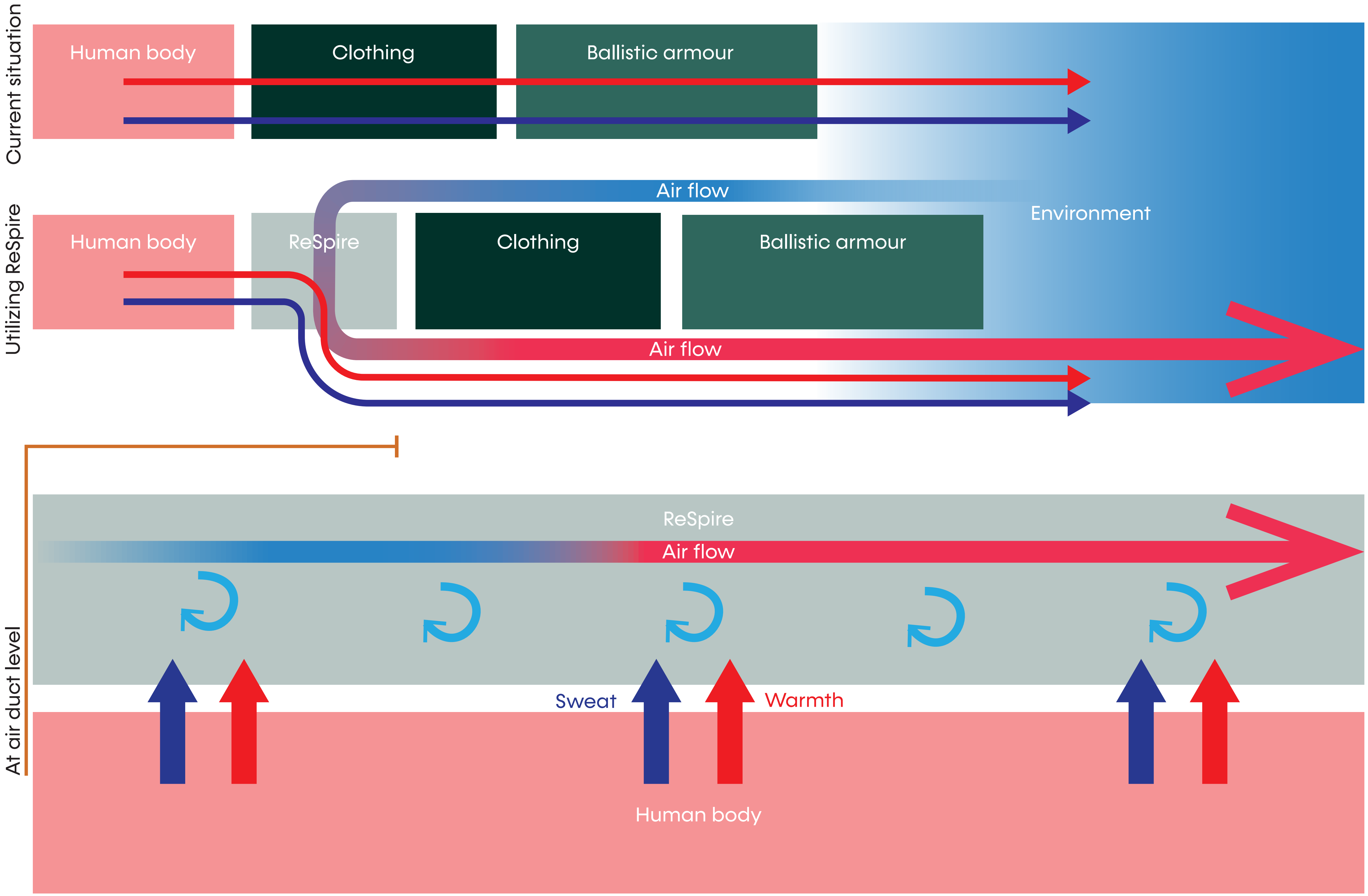


Fig. 6: Schematic diagram of functional principle of ReSpire (Linssen et al. 2020; own visualisation)

1.2 CURRENT DESIGN

The National Technology Project (NTP) ReSpire was started in 2016 in order to improve performance of Dutch military personnel in thermally challenging conditions and to prevent heat injury. Based on ventilation and effective evaporation a prototype was developed in the initial project.

In the subsequent project, NTP-ReSpire II, the system is to be developed to TRL-6 and be integrated in the VOSS-system, the equipment used by the Dutch Military.

The first design consists of front and back shells with small ventilators, integrated in pockets in a longsleeve shirt. In the second project (Linssen et al., 2020) the focus was on integration of filters at the ventilators, regulation of the velocity of the airflow, integration with a new battleshirt and air velocity evaluations in combinations with VOSS vests and backpacks. To conclude two evaluations were conducted: an operational evaluation on the LEAP obstacle course and a physiological evaluation in a climate room.

The test on the obstacle course was meant to identify how users would experience wearing the vest in combination with their normal equipment while performing. In the climate room test were conducted to determine the effect of the cooling vest on physiological indicators and cognitive responses from the subjects and how effective the design would be in various conditions.

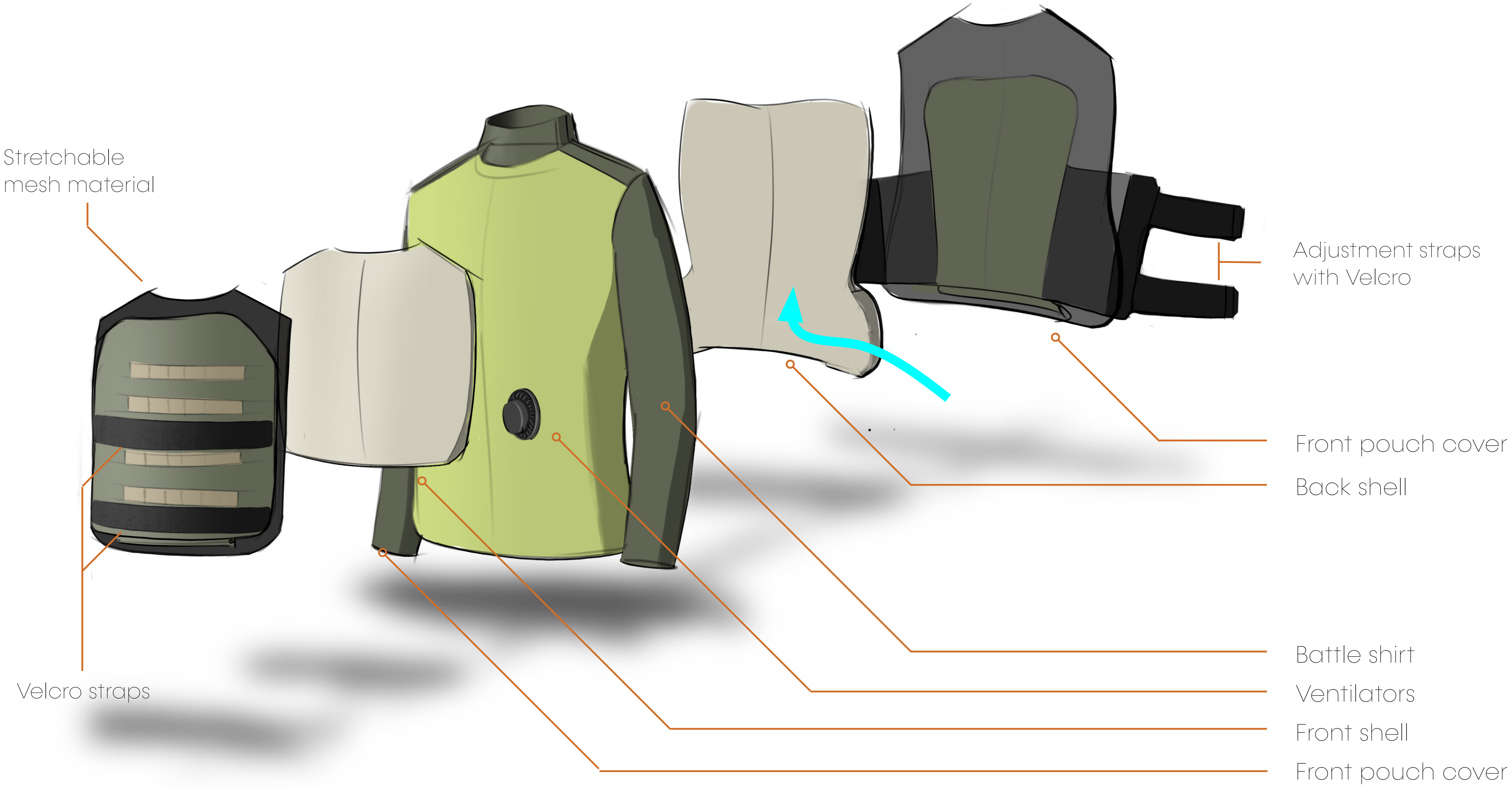


Fig. 7: ReSpire ventilation cooling vest

OPERATIONAL USER TESTS

The vest was tested for useability (in combination with VOSS) at an obstacle course with subjects (2 males and 1 female) and assessed at various criteria, such as wearing comfort, fit and ease of use, mobility of the soldier and experience of the user.

The mobility and comfort was tested during marching, at an obstacle course, when seated in a vehicle and adopting various shooting postures. Subjects conducted the procedure twice, without and with cooling vest. Gathering of measurement variables was done with questionnaires, interviews, thermal images and physiological measurements.

From the results of the test it could be concluded that the cooling vest adapted well to the VOSS. The mobility of the subjects was not affected substantially in the various situations. The cooling effect was perceived to be sufficient and valuable.

However the fit with the female subject was found to be too big and with some postures the effect of cooling was perceived to be decreased, as to excessive tightening occurred.

PHYSIOLOGICAL EFFECTS

The objective of this research was to evaluate the physiological and perceptual effects of the vest in controlled hot-dry conditions. This included moisturizing the vest prior to putting it on.

Measuring variables included the core temperature, heartbeat and skin temperature.

For perception the rating of perceived exertion, thermal comfort and thermal sensation were taken.

From the results it was concluded that a moist ventilation vest caused the most dissipation of heat via the skin. No effect was found on the core body temperature.

Both the dry and moist cooling vest cause a lower perceived heat stress compared to the situation without the vest, which can be beneficial to soldiers on their performance. The actual core temperature might be underestimated, which could lead to the soldier imposing more heat stress on himself.

1.3 PROTOTYPE ASSESSMENT

A hands-on assessment of the prototype was done to understand more of the design and the design decisions that lead to the current prototype.

SHIRT

The basis of the prototype consists of a longsleeve shirt from the brand Engelbert Strauss, with the torso part made of Merino wool. This issue was assigned as a regular fit for size Men L. The sleeves were issued in a dark desaturated green fabric, which also made up the upper shoulder parts and the neckline.

SHELLS

Moving outward are the chest and back shell, contained in dedicated pockets on the front and backside of the shirt. The chest and back shell had different outlines, accommodating for the differences in shape and required mobility between the front and backside of the torso of the soldier.

CHEST

Towards the top of the chest shell the outline was shaped in offset to the front side of the shirt. A cutout was made following the neckline, which would fixate the position of the shell correctly in relation to the shirt. The overall shape of the shell was adapted for the male chest, with slight cavities for the pectoral muscles to fit in.

Considering the channels and walls on the chest, these run smaller towards the top, which would increase the velocity of the air for a similar airflow. The entry to each channel is slightly offset to each other, with the ones in the middle starting the nearest to the bottom of the shell. Through the middle of the shell runs a wall partitioning the left and right side. The ventilators are positioned in the bottom corners, with the input channel directed to the middle.

Shape to skin alignment

With the walls running in vertical direction over the chest and back, the air ducts should align well over surface transitions in the lateral direction, as bending is relatively less restricted through inertia. Surface transitions in the vertical direction, for instance under the scapula or the underline of the pectoral muscle are more pronounced. For the walls to keep continious alignment is considered to be unattainable, as this would require detailing for each individual and uncomfortable pressurepoints in case of movement of the user.

BACK

The back shell was more tapered at the bottom and flared out towards the shoulders. The top line was less defined compared to the chest shell, however at the bottom, at the position for the ventilators, the surrounding structure protrudes further outwards from the main shape of the shell.

Similar to the chest shell the inlets from the ventilators were directed to the middle, with the middle channels starting the lowest. In contrast to the front, the channels and walls at the back run wider towards the top.

2 MILITARY ENVIRONMENT

2.1 ON DEPLOYMENT

In order to understand the context in which the cooling vest must be implemented and the military context with which it must be integrated, a number of episodes of the Kijk.nl docuseries were watched. This docuseries reports on the activities of the Airmobile Brigade dispatched to Mali. This series is relevant regarding the conditions in which the work has to be conducted and the variety of tasks carried out by this unit, recording activities both outside and inside the camp. In addition, the soldiers themselves talk about their activities and their underlying motivations and interests.

This mission conducted by the United Nations since 2013 as Minusma (Multidimentsional Integrated Stabilization Mission in Mali). The Dutch units operated from the sectoral headquarters in Gao and were stationed at Kamp Castor with German armed forces.

INSIDE THE CAMP

Activities within the camp included maintenance, preparation and cleaning of the reconnaissance vehicles like trucks and various types of equipment. The soldiers are accommodated, close together, in armoured rooms and containers, with space for their own bed and personal belongings.

Within the camp the opportunity is provided for the soldiers to participate in sports in teams or to do physical exercises like strength training.

Every week there is a so-called Mijmermoment, which is a moment for reflection in a common room. There is a small altar and sometimes someone who leads a ceremony like a priest to commemorate fallen colleagues, for example.

During the day, some instructions or recaps are provided to refresh knowledge and skills or to check customs of foreign allies to avoid confusion. Soldiers are given the responsibility to dismantle, maintain and prepare their own service weapon in a small workshop. When preparing for patrols outside the compound, soldiers are equipped with sometimes more than 25+ kg of equipment.

OUTSIDE THE CAMP

Activities outside the perimeter of the camp, such as patrols, are conducted in groups. Such activities include detecting explosives, contacting informants or checking infrastructure. Transportation is usually in trucks or special utility vehicles, but also in helicopters.

For training in the destruction of explosives, often deprecated proprietary explosives are detonated.

While on patrol, an alarm might go off, and all personnel out on the ground is required to get into their vehicles and be checked out as quickly as possible. Before resuming work, the surrounding situation is assessed.

MINDSET

What particularly emerges from the series is that deployed soldiers try to find a kind of balance between being as relaxed as possible and still being alert to anticipate situations. It is important to conserve enough energy for the moment when it is necessary to react explosively, which means some training and constant light-intensive work. There is a strong awareness of being prepared for unexpected situations and individual responsibility for having the equipment in order.

Fig. 8: Soldiers pausing during patrol outside of the camp (Goya Productions, 2018)

For the situation outside the camp there is a clear hierarchy and there are fixed protocols for risky situations. The environment is constantly monitored and caution is exercised in approaching and interacting with the local population. But also here, opportunities are created to relax and perform certain drills.

Although everyone has been trained, exercises will continue to be given and instructions repeated or fine-tuned, depending on the situation as it arises in Mali in the desert.

What is noticeable is that some vehicles have illustrations that seem to belong to the respective unit. Flags can also be seen in the camp and likely contribute to strengthening the collective spirit.

FINDINGS DOCUSERIES

- Within the camp a daily routine is assumed with a degree of freedom to work on task and prepare for operations.
- Activities outside of the camp are always in groups with multiple vehicles and with strict preparation and protocols
- Due to the hostile environment, a mindset is established to be wary of unforseen situations.

The main takeaway from the docuseries would be the structure that is established during the deployment to maintain a certain level of preparedness, but not to be constantly on edge. On the next page is a storyboard of some of the events in the series, to give an impression of the activities on deployment and how the possible threat from the surroundings is dealt with.

2.2 STORYBOARD

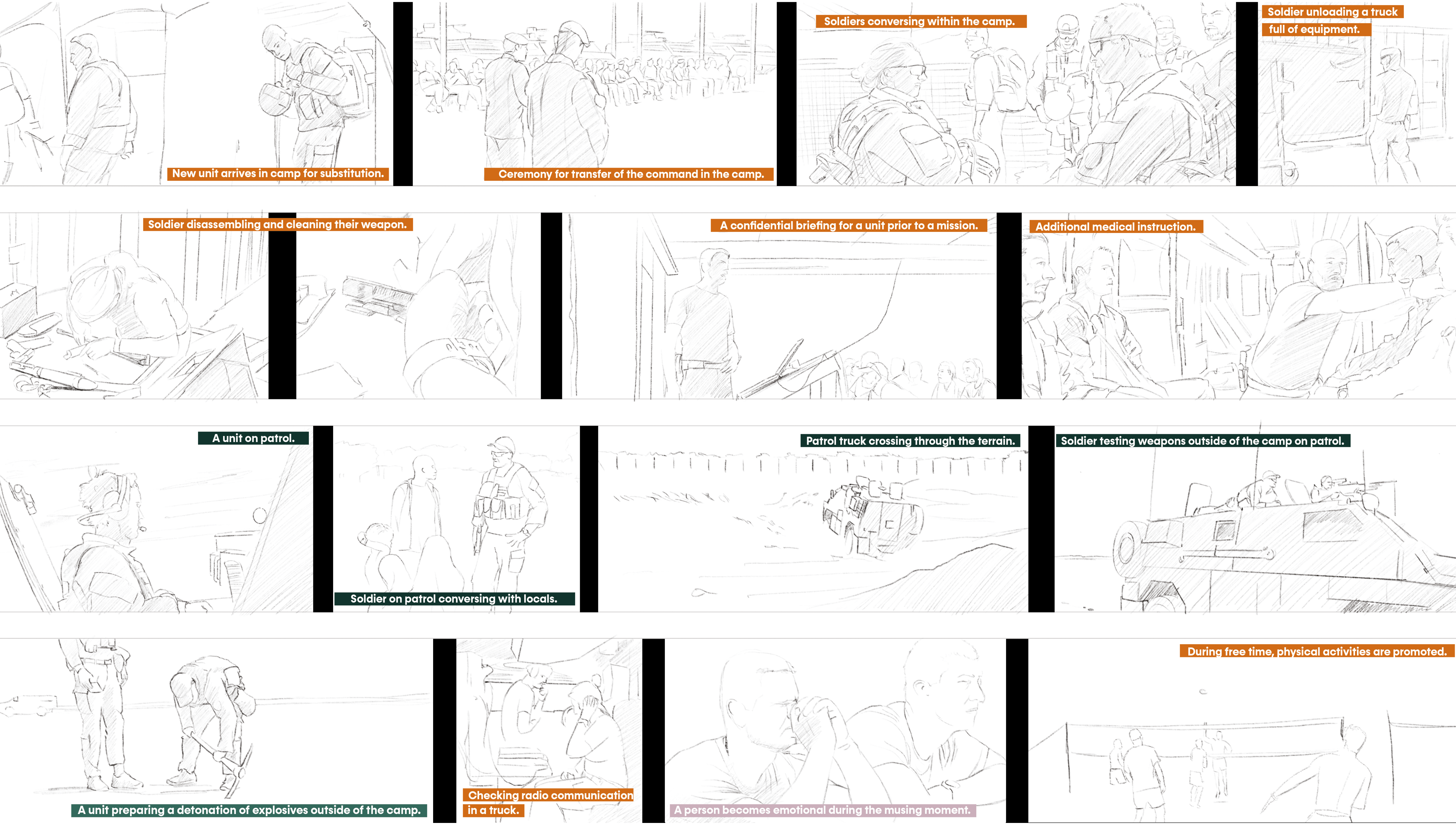


Fig. 9: Storyboard about the docuseries on the mission in Mali

2.3 VOSS EQUIPMENT

NEW EQUIPMENT

The ReSpire cooling vest is developed to be integrated withing the new equipment of the Dutch military personel, the so called VOSS, the Improved Operational Soldier System. This system was developed as part of project STRONG (Soldier Transformation OnGoing), to replace the clothing and equipment of the soldier and where all components are fitted and connected to each other.

The project embodies the clothing (DOKS), which will also include the new camo patterns (NFP) developed by TNO, the combat equipment, for instance the ballistic protection, and integration of communication equipment, as can be seen in Figure 10.

COMBAT SHIRT

Underneath the vest the soldier is wearing a combat shirt, also called an Under Protection Shirt (UPS-C), to protect him from external factors. These include holding fire retardant properties and providing thermal insulation, but also allowing transpiration to be dissipated.

At the shoulders there is padding and extra padding can be added at elbow height. Furthermore the sleeves are issued in camopattern NFP-Green.

In order to prevent undesirable pressure points at the neck, the zipper is placed diagonally. This is in case a vest with hard ballistic protection is worn, however there is a version with a vertical zipper. All versions of the shirt are sized in the range of XS up and to 4XL.

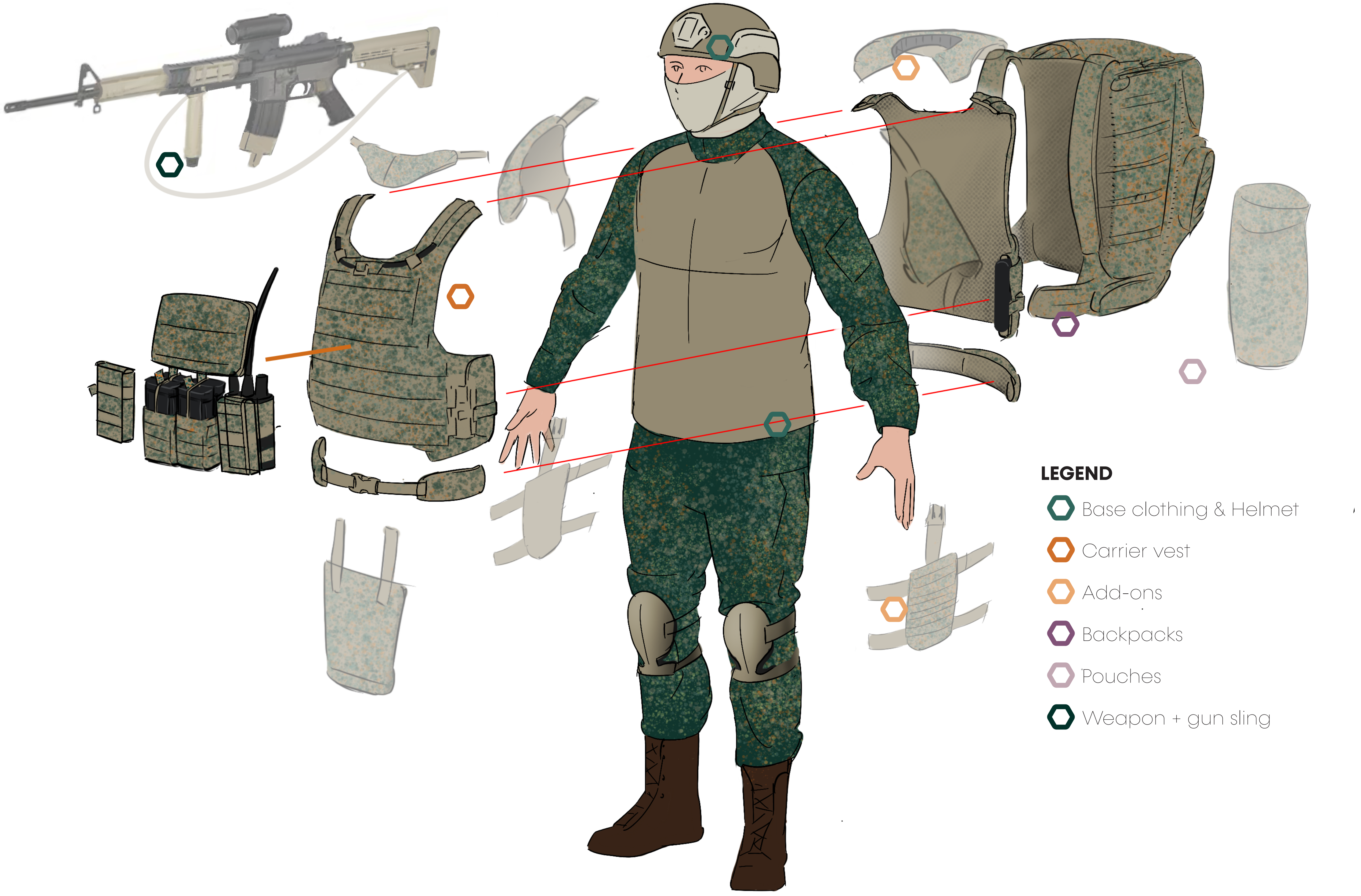


Fig. 10: Exploded view of the various types of legacy equipment on a soldier

EQUIPMENT

The equipment consists of various components which can be switched out of adapted to suit different situations.

CARRIER VESTS

Three types of vests are developed for the soldier and these contain pouches for both the soft and hard ballistic protection. For specific situation the Protection vest with the soft ballistic plates can be worn underneath Carrier vest A, in which the hard ballistic torso plates are inserted. Only the hard torso plates can be inserted in Carrier vest A and it is issued in a basic size with tailored side panels and covered in Molle webbing.

Carrier vest B is covered in molle webbing on all sides, to function as mounting points for the pouches and other accessories for the MOLLE-system. On the front at chest height a lever for the Quick Release-system is integrated, in case the vest needs to be detached from the soldier.

The vest is statically configurable at the back and dynamically adjustable at the front with straps. To close the vest, at the sides a buckle is integrated and all different ballistic protection plates can be inserted.

Additional protection can be added in the form of neck, shoulder, throat and crotch protection. A support belt can be attached to the back and around the waist to displace some of the weight to the hips.

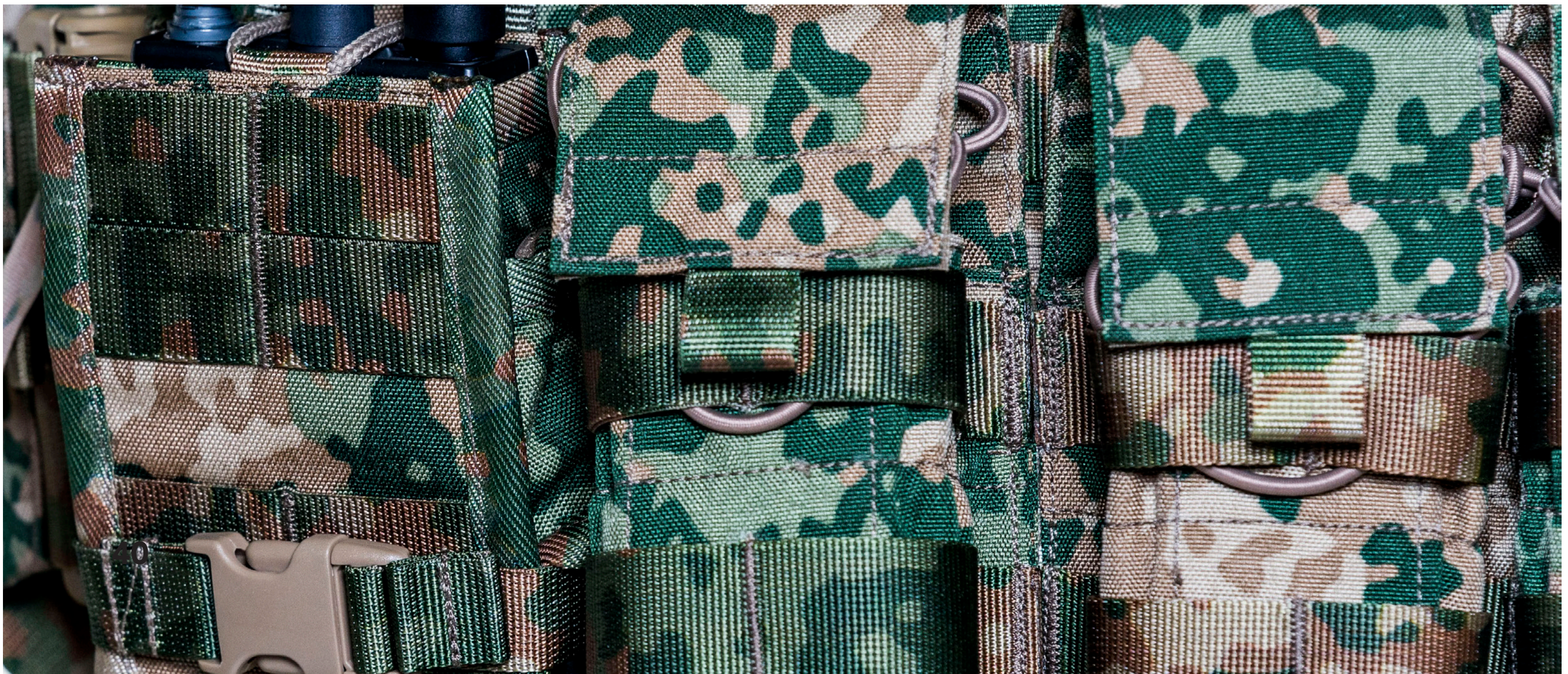
BALLISTIC PROTECTION

The soft ballistic plates are flexible and provide protection to the soldier against projectile shards and ammunition. The plates overlap each other by 2.5 cm to cover while allowing mobility.

For Carrier vest B the soft ballistic plates provide side protection and are issued in a range of S/S up and to 5XL/L. For Carrier vest A these plates are issued in a single size and these do not provide side cover, however optional side cover can be inserted in side panels for vest A. These side plates come in size S up and to 5XL.

The hard ballistic plates are not flexible and provide protection to high velocity projectiles in combination with the soft ballistic plates. These hard plates come in 2 torso plate sizes, Regular and Small, and in a single size side plates. The torso plates can be inserted in all three types of vests, however the hard side plates only fit in the side panels of Carrier vest B or in additional upper arm protection.

In order to prevent costly damage to hard ballistic plates, dummy plates are produced and which have identical dimensions and weight. These do not provide ballistic protection, but are meant for practicing by mimicking the real life factors and distinguishable by a bright red colour.



BACKPACKS

Various sizes of backpacks are provided, each developed for a specified operating window and compartments for applicable equipment. The smallest is the Cargo panel (9L) with a single compartment and applicable for short interventions. In addition to being worn with straps over the shoulders, it can be zipped to the vest or another backpack.

Next is a 37L backpack (or Grabbag) for transport of essential equipment on short to medium range operations, with two compartments that can be fully unfolded. A compartment at the back is specifically for containing the CamelBak drink system and additional bags can be attached tot the sides. The Cargo panel can be zipped to the front of the Grabbag and the complete exterior is covered in molle webbing, to attach more pouches and equipment.

The other backpack are the Patrol Pack (55L) and the 48H Pack (80L), both with a single compartment with a flap, with room for smaller compartments. Both are accessible by a u-zip on the front and the load can be expanded by attaching a pair of side bags (2x 10L or 2x 15L). The back part can be adjusted to the size of the soldier and like the Grabbag the waist band can used as a combat belt.

Both provide space for the CamelBak drink system and to the sides devices like AT-rocket launchers (anti-tank) or Haligan-tool (for forcible entry) can be attached.

The difference in application of these backpacks is in their window of operation, whereas the smaller 55L pack medium to long duration operations and the 80L pack for long duration.

Fig. 11: Grabbag + cargo panel

COMBAT BELT

The combat belt is issued with molle webbing to provide mounts for ammo and coms packs. It can be worn as a combat belt as well as a waistband when attached to the 37L backpack. On both sides are openings for attachment of leg panels and a Safariland holster.

Fig. 12: Combat belt

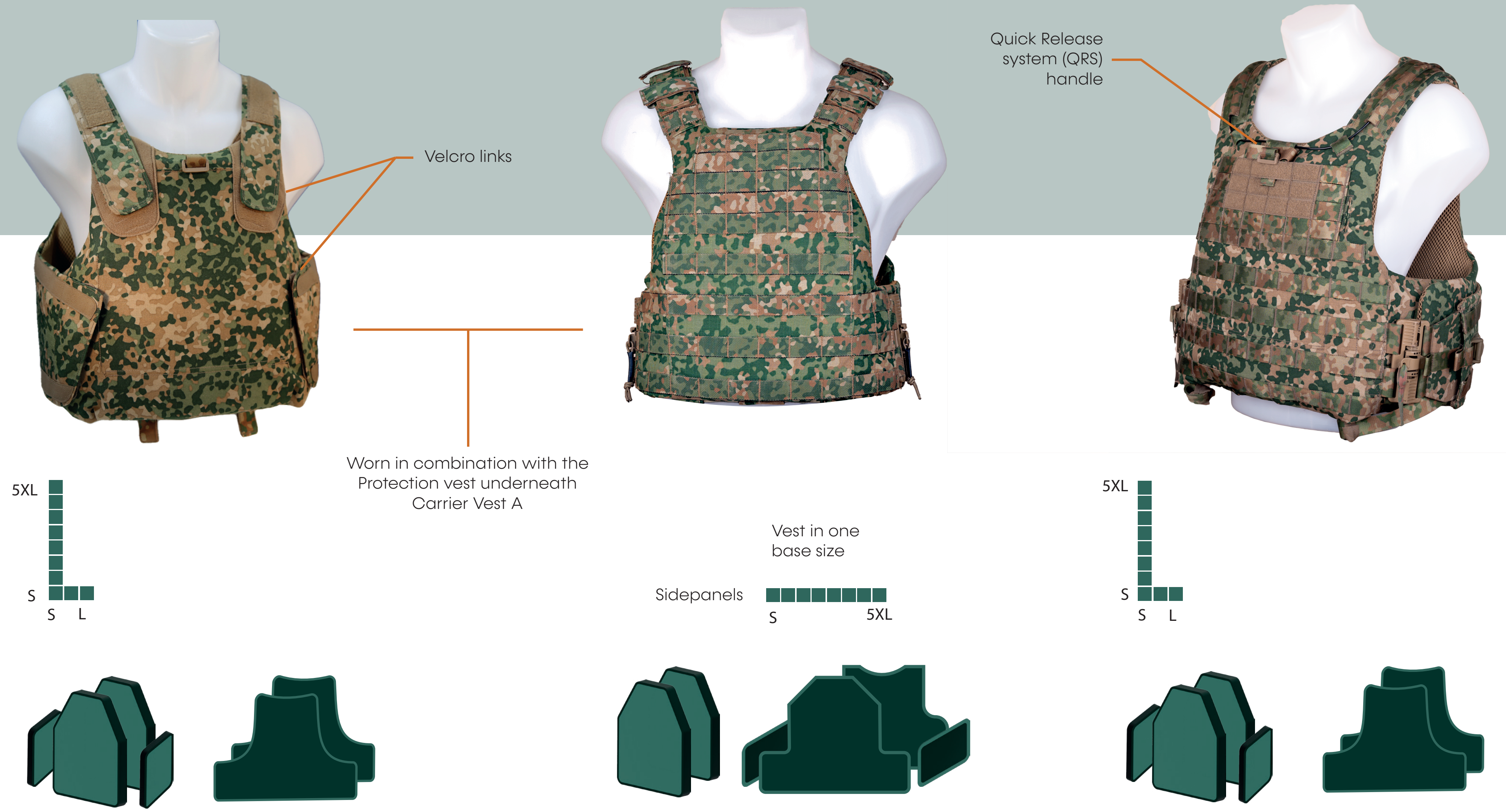


Fig. 13: VOSS Carrier vest overview

This figure 13 is to illustrate the differences between their combinations of sizing systems and variations in applicable ballistic protection.

FINDINGS VOSS EQUIPMENT

From how the equipment for soldiers is put together, it can be extracted that there is an emphasis on how all parts are integrated in order to have the most effective equipment possible and to impose the least possible restrictions on the soldier to function. Parts are easily interchangeable in order to adapt the equipment to the situation, but to limit the amount of equipment to be transported. In addition, it has been taken into account that the equipment can be expanded and there is a universal way of attaching it with the molle system.

Concerning the size, there is variety, as there are elements that are scaled multidimensionally, others in one direction, but for example the hard ballistic torso plate is only available in two sizes. The result is that for a female soldier, the size of the torso differs between individuals, this is not scaled proportionally with this component, but the soft ballistic plating and the vest are. When integrating the cooling vest, this means that scaling the parts to different sizes will counteract unpredictable deviations when merging the equipment.

