ADIRA

WOMEN IN BLUE

ENHANCING BODY ARMOUR

For Female Police Officers

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Wilson School of Design
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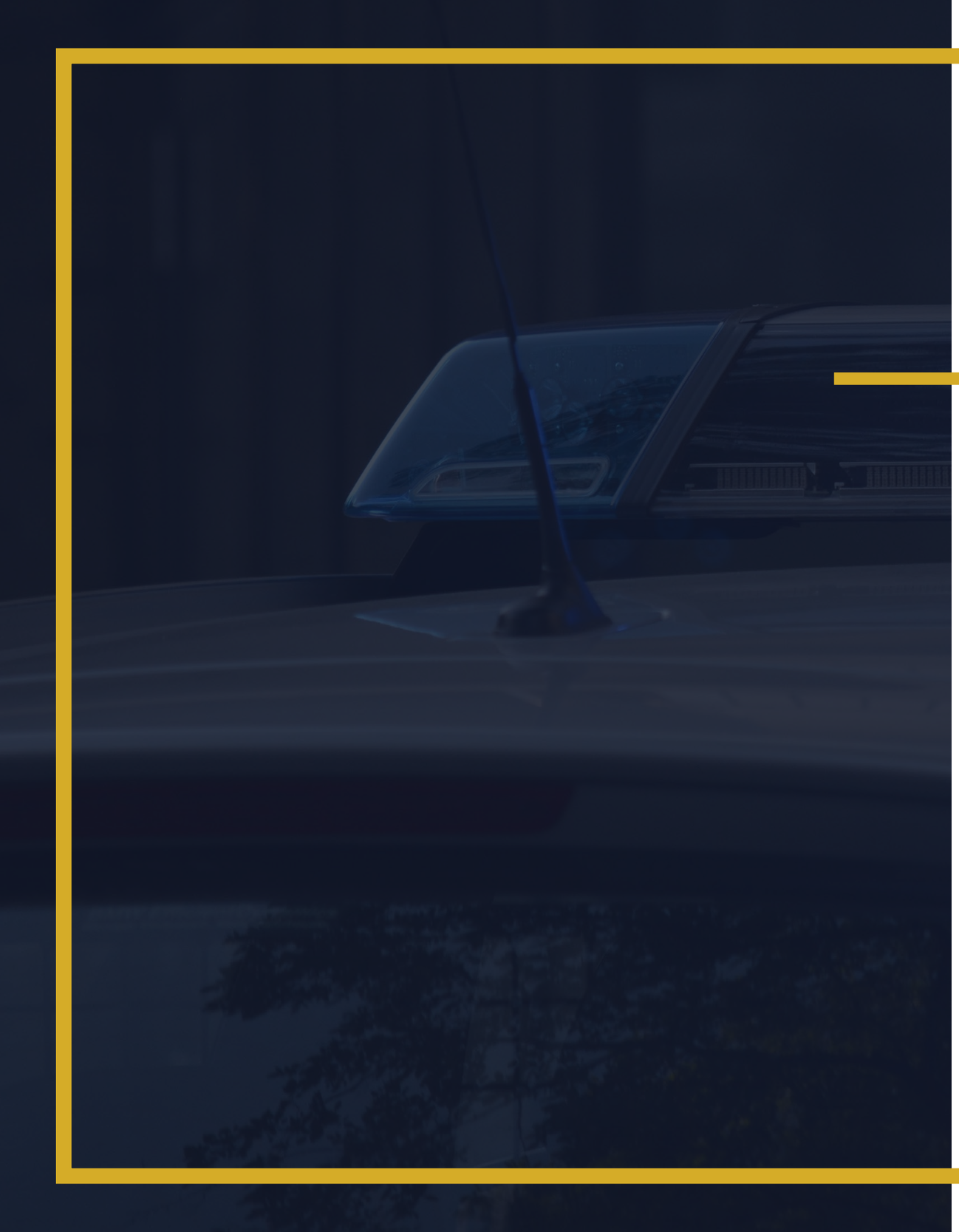
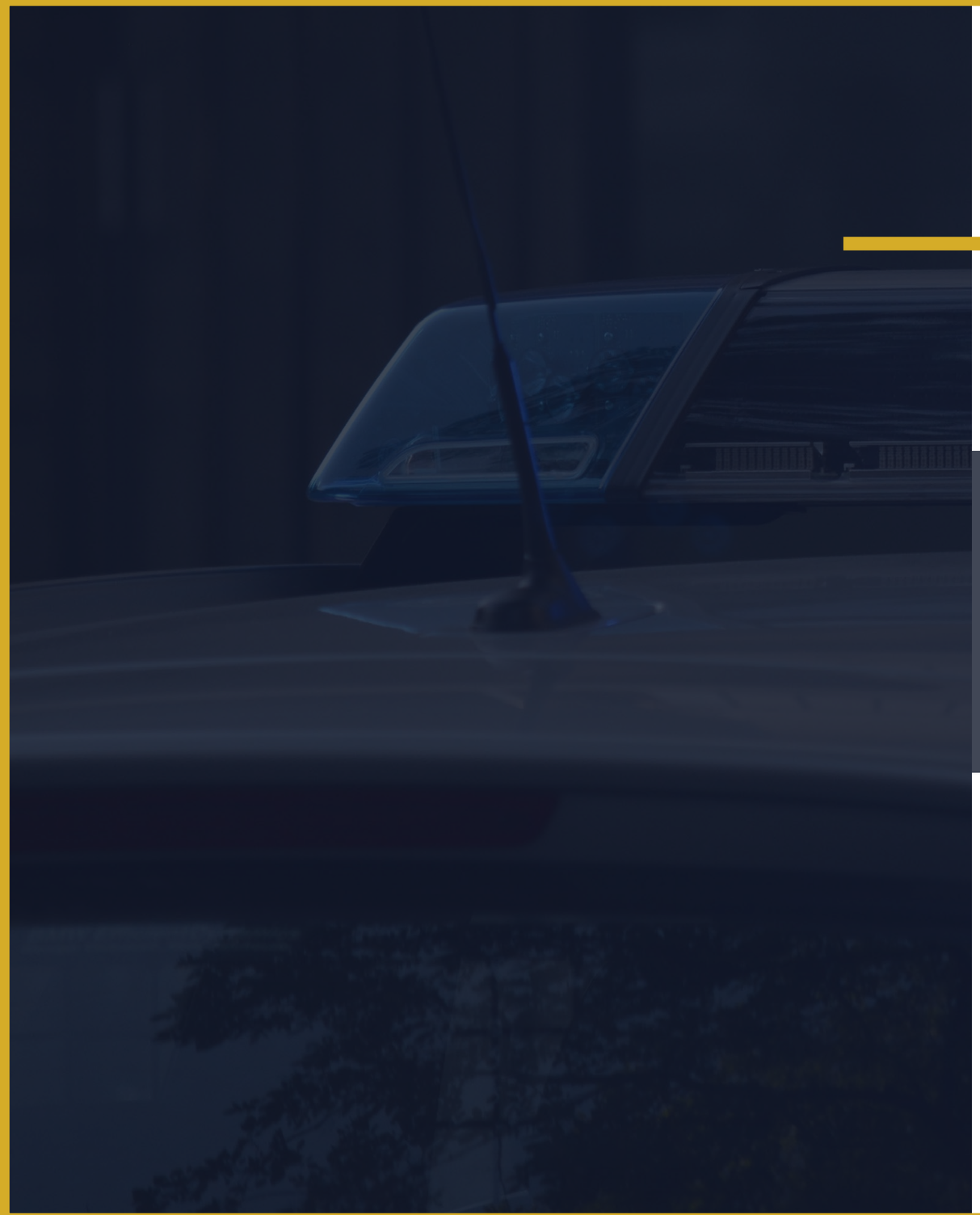


PROJECT OVERVIEW

When it comes to personal protection equipment (PPE) police branches supply their female officers with a male small or what they classify as unisex. Wearing the wrong size PPE can be life-threatening especially when working in a high-risk environment. It is time that the proper body armour is designed to accommodate the female body. Designing body armour that is based on the female anthropometric form to enhance the fit and performance of female police officers. Body Armor needs to be comfortable and accommodating to officers of all shapes and sizes.

In this project, I take into consideration the cleavage lines and lines of non-extension and got inspired through biomimicry looking at the interlocking structure of the diabolical ironclad beetle, fish scales, and chain-like structures. An interlocking structure would increase the surface area allowing the force of a moving bullet to be distributed equally creating a strong structure that would be beneficial to the construction of body armour. Through computer simulation, we can then put these complex structures to the test to see if they could withstand the force of a moving bullet and fulfil the NIJ standards – 0101.03 for armour classifications of type 1 body armour.

In the end, I was able to design and produce body armour that enhances the fit and performance of female police officers. Providing optimal protective coverage, maximizes mobility and fits female officers comfortably. Allowing officers to complete their tasks and not have to worry that they are wearing an ill-fitted PPE. Each size comes with three variable measurements, capturing females' body, upper torso, and bra size creating a diverse custom product.



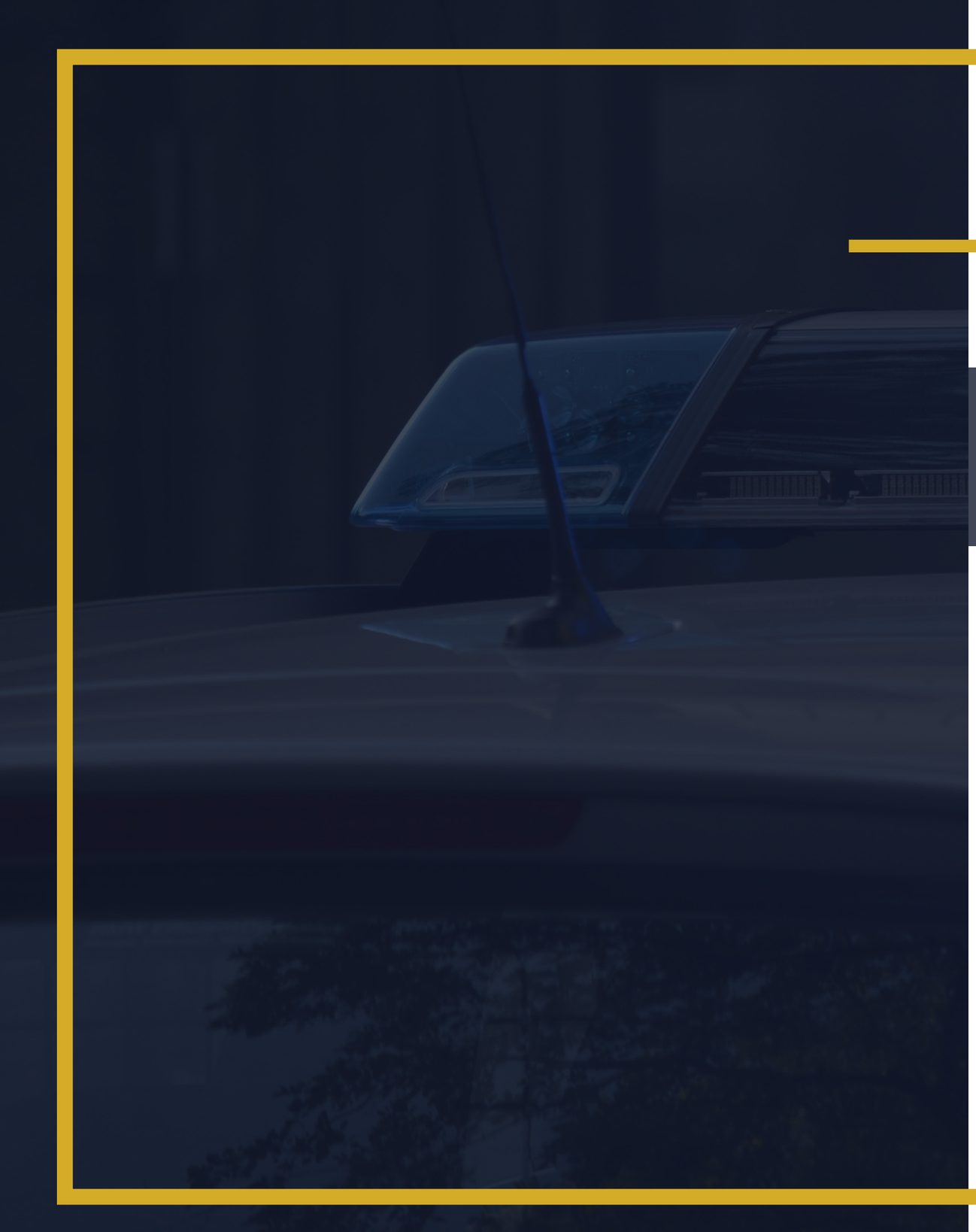
INTRODUCTION

A World Built for Men

Cities are supposed to be built for all of us; men, women, and children. Yet, they aren't built by all of us. Most cities, if not all of them, are designed and built by men. What would a city look like if it was designed by women?

