**Project 2 Report**

# REDESIGN OF BULLET RESISTANT JACKET FOR ANTI TERROR ATTACK FORCE

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# APPROVAL FORM

This is to certify that the Industrial Design Project entitled "Redesign of a Bullet Resistant Jacket for Anti terror attack force " by Sagar D Dabherao is approved for partial fulfillment for the Master of Design degree in Industrial Design.

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I, declare that this written report represents my ideas in my own words, and where others' ideas or words have been included I have adequately cited and referenced the original sources.

I also declare that I have adhered to all principles of academic honesty and integrity and have not falsified, misinterpreted or fabricated any idea, data, facts or source in my submission.

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# ABSTRACT

In the past, people have protected themselves from injury with different types of materials. In the earliest days, people used animal skins as barriers to injury and attacks. As weaponry advanced, they added wooden and metal shields to their defensive arsenals. Today various grades of bulletproof armor are worn to protect from advanced ballistic projectiles.

A bulletproof vest act as a protection layer against fast-moving projectiles such as bullets in times of war or a terrorist attack. India has recently come up with its own standards for ballistic applications, while the types of bulletproof vests available as per set specifications in the market are limited as well as do not cater to user comfort.

Current bulletproof vests, worn by the Indian armed forces and special task force commandos are quite bulky and are more generalized rather than specific to a particular application. Almost all armed forces use a similar type of vest which sometimes put the life of the user in danger due to its rigid and bulky construction.

This project focuses on redesigning such a bulletproof vest that is customized to a specific category taking its user into consideration, is comfortable, and does not compromise on safety but rather improves it.

# TABLE OF CONTENTS

# LIST OF TABLES



# LIST OF FIGURES

# INTRODUCTION

Throughout history, people have protected themselves from injury with different types of materials. In the earliest days, people used animal skins as barriers to injury and attacks. As weaponry advanced, they added wooden and metal shields to their defensive arsenals.
In the 1500s, Italian and Roman royalty experimented with the idea of bullet proof vests. They built body armor with layers of metal that were meant to deflect bullets. The outer layer was designed to absorb the bullet's impact, while the inner layer was added to stop further penetration. However, metal body armor was largely ineffective against firearms.
In the 1800s, softer body armor was developed by the Japanese, who made the armor from silk. These silk garments proved to be quite effective but also expensive.

After President William McKinley was assassinated in 1901, the US military explored the use of soft body armor as well. The silk-derived garments were shown to be effective against low-velocity bullets, but not the new generation of handgun ammunition. The US military decided against silk armor because of this, combined with the high price of silk.
The flak jacket was invented during World War II. It was made from ballistic nylon and provided protection from ammunition fragments. Flak jackets were bulky and ineffective against most rifle and pistol fire, but they were widely used, as they provided some modicum of protection and allowed soldiers to feel secure.
In the 1960s, new fibers were discovered that made truly bullet resistant vests possible. In the early 1970s, DuPont's Kevlar ballistic fabric was invented.The fabric was originally intended to replace steel belting in tires, and it was extremely strong. Waterproofing and additional layers of fabric were added to the Kevlar to make the vests more durable and wearable. The National Institute of Justice tested versions of Kevlar vests for several years, and found that the vests could stop the most common lead bullets: 38 Specials and 22 Long Rifle Bullets.
A final phase of testing monitored Kevlar armor's effectiveness. Kevlar armor was found to ensure a 95% probability of survival after being hit with a .38 caliber bullet at a velocity of 800 ft/second. The probability of requiring surgery after being hit by a projectile was found to be 10% or less.
In 1976, scientists came to the conclusion that Kevlar was bullet-resistant, wearable and light enough for police officers to wear full-time. The funny thing was that bulletproof vests had already become commercially available, even before the National Institute of Justice published these claims.
Since that time bulletproof vests have improved. Currently, a level IIIA bulletproof vest weighs approximately 5.5 pounds and can protect the wearer from almost all handgun rounds. According to the International Association of Chiefs of Police, bulletproof vests have saved over 3,000 officers' lives since 1987.

## Bulletproof vest

A ballistic vest is an item of protective clothing that absorbs impacts from gun-fired projectiles and shrapnel fragments from explosions. A soft vest, made from many layers of woven or laminated fibers, protects the wearer's torso from projectiles fired from handguns, shotguns, and small fragments from explosives such as hand grenades. If metal or ceramic plates are used with a soft vest, it can protect the wearer from rifle shots as well. When combined with metallic components or tightly woven fiber layers, soft armor offers some protection to the wearer from stab and slash by a knife. Soft vests are commonly worn by police forces, private citizens, and private security guards, and hard-plate reinforced vests are mainly worn by combat soldiers in the armies of various nations as well as police armed response units.

Ballistic vests use layers of very strong fiber to catch and deform a bullet and spread its force over a larger portion of the vest fiber. A deformable handgun bullet mushrooms into a dished plate on impact with a well-designed textile vest. The vest absorbs the energy from the deforming bullet, bringing it to a stop before it can penetrate the overall matrix. Some layers may be penetrated but as the bullet deforms, the energy is absorbed by a larger and larger fiber area.

Although a vest can prevent bullet penetration, the vest and wearer still absorb the bullet's energy. Even without penetration, modern pistol bullets contain enough energy to cause blunt force trauma under the impact point. Vests' specifications include both penetration resistance requirements and limits on the amount of impact energy that is delivered to the body. Vests designed for bullets offer little protection against blows from sharp implements, such as knives, arrows, or ice picks, or from bullets manufactured of non-deformable materials, such as steel core instead of lead. The force of the impact of these objects is concentrated in a relatively small area, allowing them to puncture the fiber layers of most bullet-resistant fabrics.

# SECONDARY RESEARCH

Modern multi-component bulletproof vests are an important and indispensable element of the equipment of the officers of various types of forces. Different types and purpose bulletproof vests exist. Recently, modular type vests are becoming more and more relevant, which can be transformed depending on the task being performed and the degree of risk. To the main part of the armor (back and chest securing section providing full torso protection at the front and rear), additional safety components in the form of separate modules can be attached to protect the side parts of the torso, shoulders, neck, and the loins. Bulletproof vests play an important role in preserving the health and life of anti-terrorists in fulfilling their duties and resolving crisis arising in various critical situations.

## Classification of bulletproof vests

Bulletproof vests play an important role in preserving the health and life of anti-terrorists in fulfilling their duties and resolving crisis arising in various critical situations.

The study carried out on the state of the art of bulletproof vests available at the market and the vests used by anti-terrorists found the existence of a wide variety of models produced by both Bulgarian and foreign companies.

Based on the analysis of the results obtained from the study, a classification of the bulletproof vests can be suggested according to the following features:

- in terms of purpose;
- by the levels of protection;
- by the way of wearing;
- by gender of the individual carrying it:
- by the protective panels material

### 1. Classification by purpose

Depending on their intended use, the bulletproof vests can be assigned to one of the following groups:

- Military
- Police
- Civil

Military bulletproof vests can be divided into:

- Tactical
- Special
- Water inflatable

Police bulletproof vests can be divided into:

- Tactical
- Special

Civil bulletproof vests can be divided into:

- Ordinary
- VIP

## 2. Classification by protection level

Some of the most widely used worldwide standardization documents on ballistic resistance of bulletproof vests are

- US National Institute of Justice - NIJ 0101.04 and NIJ0101.06;
- National Standard of Russia - GOST 50744-95;
- German - German Schutzklassen and
- VPAM; as well as those of the UK Police - PSDB and HOSDB
- BIS, India

| Ballistic protection level according to some of the leading standards in this field | | |
|---|---|---|
| GOST 50744-95 (Russia) | NIJ 0101.04 NIJ0101.06 (USA) | German Schutzklassen (Germany) |
| 1 | I | SK L |
| 2 | II — IIIA | SK 1 |
| 2a | — | SK 2 |
| 3 | — | SK 3 |
| 4 | III | SK 4 |
| 5 | — | — |
| 6 | IV | SK 4 |
| 6a | — | — |

Table 1: Comparision between some international standards

## 3. Classification by the way of wearing

- for visible wearing;
- for hidden wearing

## 4. Classification according to the materials of protective ballistic panels

- Flexible ballistic panel;
- Hard ballistic panel/armor plate

The flexible ballistic panels can be divided to:

- single-component;
- Multi-component

The hard ballistic panels can be divided to:

- single-component;
- multi-component

## Performance standards

Due to the various different types of projectiles, it is often inaccurate to refer to a particular product as “bulletproof” because it implies that it will protect against any and all threats. Instead, the term bullet resistant is generally preferred.

Body armor standards are regional. Around the world, ammunition varies and as a result, the armor testing must reflect the threats found locally. Law enforcement statistics show that many shootings where officers are injured or killed involve the officer’s weapon. As a result, each law enforcement agency or para-military organization will have its own standard for armor performance if only to ensure that their armor protects them from their own weapon. While many standards exist a few standards are widely used as models. The US National Institute of Justice ballistic and stab documents are examples of broadly accepted standards, In addition to the NIJ, the UK Home Office Scientific Development Branch (HOSDB - formerly the Police Scientific Development Branch (PSDB)) standards are used by a number of other countries and organizations. These “model” standards are usually adapted by other counties by incorporating the basic test methodologies with modifications of the bullets that are required for the test. NIJ Standard 0101.04 has specific performance standards for bullet-resistant vests used by law enforcement. This rates vests on the following scale against penetration and also blunt trauma protection (deformation) (Table from NIJ Standard 0101.04):

Textile armor is tested for both penetration resistance by bullets and for the impact energy transmitted to the wearer. The “backface signature” or transmitted impact energy is measured by shooting armor mounted in front of a backing material, typically sculpture modeling oil-clay. The clay is used at a controlled temperature and verified for impact flow before testing. After the armor is impacted with the test bullet the vest is removed from the clay and the depth of the indentation in the clay is measured.

The backface signature allowed by different test standards can be difficult to compare. Both the clay materials and the bullets used for the test are not common. However in general the UK, German and other European standards allow 20-25 mm of backface signature while the US-NIJ standards allow for 44 mm, which can potentially cause internal injury.[4] The allowable backface signature for body armor has been controversial from its introduction in the first NIJ test standard and the debate as to the relative importance of penetration-resistance vs. backface signature continues in the medical and testing communities.

In general a vest’s textile material temporarily degrades when wet. Neutral water at room temp does not affect para-aramid or UHMWPE (ultra high molecular weight polyethylene), but acidic, basic, and some other solutions can permanently reduce para-aramid fiber tensile strength.[5] (For this reason, major test standards call for wet testing of textile armor.[6]) Mechanisms for this wet loss of performance are not known. Vests that will be tested after ISO type water immersion tend to have heat sealed enclosures and those that are tested under NIJ type water spray methods tend to have water resistant enclosures.

From 2003-2005, a large study of the environmental degradation of Zylon armor was undertaken by the US-NIJ. This concluded that water, long-term use, and temperature exposure significantly affect tensile strength and the ballistic performance of PBO or Zylon fiber. This NIJ study on vests returned from the field demonstrated that environmental effects on Zylon resulted in ballistic failures under standard test conditions.

## Ballistic fiber properties

To function well, ballistic armor needs to have several characteristics. A bullet impact does damage by putting a lot of kinetic energy into a very small package; the location the bullet hits will experience a high concentration of force. The first task of ballistic armor is to prevent the bullet from passing through the material entirely, and in order do to this the fibers need to have high tensile strength and high total toughness – measurements of how much stress (force on a fiber divided by the cross sectional area of that fiber) and how much total energy input a fiber can withstand without breaking.

Just as importantly, the fibers need to be overlapped or woven in such a way that they reinforce one another to spread the energy of the impact over a larger area. The faster that energy is dissipated along the fiber strands, the less total energy needs to be absorbed by the fibers at the direct point of impact and the less likely it is that those fibers will break. Additionally, the fibers need to be able to absorb all of this energy without stretching too far, or the human body under the armor will take a larger share of the impact. A vest that could absorb all of the energy of a speeding bullet, but which had to stretch several inches like a rubber band in order to absorb it all, would not be very helpful for the person wearing it! The ability of fibers to translate force quickly along their own length and their ability to come under stress without stretching significantly are both governed by a property called the tensile modulus. The tensile modulus is a measure of stiffness; a stiff fiber with a high tensile modulus can sustain a very large amount of stress with only a small amount of stretch.

So, both tensile strength and tensile modulus are important properties for ballistic fibers. Since armor also needs be light enough to wear (and since extra thickness can be added if it is made from a lighter material), low density is also important. Therefore, the properties that are truly critical for a ballistic fiber are the specific tensile strength (also referred to as tenacity) and the specific tensile modulus – these are the tensile strength and modulus normalized by the linear density of the material. Other important prerequisites of ballistic fiber include the ability to resist wear from flexing and friction, resistance to melting and degradation due to heat, resistance to chemicals, and other issues that contribute to wearability and durability.

The materials commonly used for modern ballistic armor are aramid fibers (such as Kevlar and Twaron), and ultra-high molecular weight polyethylene (UHMWPE) fibers (such as Dyneema and Spectra). UHMWPE fibers can be made with a wide variety of formulations and therefore have a range of different mechanical properties; at the high end of their performance they are able to slightly out-perform aramid fibers in tensile strength and tensile modulus. They also have lower density than Aramids, so their tenacity and specific tensile modulus values are superior (see the table below). Aramid fibers, on the other hand, are more durable against exposure to certain chemicals and high temperatures. Aramid fibers can also be more flexible than the highest-performing UHMWPE products. The two types of fiber are sometimes used together to form ballistic armor with an optimal mix of weight, strength, and flexibility.

| | Tenacity (mN/tex) | Specific Modulus (N/tex) |
|---|---|---|
| Aramid Fibers | 2080[1] | 49 – 72[1] |
| UHMWPE Fibers | 1610 – 4250[2] | 87 – 159[2] |
| Rice University CNT Fibers | 2100[3] | 260[3,4] |
| Galvorn CNT Fibers | 1700[5] | 240[5] |

Table 2: Specifc mechanical properties of aramid, UHMWPE, and CNT fbers

# Ballistic materials

Materials used for ballistic applications include
- Carbon fiber
- Glass fiber
- Zylon
- Basalt
- Kevlar
- High molecular weight polyethylene fiber

## 1. Carbon fiber

Carbon fibers or carbon fibers are fibers about 5–10 micrometers in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high-temperature tolerance, and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared with similar fibers, such as glass fibers or plastic fibers.

### Classification and types

Based on modulus, strength, and final heat treatment temperature, carbon fibers can be classified into the following categories:

Based on carbon fiber properties, carbon fibers can be grouped into:
- Ultra-high-modulus, type UHM (modulus >450Gpa)
- High-modulus, type HM (modulus between 350-450Gpa)
- Intermediate-modulus, type IM (modulus between 200-350Gpa)
- Low modulus and high-tensile, type HT (modulus < 100Gpa, tensile strength > 3.0Gpa)
- Super high-tensile, type SHT (tensile strength > 4.5Gpa)

Based on precursor fiber materials, carbon fibers are classified into:
- PAN-based carbon fibers
- Pitch-based carbon fibers
- Mesophase pitch-based carbon fibers
- Isotropic pitch-based carbon fibers
- Rayon-based carbon fibers
- Gas-phase-grown carbon fibers

Based on the final heat treatment temperature, carbon fibers are classified into:
- Type-I, high-heat-treatment carbon fibers (HTT), where final heat treatment temperature should be above 2000°C and can be associated with high-modulus type fiber.
- Type-II, intermediate-heat-treatment carbon fibers (IHT), where final heat treatment temperature should be around or above 1500°C and can be associated with high-strength type fiber.
- Type-III, low-heat-treatment carbon fibers, where final heat treatment temperatures are not greater than 1000°C. These are low modulus and low strength materials.

## Manufacturing Process

Carbon fibers from polyacrylonitrile (PAN):
Raw Materials
The raw material used to make carbon fiber is called the precursor. About 90% of the carbon fibers produced are made from polyacrylonitrile. The remaining 10% are made from rayon or petroleum pitch. All of these materials are organic polymers, characterized by long strings of molecules bound together by carbon atoms. The exact composition of each precursor varies from one company to another and is generally considered a trade secret. During the manufacturing process, a variety of gases and liquids are used. Some of these materials are designed to react with the fiber to achieve a specific effect. Other materials are designed not to react or to prevent certain reactions with the fiber. As with the precursors, the exact compositions of many of these process materials are considered trade secrets.