An important takeaway from the composition of the equipment is that there is no clothing produced specifically for women, although it is still sufficiently suitable to be worn by women. This is partly because the cost can be high for ballistic protection that would be tailor-made for women. The proportion of women in the armed forces is not considered sufficient by the Ministry of Defence to take this into account in the new equipment.

As far as undergarments such as the combat shirt are concerned, this need not apply or cause problems, but the ballistic plating allows less freedom of form, which leads to discomfort. In this project, it may be possible that the shape of the cooling vest, because it has to fit closely against the upper body, could reduce this problem to some extent. The functionality and comfort of the cooling vest is important and it is not unlikely that this could also contribute to the wearing comfort of the Carrier vests.

Integration with clothing system

For the design of ReSpire-F it is important that despite the fact that the VOSS equipment was not designed specifically for women, the cooling vest for women is compatible with the system. This also means that it is possible for the cooling vest to bridge the male fit of the VOSS equipment to the female body shape, but it is important that the system can still be put together in all possible configurations.

2.4 SPORT BRASSIERE DESIGN

In contrast to their male counterparts, female soldiers will wear a sports bra under the cooling vest to provide the desired underpinning during physical exertion. The department of defence responsible for providing the soldier with there clothing and equipment issues an individual budget to female personnel to acquire sports adequate sports brassieres. This is because issuing a single brand or type of sports brassiere would cause problems with uncomfortable dimensions, shapes or dynamic support.

This means that an understanding is required what a sport brassiere is designed for, how it is designed and what implications this might have on the design of the cooling vest.

NECESSITY

According to Page & Steele (1999), normal physical exercise leads to large displacement of the breasts, which in turn might lead to breast pain. Brassiere manufacturers started to develop design that limit breast movement, as it was determined that excessive breast motion was the most common cause of breast pain or discomfort (Lorentzen & Lawson, 1987).

The size and shape of female breast can vary, with on average having a diameter of 10 to 12 cm and weighing around 200 grams. Overall the left breast is slightly larger than the right breast and variations in breast size is mostly attributed to varying amounts of adipose tissue (fat).
It was found that is difficult to reduce motion of the breast, as there is no strong intrinsic structural support in the breasts (Page & Steele, 1999). Providing support to the breast as documented are Cooper’s ligaments, which attach to the tissue over the pectoralis muscles (Hindle, 1991), and the skin, including the nipple and areola (Mason et al., 1999).

Fig. 14: Compression-, encapsulation- and combination sports brassier design (MacReading, 2019)

ENCAPSULATION OR COMPRESSION

The design of the sports brassiere can be distinguished in to major design types: the encapsulation brassiere and the compression brassiere.

The first one to be developed was the compression brassiere, which restricts movement by compressing and flattening the breast to the body. For females with smaller size breast (A or B) this design was evaluated to be working better. Encapsulation was thought to be more effective for females with larger breasts (C or D) as more support would be required. This type of brassiere has integrated moulded cups, which solely supports one breast (Page & Steele, 1999).

The function of the brassiere is to limit the boundaries through which the breast can move. In general the brassiere is fixated to the body by a strap under the breast over the torso in the form of an elastic band or underwire. Around the neckline of the brassiere there can also integrated an elastic layer to limit upward breast movement (Page & Steele, 1999).

MATERIAL

The fabric used in the design are mostly selected on the effectiveness and quality of the support. As these are designed to be worn during physical activities it is required that these fabrics enable mobility of the torso, but stiffness to prevent the breast motion and also for transpiration to be dissipated. For this latter feature, examples of these materials are Lycra and Coolmax. As transpiration peaks normally under and between the breast and under the arm, these fabrics are applied there (Page & Steele, 1999).

For sports brassieres the elastic properties are important for the functionality. Most fabrics are elastic in the horizontal plane, allowing the chest to expand for breathing. In the vertical direction this elasticity is more restricted in order to limit the movement of the breast (Page & Steele, 1999).

STRAPS

As for the straps, these are to be aligned vertically or in parallel to line of movement of the breast and restricted in their stretchability. To distribute the pressure on the shoulders these should be sufficiently wide (Page & Steele, 1999) or cushioned (Coltman et al., 2015), especially with cross-back strap orientation. Some females prefer cross straps as they deem this configuration to be more supportive and less prone to slip from the shoulder, however at countering vertical displacement these are thought to be less effective (Page & Steele, 1999). The vertical orientation is designed to tolerate compressive forces better than the cross-back orientation (Coltman et al., 2015).

PADDING

Some brassieres provide extra padding to prevent trauma due to external impact by decreasing the effective force over time (Page & Steele, 1999).

DETAILING

Due to physical movement, seams might lead to chafing and rubbing injuries, resulting in either seamless or covered seams in the design. Some other features include the hooks and underwire in the sports brassiere. By implementing more fabric these should be covered more to prevent irritations (Page & Steele, 1999).

According to McGhee & Steele (2020), evidence shows that the brassieres most effective at reducing breast motion are perceived as least comfortable to wear. Also during different activities there is a different demand for restriction of movement, so therefore a design that supports adjustability to the changes in displacement is desired. An example that is provided imagines a thermally activated fabric that tightens during extensive movement.

FINDINGS SPORT BRASSIERE DESIGN

From the research on sport brassiere design it can be concluded that considering the two types of support, the function is to reduce breast displacement as much as possible, so therefore these vest should not negatively affect this or support this without increasing discomfort. The current design of ReSpire does not account for this displacement, but does add compression to the torso, which in turn might add to any perceived discomfortable compression from the brassiere. Important note is that the displacement of breast tissue is mainly restricted in the vertical direction and more free in the horizontal direction, meaning that deformation due to external pressure from the cooling vest and VOSS equipment is likely to occure more horizontally than vertically.

The extra fabric does function as insulation layer, restricting transpiration to permeate to the air channels, especially at the cups for the breasts. As stated, some fabrics are specially selected to be applied in areas where there is a higher amount of sweat (under and between the breasts are areas of particular interest for the cooling vest).

This means that the area over the breasts is less effective at ventilating in evaporating sweat and returning cooling energy to the body. In other areas sweat can accumulate, which does not evaporate but run down the torso and so potential cooling is lost.

Regarding the problem of soft tissue entering the channels when excessive force is applied, the fabric that encapsulates the breast can distribute this force and prevent the channels closing from the inside. Hence the configuration of the channels in this area can be manipulated to alter the airflow and lead to more effective evaporation in other areas.

Point of concern are the presence and location of hooks and seams which, due to the combination of the cooling vest and a VOSS vest, might be prone to uncomfortable pressure and irritation with movement. Generally these features are located at the back at underbust height. To ensure that these points are limited in causing discomfort, having clearance from the separation walls would suffice.

Air flow distribution
The presence of a sports bra will have a great influence on the cooling capacity of the cooling vest, as it is an insulating layer between the skin and the air ducts. Where the skin is covered by the bra's textile, especially the cups themselves, it is better to allow the airflow to pass over them as gradually as possible and thus to ventilate the uncovered skin more, i.e. to pass over it at a higher velocity.

Female shape
From this section is is important for adaption of ReSpire to the female shape the effect of the sport brassiere on the deformation of the breast tissue. This manifests itself mainly in the fact that the tissue is more flattened against the chest and therefore protrudes less, which means that the shape transition that the chest section must make is reduced.
In addition, the textile is less elastic deformable in the vertical direction compared to the horizontal, which means that deformation of breast tissue under the foam section occurs more to the side or towards the centre.

3 FEMALE PHYSIOLOGY & PHYSIQUE

3.1 THERMOREGULATION

As stated the ReSpire project was set up to develop a way in which the risk of heat stress could be mitigated. This resulted in a design that supports the natural way the human body cools itself and therefore makes it suitable for the context in which the soldier operates, as it does not require elaborate cooling equipment with materials that are prone to performance loss over time or damage.

HUMAN THERMORAGULATORY RESPONSE

The human thermoregulatory response to heat consists of two major mechanisms: Increase blood flow to the skin – drawing heat from the core to the outside through convection - and transpiration. By means of evaporation, energy is drawn from the skin to allow the water to be vaporized and dissolve into the air, resulting in a loss of heat from the skin (Yanovich et al., 2020).

Regarding the differences in thermoregulation between sexes, some result from anatomical differences or hormonal differences, as the female thermoregulatory response varies throughout a menstrual cycle, with a fluctuation of 0.3-0.5°C (Kaciuba-Uscilko & Grucza, 2001). The threshold for body heat dissipation is higher in females and shifts with body core temperature, meaning that response for females starts later and results in a higher body core temperature when balance is reached. This balance results from reaching a limit in the amount of heat the body is able to dissipate and how much it is producing (Kingma, 2021).

The factors influencing this heat balance are the differences in temperature and the factors of heat loss – conduction, convection, radiation and evaporation. Influencing the heat resistance are the thermal properties of the human skin, where variation is present in inter and intra-subject differences. Some people hold more adipose tissue (fat), which has a lower specific heat and therefore provides more insulation. As females have an higher percentage of body fat mass, this results in on average thermoregulatory disadvantage to males in heat loss (Mclellan, 1998).

Avellini et al. (1980), Frye & Kamon (1981), Sawka et al. (1983) en Mclellan (1998) all concluded that there are no significant differences between the sexes if the subjects are matched for antropometric features, body composition or fitness. For example, if subjects were matched on body fatness, heat storage per unit of total mass and tolerance time were identical between sexes (Mclellan, 1998).

A study by Fournet et al. (2013) into developing therographic body maps of males and females shows similar distribution of skin temperature between the sexes. According to the research the skin temperature was not corresponding to the regional variations in skinfold thickness, except for the front of the torso, resulting from looking at variations per body region for fat thickness and skin temperature.
For females the higher average skin temperature at the breast was caused by the insulation from wearing a bra. The images furthermore show an increase of skin temperature at the sternum and neck (Fournet et al., 2013).

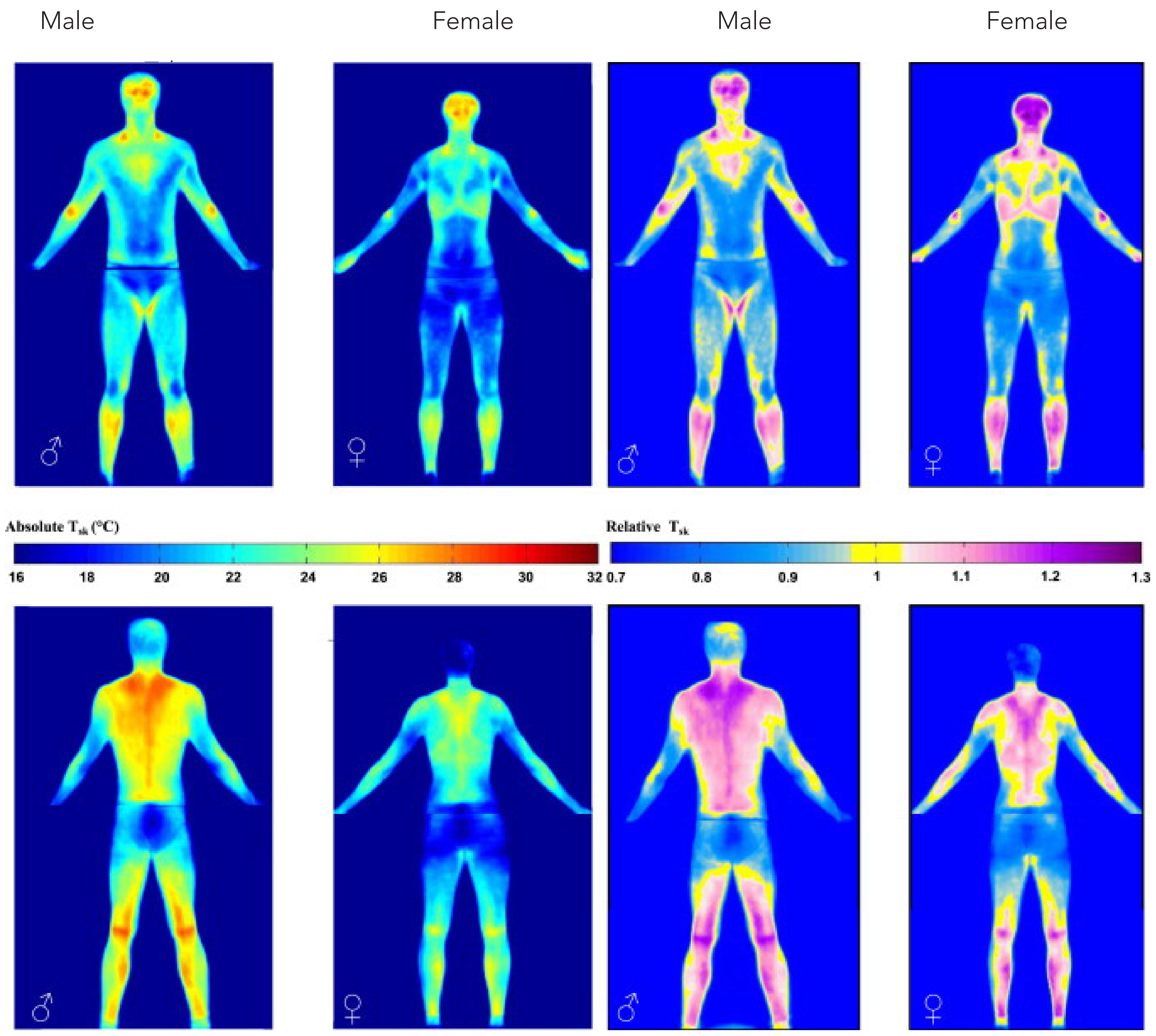


Fig. 15: Group averaged body maps of absolute (L) and relative (R) skin temperature after exercise. (Fournet et al., 2013)

3.2 PERSPIRATION

An important factor in cooling the body is the effective evaporation of sweat, which contributes for around 85% of all heat loss during intense exercise (Healthwise, 2020). For each mass of sweat excreted, heat is extracted from the body, provided it remains in contact with the body. In the case of dripping sweat falling from the body, the cooling energy cannot be returned to the body.

The evaporation of sweat to the air also depends on the humidity of the air, which affects the ratio of the vapour pressure of the skin to that of the air (Kingma, 2021). In short, when the air is so saturated with water, the evaporation of sweat takes place more slowly. As a result, in hot humid climates, the body is less able to cool itself by perspiration.

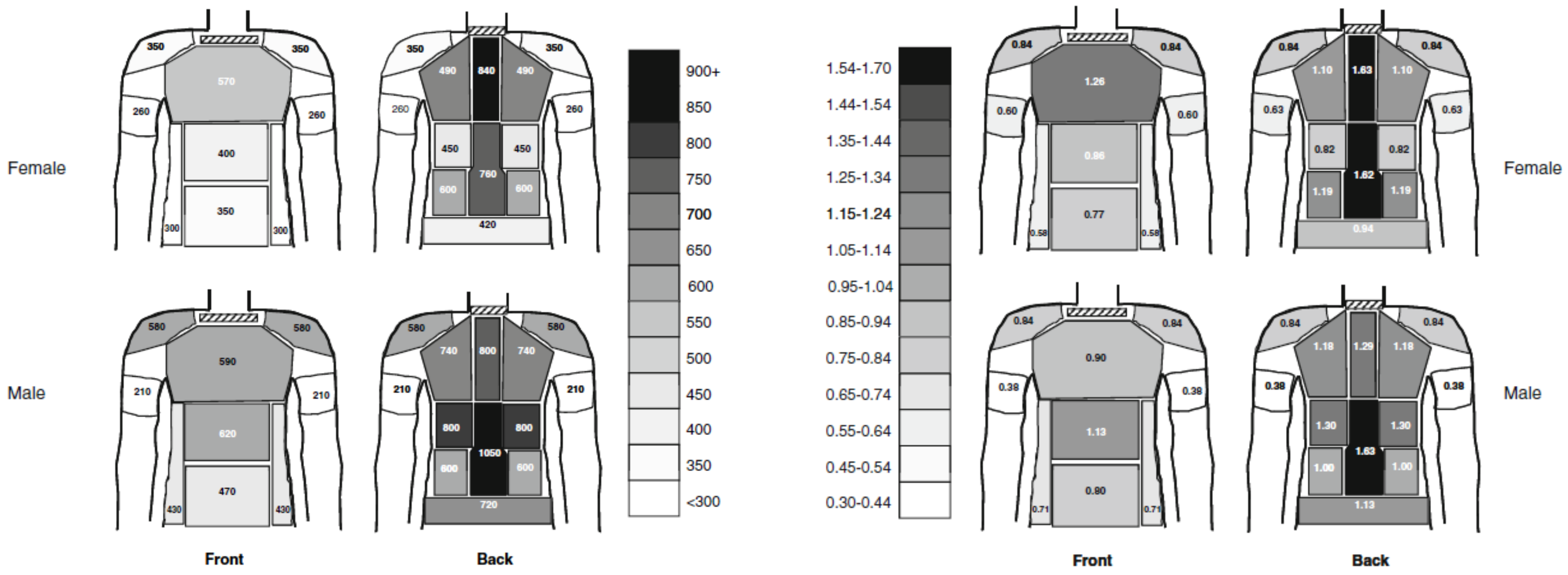
DIFFERENCES IN SWEATING BETWEEN SEXES

The amount of sweat secreted by the body is expressed as the sweating rate (SR), which consists of two factors: the amount of activated sweat glands (ASG) and the sweat output per gland (SGO) (Ichinose-Kuwahara et al., 2010). The SR in males is higher, despite that for women, the ASG is higher than for men over the whole body according to Inoue et al. (2005).

Buono & Sjoholm (1988) demonstrated that physical training increased the peripheral control of the sweating rate. They compared trained and untrained males and females on ASGs and SGO and found SR increased with training. For females physical training affects their sweating rate on both ASGs as SGO, whereas with males this increase was due to solely higher sweat output per gland.

Inoue et al. (2005) reported data on regional sweat rate with males and females in a passive heat and without exercise. Following was a study done by Havenith et al. (2007) to determine the sweat distribution on the upper body with both male and female runners. They concluded that males show a wider variance in high-to-low sweat rates, for instance the central back in relation to the upper arm. For both sexes the sweat rate was higher along the spine and sternum.
Overall the sweat rate is higher on the back than on the chest, which does not correspond to the evaporative heat transfer potential. During running the chest side is the windward side, with the back as the leeward side, which would cause the evaporative heat transfer coefficient to be higher.

Why the sweat rate is higher at the back is speculated to be related to evolutionary development of humans becoming bipedal. On four feet the back would be more exposed to the environment, so that sweat would evaporate more quickly (Havenith et al., 2007).



Regional sweat rate $g/m^2/h$

Mean regional sweat rate

Fig. 16: Regional sweat distribution (Havenith et al., 2007)

This was illustrated in two figures, comparing the sweat rate distribution of males and females for the front and back and in ratio to the mean sweat rate of all measured zones. From the mean regional sweat rate ratio for females it can be concluded that on the chest the sweat rate on the upper side is above average and the underside of the chest slightly under. At the back this is similar for the lateral sides, however along the spine the sweating rate is significantly higher, with minimal difference between top and bottom of this area. Bar-Or (1998) speculated that, since female show a higher activated sweat gland density, which indicates more but smaller sweat drops, these smaller drops have a higher evaporative efficiency.

The distribution of evaporation rate (Esk) of the human body was studied (Park & Tamura, 1992) and showed no correlation between the skin temperature and evaporation rate. However, a ranking was found for the evaporation ratio from high to low on the lower back to the upper back to the bottom of the chest and finally the top of the chest.

FINDINGS

As stated, due to intense exercise the sweating response is the most significant factor in cooling the body. Especially in comparison to the effect of convection, the functionality of cooling with the ReSpire is mostly dependant on the vaporization of sweat. The presence of sweat or liquid water is therefore critical to the efficiency of the design. When distributing airflow over the surface of the skin, it would be restrictive if the amount of sweat was minimised to such an extent that cooling by evaporation no longer takes place, but in other places too little air is supplied that sweat remains and for instance starts to drip.

This relates to the sports bra, which, as an extra layer, will restrict the flow of sweat to the air ducts and also allow sweat to accumulate at the bottom of the cup. A consideration may be to reduce the supply of air over this surface or to allow it to be less turbulent, so as to provide the skin surface further along the channel with more fresh air or at a higher velocity.

The higher density of activated sweat glands and smaller droplet size cannot (yet) be linked to a design consideration.

However, the distribution of regional sweat ratios suggests that it may be more important to ventilate more on the back than on the chest, as can be seen in Fig 16. More locally, it can be more effective for women if more air is directed along the spine or sternum. A higher air velocity can also contribute to greater effectiveness, but it should be taken into account that more evaporation earlier in an air duct can result in the air becoming saturated more quickly, making evaporation more difficult later in the duct.

Air flow distribution

Result on the regional sweat distribution suggest increasing evaporation effectiveness at the areas along the sternum and spine by increasing the air flow velocity. This is compensated for by reducing the airflow speed in areas with lower sweat distribution.

VISUALLY COMBINING SKIN TEMPERATURE & SWEAT DISTRIBUTION

By combining the figures of Havenith et al. (2007) and Fournet et al. (2013) through symmetry, an illustration for the female body is created that shows the importance of adequate ventilation over the central part of the chest as well as the back. For females, it must be considered that the bra interferes a lot with the thermographic illustration on the left, with increased temperature for the breast tissue. For sweat distribution, the bra prevents it from evaporating directly and thus builds up at the bottom of the bra before it flows further down and evaporates.

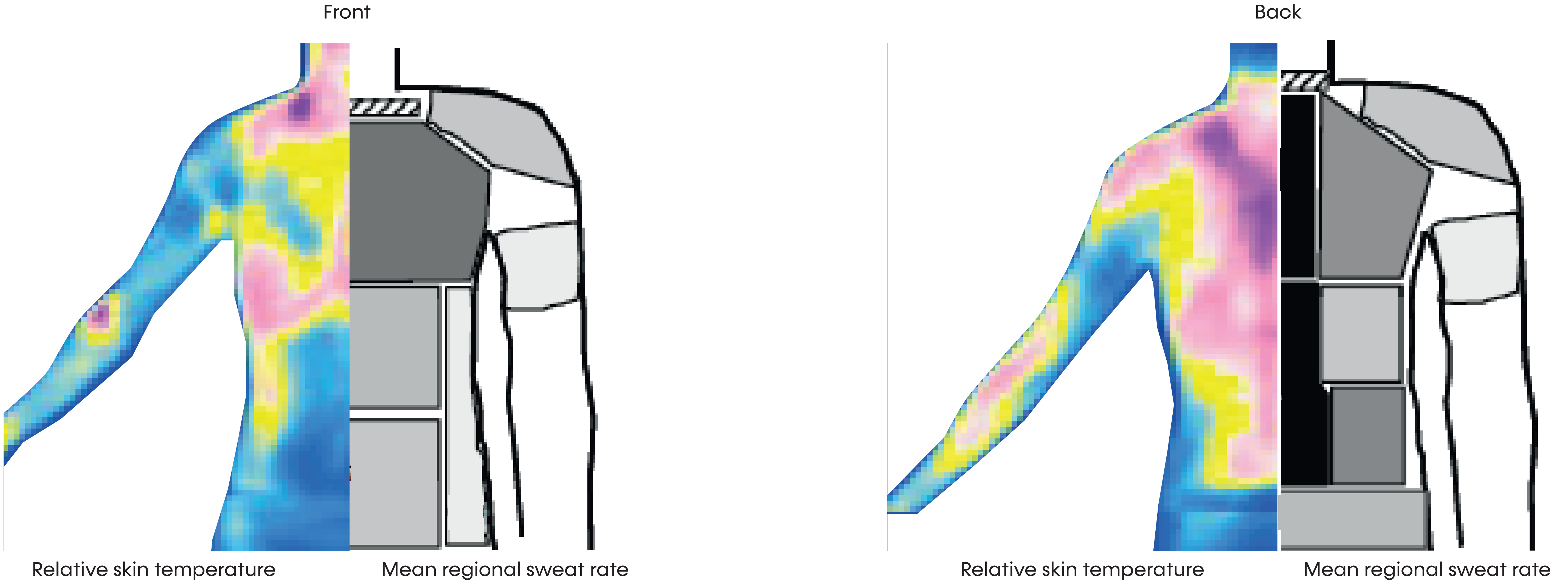


Fig. 17: Combined visuals of thermal image of the skin (Fournet et al., 2013) and regional sweat rate distribution (Havenith et al., 2007)

3.3 AERODYNAMICS IN AIR DUCTS

To achieve the desired acceleration of the airflow, it is necessary to look at how aerodynamics works in air ducts and how it can be influenced. For this consideration was given to how the airflow can be effectively guided and where necessary minimise resistance.

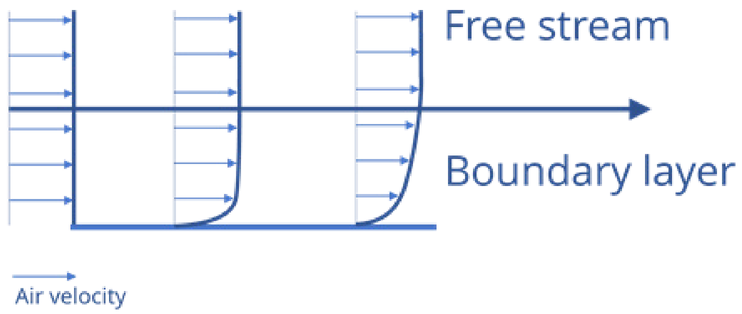


Fig. 18: Airflow through duct

FLOW SEPARATION

The first is how the air flow normally takes place in the air ducts, which is illustrated in Figure 19 as a cross section. Because of friction forces in air flowing along an object, the velocity is reduced and to zero at the surface – which is called a no slip condition. The boundary layer is located between the unobstructed airflow and the stalled air at the surface (Remmerie, 2018).

Something that can occur when air flows over a surface where there is a transition is that the air flow separates and no longer follows the surface. After the surface transition, a turbulent wake is created due to the separation of the air flow. In the resulting cavity, negative pressure is created, which has an aspirating effect. In the process, energy and speed of the airflow is lost (Remmerie, 2018).

This means that changes in the direction of the air ducts, for either the partitions or the outer wall, should be as gradual as possible or adjustments made to reduce turbulence. This also concerns the starting points and end points of the partitions when dividing into the various air ducts.

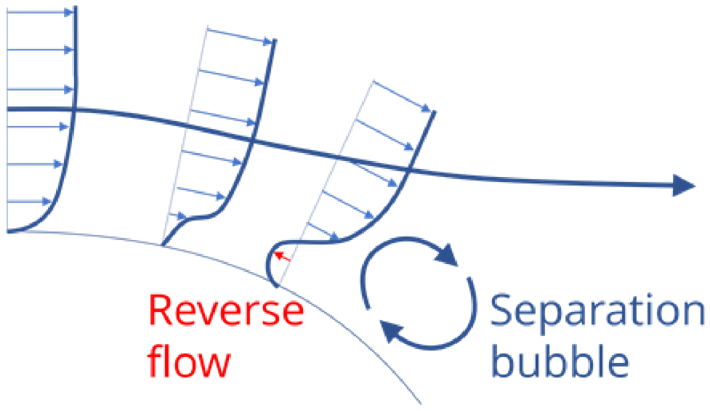
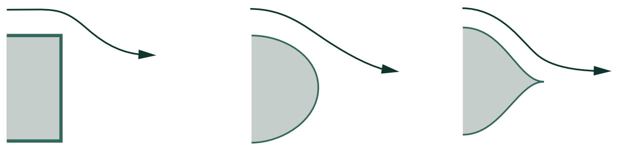


Fig. 19: Airflow over surface transition



CONVERGING SURFACES

To reduce the wake from flow separation behind an object in air flow, the surface should gradually narrow to allow for the flows from both sides to converge smoothly. Reducing the turbulence from truncated surfaces also affects the effectiveness of the flow further along the tunnels (Katz, 2018) (Foale, 1986). It is therefore preferable to limit breaks in the air ducts or to have them at the exit.

VORTEX GENERATORS

To delay the separation, in the boundary layer the airflow is to be injected with a high energy flow with a vortex generator. The unobstructed airflow follows the curvature of the surface longer, as it is mixed more with the boundary layer (Remmerie, 2018).

Vortices are created by for example inserting vertical plates with an angle relative to the airflow. A disparity in pressure is created between the front edge and rear edge, resulting in spillage over the sides which lead to vortices (Remmerie, 2018).

Vortex generators in turn create drag, so therefore implementation must be offset against the reduction in drag due to the surface transition. The shapes should be minimized in size, relative to the height of the boundary layer (Remmerie, 2018).

DIMPLES AS VORTEX GENERATORS

To increase the range and speed at which golf balls can travel through the air, dimples are added to create turbulence over the surface. Therefore the unobstructed airflow trails the surface for a longer distance, which causes a reduction in drag (Prabhu, 2021).

DIMPLE GEOMETRY

An important factor in the drag coefficient is the geometry of the dimple. Chowdhury et al. have shown that the increase in dimple depth ratio or in other words the surface roughness can shift the transition to a lower Reynolds number and increase the drag in the transcritical regime.

Regarding the similarity between determining the dimensions of the winglets or dimple for the air tunnels and the offset between the additional drag and reduced drag trough wake, the dimple depth is to be balanced with regards of the dimensions of the tunnel and the airflow (Chowdhury et al., 2016). Adding and developing these features is for finalization of the shells, as it will not affect air flow distribution, but is likely to reduce resistance and increase mixture of damp airflow with dryer airflow and in turn increase effectiveness.

DUCT SHAPES

In air ventilation systems 3 different shapes of ducts are commonly used, each with its own advantages and disadvantages for variable situations. Round ducts is considered the most efficient shape in terms of resistance. This is due to the ratio between cross-sectional area and the contact surface being the biggest and thus a correspondingly lower resistance for the amount of air flowing through it. Besides, the acoustic performance is deemed to be better, as less breakout noise permeates through the surfaces and low-frequency sound is well contained. A drawback of this shape for air ducts is the required clearance for the height of the duct. Rectangular ducts are regarding the required clearance the most efficient for construction. For efficiency the width-to-height ratio is optimal with a ratio close to 1 for transportation of air flow. Greater aspect ratio are less efficient in material use and with additional pressure loss.

A trade-off between these to types is the oval duct shape, where the aspect ratio is advantageous compared to round ducts, however it also holds some of its advantages.

FLOW RATE OF AIR DUCTS

The flow rate in an air duct, in cubic meters per second, is determined by the velocity of the airflow in the duct, commonly expressed in meters per second, and the duct size or cross-sectional area, in square meters. According to the air flow principles, a reduction in the cross-sectional area means the velocity of the air flow increases disproportionately (Bhatia, 2014). Given that the evaporation of sweat is accelerated due to increased air flow velocity, this principle can be applied to locally manipulate the duct size to increase the efficiency of sweat evaporation. This means narrowing the duct where more sweat is excreted to speed up evaporation.

Regarding the design of the air ducts in ReSpire, the adjustment of the cross-sectional area is possible by reducing or increasing the distance of the partitions or the depth of the ducts. This translates into raising or lowering the partition walls, but the separation line between the boundary layer and free stream can shift, so much so that there will no longer be a free flow of air. This could be beneficial to the mixing of the ‘dry’ and ‘humid’ air, especially at the end of the air ducts, when saturation may be highest.

AIR DUCT DESIGN PRACTICES

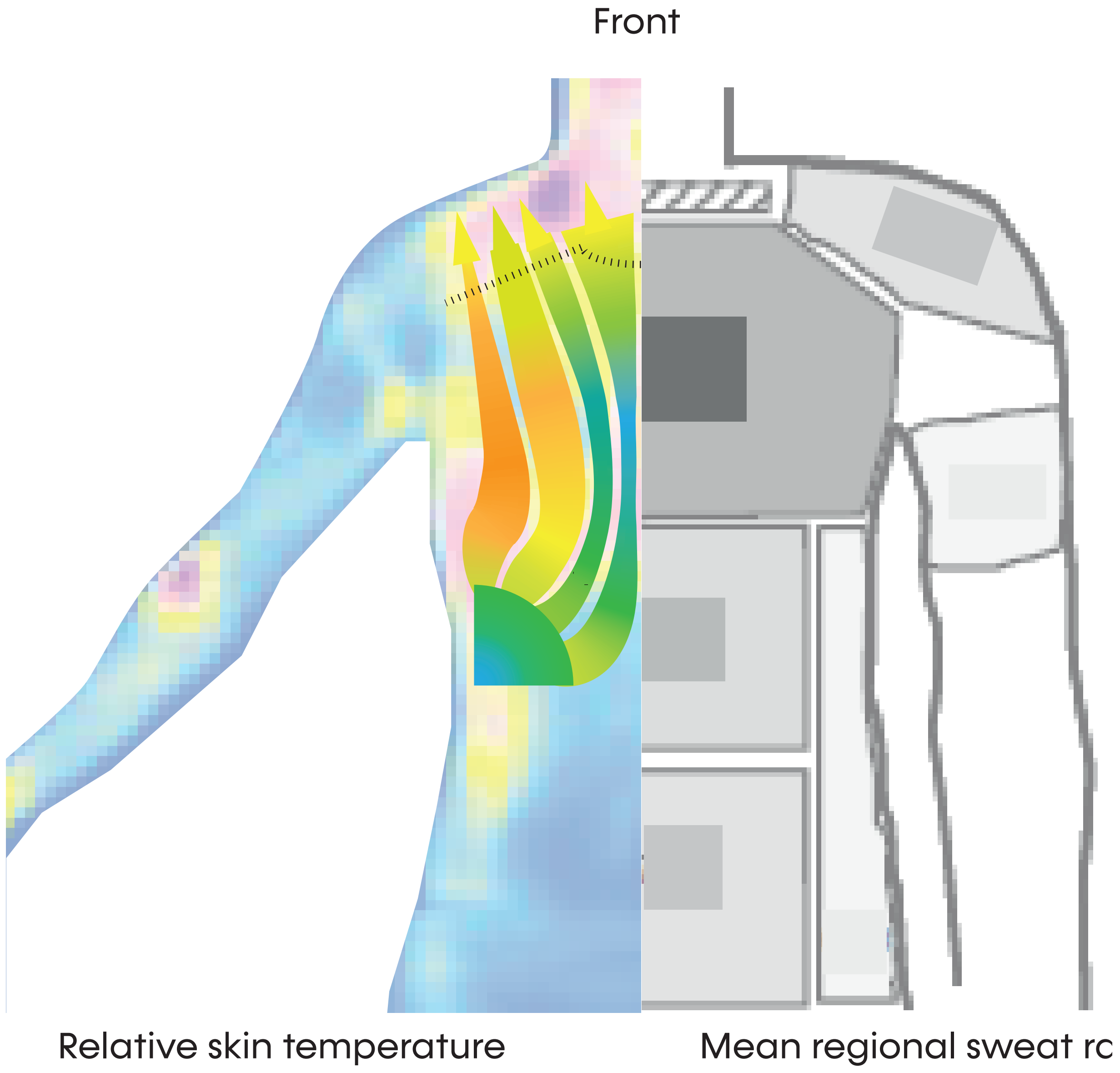
Reduce loss of energy by designing straight ducts, as this is the most efficient for air to move. A reduction of bends is preferred when configuring a system.
Also adopting the correct size for ducts is important, as too small dimensioned ducts are not adequate in transporting enough air, however oversized air ducts lead to loss of air, energy and efficiency in the system.

FINDINGS

For the design of the air ducts, it is important to minimise disruption, for example when changing the direction of the air flow and opt for gradual adjustments.
In the event that this is necessary, the effects of turbulence can be limited with, for example, vortex generators, however, the effect of this was limited and not directly detectable in measurements of airflow. Therefore, it is not advantageous enough for the development of the design in the initial phase, but it is, for example, at finalization.

With the illustration on the right, it is shown what an appropriate airflow over the chest side of a woman would be, related to the regional sweat distribution.