> Women have always worked. They have worked unpaid, underpaid, underappreciated, and invisibly, but they have always worked. [Yet] the modern workplace does not work for women.
>
> – Caroline Criado-Pérez, Invisible Women: Data Bias in a World Designed for Men

The majority of companies supply their female workers with a male small or what they classify as unisex. I started by asking myself how many people have been affected while on the job and how can I help reduce injuries by enhancing fit and performance. Currently, the vest's are complied in two parts. This includes a flexible durable garment made with Kevlar and a hard plate that gets inserted within the vest. "Hard plate armour available for police officers fits female bodies in such a way that extra space is exposed at the chest as breast tissue pushes the flat plate away" (West, S. 2019). This causes back and spinal pains as well as "exposes vital organs and increases the possibility of a fatal shot" (West, S. 2019). With more women joining the police force it is time for a change and there is a need for proper body armour to be designed for the female's body.



BACKGROUND

As designers, we can influence how the world is shaped. Therefore, gender equality is essential to consider when designing products and systems.

“Our widely adopted, unisex design approach, that uses the standard (western) male, to design our spaces, cars, and algorithms around is letting women, (and sometimes men too) down. It has led Google Translate to believe “doctor” is male. It makes women 47% more likely to get seriously injured in a car crash, and it enables voice recognition software to 70% more accurately recognize male speech than female speech” (Criado-Pérez, 2019).

Male bias is rooted in our society; however, it is the twenty-first century, and it is time to recognize the potential and independence of women. They are doctors, police officers, and firefighters. Let us change the design process accordingly and design for all! Diversity in design teams is essential to have, to develop better products. Having people of different backgrounds on a design team allows us to uncover hidden biases and break social norms. The more diversity on a team, the fewer knowledge gaps we have.

As a designer, I wanted to explore and investigate male-dominated occupations for my fourth-year capstone project to see how they provide personal protective equipment (PPE) for their female workers. Many female officers on active duty work at the front lines to protect our communities. Unfortunately, their body armour is designed for ‘standard’ male bodies. Wearing these vests can be uncomfortable for women as it is ill-fitted and raises significant safety and health issues. It can leave more extensive areas of the body unprotected, hindering movement, and putting strain on organs in the female body.

LOOKING INTO THE INDUSTRY

Many of the barriers women face in policing are not specific to policing; rather, they are reflective of larger societal issues and stereotypes.

Experiences

Male bias is firmly ingrained in our society that it has created this perception that females should not be officers even though they passed both the written and physical exams. Due to this, female officers act stoic and more aggressive for the public to perceive them as capable and comply with their orders. Female officers had reported that “citizens would ask when the ‘real police’ would arrive when [female partners] responded to a call” (National Institute of Justice Special Report, 2019).

When female officers were first recruited for regular police duties, they faced backlash. Not only did their male counterparts not want to work with them, but their wives complained too. Many female officers would have trouble depending on their male partners because they did not know if they could rely on them. Several officers said they nearly left law enforcement because of this. “No one valued [them] on the job. [They] teach police officers that everything is a threat. For women, not only can they not trust the people they [are] policing, but they also can [not] trust the people who are supposed to have their backs.” (National Institute of Justice Special Report, 2019).

On top of that, female officers would deal with harassment. They deal with it so regularly that it has become “normalized” to a point where they do not consider it harassment. It is just part of the work environment. “A lot of the things [female officers] experience would be considered harassment in another field” (National Institute of Justice Special Report, 2019). Over the years, there have been progressive changes regarding these issues, “yet, female officers are still fighting the same fights as the previous generation (National Institute of Justice Special Report, 2019).”

Women on The Force: THE BEGINNING

1800

Self Appointed Policewoman

Rose Fortune, a Black Loyalist born into slavery, becomes the first woman in Canada known to have taken on police duties. The successful entrepreneur imposes and enforces curfews at the wharf in Annapolis Royal, Nova Scotia.

1900

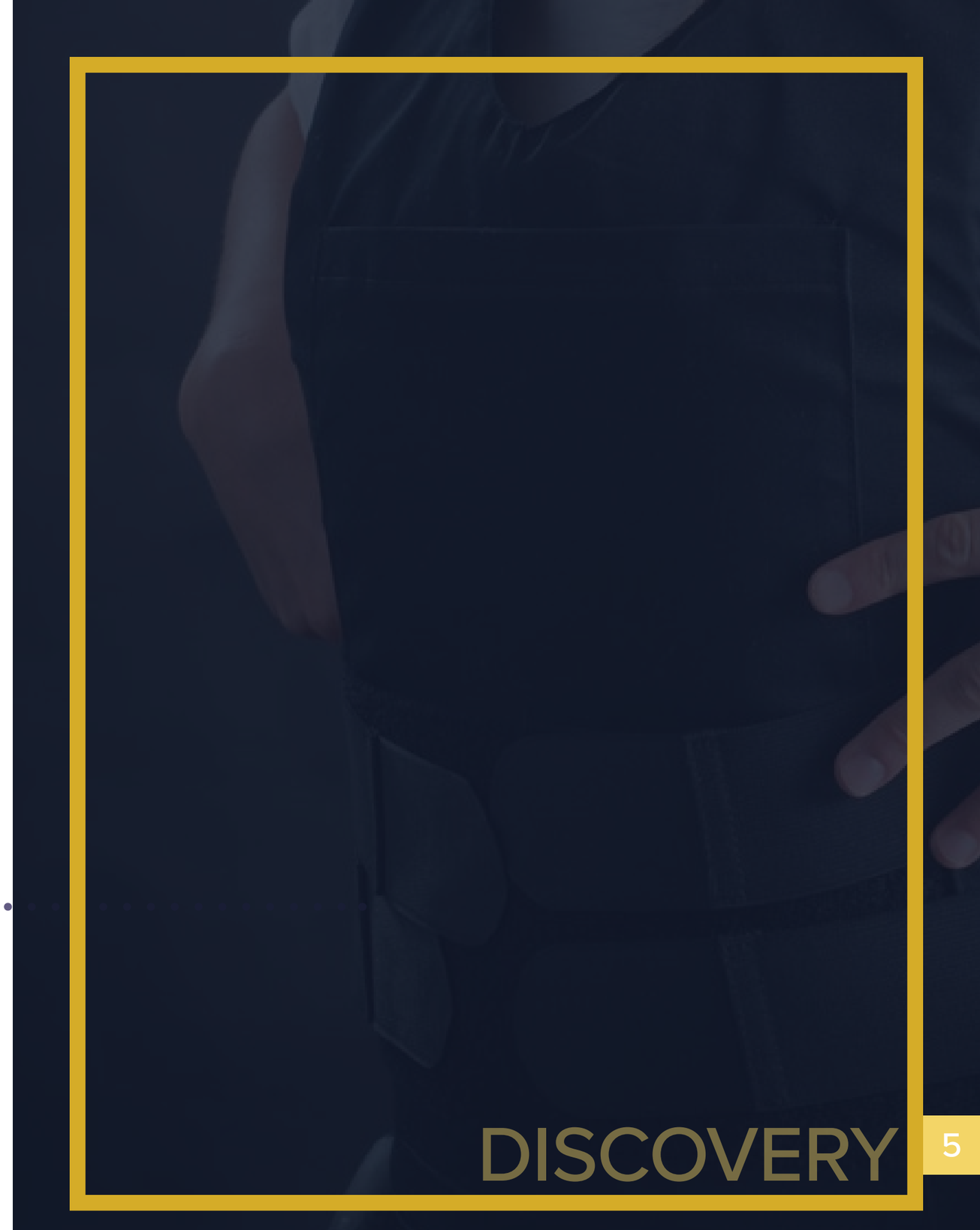
Women Were Hired

Women were hired as fingerprint and lab technicians. Their duties ranged from answering phones and taking complaints, to searching female offenders, providing meals to prisoners, as well as providing lodging and meals to visiting officials.

1974

Working with Men

In Toronto, female officers were assigned to patrols with men. For the first time, thirty-two female officers took up duties as the RCMP’s first female officers.



Statistics

22%

Female Police Officers in Canada

30%

Female Police Officers in BC

30

Average Age of Female Police Officer

60th

On Average Female Police Officer are within the 60th percentile keeping there body mass to 30%

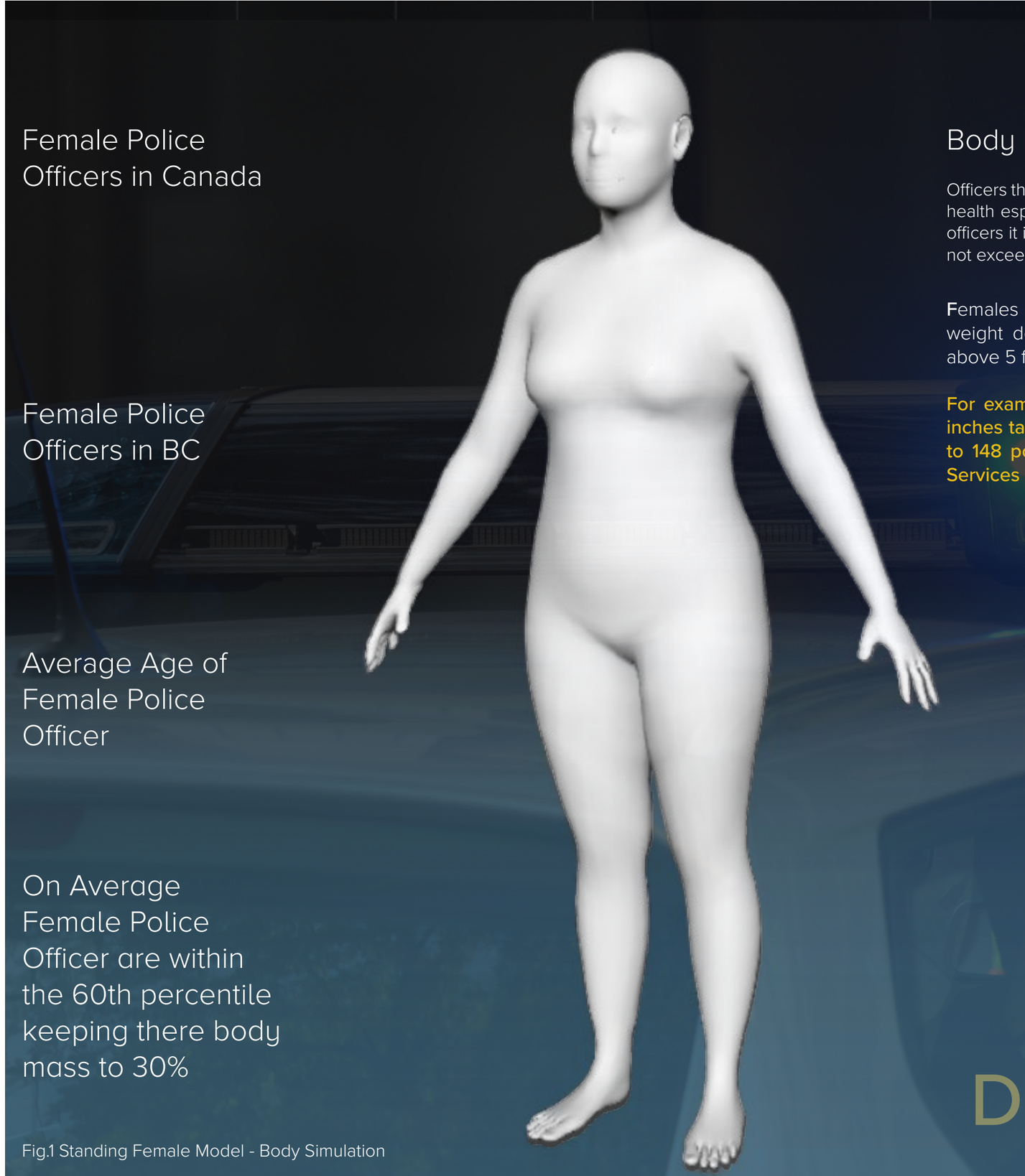


Fig.1 Standing Female Model - Body Simulation

Body Mass

Officers themselves must maintain their bodies and health especially when on active duty. For female officers it is recommended that their body fat must not exceed 30%. For males it's 22%.

