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Procedia Engineering 43 (2012) 374 – 378

Procedia Engineering

www.elsevier.com/locate/procedia

International Symposium on Safety Science and Engineering in China, 2012 (ISSSE-2012)

Design Feature Analysis and Pilot Ergonomic Evaluation for Protective Fire Gear

Constance Luo[a,*], Janet Jin[a]

[a]*Honeywell Safety Products, #430 Libing Road, Shanghai 201203, China*

Abstract

Well established fire suit is usually constructed by several layers to provide protection against many hazards on fire ground. This kind of fire gear system has some side-effects such as lowering the operating efficiency and flexibility of firefighters. Fire gear manufacturers have been continuously trying to improve the mobility and comfort of fire suits without sacrificing protective performance by optimizing designs, structures and materials etc. Many attempts have been made to understand human body structure and movements and further optimize the designs to improve the flexibility and mobility of firefighters. As partial results of a comparative study, the ergonomic design features such as "tail coat", "ergonomic under arm bellow", "contoured knees", and "F. R. O. M crotch" that theoretically benefits the movements of firefighters were analyzed in this paper. The differences and benefits of those ergonomic designs were analyzed and evaluated by comparing with traditional cut design. Distinguished ergonomic design features improved the range of motion (ROM) - mobility and flexibility of the wearers.

Keywords: Fire suit, Ergonomic design, Range of motion

1. Introduction

Firefighting is one of the most dangerous and physically demanding operations, requiring firefighters to perform energy-consuming activities with efficiency, while being exposed to numerous hazards. The most common hazards are as follows: heat hazard (flame, radiant, conductive and convective heat), which may cause heat stress, burn injury; physical hazard (impact, electrical shock, debris and rough surfaces) may lead to physical damage to protective clothing and body injuries; liquid, chemical, radiological and biological hazards may break through garment barrier, resulting in clothing contamination and direct body contact [1]. At early 1930s the standard clothing for firefighters was rain coat with rubber boots. The protection provided therefore was very limited. With the development of technologies, more and more advanced materials were applied to fire gear, e.g., aramid, PBO fiber, PTFE membrane etc. Revolutionary changes have also been witnessed on the clothing design, from single-layer raincoat to multi-layer 2 pieces fire suit, so as to provide protection against different hazards that may occur on fire ground. Well established protective clothing for firefighters nowadays is usually comprised

* Corresponding author. Tel: 86-21-28942632, Fax: 96-21-60756582
E-mail address: constance.luo@honeywell.com

1877-7058 © 2012 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2012.08.065

of a multi-layer system including outer shell, moisture barrier and thermal barrier. Outer shell mainly contributes to physical protection; moisture barrier is for liquid barrier protection; while thermal barrier plays the key part of heat insulation. The whole multi-layer system is capable of providing good protection against major hazards for firefighters. However, protective clothing with multiple-layer may also have some side-effects for firefighters such as lowering heat sensation, decreasing mobility and flexibility and increasing muscular strain etc [2]. On fire ground, responses delayed in seconds due to lack of mobility and flexibility can cause injuries and lives [3]. It is always a challenge to make protective clothing capable of facing different kinds of hazards while being breathable, lightweight, and flexible for wearers to move and operate efficiently and feel comfortable. Lots of experts have poured energy on research of material development, garment/material construction modification, garment design, cross functional technology application etc. to address the challenges. Many attempts have been made by major fire gear manufacturers such as Morning Pride®, Sperian®, Lion® to optimize the designs. Products released were also claimed with ergonomic features to grantee enhanced operation efficiency, comfort and fit for firefighters. Lots of patents were filed with innovative garment construction or design features by manufacturers in North America, such as firefighter's garments having enhanced flexibility and minimum weight (USRE35436) [4]; buttock region of a pair of firefighter pants (US00D581133S) [5]; protective clothing with tapered pockets (US007784109B2) [6]; height adjustable protective garment (US007168103B2) [7].
This study is focusing on analysis ergonomic design features, as well as the design differences and effectiveness for improving mobility and flexibility of "Ergonomic" fire suit by comparing with" Traditional" fire suit.

2. Ergonomic design features analysis

Traditional cut fire suit were constructed by three layers with standard features such as: front closures of jacket and pants fly, pockets at various locations, high visibility trim configuration were also applied. Complains of fire suits being too heavy and inflexible were captured from firefighters of different fire departments in a council meeting held by Honeywell First Responder in June of 2010 in Dayton, Ohio [8]. Major fire gear manufacturers were trying to provide fire suit with innovative ergonomic design features without changing major materials to improve the flexibility and mobility [9]. In a study completed in 2011, the authors made a comparative evaluation of a series of fire gear. In this paper, the analysis of some well accepted ergonomic design features such as "tail coat", "ergonomic under arm bellow", "contoured knees", "F.R.O.M crotch" that theoretically benefits the movements of firefighters were reported. The differences and benefits of ergonomic design were analyzed and summarized by comparing with traditional cut design. Evaluation method and results of ROM 1-5 correlated with all ergonomic features analyzed as follows were presented in section 3.

2.1 Ergonomic tail coat

To lower the burden of garment weight "Tail jacket" design was created (as show in picture 1 - left). It has been registered as a trademark as "Tail^{TM} system" which is a well recognized ergonomic design in North America market. This design is claimed to be built based on deep understanding of human backbone structure that guarantees 95% of all mid-body flex occurs to the front (causing rear body extension only), and the operating protective needs of firefighters [10-1]. Since it is body extension that can cause a protection gap between coats and pants in certain body positions, this implies coats can be worn much shorter in front than in the rear. Shortening the non-functional front and keep the same back length, coat front reduces garment weight between 18%-25%, improves ventilation, allows unrestricted upper leg mobility, and fights fire fighter stress [10-2]. Theoretically, tail construction was proved to be an anti-stress clothing system concept. As shown in figure 1, it's easy to identify the dimension and weight benefits of tail design (left) by comparing to traditional cut design (right). Improvement of mobility and flexibility can be further verified by measurement in certain static position of wearers like hip extension in figure 5, ROM 1– measuring maximum angle when bending forward and backward.

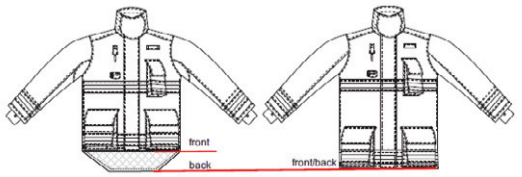

Figure.1. Tail jacket Vs Traditional cut jacket

2.2 Ergonomic underarm bellow