The contours are based on the current shape of the foam section, location of the fans and outlets and a fixed depth of the channels. The change of colour from green to blue illustrates an acceleration of the air and thus more cooling by ventilation, and from green to orange of deceleration, thus less cooling. Increased velocity across the centre of the chest was chosen by a wide start of the ducts, followed by a narrowing.



Air flow distribution
An initial step is made to alter the air flow velocity to the sweat distribution in a shell design with uniform depth and an unaltered outline shape. The starting points of the channels are in this illustration at an uniform distance from the position of the ventilator with an airflow directed outward from the center. As these ventilators do have a single direction of output, the eventual design has to be altered to provide the desired airflow. This can be done by changing the opening and angle of cut to balance out the input of air with minimal disruption of the flow. In the illustration, the current outside line has been applied, however this shape is still up to be changed to fit the female torso shape.

3.4 ANTHROPOMETRIC RESEARCH

Before starting, it is important to consider what work has already been conducted to adapt, for example, military equipment to the female body. Although there has been much change, the proportion of women in the armed forces worldwide is not large. Equipment is generally designed and assembled to male standards.

BALLISTIC PROTECTION FOR FEMALE MILITARY

By adapting a bulletproof vest to the female soldier, a balance should be provided of protection and comfort (Toma et al., 2016). In this study it was found that females in general would wear smaller sizes of body armour, causing problems as it would be tight across the chest, but loose around the middle. Besides bringing discomfort, the armour would offer less protection. Wearing the wrong size or obstruction of respiration due to pressure could lead to injury.

Most problems would be related to the difference between the chest circumference and the under bust circumference, which relates to the cup size of the female body. To reduce the problem, the room at bust level was increased and tightened around the middle. Furthermore the length of the front, side and back was increased, as compared to males the width of the torso was less for the same height (Toma et al.,2016)

Also two Australian studies were conducted to identify problems of body armour on female soldiers (Coltman et al., 2021)(Coltman et al., 2020). In the earlier study there was a reportage of 68% of ill-fitting body armour and its relation to musculoskeletal pain and discomfort.

Oversized armour was reported to interfere with performance, even in combination with a combat belt or in operational tasks. When adopting other positions these issues were amplified, for instance with in prone position. Movement of the armour would cause imbalance, discomfort and distraction, resulting in performance loss (Coltman et al., 2021).

Also the limited space for the bust was identified as an area for improvement. Besides compromised respiration, chafing around the waist and painful bouncing of the armour were cited to be caused by the tightness. Suggestion were made by the participants, including proposing multiple points of adjustment(Coltman et al., 2021).

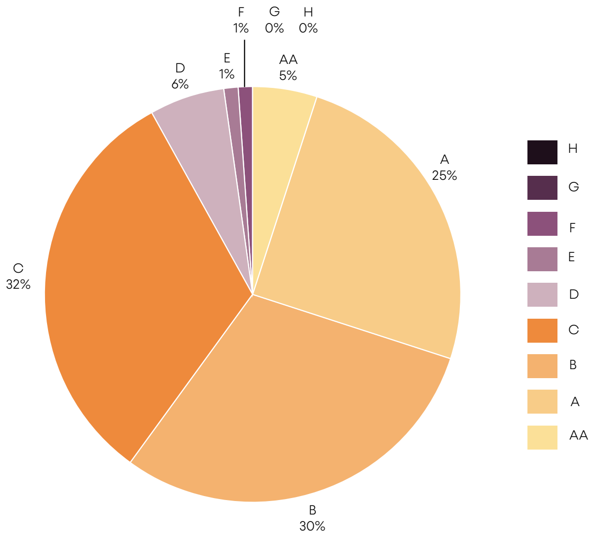
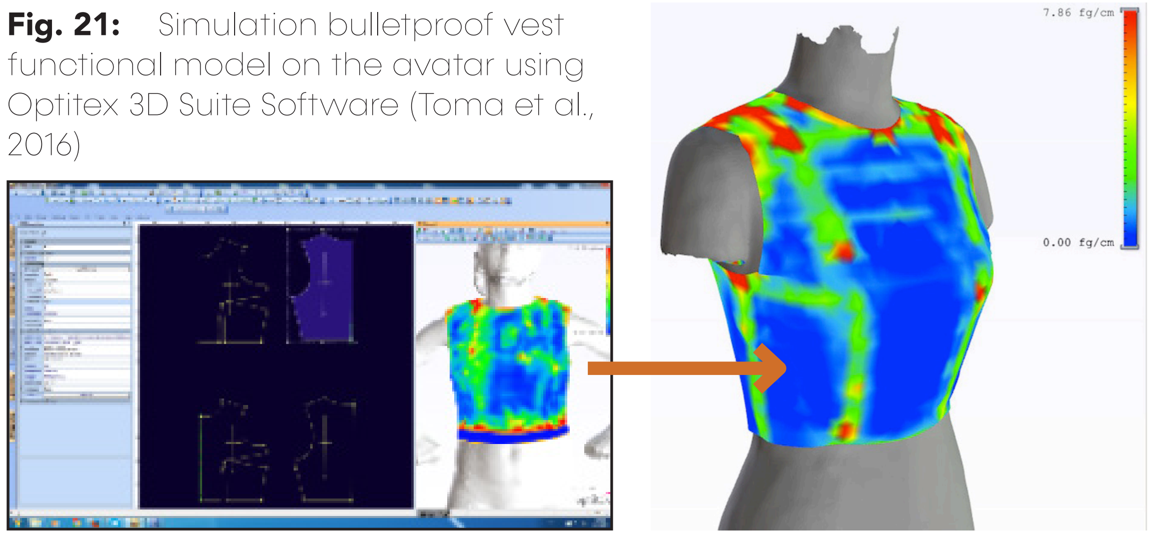


Fig. 20: Cup size distribution (Toma et al., 2016)

Fig. 21: Simulation bulletproof vest functional model on the avatar using Optitex 3D Suite Software (Toma et al., 2016)



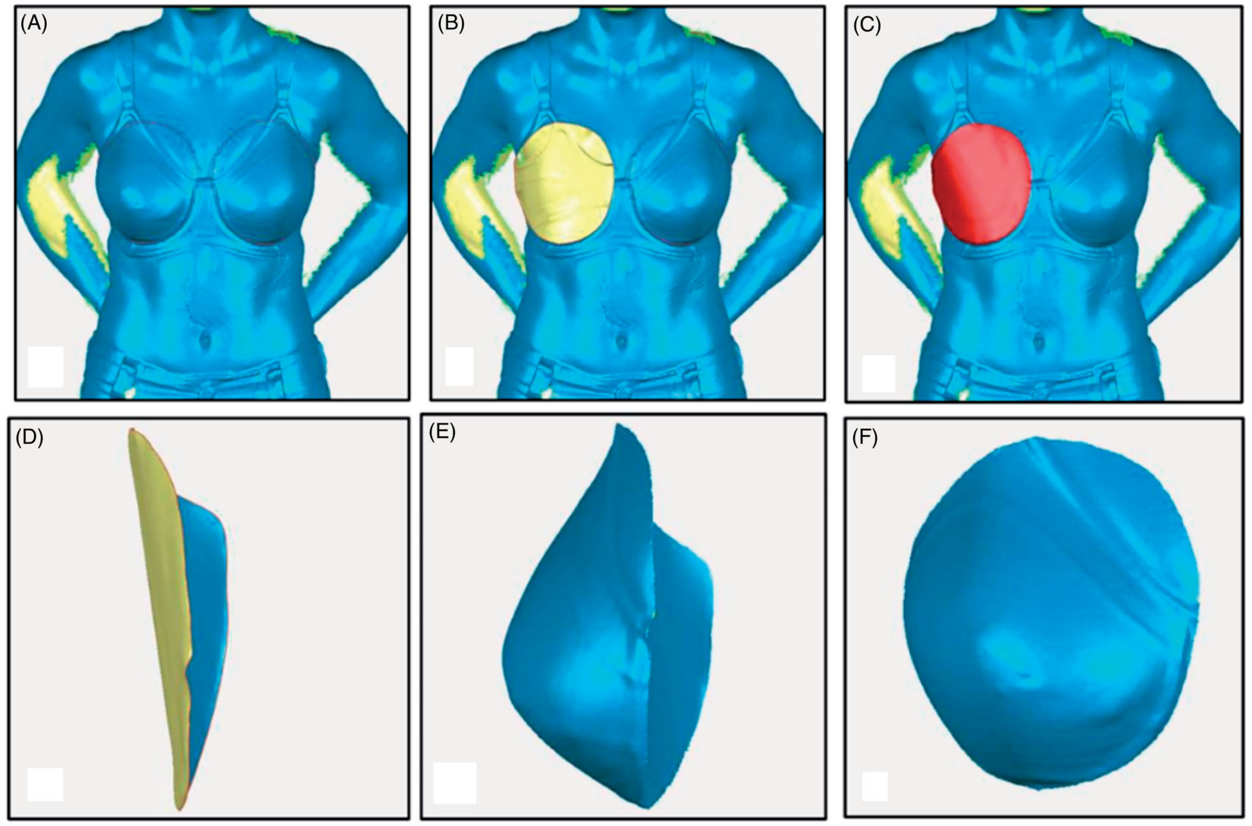


Fig. 22: Steps in calculation of breast volume using Geomagic software (Coltman et al., 2021). By defining the borders of the breast, the breast was subtracted from the anterior chest wall

3.5 BODY COMPOSITION ANTHROPOMETRICS

Thermoregulation is highly dependent on body composition as previously established. Therefore, it is important to look at the differences between men and women and the possible influence of physical training on this composition as this distinguishes female soldiers from the average female population.

BREAST DIMENSIONS AND POSITIONING

According to Gefen and Dilmoney (2007), there is a large individual variance in size and weight of the female breast and also a significant variation in position of the breast (Avsar et al., 2010). This anatomic variation is described as the volume, width, length, projections, shape and position of the breast on the torso.

Brown et al. (2012) found a positive correlation between BMI and breast mass, with fat mass attributing to the greatest increase from smaller to larger breasted women.

Coltman et al. (2017) affirms that an increase in BMI relates to a higher breast volume and attributes nearly half of the variance in breast volume – 47% for the left breast and 49% for the right breast – to differences in BMI. The median breast volume doubles from participants with normal BMI (327 mL) to those who are overweight (545 mL) and triples to those who are determined as Obese (954 mL), see Figures 23 & 24.

PHYSICAL TRAINING

The effects of different types of physical training on body composition were researched in a study where in following a program of 16 weeks (Soares Costa de Mendonça et al., 2014). Participants were divided among three types of program: strength training, dance and hydrogymnastics and a control group. It could be argued that the physical training of soldiers would partly resemble strength and dance training.

Overall there is an healthier anthropometric profile with physical training compared to the control group, for instance lower body fat mass. The training group with the most similar characteristics to the control group was the one that followed hydrogymnastics training.

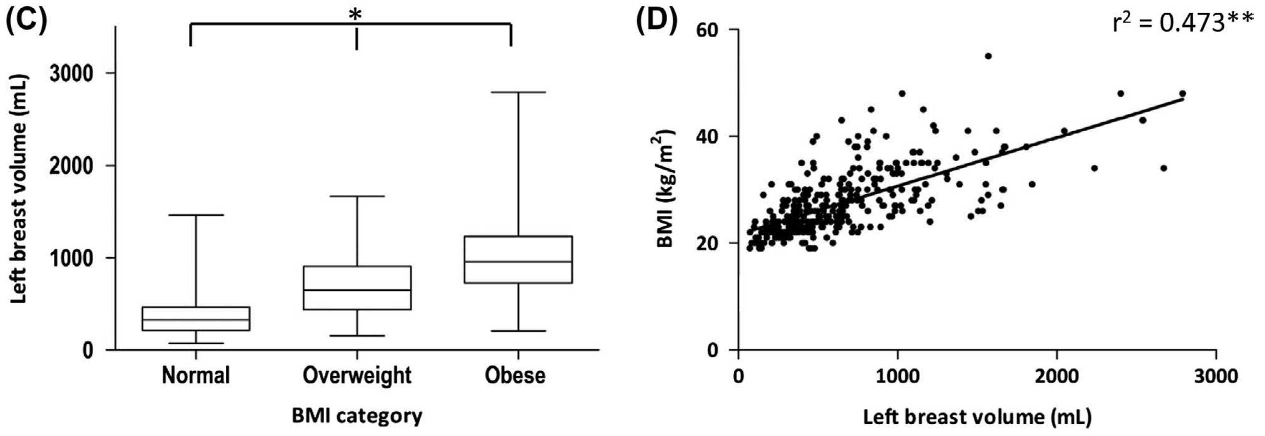


Fig. 23: Breast volumes plotted against BMI values for the left breast (Coltman et al., 2017)

FEMALE RUGBY PLAYERS

A study was conducted on the chest and torso characteristics of female rugby players, with the aim of identifying implications on the design of sports bras and breast protection (Brisbine et al., 2020). This study provides relevant insights into the physical characteristics of a group of women who are more physically challenged. It showed that the range of different breast volumes and below-chest torso circumferences are fairly similar to the average female population, with most falling into the small-medium range for both.

What emerged was that the shape and location of the breasts has important implications for the design of the garments over the breast. This is to ensure the breast is adequately covered and provides optimal protection.

A recommendation was made to include scans with bare-breasted females as well as scans with females wearing correctly fitted sport brassieres, as these might differ due to the compression or tension applied to the tissue with a garment (Brisbine et al., 2020).

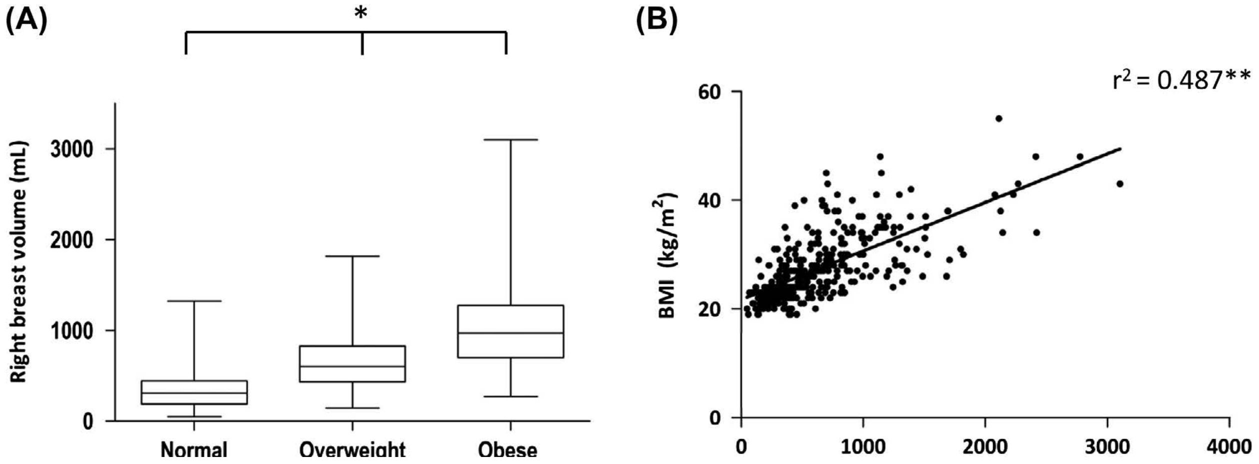


Fig. 24: Breast volumes plotted against BMI values for the right breast (Coltman et al., 2017)

EFFECT OF BREAST DIMENSIONS AND SHAPE ON WEARING COMFORT OF BODY ARMOUR

In a study by Coltman et al. (2022), the measurements to determine the anthropometric characteristics of the female torso were assessed on their association with the rated fit of body armour. Anthropometric measurements were collected via scans of female Australian soldiers and ratings of perceived fit of their body armour by means of a questionnaire.

The Australian female soldiers in this study showed smaller chest- and waist circumferences, however on average larger hip girths were measured than compared to their male counterparts. Indicative measurements for poor body armor fit were Stature and Suprasternale Height for subjects deeming the armour too large, suggesting excessive length of the armour to interfere with mobility.

For subjects deeming the armour too small, the measurments on torso circumference, for instance, chest circumference, depth or breadth or Mass were significantly greater. This suggests the armour systems should accomodate wider ranges or adjustability has to be expanded.
The adjustment points in torso armour should accomodate for variability in chest curvature of the female torso, as a result of additional breast tissue (Coltman et al., 2022).

In the study it was also suggested that for females with larger breast sizes a body armour system that provides more space for breast tissue would significatly improve their wearing comfort. Subjects indicating their armour to be too large had similar breast size measurements (340.5 mL) as those deeming their armour to be a good fit (344.5). Subjects rating their armour too small had on average larger breast sizes (503.0 mL), suggesting the larger breast sizes are affected more by the sizing of torso body armour.

Breast shape characteristics, such as Anterior Breast Projection, also affect the perceived fit of body armour (Coltman et al.,2022). As a result of compression and deformation of the breast, which is greater amounts of breast tissue, problems with breathing or mobility increase.

The position of the breast on the chest wall is also related to the fit of body armour with female soldiers. Lower positions of the breast is suggested to correspond with subjects rating their armour too small (Coltman et al., 2022).

FINDINGS

Compared to male soldiers, female soldiers require different measurements and overall shape for the cooling vest in order to have it closely fit and be suitable with the VOSS equipment. As the VOSS equipment is not adapted to the female soldier, some issues occur with sizing, resulting in compromised mobility.
Due to the presence of breasts with female soldiers, issues occur with perceived comfort, related to compression and deformation of the tissue. As variability is significant with breast size and shape, the required space for to suit for each female individual is challenging to determine, however deformation of the tissue provides an opportunity, if as long as the tissue is not too constricted.

Female shape
From the issue of the fit of body armour systems with female soldiers it is clear that due to the differences in torso shape to male soldier, it is clear that alterations in dimensions of the ReSpire vest are required. Even though the shells are made of flexible foam, interference with mobility and displacement of the shells should be limited.

Shape variability
Due to the variability in breast sizes, shapes and positions and how these affect perceived fit, the design should accomodate for the variance. As breast tissue is subject to compression and deformation by the weight of the covering body armour, the shaping of the shell inbetween could cater to this variability, by controlling this deformation to a certain extent.

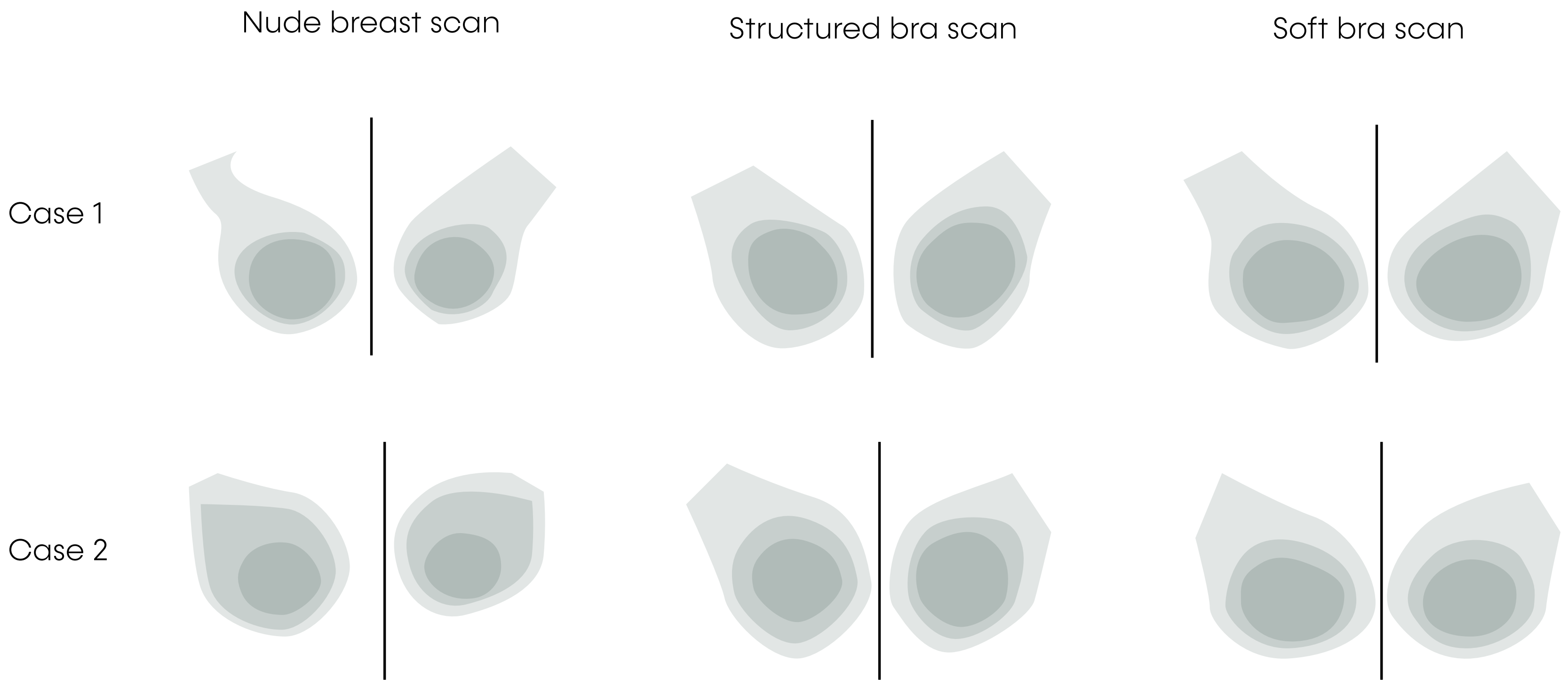


Fig. 25: Simplified illustration from study into breast shape variations in different body scan conditions, with vertical line to indicate symmetry. Based on illustration in study, representing the effect of a bra on symmetry (Pei et al., 2019, own illustration)

3.6 DEVELOPMENT OF AN ANTHROPOMETRIC MODEL

For the creation of CAD models and prototypes, it is desirable to have representative models of the target group for whom the garment is intended, as the chest and back shells must closely fit to the torso. Since the database from the earlier study with scans of defence personnel is not available (ter Haar et al., 2013), the CAESAR database with scans of Dutch women was used (Robinette et al., 2002).

FEMALE ARMED SERVICES EMPLOYEES

The scans were processed in ParaView 3D and filtered for groups representive of female military personel using the included Excel sheet. A first model is made of the scans of women between 18 and 35 years old who filled in that they are employed by the Armed Services.

The group size was small (N=21) and what also stood out from the supporing data sheet was that the values entered for fitness were on the low side, as well as the predominantly sedentary work posture prevalent for this group. Therefore, this group is probably not representative of the regular female soldier who may be deployed.

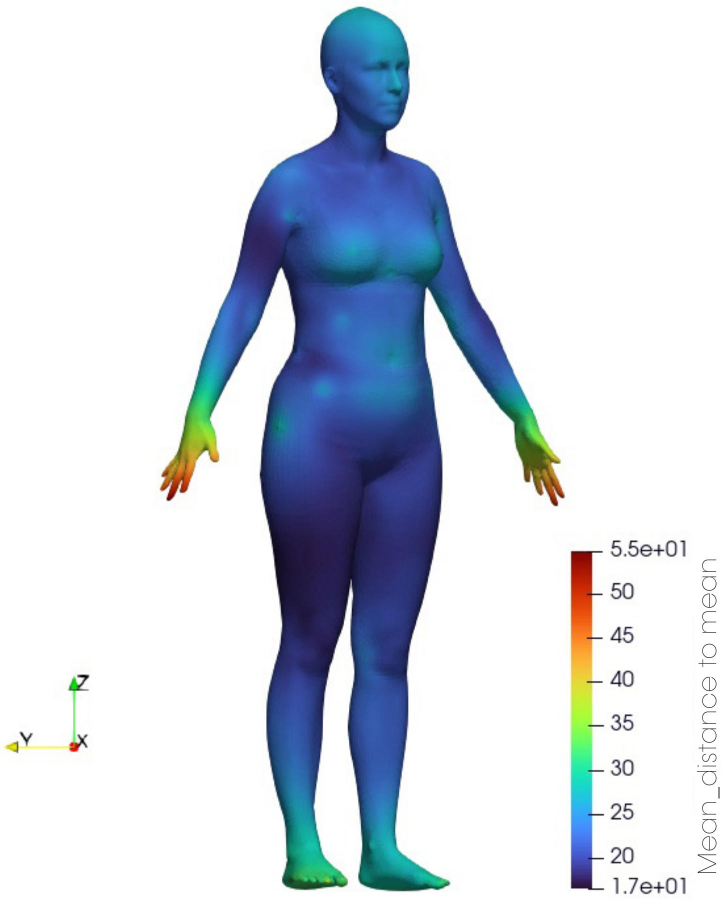


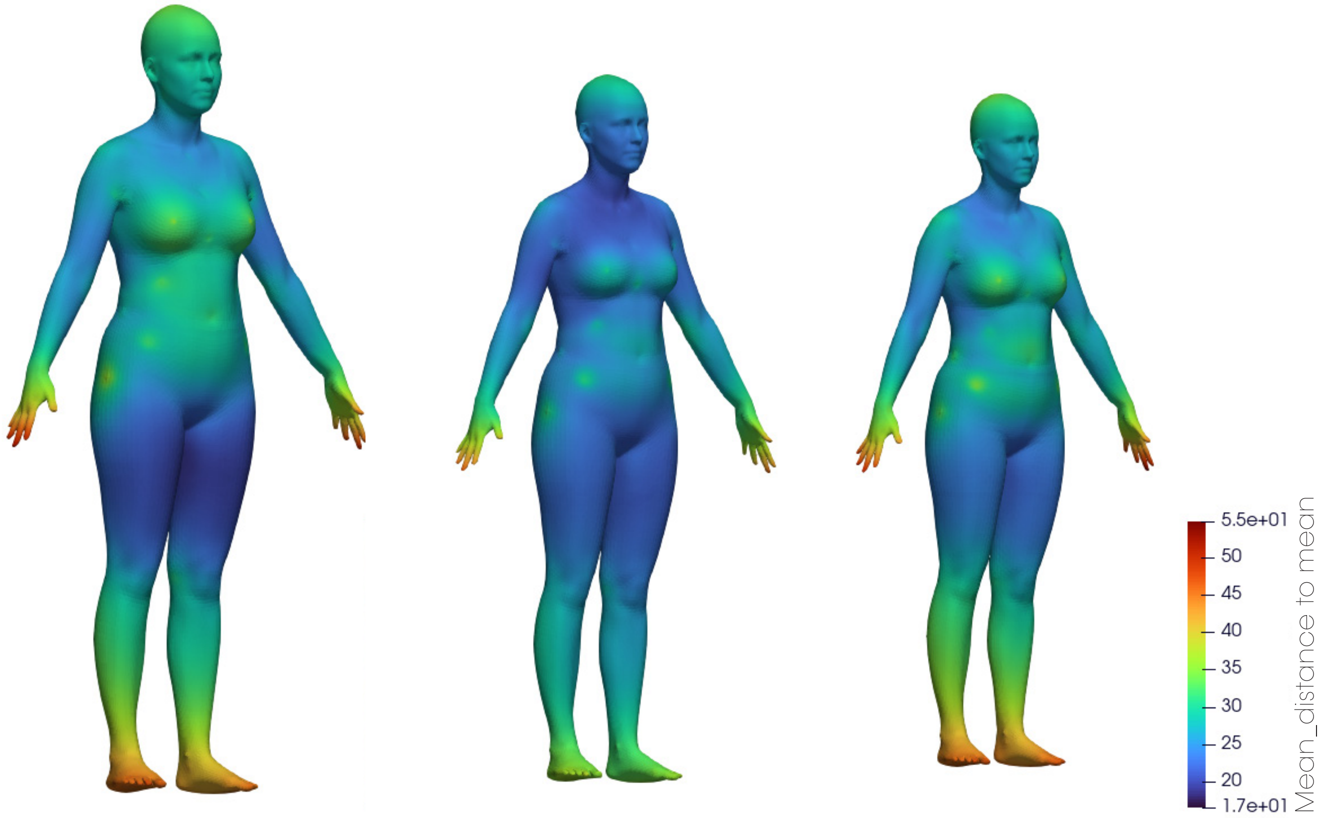
Fig. 26: Average female armed services employee from CEASAR database (Paraview 3D)

BASED ON FITNESS RATING

The following average models were created from group selected for fitness, to understand the effect this has on body composition and where it causes more variability. The fitness group of 0 - 1 hour per week was about 50 persons, that of 2 - 3 hours per week was about 112 subjects, 4 - 6 hours per week was about 70. For the groups of 6 - 10 hours per week this was only 30 and for more than 10 hours per week only 18, which means that the calculated model is less accurate and less reliable.

What appears to emerge from the models is that with an increase in fitness hours to 6 hours per week, the models have a more accentuated waist. So the ratio of circumference at the waist to circumference at the hips and higher around the torso has decreased.

Furthermore, no noteworthy differences were observed depending on fitness.



(0-1 hrs/week) (2-3 hrs/week) (4-6 hrs/week)

Fig. 27: Averaged female models based on different fitness levels (Paraview 3D)

BLOUSE SIZE GROUPS

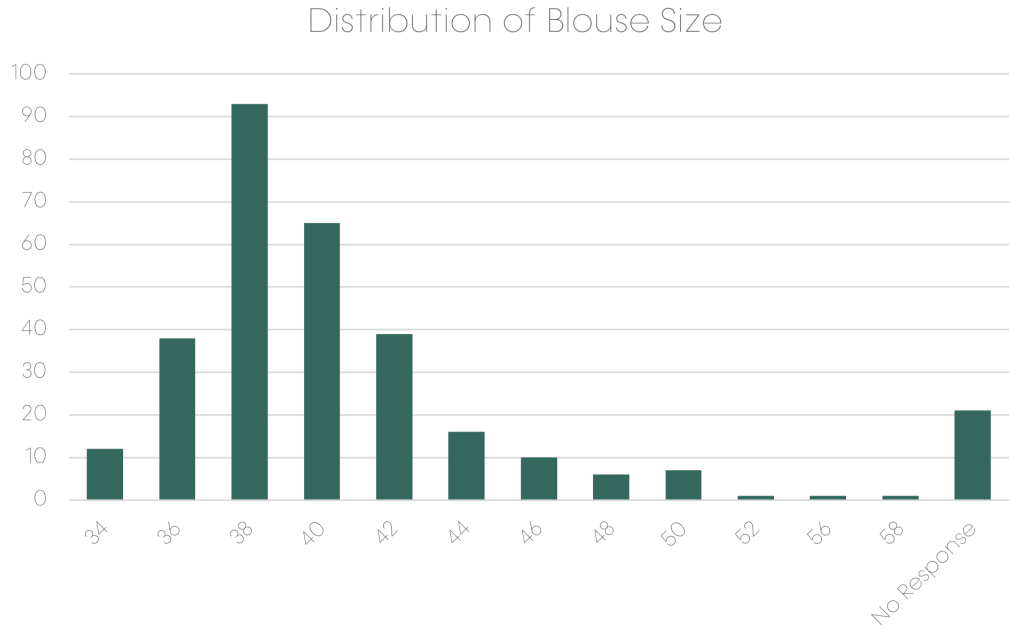
Groups were then selected based on the blouse size specified in the data sheet. This was done to obtain models to compare what differences in physique occur between these different sizes. From this, more can be observed where variability occurs and how diverse it can be.

Selections were made based on the numerical blouse sizes, and from these four models emerged that included enough scans for reliable comparison.

What emerges is that for the smaller blouse sizes, the models are visibly slimmer in addition to smaller in length. In addition, the variability in breast size for the small blouse sizes is smaller and increases with the increase in blouse size.

The shape transition from the upper abdomen to the chest is more emphasized in the larger blouse sizes, resulting in the fact that, in combination with the larger chest size and variance, relative to the existing shape of the chest bust, a more acute shape transition is also required. For the flow in the air ducts this can be problematic because it can be more disturbed by a sharp transition, but if this shape transition does not fit closely enough there can also be too much air leakage.

On the back side, it can be seen that for the smaller blouse sizes, there is a more emphasized concave shape transition between the shoulder blades across the spine. In the scans, this is partially concealed by the presence of the bra strap during scanning. In order to get the connection especially at the bottom of the form, this may be another important aspect. In other postures, and thus flexing of the muscles, this shape transition may disappear, but it does take place at a critical location for effective airflow.



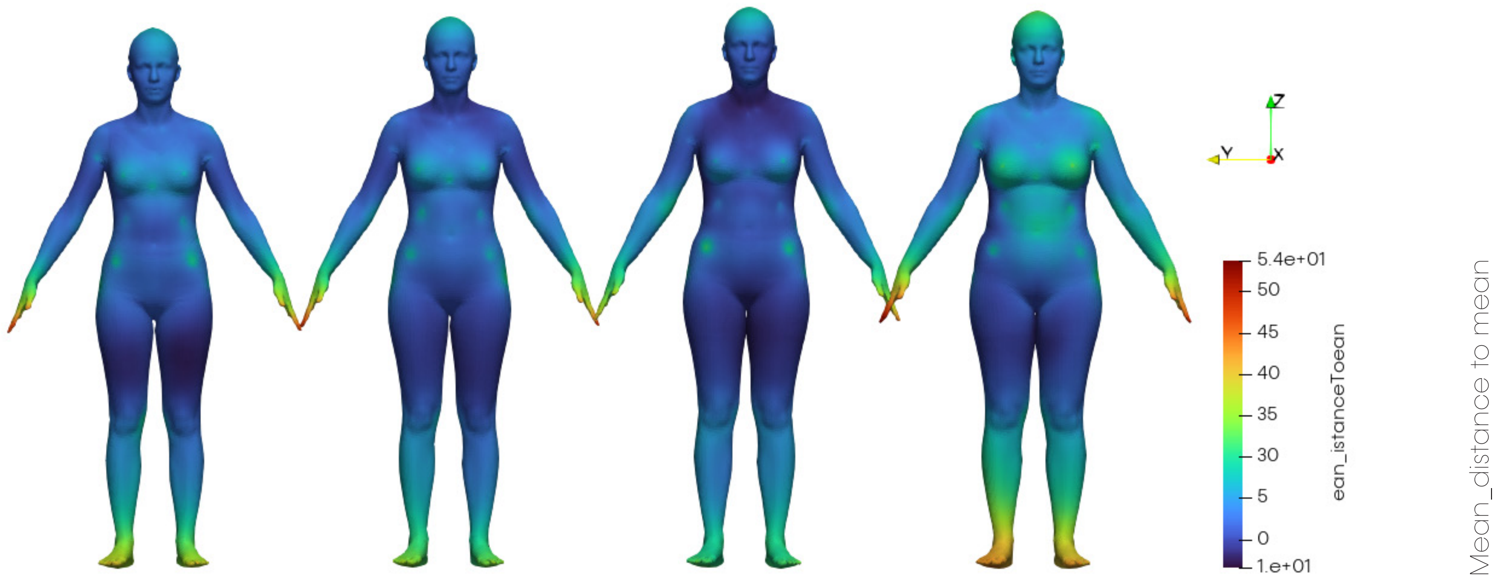


Fig. 29: Four blouse size groups (front)

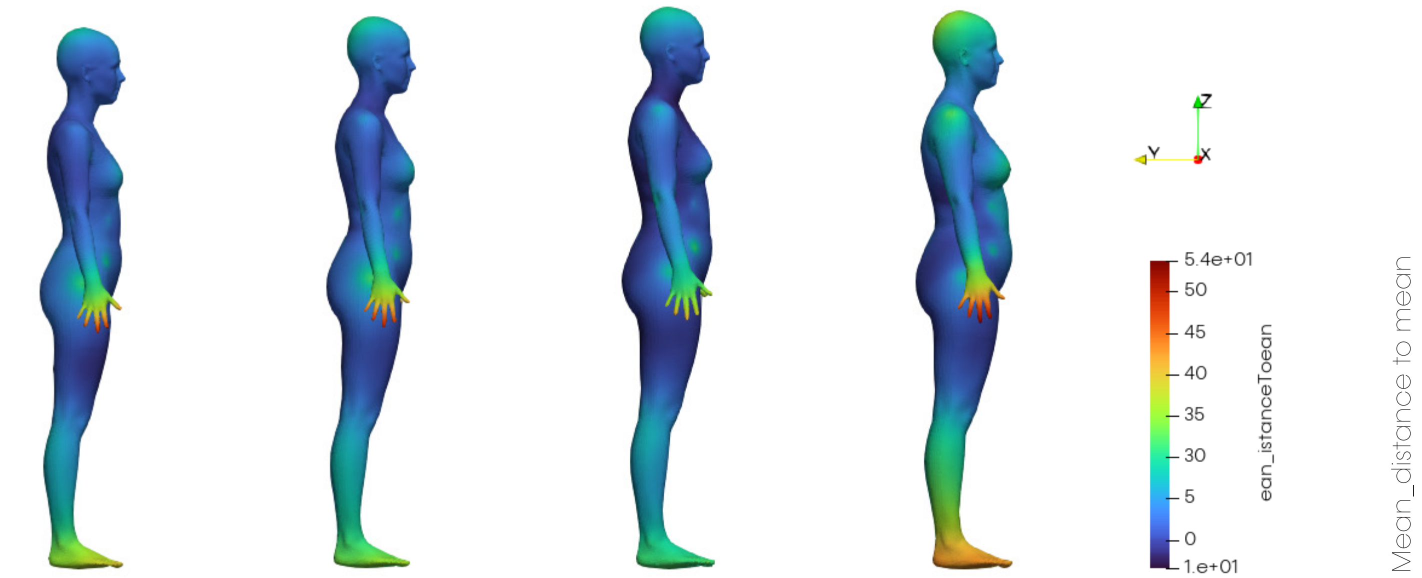


Fig. 28: Four blouse size groups (side)

To illustrate the findings from the 3D anthropometric models, scatter plots were created with data from certain measurement data from the datasheet. Hence, one can see in a diagram the subscapular skinfold plotted against the blouse size. In it, it can be seen that the dispersion increases as the blouse size increases, indicating that for the smaller blouse sizes there are more women with approximately equal skinfold thicknesses.