Females who are 5 feet tall should get their weight down to 124 pounds. For every inch above 5 feet, add 4 pounds.

For example, a female who is 5 feet and 6 inches tall, should try to get her weight down to 148 pounds (124 +(6 x 4) = 148) (Medical Services Division).

INJURIES

Blunt trauma can cause **Rib Fractures** and damage vulnerable organs including the **Heart, Lungs, Liver, Spleen, Kidney, Breast Tissue & Skin.**

Fig.2 Female Human Anatomy

BODY ARMOUR

A ballistic vest or bullet-resistant vest, also called a bulletproof vest, is an item of body armor that helps absorb the impact and reduce or stop projectiles fired from a firearm and shrapnel from explosions. Currently, the vests our comprised of two parts this includes a flexible durable garment called a carrier and a hard plate that get inserted between layers of the vest.

Carrier

Soft armour panels are typically constructed of multiple layers of ballistic-resistant materials. This can include “as few as eight layers, or as many as 25, depending on the level of protection desired.” (How Products are Made, n.d.)

Fig.3 Safe Life Defense Body Armor

Ballistic Materials Properties

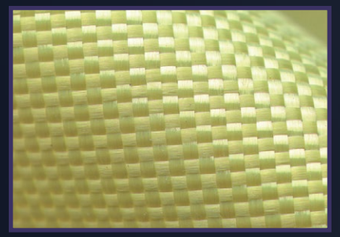


Fig.4 Close up of Twaron

TWARON – Synthetic Fiber

- High strength: excellent strength-to-weight ratio
- High modulus
- High dimensional stability: very low creep, small negative thermal expansion coefficient
- Excellent thermal stability: usable across a wide temperature range, no melting point, high heat stability, low heat conductivity
- High cut resistance
- Good chemical resistance
- Low flammability
- Electrically non-conductive
- Long, well-defined lifetime

Fig.5 Close up of Dyneema

Dyneema – Ultra-High-Molecular-Weight Polyethylene

- Lightweight
- Floats on water
- Durable
- Resistant to moisture, UV, chemicals

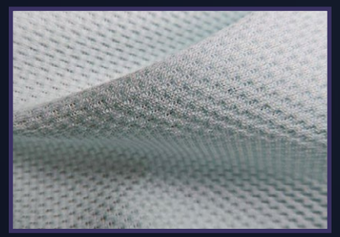


Fig.6 Close up of CoolMax

CoolMax – Polyester Fabric Good For Moisture-Wicking And Is Breathable

- Lightweight
- Soft on skin
- Wicks moisture away quickly (keeps your skin dry, feeling cool and fresh, helps prevent odour, prevents the risk blisters)
- Breathable
- Durable
- Cushions
- Dries fast
- Resistant to fading, shrinking and wrinkling
- Light compression and support
- Freedom of movement

Kevlar – Synthetic Fiber

- Durable
- Lightweight
- Abrasion Resistance
- Flame Resistance
- Chemical Resistance (Acid, Alkali & Organic Solvent)

Fig.7 Close up of Kevlar

Spectra – Ultra-High-Strength Polyethylene Fiber

- Durable
- High flex strength
- Good UV resistance (comparable to polyester)
- Very high initial modulus numbers
- Superior breaking strength
- Susceptible to creep
- Light enough to float
- High resistance to chemicals, water, and ultraviolet light
- Melting temperature (150°C or 300°F)

Fig.8 Close up of Spectra

Goretex – Waterproof, Breathable Fabric Membrane

- Waterproof
- Breathable
- Windproof
- Lightweight
- Durable

Fig.9 Close up of Goretex

Hard Plates

Hard armour plates may be constructed from ceramics, compressed laminate sheets, metallic plates or composites that incorporate more than one material. Hard armour plates work in one of two ways: they can capture and deform the bullet, or they can break up the bullet. In both instances, the armour absorbs and distributes the force of impact.

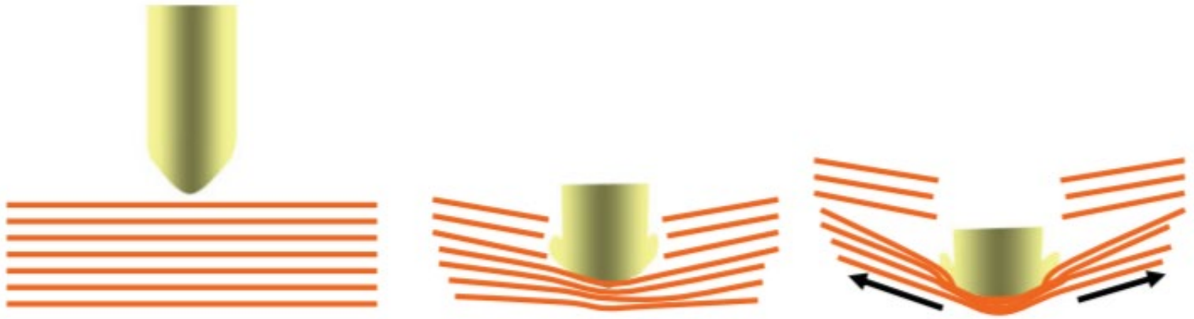


Fig.10 Distribution of Force

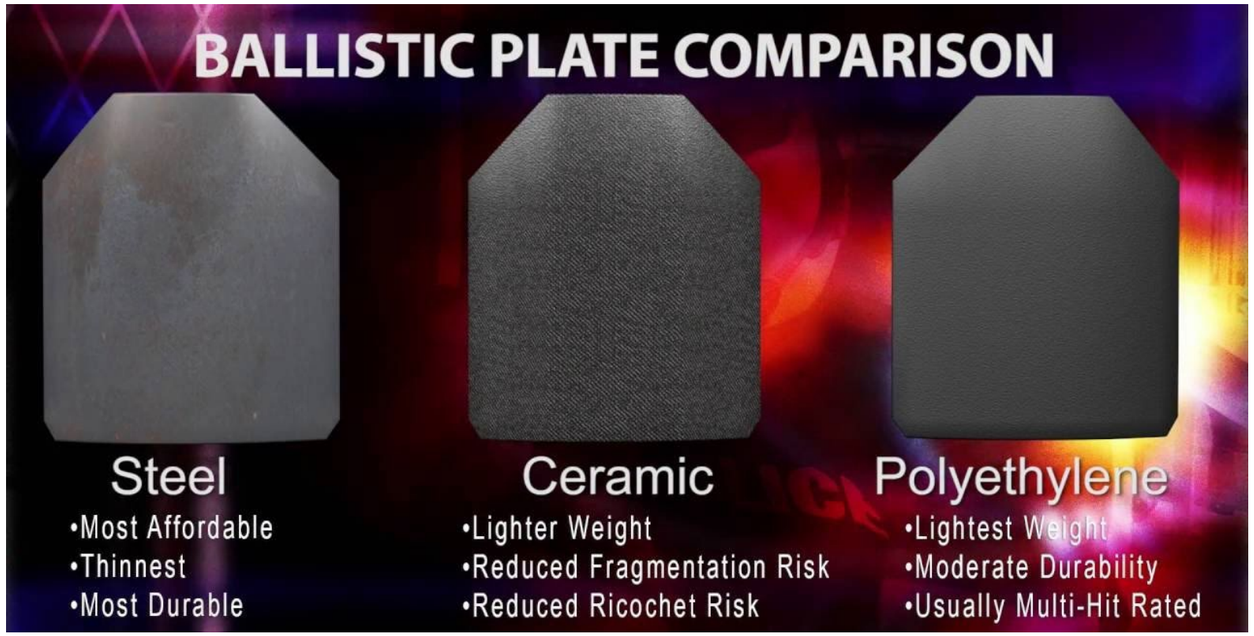


Fig.11 Galls Ballistic Plate Comparison

Regulations & Standards

The National Institute of Justice (NIJ) Standard for the Ballistic Resistance of Police Body Amour NIJ Standard–0101.03 establishes six formal armor classification types, as well as a seventh special type, as follows:

1. Type I (.22 LR; .38 Special)
2. Type II–A (Lower Velocity .357 Magnum; 9mm)
3. Type II (Higher Velocity .357 Magnum; 9mm)
4. Type III–A (.44 Magnum; Submachine Gun 9mm)
5. Type III (High-Powered Rifle)
6. Type IV (Armor-Piercing Rifle)
7. Special Type

Types I, II–A, II, and III–A armor are required to prevent penetration from the impact of six bullets at specified velocities and locations for two types of ammunition. Two of the impacts in each six-shot sequence must be at a 30° angle. Furthermore, the deformation of the backing material (a measure of blunt trauma protection) must not exceed 44mm (1.73 in). The armor must meet these requirements while both dry and wet (U.S. Department of Justice. 2001).

Type III armor requirements are identical to those above, except that only one type of ammunition is specified, and all six test rounds are fired perpendicular to the surface of the armor (U.S. Department of Justice. 2001).

Type IV armor is required to resist penetration from only a single type of ammunition (armor piercing) and is only required to prevent penetration from a single perpendicular impact (U.S. Department of Justice. 2001).

The neck opening should have the maximum coverage without sacrificing comfort.

The shoulder straps should be wide enough for comfort and to distribute the weight of the armour.

The armholes should have the maximum coverage without impacting the officer's preferred shooting stance.

Fig.12 Bulletproof vest

The armour should allow for adjustment while retaining an overlap and protection on the sides; ensuring at least 2" of overlap.

The armour should extend from just below the jugular notch to 2 -3 finger width above the top of the officers' duty belt when standing. Having standard clothing industry sizes such as 38cm long, 32cm short.

Additional and/or optional garments can be attached to the armour. Incorporating tails that can be tucked in preventing the armour from riding up and create additional protection in the lower torso.

The protection level should be based on a risk assessment and offer protection against the common threats encountered by the officer.

Vulnerable Zones

Police officers are exposed to high-risk environment they have the chance of failing to return home while on active duty. Looking into crime reports of officers killed while wearing protective armour it was reported that after head wounds, upper torso wounds are the second most at-risk part of the body. Breaking down the cause of deaths in the upper torso to 51.2% between the vest panels, 26.8% above the vest panel, 17.1% of rifle or handguns that penetrated the vest, and 4.9% from the back or below the vest. “One thing is certain: armour that is absolutely guaranteed to fail to protect the wearer is the armour that is not worn at all” (U.S. Department of Justice. 2001). Officers should always wear their body armour while on active duty because you never know when a situation can escalate. That is why it is important that we design body armour to fit properly increasing the comfort level encouraging officers to wear their PPE for longer periods of time.

When female officers wear male sizes or unisex armour it does not sit against the body. It sits in such a way that it creates extra space between the carrier and the body. Putting female officers at higher risk of a fatal shot. When designing garments for females it is important to consider the different curves and shapes of the female body. In the cases study “Customization of A Lightweight Ballistic Vest for Females” By F. Boussu, A. Ragot, M. Kulinska, X. Legrand, P. Bruniaux they compared the different measurements of male and female officers’ bodies and established 3 different zones to consider when designing armour for the female body. In order for the female carrier to lay against the body with minimal to no gaps. “The different zones have been delineated to specify the various darts positions (only for the para-aramid fabrics) to conform to the shape of the female body and not to avoid the ballistic protection efficiency” (Boussu, Ragot, Kulinska, Legrand, & Bruniaux, 2008). When sketching and ideating I took into consideration these 3 zones as well as consider the cleavage lines and lines of nonextension.

