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CONCEPTUAL DESIGN APPROACH AND ERGONOMICS ANALYSIS OF FIRE RESISTANT PURPOSE SHIELD

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ABSTRACT

Shield was used as protection from danger centuries ago. Until this moment, there was still no shield available for firefighting purpose in safe and rescue operation. This factor has put a limit to firefighters, causing death to many victims who were in critical and dangerous situation. In this project, conceptual design will be proposed aimed to protect firefighters against fire and heat. The project was based on the existing design of Federal Reserve Unit (FRU) shield and innovated by adding the application of resisting fire. The methodology used are customer survey to fire fighters, house of quality in defining customers' needs, morphological chart in defining concepts, Rula-analysis in measuring ergonomic score and Pugh method for selection of best design. Carbon fibre was selected as the main material for the shield because it has a very low material density of approximately 1.75 g/cm3 and very high melting point of approximately 3500 °C. In Rula-Analysis, the ergonomics final score was 3. Results show that carbon fibre is appropriate for lightweight and fire-resistant shield. Ergonomics score of 3 for standing and kneeing position while holding shield is acceptable and further investigation can be recommended.

Keywords: rula-analysis, fire resistant shield, lightweight, high melting point.

INTRODUCTION

Throughout the years individuals have constantly attempted to protect themselves from their enemies, whether it was in the times of the stone age man, the Roman warriors or in our general public today. Shield is one type of body armour. Body armour is normally worn for delayed timeframes and over long separations amid military, police, law requirement, and security exercises. The historical backdrop of the body shield does a reversal to Stone Age which is a thousands of years ago. In the initially written history, body defensive layer was the Stone Age man's dress produced using thick animals' skin as covers up for protection. Later on shields made of wood or metal were utilized to protect the body. Chronologically, the main iconographical source representing without doubt Roman troopers with Italic oblong shields are reliefs from the Emilius Paulus landmark, dating to the mid-second century BC [1]. The shield and body armour is also being used by the Greeks. A study by Grant *et al.* [2] state that, significantly more than the noise and the dust storms raised by men and stallions, the blazing of bronze covering and weapons is normal for Homeric fight scenes. At the point when the Greeks outfitted themselves with caps, shields, corselets and lances, the splendor lit up the sky, and all around the earth channelled in the sparkle of bronze. After that, the use of body shield does goes back to 1931. In between 1971 and 1976 the National Institute of Justice put more than 3 million dollars into the development of body armour. However, very limited effort has been put in developing framework for firefighting shield. The armor against fire or heat will assist firefighters in saving lives through emergency and danger.

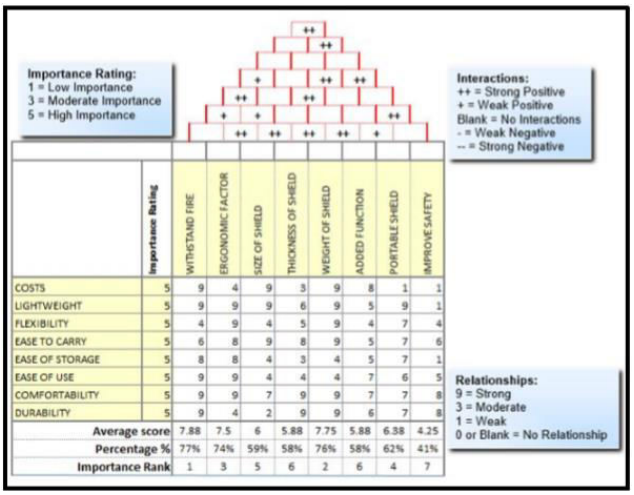
METHODOLOGY

The survey questionnaire is distributed to the members of Fire Department. It consist of 15 questions regarding the specific properties and description on how the shield should be developed. In house of quality, there are a few important steps such as Start Clarifying, Customer Needs, Interrelationship Matrix, Technical/Design Requirements, Technical Correlation Matrix andTarget Value/Specification [3]. First, the customers stress on four main characters which are cost, lightweight, flexibility and potability. This shield must also be lightweight as it can correlate with the flexibility and portability to ensure the users safety. Besides, this shield must be made to withstand flammability. Flammability is the main course in this project as it main target is to be used by firefighters in firefighting. The market segment for this shield is malaysian users. In general, anthropometric data shows that Malaysian are smaller and shorter compare to European [4]. This concept is also related to the size of shield that will be developed. The thickness of the shield must also be considered to withstand the extreme temperature. For Technical Correlation Matrix, we can relate those technical requirements. If the correlation is strong, the requirement

must be put as top priority. In the centre of House of Quality, there is a section that called Interrelationship Matrix. The main function is to establish the connection between the customer requirements and the performance design to improve the product quality. In following stage, Morphological Chart will be tabled to structure the problem for the synthesis of different components in fulfilling the same required functionality. Ergonomics score will be determined in RULA Analysis in designing ashield and analyze the suitability and comfort between manikin and shield in standing and kneeing position [7]. The process of designing a shield will be produce from conceptual designs.