Since it can be assumed that female military personnel are generally much fitter and will therefore have lower values for skinfold thickness, it is plausible that the differences in blouse sizes are smaller.

In a scatterplot where the subscapular skinfold thickness is plotted against the Delta chest circumference, that is, the overbust circumference minus the underbust circumference - which relates to breast size, an optical correlation between these measurements becomes apparent. As skinfold thickness decreases, so does chest size and the variation in these readings.

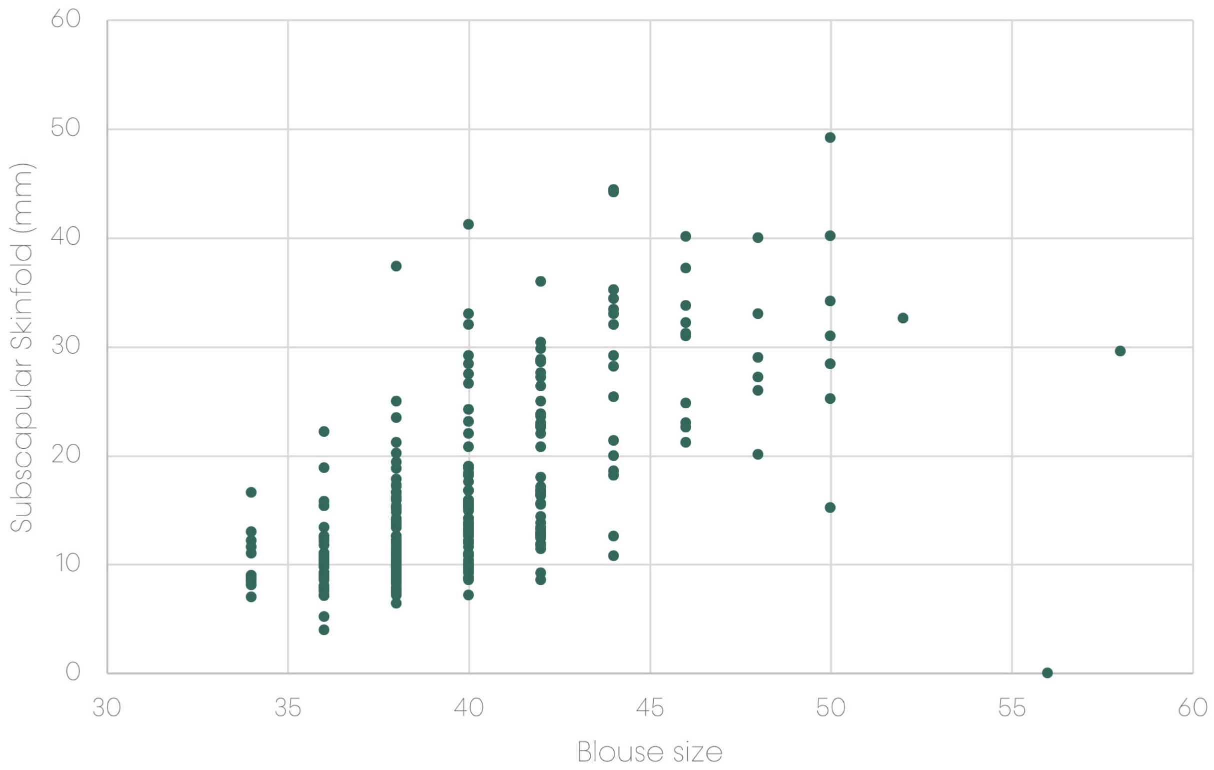


Fig. 30: Subscapular skinfold measurments accross the different blouse sizes (CEASAR, 2002)

Shape variability

To take away from the development of the anthropometric model is that for smaller shirt sizes in women, the variability in breast sizes and shapes is less. For larger shirt sizes, there is more possibility for women of different torso sizes to have underlying other body compositions, such as higher fat percentage, which correlates with variation in breast sizes. Thus, for the development of the female version, it is more advantageous to develop for a medium to large shirt size and assess how shape variability issues occur here in wearing comfort. In addition, it is interesting to see how this size would be experienced by women with smaller torso sizes as well as those with larger torso sizes.

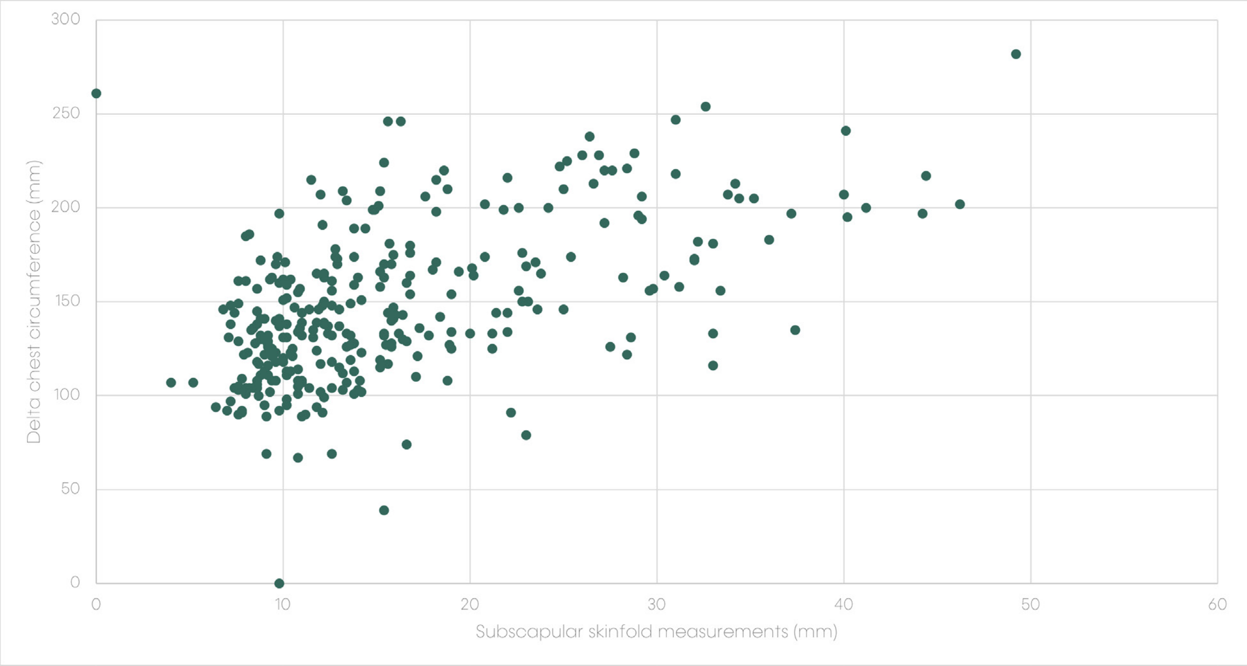


Fig. 31: Delta chest circumference plotted against the subscapular skinfold measurments (CEASAR, 2002)

3.7 OVERVIEW OF CHANGES TO FEMALE PHYSIQUE

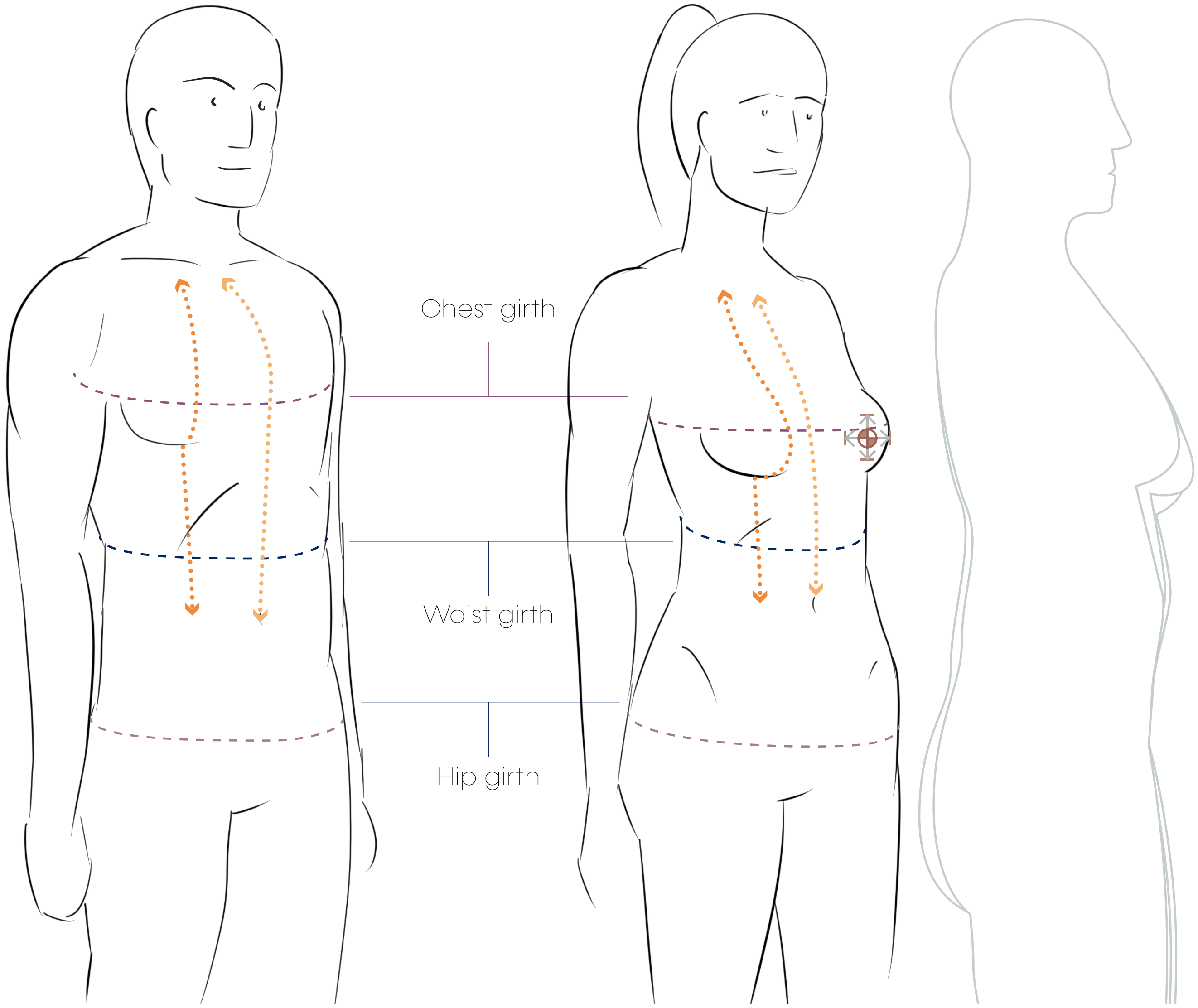


Fig. 32: Overview of changes from male soldier to female soldier physique

4 DESIGN DIRECTION

4.1 DESIGN VISION STATEMENT

For the design of the women's cooling vest, the study of the prototype showed that it is important that the air channels fit correctly against the body and conduct the airflow as smoothly as possible.
The current molds, combined with the pressure of the ballistic vest, deform in such a way that this connection is reduced and, as shown in previous studies of the comfort of wearing ballistic protection for female soldiers, this can be discomforting and even annoying. The moulds could be shaped to make this fitting as well as to increase the wearing comfort in combination with the ballistic vest by balancing the differences between these shapes.

In addition, the presence of a sports bra and the difference in regional sweat distribution between men and women give rise to a different distribution of airflow and thus increase the effective evaporation of sweat. Here the supportive function of the sports bra can be taken into account, which also shapes the breast in a predictable way. One option is to have less air flow over the covered part of the chest and more between the breasts and over the back at a higher rate over the spine, where there is higher sweat production.

To make the vest suitable for multiple sizes, the change in body composition between different shirt sizes for women was examined. This shows that in addition to variation in breast size, the circumference at the waist or under bust line can also vary greatly or the distance between the two. Regarding the shape transition that may be required for air conduction and body coverage under the ballistic vest, this is an important area. When assuming different postures, it is important here that there is sufficient room for movement and the risk of damage is small.

For the moulds, it is important to check how they fit a certain range of different body sizes. For women with smaller breast sizes, a mould shape could be similar to the one used for men. For research purposes, it is advantageous to design for more extreme shape transitions and to evaluate how the solution works out, both in terms of airflow conduction and wearing comfort.

With an effective design of the mold for the chest and back, the design of the vest is considered. The freedom of movement in combination with the ballistic vest is a focus for how the vest is ultimately adjusted to the body. To this end, research has been carried out into how comfortable pressure can be exerted on the upper body and how, for example, the sports clothing industry takes account of freedom of movement and simple adaptability.
In conjunction with the evaluation of the moulds, a sizing system will be established for the women's cooling vest so that there is a workable design for different shirt sizes.

4.2 PROGRAMME OF REQUIREMENTS

In order to limit and guide the design process, requirements are set, based on the conducted research in the initial phase and the set design direction and the prescribed programme of requirements for the DOKS (Defense Operational Clothing System). The POR established in DOKS is based on the Operational Concept Description (OCD), which describes the various requirements for single or multiple user sets, allowing the user to prepare different configurations of the equipment for varying activities. From this list, several relevant requirements were derived and formulated according to usefulness for the design of the ReSpire-F.

These have been supplemented with requirements that correspond to the preceding research and the requirements of the educational institution, with regard to sustainability and productionability.

Category	**ID**	**Requirement**	**Ref**
System	SYS_01	Garment shall form a system, to allow for selection and composition of appropriate configuration, meaning with the various types of clothing and legacy equipment.	
	SYS_02	The garment should efficiently cover for different situations, meaning in different climatic conditions such as temperature and humidity.	
	SYS_03	User shall be able to make adjustments with and within	
Comfort	COM_01	1.5 LEO for skin irritation, itchiness & pressure points.	
	COM_02	2 LEO with legacy equipment	
Mobility	MOB_01	Unhampered movement, meaning no different from wearing sports clothing.	
	MOB_02	Reduction of range of motion limited to 10%, compared to users wearing sports clothing.	
Sizing	SIZ_01	Primary dimensions used to determine the sizing system shall be: Body height and Chest girth	
	SIZ_02	Secondary dimensions used to determine the sizing system should be: Waist-, Hip girth and Arm length	
	SIZ_03	All users within one size with the corresponding body dimensions shall fit this size.	
Produceability	PRO_01	The shells shall be produceable with a minimal amount of steps.	
	PRO_02	The shells shall be cast in the same and single mould	

4.3 AREAS OF ATTENTION

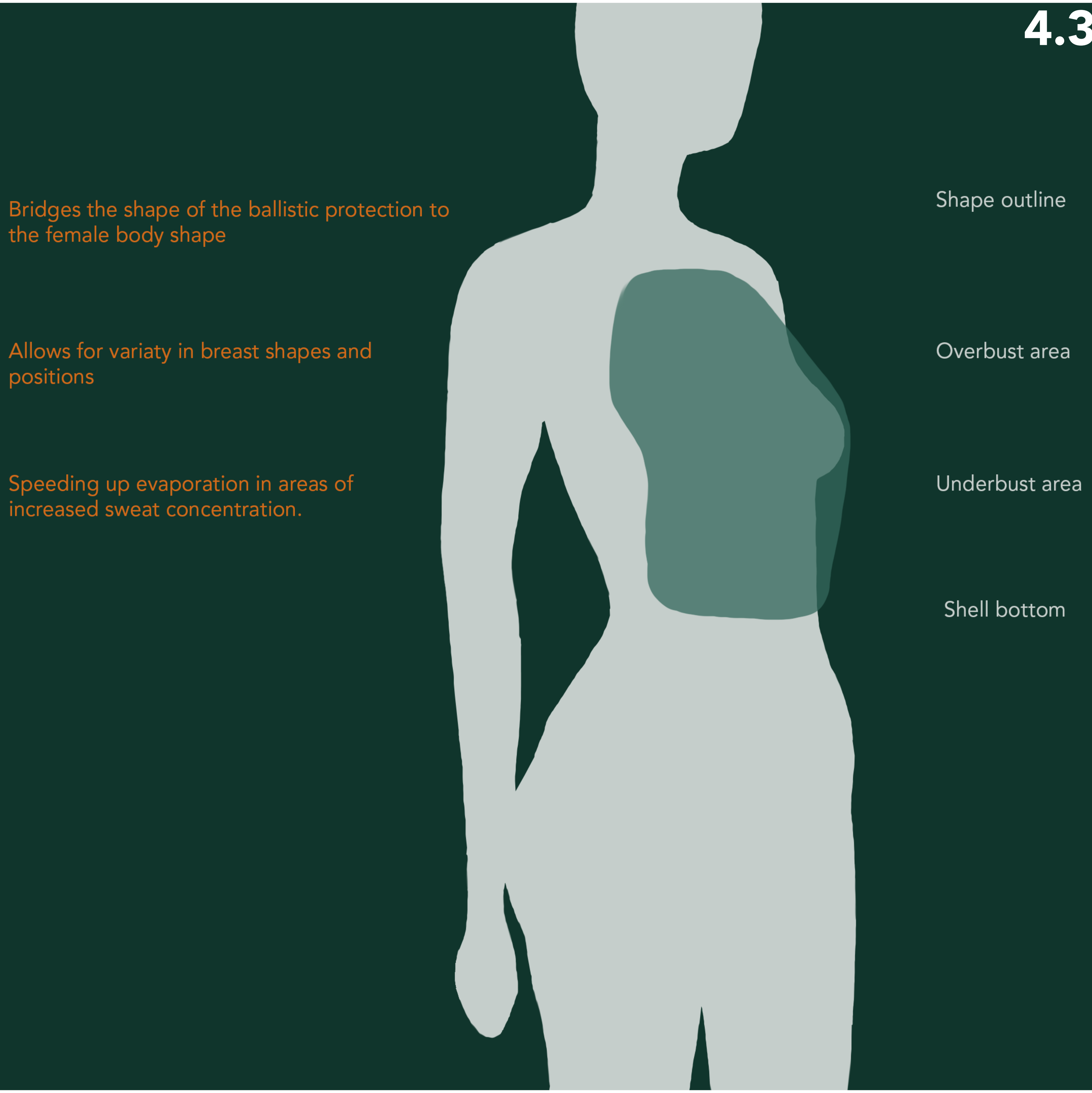


Fig. 33: Areas of attention

DESIGN DRIVERS & CHALLENGES

Some areas of attention in the design in starting the ideation phase were identified from the evaluation of the current prototype and from the research. A visual representation is provided (Fig. 33).
As it is difficult to qualify the impact of a certain area with regards of the wearing comfort for the user, the adaptability to various body shapes and the effective cooling through the vest, these are not to be seen established evaluation criteria. Rather they form a subproblem that could be solved in any imaginable way. Further along the various solutions can be clustered and be developed to a more solid concept and scrutinized.

5 IDEATION

5.1 INSPIRATION & DESIGN DRAWING

SPORTSWEAR INSPIRATION

In the sports industry, knowledge and experience is already acquired in how to adapt clothing or design clothing for the female shape. Especially in martial arts or certain contact sports, like American football, many products are designed not only to fit female athletes, but also allow for the various shapes and sizes of females and their particular desire for protection. These forms of equipment often contain hard or soft shells and stretchable materials, to both accommodate range of sizes, as well as offer tightening options to avoid hindrance.

Fig. 35: TUF Wear torsoprotection (Fightshop4u, n.d.)

Fig. 37: Spine VPD air WO vest (Ridestore, 2021)

Fig. 34: HER Protection Shoulder pads (Footygirls, n.d.)

Fig. 36: Triflex Lite Rugby Shoulder Pads Rugbystore, 2021)

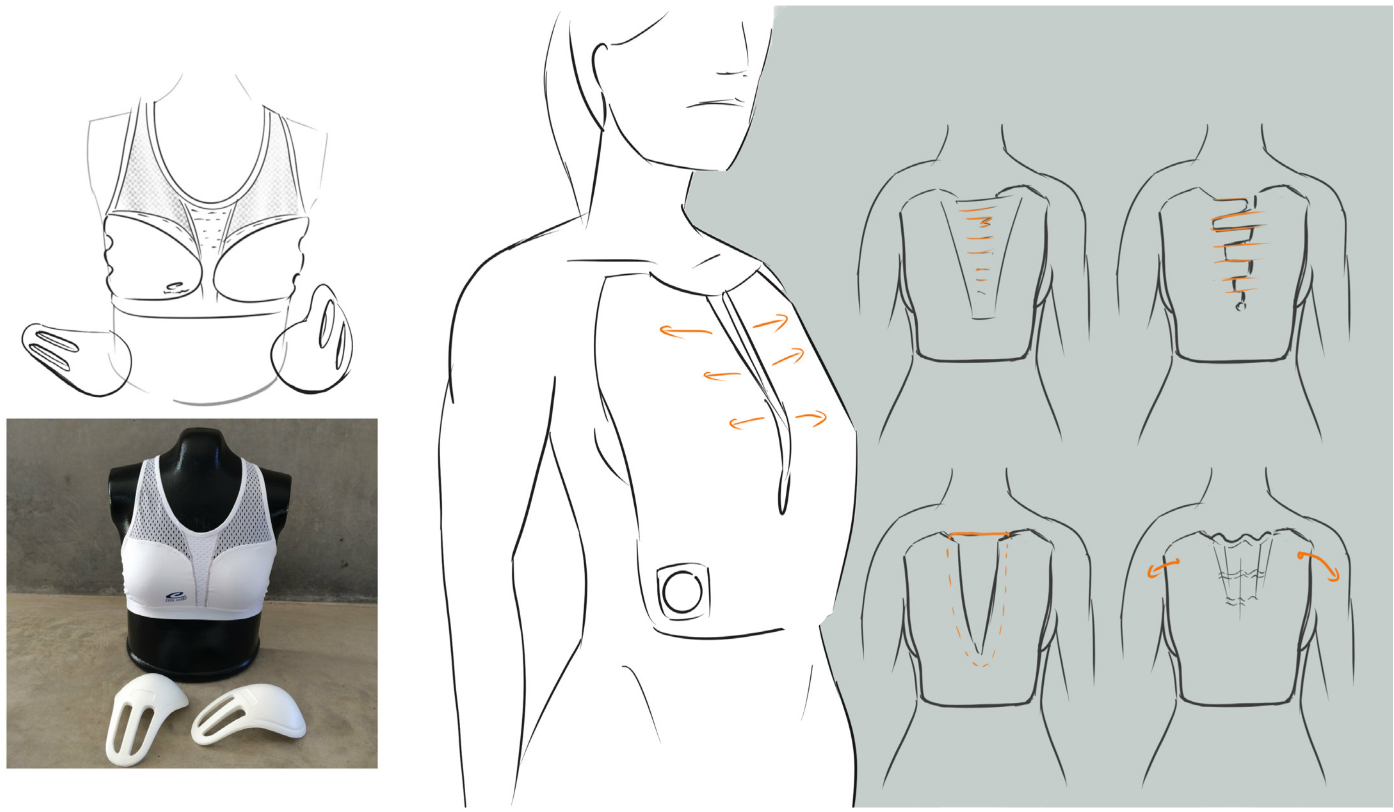


Fig. 38: Coolguard inspired shell designs (Aiki-Budo Sport, 2022: own visualisation)

What is noticeable is that the commercially available torso protection products avoid having large hard parts encompass the entire upper body in one view. Each breast is usually protected by an assigned part that could be correctly positioned and shaped along with it, dictated by the stretchability of the material or the pouch it is in. An example of this is the gilbert and fightshop4u chest protectors (Fig. 35), where both separate chest parts can slide sideways.

In football protection, it is noticeable that the protective pads have geometric fracture lines on the outside that are intended to provide flexibility, but also allow the material to be sufficiently thick to provide protection (Fig. 34 & 36). In the case of the foam bushes, this would inspire the implementation of such grooves on, for example, the outside in order to increase the concave flexure.

The Spine VPD Air WO vest (Fig. 37) has a back section in which perforations have been made, the main purpose of which is to increase ventilation. This passive form of cooling is said to be less effective than the ReSpire principle, but the holes offer more flexibility and could be a possible advantage in some areas where the foam part covers the body, but ventilation with an air flow is difficult.

The Coolguard chest protector is an example of how the principle of this flexibility can be accommodated for different body shapes. For the ReSpire foam chest piece, the continuation of the air channels should be taken into account to maintain the effective evaporation of sweat.

TRIMMABLE INSOLES TO SHAPE ADJUSTABLE FOAM MOULDS

A minor inspiration for making customizable foam shape to individual torso shapes is allowing for the foam mould to be trimmable, similar to insoles for footwear. By cropping the outer edge, mass produced insoles can be adapted to individual foot- and shoe shapes (Foothealth, 2021). These insoles are oversized in length and width and sometimes issued with guiding lines for users to crop by themselves to their desired shape. Around the heel the offset between guidelines for various sizes tend to minimal and near the toes the space inbetween is likely to be the widest.

For the foam shells trimming the outer edge would be a possibility to limit the excess coverage of a shell of similar size for a user with similar height proportions as another user, but smaller chest- or waist girth. However on the inside, the air ducts will run parallel to the trim edge, and cutting the width of the shell would affect the integrity of the outer air duct. Except a each guided trimline would be corresponding to an air duct and eliminating the outer air duct would induce significant leakage of air (close to the position of the ventilators), there would be legitimacy in testing this solution.

Another possibility would be to trim the top edge of the shell. This was also done in a certain way in earlier versions of the prototype by taking a strip across the width of the part and reconnecting it. It would be more advantageous if only the top line was involved, following the normal contour for the neck. The trimming of the top edge would make it more suitable for users of similar girths but different breast heights and sizes.

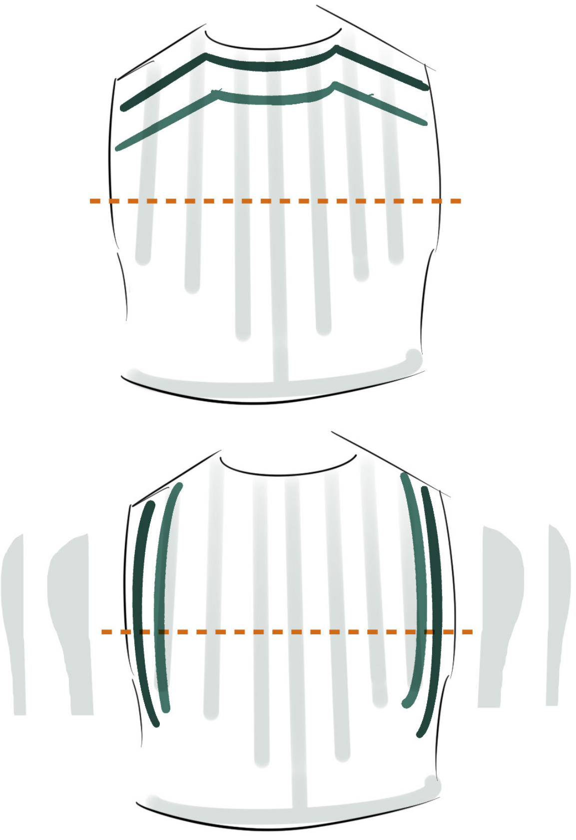


Fig. 39: Trimmable shells

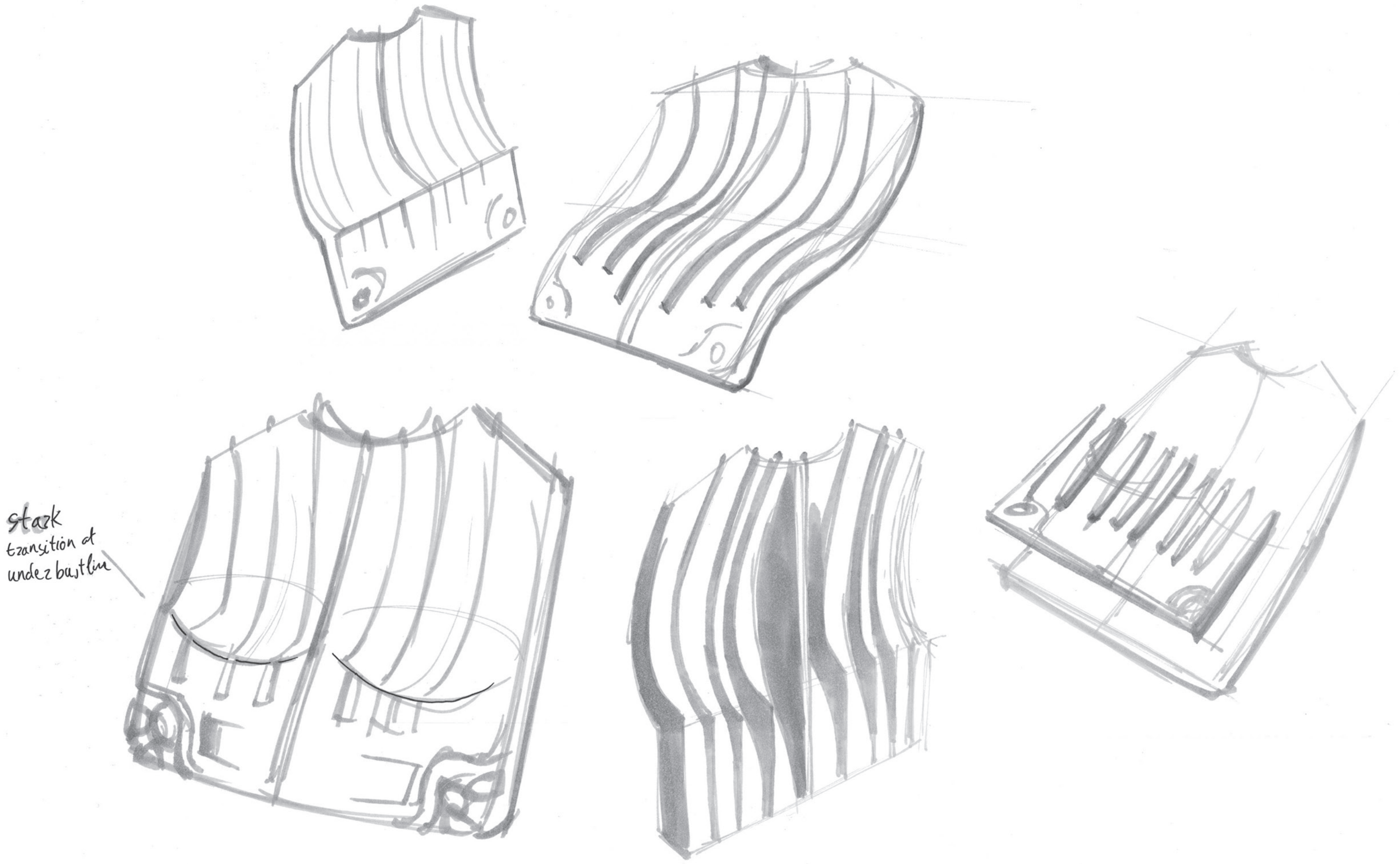


Fig. 40: Shape configurations

SHAPE CONFIGURATIONS

To adapt the front shell for the male soldier to the upper body of the female soldier, the shape will have to accommodate for the breast tissue and greater versatility. This becomes more challenging as the shape bends a certain direction and hampers the flexure in another, but it becomes even more complicated when it involves a concave shape. For example, this is problematic for the strong shape transition at the underside of the breasts, as a matching shape would then also have to have a sharp transition.

This transition fixes where the foam part would be placed on the body, especially in the vertical direction. In the event of displacement due to movement, this could result in a pressure point and possibly a subsequent correction by the user to achieve the most comfortable positioning. However, it is important to consider how a shape transition like this is perceived and the possible effects on airflow through the cooling vest.
It is to be noted that both the walls of the channels and the top wall are sharply formed. bigger transition for one of these features would also affect the airflow as well as the wearing comfort.

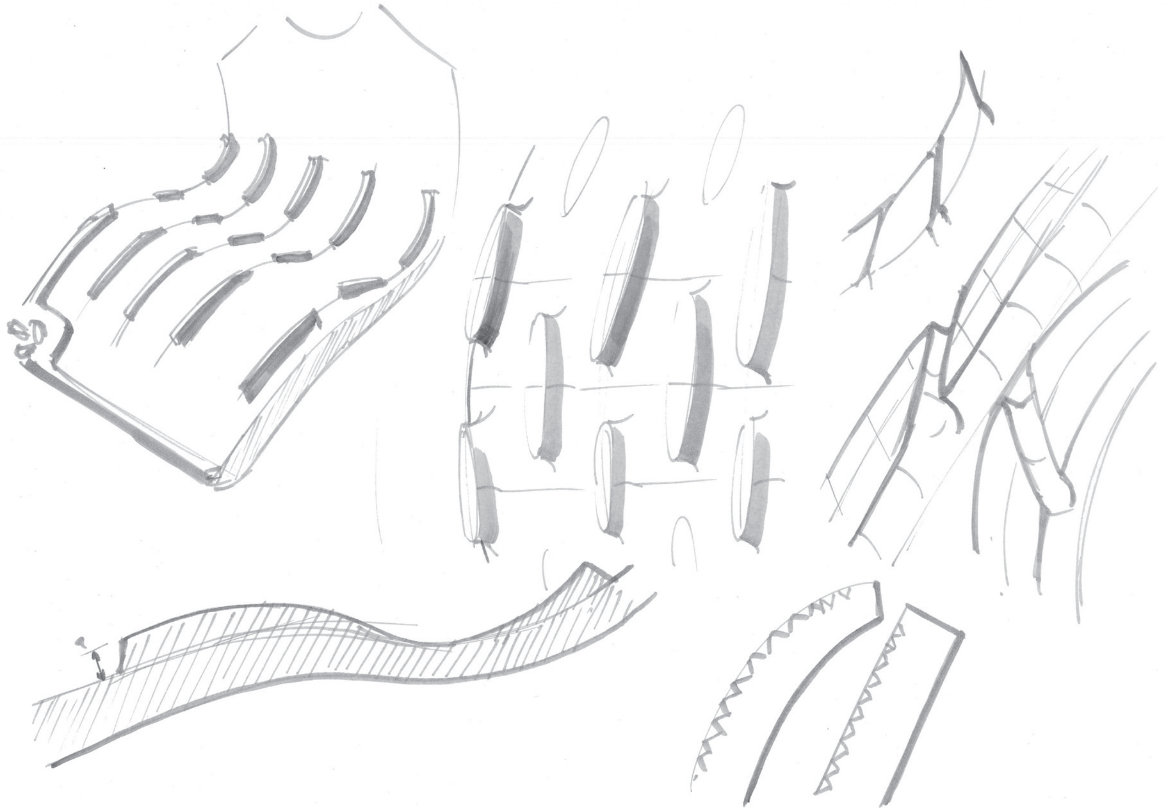


Fig. 41: Wall configuration

WALLS CONFIGURATION

The channels are shaped by the partitions, which are intended to direct the air as precisely as possible, but are also the actual point of contact with the user's body. In addition, the geometry of these strongly influences how the bust bends.
For the male version of the chest section, the air channels are very linear and the difference in channel depth is gradual from top to bottom and moderate from the centre to the outside. In order to increase flexibility, interrupting the walls could help to reduce internal stresses.
Certain patterns are then possible, such as where parallel walls are positioned with an offset to each other or aligned. The former is preferred here, so that not all the flexure is directed at a single line. The fracture line between these walls could also be oriented so that the surface of the air ducts is contoured as much as possible, but bending in the concave or convex direction is facilitated by allowing more slack with oblique fracture lines.