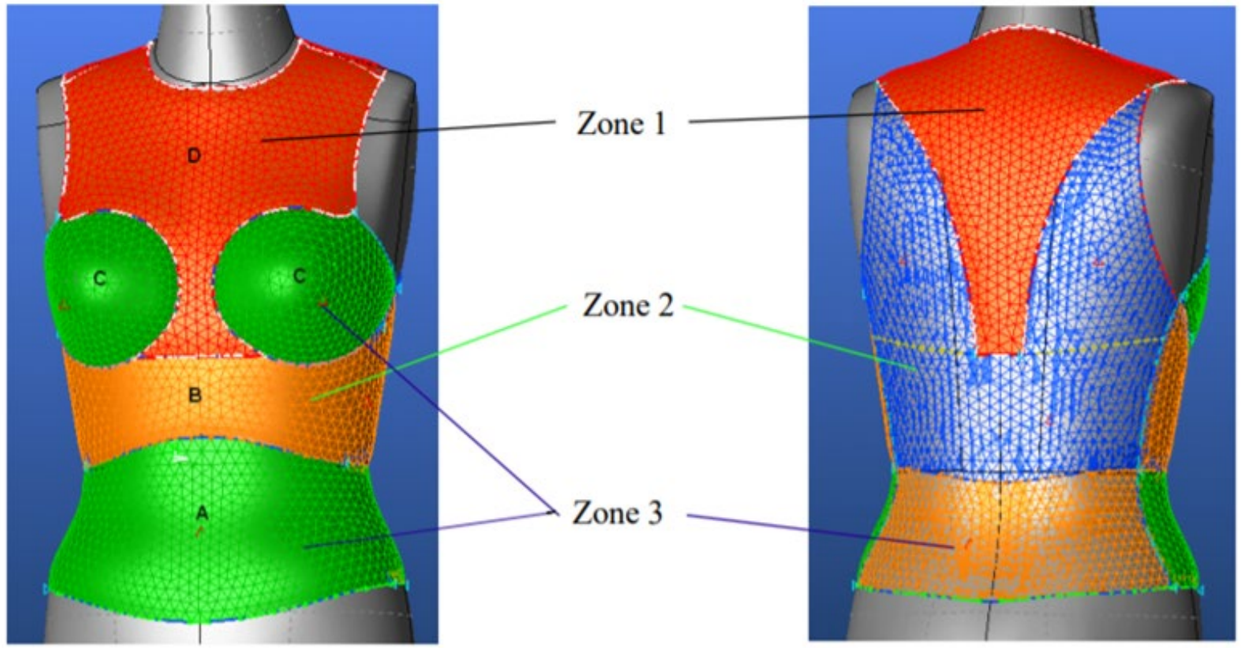
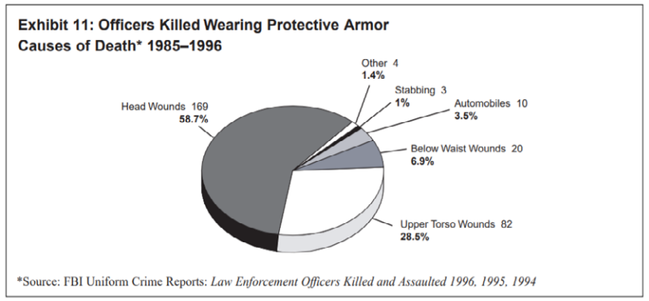


Fig.13 Zones to Consider While Designing Female Armour



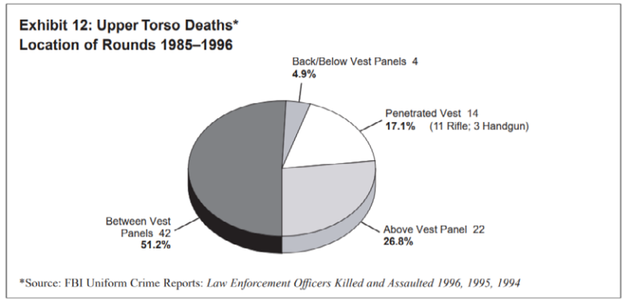


Fig.14 Officers Death Statistics

Cleavage Lines & Lines Of Nonextension

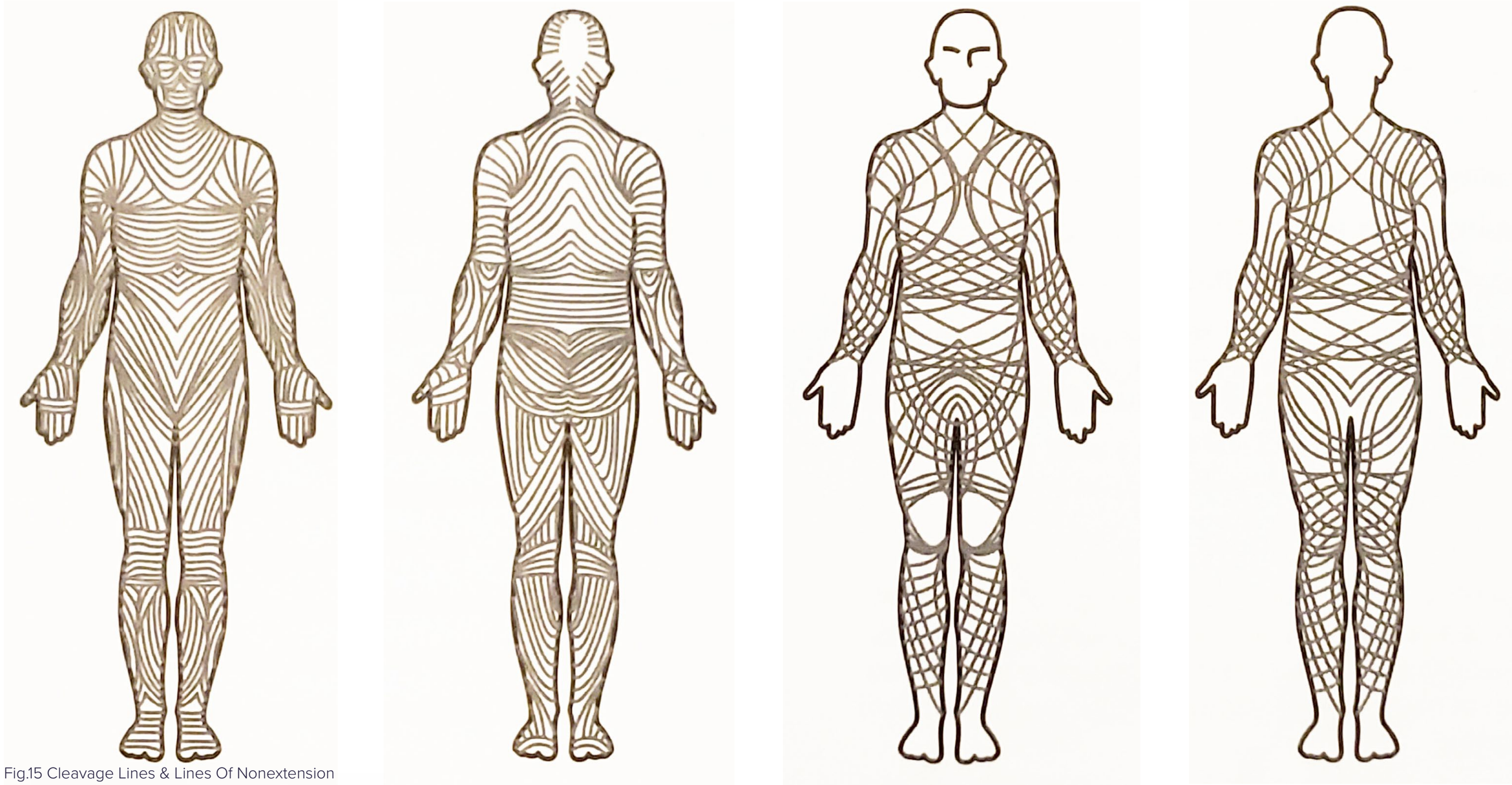


Fig.15 Cleavage Lines & Lines Of Nonextension

Fig.16 Lines of Extension Icons

Undergarments

One of the main differences between male and female officers is that majority of females wear undergarments. I wanted to research to see how this additional garment could affect the performance of an officer while wearing body armour. “The effect of breast size and bra type on comfort for UK female police officers wearing body armour” by Chris Malbon, Dr. Clare Knock, Dr. Richard Critchley & Prof Debra J Carr (Malbon et al., 2020) is a case study done in the UK that discusses the effects and injures that happens to female police officers’ breasts. They also talk about how 3D technology has made it easier to create better formed shaped body armour. In part of the case study, they experiment to see which type of bra would be best fitted to work with the current armour. You have to consider that the profile of the female body is dependent on breast size, body shape and type of bra worn, that the design of the body armour has to conform to in order to create a design that optimizes protection and fit. This paper aimed to “develop insights of preliminary data of factors that may affect the comfort, fit and usage of body armour by UK female police officers by understanding

• The type of bra that is normally worn by a female police officer in combination with body armour,
• The range of bra sizes worn by female police officers in England and Wales,
• Which areas on the body are uncomfortable for female officers and
• Other factors that may influence the comfort of the body armour.”

Key insights:
“One of the main areas of concern with relation to armour design for females is the correct fit.”
“The most common UK size of bra worn was 32B and the most common type of bra worn by UK female police officers was underwired.”
“The most reported areas of rubbing and/or discomfort were around the anterior mammary regions and posterior lumbar-sacral region.”
“Walking was the easiest task performed compared to running which was considered the most difficult. The use of a firearm or TASER was balanced between easy and difficult.”
(Malbon, C., Knock, D. C., Critchley, D. R., & Debra J Carr, P. 2020).

Activity	Bra type (n)	Very Easy	Easy	Difficult	Very difficult
Sitting in a car	Underwire (1775)	2%	37%	48%	13%
	Sports (424)	1%	34%	49%	15%
	Padded/push up (212)	3%	41%	46%	11%
	Other (82)	0%	35%	52%	12%
	No bra (8)	0%	25%	50%	25%
Driving a car	Underwire (1754)	1%	25%	52%	20%
	Sports (420)	1%	23%	51%	23%
	Padded/push up (212)	2%	30%	52%	15%
	Other (80)	0%	33%	46%	18%
	No bra (7)	0%	0%	75%	13%
Walking	Underwire (1764)	3%	71%	23%	3%
	Sports (423)	3%	72%	22%	3%
	Padded/push up (211)	4%	73%	21%	2%
	Other (81)	2%	72%	25%	1%
	No bra (7)	14%	71%	14%	0%
Running	Underwire (1776)	1%	8%	45%	47%
	Sports (425)	0%	6%	44%	50%
	Padded/push up (210)	0%	7%	48%	44%
	Other (82)	0%	11%	42%	46%
	No bra (8)	0%	0%	50%	50%
Self defence	Underwire (1714)	1%	22%	57%	18%
	Sports (408)	0%	21%	57%	20%
	Padded/push up (202)	1%	29%	53%	15%
	Other (79)	0%	27%	47%	22%
	No bra (8)	0%	25%	63%	13%
Using a firearm/TASER	Underwire (191)	3%	45%	36%	16%
	Sports (62)	5%	47%	34%	15%
	Padded/push up (23)	0	57%	39%	4%
	Other (6)	0	50%	33%	17%
	No bra (0)	0	0	0	0

Bra type (n)	Very Comfortable	Comfortable	Uncomfortable	Very uncomfortable
Underwired (1849)	1%	31%	53%	14%
Sports (445)	1%	25%	56%	18%
Padded/push up (219)	2%	42%	45%	11%
Other (87)	0%	38%	52%	10%
None (12)	8%	17%	67%	8%

Bra size (n)	Bra type				
	None	Sports	Underwired	Padded/Push up	Other
32C (78)	0%	13%	68%	15%	4%
34B (220)	1%	14%	64%	17%	4%
34C (207)	0%	12%	73%	12%	3%
34D (151)	0%	15%	76%	8%	1%
34DD (145)	1%	12%	79%	6%	1%
36B (148)	1%	16%	69%	10%	4%
36C (212)	0%	19%	67%	8%	5%
36D (135)	0%	18%	75%	4%	4%
36DD (110)	0%	25%	68%	5%	3%
38C (74)	0%	27%	65%	3%	5%

Primary role (n)	Type of bra (% by primary role)				
	No bra	Sports bra	Underwired bra	Padded/push up bra	Other
Routine Patrol (2008)	0	17	71	9	3
Specially trained firearms officer (19)	0	16	74	5	5
Specially trained public disorder officer (16)	0	25	63	6	6
Traffic officer (66)	2	23	65	6	5
Detective (311)	0	14	74	9	4
Custody/Offender management (58)	0	19	74	3	3
Police community support officer (14)	0	20	73	0	7
Civilian staff (49)	0	18	63	6	12
Other (81)	1	17	70	9	2
Total across all roles (2622)	0	17	71	8	3

Fig.17 The effect of breast size and bra type on comfort for UK female police officers wearing body armour

ON THE MARKET

User Feedback

"**Blocking Bullets** is top priority. A Close second, Body Armor needs to be **comfortable**, and **accommodating officers of all shapes & sizes.**"

"Needs to be more **comfortable, breathable, flexible, and user friendly.** A User-friendly vest that we could go out on patrol and **wear with our other equipment** that **provides the maximum protection and coverage** that we need, in order for us to survive. When a female officer receives a vest from the vendor it's not fitting properly, it's an ill-fitted vest. There seems to be very vague explanation as to why that female vest, when it was specifically measured for that officer does not fit properly when it's received. I think more education needs to happen in the process, of measurement, production and end product."

