UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN AND DEVELOPMENT OF SHIELD FOR FIRE RESISTANCE PURPOSE

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Engineering Technology Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.

by

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DECLARATION

I hereby, declared this report entitled “Design and Improvement on a Fire Resistance Shield” is the results of my own research except as cited in references.

Signature : ……

Author’s Name : ……

Date : ……

APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours. The member of the supervisory is as follow:

……

(Project Supervisor)

ABSTRAK

Perisai telah digunakan sebagai alat pertahanan untuk infantri dan kesatria sejak berabad-abad dahulu. Evolusi besar perisai terus berlaku dan ini membawa kepada pembangunan progresif dan peningkatan reka bentuk perisai, contohnya perisai yang banyak digunakan oleh anggota penguatkuasaan undang-undang hari ini. Walaupun begitu, perisai untuk tujuan penyelamatan api masih belum direka. Kesesuaian interaksi antara perisai dengan penggune juga menjadi suatu persoalan. Oleh itu, objektif projek ini adalah untuk mencadangkan reka bentuk konseptual perisai, dengan pertimbangan faktor ergonomik perisai. Metodologi yang digunakan adalah kaji selidik terhadap ahli bomba untuk menentukan keperluan terhadap reka bentuk perisai, House of Quality (HoQ) dalam menilai keperluan ahli bomba, carta morfologi dalam menentukan konsep, kaedah pemilihan Pugh untuk pemilihan rekan bentuk yang paling sesuai, analisis RULA dalam mengukur ergonomik, and akhirnya Finite Element Analysis (FEA) dalam mensimulasikan kesan perisai bawah tekanan haba dan beban. Perisai berbentuk scutum telah dipilih sebagai reka bentuk konseptual, dengan aloi aluminium 6061-T6 sebagai bahan teras perisai, dan dibalut oleh serat karbon jenis modulus elastik (HT). Reka bentuk perisai telah mencapai skor akhir 3 dalam analisis RULA untuk kedudukan bediri dan melutut. Skor ini menunjukkan reka bentuk perisai mempunyai risiko gangguan muskuloskeletal (MSD) yang rendah. Selain itu, keputusan FEA telah membuktikan sifat mekanik kedua-dua bahan yang digunakan dalam reka bentuk perisai adalah selaras dengan penemuan kajian literatur.

ABSTRACT

Shield has been used as a reliable defence for infantrymen and knights since centuries. Great evolution of armours went on and this led to progressive development and improvement on the design of shield, for example the various shields used by law enforcements today. However, a flexible shield for firefighting purpose is yet to be designed and developed. The suitability of interaction between the shield and user also remained questionable. Thus, the objective of this research is to propose a conceptual design of a shield for firefighting purpose, considering the ergonomics factors of the shield. The methodology used are customer survey to define fire fighters' needs, House of Quality (HoQ) in quantifying customers' needs, morphological chart in defining concepts, Pugh selection method for selection of the best design, RULA analysis in measuring ergonomics score, and lastly Finite Element Analysis (FEA) in simulating the behaviour of shield under thermal and load exertion. Scutum-shaped shield has been selected as conceptual design, with aluminium alloy 6061-T6 as the inner body material of shield, and is wrapped by the standard elastic modulus type (HT) carbon fiber. The shield design has achieved a final score of 3 in RULA analysis for both standing and kneeing position, which indicated the shield possess only low risk of Musculoskeletal Disorder (MSD). Besides, the results of FEA have proven the mechanical properties of both the materials used in shield design to be consistent with the findings of literature review.

DEDICATION

To my respected supervisor,
my beloved family,
and all my friends,
Thanks for your support.

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First and foremost, praises and thanks to God, the Almighty, for His showers of blessings to complete this final year project successfully.