CROSS-SECTION

The geometry of the cross-sections of the walls can also be adjusted. In addition to adjusting the depth and width, an oblique orientation with respect to the normal of the bust is depicted in Figure 42. Under skin pressure, these walls would deform differently, e.g., more inwardly, and thus possibly better fit to different convex body shapes and reduce the chance of air leaking from the sides.

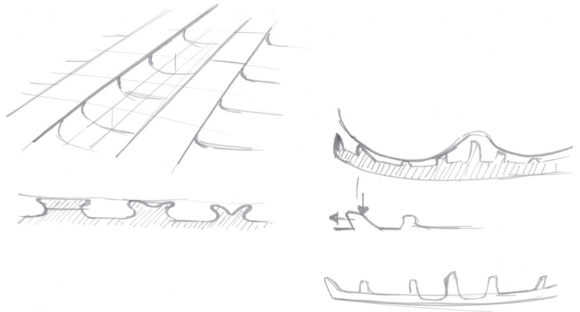


Fig. 42: Cross-sectional wall design

EXTERNAL SUPPORTS

Currently the exterior of the foam busts is a smooth surface, only gradually variable in thickness to the interior contact surface. As the soldier is also wearing a VOSS ballistic protection vest, there is external pressure for the foam bust to align to the skin. However since the internal shape of the VOSS vest is based on the male soldier this would allow room with the shape of a female soldier. The external supports, when combined with the ballistic vest, would allow the foam bust to be more compressed in specific locations and in potentially more controlled. The supports could also be trimmed to reduce the applied pressure to the extent less deformation is required due to a flatter body shape of the soldier.

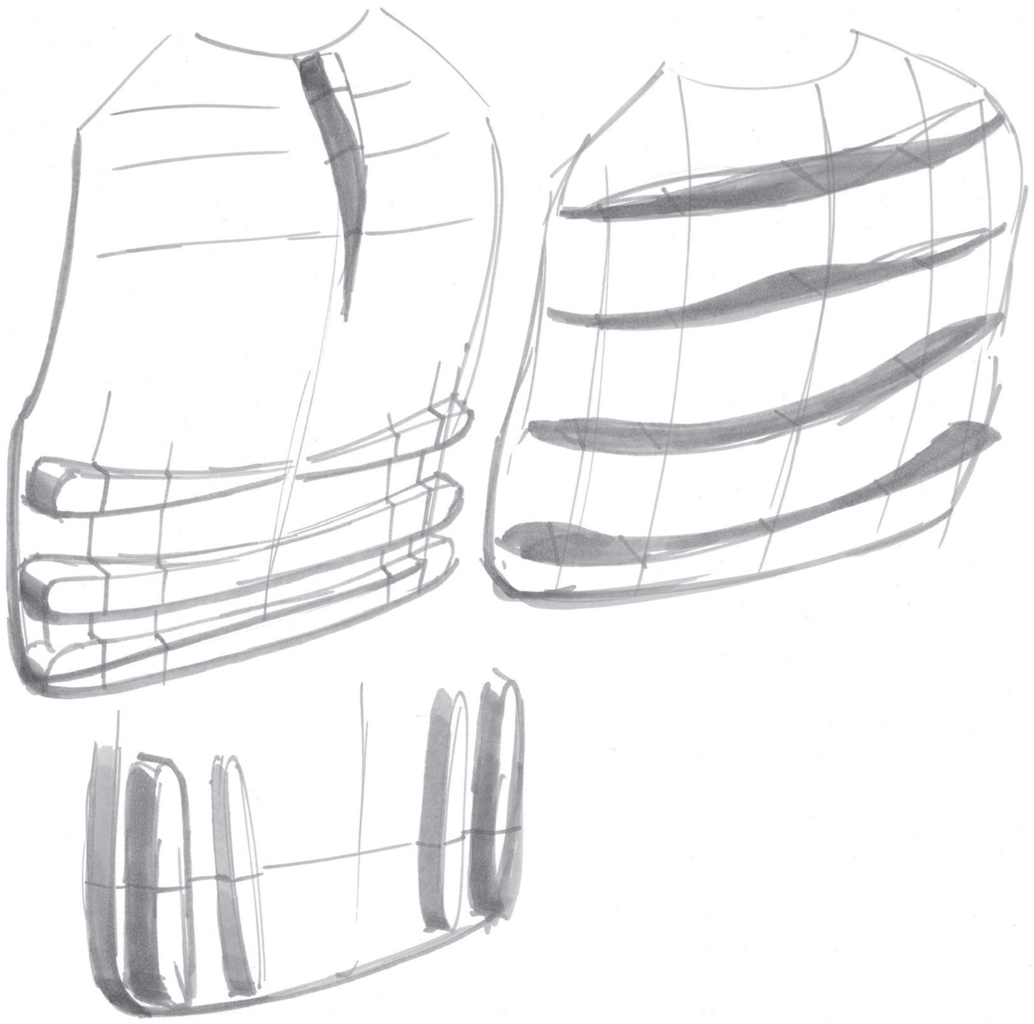


Fig. 43: External support structures

5.2 CONCEPT GENERATION

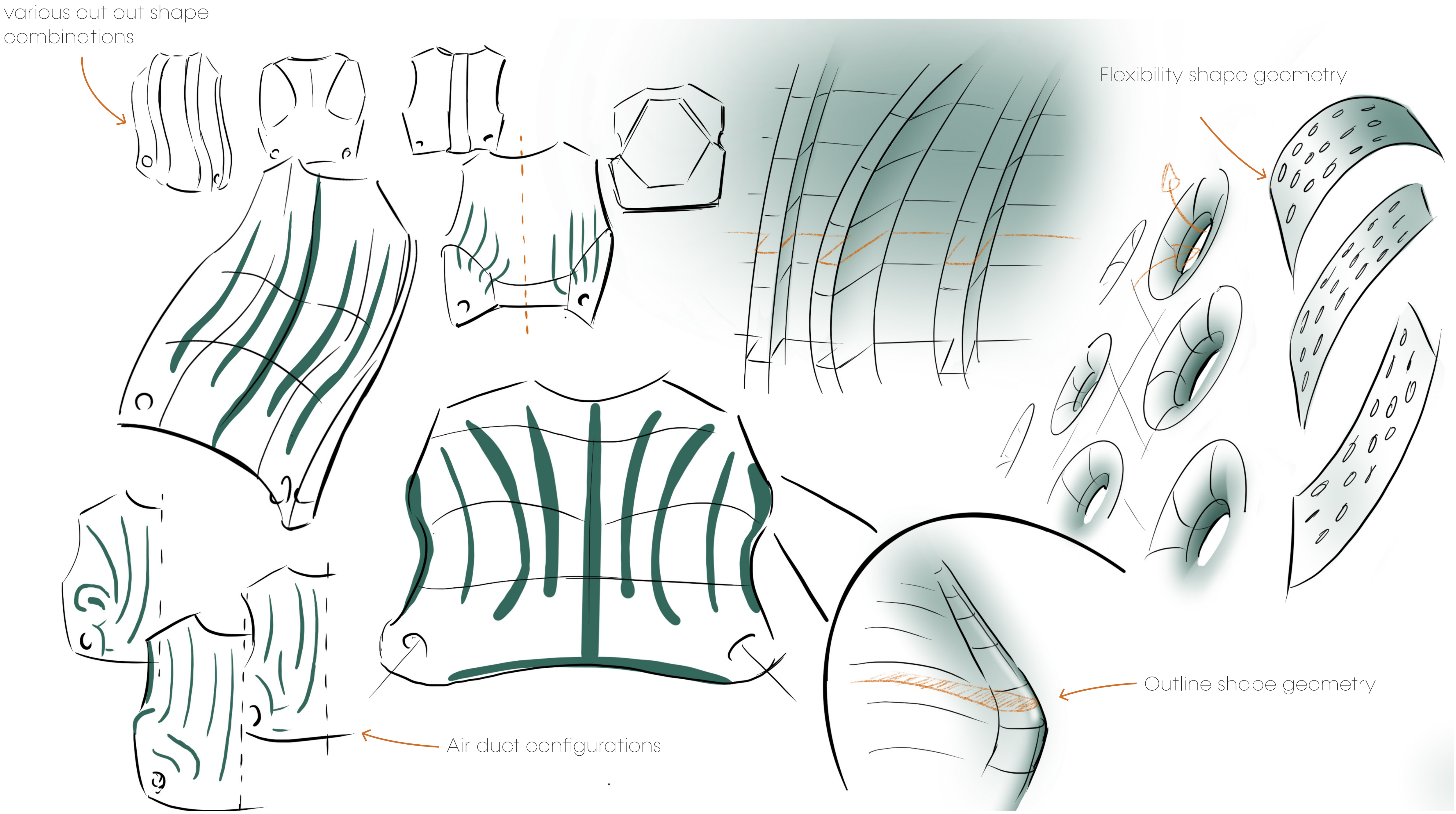


Fig. 44: Clustering and directing ()

As the findings from the research direct the desired airflow to be concentrated at area around the sternum and the spine, the differentiation in ideas was in finding how to accomodate for the different body shapes and ensuring enough sealing between the shell and skin to provide effective airflow. By sticking to the current design, this meant that a single mould would need to be flexible and predictable in deformation enough that, despite sharp transitions, the airflow would not be able to escape directly from under the bust. By means of pre deformed features this shell would be tucked in tightly at this area.

Another direction would be to allow for more sharp and angled geometry at areas like the underbust without compromising for variability, by allowing for the shape to be trimmed and adjusted for multiple body measurements. For the direction of the airflow would largely remain the same under different alignments and trimmages. The area between the underside of the shell, dictated by the underedge of the VOSS vest, and the underbust line would then be covered by one part of the design, whereas another part would cover the overbust area

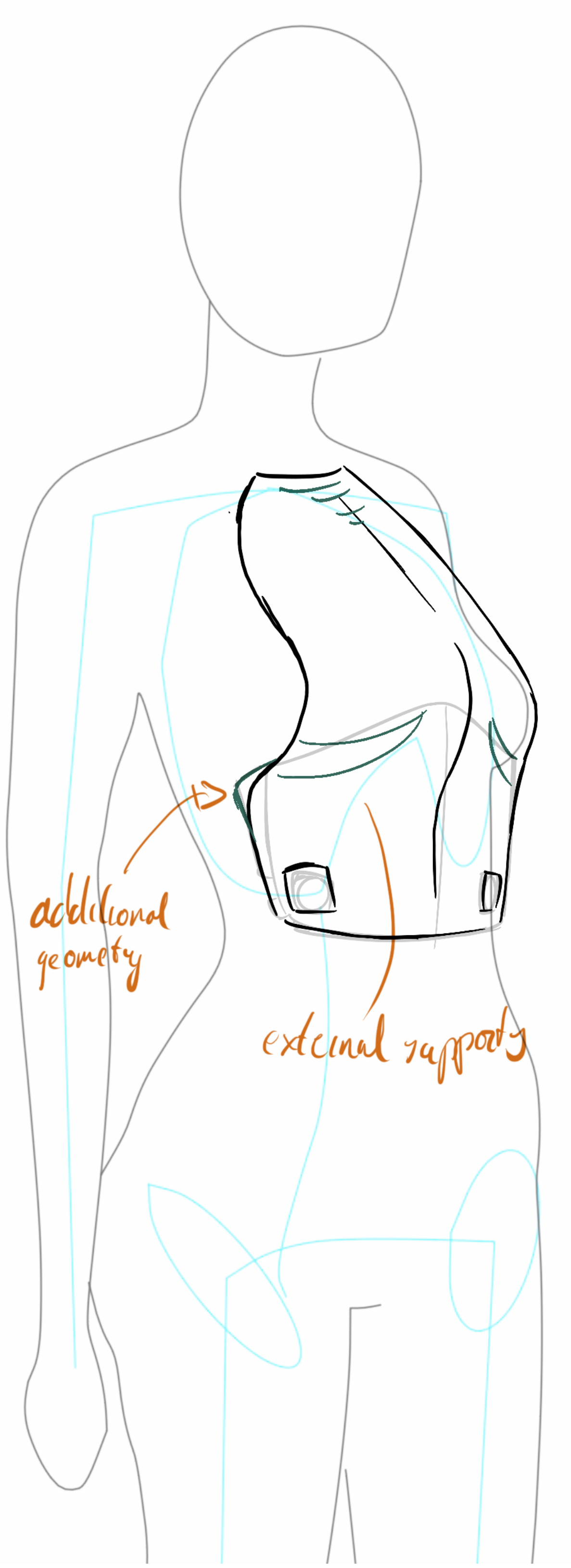
A more extreme variant of this direction would be to only effectively cover this area of the female body, as the sport brassiere complicated the cooling by ventilation of a major share of the overbust area. The sweat that is not able to evaporate under the fabric of the brassiere will as dripping sweat enter the underbust area, where it can be vaporised by the amplified cooling in this area.

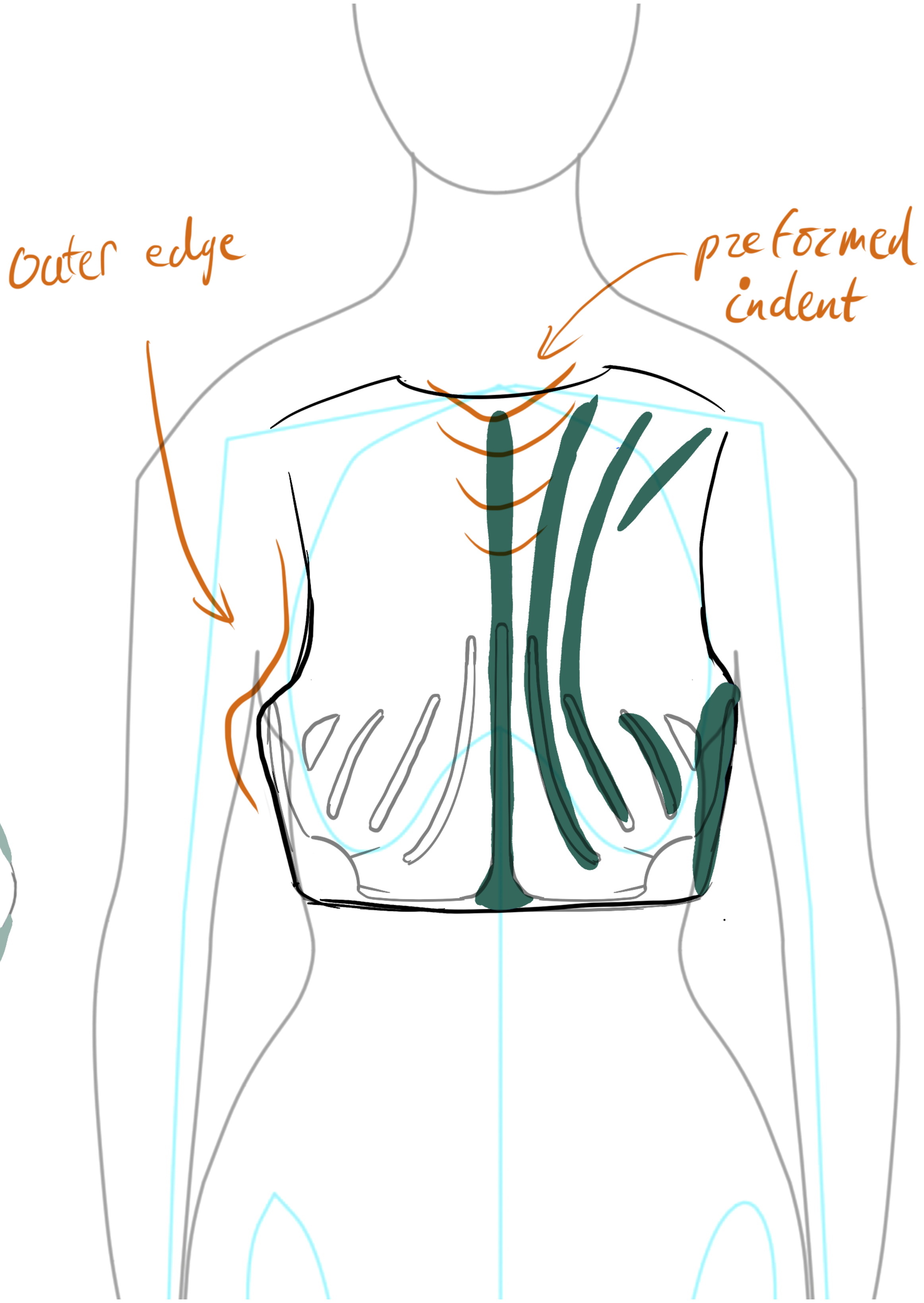
5.2.1 CONVENTIONAL

This concept is similar to how the current front shell is designed, however with the particular body shape characteristics of the female subject in mind. This has as an advantage that the pouch for insertion is not likely to require significant revision. For this concept the flexure in the under bust area is important, as here it will need to be flexible enough to align to the skin, but it can be enforced by having the outer line already follow a tighter radius. By tightening the straps and under pressure from the Carrier vest, the shape would accommodate correctly.

The upper part of the shape can be trimmed to fit more sizes, reducing the need for different molds for multiple sizes. Determining the correct thickness will be more challenging, as the shape will be bend in multiple directions and that could lead to undesirable interaction with the subject.

To allow for the shape to fit correctly in the concave areas, implementation of external supports might be beneficial. At the under bust line the outer edge of the shape is trimmed further outwards to seal this area, before it tapers in over the bust area.



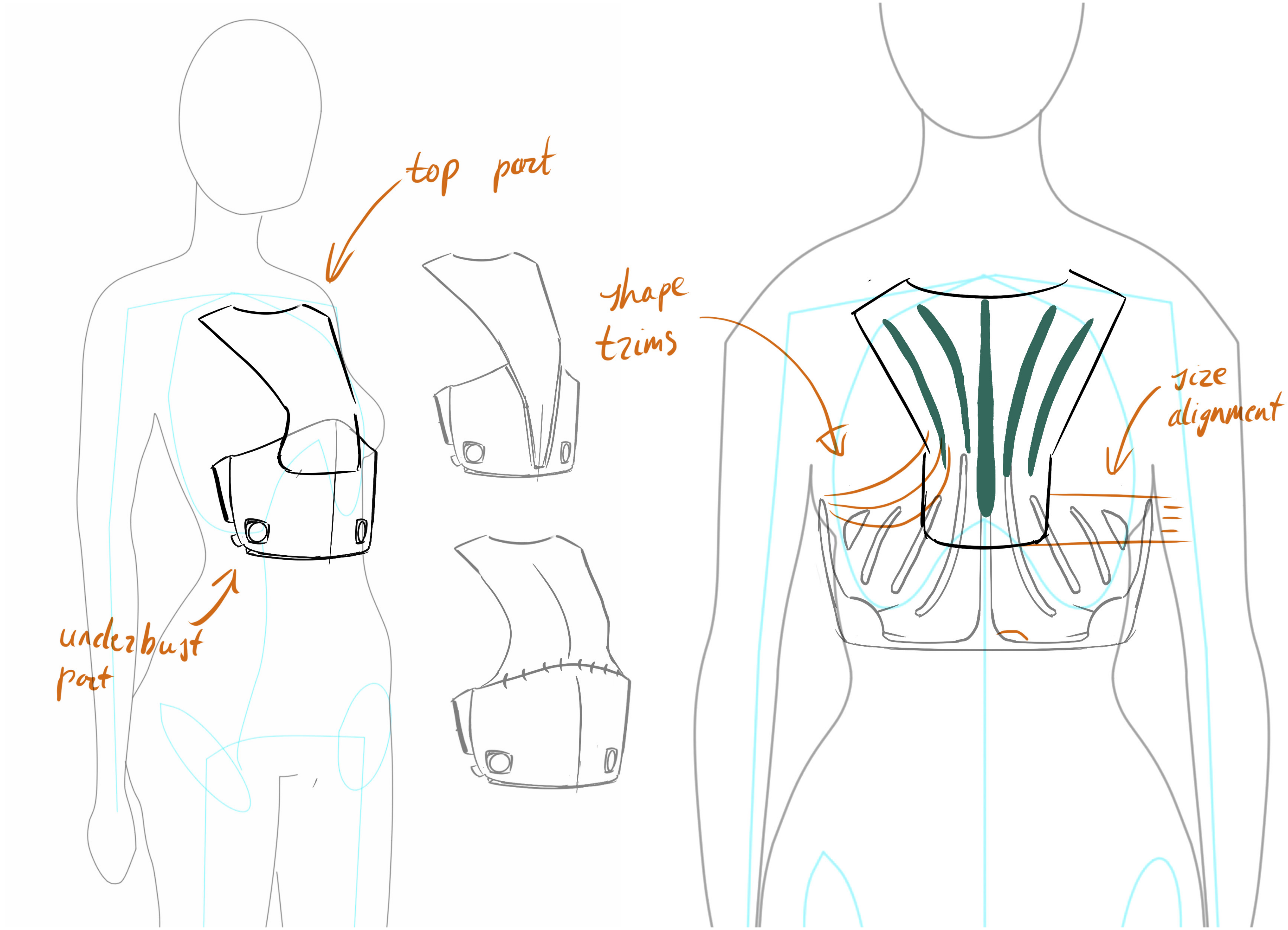


5.2.2 2-COMPONENT

This concept allows for multiple size adaptations, as both components can be trimmed at their respective top edges and be aligned at different heights. Adaptation of the pouch in the carrier vest will be minor, as the shape is slimmer at the top and is therefore prone to misalignment. The ventilation will be more targeted with this concept, leaving a significant part of the covered breast to be unventilated.

The design does require more manufacturing steps, as the components will have to be connected, likely with adhesives. As this increases the geometry at overlapping parts, the shape is less flexible and therefore insertion into the pouch is more difficult.

Further development will need to be put in how to align the corresponding walls from the underbust part to the overbust part and how the airflow is affected at the parting line.



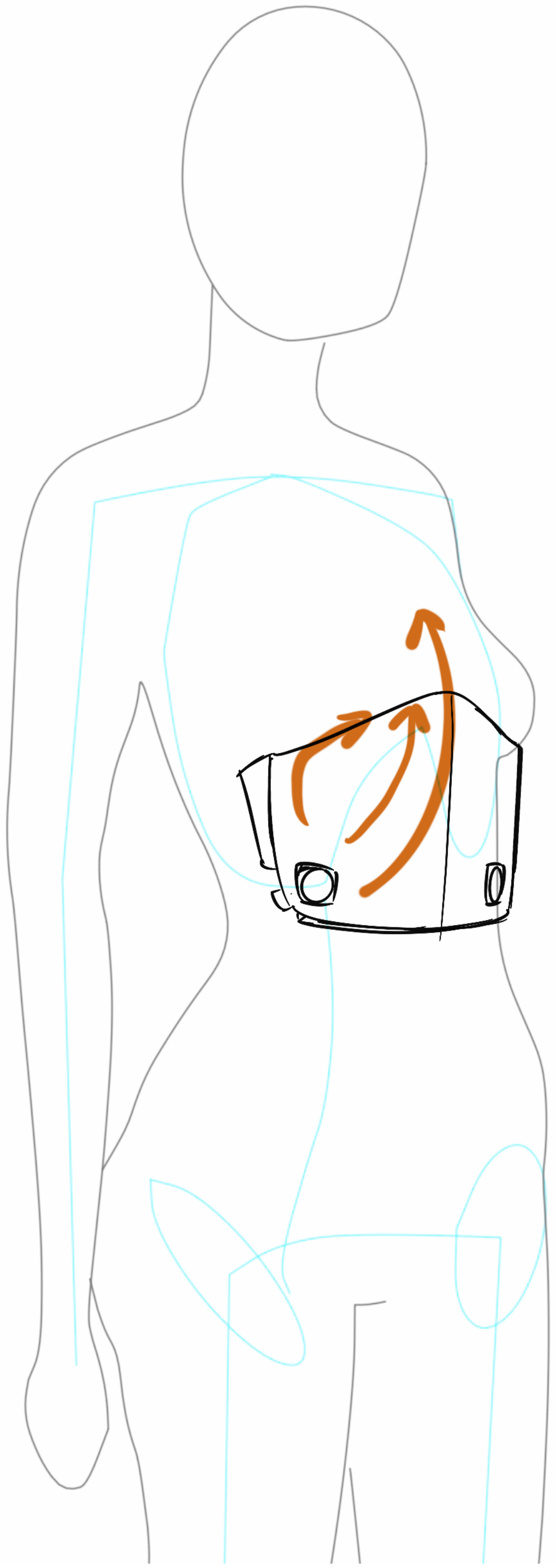
5.2.3 UNDERBUST SHELL

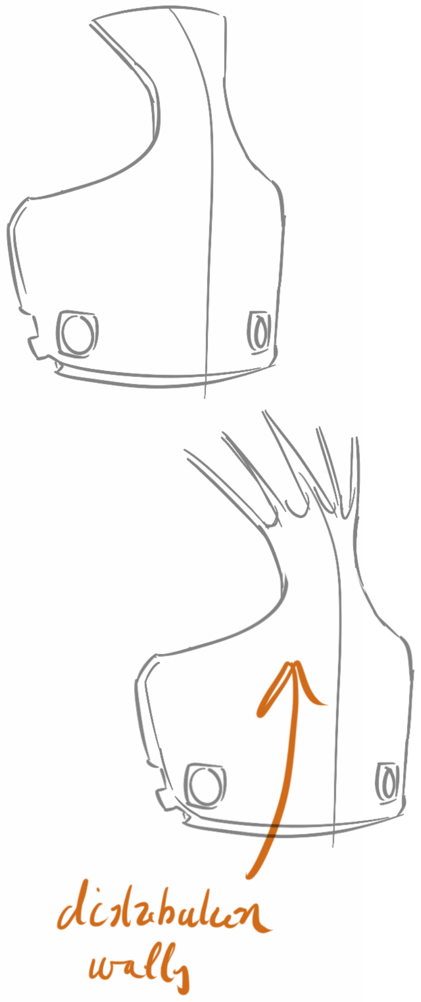
The third concepts is the most extreme, as it leaves a large portion of the front torso uncovered and thus not ventilated. The surface that in turn is more ventilated is subject to higher airflow and wind speed, increasing the effective ventilation. Also the shape can be trimmed more closely to individual shape characteristics.

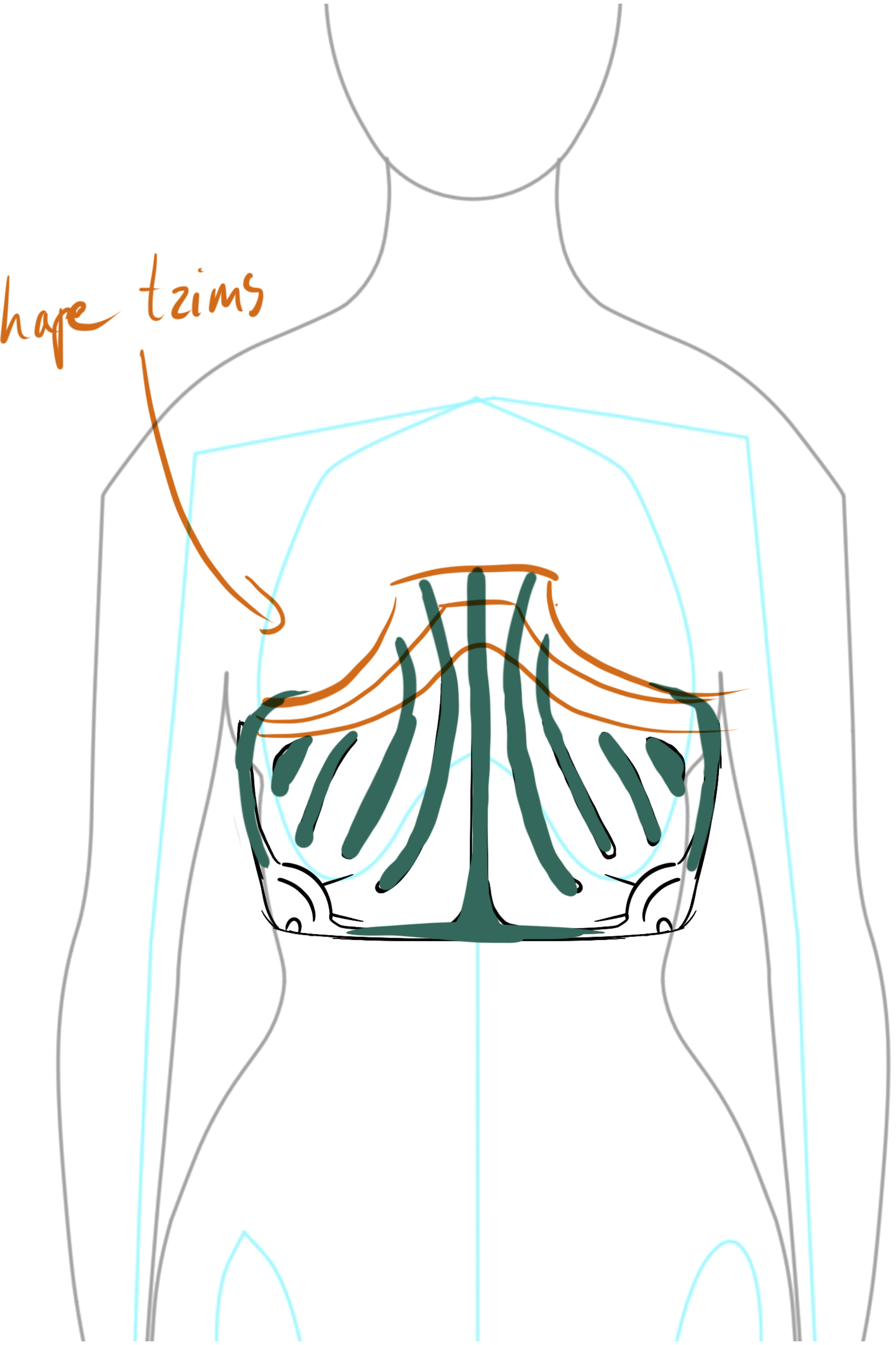
This requires more manufacturing steps and for fixation in the pouch (of the carrier vest) it is likely some connectors are required.

A distribution piece, where the walls of the ducts are continued, is a possibility for more targeted ventilation of the upper part of the chest.

The shell might also be prone to be dislocated within the pouch.







5.3 WEIGHTED CRITERIA

CRITERIA

Fit & comfort 35
Because the cooling vest must integrate with the soldier's combat equipment and is in direct contact with both the soft tissue and the ballistic protection vest, this is an important criterion which is difficult to divide. What factors into this criterion are the additional load under vest and the possible deformation this gives to the foam shapes, the range of movement that the design allows and how the design compensates for the shape variability.

Cooling effectiveness 30
For this criterion, it is important what the expected effective cooled surface is, how the air flow is distributed at a certain speed and how the air flow is controlled as gradually as possible. The cooled surface should preferably be as large as possible, but if the airflow has become so saturated or is disrupted by abrupt changes in direction, this is also a consideration in the end.

Ease of assembly 20
The easy application of the foam loops is a design criterion for the cooling vest, as it is a requirement for the repeated cleaning of the vest. Thus, the part must be removable and attachable by the user and the risk of damage must be limited, both to the foam part and to the carrying vest as well as to the electronic components.

Implementability in sizing system 10
This criterion is important for how the final design of the foam bust can be implemented in the sizing system for the cooling vest. For this it is important that the component has the ability to sit in different sizes of pouches of the vest, fit correctly and remain fixed in position under the influence of movement and in certain postures. This criterion is different from the first one because there is still the possibility for post-processing of this component and the composition of a sizing system needs to be further elaborated depending on the chosen design for the component.

Sustainabi lity 5
This is a criterion that contributes to the consideration of a design that takes into account the limited expected circulation, lifetime and repairability of the design. The part is the most speculative, because it has a lot to do with how the user interacts with the product and as something that can be determined in the long term.

SELECTION

The weighted criteria table indicates that according to the set criteria, the 2-component concept shows the most potential, followed by the conventional shell. The decreased cooling effectiveness of the underbust shell is not likely to be compensated enough on other criteria. Ease of assembly score of the shell is low as it is expected to be requiring additional fixations.

The other two concepts are to be furter developed in comparison to the anthropometric model to acquire the correct dimensions. The weighted criteria matrix reveals more areas for improvement. For further treatment of these, the prototypes will be developed first to get a better understanding of how the designs can actually be shaped.

Criteria	Weighting	Concept 1 Conventional		Concept 2 2-Component		Concept 3 Underbust	
		Score	Total	Score	Total	Score	Total
Fit & Comfort	35	3	105	4	140	4	140
Cooling effectiveness	30	5	150	4	120	3	90
Ease of assembly	20	3	60	3	60	3	60
Implementability in sizing system	10	3	30	5	50	4	40
Sustainability	5	3	15	4	20	3	15
Total	100		360		390		345

SCORING SUBSTANTIATION

Fit & comfort:
On the first criterium, the Conventional concept scores a 3 out of 5, as the shape would be largest in outline and therefore tend to limit the user's mobility, on top of the inherent rigidity of this shape. In combination with the ballistic protection vest this concept is able to distribute the external pressure over a larger area of the torso. For the 2-Component concept and the Underbust concept are more narrow and thus more flexible with the deformation of the torso during movement.

In addition, the 2-component model offers more freedom of adjustment by placing the parts on top of each other at different distances and even trimming both. The underbust concept also offers this, but to a lesser extent, but makes even better use of the existing space between the ballistic vest and the female torso. The thickness of the 2-component concept can be very rigid around the underbust point and with the underbust shell, the dividing piece between the breasts can also feel uncomfortable under the external pressure.

Cooling effectiveness
The conventional concept is expected to be the most effective of the concept, as it covers the largest surface. Also the air flow distribution is to be the most linear and least disrupted. The 2-component prototype cover less surface area, however this lost area is mostly covered by the sports brassiere. A similar amount of air flow can be applied to a smaller area of exposed skin at the top of the chest, countering the saturation of water by increase of velocity.

The underbust component also covers an even smaller area, however the underbust area should be ventilated more effective, as the shape should allow for the airflow to stick close to the skin. With this concept however, the airflow is to make abrupt changes in direction with severe turbulence as a consequence, which in turn leads to less effective evaporation at further locations in the ducts.

Ease of assembly

During insertion and extraction of the component in and from the pouch, the conventional prototype will be the most difficult to get through the opening at the bottom as it will need to be rolled bend all over the length. When placed the other two concepts are likely to move within the pouch in its current design. With addition of fastening components or alteration of the pouch to secure the foam shells in place, the ease of assembly will decrease. Therefore on this criterium with all three components, it depends on how the final pouch is constructed and how quickly the user gets skilled with putting it together.

Implementation into sizing system

The 2-Component concept offers the widest range of possible adjustments and a customization possibilities and fit within the expected convection sizes of the carrier vest. As part that covers the overbust area and the one for the underbust area can be selected independently from each other, the likeliness of ill-fitting configurations is small. For the Underbust concept this is less applicable, as it will only cover this area and is more susceptible to displacement.