"Ill-fitting vests can be more than an annoyance. Design elements such as **darts and folds in female vests can cause them to be bulky, restricting movement** and causing gaps under arms that make officers more venerable. Problems include: **Rides up, crushes breast, lack of ventilation, gap between side plate.**"

Problem Areas

Fig.12 Bulletproof vest

DESIGN CRITERIA

- Durable
- Enhances Fit
- Accommodates All Shapes & Sizes
- Enhance Performance
- Increase Ventilation
- User Friendly
- Light Weight & Less Bulky

INSPIRATION

Biomimicry

Diabolical Ironclad Beetle:

“The diabolical ironclad beetle is like a tiny tank on six legs. The diabolical ironclad beetle, which dwells in desert regions of western North America, has a distinctly hard-to-squish shape. Analyses of microscope images, 3-D printed models and computer simulations of the beetle’s armor have now revealed the secrets to its strength. Tightly interlocked and impact-absorbing structures that connect pieces of the beetle’s exoskeleton help it survive enormous crushing forces, [...]. Those features could inspire new, sturdier designs for things such as body armor, buildings, bridges and vehicles” (Science News, 2020).

Engineers are working on an 8-million-dollar project funded by the US Air Force; looking into how the beetle operates to create an impact-resistant material. They can withstand compression of up to 39,000 times their body weight. A car could run them over and they would be fine. The beetle’s fused elytra [are] interlocked. While other beetles have interlocking elytra, the diabolical ironclad had a greater number of interlocking sections, resembling connected jigsaw-puzzle pieces.

Its been“report that joints and supports in the exoskeleton of Phloeodes diabolicus help to account for the insect’s remarkable crush resistance. A joint known as a suture locks together the beetle’s hardened forewings (the elytra). The suture consists of inter-locked, ellipsoidal structures called blades. This interlocked structure, combined with the layered microstructure of the blades (not shown), enhances the suture’s toughness. Three types of lateral support connect the ventral cuticle to the elytra: interdigitated, latching and free-standing. The interdigitated joints are the stiffest and strongest under compression, whereas the latching and free-standing supports allow the exoskeleton to undergo some deformation when compressed” (Nature, 2020).

Taking inspiration from the interlocking structure of the diabolical ironclad beetle. This interlocking structure increases the surface area creating a strong material that would be beneficial to the construction on body armour. Allowing for flexibility and optimizing strength.

Fig.18 The diabolical ironclad beetle

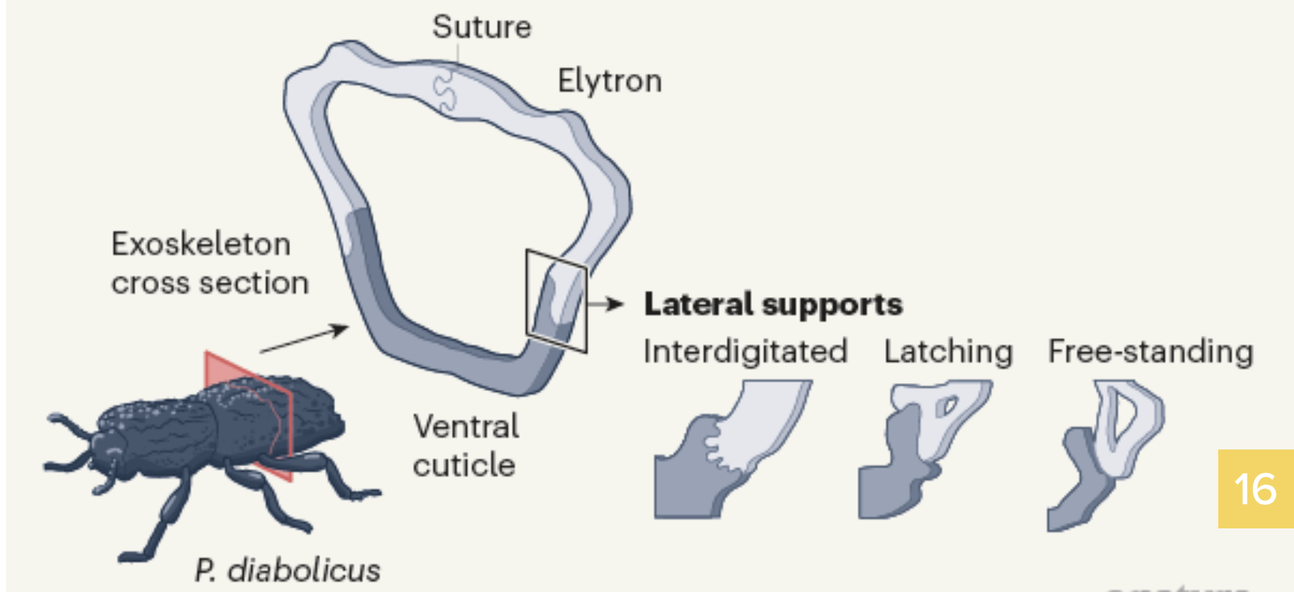


Fig.19 Tough joints and interfaces

IDEATION &
CONCEPTUALIZATION

Pangolins & Striped Bass Fish:

Both of these species are structured in similar ways. These structures allow for flexibility and movement, providing additional strength through layering. This layered protection keeps predators from puncturing its outer shell. “The striped bass scales are about 0.2 to 0.3 mm thick and can stop about 3 Newtons” (Ask Nature, 2017).

Fig.20 Pangolin

Fig.21 Fish Scales

IDEATION & CONCEPTUALIZATION

Golden-Scale Snail:

The Sea Snail uses a hard, armour like shell with a tri-layered composition. This is similar to how current body armours are constructed using multiple layers to absorb the impact.

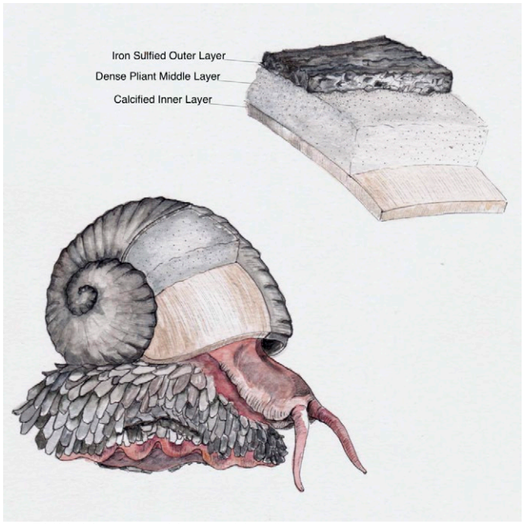


Fig.22 Golden-Scale Snail layers

Fig.23 Golden-Scale Snail close up

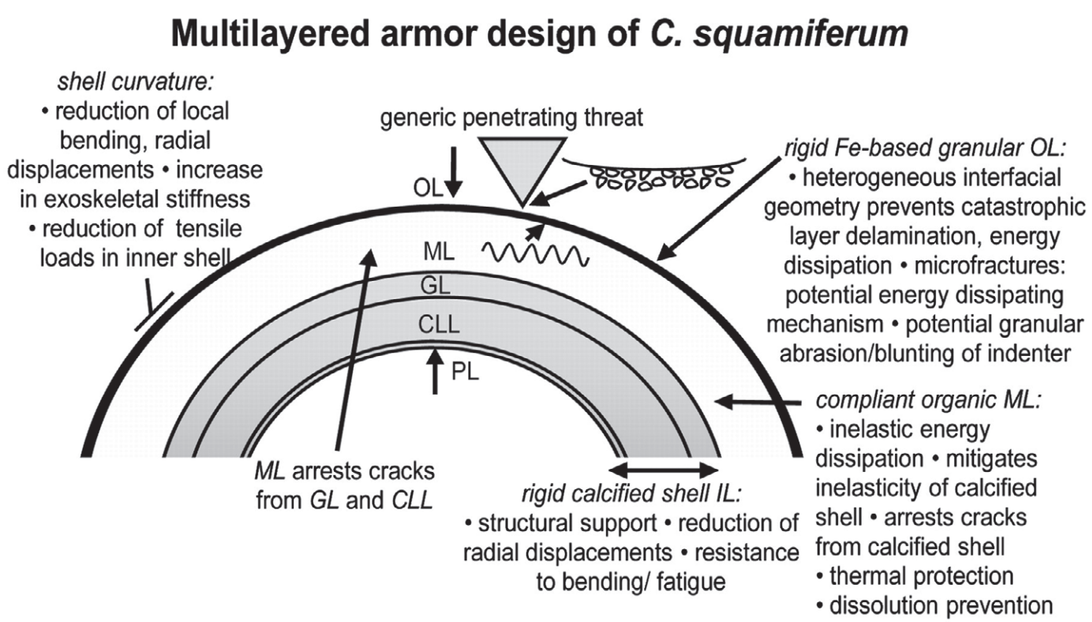
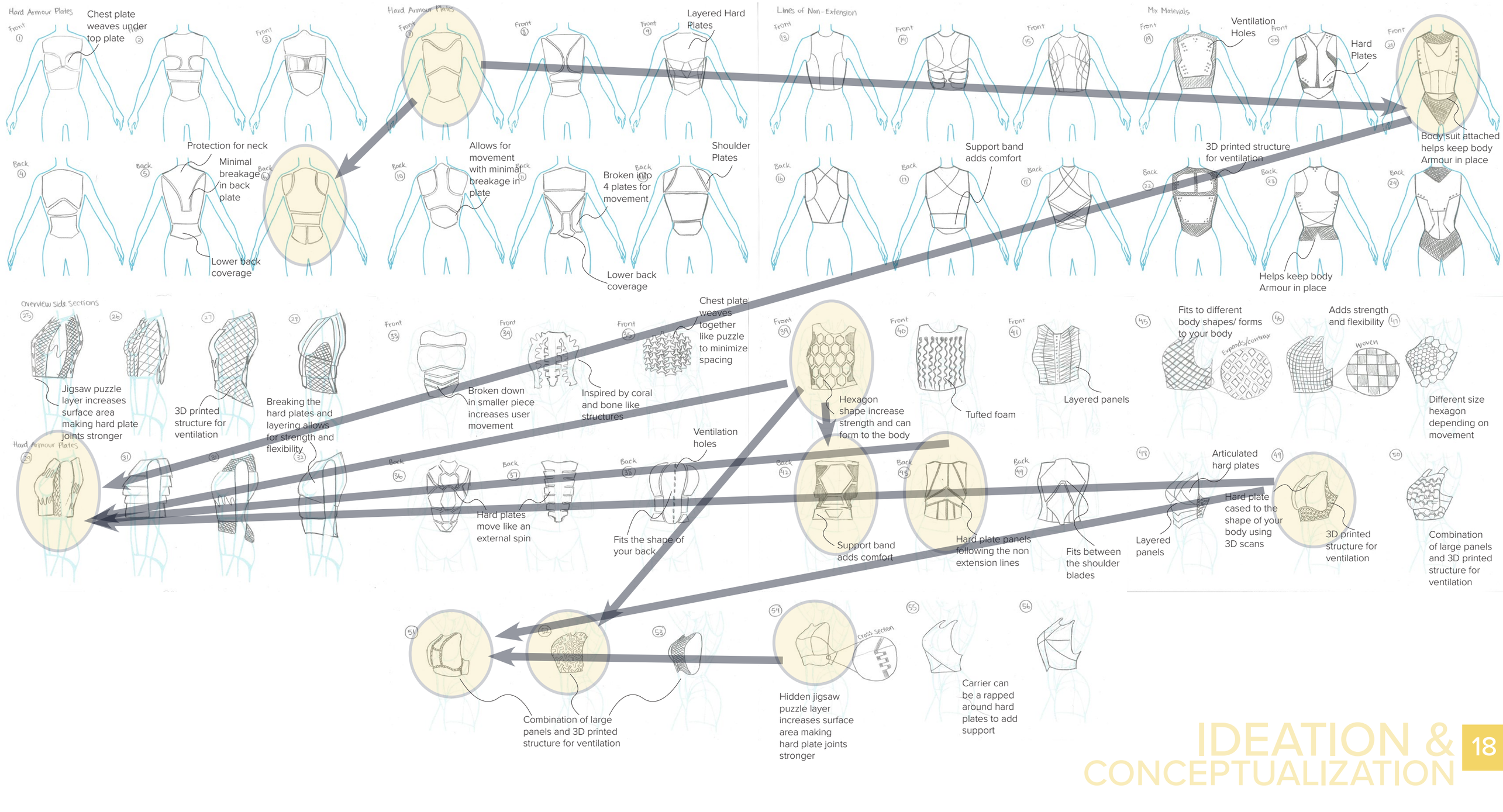