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In my journey towards this degree, I am blessed to have bunch of lovely friends and classmates who cheered and supported me along the way. We were not only able to support each other by deliberating over our problems and findings, but also happily by talking about things other than just our project works.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

FEA	-	Finite Element Analysis
GPa	-	Giga Pascal
HoQ	-	House of Quality
M-Chart	-	Morphology Chart
mm	-	Milimiter
MPa	-	Mega Pascal
ms-1	-	Meter per second
^{o}C	-	Degree Celcius
QFD	-	Quality Function Deployment

CHAPTER 1
INTRODUCTION

1.1 Background

Ever since the ancient times, mankind have always attempted to protect themselves from antagonist. The caveman's clothing made of thick animal skin was found to be the first body armour documented in history, followed by the invention of wooden and metal shields to protect one's body (Stanley, 2004). Body armour is usually worn for an extended period of time and over long distances during military, police and law enforcement activities (Ricciardi et al., 2008).

Armours have been developed to accommodate the increasing and ever-changing methods of inflicting harm. A study done by Howard et al., (2013) showed some of the earliest armours worn by the soldiers in Japan during the fourth century includes iron helmets and cuirasses, followed by the lamellar armour which found to be used by the fifth century. Cuirasses are made of iron plates strapped together with metal thongs, whereas lamellar armours are configured by stitching metal pieces or rectangular leather together in rows. These designs of armours can greatly reduce the impact of sword blows and arrows, hence provide protection to the part of body where the armour offered protection. However, soldiers during these early centuries were not equipped with a full and complete set of armours. They relied on a large piece of shield for protection of all parts of their body (Ffoulkes, 1967).

According to Howard et al., (2013), a decisive change where a great evolution of armours and arms occurred in history was aroused from the Crusades and went on throughout the middle age. During the period of first Crusades, armour has transformed to other forms besides cuirasses and lamellar patterns. A shirt comprised a mesh of thousands of metal rings woven together, known as chainmail turned up to be a prominent armour by the time. Although some developments were made during the Crusades, the high requirement on the design and composition of arms and armours

for a better protection had kept the developments went drastically with both the Western and Eastern civilisations having immense clash over the 11th to 13th century.

Shields were usually reliable defence for infantrymen and knights before plate armour became a commonplace form of guard. Various types of material, either metal or non-metal like wood, had been used in crafting shields. Soldiers who can afford only low price shields used to combine thick sheets of wood with paste and tanned leather to create a durable aegis. However, it differed from iron-made-shields which simply dent under blows from weapons, wood-crafted-shields tend to crack and fall apart if they were suffered from heavy impact (Howard et al., 2013). Investigation on suitable material in the making of shield has grown progressively, while more and more lightweight, yet high strength material are made possible for shields of different purposes, such as riot shields, ballistic shields and military shields. For instance, soft ballistic vests which are made of synthetic fibres: Kevlar, Spectra, or Zyloflex, have been available to law enforcement officers since 1973.

Over the time, development of shields focused not only on its crafting material or composition, but on the ergonomic factor as well. For instance, as described by Howard et.al (2013), the straps located behind the blocking part of shield were reshaped for better control over blocking. A handle or strap would be grasped by hand, and the secondary strap would fit over arm. This enables soldiers to put the power of their weight behind blocks and attacks. This is supported by Czarnecki & Janowitz (2003) that modern body armour is more comfortable and flexible than ever.

In the last few decades, unlike the past where shields were made by combination of several material, shields had been made monolithic, usually of high hardness steel, but yet they are too unwieldy to be carried. Wees (2013) illustrated the Hektor and other heroes possess superhuman strength so they could easily carry shields that would be too burdensome for ordinary mortal. Thus, the demands to have lightweight shields for personal protections led to the study and discovery of alternative materials in crafting shields. Non-metallic materials, such as ceramics and composites, have been progressively incorporated into more efficient lightweight armours (Fawaz et al., 2004).