The shape of the Conventional concept is most similar to the shape of the pouch, however with solely trimming the length the possibilities for size adaptation are minor.

Sustainability

The Conventional prototype is in order to be adjusted to a wider range of sizes to be trimmed at the top or a wider range of moulds will be required. However, since the shape is simple, with no major area susceptible for damage and in turn shortened lifetime, the concept score quite moderate on sustainability. The Underbust components also scores moderate as this concept has more geometry that can be damaged during use, but in case of irreparability, the loss of material is smaller.

The 2-Component concept is in between both concepts on pronation to damage and following loss of material in case of irreparability, however as on or the other component is severely damaged, the intact component can still continue to be used.

5.4 PROTOTYPING

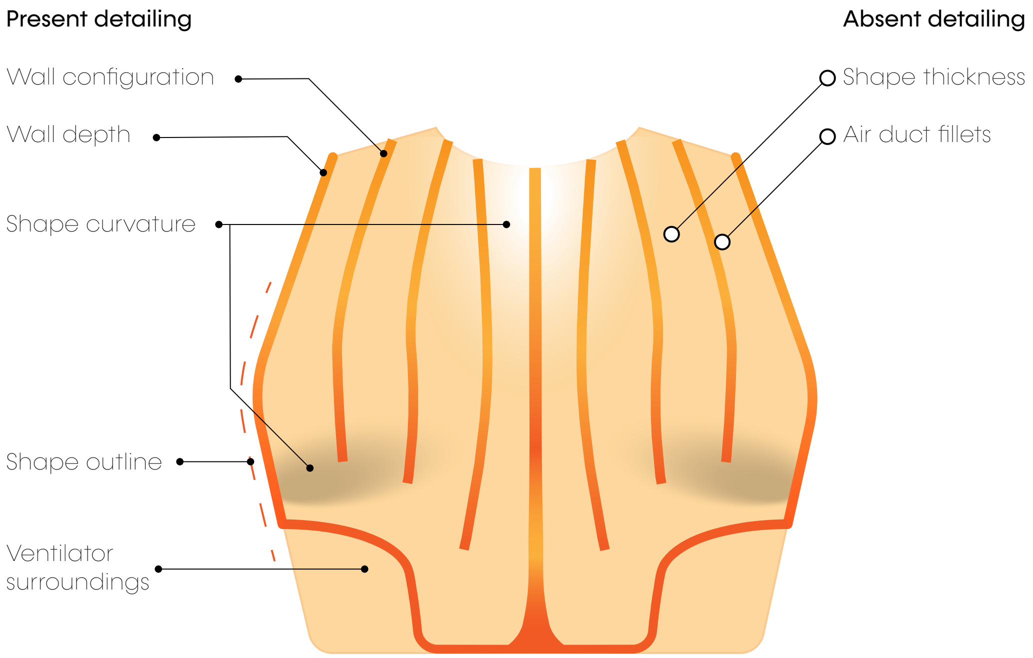
OBJECTIVE OF PROTOTYPING

The reason to translate the concepts into physical prototypes is to test how the shape and construction of the foam shell would behave in reality with the human body and how the user would perceive the prototype during use. How the airflow will be distributed within the shell is something that can be assessed, however to a limited extent, as this is highly affected by the shape on which the shell is placed and how the body deforms under it in reality.

The degree of elaboration of the physical model is the size and shape of the overall form. This also means where and how it is curved towards the body and where the geometry becomes thicker or thinner, according to the desired dimensions and configuration of the channels and the presence of the fans and surrounding geometry, for air inlets and the opening to the inside.

The decreasing thickness of the overall shape towards the top and the outside is not included, as it requires a lot of processing per model and for the evaluation it is less accurate to verify how this affects the wearing comfort in the absence of a ballistic vest.

In addition, the fillets in the channels will not be applied, as this would require considerably more material and processing time to integrate all the concave shape transitions. The added value applying fillets would be in reducing the resistance caused by turbulence in the ducts, however, this would increase proportionally for each duct and thus have limited influence on the distribution of air flow and speed. For this stage of development the level of detailling is sufficient to check with subjects and to conduct lowkey air flow testing.



PROTOTYPE CONSTRUCTION PLAN

To make this prototype, it is important to frequently check during the building process whether the three-dimensional shapes continue to correspond to the defined dimensions and how parts fit together. Therefore, the main shape was first determined as a cut-out of the foam sheet by the Clo3D measurements, before it was cut out and shaped. Only then were the walls for the channels cut out and the further detailing applied.

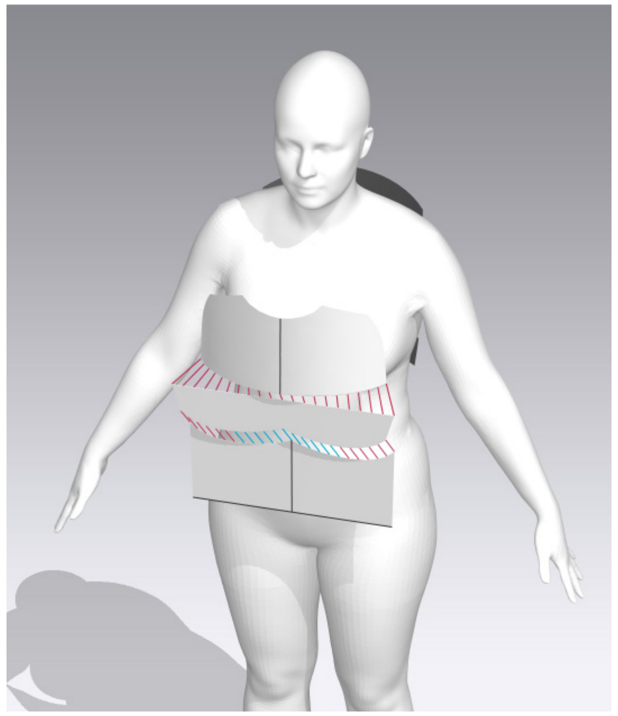


Fig. 45: Pattern building on anthropometric 3D model in Clo3D software (Clo3D 6.2, 2022)

CLO3D SOFTWARE

By using the Clo3D software in combination the anthropometric model (Fig. 46), patterns could be developed with three dimensional properties and in the correct dimensions (Clo3D 6.2, 2022). The software is used in the industry to digital design and simulated how these would interact with a 3D mannequin.

Based on templates within the programme and the size of the normal shell, for male soldiers, compared to the VOSS B vest. The 2D patterns were then exported as an Adobe Illustrator file, so these could be printed on paper.

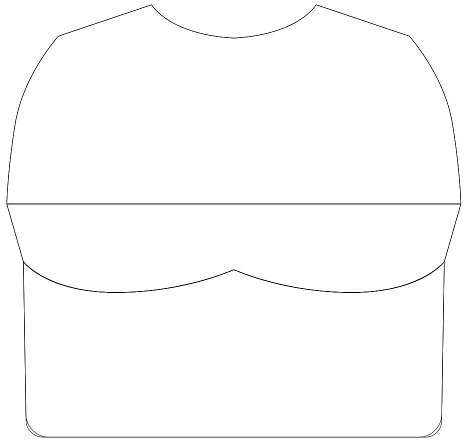


Fig. 46: Base Illustrator template extracted from Clo3D pattern

MANNEQUIN DESCRIPTION

A mannequin was purchased to make and test the prototypes. This mannequin was chosen in preference to the stylised mannequins used for displaying clothes.

The mannequin is of a small and slender size, with a waist circumference of ~63 cm and ~85 for the overbust circumference.

In addition, the breast parts protrude far from the chest, but this is advantageous for the thermoforming of the breast parts. Since the moulds always return somewhat to their original state, more extreme deformation is required before the desired curvature is obtained.

Following are images of the uncovered mannequin. A stand was also provided, so that prototypes can be hung on the mannequin with additional weight to carry out certain tests, to check the effect of loads.

EVA FOAM PROTOTYPING

For materializing the prototypes, EVA Foam was acquired, which is used by hobbyist but also in the industry to make mock-ups of sturdy garments. The foam can be easily worked on with tools such as box cutters or a Dremel with a sanding head. First, the shapes are cut out on the basis of the paper patterns before they can be shaped in 3D. The 3d forming was done by heating the shape with a heat gun and then deforming it over, in this case, a mannequin. After cooling, the foam is able to hold this shape and the various 3d shapes can be glued on.

It was then possible to measure the desired partition walls before they were cut out and, if necessary, thermally deformed and glued in.

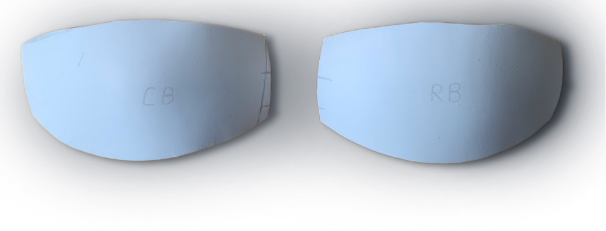


Fig. 48: Underbust foam cutouts after thermally forming these to 3D shapes

TEST PROTOTYPE

The first prototype made was tested as a the normal shell projected on the female shape. This involved changing the current shape of the prototype to match the shape of the female torso, but with the same configuration of the air ducts. The shape, therefore, involves making room for the breast tissue and the sharp transition at the bottom of the breasts.

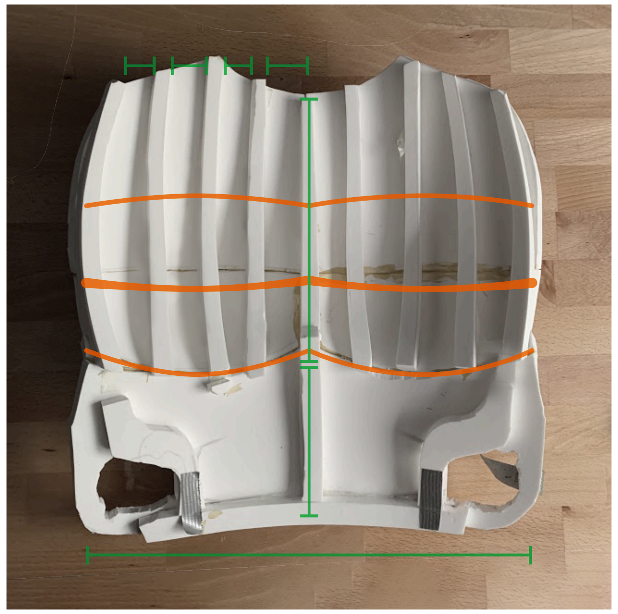


Fig. 47: Test prototype

The first prototype made was tested as a the normal shell projected on the female shape. This involved changing the current shape of the prototype to match the shape of the female torso, but with the same configuration of the air ducts. The shape, therefore, involves making room for the breast tissue and the sharp transition at the bottom of the breasts. The effect of movement and the expected dislocation of the foam form also applies here.

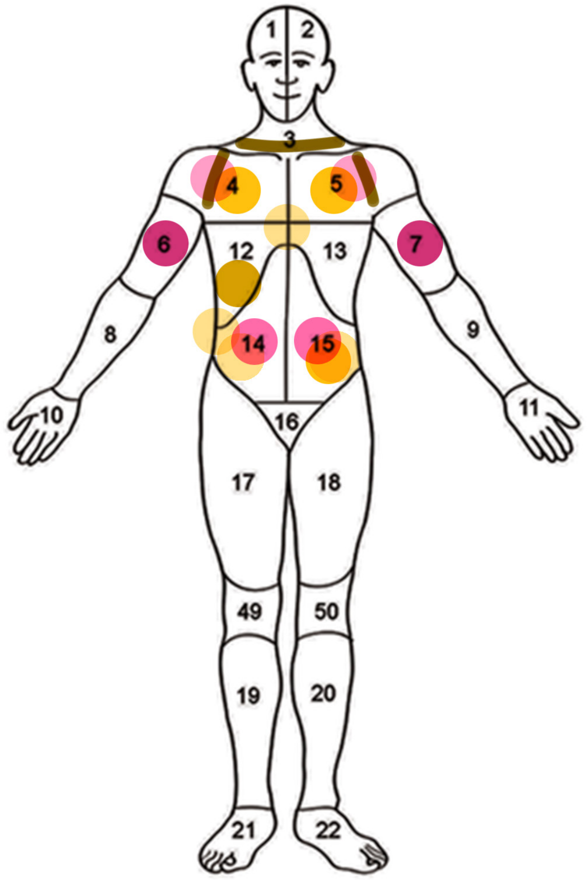


Fig. 49: LEO-scale visualisation for test protype

From the test, which is explained in more detail in the next section 5.5, the following results were obtained for the test prototype on the LEO scale (Fig. 49). How the visual is obtained and what it represents will be explained in results of the Comfort and mobility assessment (section 5.5).

What emerges is that even for test persons with a large shirt size, the outlines contribute to the experienced discomfort. In addition, for the smaller shirt sizes, some pressure points were observed within the contours of the foam part, such as just below the chest and on the sternum. Participants also reported that they could feel the foam component pressing against their lower ribs when raising their arms.

BACK PIECE PROTOTYPE

For the test, a model of the back section was also made, because in order to compare the different concepts for the chest section, the interference with the back must also be present. By testing only the chest section in the vest, the textile is deformed differently and therefore the tension is distributed differently over the upper body.

The dimensions of the back section were also obtained from Clo3D with the anthropometric model. Thus, the shape is cut differently from how it would be in the male version, so it is narrower and less tapered towards the waist.

In order to improve the cooling efficiency by allowing more air to pass along the spine and at a higher speed, this has been modified with a different configuration for the air ducts and thus also included in the test with subjects. The results will follow those of the two different chest sections.

CONVENTIONAL PROTOTYPE

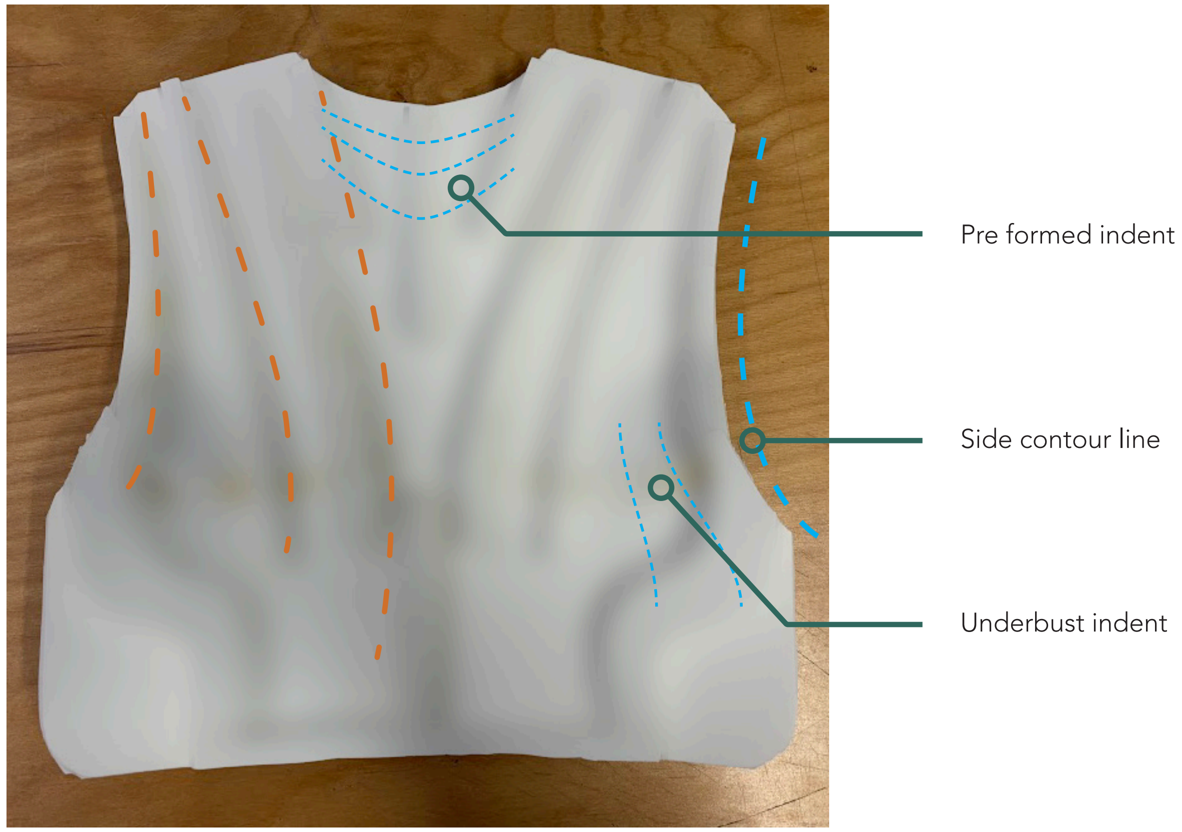
The conventional prototype is made of two parts for the front shape, an upper part and a lower chest part. First, the over-chest part was shaped correctly by cutting away some material with an incision on both sides. This was made from two cutouts, as 3d forming this as a complete shape would be challenging to the desired curvatures. Then it was thermally formed on the mannequin to hollow out the shape.

Next, the underbust area was trimmed to create a matching joint line. Before gluing, this lower part was also thermally deformed to obtain the desired underbust indent on the sides.

The walls are cut out with gradients in height and heated before gluing and shaped to the basic For this model, it was decided to break up the middle partition wall and reinstall it higher on the model. This is where the depth of the ducts decreases and so there is the additional support of keeping them open, but that the air is more accelerated despite the widening.

The interruption of the middle wall is done to make room for the textile of the sports bra and to increase the flexibility at this height of the shell.

The contour line of this model is a focus for testing with test subjects, to see how the shape fits around the torso and whether this has a noticeable



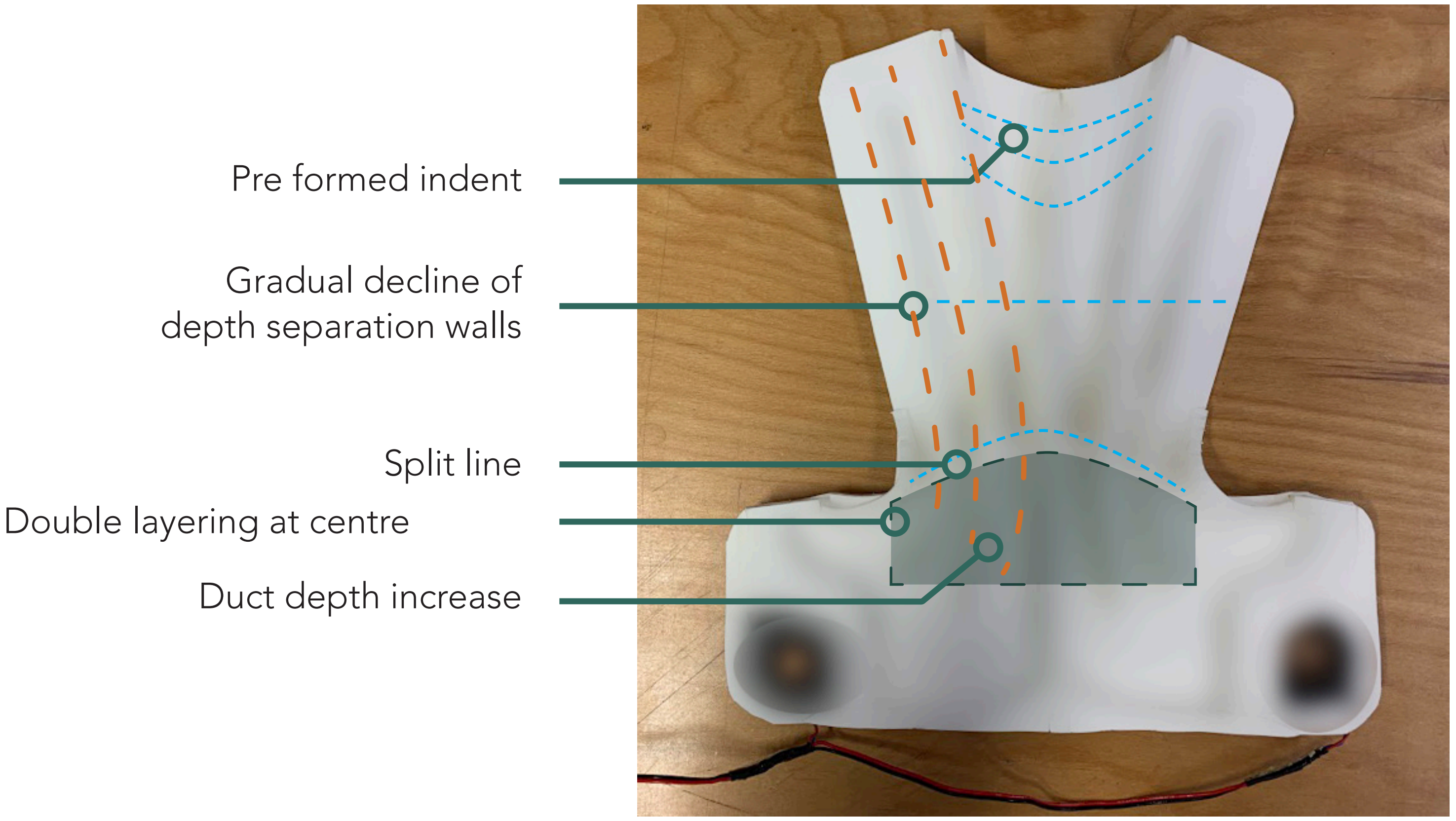
2-COMPONENT PROTOTYPE

The 2-component prototype was created with the idea that it should be two parts that can be joined together in different configurations (distances), in order to fit multiple shapes. The outline is thus slimmer than the conventional prototype, as when the upper component would be wider, it would affect how the lower component would wrap around the body.

Due to the overlapping foam parts and the required connection, the central part of the lower chest part will be stiffer, as a concequence of increased moment of inertia of the geometry. Whether this has any noticeable effect on comfort will have to be seen in tests with test subjects. In this prototype as well the partitions gradually narrow in both the depth and width of the air ducts.

This prototype will cover a smaller area of the upper body but will also exert pressure on it, and in this case will be stiffer in some areas. The upper part is shaped inwards, indicated as preformed in the figure, so that it follows the shape of the upper body when tightening the straps of the vest and thus fits closely to the skin.

As this prototype is significantly narrower than the conventional one, it will be interesting to see how it is perceived by the test subjects. The foam part has more room to move around in the vest, so the possibility of dislocation is greater. When and how this takes place will therefore probably become apparent from the tests.



5.5 COMFORT & MOBILITY ASSESMENT

The requirements package for the DOKS clothing stipulates certain requirements for the range of movement and wearing comfort of military personnel. This defines tests and criteria that a garment must meet, such as performing range of motion tests. In these tests, a test person assumes various postures in which a certain measured value is registered, such as how far a person can reach forward while sitting. These values can be compared to a situation in which the test person is not wearing restrictive clothing, but it is also possible to ask the person which barriers are experienced or to make observations.

For the test with the prototypes, the most relevant tests were selected:

- Stand and reach
- Sit and reach
- Arm abduction
- High knee
- Arm across chest

To which three standard shooting positions were added:

- Standing
- Kneeling
- Prone

Also the subjects were asked to walk a short distance and to report if abrasions would develop due to motion.

From the time of donning and carrying out the tests to the time of taking off the prototype, all the observations and comments made by the test subject were noted, as were observations such as the striking deformation of the foam parts.

Test subjects were then asked to index where and how much discomfort was experienced when wearing the vest using a Locally Experienced Discomfort scale.

To conclude the subjects were asked to answer some questions about the size of shirt they normally wear and which brassiere measurements they have, which can provide more information on how the prototypes are perceived on users with various body measurements.

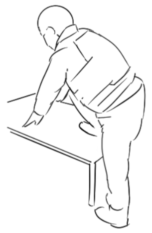
PROTOTYPE CHECK

The foam part was then placed in the vest and checked that no problems arose due to undesirable tensions in the textile. Cut-outs were made to fit a set of fans for all front prototypes. Before the test, the prototype in combination with the vest was inspected by a safety expert of the faculty. Based on instructions, the protocol for testing with test subjects was established.

Dressing up


Donning

Range of Motion


Stand & Reach


Sit & Reach


Arm abduction


High knee


Arm across chest

Shooting postures


Standing


Kneeling


Prone

Moving


Walking

Undressing


Doffing

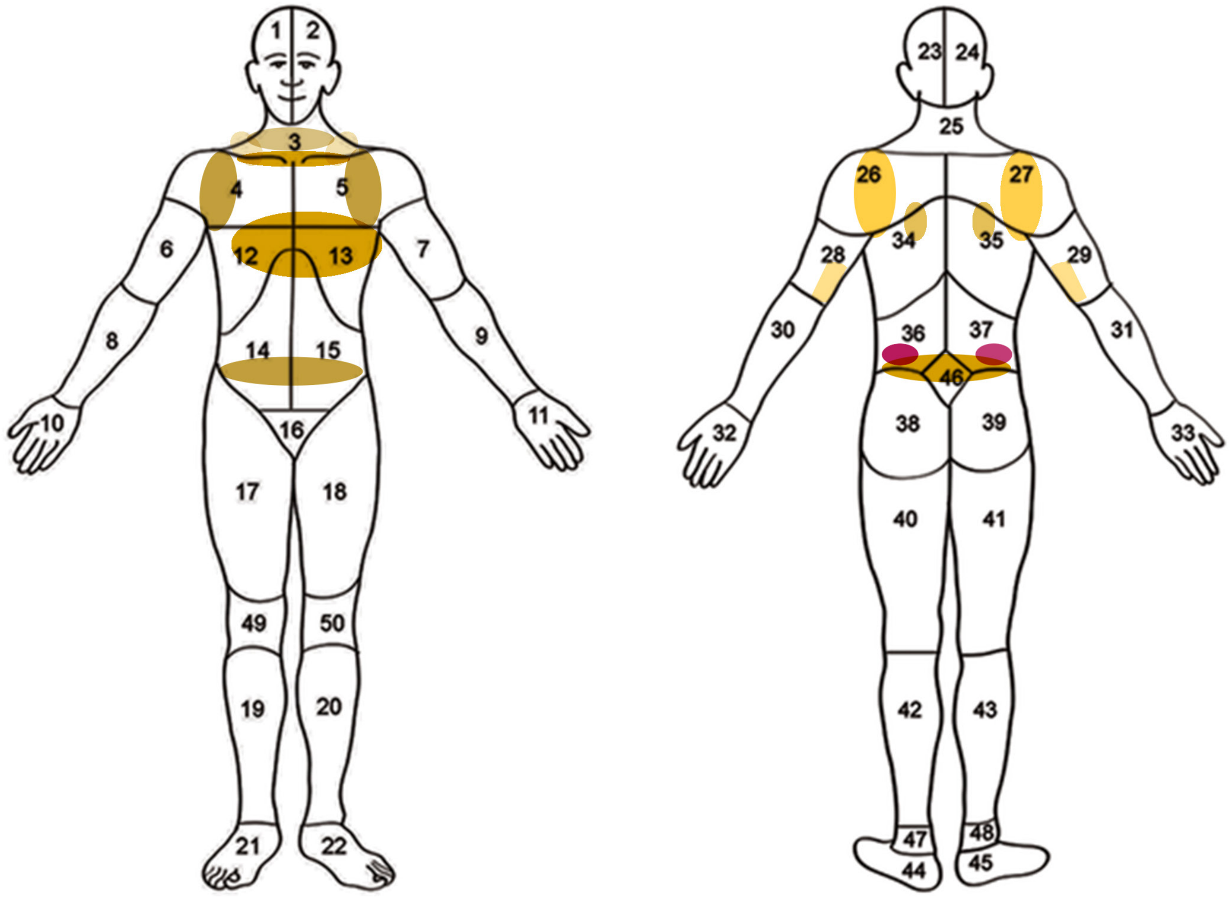


Fig. 50: LEO-scale Conventional prototype

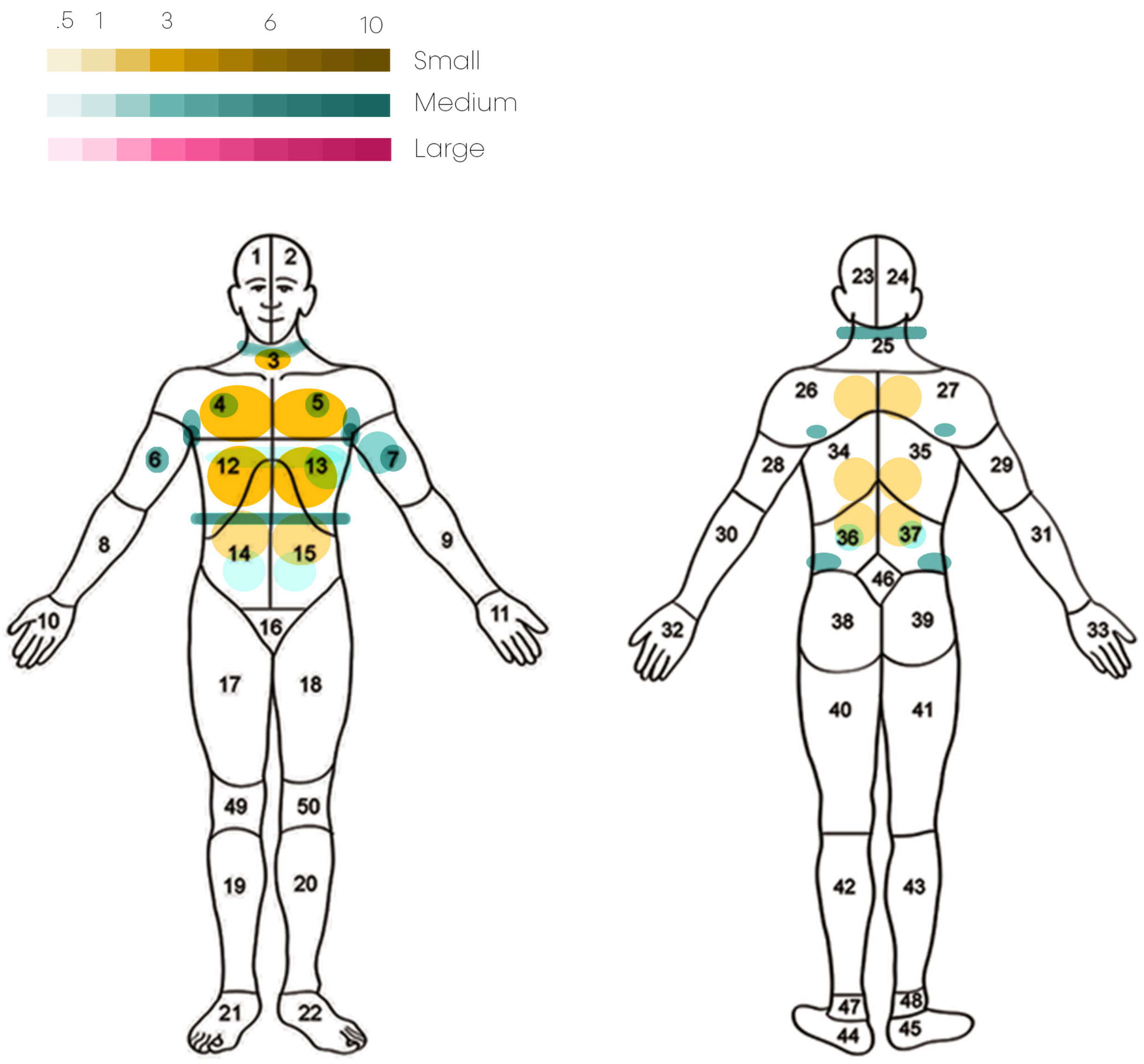


Fig. 51: LEO-scale 2-Component prototype

RESULTS COMFORT AND MOBILITY ASSESSMENT

The results from the comfort assessments with the LEO-scale were processed and visualized for both prototypes in Figure 50 & 51. Based on the indicated level of discomfort and its perceived location, for different shirt size of the user, the results are mapped out. What shows are for both prototypes how these perform on different subjects with the same foam part for the back.

As the composition of both groups of subjects was different and every subject rates their perceived discomfort differently, it is difficult to draw conclusions from these figures alone. What does show is that for both prototypes the outline of the shape is most what is perceived as impacting the comfort the most. Especially around the shoulder joint and at the neck and waistline, the outer edge shows clearly on both visuals. The different depths and configurations of the inner walls do not seem to affect the perception of comfort as no small marks are pointing at pressure or abrasion points within the contours of the shape. For the conventional prototype however, a subject marked the overbust area as being under stress.

5.6 AIRFLOW DISTRIBUTION TEST

Between the two designs, the outer lines are very different, especially for the two-component prototype. Within the contours a different configuration for the air ducts has been incorporated, which should be considered to give a more effective ratio of distribution and airflow velocity. For this purpose, the fans were placed in both prototypes and fixed on the mannequin. With an anemometer, the air velocity can be measured separately in each duct and, using the cross-section measurements, the air flow can be calculated for each duct.

Since the mannequin has a smooth surface finish, a textile shirt has also been pulled over it to approximate the usual resistance of the fabric used in the vest.

In order to measure properly with the anemometer, it is not possible to have the prototypes connected all over the mannequin, because the anemometer has to be held in a certain position and the necessary fixations would make this difficult. Therefore, it was decided to measure at a fixed height on the mannequin for both prototypes, halfway the air ducts where they still connect to the mannequin. This way, the speed in the different air ducts can be measured, but not how this progresses through a duct.

The result were evaluated to check whether the implemented configuration would affect the distribution.

Fig. 52: Airflow distribution test setup Conventional prototype fixation on mannquin

Fig. 53: Airflow distribution test setup 2-Component prototype on mannequin

5.7 EVALUATION OF PROTOTYPES & TESTING

The following conclusions are drawn from the results of the comfort and mobility assessment and the airflow distribution test:

WEARING COMFORT

Both prototypes score about the same for user comfort, despite the fact that the 2-component prototype was not adjusted for size with the two parts separately. However, the conventional prototype could be further improved by shaping the contours of the form even more extensively.

AIR DUCT CONFIGURATION PERCEPTION

The design of the internal partition walls for the air ducts is not readily apparent to the user. The differences in the depth of the walls and their direction and gradient did not seem to produce any noticeable difference between the prototypes. This means that there is still a possibility to make changes in this, in response to a different desired distribution and, where necessary, acceleration of the air flow.

AIRFLOW DISTRIBUTION

The airflow distribution test shows that, although the shape does not always match the fit, the desired distribution can be achieved by the configuration of the partitions. However, since the test is now performed on a hard dummy with a single shape, it would be valuable to perform this test on multiple dummies and do further checks on how the shells fit.

ADJUSTABILITY DISTRIBUTION

In addition, the distribution can be adjusted a bit further for both parts, as the desired ratio between flow and speed of the airflow will have to correspond more to the required ventilation for the areas covered by these.

For the final design, the conventional design will be further elaborated, according to indications for improvements from the comfort and mobility test and the air flow distribution. This design is more similar to the current design for the male soldier and can therefore be better integrated into the vest and its sizing system. In order to have a workable foam shape for female soldiers, further development of this shape as an extremis of the female shape is more appropriate.

The two-component design certainly has potential, but with the expected wearing comfort in combination with the ballistic vests it cannot be promoted enough to be substantially better implemented.

Furthermore the configuration of the partition walls must still be accurately determined according to what the desired ventilation per area of the female torso should be.

In addition, the back part will also be worked out more accurately, so that the perceived discomfort is reduced and the correct configuration of the air channels is also achieved.