Fig.24 Golden-Scale Snail Diagram

PROCESS DEVELOPMENT MAP



STRUCTURE EXPLORATION

During this exploration stage, I was investigating into different structures that could allow for flexibility, air circulation, and provide optimal protection. Looking at creating different layers, form, and materials, exploring different concepts to see what direction I should develop forward.

Key Insights:

- Hexagons allowed for maximum flexibility and strength
- Interlocking & layered structures increased surface area resulting in a stronger and durable outcome.

IDEATION & CONCEPTUALIZATION

Fig.25 Structure Exploration 1

Fig.26 Structure Exploration 2

Fig.27 Structure Exploration 3

Fig.28 Structure Exploration 4

Fig.29 Structure Exploration 5 - Bend

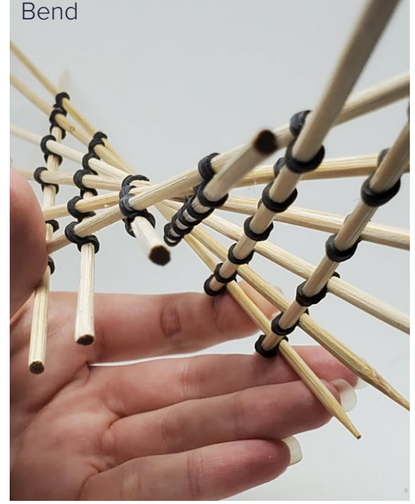


Fig.30 Structure Exploration 5

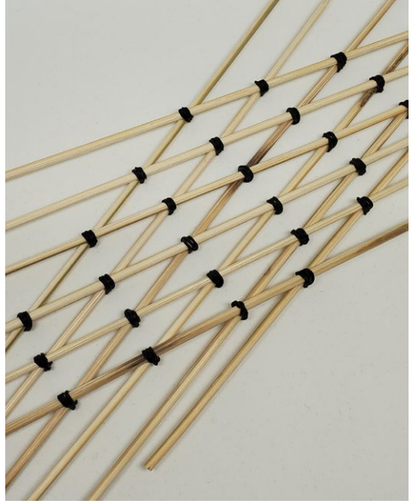


Fig.31 Structure Exploration 6

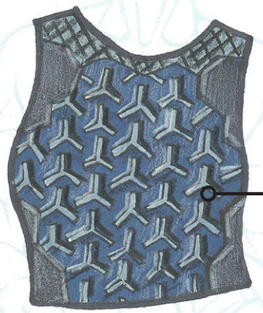
Fig.32 Structure Exploration 7

Fig.33 Structure Exploration 7 - Bend

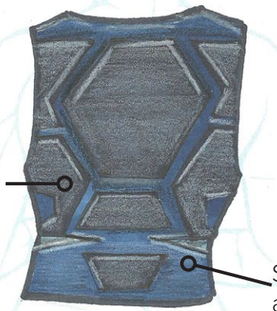
DESIGN CONCEPT

My initial conceptual exploration looked into exoskeletons structures and the possibility of having the inner structure allow for air circulation yet still could withstand the force of a moving bullet. Quickly realizing that adding this additional development into body armour would be a bigger project than the time frame and scope of this project. This type of concept would be something I would like to continue to develop and explore further in the future.

A.



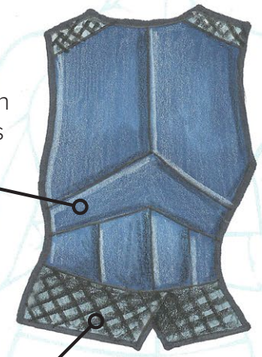
Hard plates broken into large & smaller pieces to allow for easer movement in different parts of the body



Support band adds comfort

B.

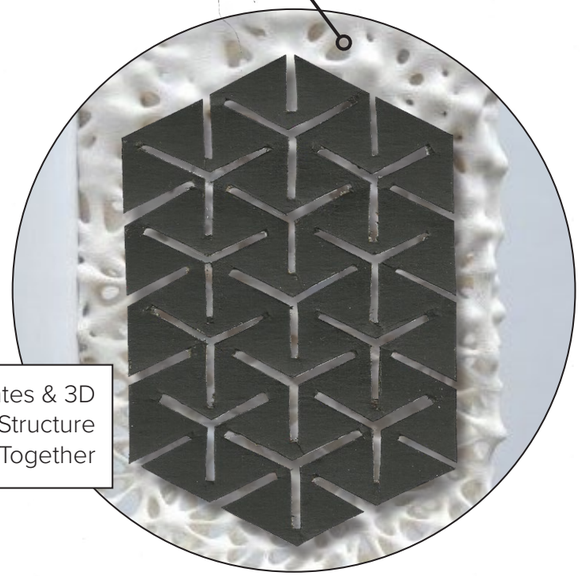
Hard plates broken into smaller pieces to allow for easer movement



Helps keep body armour in place & provides protection to lower organs

3D printed structure allows for ventilation, absorbs shock impact & flexibility

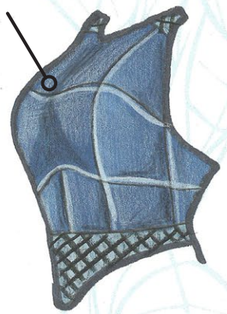
Triangle shape increase strength & move/form to the body

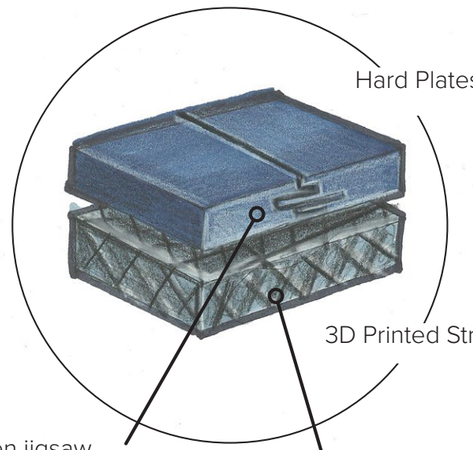


Hard Plates & 3D Printed Structure Infused Together

Fig.34 Sponge Wall

Hard plates cased to the shape of your body using 3D scans





Hidden jigsaw puzzle layer increases surface area making hard plate joints stronger

3D printed structure allows for ventilation & absorbs shock impact

PROTOTYPING

Anthropometric Data

Using the data from the ASTM Standard's 3003 & 5585 I was able to create, and 3D print a half scale mannequin that included the measurements of the 60th percentile female. On average female officers fall within the 60th percentile female. For prototyping purposes, I when with the following measurements of a 60th percentile female. Keeping in mind that each female is shaped differently I came up with a custom measuring system for my body armour found on page 99.

ASTM Standard 3003 for Body Armor

E3003 – 15

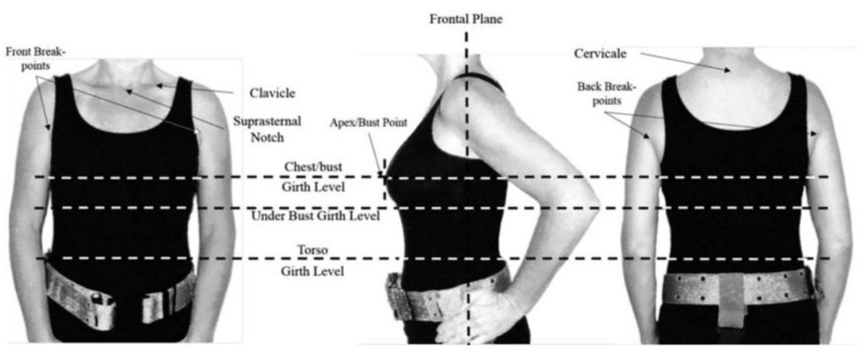


FIG. 1 Female Torso Body Landmarks

Fig.35 ASTM Standard 3003

ASTM Standard 5585 Body Measurements for Adult Female Misses Figure Type, Size Range 00–20