Spinning

- Acrylonitrile plastic powder is mixed with another plastic, like methyl acrylate or methyl methacrylate, and is reacted with a catalyst in a conventional suspension or solution polymerization process to form a polyacrylonitrile plastic.
- The plastic is then spun into fibers using one of several different methods. In some methods, the plastic is mixed with certain chemicals and pumped through tiny jets into a chemical bath or quench chamber where the plastic coagulates and solidifies into fibers. This is similar to the process used to form polyacrylic textile fibers. In other methods, the plastic mixture is heated and pumped through tiny jets into a chamber where the solvents evaporate, leaving a solid fiber. The spinning step is important because the internal atomic structure of the fiber is formed during this process.
- The fibers are then washed and stretched to the desired fiber diameter. The stretching helps align the molecules within the fiber and provide the basis for the formation of the tightly bonded carbon crystals after carbonization.

Stabilizing
Before the fibers are carbonized, they need to be chemically altered to convert their linear atomic bonding to a more thermally stable ladder bonding. This is accomplished by heating the fibers in air to about 390-590° F (200-300° C) for 30-120 minutes. This causes the fibers to pick up oxygen molecules from the air and rearrange their atomic bonding pattern. The stabilizing chemical reactions are complex and involve several steps, some of which occur simultaneously. They also generate their own heat, which must be controlled to avoid overheating the fibers. Commercially, the stabilization process uses a variety of equipment and techniques. In some processes, the fibers are drawn through a series of heated chambers. In others, the fibers pass over hot rollers and through beds of loose materials held in suspension by a flow of hot air. Some processes use heated air mixed with certain gases that chemically accelerate the stabilization.

Carbonizing
Once the fibers are stabilized, they are heated to a temperature of about 1,830-5,500° F (1,000-3,000° C) for several minutes in a

furnace filled with a gas mixture that does not contain oxygen. The lack of oxygen prevents the fibers from burning in the very high temperatures. The gas pressure inside the furnace is kept higher than the outside air pressure and the points where the fibers enter and exit the furnace are sealed to keep oxygen from entering. As the fibers are heated, they begin to lose their non-carbon atoms, plus a few carbon atoms, in the form of various gases including water vapor, ammonia, carbon monoxide, carbon dioxide, hydrogen, nitrogen, and others. As the non-carbon atoms are expelled, the remaining carbon atoms form tightly bonded carbon crystals that are aligned more or less parallel to the long axis of the fiber. In some processes, two furnaces operating at two different temperatures are used to better control the rate de heating during carbonization.

Treating the surface

After carbonizing, the fibers have a surface that does not bond well with the epoxies and other materials used in composite materials. To give the fibers better bonding properties, their surface is slightly oxidized. The addition of oxygen atoms to the surface provides better chemical bonding properties and also etches and roughens the surface for better mechanical bonding properties. Oxidation can be achieved by immersing the fibers in various gases such as air, carbon dioxide, or ozone; or in various liquids such as sodium hypochlorite or nitric acid. The fibers can also be coated electrolytically by making the fibers the positive terminal in a bath filled with various electrically conductive materials. The surface treatment process must be carefully controlled to avoid forming tiny surface defects, such as pits, which could cause fiber failure.

Sizing

- After the surface treatment, the fibers are coated to protect them from damage during winding or weaving. This process is called sizing. Coating materials are chosen to be compatible with the adhesive used to form composite materials. Typical coating materials include epoxy, polyester, nylon, urethane, and others.
- 8 The coated fibers are wound onto cylinders called bobbins. The bobbins are loaded into a spinning machine and the fibers are twisted into yarns of various sizes.

## Properties

- Carbon Fiber has High Strength to Weight Ratio (also known as specific strength)
- Carbon Fiber is very Rigid
- Carbon fiber is Corrosion Resistant and Chemically Stable
- Carbon fiber is Electrically Conductive
- Fatigue Resistance is good
- Carbon Fiber has good Tensile Strength
- Fire Resistance/Non Flamable
- Thermal Conductivity of Carbon Fiber
- Low Coefficient of Thermal Expansion
- Non Poisonous, Biologically Inert, X-Ray Permeable
- Carbon Fiber is Relatively Expensive
- Carbon Fibers are brittle

### Applications

- Bike frame
- Aircraft Wings
- Automotive drive shafts
- Propeller blades
- Car components

## 2. Glass fiber

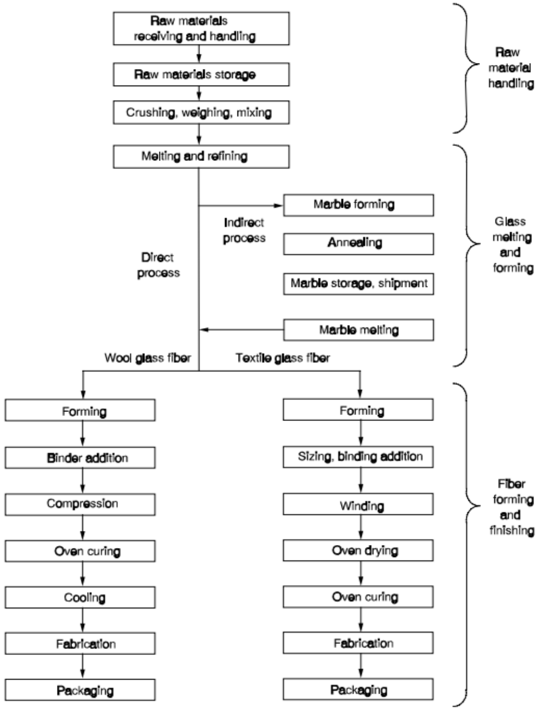
Glass fiber (or glass fiber) is a material consisting of numerous extremely fine fibers of glass.
Glass fiber has roughly comparable mechanical properties to other fibers such as polymers and carbon fiber. Although not as rigid as carbon fiber, it is much cheaper and significantly less brittle when used in composites. Glass fiber-reinforced composites are used in the marine industry and piping industries because of good environmental resistance, better damage tolerance for impact loading, high specific strength, and stiffness.

### Classification of glass

The most common type of glass fiber used in fiberglass is E-glass, which is alumino-borosilicate glass. Other types of glass include
- A-glass (Alkali-lime glass with little or no boron oxide
- E-CR-glass (Electrical/Chemical Resistance; alumino-lime silicate with less than 1% w/w alkali oxides, with high acid resistance
- C-glass (alkali-lime glass with high boron oxide content, used for glass staple fibers and insulation
- D-glass (borosilicate glass, named for its low dielectric constant
- R-glass (alumino silicate glass without MgO and CaO with high mechanical requirements as reinforcement)
- S-glass (alumino silicate glass without CaO but with high MgO content with high tensile strength)

## Manufacturing

Glass fiber manufacturing is the high-temperature conversion of various raw materials (predominantly borosilicates) into a homogeneous melt, followed by the fabrication of this melt into glass fibers. The 2 basic types of glass fiber products, textile, and wool, are manufactured by similar processes. A typical diagram of these processes is shown in Figure 11.13-1. Glass fiber production can be segmented into 3 phases: raw materials handling, glass melting and refining, and wool glass fiber forming and finishing, this last phase is slightly different for textile and wool glass fiber production.




fg.1 Glass fber production

## Properties of glass fiber

Thermal
Fabrics of woven glass fibers are useful thermal insulators because of their high ratio of surface area to weight. However, the increased surface area makes them much more susceptible to chemical attacks. By trapping air within them, blocks of glass fiber make good thermal insulation, with a thermal conductivity of the order of 0.05 W/(m·K).

Mechanical properties
The strength of glass is usually tested and reported for “virgin” or pristine fibers—those that have just been manufactured. The freshest, thinnest fibers are the strongest because the thinner fibers are more ductile. The more the surface is scratched, the less the resulting tenacity. Because glass has an amorphous structure, its properties are the same along fiber and across the fiber. Humidity is an important factor in tensile strength. Moisture is easily adsorbed and can worsen microscopic cracks and surface defects, and lessen tenacity.

Applications
Uses for regular glass fiber include mats and fabrics for thermal insulation, electrical insulation, sound insulation, high-strength fabrics or heat- and corrosion-resistant fabrics. It is also used to reinforce various materials, such as tent poles, pole vault poles, arrows, bows and crossbows, translucent roofing panels, automobile bodies, hockey sticks, surfboards, boat hulls, and paper honeycomb. It has been used for medical purposes in casts.

Glass fiber is extensively used for making FRP tanks and vessels. Open-weave glass fiber grids are used to reinforce asphalt pavement. Non-woven glass fiber/polymer blend mats are used saturated with asphalt emulsion and overlaid with asphalt, producing a waterproof, crack-resistant membrane. The use of glass-fiber reinforced polymer rebar instead of steel rebar shows promise in areas where avoidance of steel corrosion is desired.

## 3. Zylon

Zylon (IUPAC name: poly(p-phenylene-2,6-benzobisoxazole)) is a trademarked name for a range of thermoset liquid-crystalline polyoxazole.

### Properties

Zylon's tensile strength is about 10 times that of steel—a Zylon thread only 1 mm thick can hold an object weighing 450 kg! Zylon has excellent flame resistance, withstanding temperatures up to 650°C, and is more impact-resistant than even steel or carbon. Zylon has 5.8 GPa of tensile strength, which is 1.6 times that of Kevlar. Additionally, Zylon has a high Young's modulus of 270 GPa, meaning that it is stiffer than steel.

### Applications

- Body armor
- Space elevator research
- High-altitude balloon science
- Motorsport
- Standing rigging
- Parachutes
- Conductive textile
- Structural rehabilitation
- Loudspeakers

## 4. Basalt fiber

Basalt fiber is a continuous fiber made of melting basalt stone at 1450 to 1500 degrees through Platinum rhodium alloy bushing. It is a new environmental protection fiber which is known as the twenty-first Century 'volcano rock silk', it is also called golden fiber because its color is golden brown.

### Manufacturing

Basalt fiber is made by the pultrusion of volcanic rocks, melted in blast furnaces. The fiber is drawn, as opposed to extrusion. This process makes it possible to create a continuous fiber, reinforced with a polymer.

The technology of production of basalt continuous fiber (BCF) is a one-stage process:
- Melting,
- Homogenization of basalt and
- Extraction of fibers.

### Properties

- basalt fiber has excellent tensile strength and modulus of elasticity
- High corrosion resistance and chemical stability
- Basalt fiber has higher electrical insulation than glass fiber. It can also be used as a heat-resistant insulating material in the electronic industry.
- High thermal stability and high acoustic and thermal insulation properties
- Good compatibility with metal, plastic, carbon fiber, and other materials.

### Applications

One of the main applications of basalt fiber products is construction
- basalt reinforcement in form of mesh and scrim
- geogrid mesh for road reinforcement
- basalt rebars and pultruded profiles
- basalt fiber reinforced concrete

Another important application of basalt fiber products is the automotive industry
- Headliners
- CNG cylinders
- Basalt brake pads and clutch plates
- Thermo insulation for exhausting systems
- Muffler's filler
- Interior and exterior parts based on fabrics
- Parts and components of basalt fiber thermoplastic compound

## 5. High molecular weight polyethylene fiber

Ultra-high-molecular-weight polyethylene (UHMWPE, UHMW) is a subset of thermoplastic polyethylene. The longer chain serves to transfer load more effectively to the polymer backbone by strengthening intermolecular interactions. This results in a very tough material, with the highest impact strength of any thermoplastic presently made.
UHMWPE is odorless, tasteless, and nontoxic. It embodies all the characteristics of high-density polyethylene (HDPE) with the added traits of being resistant to concentrated acids and alkalis, as well as numerous organic solvents. It is highly resistant to corrosive chemicals except for oxidizing acids, has extremely low moisture absorption and a very low coefficient of friction, is self-lubricating, and is highly resistant to abrasion, in some forms being 15 times more resistant to abrasion than carbon steel. Its coefficient of friction is significantly lower than that of nylon and acetal and is comparable to that of polytetrafluoroethylene (PTFE, Teflon), but UHMWPE has better abrasion resistance than PTFE.

### Production

Ultra-high-molecular-weight polyethylene (UHMWPE) is synthesized from its monomer ethylene, which is bonded together to form the base polyethylene product.
UHMWPE is processed variously by compression molding, ram extrusion, gel spinning, and sintering.

- In gel spinning a precisely heated gel of UHMWPE is extruded through a spinneret.
- The extrudate is drawn through the air and then cooled in a water bath.
- The end-result is a fiber with a high degree of molecular orientation, and therefore exceptional tensile strength.
- Gel spinning depends on isolating individual chain molecules in the solvent so that intermolecular entanglements are minimal.

### Properties

- UHMWPE is an extremely long chain of polyethylene
- poorer heat resistance
- It becomes brittle at temperatures below −150 °C (−240 °F)
- UHMWPE does not absorb water readily, nor wet easily, which makes bonding it to other polymers difficult.
- Strength-to-weight ratios for UHMWPE are about 40% higher than for aramid

### Applications

Dyneema and Spectra are brands of lightweight high-strength oriented-strand gels spun through a spinneret.
Derivatives of UHMWPE yarn are used in composite plates in armor, in particular, personal armor and on occasion as vehicle armor.

Civil applications containing UHMWPE fibers are

- cut-resistant gloves
- bow strings
- climbing equipment
- automotive winching
- fishing line
- spear lines for spearguns
- high-performance sails
- suspension lines on sport parachutes and paragliders
- rigging in yachting
- kites, and kite lines for kites sports.

## 6. Kevlar

Kevlar (para-aramid) is a strong, heat-resistant synthetic fiber, related to other aramids such as Nomex and Technora. It is typically spun into ropes or fabric sheets that can be used as such, or as an ingredient in composite material components.
Kevlar has many applications, ranging from bicycle tires and racing sails to bulletproof vests, all due to its high tensile strength-to-weight ratio; by this measure, it is five times stronger than steel.It is also used to make modern marching drumheads that withstand high impact, and for mooring lines and other underwater applications.

Different types of Kevlar

- Kevlar – Tire cord yarn
- Kevlar 29 – Multipurpose yarn
- Kevlar 49 – High modulus yarn
- Kevlar 68 – Moderate modulus yarn
- Kevlar 100 – Coloured yarn
- Kevlar 119 – High elongation yarn
- Kevlar 129 – High tenacity yarn
- Kevlar 149 – Ultra high modulus yarn

## Production of kevlar

P-phenylene diamine + terepthaloyl chloride

↓ (Condensation polymerization with lithium chloride with low temp)

Poly (p-phenylene terephthalamide) + HCL

↓

Liquid crystal polymer (LCP)

↓

Dry-Jet wet spinning2

↓

Drawing at more than 300 ° c at 15-20 draw ratio

↓

FDY or staple fibre of Kevlar

fg.2 Process of production of Kevlar

## Properties

- high tensile modulus
- high breaking tenancy
- High kinetic energy absorption
- toughness
- thermal stability

## Applications

- Brake pads
- Gaskets
- Clutches
- Vehicle armor
- Marine composites
- Armor system
- Aerospace, marine, rail
- Automotive
- Fiber optics
- MIlitary helmets
- Ropes and cables
- Sporting goods apparel and accessories

## Materials evaluation for ballistic applications

Insights were generated based on detailed research on ballistic materials. Conclusions were drawn towards which material suits best for the bullet resistant jacket.

### Carbon fiber

The manufacture of CNT fiber and other solid CNT materials is still a very new industrial technology, especially compared with the history of aramid and UHMWPE fibers, each of which have been in production for several decades. The rapid and continued advancement in CNT fiber properties over the last decade, as understanding of manufacturing has deepened and improved, is a hopeful sign that this material has not yet reached its full potential. CNT fibers already have a superior tensile modulus compared to aramid fibers and UHMWPE, and as their tenacity continues to improve, CNT fibers could very well displace the current generation of ballistic polymers and herald a new generation of ultra-lightweight body armor.

**Conclusion:** currently not in use for ballistic vest.

### Glass fiber

Not used as the primary material. Used as a polymer matrix component.
The results showed that the manufactured body armor prevents the penetration of a 9 mm bullet enabling its potential use as an urban armor level III-A, according to NIJ-Standard-0101.04. However, after testing with weapons larger than 9 mm in caliber, it was permanently deformed (5.56 mm and 7.62 mm weapons), which is why level IV is not recommended.