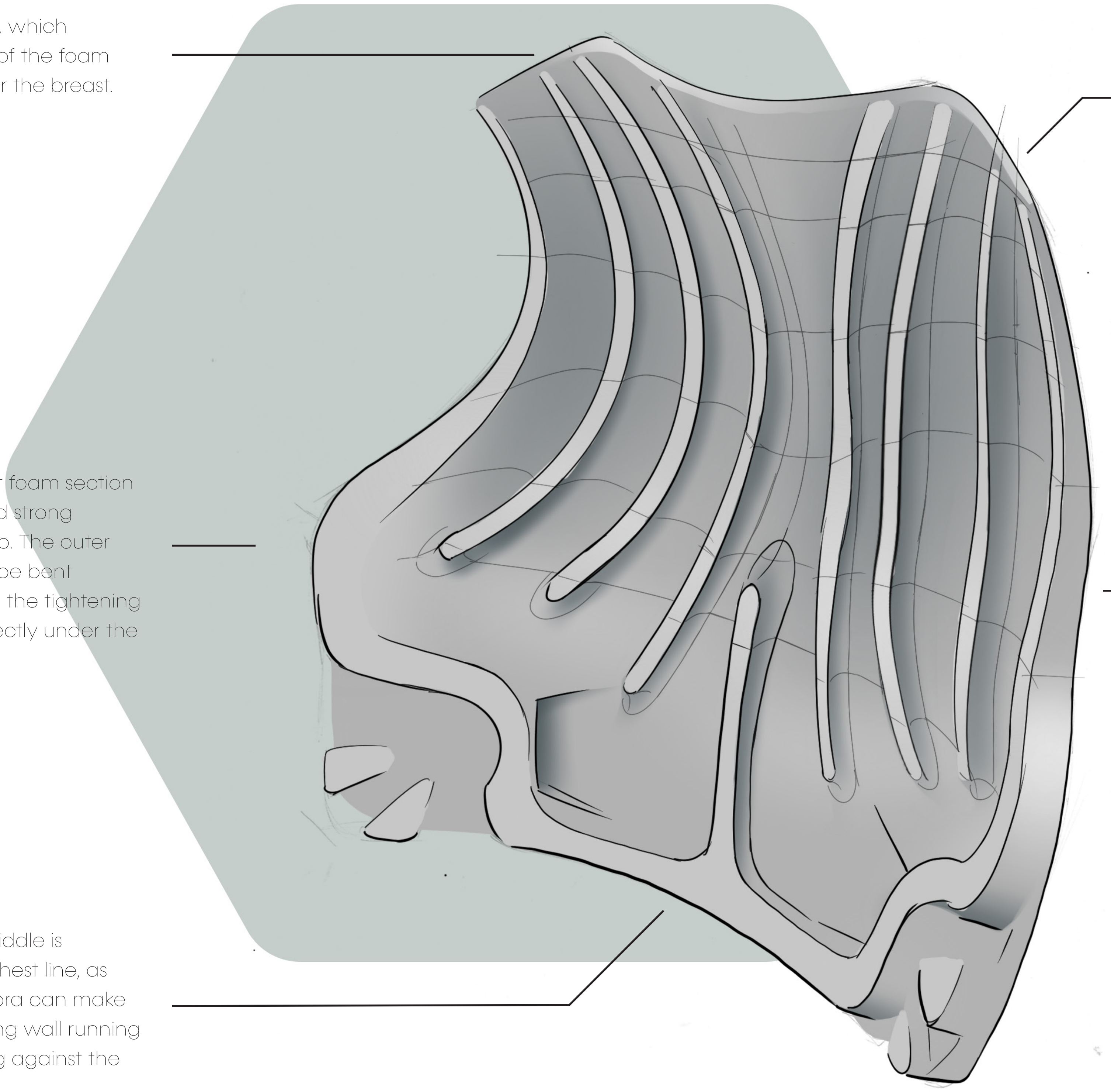
6 FINAL DESIGN

6.1 FINAL DESIGN EXPLANATION

In Figure 54 shows the final design of the front shell for the female soldier. The features that differentiate it from the design for male soldiers and adapt it to the female body shape are annotated.

The most important element in making the breast part suitable for the female form is the outer line, which allows the shape to curve across the breasts and align against the body, as well as closing the shape transition under the breast at the sides. Instead of allowing the shape to connect in the frontal plane by protruding geometry, the shape can be connected gradually around the body below the chest, partly due to the straps that are located at this height. By allowing the side of the chest section to protrude laterally, it can be bent in a controlled manner around the vertical axis.

The thickness of the shell is reduced at the center of the breast, to reduce the inertia related to the geometry of the foam, so the shape can adapt easier to the curvature.



Pre-curved breast section, which requires less deformation of the foam section to fit correctly over the breast.

In the middle, the shape bends even further inwards, so that the air ducts from the middle are additionally pressed against the skin.

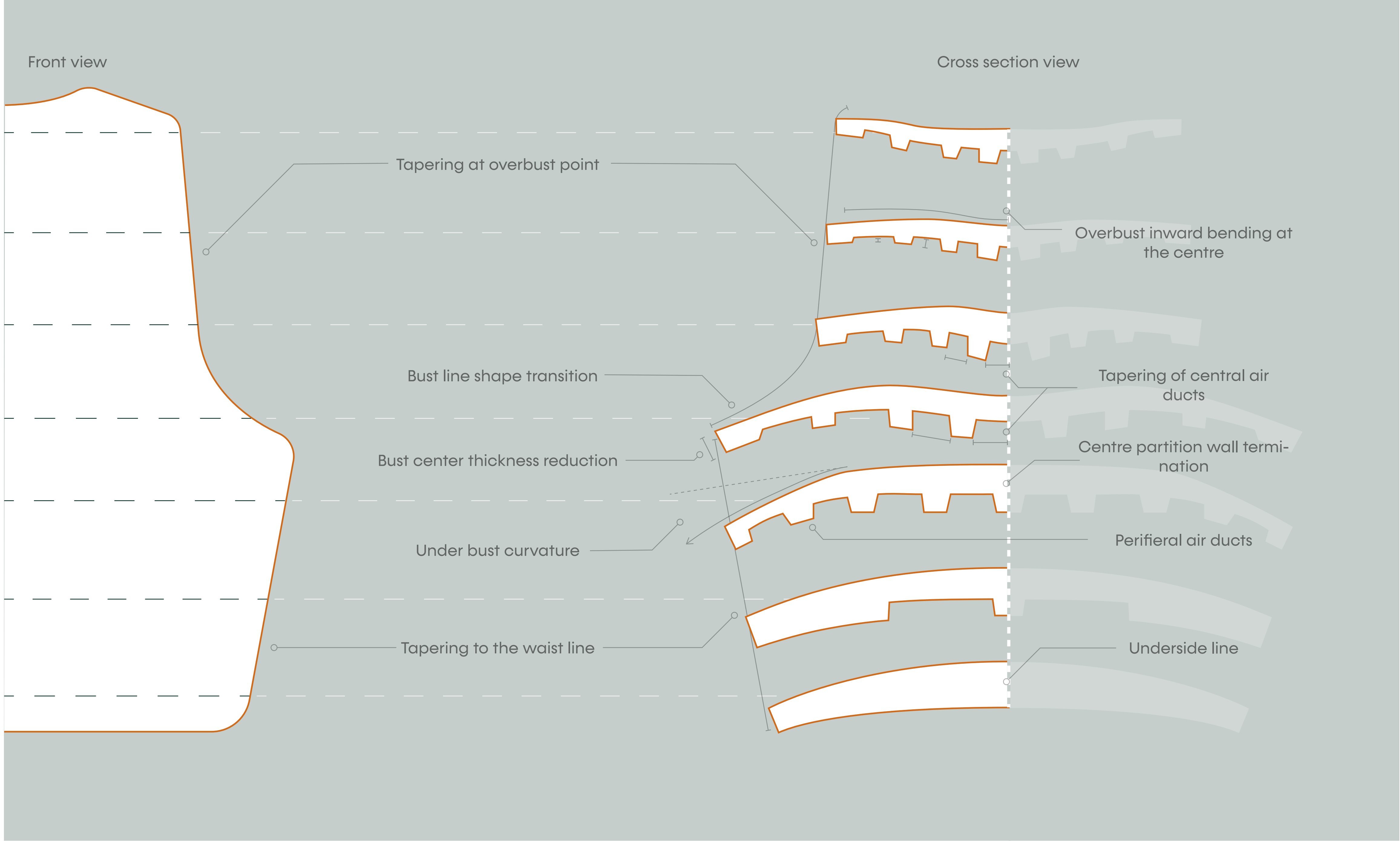
The outer line of the chest foam section with a slight widening and strong narrowing towards the top. The outer line on this part is able to be bent inwards under the load of the tightening straps and connects correctly under the breast.

In addition to adjusting the height and direction of the walls for more efficient cooling, the contact area of the partitions is oriented so these fit as flush as possible against the chest.

The dividing wall in the middle is interrupted at the lower chest line, as the presence of a sports bra can make it difficult to have a dividing wall running through here and pressing against the skin.

Fig. 54: Final front shell design drawing

6.2 FINAL DESIGN DETAILING



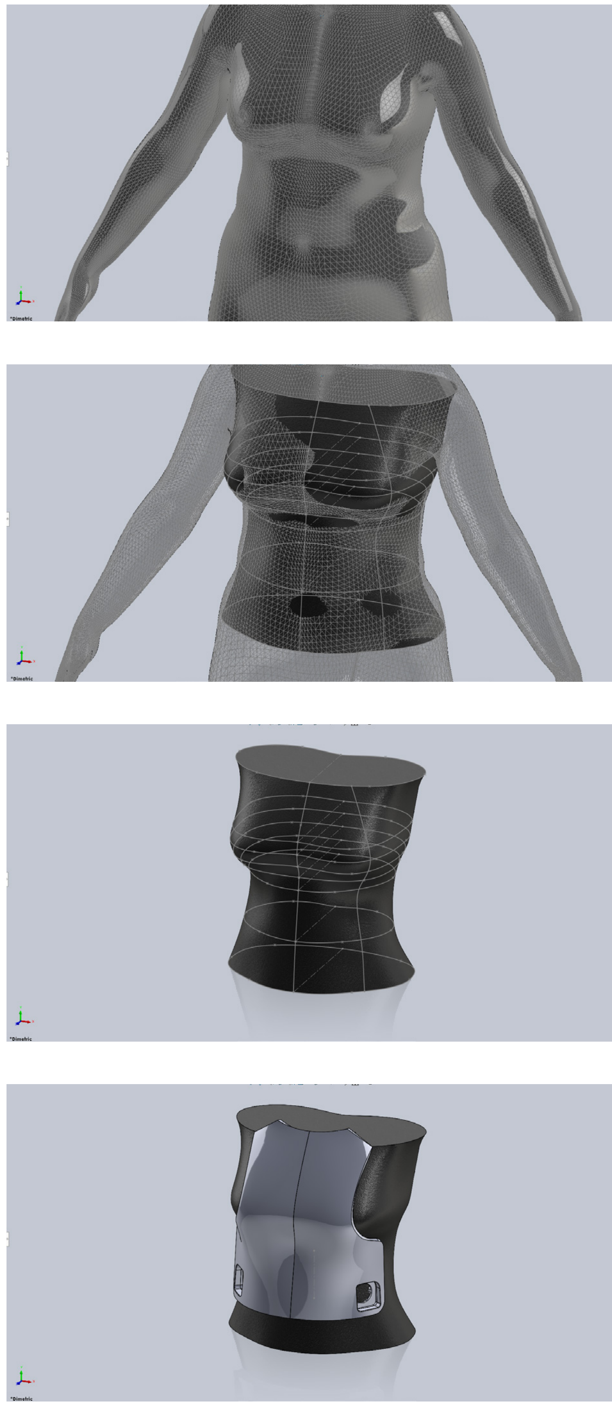
The drawing on the right shows how the chest section should be shaped in cross-section, i.e. what the dimensions and orientation of the ducts should be in order to achieve the desired airflow distribution and airflow velocities. From the cross-sections, it can be seen that the shapes of the under breast and over breast sections are quite different. Whereas for the lower part the outer edge is protruding further backwards, at the top the central section is shaped inwards, so at the central area the shell is preformed close to the skin.

A transition also takes place in the design of the partition walls and associated air ducts. As the height of these walls decreases towards the top, overall increasing the airflow velocity.

The central air ducts open wide and get progresivelly narrower at breast height to increase airflow velocity, after which the air ducts widen slightly and decrease in depth.

6.3 FINAL DESIGN MODEL

SOLIDWORKS MODEL DEVELOPMENT



A model for the front shell was developed in SOLIDWORKS, Computer Aided Design (CAD) software package. The model was based on the virtual 3D-anthropometric model used in the previous chapters. From the model more exact dimensions could be extracted for the final prototype to be based on. Furthermore the software provides opportunities to conduct basic computational fluid dynamic (CFD) simulations. These simulations could provide insight in the changing airflow velocity in the various air ducts, on top of the distribution of air over the different ducts as well. This simulation can be found with the further evaluations.

The model was constructed based on three different 3D surfaces: the inner surface, which would be in contact with the skin of the user, the outer surface, making up the exterior surface facing the ballistic vest covering the shell, and the surface constructing the roof of the air ducts and therefore determining the depth of the airducts. The distances between the different surfaces are therefore gradually different in several locations on the chest side of the vest.

In the 3D model some dimension were extracted from the model for the male shape, for instance the required geometry for the placement of the ventilators. The underside of the shell was placed a similar height as the regular shell would be on the male torso, so around umbilicus height. Measurements were derived from the SolidWorks model, in order to check with the construction of the physical prototype.

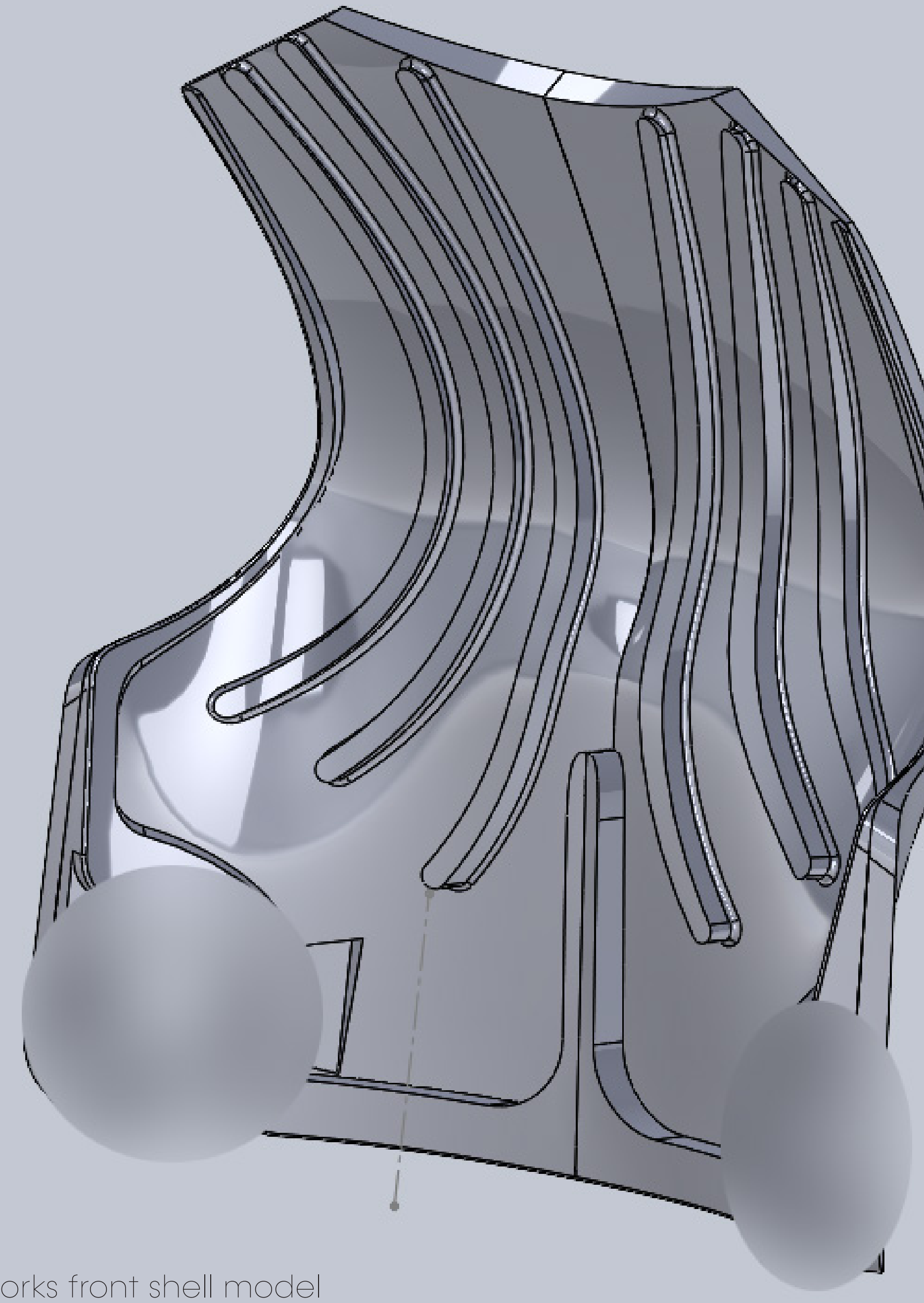


Fig. 55: Solidworks front shell model

In the Figure 54 the model of the front shell is shown on the 3D anthropometric model, with a transparent outer layer to show the direction of the air ducts over the upper body. From top downwards, the outline of the shell runs vertical over the upper part of the breast tissue, passing the most protruding area and thereafter bending outwards and backwards to the side of the human model.

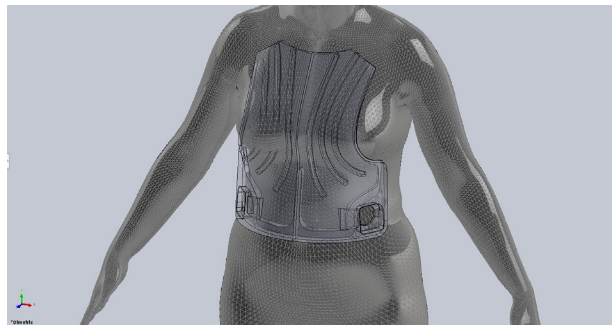


Fig. 56: SolidWorks front shell model on virtual 3D-anthropometric model

6.4 FINAL PROTOTYPE

For construction of the final prototype, an attempt was made to use a single cut-out as a base for the shell. As the final design inherently requires less extreme 3D curvature in order to correctly shape to the female body, the prototype could be made without bending separate cut-outs and assembling these using adhesives. Complex curves could be achieved by heating the foam more thoroughly. Increasing the foam heat allowed for the under bust area and the over bust area to be bend in the complex combination of curves with the central inward bending at the top of the shell.

The base cut-out was made and thermally formed to the desired shape as the outer shell. The air duct shapes were formed in accordance with the solidworks model, and adhesively attached to the outer shell. The partitions walls were then cut-out as strips and in some instances thermally bend or elongated, to reduce the required sanding and post-processing time.

To achieve the slant edges, these walls were shaped to dimension using a Dremel and sandpaper. Due to build up internal stresses with the adhesion of additional geometry and the heat absorption from the post processing action, the prototype slightly deformed. To correct this, the shape was heated again and bent into the desired shape.

Fig. 57: Front shell prototype on top of the regular front shell.

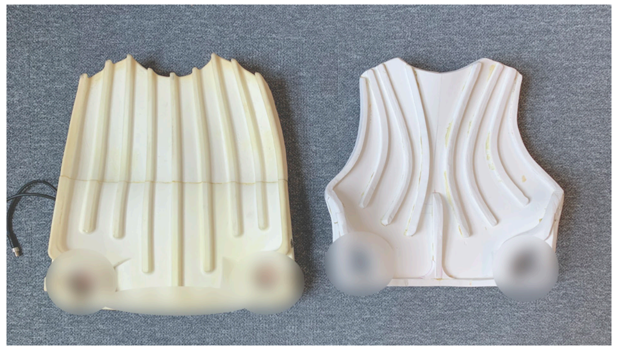


Fig. 58: Regular front shell next to the final front shell prototype

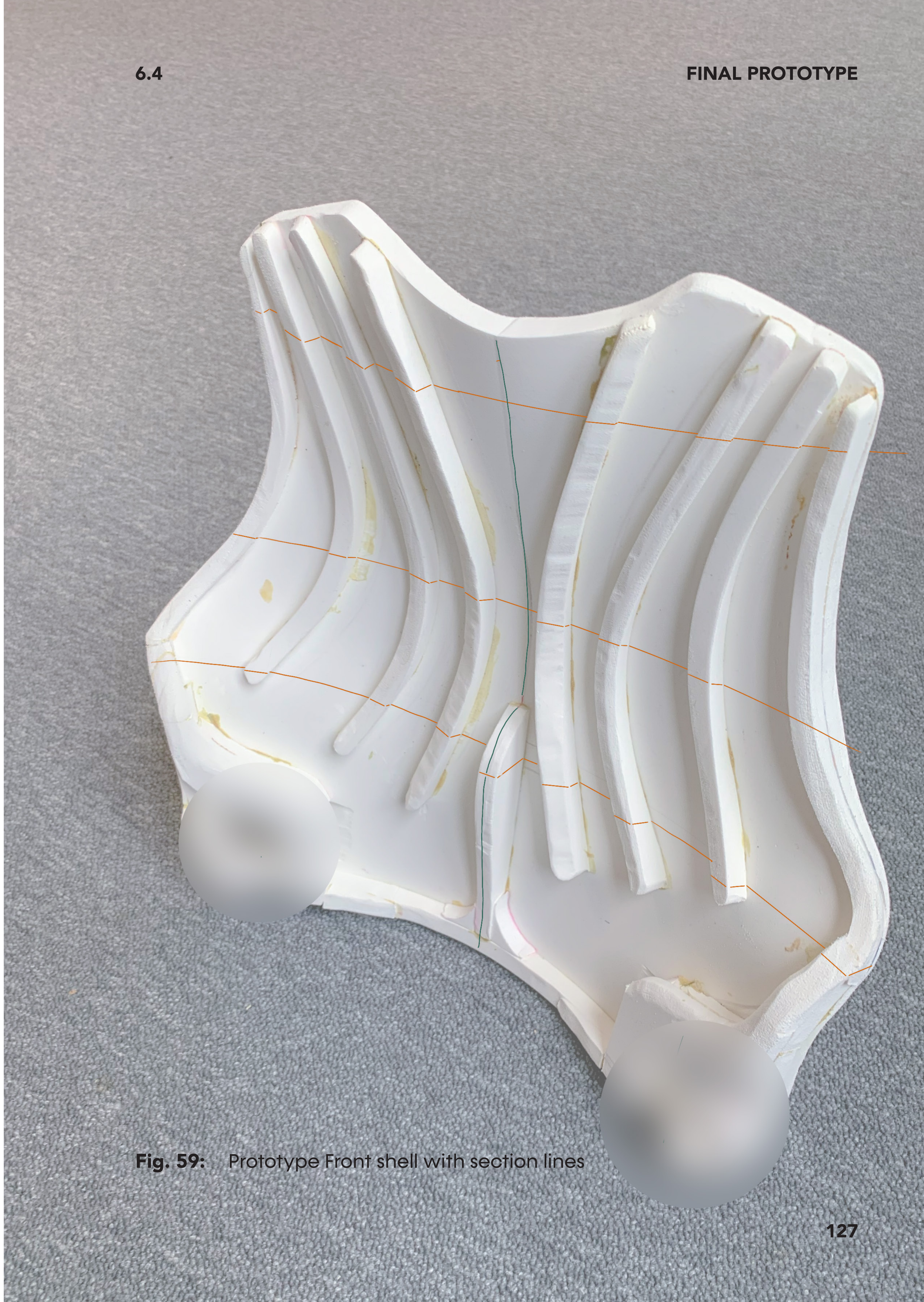


Fig. 59: Prototype Front shell with section lines

Fig. 60: Prototype Back shell with section lines

The back shell was constructed in similar steps, however it required less elaborate alterations compared to the front shell. The shell is more tapered at waist height and widens towards the shoulder area. The airducts are shaped more gradually with respect to the prototype of the back shell used during testing in a previous chapter.

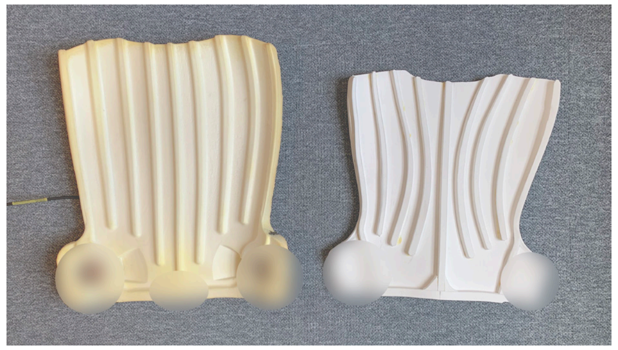


Fig. 62: Regular back shell next to the final back shell prototype

Fig. 61: Back shell prototype on top of the regular front shell.

6.5 PROTOTYPE EVAPORATION EFFECTIVENESS

To check whether the desired distribution of the airflow and air flow velocity is achieved to effectively evaporate sweat from the female torso, a test is conducted with a wetted carrier vest. By evenly moisturizing the carrier vest, as seen in Figure 63, the effectiveness of the airflow distributed over the torso can be checked, as this would show by the areas that would be most effectively cooled to be the first to dry.

To ensure that the carrier vest was evenly moist, it was soaked and subsequently wrung out carefully. When running tap water over the carrier vest, the merino wool and the material of the sleeves would not absorb the water evenly, thus a thorough soaking was required. The ventilators were placed in the front shell, which was in turn inserted in the wetted carrier vest. The prototype was then placed on the mannequin as shown in Figure 63, after which the ventilators were switched on.

As the power supply connection of the ventilators was fragile, resulting in a loss of power, the straps were adjusted after turning the ventilators on. The Velcro straps were then tightened, so the bottom edge of the shell would seal to the mannequin, after which the straps above would be tightened. At various intervals the vest would be turned off and removed from the mannequin, to check the progression in evaporation of the water from the vest. The inside fabric was checked for humidity and recorded through photograph, as no measurements of humidity in the fabric were possible. Observations on humidity of the fabric were documented.

Fig. 63: The carrier vest with the final protoypes inserted prior and evenly wetted

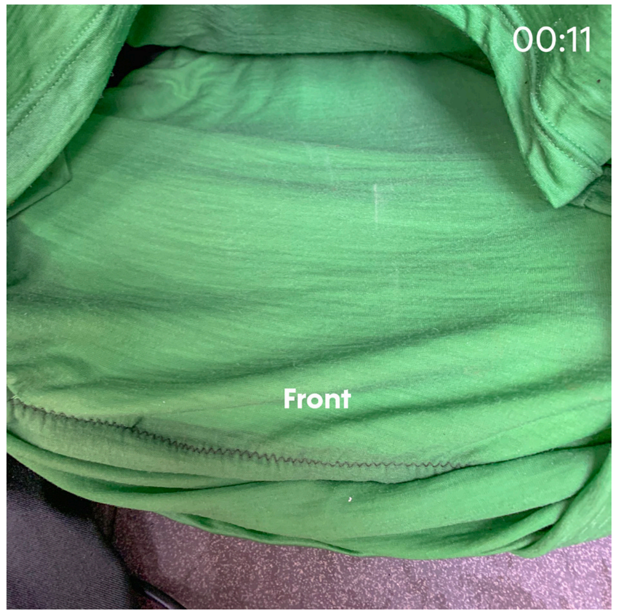


Fig. 64: Humidity check at 11 min.

As the mannequin did not generate heat for accelerated evaporation, it took some time for the fabric to noticeably dry. The transition from damp to dry at various locations in the textile was generally subtle. Vast differences were not visible at the location contact between the mannequin and the shell walls and where the fabric was exposed in the air ducts. This was likely a consequence of the water being able to distribute along the circumference of the fabric, effectively equalizing the humidity at all location under the front shell.

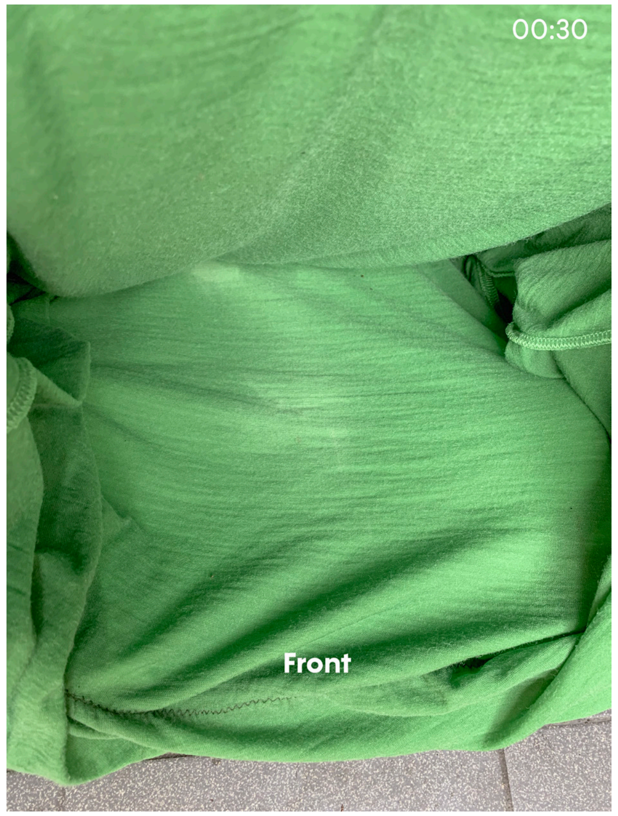


Fig. 65: Humidity check at 30 min.

Fig. 66: Humidity check at 56

Nevertheless there was a noticeable reduction in humidity of the fabric at the centre in relation to the sides above the ventilators. During testing, a higher level of drying was observable at the middle of the shell, where the first dry patches appeared, as can be seen in Figure 65.
After approximately an hour, the chest side was nearly dry, as indicated by the equalised humidity along the circumference of the vest under the shell. Outside of the area covered by the front shell, the fabric was noticeably more humid, as expected.

6.6 PROTOTYPE COMFORT & MOBILITY ASSESSMENT

The prototype of the final design was assessed as well with a comfort & mobility test with a female subject. This was done to check how the fit of shells would be perceived by the user, how these would affect the mobility user and how the shells would interact with the carrier vest.

Since the cooling vest is worn under the ballistic vest in the eventual context, the test was performed by the subject wearing the prototype in combination with the ballistic vest. In VOSS carrier vest B, both the soft ballistic plates and the hard ballistic torso plates and side plates were placed. Due to the added weight and rigid geometry, the cooling vest is loaded more and differently. This leads to a different interaction of the prototype with the user's body, as well as to a change in the user's perception of comfort and mobility while wearing it.

The procedure for the test is the same as it was in section 5.5, but with the additional step of putting on the ballistic vest. All questions to the subject were asked according to the situation in which both garments were worn.

OBSERVATIONS AND REMARKS

The initial remarks from the subject after donning the prototype and the ballistic vest, was the width of the back shell, which noticeably restricted the arms from moving behind the back. When bringing the arms forward, the subject noticed pressure on the middle of the upper chest.

With the range of motion test, some pressure was perceived by the subject in the Sit&Reach posture on the middle of the back, but no limitation in mobility. With the following Stand&Reach, the front shell was commented as too wide at the top. With the Arm abduction posture, some obstruction was noticed at the end of the movement. Some pressure points were also experienced when adopting shooting positions, such as on the right chest when shooting standing up and when lying on the back and side.

More remarkable was that, due to contact of the upper leg with the VOSS vest, the subject noticed the chest shell to detach from alignment with upper chest.

Figure 67 shows the LEO-scale filled in by the subject after the test. Despite the additional weight and rigidity of the ballistic vest, the discomfort was not perceived as excessive. The noted discomfort was mostly located at the edges of the shells and to be associated with certain postures, whereby the interaction with the VOSS vest was underlying.
The top of the chest shell may still be overly wide, where it was observed to protrude under the side of the ballistic vest. Together with the interaction of the arms that led to pressure on the middle of the chest, the top of the chest section should be narrower still.

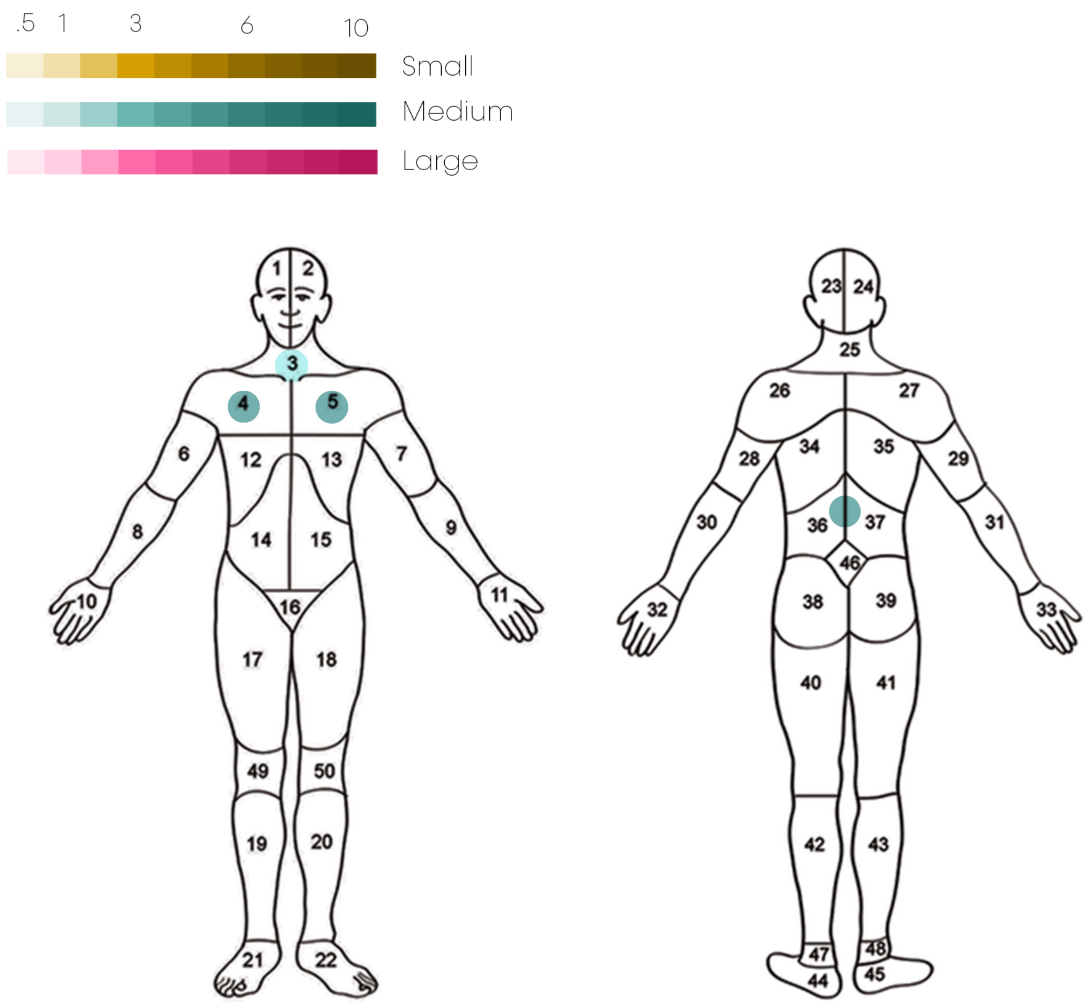


Fig. 67: LEO scale visualisation for test with final prototype in combination with Voss carrier vest B

6.7 COMPUTER MODEL EVALUATION

CONSTRUCTION CFD SETUP

The SolidWorks software containts a package able to conduct internal CFD simulation using a predefined model. In addition to the air flow test with the physical prototype on the mannequin, the air flow was visualised in 3D through the front shell. These simulation illustrate the shifts in air flow velocity due to air duct transitions and turbulences as a consequence of the configurations of the walls.

For the CAD-model this meant it had to enclose a volume, so an additional surface was added to function as the skin of the user and seal the air ducts. The addition of the surface layer uniformly reduced the airduct height by 1 mm, which would be similar to fabric and skin protruding into the canals.

The lids that are required for the setup of the flow simulation were placed at the position of the ventilators and the openings at the top. The lids functioning as the starting points for the airflow were situated at where the outport of the ventilators would be. As the geometry surrounding the ventilators is to be identical to the optimised design of the regular shells in ReSpire, this is not part of the defined model for the simulation.