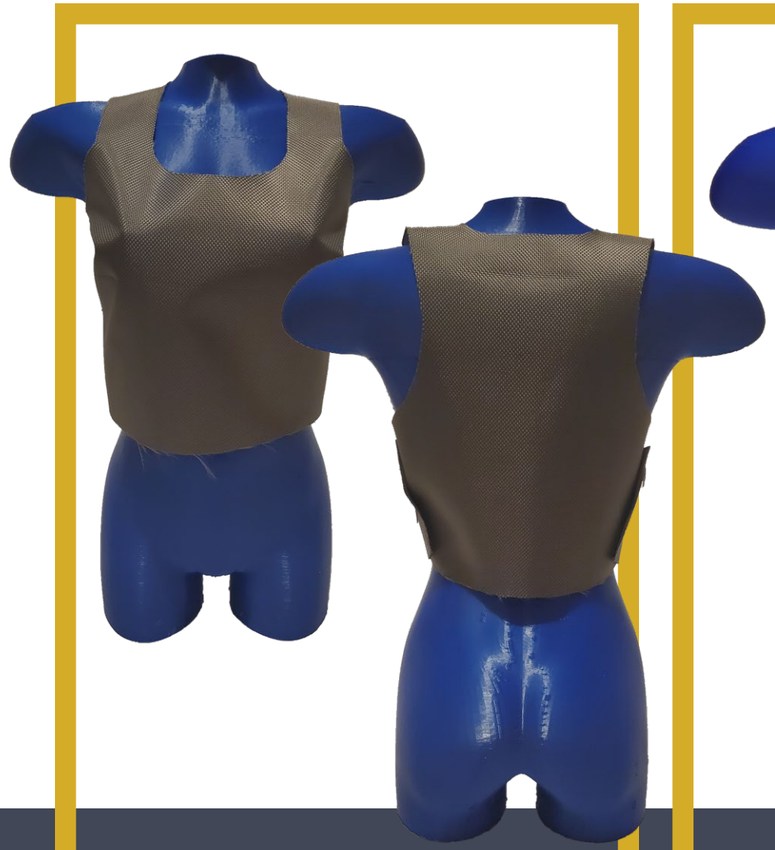
D5585 – 11$^{\varepsilon 1}$

TABLE 1 Body Measurements, Inch-Pound Units

Size	00	0	2	4	6	8	10	12	14	16	18	20
Body Weight (Mean), lb	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Body Weight (Range), lb	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Girth Measurements, in.	00	0	2	4	6	8	10	12	14	16	18	20
Head Girth	21¼	21¼	21½	21½	21¾	21¾	22	22	22¼	22¼	22½	22½
Neck Base Girth	13¼	13½	13¾	14	14¼	14⅜	14⅞	15⅛	15½	15¾	16	16⅜
Mid-Neck Girth	12⅜	12⅝	12⅞	13⅛	13⅜	13⅝	13⅞	14¼	14⅝	15	15½	16
Shoulder Girth	37⅛	37¾	38⅜	39	39¾	40½	41¼	42	43	44¼	45½	46⅞
Chest/Bust Girth	31⅛	31¾	33	34⅛	35¼	36¼	37¼	38¾	40⅜	42⅛	44	46
Under-Bust Girth	25¾	26½	27¼	28	29	30	31	32½	34	35¾	37⅜	39⅝
Upper-Chest Girth	31¾	32¼	33¼	34⅛	35	35⅞	36¾	38	39¼	40⅝	42¼	43⅞
Waist Girth – Curvy	23⅞	24⅝	25⅜	26⅛	27	28	29	30¾	32½	34½	36¾	39
Waist Girth – Straight	25⅜	26⅛	26⅞	27⅝	28½	29½	30½	32¼	34	36	38¼	40½
High-Hip Girth – Curvy	29½	30¼	31⅛	32⅝	33¾	34¾	35¾	37¼	38⅞	40½	42¼	44⅛
High-Hip Girth – Straight	29¾	30½	31⅜	32⅞	34	35	36	37½	39⅛	40¾	42½	44⅜
Hip/Seat Girth – Curvy	34	34⅝	35⅞	37⅛	38¼	39¼	40¼	41¾	43¼	45	46¾	48¾
Hip/Seat Girth – Straight	33¼	33⅞	35⅛	36⅜	37½	38½	39½	41	42½	44¼	46	48
Thigh Girth – Curvy	20½	20⅞	21¼	21⅝	22⅛	22⅝	23⅛	24	24⅞	26¼	27½	28¾
Thigh Girth – Straight	20⅛	20½	20⅞	21¼	21¾	22¼	22¾	23⅝	24½	25¾	27	28¼
Mid-Thigh Girth – Curvy	18⅜	18¾	19⅛	19½	20	20½	21	21⅞	22¾	23¾	24⅞	26
Mid-Thigh Girth – Straight	18⅛	18½	18⅞	19¼	19¾	20¼	20¾	21⅝	22½	23½	24⅝	25¾
Knee Girth	12⅝	12¾	13	13⅜	13¾	14⅛	14½	15	15½	16	16½	17
Calf Girth	12⅛	12¼	12½	12⅞	13¼	13⅝	14	14½	15	15½	16	16½
Ankle Girth	8⅛	8¼	8⅜	8⅝	8⅞	9⅛	9⅜	9⅝	9⅞	10⅛	10⅜	10⅝
Armscye Girth	14½	14¾	15⅛	15½	15¾	16	16¼	16⅞	17½	18⅛	18⅞	19⅝
Upper-Arm Girth	9¾	10	10¼	10½	10¾	11⅛	11½	11¾	12⅛	12½	13	13⅜
Elbow Girth	9⅛	9¼	9⅜	9½	9⅝	9¾	9⅞	10⅛	10⅜	10⅝	11	11⅞
Wrist Girth	5⅛	5¼	5⅜	5¾	5⅞	6	6⅛	6¼	6⅜	6½	6⅝	6¾
Hand Girth	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Trunk Length (total vertical girth) – Curvy	57⅛	57½	58	58½	59	59½	60	60⅞	61¾	62⅞	64	65⅛
Trunk Length (total vertical girth) – Straight	57	57⅜	57⅞	58⅜	58⅞	59⅜	59⅞	60¾	61⅝	62¾	63⅞	65

Fig.36 ASTM Standard 5585

Carrier Iterations - Half Scale



HFSC-F1LC-01 Fig. 37
(Half Scale – Female 1 Layer Carrier – 01)

This prototype explored the basic shape of body armour female officers currently wear. This boxy garment did not sit flat on the model's body. There was a lot of extra space between the garment and the body.

HFSC-F1LC-02 Fig. 38
(Half Scale – Female 1 Layer Carrier – 02)

This was a paper prototype that explored articulation positions to change the basic shape and make the garment form fitted to the female body.

HFSC-F1LC-03 Fig. 39
(Half Scale – Female 1 Layer Carrier – 03)

This prototype was a product of HFSC-FCBS-02 and the articulation points on the front piece. The back piece was taken in and followed the princess seam style to form along the curve of the back. The Velcro enclosure was placed on the back. Key Insights: Velcro enclosure on the back made it hard to put on the garment properly and discovered that the garment needed another articulation point on the front pieces to take it in at the waist.

HFSC-F1LC-04 Fig. 40
(Half Scale – Female 1 Layer Carrier – 04)

In this prototype, I explored different seam lines in the front and back pieces. For the front piece, I took inspiration from the seam lines of a corset bandeau top. This structure allowed the garment to be form fitted while eliminating the need of having multiple darts in the front piece. For the back piece, I experimented with using the cleavage lines and lines of nonextension

EXPERIMENTATION & DESIGN DEVELOPMENT

Carrier Iterations - Half Scale

HFSC-FCFS-01 Fig. 41

(Half Scale – Female Carrier Front Side – 01)

This prototype explored style lines in order to have the garment lie flat against the chest. The style lines were in the right placement but did not change the position of the garment.

HFSC-FCFS-02 Fig. 42

(Half Scale – Female Carrier Front Side – 02)

In this prototype, I split the chest panel in two and increased the curve. In doing so it created a dome like structure. These new configurations allowed the garment to sit flat against the female body.

HFSC-FCFS-03 Fig. 43

(Half Scale – Female Carrier Front Side – 03)

This prototype explored style lines in order to create continuous lines.

HFSC-FT1C-01 Fig. 44

(Half Scale – Female Type 1 Carrier – 01)

This was the first prototype to be constructed using multiple layers. Including the following layers: Ballistic Nylon, Twaron, Kevlar Felt, Spectra, and a Dupont Coolmax Lycra Moisture Wicking Fabric. Using the front style lines of HFSC-FCFS-03 and an adapted back style line of HFSC-F1LC-04 removing the centre back seam and creating two lower back princess seams. Key Insights: It was hard to insert the 3D body scan hard plate into the inner pocket and that having the outer layer be a simpler design would bring female officer's psychological comfort.

EXPERIMENTATION & DESIGN DEVELOPMENT

Carrier Iterations - Full Scale

FLSC-FT1C-01 Fig. 45
(Full Scale – Female Type 1 Carrier – 01)

This was the first full scale prototype to undergo user testing. Key insights: The side seam placement was too close in the armpit region; over time it would cause chafing. When bending over to reach down, the material in the upper chest region would scrunch opening the current pocket exposing the front hard plate. There was also some discomfort in the center bridge seam that it created a lot of bulk at one point.

FLSC-FT1C-02 Fig. 46
(Full Scale – Female Type 1 Carrier – 02)

In this prototype, I added a flap and hook and loop fasteners to the welt pocket and changed the front seam. I also took in the front side arm seam by 3cm this eliminated the chafing problem in the armpit region and created a single waist loop fastener adding additional length for the maximum waist adjustment for that size garment. Key insight: That the upper torso was too long and was interfering with the equipment on the duty belt. Twaron layer snags easily when putting in hard plates.

FLSC-FT1C-03 Fig. 47
(Full Scale – Female Type 1 Carrier – 03)

In this prototype, I raised the bottom hemline in the front by 3cm and in the back 2cm, this allowed the carrier to sit on the torso and not interfere with the equipment on the duty belt. I added an additional layer between the outer layer and the Twaron. The prototype now was constructed with the following 6 layers: Ballistic Nylon, Twaron, Kevlar Felt, 2 Spectra layers, and a Dupont Coolmax Lycra Moisture Wicking Fabric.

EXPERIMENTATION & DESIGN DEVELOPMENT

Hard Plates Iterations - 3D Body Scan

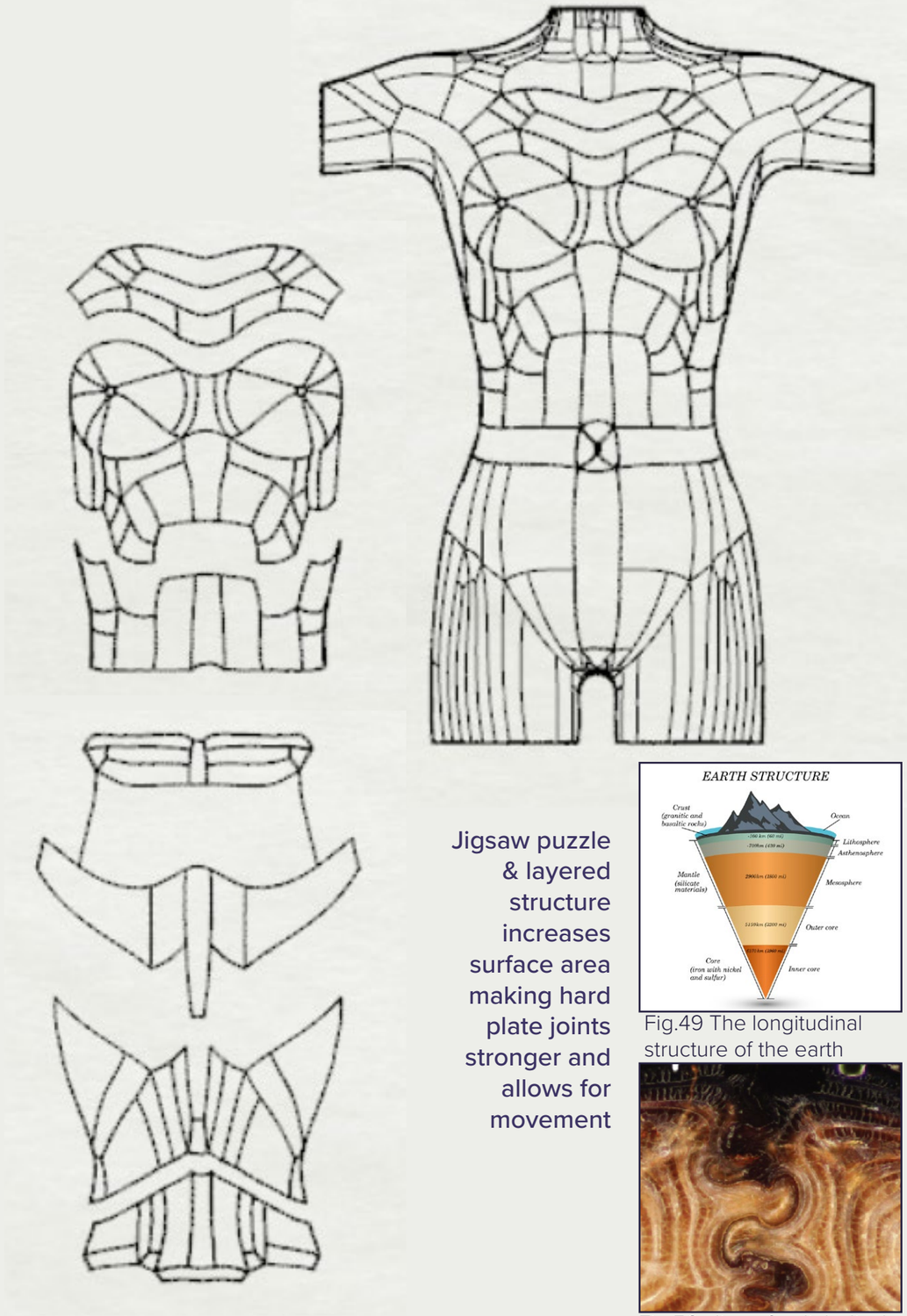


Fig.48 3D Body Scan Hard Plates

Jigsaw puzzle & layered structure increases surface area making hard plate joints stronger and allows for movement

Fig.49 The longitudinal structure of the earth

Fig.50 slice of a diabolical ironclad beetle

In this prototype, I used the 3D body scan of my model to create a custom hard plate form that would fit to her body. To allow for movement I broke the hard plate into different sections. Taking inspiration from the earths Tectonic Plates and the Diabolical Ironclad Beetle jigsaw puzzle like structure.