1.2 Problem Statement

At present, there are a lot of shields designed for law enforcement, but a shield for fire fighting purpose is yet to be designed and made. In fact, it is undeniable that the use of fire fighting shield will greatly reduce the risk of hazards faced by fire-fighters during fire rescue activities. A study done by Fahy et al. (2015) indicated a total of 64 fire-fighters was reported dead while on-duty in the U.S. in 2014. The two double-fatality fires, both occurred in apartment buildings are the largest multiple-death incidents occurred in U.S. in 2014. In one of those fires, there were two victims who caught in a rapid fire event and suffered from fatal burns while they were operating a hoseline. In another fire, two victims were trapped in the basement were primarily identified to suffer from fatality burns, and died of smoke inhalation. One additional fire which is also occurred in an apartment building had killed a fire-fighter who was trapped by rapid progress of fire while searching for dwellers in the high-rise building. Thus, a shield for fire fighting purpose literally provides the fire-fighters with a large coverage of protection against the failing high-heat structures or objects.

According to Cheuvront et al. (2008), a research done by military has demonstrated a significant decrease in performance and a greater physiological demands when individuals are required to carry excess weight for an extended period of time. The law enforcement equipped with excessive protection will have limited movement ability and they are most likely to struggle with the more important movements for survival purpose. They are decreased not only in tactical mobility, but in their velocity and acceleration as well (Lewinski et al., 2015). Therefore, lightweight raw material is sought in designing the fire fighting shield to ensure fire fighters retain their flexibility in their movements.

Another problem that can't be overlooked is no other than the ergonomics concept. There are three priorities in ergonomics and safety issues that are crucial for law enforcement, which are public safety, officer survival, and avoidance of litigation. The law enforcement serve and protect the public, guarantee their own safety, and make sure their actions do not create prosecution against themselves as well as the public. Therefore, to support the priorities as mentioned, the equipment used by law enforcement have to be effective, safe and reliable (Czarnecki & Janowitz, 2003). Ergonomic takes thorough consideration in physical, intellectual, social and ecological

parts of human exercises (Cañas & Velichkovsky, 1997). It is in particular responsible for the design and evaluation of shield to make it compatible with the working environment, needs and limitations of fire fighters. This is supported by Czarnecki & Janowitz (2003) in which an equipment has to be evaluated for its efficacy, reliability, risks for acute or chronic injuries, and associated risk for litigation.

1.3 Objectives

Based on the problem statements discussed above, the objectives of this study are:

1. To conduct a survey on the ergonomic factors in designing a fire resistance shield.
2. To design the concept of lightweight fire resistance shield according to customer requirements.
3. To analyse human factors in the handling of shield, and to perform Finite Element Analysis (FEA) on the shield.
4. To fabricate a lightweight shield prototype with fire resistance properties.

1.4 Scope of Research

The scopes of this research work are established based on the objectives mentioned:

1. The survey is done by interviewing at least twenty fire department officers stated in Malaysia.
2. The customer requirements are defined and translated into engineering characteristics for further design process development of fire resistance shield.
3. The suitability and comfort between manikin and shield is analysed by using RULA analysis, and the Finite Element Analysis is performed by using solidThinking Inspire software.
4. The prototype of fire resistance shield is fabricated.

CHAPTER 2
LITERATURE REVIEW

2.1 Types of Shield

Shields, as in any type of armour or weapon, developed and changed over centuries. They are also changed in shape and size, as well as the addition of special features to provide convenience and extra functions to the shield.