**Conclusion:** Used till armor level III-A ( as a component in the polymer matrix ).

### Zylon ( para-phenylene benzobisoxazole)

It is far superior to Kevlar and other aramids in both mechanical properties and resistance to such environmental effects as heat, moisture, abrasion, and seawater corrosion.
U.S. government's National Institute of Justice decertified Zylon for use in its approved models of ballistic vests for law enforcement.

**Conclusion:** Degrades faster, hence, unsuitable for ballistic applications for longer periods.

### Basalt fiber

Basalt fibers are not expected to outperform some of the higher ballistic performing materials such as aramid and polyethylene fibers; however, due to the lower manufacturing costs, basalt fibers are an interesting alternative.

**Conclusion:** Not used for ballistic vests

HMWPE

UHMWPE composite may be preferred over Kevlar/ epoxy composite for ballistic protection purposes

**Conclusion:** The ballistic limit velocity of the UHMWPE plate is higher among the Kevlar/epoxy composite and alumina plate with lighter weight.
The energy-absorbing capacity of the UHMWPE is superior to the other considered materials.

## How are bulletproof vests made?

A bulletproof vest consists of a panel, a vest-shaped sheet of advanced plastics polymers that is composed of many layers of either Kevlar, Spectra Shield, or, in other countries, Twaron (similar to Kevlar) or Bynema (similar to Spectra). The layers of woven Kevlar are sewn together using Kevlar thread, while the nonwoven Spectra Shield is coated and bonded with resins such as Kraton and then sealed between two sheets of polyethylene film.
The panel provides protection but not much comfort. It is placed inside of a fabric shell that is usually made from a polyester/cotton blend or nylon. The side of the shell facing the body is usually made more comfortable by sewing a sheet of some absorbent material such as Kumax onto it. A bulletproof vest may also have nylon padding for extra protection. For bulletproof vests intended to be worn in especially dangerous situations, built-in pouches are provided to hold plates made from either metal or ceramic bonded to fiberglass. Such vests can also provide protection in car accidents or from stabbing.
Various devices are used to strap the vests on. Sometimes the sides are connected with elastic webbing. Usually, though, they are secured with straps of either cloth or elastic, with metallic buckles or velcro closures.

### Manufacturing process

Some bulletproof vests are custom-made to meet the customer's protection needs or size. Most, however, meet standard protection regulations, have standard clothing industry sizes (such as 38 long, 32 short), and are sold in quantity.

**Making the panel cloth**

- To make Kevlar, the polymer poly-para-phenylene terephthalamide must first be produced in the laboratory. This is done through a process known as polymerization, which involves combining molecules into long chains. The resultant crystalline liquid with polymers in the shape of rods is then extruded through a spinneret (a small metal plate full of tiny holes that looks like a shower head) to form Kevlar yarn. The Kevlar fiber then passes through a cooling bath to help it harden. After being sprayed with water, the synthetic fiber is wound onto rolls. The Kevlar manufacturer then typically sends the fiber to throwsters, who twist the yarn to make it suitable for weaving. To make Kevlar cloth, the yarns are woven in the simplest pattern, plain or tabby weave, which is merely the over and under pattern of threads that interlace alternatively.
- Unlike Kevlar, the Spectra used in bulletproof vests is usually not woven. Instead, the strong polyethylene polymer filaments are spun into fibers that are then laid parallel to each other. Resin is used to coat the fibers, sealing them together to form a sheet of Spectra cloth. Two sheets of this cloth are then placed at right angles to one another and again bonded, forming a nonwoven fabric that is next sandwiched between two sheets of polyethylene film. The vest shape can then be cut from the material.

**Cutting the panels**

- Kevlar cloth is sent in large rolls to the bulletproof vest manufacturer. The fabric is first unrolled onto a cutting table that must be long enough to allow several panels to be cut out at a time; sometimes it can be as long as 32.79 yards (30 meters). As many layers of the material as needed (as few as eight layers, or as many as 25, depending on the level of protection desired) are laid out on the cutting table.

- A cut sheet, similar to pattern pieces used for home sewing, is then placed on the layers of cloth. For maximum use of the material, some manufacturers use computer graphics systems to determine the optimal placement of the cut sheets.
- Using a hand-held machine that performs like a jigsaw except that instead of a cutting wire it has a 5.91-inch (15-centimeter) cutting wheel similar to that on the end of a pizza cutter, a worker cuts around the cut sheets to form panels, which are then placed in precise stacks.
- Sewing the panels
- 6 While Spectra Shield generally does not require sewing, as its panels are usually just cut and stacked in layers that go into tight fitting pouches in the vest, a bulletproof vest made from Kevlar can be either quilt-stitched or box-stitched. Quilt-stitching forms small diamonds of cloth separated by stitching, whereas box stitching forms a large single box in the middle of the vest. Quilt-stitching is more labor intensive and difficult, and it provides a stiff panel that is hard to shift away from vulnerable areas. Box-stitching, on the other hand, is fast and easy and allows the free movement of the vest.
- 7 To sew the layers together, workers place a stencil on top of the layers and rub chalk on the exposed areas of the panel, making a dotted line on the cloth. A sewer then stitches the layers together, following the pattern made by the chalk. Next, a size label is sewn onto the panel.

### Finishing the vest

8 The shells for the panels are sewn together in the same factory using standard industrial sewing machines and standard sewing practices. The panels are then slipped inside the shells, and the accessories—such as the straps—are sewn on. The finished bullet-proof vest is boxed and shipped to the customer.

## Bullet resistant jacket manufacturers in India

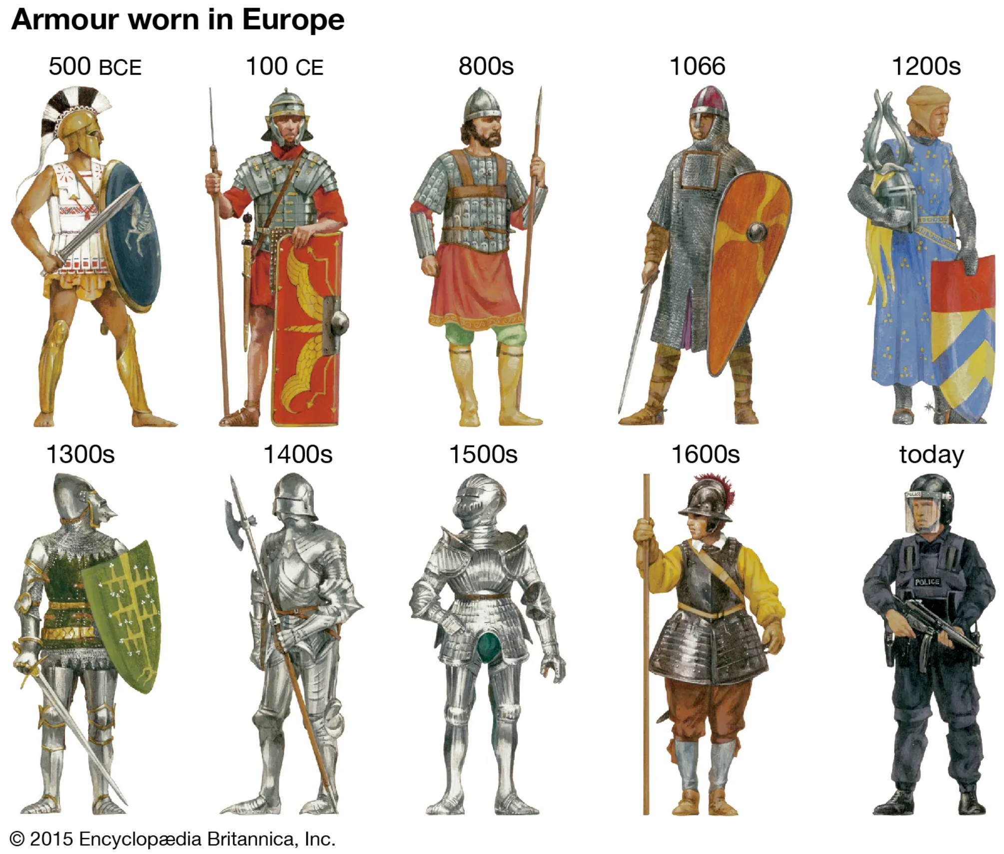
- Medani and Ordnance factory at Avadi, Chennai
- Private firms SNPP (Palwal)
- Starwire (Faridabad) in Haryana
- MKU (Kanpur) in Uttar Pradesh
- SMPP Group
- Indian Armour

# DESIGN RESEARCH

## History of armors

Armour, also spelled armor, also called body armour, protective clothing with the ability to deflect or absorb the impact of projectiles or other weapons that may be used against its wearer. Until modern times, armour worn by combatants in warfare was laboriously fashioned and frequently elaborately wrought, reflecting the personal importance placed by the vulnerable soldier on its protection and also frequently the social importance of its wearer within the group. Modern technology has brought about the development of lighter protective materials that are fashioned into a variety of apparel suited to the hazards of modern warfare. With the rise of terrorism and the use of powerful personal weapons by criminals, armour is now frequently worn by police, by private nonmilitary security forces, and even by noncombatants who might be targets of attack.

Types of armour generally fall into one of three main categories:
(1) armour made of leather, fabric, or mixed layers of both, sometimes reinforced by quilting or felt,
(2) mail, made of interwoven rings of iron or steel, and
(3) rigid armour made of metal, horn, wood, plastic, or some other similar tough and resistant material. The third category includes the plate armour that protected the knights of Europe in the Middle Ages. That armour was composed of large steel or iron plates that were linked by loosely closed rivets and by internal leathers to allow the wearer maximum freedom of movement.




fg.3 Evolution of armor

## Modern armor

Modern warfare subjects soldiers to a variety of lethal projectiles. Bullets fired from rifles, pistols, and machine guns can penetrate flesh and often create terrible wounds by "tumbling" when they hit a hard substance such as bone. Shell fragments—jagged pieces of metal formed by the explosion of a grenade or artillery projectile—can inflict substantial damage to the human body. Mines, booby traps, and improvised explosive devices target soldiers at close range and kill or wound through the force of explosion or the effects of fragmentation. Shaped charges are designed to penetrate vehicle armour with streams of molten metal. Soldiers in the path of those metallic streams often suffer death, serious injury, or amputation of limbs.

As a result of such developments, soldiers in modern war suffer far more wounds from projectiles and fragmentation than from slicing or stabbing, as was the case before the advent of gunpowder and high explosives. All unprotected portions of the body are vulnerable to modern weaponry, but protection of the head and torso is especially necessary to prevent serious injury or death. To protect the critical areas of the body, modern armed forces have developed combat helmets and body armour for use by members of the armed forces on the battlefield, in combat aircraft, and in naval vessels.

Gunpowder weapons eventually made the heavy and expensive armoured suits of the medieval period obsolete, so that from the Renaissance onward armies increasingly opted not to outfit their soldiers with body armour in order to improve their stamina and ability to engage in long marches. However, the introduction of trench warfare during World War I and the devastating effects of

fg.4 Modern weapons scenario

artillery barrages caused armies once again to outfit their soldiers with metal combat helmets to protect against fragmentation wounds to the head. The German army even outfitted some soldiers in exposed positions—machine gunners, snipers, and sentries—with steel breastplates. Steel helmets were standard-issue for foot soldiers during World War II as well. In addition, bomber crews in that conflict wore heavy "flak jackets" designed to protect against fragmentation from air-defense guns.

fg.5 NSG Commandos in action

## New materials

In the decades since the Vietnam War, the development of new materials such as Kevlar and advanced ceramics gave engineers the ability to create lightweight body armour that is effective against both fragmentation and bullets. Advanced fibres absorb the impact of bullets or fragments and disperse their energy across a large area as the projectiles move through successive layers of material. The bullets or fragments deform, or “mushroom,” rather than penetrate the material. Likewise, a bullet’s energy dissipates as it passes through a ceramic plate. A soft vest of tightly woven or laminated fibres thus provides basic protection against handgun rounds, small-calibre rifle rounds, and grenade fragments, and the addition of ceramic plates into pockets in the soft vest enables protection against high-velocity rifle rounds.

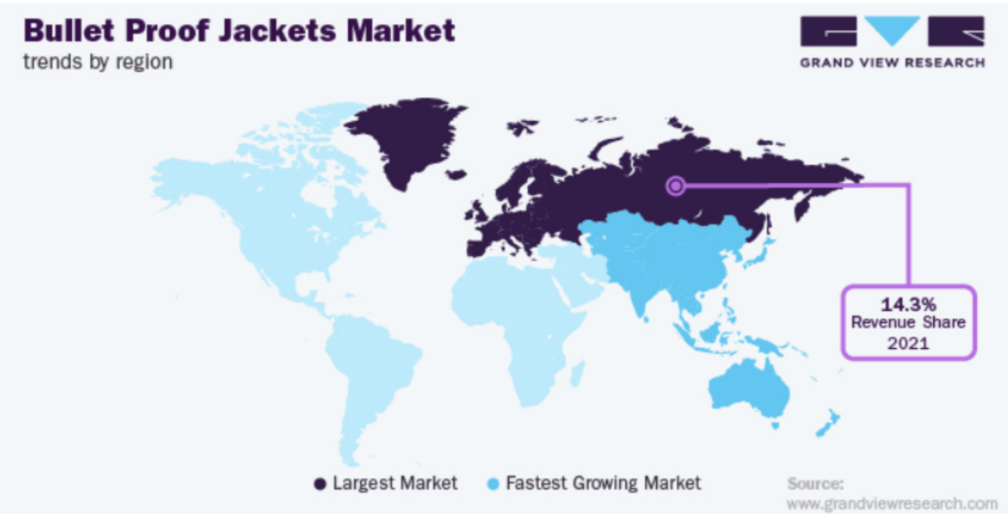
Ballistic vests are generally rated using a system devised by the National Institute of Justice, the research and standards division of the U.S. Department of Justice. It classifies the degree of protection offered, from Type IIA (proof against 9-mm or .40-calibre bullets) to Type IV (proof against .30-calibre [7.62 mm] armour-piercing rifle bullets).

Soldiers in Western-style armies routinely enter into combat outfitted with a helmet (now often made of lightweight Kevlar rather than steel) to protect the head and with body armour (incorporating both Kevlar and ceramic) to protect the torso. Law-enforcement personnel routinely wear lightweight vests protective against handguns, and bomb-disposal experts wear even heavier suits designed to give them extensive full-body protection against explosions at close range.

## Bulletproof jackets around the world

The global bullet proof jackets market size was estimated at USD 1.20 billion in 2021 and is expected to expand at a compound annual growth rate (CAGR) of 5.7% from 2022 to 2030. Rising demand for lightweight body armor from end-use industries such as defense, law enforcement, and civilians is likely to drive industry expansion.

India is the fourth country after the US, UK and Germany to have its own national standard on bulletproof jacket which provides 360-degree protection.




fg.6 Bullet proof jackets market

### Russia

GOST R 50744-95 is the Russian Federation standard for body armor. Threat classes range from BR1 to BR6.

### US Army

NIJ Standard-0101.06 has specific performance standards for bullet-resistant vests used by law enforcement.

## EU army

The VPAM scale as of 2009 runs from 1 to 14, with 1-5 being soft armor, and 6-14 being hard armor.

## Germany

The Technische Richtlinie (TR) Ballistische Schutzwesten is a regulation guide in Germany for body armor. It is mainly issued for body armor used by the German police, but also for the German armed forces and civilian available body armor. It specifies five different classes ranging from L to 4 of ballistic protection ( SK L, SK 1 to SK 4 ).

## British Army

The Home Office Scientific Development Branch is governing standards and testing protocols for police body armor.

## Indian Military

BIS specifies 6 threat levels faced by the Indian Army and Paramilitary (Levels 1 to 6).