In the event the ventilators would be oriented and positioned differently than to the regular ReSpire shell and this would subsequently require further examination and development as the surrounding geometry of the shell would require change.

SIMPLIFICATION OF THE SOLIDWORKS MODEL

Multiple errors kept occurring when running the simulations using the SolidWorks model. The software indicated invalid geometric volumes prevented the construction of the flow volume inside the shell. This was a consequence of the model being constructed from various features with intersecting dimensions. These were not allowed by the software to be merged, leading to zero-thickness volumes which prevented the computation of the flow volume.

After unsuccessful attempts at resolving the issues, the choice was made to construct a more basic model. This model included a flat shell which made computing the flow volume possible. The effect of the curvature of the shell on the internal airflow is arguably of limited significance, as this component is likely to be bend in various radii around various users.

RESULTS

As can be seen in the visualisation of the airflow in Figure 68, the airflow is mostly directed through the central area of the vest as indicated by the density of the flow arrows. The shift in air flow velocity is indicated by the changing colour, underlining the effect of the smaller cross section of the air ducts.
For the desired effectiveness of the airflow based on the sweat distribution, the velocity and size of the air flow over the central area can be excessive, as the amount of arrows directed over the breast area is small and not in relation to the centre. The velocity is also reduced to approximately 20% of the modelled exit velocity of the ventilators.
While running over the covering sports brassiere fabric the low speed is not needed, however at the top of the chest, the skin will be exposed again, at which higher air flow velocity is beneficial to increasing cooling. Therefore, the cross section of the outermost air duct should reduces with the tapering of the outline of the model to increase velocity. Other options to reduce the cross section area for increased velocity in this duct are decreasing air duct height or widening of the central ducts.

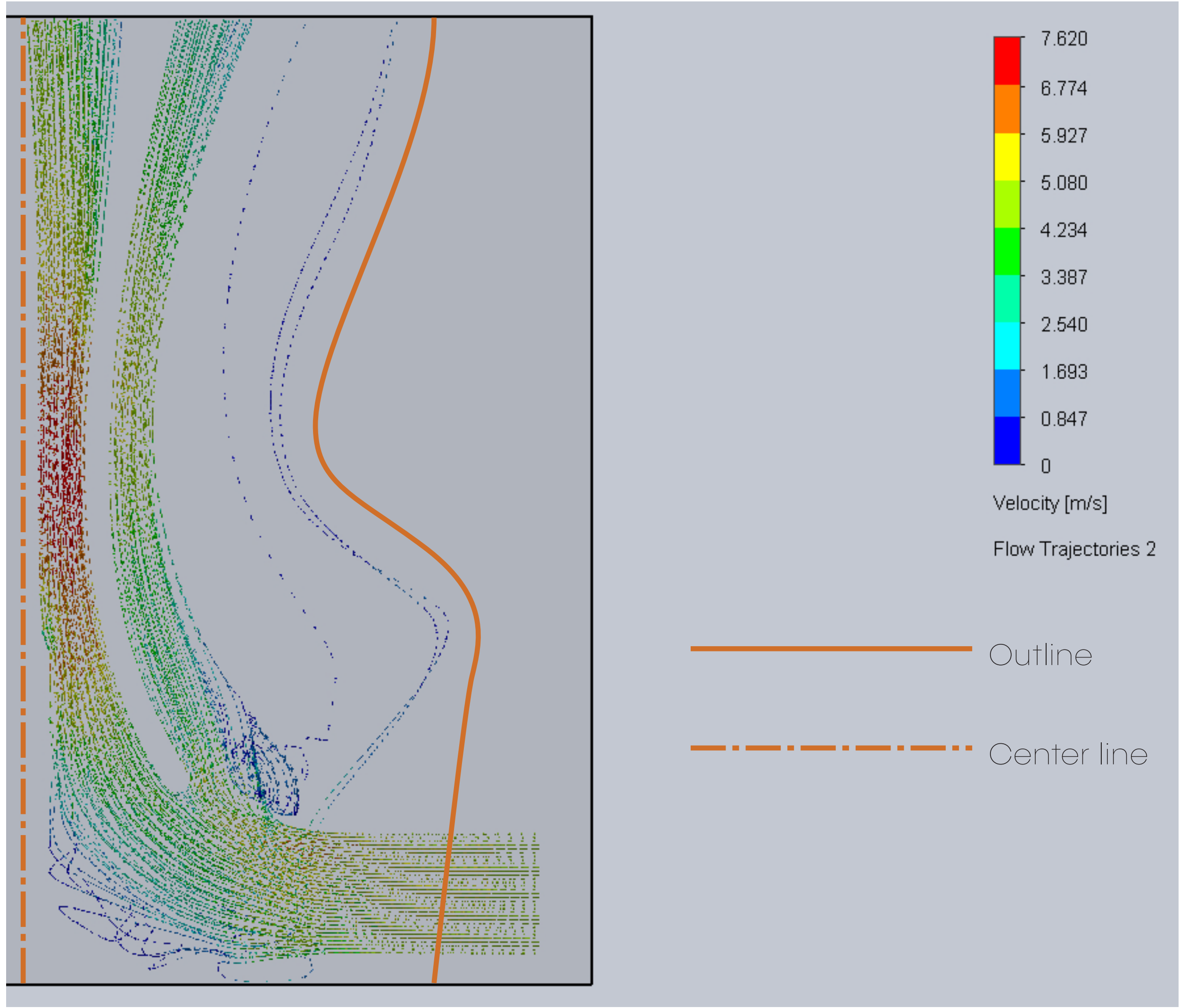


Fig. 68: CFD simulation visualisation from SolidWorks

7 DEVELOPMENT RECOMMENDATIONS

DEVELOPMENT OF THE SHELLS

VENTILATION EFFICIENCY IMPROVEMENT

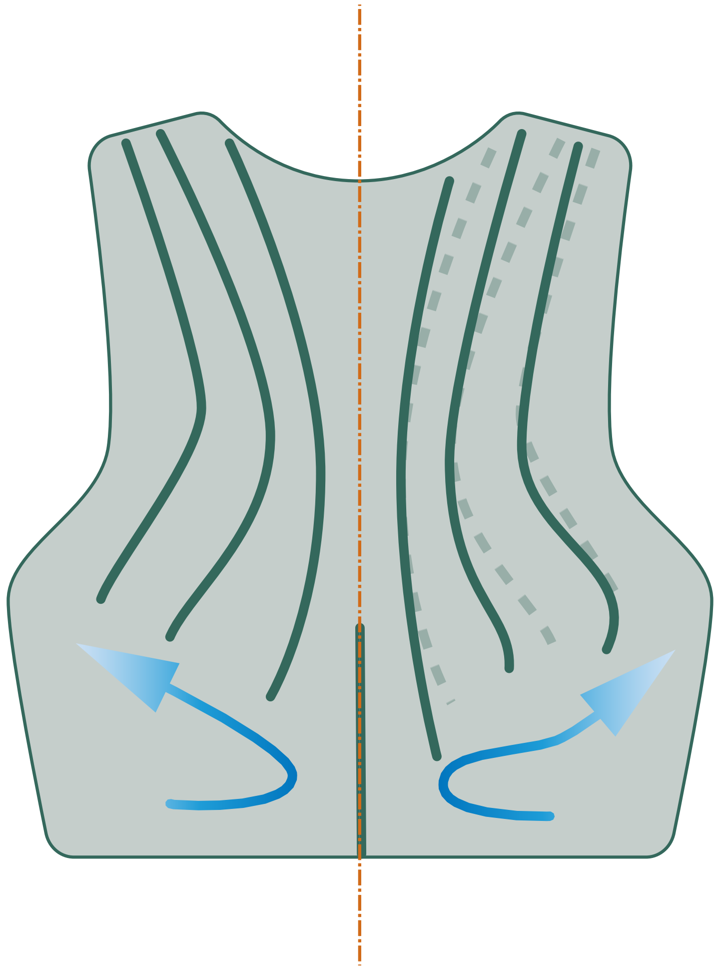
The test with the damp vest has shown that, with the current air channel design and configuration, the central area between the breasts is ventilated effectively. This is supported by the CFD simulation in Solidworks, which shows that the flow rate is higher in the central area. However, these tests are not representative of sweat evaporation in the cooling vest worn by women. Affecting factors are skin surface temperature, actual sweat distribution and the influence of insulation due to the sports brassiere, as well as those differences that occur due to body build.

The final design of the front shell provides a shape for the outline which should fit for various female body types and interact predictably with the VOSS Carrier vest to a sufficient level of wearing comfort. There are opportunities for improvement here in order to distribute the airflow as efficiently as possible. Since the airflow through the outer ducts is now so small that there would be too little ventilation just below the breast cup and just above it.

The height of the airduct walls and the slope that runs along their length are dictated by the shape that would close well against the user in order to keep deformation of the chest tissue as comfortable as possible and to distribute the pressure of the ballistic vest. Nevertheless, the walls can be moved laterally, less high and less inclined, to manipulate the airflow velocity where it is less necessary in order to compensate for other areas.

AERODYNAMIC IMPROVEMENT

The CFD simulations also showed that there are airflow distortions, for example around the opening of the outer ducts. The lower ends of the partitions could be altered for optimised airflow, however a turning vane in the middle of the bend could also make an improvement. It could optimise the deflection of the airflow, because the air at the inside of the bend can fan out less to the outside and cause extra turbulence. The thickness of a vane can be small, as the external pressure should be distributed sufficiently over the existing airduct walls.

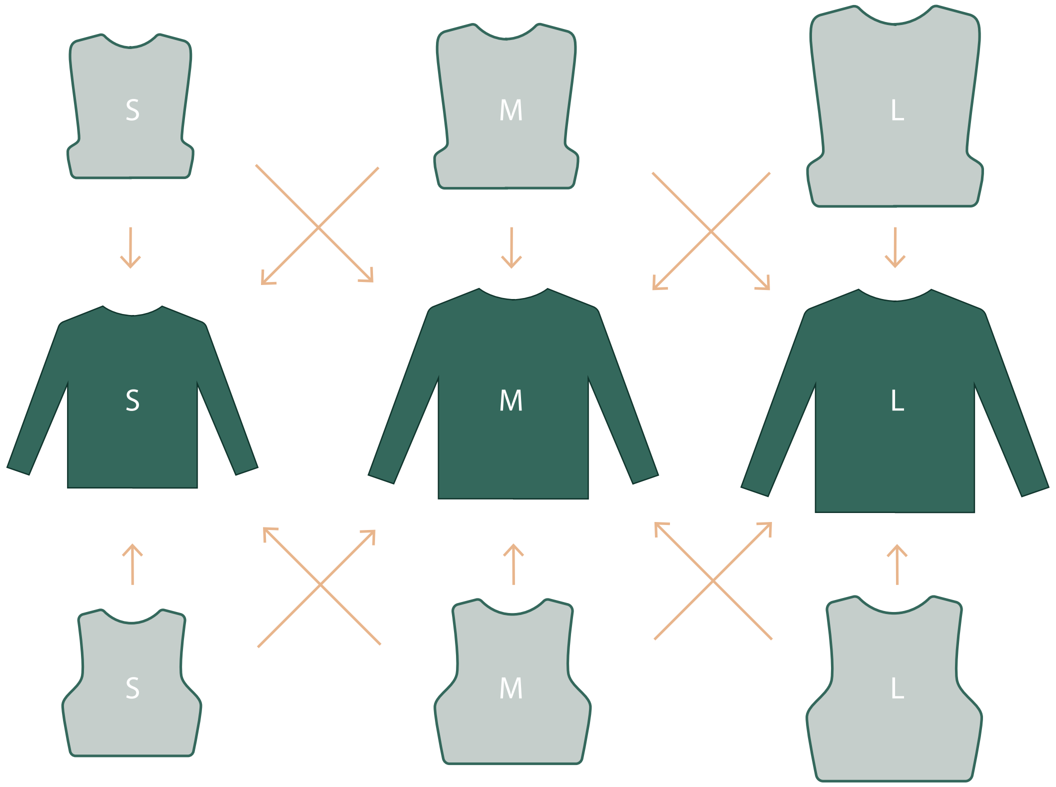


DEVELOPMENT OF SIZING SYSTEM

As the foam section on the inside has no hard transitions, and is shaped for deformation of the body under external pressure, it should accommodate different breast sizes and positions. Additionally, the external contour line should allow the shell to seal with the body underneath the ballistic vest, as for the smaller breast sizes the shell will line up further laterally. This is in contrast to females with larger breast sizes, as then the shell will tuck in more underneath the tissue and still allign with the skin.

The top of the shell is preferrably constructed in a manner which allows it to be trimmed without affecting the effectiveness of the ventilation, but increasing the wearing comfort and mobility of the user. For female soldiers with larger breast sizes, extra length is needed from the upper part of the vest to cover far enough upwards over the torso to the shoulders. A lack of shell length could mean that women with large breasts do not have adequate cover at the upper chest by the shell.

The size of the shells should reasonably correspond to the size of the vest, where preferably it corresponds to the dress size of shirts for women. In specific cases, combinations of vest and shell sizes might be best suited for certain body shapes. As the pouch is stretchy, there may be enough slack to allow for this. Placing a smaller shell in a larger sized vest is possible, but will result in potential displacement of the shell during movement.



DEVELOPMENT OF CARRIER VEST

POUCHES

For female version of the ReSpire cooling vest some changes to the carrier vest are required based on the shape of the female body and the new design of the shells. The new shell should allow for more variations in body shapes, for instance breast sizes and positionings. However, as this design is smaller on the upper half of the front shell, the pouches in the normal vest provide more room, on top of the stretchiness of the fabric. In the vertical direction this would accommodate for taller dimension of the front shell. In the lateral direction however, this will result in more freedom of movement within the vest. The misalignment in the vest, and the resultant misalignment with respect to the body, can restrict the freedom of motion of the person wearing the vest.

When the outer layer of the pouch is attached, the width of the pouch at the top will have to be tapered. A gradual narrowing would make the shell easy to insert and remove, but ensure that it remains positioned in the centre. In addition, the pouch can stretch less far outwards, so that the shell is no longer in contact with the body across its entire width.

FABRIC STRETCH & PATTERN BUILDING

To accomodate the proposed changes, the patterns will require some alterations. The woven pattern supporting the MOLLE system on the front should stay intact, therefore restricting the degree to which the size can be reduced. If this pattern becomes wider in proportion to the width of the pouch and there is to be sufficient stretch for the shell, some additional mesh textile may be required.

To accommodate the variation in chest size, the stretch fabric that surrounds the torso requires more stretch at chest level. This means that the pattern has to be widened on the sides of the chest in the direction of the front.

When compared to males, females generally have smaller waist to hip circumference ratio. Below the waist line in direction to the hips the fabric will need to provide more room. For female soldiers, the widening at the hips may occur to a lesser extent, due to a higher physical condition, resulting in lower body fat mass. Nevertheless, with respect to males this ratio is higher with female soldiers.

ULTIMATE DEVELOPMENT STEP

A ultimate development step of the ReSpire-F cooling vest would be that it can be worn without a sport brassiere, meaning the required support for the breast tissue is provided by the cooling vest. The supporting fabric or structure could be designed in a way that it compresses or encapsulates the breast tissue to reduce vertical displacement during moving, but leaves the skin exposed. The main benefit of a cooling vest that can be worn without a sports brassiere is de additional cooling achieved as a result of an increased airflow contact surface.

One option to provide the required support would be to implement a multitude of intermediate walls in the shell. These could be less wide and closer together to distribute pressure evenly, without trapping the skin. The distribution of the airflow will have to be optimised for the new situation.

The willingness of women to wear this solution is dependant on if the women would perceived this as inconvenient to wear or impractical in case of clothing changes. Additionally, this requires insight how the bare breast deforms under the shell, which can be highly variable between women due to differences in firmness of the breast tissue.

8 DISDISCUSSION & CONCLUSION

8.1 DISCUSSION

The objective of this project was to adapt the ReSpire cooling vest from the male soldier to the female soldier. This required insight in how the current design came to be and what where the underlying design choices. To this end, the reports on the development steps of the current design were studied and, where necessary, clarification was sought from experts. On top of that came the study of the soldier’s work and equipment, as this largely dictates the design of ReSpire and thus the final design of a version for women. The functional principle of ReSpire was adhered to for this cooling vest, as it had previously been determined to be the most appropriate way for to cool the soldier this context.

Previous research
The research in physiological differences between men and women revealed that there are substantial differences in regional sweat distribution, which meant that ventilating the central parts of the chest and back provides more efficiency. Other factors such as local skin temperature were found to be of less importance to the design because the efficient operation of ventilation depends on the presence of liquid sweat that can evaporate. What did influence the choice of airflow distribution is the presence of the sports bra, which as an insulating layer prevents the passage of sweat to the air channels. Thus, it was determined what could be a more advantageous distribution of airflow through the ducts. Within this project, testing the design for thermophysiological cooling capacity would require considerable expertise and time, with a choice to leave this open to optimization.
To fit the body shape of the female soldier, it was examined how it differed from the male soldier and how physical dimensions related to the cooling vest differed between women. For example, within the same dress size, body composition can differ, such as body fat percentages correlate with breast size. The assessment of the fit of the design has been tested with a small group of test subjects, however, for further development of the design a larger and more representative group of end-users should be used to more accurately determine the effects of body variation on wearing comfort.
The design was tested a single time inin combination with the ballistic vest and on a small scale. To properly determine discomfort of the cooling vest, the duration of wearing would need to be longer with more dynamic tasks to determine the effects of movement on wearing comfort.

8.2 CONCLUSION

For the adaptation of the design of the ReSpire cooling vest for the female soldier, various factors had to be taken into account in order to achieve a design which would eventually be developed to an operational product. In addition to the obvious physical differences, the functional principle of ReSpire also meant that physiological differences had to be accounted for. Also, as the eventual cooling vest is to be used in an operational military context, there were requirements in place that would inhibit certain possibilities for this adaptation. Nevertheless, the final design embodies the potential to adapt the ReSpire design for female soldiers.

USER BENEFITS

For the female soldier, the ReSpire-F design has a fit that better suits the female body and integrates better with the soldier's equipment. The front shell provides room for the breast tissue to deform comfortably and accommodates for various breast dimensions and positions. To improve the cooling capacity, the air flow has been adjusted so that where there is a lot of sweat, it can evaporate and remove heat from the body. Pre-forming allows the shell to fit more comfortably against the body and allows air to pass through the channels better. Furthermore, the user's mobility is increased as the front shell is narrower towards the top.

DEVELOPMENT

For the development of the ReSpire cooling vest as a whole, the new design can be adopted for further development within the project, as it is not inherently different from the regular design. Both the front and rear shell can be manufactured in the same way as the current ones, via injection moulding and with similar post-processing steps. As far as the adjustments to the vest are concerned, the design of the ReSpire-F shells is based on the regular vest design. In order to fix the shells in the pouches and prevent misplacement, it has been suggested that the space should be narrowed and the elasticity of the textile should be used as a means of tightly fitting these.

IMPLEMENTATION

In the project, a consideration was made as to how a potential sizing system for the ReSpire-F could be established. For female soldiers, this design offers the possibility of a suitable combination of one size for the vest with another size for the chest or back shell. The evaluation of the prototype showed that there is potential for optimisation of the cooling efficiency. The configuration of the ducts can still be manipulated to send more or less airflow through the design at higher or lower speeds, with a small chance of noticeable difference by the user.

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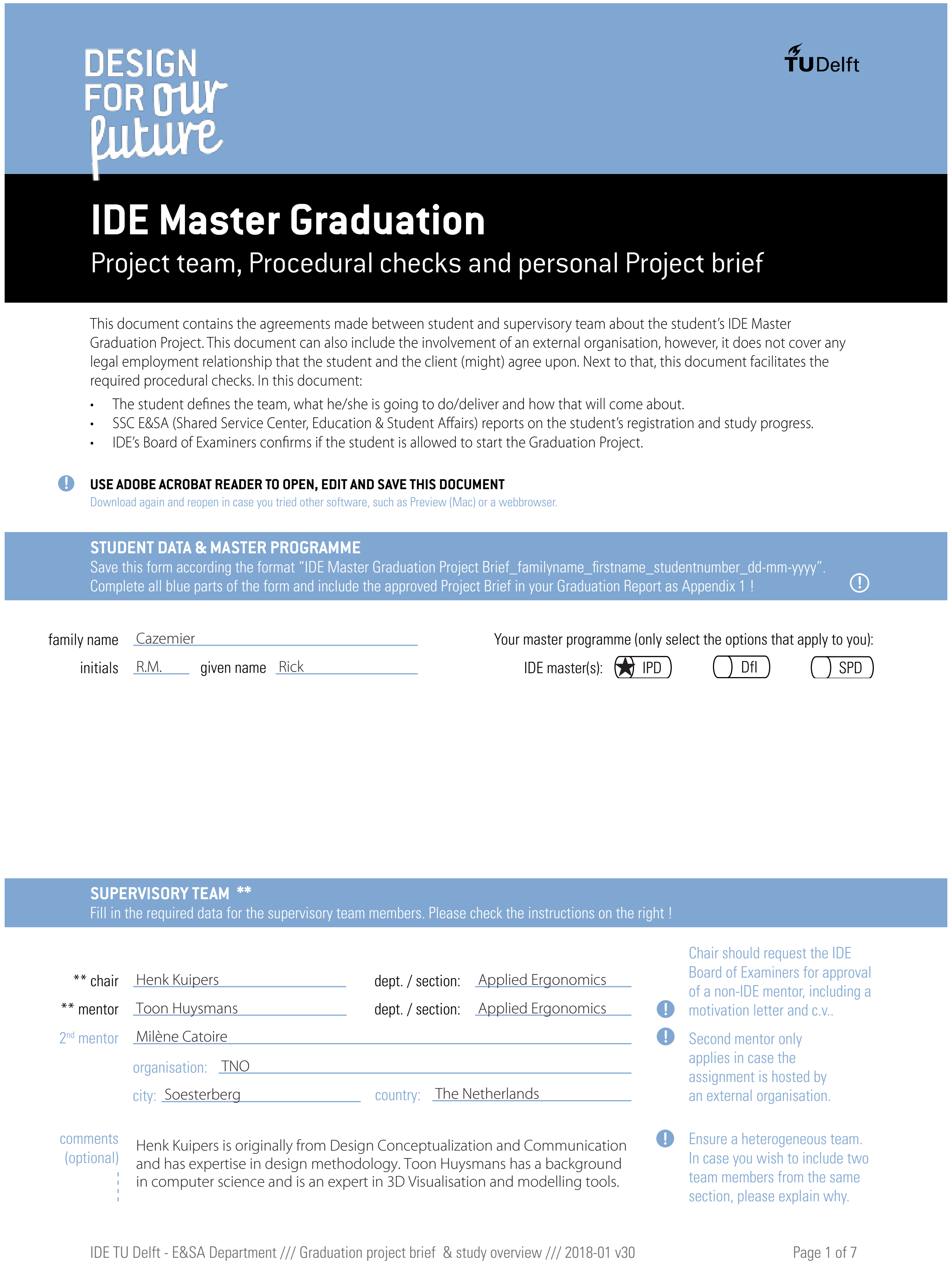
APPENDIX

A PROJECT BRIEF



TUDelft

DESIGN FOR our future

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

! **USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT**
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME
Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 ! !

family name Cazemier
initials R.M. given name Rick

Your master programme (only select the options that apply to you):
IDE master(s): ● IPD ○ DfI ○ SPD

SUPERVISORY TEAM **
Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair Henk Kuipers dept. / section: Applied Ergonomics
** mentor Toon Huysmans dept. / section: Applied Ergonomics
2nd mentor Milène Catoire
organisation: TNO
city: Soesterberg country: The Netherlands

comments (optional) Henk Kuipers is originally from Design Conceptualization and Communication and has expertise in design methodology. Toon Huysmans has a background in computer science and is an expert in 3D Visualisation and modelling tools.

! Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

! Second mentor only applies in case the assignment is hosted by an external organisation.

! Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 1 of 7

APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair Henk Kuipers date 12 - 11 - 2021 signature Hkuipers Digitally signed by Hkuipers Date: 2021.11.12 10:03:07 +01'00'

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 30 EC
Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC
List of electives obtained before the third semester without approval of the BoE

○ YES all 1st year master courses passed
○ NO missing 1st year master courses are:

name date - - signature

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ○ APPROVED ○ NOT APPROVED
Procedure: ○ APPROVED ○ NOT APPROVED

comments

name date - - signature

ReSpire cooling vest for female military personel: ReSpire-F project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 01 - 11 - 2021 08 - 04 - 2022 end date

INTRODUCTION **
Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

TNO is developing a cooling vest for military personnel operating independently of a vehicle or other platform and is designed in a way that the vest integrates with the outfit and gear of the soldier. This project is called the ReSpire project and is performed in cooperation with INUTEQ. The project is carried out on behalf of the Dutch ministery of Defense. The Ministry of Defense is ultimately in charge of the project, however TNO is the party mainly executing the project.

TNO is The Netherlands Organisation for applied scientific research. TNO is developing as well as knowledge also practical applications for clients. At the location of Soesterberg research is conducted for and in collaboration with the Ministry of Defense. This project is conducted for the department of Human Performance, a section of Defence and Security at TNO.

INUTEQ is one of world's leading company in developing and manufacturing innovative personal cooling technologies and products. INUTEQ is the industrial partner involved in this project and is the designated commercial seller of the cooling vest. INUTEQ is involved to support in designing the concepts of the vest, providing information and developing prototypes.

The Ministry of Defense is interested in acquiring these cooling vest to better equip their personnel for operating in high temperatures, keeping in mind the effects of climate change and the possible locations of deployment. During the project there will be opportunities to test the design in controlled context, with soldiers from Defense. For soldiers an efficient cooling vest will increase their level of performance in these conditions, both physiological as well as cognitive.

By the principle of ventilation, air is blown through the gear on the chest and back, which causes sweat to be vaporised faster. The design should be able to be worn by a soldier in combination with a VOSS (Improved Operational Soldier System). VOSS is a integrated system of load carriage and protective vests and backpacks. The design should provide the user with mobility and comfort and not restrict in performing tasks. In addition, the design must meet som

The current design is developed for male personel, however females are an increasing target group within the defense department (TNO-rapport 2019 R11998, Eindrapport NTP ReSpire, mijlpaal 7).
For all stakeholders (TNO, INUTEQ and the Ministry of Defense) there is a desire for the cooling vest to be adapted for female soldiers, so that it fits well and cools efficiently.

The objective of the project is to adapt the current design of the ReSpire cooling vest so that the vest has a good fit for the female soldier. This shape should increase the comfort of wearing the vest and the capacity for cooling is increased.

space available for images / figures on next page introduction (continued): space for images

image / figure 1: ReSpire koelvest from NRC by Bram Petraeus. Test with subject on an obstacle course.

image / figure 2: ReSpire: Shell and filters on the left, complete vest on a mannequin on the right.

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The current design for the cooling vest is developed for male soldiers and are not suitable for female soldiers, as its affects the performance of the female soldier and cooling capacity seems impaired. During previous tests, it was found that the fit of the vest was too big and wide for the female participant, so it crept up during movement. When the female soldier changed into for instance in lying position, a reduction of cooling was sensed.
In the event that more pressure is exerted on the vest, for example by carrying a backpack with a pack, it was found that the channels provide less airflow, as the body tissue fills the channels from the inside. The obstruction of tissue by tissue can be a bigger problem for women when carrying loads, since the skin is different to men.

Improving the vest for female soldiers means taking into account the different measurements and shapes of the torso and ensuring the mobility and comfort of the female soldier. Female military personnel have breasts that can make it difficult for the shell to fit closely against the body, aside from the differences in skeletal and muscular structure. Also, variations in physique may occur very differently in female military personnel than in their male counterparts. In addition, there may be differences in how pressure can be comfortably applied to the body in women compared to men.
The vest should fit correctly to the body in order to ventilate the skin and evaporate sweat faster and efficiently. Females perspirate differently to males, as well as in sweating rate as in distribution over the torso.
The vest should also fit with the gear the soldier is using for operation, such as a VOSS, and provide cooling capacity.
The project is open to improvements that can be applied to both the female and male versions.

VOSS = Verbeterd Operationeel Soldaat Systeem (Improved Operational Soldier System)

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

Adapting the current design of the ReSpire cooling vest to allow for different fits for female soldiers, by indicating where modularity might be needed and how it can be achieved. Subsequently, various options for fitting will be incorporated into prototypes that will be low-key tested before being improved and tested again. Prototypes will then be tested in a controlled setting with subjects from the target group, after which the findings will be integrated in a final prototype.

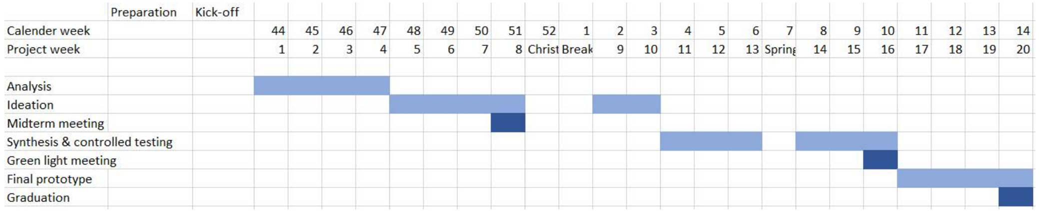
The vest consist of different components, with mainly the cooling shells that are to be optimised. The cooling shells shape the channels for the airflow to be guided from the waist to the opening at the neck. For these channel to function effectively, these should seal to the body of the user. Therefore this component is to be adapted to the shape and size of the female soldier.
In the bottom corners of the shells ventilators are placed, which draw the air in from outside the vest and then through the channels of the shell.
To hold the shells in place there is a carrying vest, consisting of a shirt on the inside and an outer layer providing cavities for the shells to be placed in. These components are made so that they can be stretched where necessary and restrict the flow of air as little as possible. The cloth should be optimised as well to fit the female soldier.
In addition, there are zips and straps for taking the vest off and on and for positioning it correctly against the body.
These parts will also be optimised in combination with the shells and the fabric.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 1 - 11 - 2021

8 - 4 - 2022 end date



	Preparation	Kick-off																							
Calender week			44	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project week			1	2	3	4	5	6	7	8	Christ	Break	9	10	11	12	13	Spring	14	15	16	17	18	19	20
Analysis			▨	▨	▨	▨																			
Ideation							▨	▨	▨	▨			▨	▨											
Midterm meeting										■															
Synthesis & controlled testing															▨	▨	▨		▨	▨	▨				
Green light meeting																					■				
Final prototype																						▨	▨	▨	▨
Graduation																									■

In the first phase, I will look into where the current design problems are in the fit for female soldiers and the efficiency of ventilation through the vest. The differences between males and female in how they transpire, how skin interacts with the shell will be examined. Furthermore, the change in shape and sizes between female soldiers in relation to each other and normal female antropometry. A digital 3D model will be made on which different iteration can be checked in the next phase. Then I want to look at existing solutions and possibilities in the field of materials and techniques in the field of clothing.
In the next phase, these insights will be applied and tested on a small scale for various partial solutions. Iterations on for example the shells will be made in modelling programs and simulated to check mobility and that the desired deformation is achieved. In the synthesis phase, these will be combined and tested in controlled conditions for both comfort and function with hardware prototypes.
The digital model will be used to check for discrepancies through changes in the design of components between different possible sizes of female soldiers. The model also provides possibilities to check the integration of the design with the gear of the soldier and to simulate different poses, for instance shooting postures. Lastly, the model might aid in making the correct measurements for the production of a prototype.
In the final phase, the prototype will be manufactured, optimised from all the findings of the previous phases. The aim is to evaluate the final design with test subjects in controlled settings such as a climate chamber.

MOTIVATION AND PERSONAL AMBITIONS

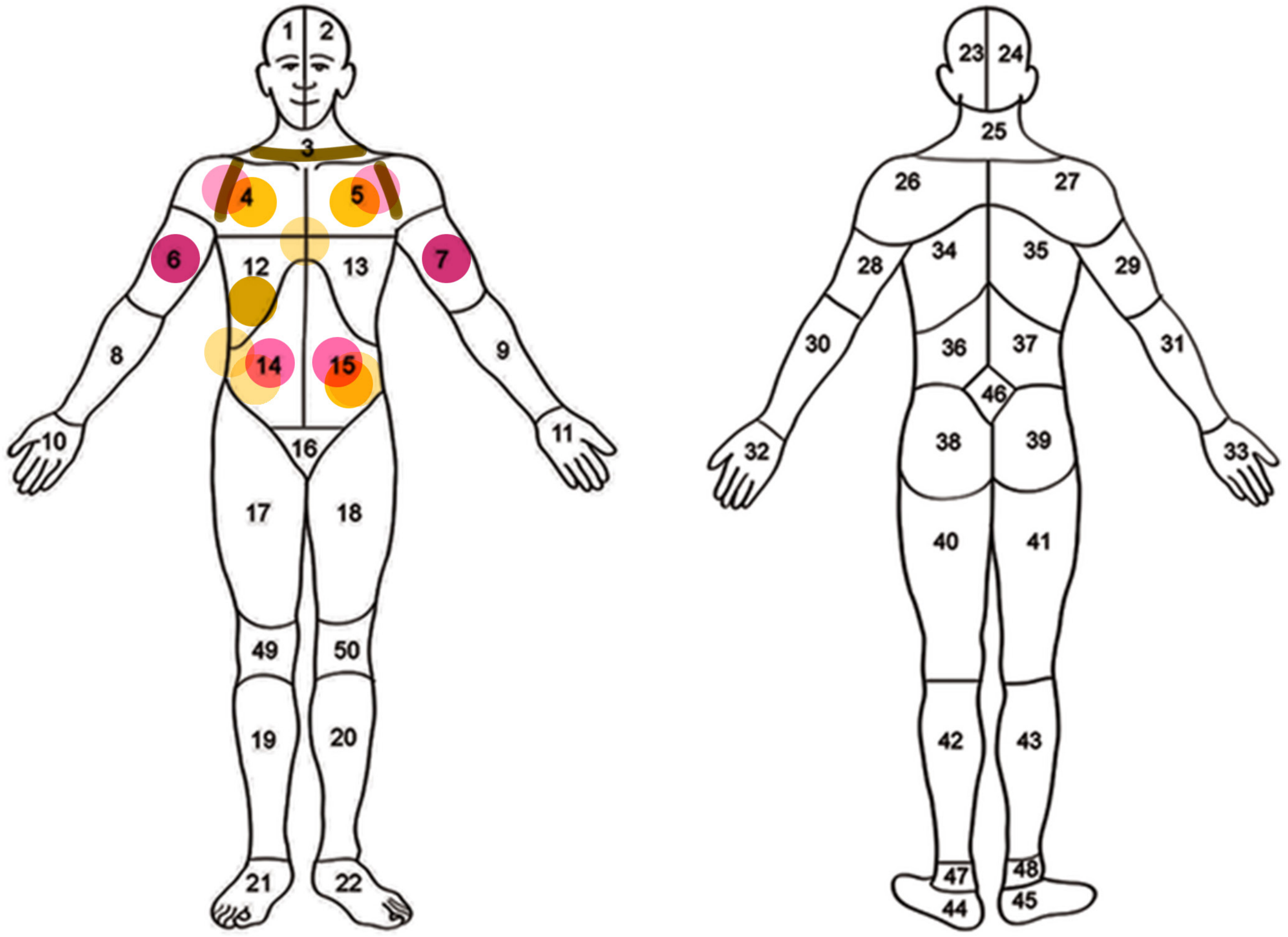
Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

I chose this project because I found it a fascinating subject to design given the circumstances in which the product is to be used.
In addition, I see possibilities for myself to build many prototypes and therefore to become better at it. Especially with 3D printing, I think I need to get more involved and plan the development process of a prototype.
I also want to show that I can comprehend and solve complex technical problems.
In addition, it is important for me to be able to conduct good tests with subjects and to process and represent the results. In my opinion, this is something I can improve upon in the area of visualisation.
A graduation internship is an excellent opportunity for me to take another step in working independently within a company and to make use of all its possibilities.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

B LEO SCALE VISUALISTATIONS



Test prototype