RESULTS AND DISCUSSIONS

After the survey is being done, there were a few important data that collected and then included into the project. The questionnaire consist of fifteen questions that being gave to respondents which are the member of the Fire Department. All of the fire-fighters have height between 170 cm and 179 cm. 80% of respondents agreed that normal temperature of a burning house is between 600°C and 800°C. In terms of weight, 60% fo the respondents agreed that it must be below 2 kg, while the other 40% agreed that it must be below 4 kg. In overall, it can be said that the shield must be lightweight and has high melting point. From the House of Quality as shown by Figure-1, the customer needs discussed were cost, lightweight, flexibility, ease of carry, ease of storage, ease of use, comfortability and durability. The product features also consist of 8 things that can be considered. They were ability to withstand fire, ergonomics factor, size of shield, thickness of shield, weight of shield, the added function to the shield, portability and improve safety. If the relationship between the customer needs and the product feature is strong, the rating will be 9 while the moderate is 3 and 1 for weak relationship. If the requirement is not relateds, the rating will be 0. For the first customer needs, the first thing that the customer stresses was about the cost. As we can see, the relationship between cost with ability to withstand fire, size and weight of the shield was very strong. From this, it can be interpreted that shield must have ability to withstand fire and the cost can be very high. After that, the second customer needs was the lightweight shield. Lightweight shield had many strong relationships that rated 9 with the ability to withstand fire, ergonomics factor, size and the weight of the shield and portable shield.



	Importance Rating	WITHSTAND FIRE	ERGONOMIC FACTOR	SIZE OF SHIELD	THICKNESS OF SHIELD	WEIGHT OF SHIELD	ADDED FUNCTION	PORTABLE SHIELD	IMPROVE SAFETY
COSTS	5	9	4	9	3	9	8	1	1
LIGHTWEIGHT	5	9	9	9	6	9	5	9	1
FLEXIBILITY	5	4	9	4	5	9	4	7	4
EASE TO CARRY	5	6	8	9	8	9	5	7	6
EASE OF STORAGE	5	8	8	4	3	4	5	7	1
EASE OF USE	5	9	9	4	4	4	7	6	5
COMFORTABILITY	5	9	9	7	9	9	7	7	8
DURABILITY	5	9	4	2	9	9	6	7	8
Average score		7.88	7.5	6	5.88	7.75	5.88	6.38	4.25
Percentage %		77%	74%	59%	58%	76%	58%	62%	41%
Importance Rank		1	3	5	6	2	6	4	7

Figure-1. House of quality.

This means that the lightweight shield can be considered as prime factor that needed to be considered in the customer needs. Then, the other customer needs that need to be considered were the flexibility of the shield. From the Figure-1, we can see that the flexibility has strong relationship between the ergonomics factor and the weight of the shield. When the weight is increase, it hardens the shield. Next, the comfort ability and the durability of the shield must be considered. The strongest relationships were between the ability to withstand fire, the thickness of the shield and the weight of the shield. At the bottom part of the House of Quality, there were raw score, relative percentage and the importance rating that been shown. The product feature that had highest percentage and raw score were the ability to withstand fire, the weight of the shield and the ergonomics factor, while the safety improvement had the lowest percentage and raw score. Function analysis from House of Quality has been analyzed and the solution are diversified as shown by Table-1. From the possible solution, there were five selected concepts that will be developed and analyzed ergonomically using RULA Analysis. It can calculate and analyse the relation between human and the object that being used by them. It was to avoid ergonomic problems in the early planning stages of a production line and achieve more satisfactory planning and design. The human that being used in ergonomics simulations was an Asian man. Specifically, the man that been used was Japanese and there were two position that being considered when using the shield which were standing and kneeing. The results of the simulation are shown by Figure-3 and Figure-4.

Table-1. Morphological chart.

Parameter	Possible Solution		
Shield Type	Regular	Slide-In	Flip-Able
Shield Design	Rectangular	Round/Oval	Curvature
Outer Body Material	Fibre	Steel/Metal	Polymer
Shield Stand Material	Fibre	Steel/Metal	Composite
Shield Handles Material	Polymer / Plastic	Steel/Metal	Wood
Ergonomics Concepts	Malaysian People	American People	European People

Table-1. shows the measured and calculated value for below synchronous speed mode. From the table, it can be seen that measured values confirmed the calculated values. A very small deviation of 1% in torque measurement arises because the software MATLAB/Simulink is not a real-time system.

Figure-2. Concepts from morphological chart.

Figure-3. Manikin in standing position.