# Design Specifications

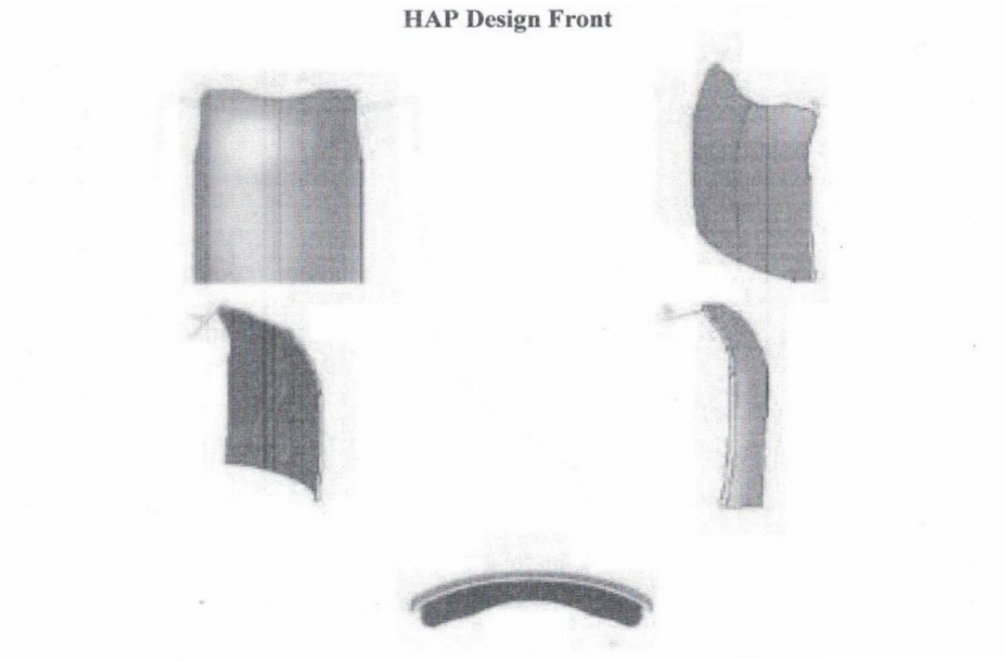
## Design parameters for BR Jackets

Shall conform to Trial Directive, “Ballistic Resistance of Body Armor,” Protection against all of the following ammunitions fired from weapons mentioned against each:

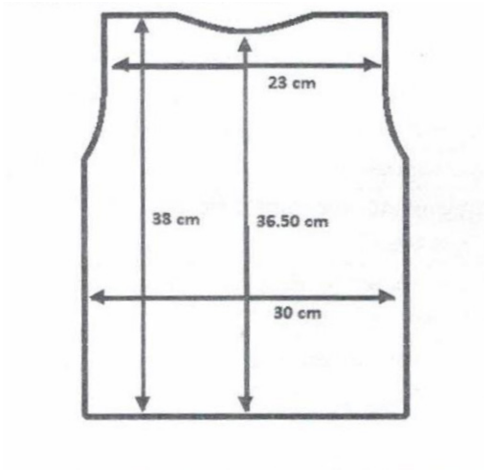
1. 9x 19 mm cartridge fired through Sub Machine Gun (Such as Sten Machine, MP-5, Carbine, any other variant) from a distance of 5 meters to achieve a muzzle velocity 430 ± 15 m/s and the weight of the bullet between 7.4 gm to 8.2 gm.
2. 7.62,0 lmm cartridge NATO ball ammunitions fired through 7.62mm SLR/Bolt action rifle from a distance of 10 meters to achieve a muzzle velocity 838 ± 15mJs and the weight of the bullet 9.4 gm to 9.6 gm.
3. 7.62 x 39mm (mild steel core bullet) cartridge frred through AK series rifles from a distance of 10 meters to achieve a muzzle velocity 715 ± 15m/s and the weight of the bullet 7.45 gm to 8.05 gm.
4. 7.62 x 39mm (hard steel core bullet) cartridge fired through AK series rifles from a distance of 10 meters to achieve a muzzle velocity 635 ± 15m/s and the weight of the bullet 7.45 gm to 8.05 gm.
5. 5.56 x 45mm Ball MK M (Equivalent to 5.56 mm NATO (M 193)) cartridge fired through INSAS rifles from a distance of 10 meters to achieve a muzzle velocity 890±15m/s and the weight of the bullet 3.5 gm to 4.0 gm.

SIZES OF SOFT ARMOUR PANEL (SAP)- STANDARD, LARGE & EXTRA LARGE. SAP shall be covered with durable water repellan fabric that exhibits excellent sealing properties thus protecting the ballistic material from moisture.

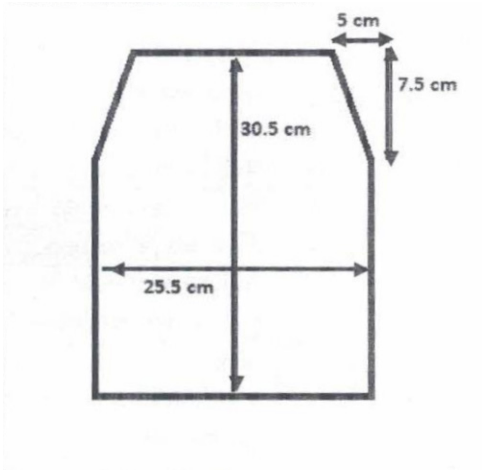
Shall consist of an outer carrier, removable Soft Armour Panels (SAP) of suitable material and Two Hard A:mour panel (HAP) made ofHlgh Performance Polyethylene Platics/Aramid Fibre/Composite material or any other superior quality material.



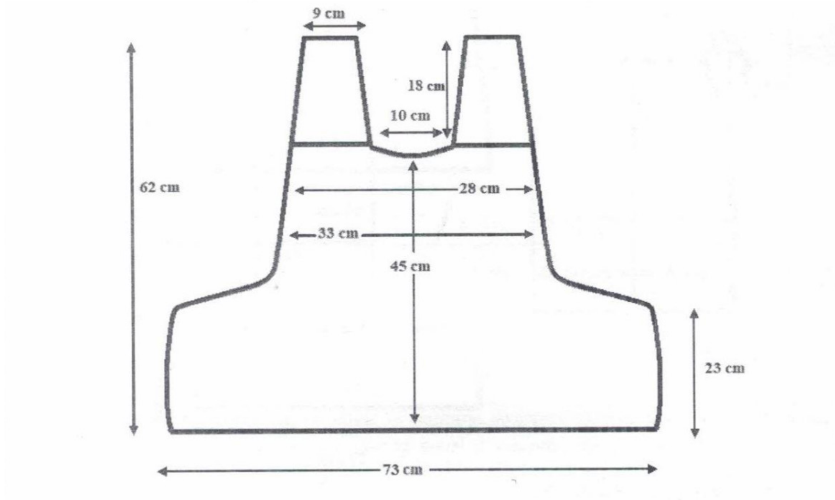

fg.7 Front Hard Armor Panel



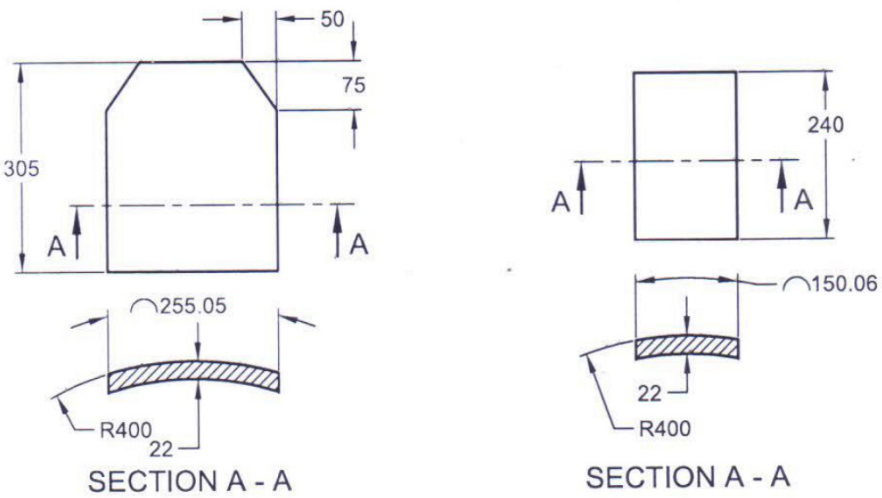

fg.8 Front HAP dimensions



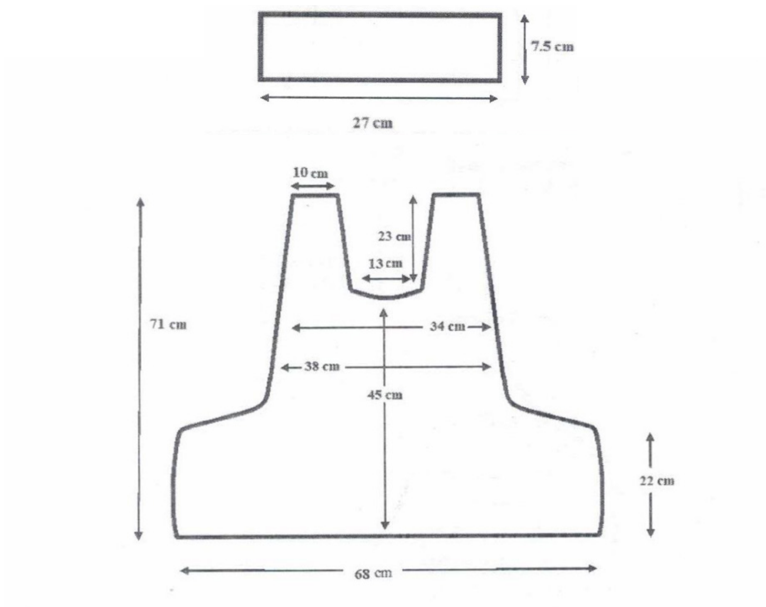

fg.9 Rear HAP dimensions




fg.11 Outer carrier front dimensions




fg.10 Rear HAP & side HAP section & curvature




fg.12 Shoulder pad & Outer carrier rear dimensions

1. The outer carrier shall be made of high. tenacity, heavy duty, Abrasion Proof and 100% vest integrity fabric having in-built water resistant and fire retardant properties.
2. The fabric shall be treated for protection against water, fire (fire retardant) and ultra violet rays' exposure .
3. The fabric must be suitable to wear in the Indian conditions of heat, rain, and humidity. It must be iight, breathable, soft and pliable.
4. The inner side (body side) shall also be of a similar fabric and shall be treated for moisture and water repellency.
5. The cloth of the carrier must be pre-shrunk before stitching.
6. BR Jackets should be UV Proof.

VEST FIT

1. The overall length of the BR Jacket shall be such that there is no "ride up" while sitting.
1. The overlapping degree of front and rear panels shall be such as to provide for maximum freedom of movement.

SOFT ARMOUR PANEL (SAP)

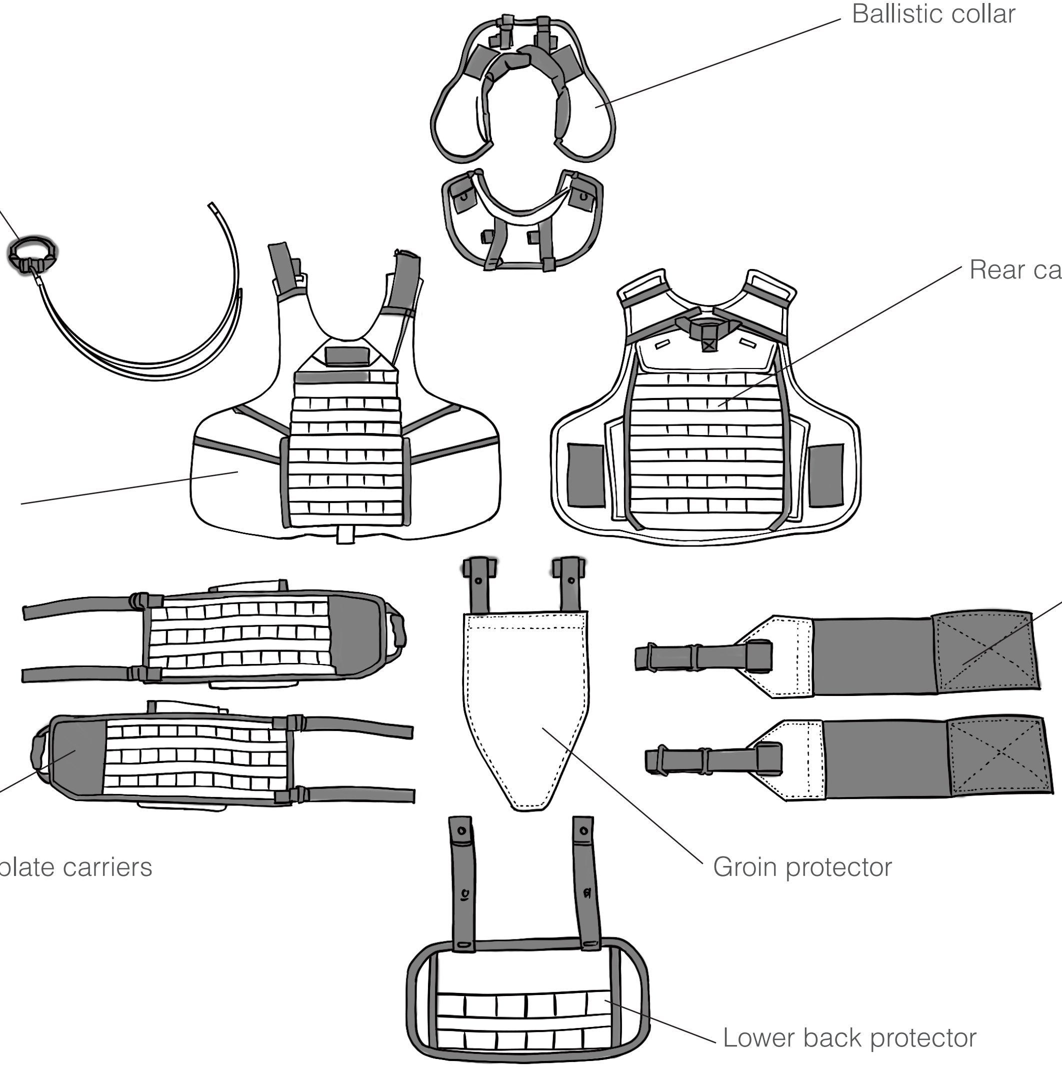
1. SAP shall be able to withstand NIJ threat level IIT A in respect of the caliber & the w~apon selected for trial and other parameters such as weighr & velocity or t!"le bullet in ammunition selected tor trials.
2. Shall protect both from and back torsos.
3. Shall be made of suitable materia l.
4. The weight of the material shall be so balanced as to make the SAP lightweight, breathable, soft and pliable.
5. The aerial density of the panels shall be such as 10 provide tile

6. rated ballistic and trauma protection.
7. No tears, rips, worn spots, discolorations, loose or tom stitching and set wrinkles on the HAP shall he allowed.
8. The panel shall be treated with approved and durable water rcpellant.
9. The SAP shall be removable frorr: outer carrier to a 110 ..... ' for periodic cleaning.
10. The SAP shCl ll be placed in tightly sealed with ~ome material so as to make it completely water repellent and waterproof.
a. Hydrostatic Head-Minimum lOOcms of water (Test Method rs 391-197.5).
b. Waler penetration should be zero (test Method IS 392- 1989).