2.1.1 Capture Shield

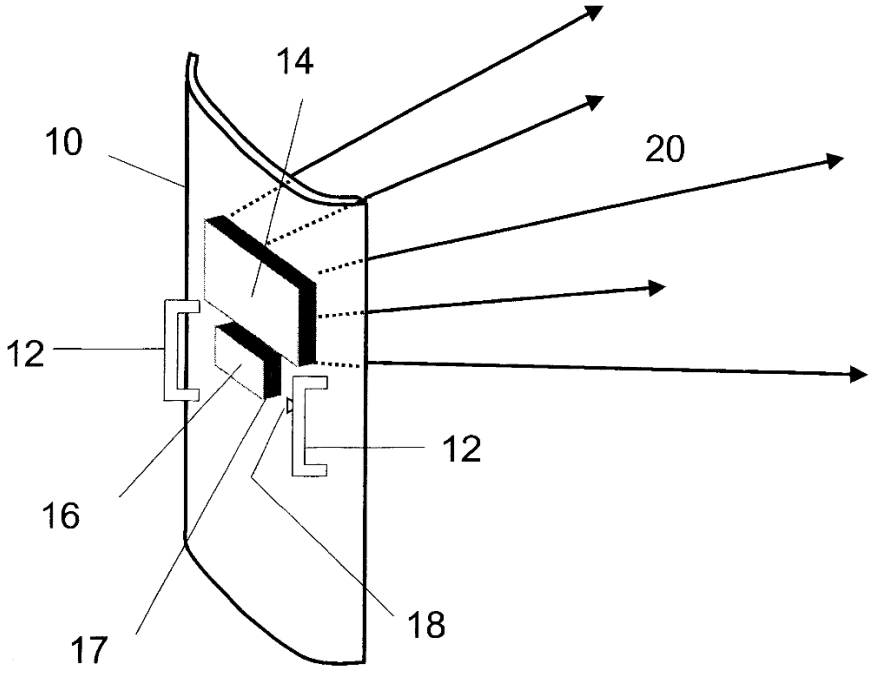

Figure 2.1: Capture Shield (Tocci et al., 2002)

Figure 2.1 shows the desired embodiment of the Capture Shield. Shield (10) is preferably to be made of clear and durable plastic, such as polycarbonate

or Lexan®. The shield (10) is equipped with sturdy handles (12). A light housing (14) is mounted on the centre of shield (10) and it is electrically connected to a power supply housing (16), with a main power switch (17). On one of the handles (12), a three position action switch (18) is mounted. When it is pressed, the LED array turns on with continuous light output (Tocci et al., 2002).

During the task of seizing an uncooperative, and perhaps armed criminal, officers can use a "capture" shield to pin the subject down. The capture shield which its edges curved outward allows the officers to entrap the struggling inmate against a wall or floor. The effectiveness of this capture shield to subdue an inmate is further enhanced through the high-intensity, broad-area light source to deter and disorient the inmate. This present invention uses a plurality of high-brightness light source arrays to provide a large area of high luminous intensity for visual response. The sudden burst of light source arrays will surprise the inmate and he or she may close his or her eyes, or to look away. This allows the officer to seize the chance to effectively tackle down the subject (Tocci et al., 2002).

Light-Emitting Diodes (LEDs) or lasers which both are of high-intensity level of brightness light sources offer few options to control dangerous situations. They bring a non-fatal means of force and give: (1) a language-independent, explicit warning, (2) psychological impact such as mental turmoil and fear, (3) temporary visual impairment, (4) mind disorientation and (5) great reduction of ability to perform sharp and violent confrontation (Tocci et al., 2002).

2.1.2 Ballistic Shield

Figure 2.2: Ballistic Shield (Front View) (Dovner, 2010)

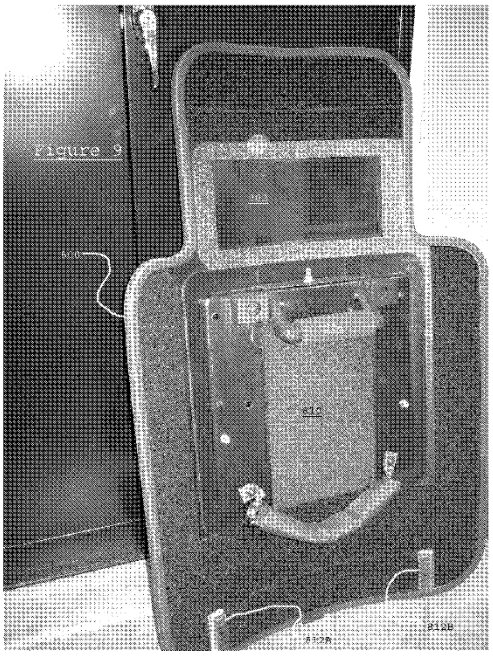

Figure 2.3: Ballistic Shield (Back View) (Dovner, 2010)