Fig.51 3D Body Scan

Fig.52 Hard Plates on Mannequin

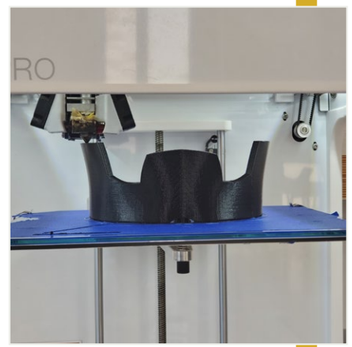


Fig.53 Printing Hard Plate

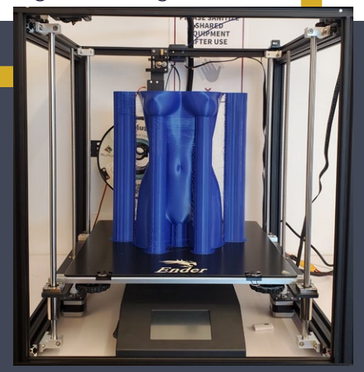


Fig.54 Printing Mannequin

Fig.55 ADIRA
Product Photo 1

ADIRA

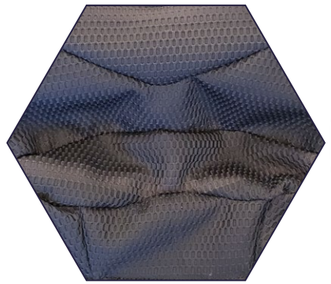
WOMEN IN BLUE

ADIRA is a Type 1 Classified Body Armour for female police officers. Providing optimal protective coverage, maximizes mobility, and fits female officers comfortably. Allowing officers to complete their tasks and not worry that they are wearing ill-fitted personal protection equipment (PPE). Studying the anthropomorphic characteristics of female bodies, I was able to design and produce body armor that enhances the fit and performance of female police officers. Each size comes with three variable measurements, capturing females' body, upper torso, and bra size creating a diverse custom product.

The name ADIRA means strong, noble, and powerful. Which I think is suitable for describing the attributes of female officers as well as allows them to accomplish these traits while wearing my garment. ADIRA is also an acronym for Active-Duty Impact Resistant Armour.

ADIRA's Features:

Shoulder Straps– Loop Fasteners along the full length of straps allows for maximum shoulder length adjustability. Accommodating female officers with a longer or shorter upper torso. Shoulder straps should be adjusted accordingly making sure the carrier sits just below the jugular notch and 2 to 3 finger width above the duty belt when standing.

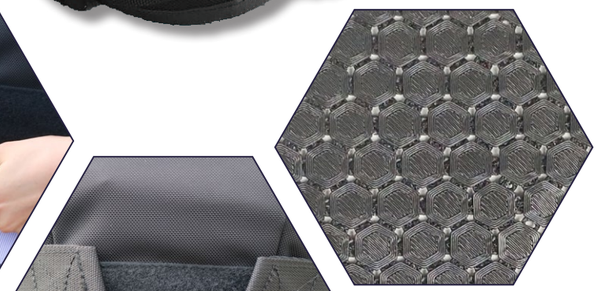


Hard Plate Pockets– The pocket allows for easy access to the hard plates. So that you can easily interchange the hard plates with different bullet impact resistant standards.

Articulated Layers– Having the inner layers of the carrier be articulated allowed for optimal protective coverage, eliminated the unnecessary empty space that put female officers at higher risk.

HardPlate–TheHexagon shape adapts to the user's body and accommodated for slightly different bust positions creating a flat surface for optimal protection.

Adjustable waistband– Loop Fasteners along the waistband has been measured accordingly to account for multiple layers worn under the garment indicating the maximum size while retaining an overlap and protection on both sides; ensuring at least 2" of overlap.



Waist Straps– V-Shaped waist straps increases enclosures strength and keeps carrier fitted around females' waists.

Fig.56 ADIRA Body Armour Features

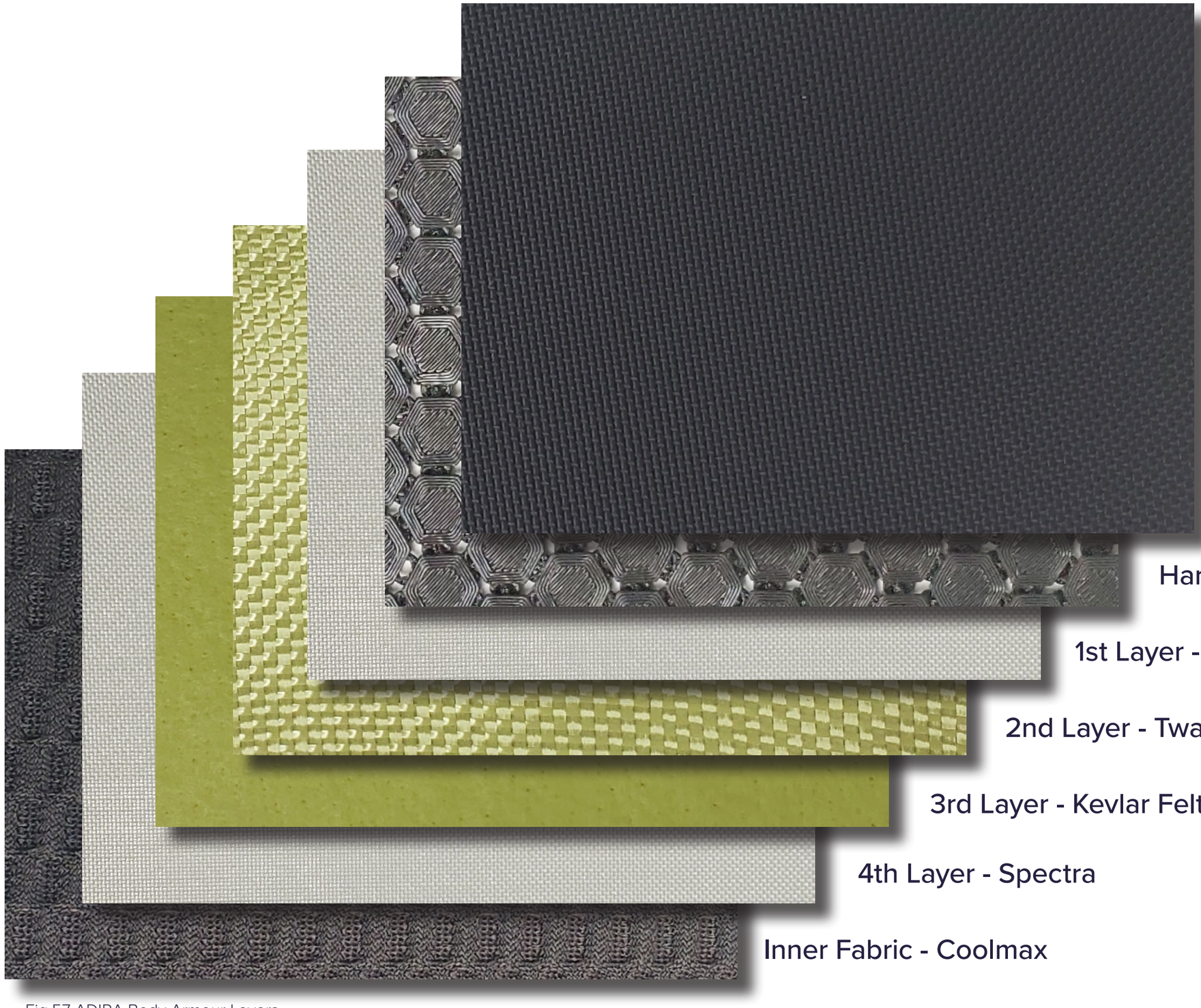


Fig.57 ADIRA Body Armour Layers

Layers:

Bulletproof garments are made by stacking 25 different layers of fabric on top of each other. Using a combination of different types of ballistic fabrics. Considering the material properties and the size of the weave that can withstand the force of the bullet. When shot the force of the bullet gets dispersed over the surface of the vest spreading the energy of the bullet, stopping the bullet from penetrating the body.

Getting Fitted:

When a female officer is inquiring about an ADIRA body armour, the female officers must submit their following measurements and choose their correct size under the following size chart.

ADIRA's sizing chart considers three different measurement categories: the body, upper torso, and bra size, following the industry standers for each category. Including this in-depth sizing chart in my design was necessary because one size does not fit all. We must design for all shapes and sizes. It is crucial that when working in a high-risk environment, these primary users can purchase body armor that fits their bodies correctly. These three different measurement categories ensure more variation in sizing, and female officers can receive a garment custom to each user's body.

Sample Size: **S-S-34B**
Body: **Small**
Upper Torose: **Short**
Bra: **34B**

Fig.58 ADIRA's Body Armour Label

ADIRA's Size Chart:

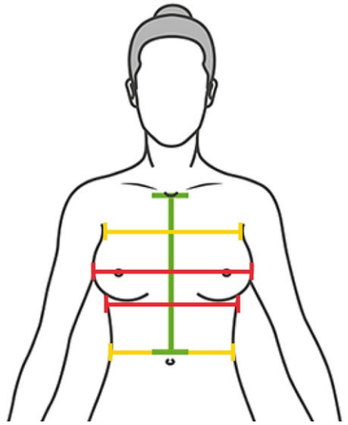
Body, Upper Torso & Bra Measurement

Body Measurement

	S	M	L	XL	XXL	3XL	4XL
Chest	34-36”	38-40”	42-44”	46-48”	50-52”	54-56”	58-60”
Waist	28-30”	32-34”	36-38”	40-42”	44-46”	48-50”	52-54”

Upper Torso Measurement

	SHORT	AVERAGE	LONG
Length	12-13”	14”	15-17”



Bra Measurement

UNDER BUST MEASUREMENT	27-28”	29-30”	31-32”	33-35”	36-38”	39-42”
Band Size	32	34	36	38	40	42
Cup Size	BUST MEASUREMENT					
A	33”	35”	37”	39”		
B	34”	36”	38”	40”		
C	35”	37”	39”	41”		
D		38”	40”	42”	44”	46”
DD		39”	41”	43”	45”	47-48”
E				44”	46”	49-50”

Fig.59 ADIRA's Size Chart

Fig.60 Body Positive

FIGURES

Fig. 1, Page 6: Bio Human. (n.d.). Standing Female Model [Body Simulation]. Retrieved from http://humanshape.org/AdultShape/standingfemale/

Fig. 2, Page 7: Nerthuz. (n.d.). Female Human Anatomy [3D Illustrator]. Retrieved from https://www.shutterstock.com/image-illustration/human-stomach-anatomy-286706111

Fig.3, Page 8: Apache Industries. (2020). Safe Life Defence Body Armor. http://www.apacheindustriesusa.com/ballistic-protection/vests-and-carriers/safe-life-defence-body-armor Bulletproof Zone. (2019).

Fig.4, Page 9: Officers. (n.d.). Close up of Twaron [Photograph]. Retrieved from https://www.officer.com/on-the-street/body-armor-protection/ballistic-fiber/product/11221889/teijin-aramid-usa-inc-twaron-ct-608-next-gen-aramid-fabric

Fig.5, Page 9: Textile Gence. (2019). Close up of Dyneema [Photography]. Retrieved from https://www.textilegence.com/en/dyneema-carbon-perfect-for-lightweight-performance/

Fig.6, Page 9: IndiaMart. (n.d.). Close up of CoolMax [Photograph]. Retrieved from https://www.indiamart.com/emtech-solutions/blood-repellent-fabric.html

Fig.7, Page 9: Clip CarBono. (n.d.). Close up of Kevlar [Photograph]. Retrieved from https://www.clipcarbono.com/en/fabrics/280-commercial-sample-woven-of-kevlar-fiber-2x2-3k-weight-180grm2-250mm-x-200mm.html

Fig. 8, Page 9: Backpacking Light. (n.d.). Close up of Spectra [Photograph]. Retrieved from https://backpackinglight.com/forums/topic/82862/

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