HARD ARMOUR PLATE (HAP)

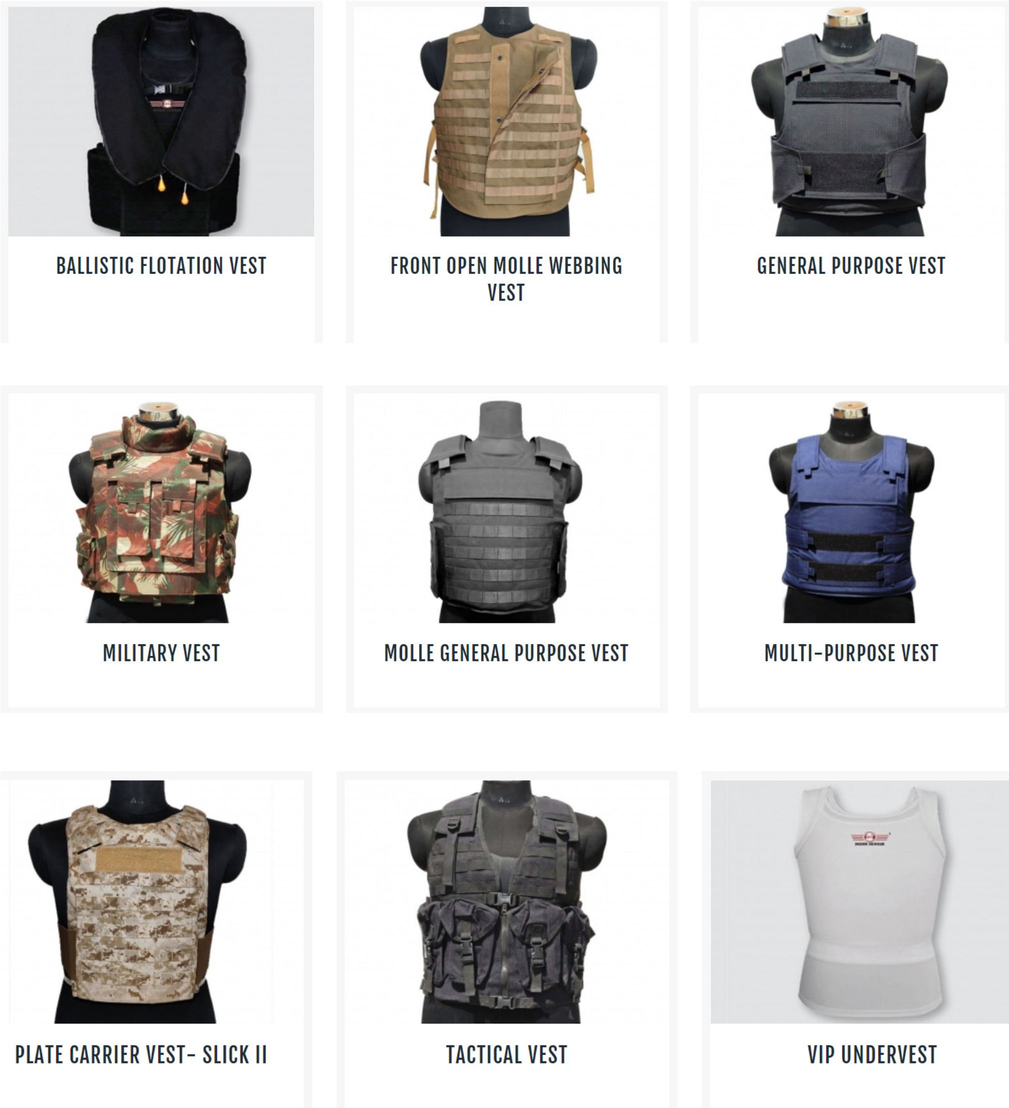
1. Shall be made of High Performance PolyethylenelArcunid fiber/ Composite or any other superior material.
2. Shall provide protection against anununilion mentioned above at Para A from a distance of 10 meters in conjunction with Soft Annour Panel.
3. Each HAP plate (Front and back) should not weigh more than as specified in Table NO.4.
4. In case of 3600 protection Each side plate of HAP should not weigh more than a5 specified in Table No. 4.
5. Each standard HAP plate (Front and back) shall be of minimum size 305mm x 254mm to cover the vital parts of the body.
6. Curvature of the HAP shall be suitable to fit the body contour.
7. HAP shall be shielded with some material so as to make it completely water repellent and waterproof.

# Typical bulletproof vest




fg.13 Parts of a typical bulletproof vest

## Bulletproof vests available in Indian market




fg.14 Different types of bulletproof vests available in Indian market

# PRIMARY RESEARCH

## User

Anti-Terror Attack Force- A specialized counter-terrorism unit of the Mumbai Police to guard the Mumbai metropolitan area, is one of the largest metropolitan areas in the world, formed by the Government of Maharashtra on the lines of National Security Guards (NSG).

**Anti-Terror Attack Force commandos** were taken as the primary users for the scope of this project.
The specially trained commandos serve for 5 years in the force and use the highest protection level bulletproof vest on duty (Level 6). They perform highly physically intensive activities while wearing the vest, such as Firing, mock drills, room interrogation, helicopter landing, building crossing, etc. All these activities require swift movement of the commandos, so the bulletproof jacket should not become a hindrance while performing these intense activities.

## Questionnaire

A questionnaire was prepared to understand the daily routine of the commandos and their interaction with the bulletproof vest.

1. **Tell me about yourself. What do you do? Where are you from? Take me through your journey.**

My name is Ashok Kumar. I'm 28 years old. I'm from Hingoli but currently living in Kalyan with my family. My educational background is B.A. Arts and I joined the task force in 2020. I joined the Maharashtra Police force and was deputed to train in Pune after which I was selected for the Anti-terror attack force.

2. **How long do the commandos serve here?**

Generally, it's 5 years of service. But, some people have still been serving for 7 years now. If you are physically fit and able, you can still continue on request.

3. **Can you take me through your daily routine? What's your day like?**

The attack force is divided into two modes, "Alert mode" and "Training mode". Though they are almost the same, only certain activities differ. We have Fall-in at 5:35 am in the morning followed by PET, report, and breakfast. There are lectures/motivational talks/Practice/Firing depending on the mode. We have lectures again after lunch, followed by a tea break at 04:25 pm, followed by PT/Gym. On nights we have movies or operations or GD. That's roughly the routine. There are monthly operations as well which may happen irrespective of the time mentioned.

**4. Have you worn a bulletproof vest? When do you wear it?**
Yes! We wear the BP Jacket every day for the morning briefing. We wear it for mock drills which are performed outside campus once a month. Mock drills are also conducted at the Headquarters, where we also have to wear jackets.

**5. How long do you wear the bulletproof jacket?**
When at the headquarters, we usually wear it for 3-4 hours, while if we are outside the campus for the drill, we have to wear it for 6-8 hours.

**6. Can you explain how you wear it?**
We wear it from one side though there are openings from sides on both sides. One side is always closed. The plates are always in place, we never remove them. We never change anything. We usually wear it ourselves and don't need anyone's help wearing it.

**7. What kind of activities do you perform while wearing the bulletproof jacket? What kind of positions are involved?**
Room interrogation, Firing, Mock drills, Operations, guard duty, weapons handling drill, running, obstacle tackling, tactics, rapling, slithering, building crossing, etc.
Positions such as Standing position, High kneel up, high kneel down, kneeling, sitting down, lying down, and running position.

**8. Were you ever shot?**
No. We never encountered anything like that.

**9. What all things does a bulletproof vest carry?**
We carry alot of equipment and ammunition on the current bulletproof vest. Things like HE grenade, Stun grenade, WT, batteries, GTL, handcuffs, knife, hydration pack (1 Litre) and First Aid kit.

**10. Can you describe your experience wearing the bulletproof jacket? Were you comfortable wearing it?**
The ones which we wear are by the company called MKU. It feels quite bulky while wearing, " fugalela vatte". It hinders a lot of body movements, we can't turn, and shoulder movements are restricted. The jacket moves up and the pouches move while running. The velcro makes sound while removing a grenade or magazine, for us, camouflage is very important and we can't make any noise during an operation such as a rescue mission.
It is too hot, we sweat a lot while wearing it, causes a lot of discomfort. Shoulder pads are too wide, they can be narrow but strong. The pads on the side make sound while moving through narrow lanes. Cannot see down since its too bulky, the velcro gets loose, and the extra cushioning is just not required. We're fine without it!

**That should be all. Thank you!**

## Interview insights

Various insights were generated by interpreting the interview.

1. The weight of the vest must be low
2. BRJ are quite bulky and in turn restrict movement
3. Body tight armor would help improve agility
4. Accessories such as HAP, grenades, essentials, medical kit, ammunition, etc inside the pockets should not move
5. Body heat regulation - since a lot of sweating is observed in commandos causing discomfort
6. Vest needs to be compact,
7. Velcro on the jackets are of poor quality and also make sound, which may alarm the enemy.

fg.15 Commandos in action

fg.16 commandos in action Helicopter jumping(top), building crossing(bottom)

## User persona

Name: Ashok Kumar
Age: 31
Education: BA
Occupation: Anti terror attack force commando
Location: Mumbai

- Ashok wears BPJ regularly on duty ( 2 hrs ) as guard that involves standing position.
- Performs monthly mock drills.
- Drills involve high physical activities like running, building jumping, interrogation, infiltration, helicopter jumping, etc.
- Occupies different positions during operations such as running, kneeling, kneeling up, standing, lying down.

### Problems faced by Ashok

- Finds the bulletproof jacket very heavy
- Discomfort due to heat and sweating
- Jacket is very bulky, occupies more space, has unnecessary cushioning
- Jacket makes sounds while moving
- Pockets are unnecessarily large
- Grenades and other accessories move inside the pocket while running
- Velcro comes off, very poor quality
- Water bag is an added accessory that restricts movement as it moves while running (hits the back and makes sound)
- Shoulder pads are too wide

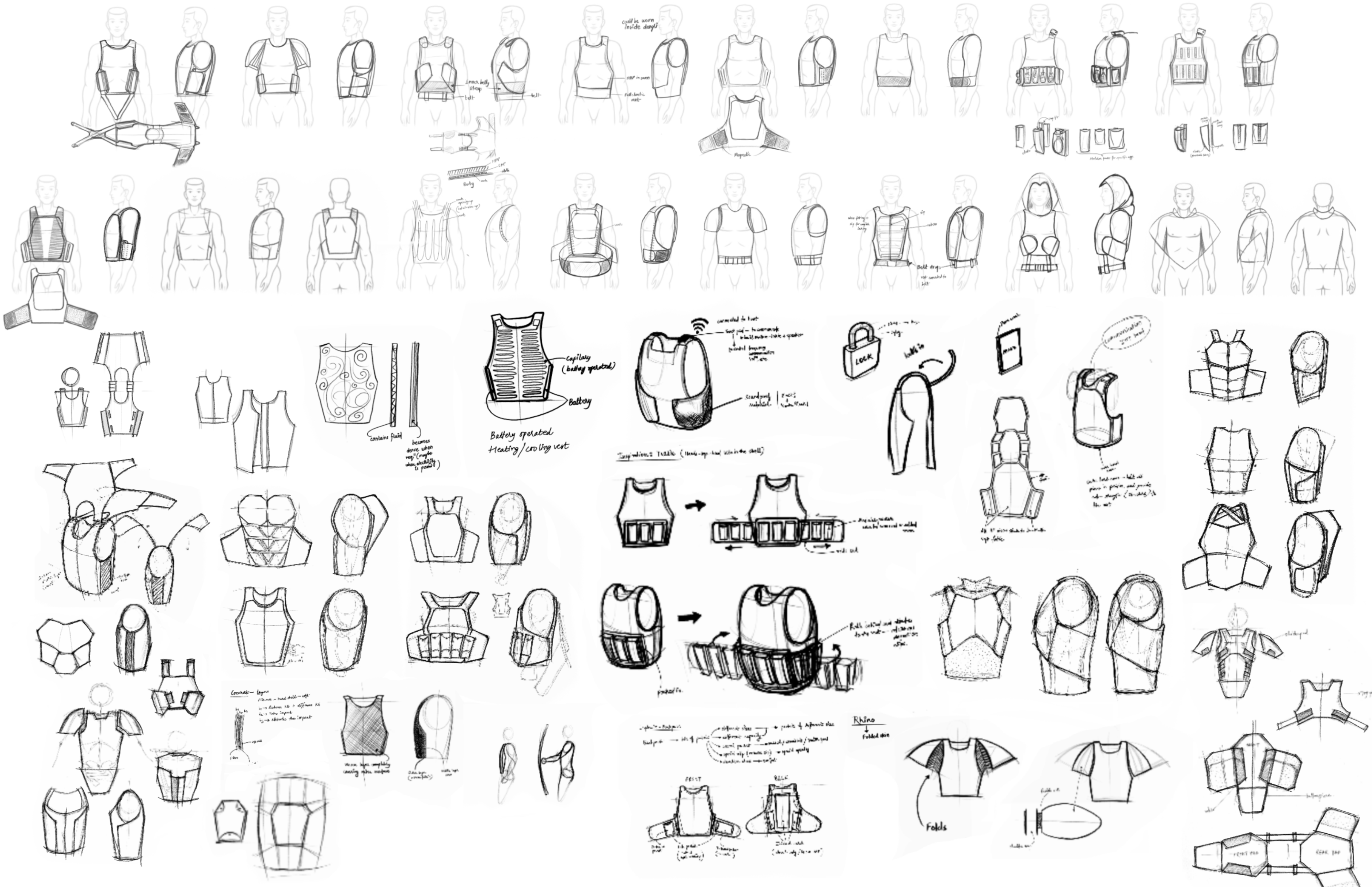
fg.17 user persona

# PRODUCT BRIEF

Based on the data collected, secondary, primary research, and interview insights, a product brief was arrived at.

- **Weight of the vest should not be more than 10 kgs**
- **Vest should be adaptable to hot/cold climate**
- **Arm movement should not be restricted**
- **Slim fit**
- **Should be able to fit all accessories whenever required**
- **Should not make sound**
- **Accessories should not move or make sound while running/ jumping**

# IDEATION



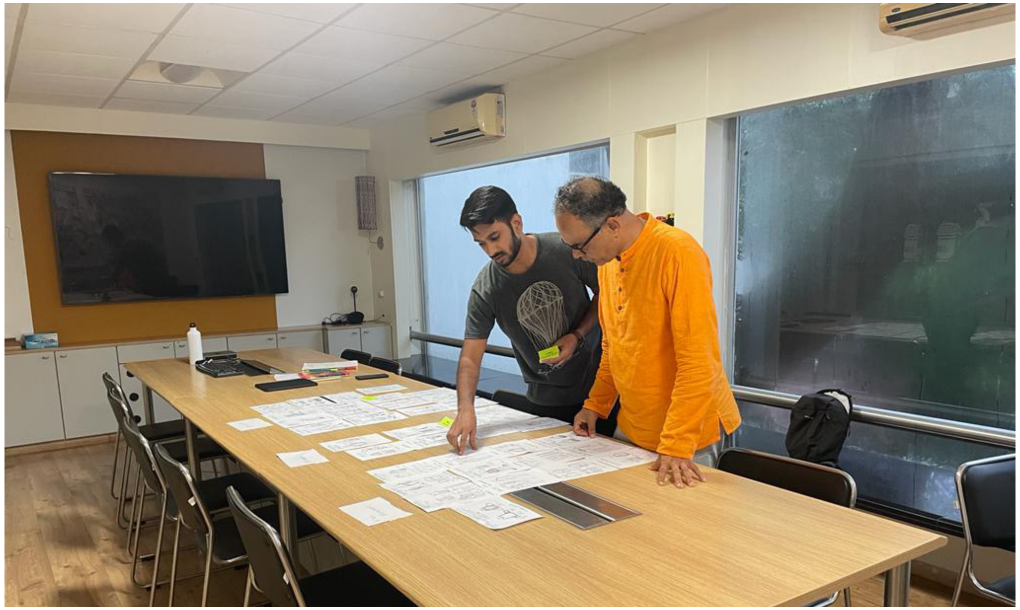

fg.18 ideation sketches

## Clustering

Ideas were printed and sorting was done in order to find close relation between them.
All the sheets were layed down on the table and then sorted while disccusing about each idea. What each idea represents or what does it indicate?
Questioning each idea enabled taking an informed descision while sorting the sheets. After sorting, a suitable title was chosen based on what characteristic the cluster collectively indicated towards.