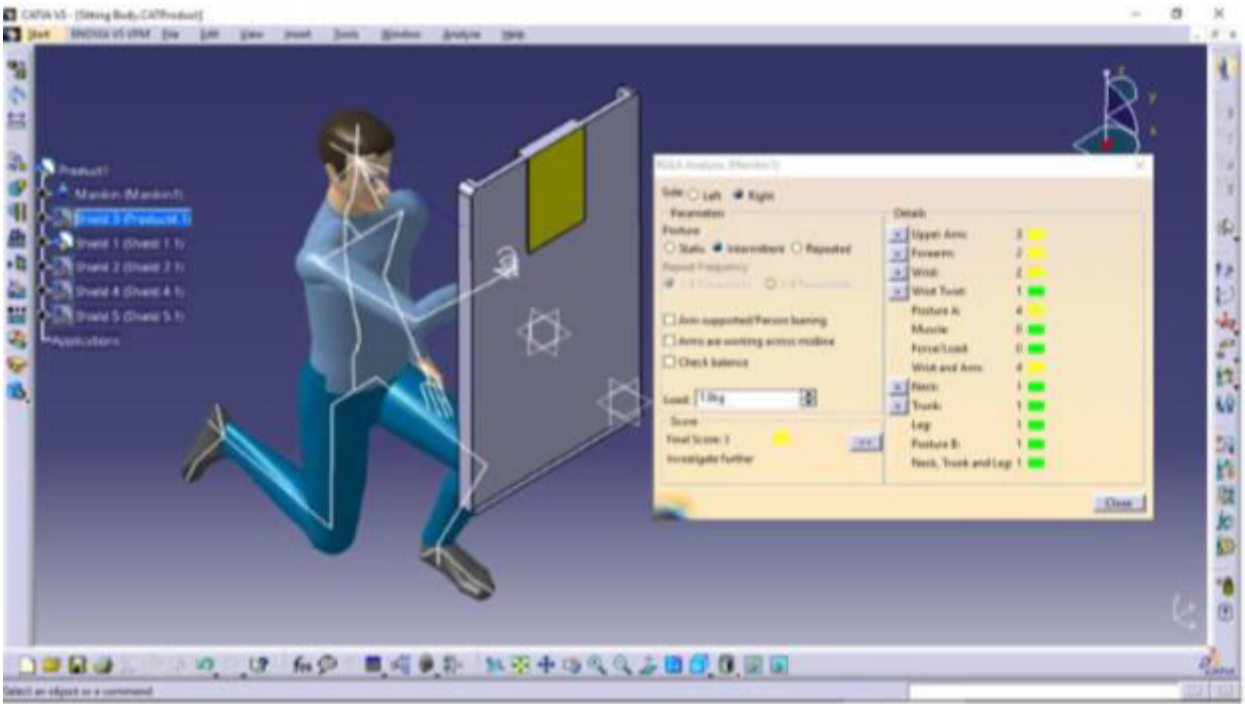


Figure-4. Manikin in kneeing position.

Based on analysis, the selected conceptual design of shield is a regular type with curvature shape. The material for the outer body is carbon fiber and the handle is made by plastic/polymer. Carbon fiber is a type of material with low density (1.75-1.93 g/cm3) [6] and high melting point [7]. Thus it is a very suitable material to be used for fire resisting. The value of the final score for both shield were 3. The maximum loads weight was set as 2kg and proper posture was intermittent. In the details, we can see where the body parts that affected when the shield was being hold. The majority of the colour indicators were green among all body parts except upper arm, forearm, force/load and wrist and arm. This was due to the shield is being hold with the hand and although 2kg seems light, but if the shield was being used for a long time, there will be muscle strain at wrist and arm.

CONCLUSIONS

The first objective was to conduct a survey on ergonomics factor in designing firefighting shield. The survey was done by interviewing respondents whereby all of them are firemen. The questionnaires were about the suitability and requirements that needed by firemen in order to get the proper and functional shield so that they can use it to protect themselves from heat and fire. The second objective was to analyze the suitability and between manikin and shield using CAE. The meant by comfort is the ergonomics or human factor when using the shield. The simulation was being done by using Catia V5 software as it can calculate and analyze the relation between human and the object by using RULA Analysis. The human builder that being used in the simulation was a Japanese man and there were two positions that being chose which were standing and kneeing. The posture that being chosen is intermittent as the movement was occurring at irregular intervals which are not continuous or steady. The third objective is to design and fabricate the shield with the lightweight and fire and heat proof material. Five conceptual designs were drawn which all of them were having different designs and specifications such as the shape and material selection. The most recommended design was the rectangular shape shield with carbon fiber as the body material because it has low density 1.75 g/cm3 and high melting point of about 3500°C. The mass of the shield was around 1.9 kg and the target for the shield to be less than 2 kg was achieved. For future works, it is recommended to do structure analysis using topography optimization [8] in finding stress distribution at every point of the shield.

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