Figures 2.2 and 2.3 show the commonly used ballistic shield by law enforcement and military personnel. The shield comprises of an upper part

which a viewport, measure about 5.5 × 10 inches in size and made of transparent ballistic material such as polycarbonate is allocated to provide law enforcement personnel with visibility therethrough. The upper part has a width sufficiently wide to provide coverage to the head of user. The lower part of the shield is configured to protect the user body from ballistic harm. Its width is at least a torso of the user, which is simply greater than the upper part. In order to enable the shield to stand in an upright position by itself, this present invention of ballistic shield consists at least one connection position at the lower part of shield where foot can attach thereto.

The upper part of ballistic shield is configured to be centrally aligned in relation to the lower part. This is to facilitate ambidextrous use of shield by law enforcement personnel. This configuration permits user to deploy firearm and shield with either of their hands. The flanges designed at each side of intersection between the upper and lower parts provide support for firearm. The flange is configured at both sides of the shield so that either a left-handed or a right-handed user can utilize the shield well. As seen in these figure 2.2 and 2.3, the shield may also include battery-operated spotlights, handle, strap and padding to ease the user grip and manipulate the shield (Dovner, 2010).

The ballistic shield is needed during the event of ballistic threats such as bullet strike, shrapnel strike, or the like to minimize the risk of fatality and injury. However, ballistic shields are not impenetrable to all kinds of strikes as the possibilities depend on the various conditions and situations. The protective shields in modern ages now are to be claimed to have a reasonably light-weighted, and yet provide adequate resistance against ballistics penetration (Dovner, 2010).

2.1.3 Riot Shield

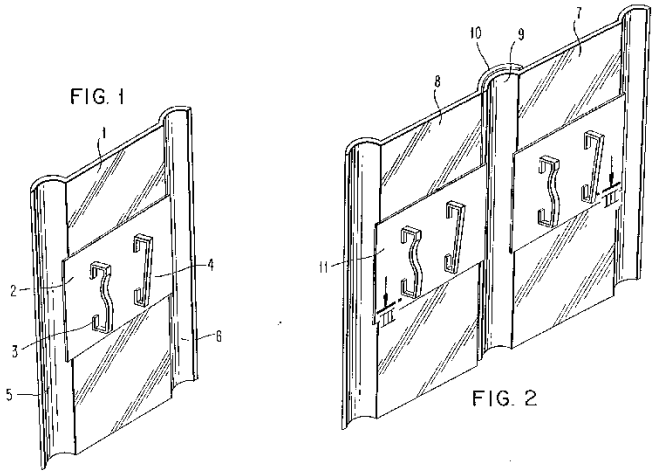

Figure 2.4: Riot Shield (Bauer, 1989)

Figure 2.4 illustrates the present invention of riot shield. A riot shield is essentially made of polycarbonate sheet with two handles secured at its back which allow the law enforcement personnel to carry it. Since the riot shield is made of polycarbonate material, it is lightweight, yet tough as well as shock and fire resistant. Moreover, polycarbonate material can be in transparent, thus allows officer to see through it the situation faced. These features have made it perfectly meet the requirements as a riot shield.

A single riot shield of this present invention can be combined with a plurality of other riot shields to form a strong and secure defensive wall against rioters. According to the conventional design of riot shield, there is no securing means to interlock the riot shields together to form a secure and strong defensive wall. The only way to keep riot shields together was to brace them against the ground. This form of defensive wall is vulnerable to rioters in large numbers if they strike violently and break through the defensive wall. Hence, this present invention of riot shield is configured with an open channel section integrally formed at both sides of the riot shield, which channel section opens towards the back of shield member. The locking means is to lie over its open channel section to the back of second riot shield and secure them together with clips located within the channel section (Bauer, 1989).