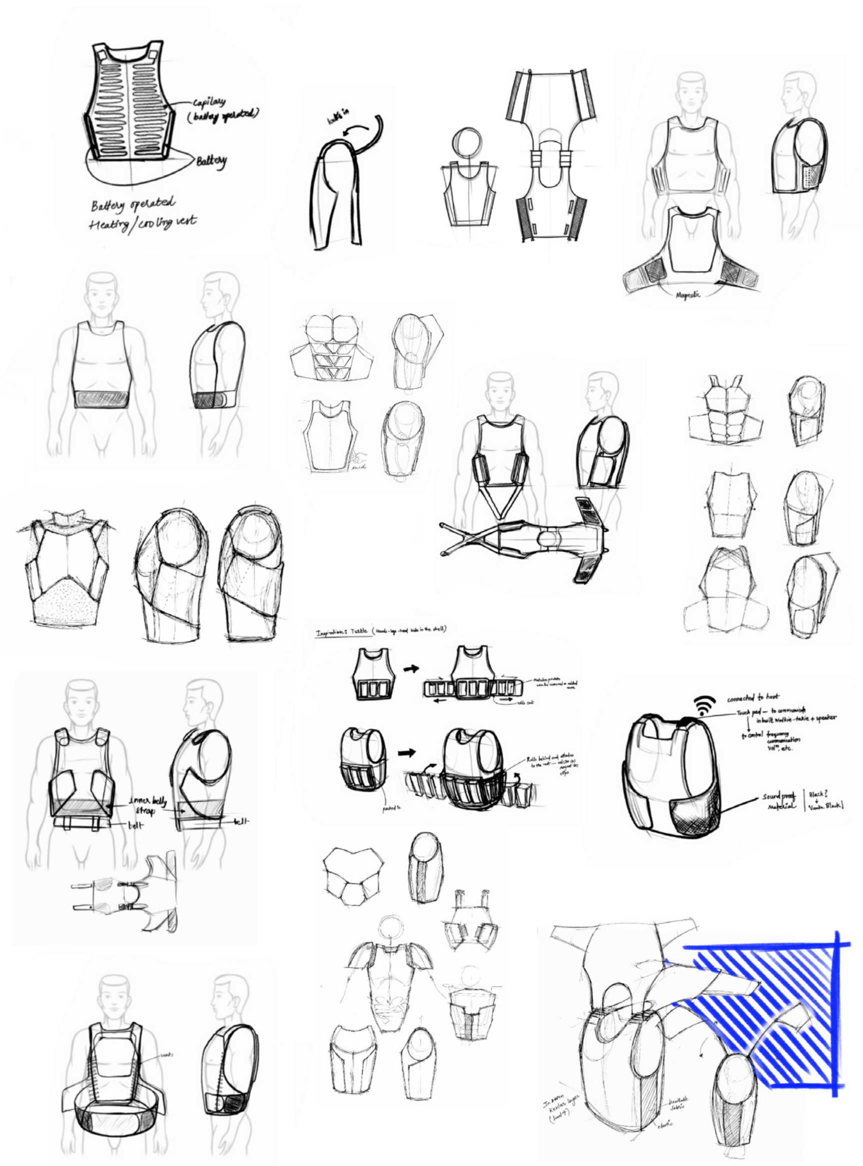
Clusters were made based on

- ease of wearing
- body fit/snug fit
- comfort
- ease of movement
- universal-fit design
- ease of accessorization
- futuristic
- breathablility



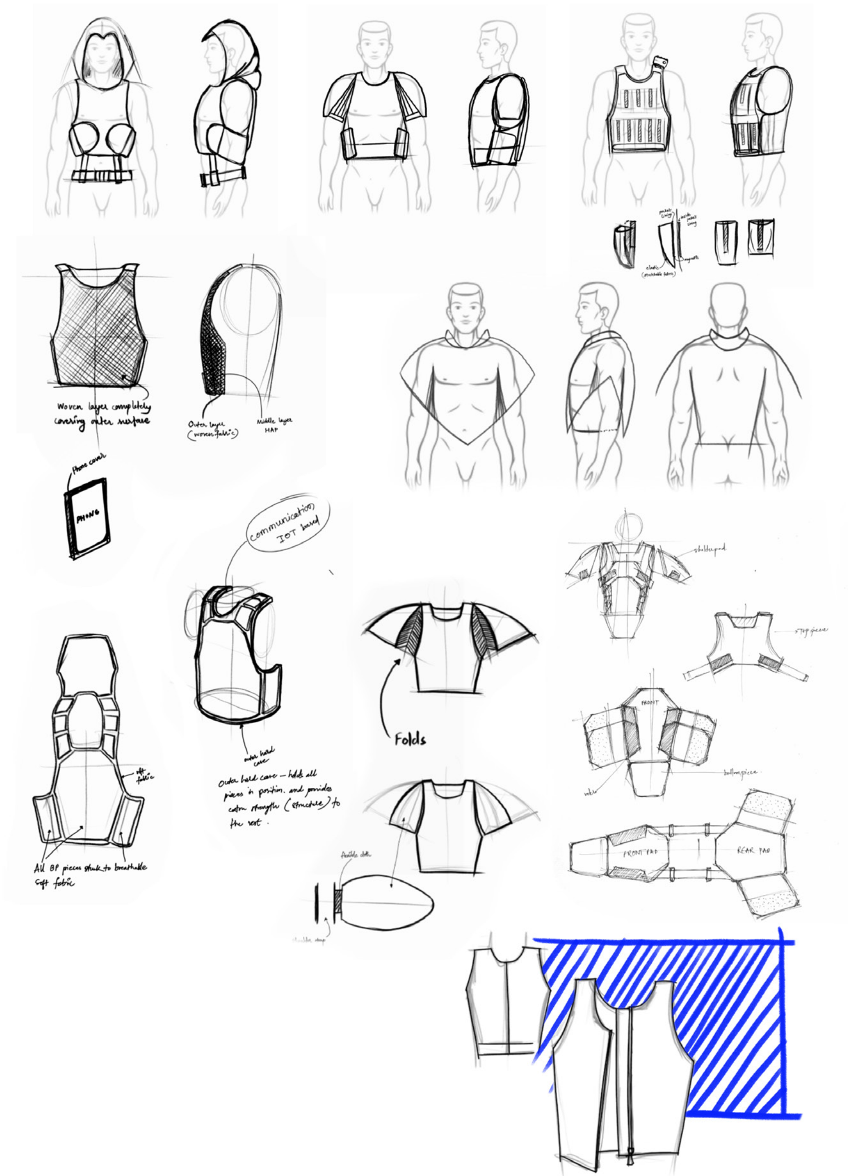
fg.19 ideas sorting and clustering

## Cluster 1: Body fit



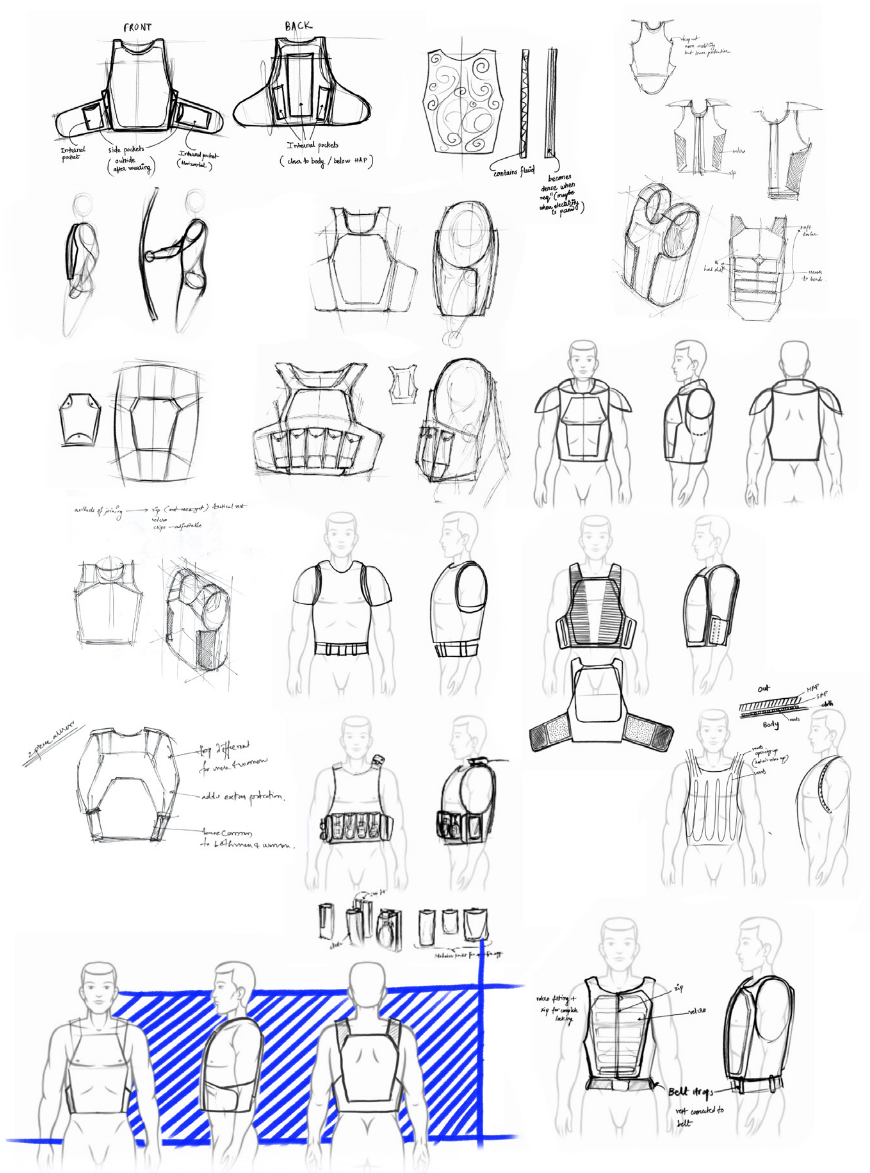

fg.20 body ft cluster of ideations

## Cluster 2: Wearability




fg.21 wearability cluster of ideations

## Cluster 3: Free movement

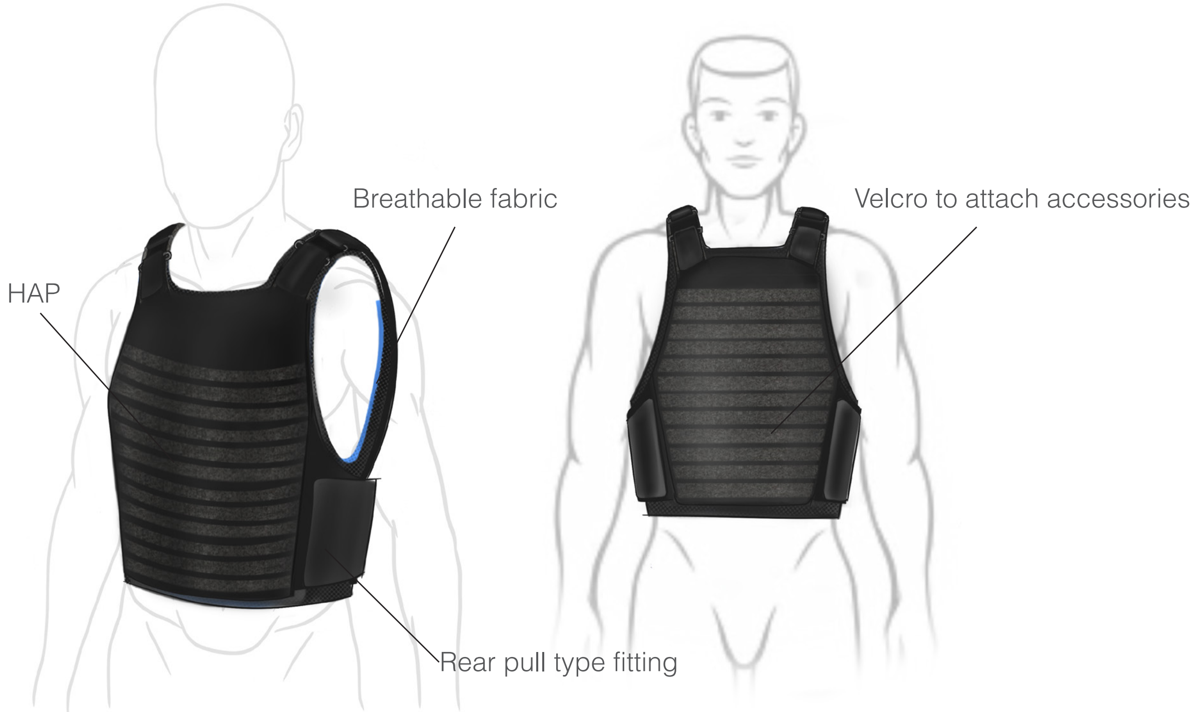



fg.22 agility or free movement cluster of ideations

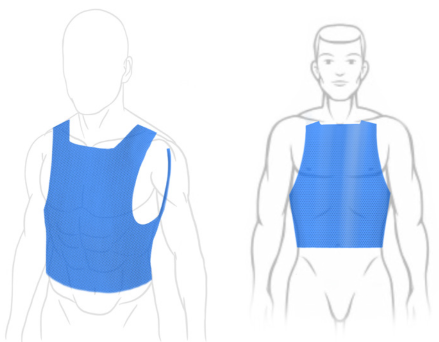
In each cluster, a champion idea was chosen which would act as the base for further development. The identity of the champion idea was to be retained, while any modifications can be made based on other ideas in the cluster.
Hence, three concepts were generated in detail combining relevant properties of each idea into one. Mockups of these concepts were made and tested for comfort, wearability, movement and body fit.

# CONCEPTS

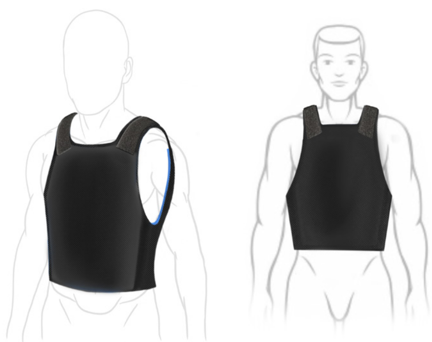
## CONCEPT 1




fg.23 concept 1: full armor



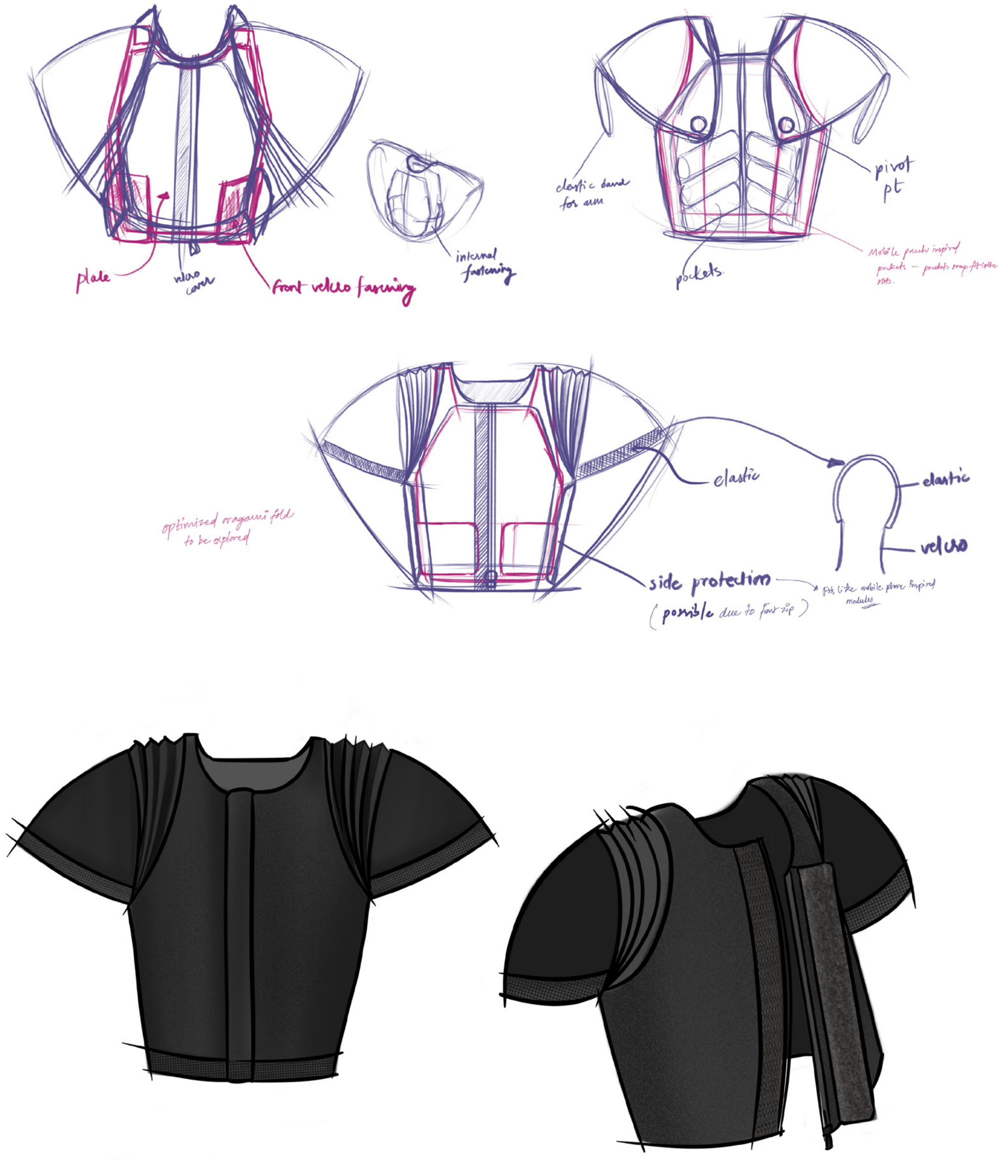
fg.24 breathable layer



fg.25 SAP layer

fg.26 concept 1 mockup

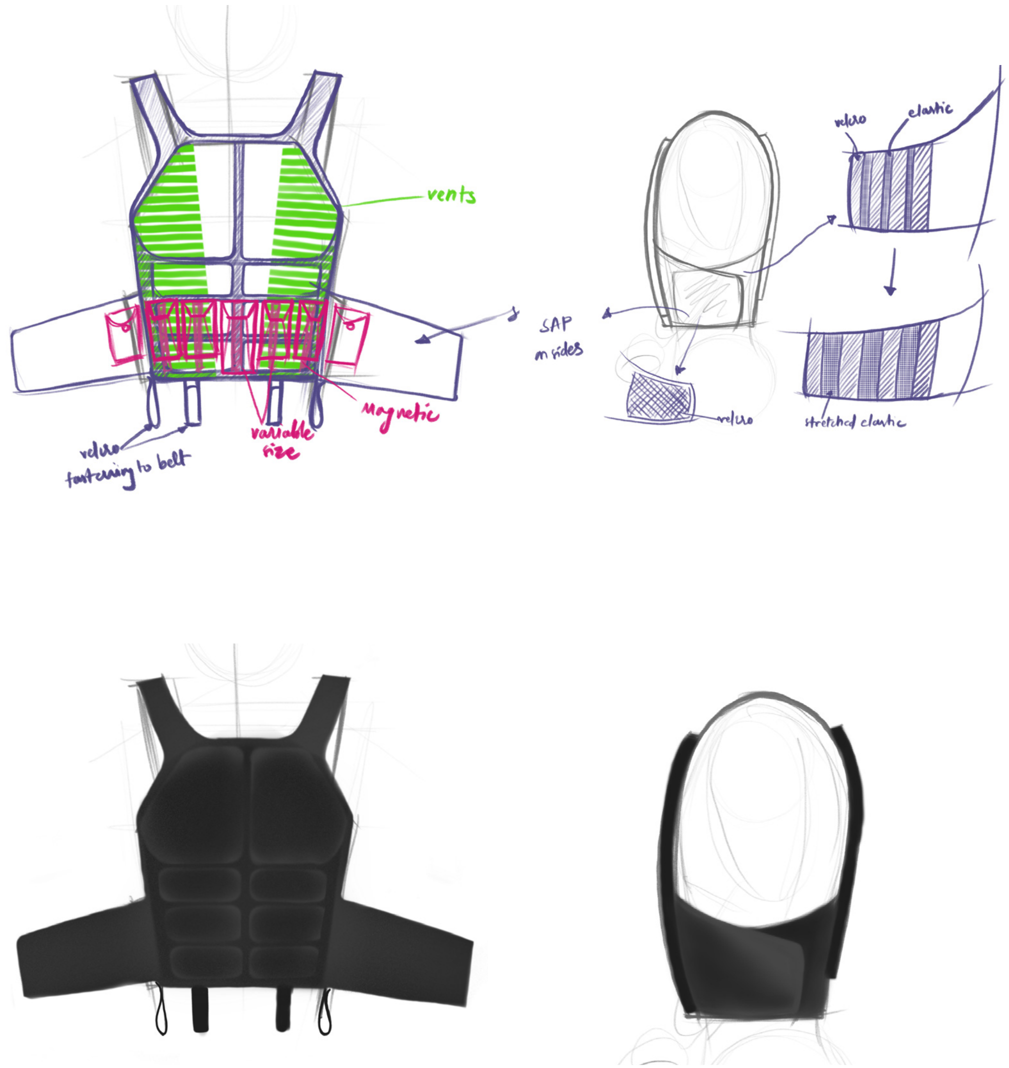
## CONCEPT 2




fg.27 concept 2


fg.28 concept 2 mockup

## CONCEPT 3




fg.29 concept 3

fg.30 concept 3 mockup

# EVALUATION OF CONCEPTS

fg.31 concepts evaluation and testing based on selected criterions

Evaluation of the mockups was done based on set criteria, such as Ease of wearing/removing, Accessibility, arm movement, snug fit, and comfort.
Concepts were graded by the users based on the abovementioned criteria. Each criterion that was valued higher was taken into consideration while finalizing details for the final concept.

## Concept finalization

Key features from each concept was taken and a new final concept was developed.

| | **Concept 1** | **Concept 2** | **Concept 3** |
|---|---|---|---|
| **Key Features** | Rear pull type fastening | Zip type enclosure | Split armor - enables more bending |
| | Adjustable straps | Ease of wearing | Elastic sides |
| | Snug fit | Single piece armor | Single piece armor |
| | Worn same as existing vests | Elastic sides | Wide head opening |
| | 2 part armor | | |

Table 3: fnalizing concept based on selected criterions

# FINAL CONCEPT

fg. 32 fnal concept renders

## Brief verification

**Modular accessorization**
Velcro stitched on the front face and loops allow various accessories to be atached as and when needed.

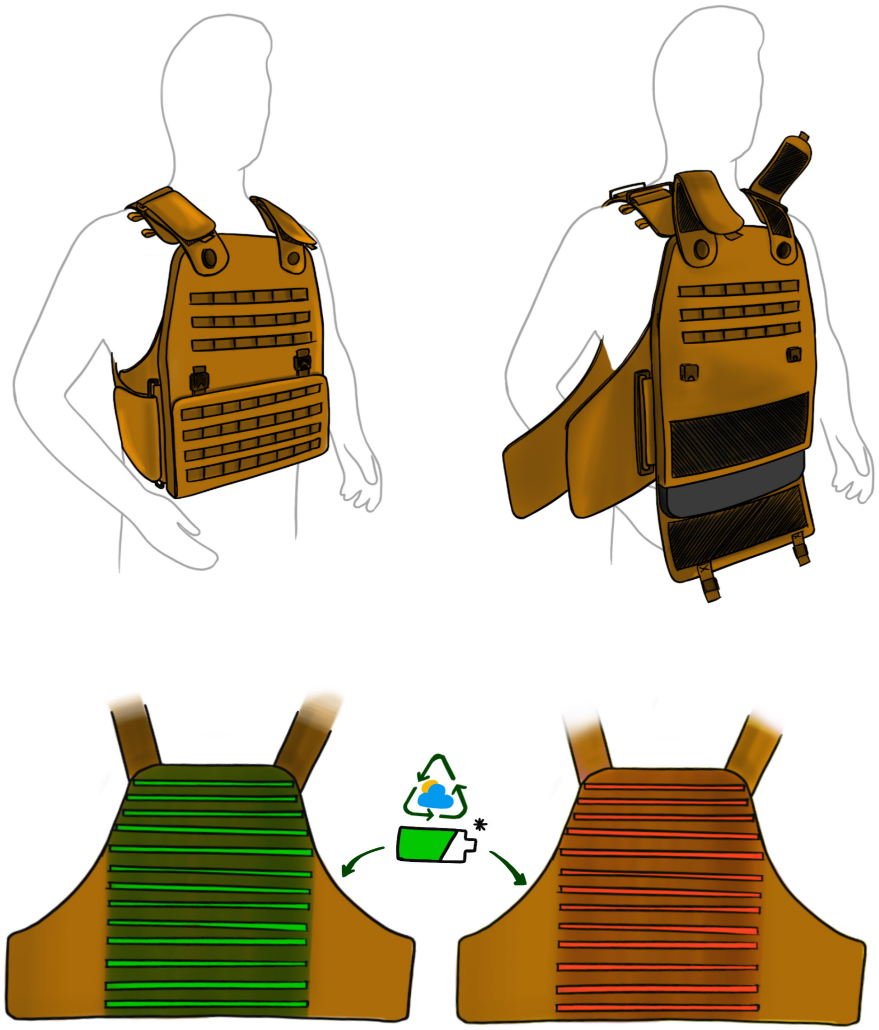
**No sound**
Snug fit type design ensures no lateral movement between body and the jacket. All the accessories are elastically set to the vest with the help of external strap.

**Impact absorption**
The ventilation fins create an air gap between the body and the vest. This air gap can absorb alot of impact and prevent penetration of the bullet in the body in case the HAP is broken through.

**Snug fit**
Rear pull type side strap mechanism provides tight fit to the body.

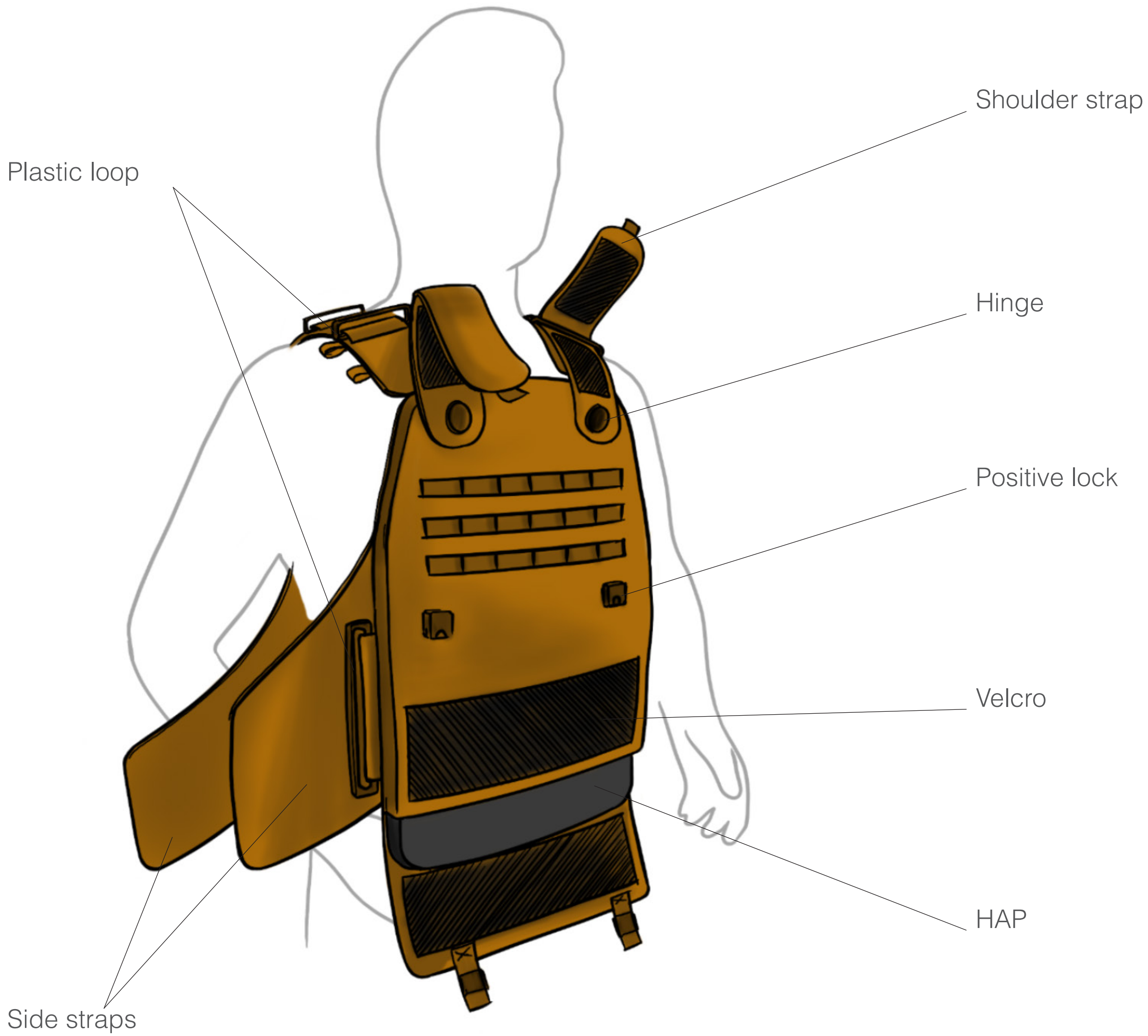
**High agility**
Wide openings on the sides that aligns with the body contour and hinged straps allow full shoulder rotation.

**All weather adaptation**
Vest is provided with vents which use natural convection to cool the body. It may also be used in cold weather when operated with the help of a battery.



fg.33 brief validation

## Parts & Materials




fg.34 various parts of the bulletproof vest concept

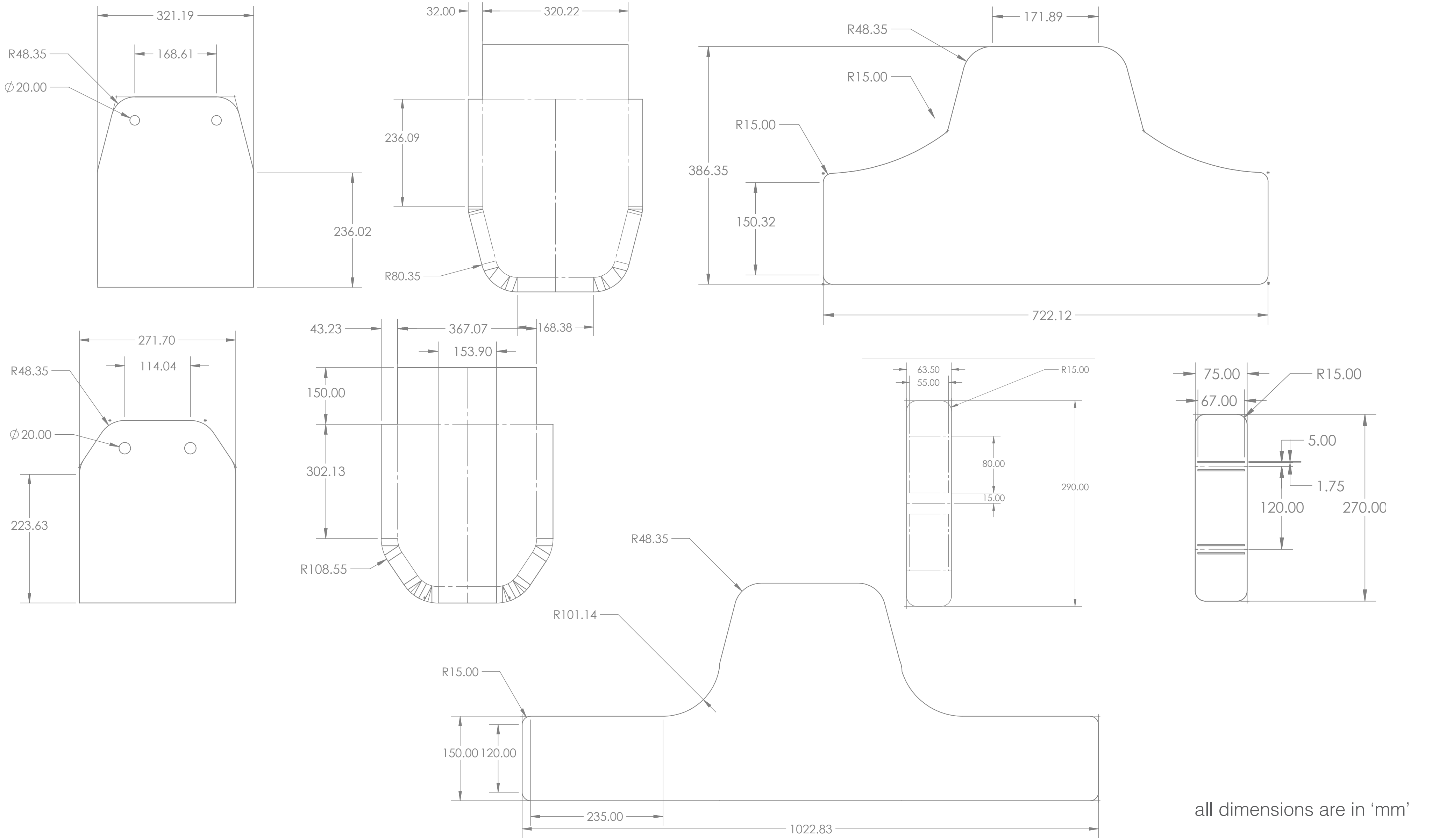
## Materials

Fabric
Light-weight, waterproof, fire-proof, strong and durable fabric of highest quality.

Velcro/ Adhesive rolls
Industrial adhesive rolls for high performance adhesion of thr straps and panels.

Plastic
High impact resistant, tough and durable plastic for high performance and loading.
(HDPE/UHMW)

# Dimensional drawing




all dimensions are in ‘mm’

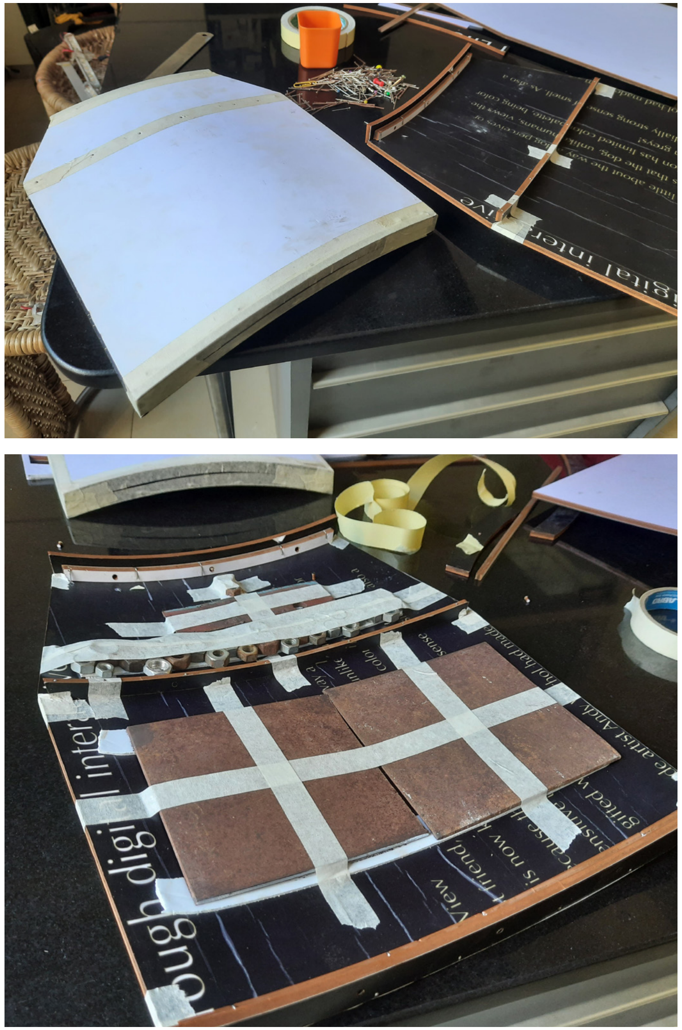
fg.35 dimensional drawings of each part of the bulletproof concept

# FINAL MOCKUP PROCESS

## Making the HAP ( mold ) as per specifications

Standard size of the front and rear HAP were considered. Panels were made to mimic the form and weight of real HAP that goes inside the BRJ. HAP were filled with metal nuts, metal plates, etc and made to weigh 1.5 kg each.

fg.36 making HAP mockup



fg.37 Adding metal weight to mimic actual HAP weight

fg.38 weighing mock HAP

## Finishing the mold

Plates were coated with resin to seal it and provide smooth finish in the surface. Since the process of pattern making demands smooth surface finish.
After putting the first coat of resin, the plates were sanded to re-move any irregularities, and fillet was provided on the edges.
It was coated with another layer of resin and finished.

fg.39 Mixing resin in 3:1 ratio

fg.40 applying resin to achieve smooth surface for pattern making

fg.41 sanding and fnishing HAPs

## Creating the master

Creating a master by covering the panel with masking tape. The panel was completely covered by 1 inch wide masking tape.
The tape is overlapped on the previos layer at every round to ensure complete removal of the tape layer created that wil act as a master.

The traditional method of masking the mold with tape so as to make a master was introduced by manufacturing guide Mr. Harish Vora.

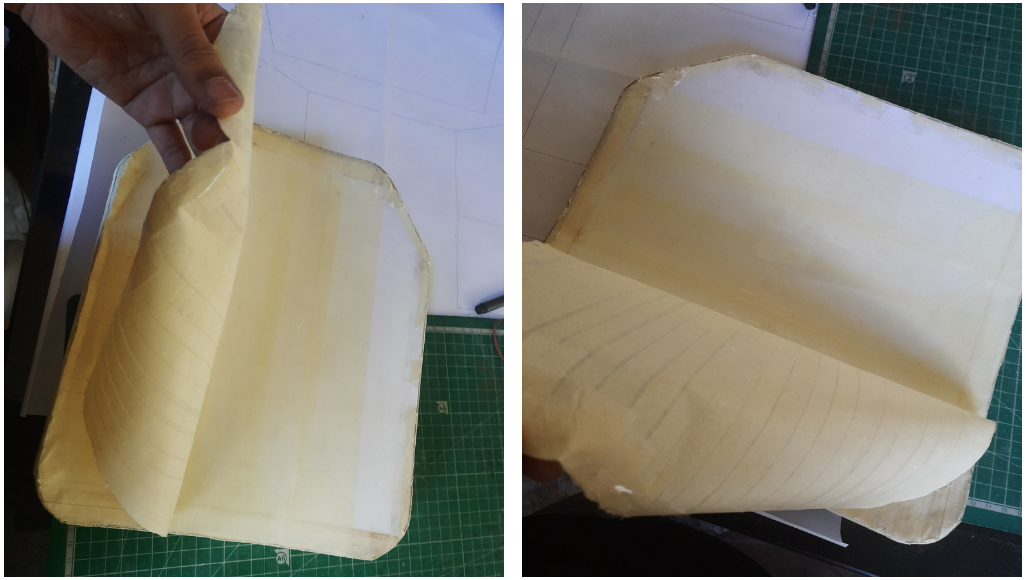
Mr. Harish has been working in bag maufacturing industry for more than 30 years and had agreed to guide me with making the prototype for the bulletproof vest.

fg.42 Learning the process

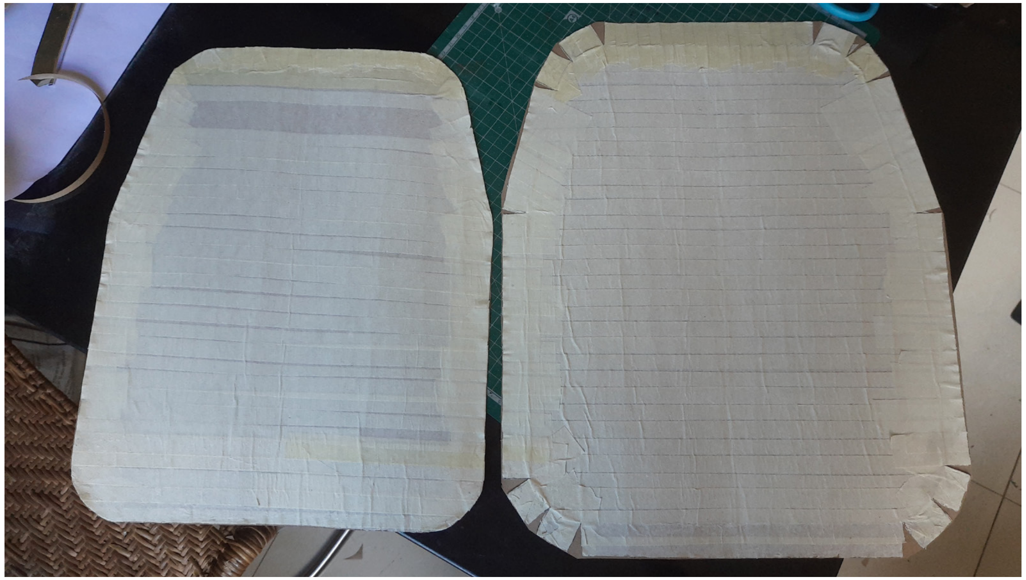
fg.43 masking the HAP mold with masking tape for making master pattern

fg.44 creasing and cutting from the edges to make the master

After layering the panels with masking tape, the next step is to cut the tape from the crease.
In this case, inner surafce was removed first and then by cutting V-notches on the radii, front surface was removed creating a very precise master.



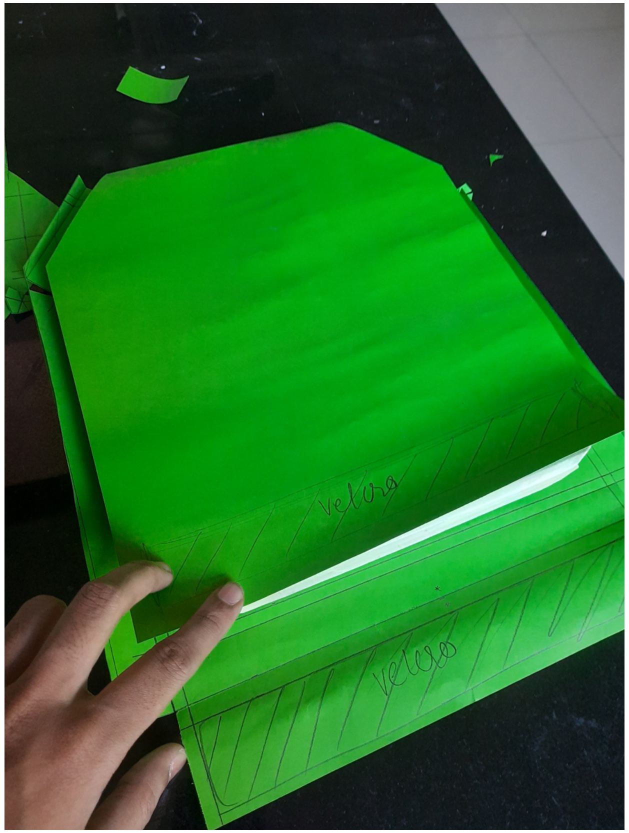
fg.45 removing the masking tap layer



fg.46 fnal master of front HAP

## Creating the temporary template for the mockup

A template pattern was made for the final mockup. A t-shirt was also used to trace the body contours, and then with the help of template, markings were traced to make the side panels of the jacket.



fg.47 template used to make marking on t-shirt

fg.48 fnal mockup development process

## Final mockup

fg.49 fnal mockup

fg.50 fnal mockup views


fg.51 fnal mockup details

## MOCKUP TESTING

fg.52 Final mockup wearability test

fg.52 Final mockup wearability test

fg.52 Final mockup wearability test

fg.52 Final mockup wearability test

# PROTOTYPING

# BUILDING PROTOTYPE WITH HONEYBADGER

Mr. Harish Vora, taught me the traditional method of masking the mold with tape so as to make a master. And with the help of the master made, he demonstrated the stiching of the straps of the vest in denim fabric.

Mr. Harish has been working in bag maufacturing industry for more than 30 years and had agreed to guide me with making the prototype for the bulletproof vest.

## BUILDING PROTOTYPE WITH ECOSTYLECRAFTS

Ecostylecrafts is a clothes factory, where clothes are stitched by highly skilled work staff. Their master tailor, Master Ashok, was assigned to guide me on my project for stitching the vest.
First step was to validate the pattern made. The patterns were matched with the mockup and validated.

The patterns were correct, thus validating the process that I undertook to make the master.

## Constructing a rough fabric mockup

Master started by making a rough mockup to test the details.

A rough mockup was built with reference to the paper mockup.

The mockup was made and HAP was placed in it. Minor modifications were made and noted. Dimensions were standardized at this stage once the fabric mock-up was made. Area of coverage of the side straps was also noted.

After building the rough mockup and establishing standards for dimensions and stitches, a semi-final prototype was made. This prototype was made with canvas (actual material to be used to make the BRJ), along with all the accesories such as straps, loops, belt, etc.

The pre-final version was worn and tested. After finalizing the details of shoulder hinge, and flaps design, a final prototype was started.

This design was made as a base model of the BRJ, onto which other accessories can be attached.

## FINAL BUILD









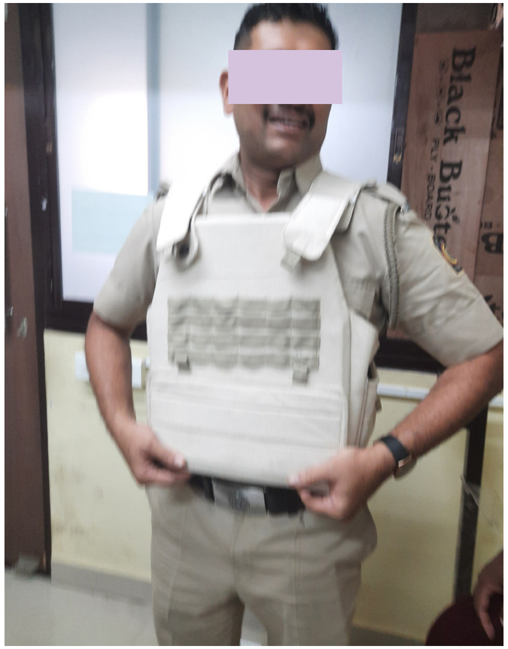
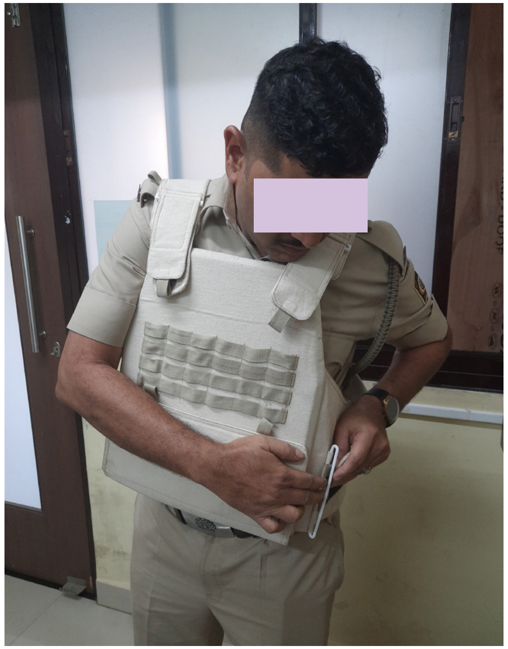
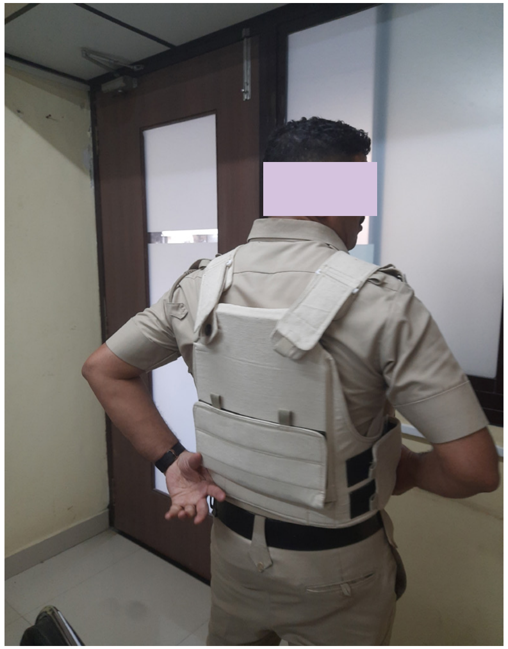
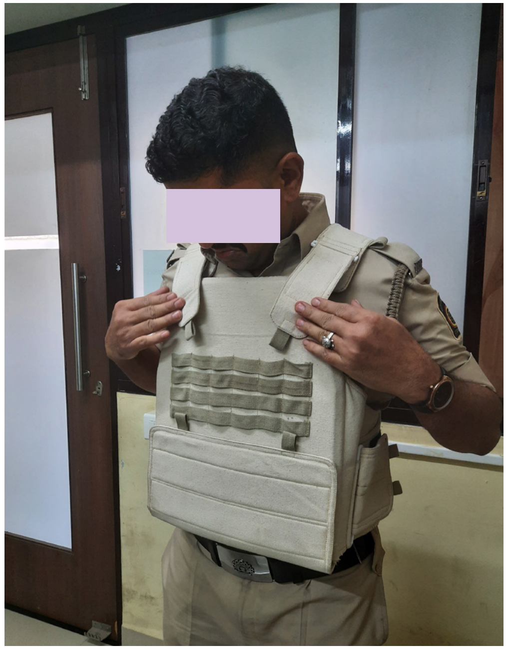




# USER TESTING





## User Feedback

Positive feedback
- Very comfortable to wear
- No restriction in mobility
- No ride-up
- Good fit

Negative feedback
- Loop is difficult to see while wearing
- Overhanging flaps

## FUTURE SCOPE

- Rework based on feedback
- Accessorization
- Pocket design
- Improving visual identity
- Design for Manufacturing
- Manufacturing

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