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An experimental study on the ergonomics indices of partial pressure suits☆

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ABSTRACT

Partial pressure suits (PPSs) are used under high altitude, low-pressure conditions to protect the pilots. However, the suit often limits pilot's mobility and work efficiency. The lack of ergonomic data on the effects of PPSs on mobility and performance creates difficulties for human factor engineers and cockpit layout specialists. This study investigated the effects of PPSs on different ergonomic mobility and performance indices in order to evaluate the suit's impact on pilot's body mobility and work efficiency. Three types of ergonomics indices were studied: the manipulative mission, operational reach and operational strength. Research results indicated that a PPS significantly affects the mobility and operational performance of the wearers. The results may provide mission planners and human factors engineers with better insight into the understanding of pilots' operational function, mobility and strength capabilities when wearing PPS.

1. Introduction

Flying high-performance fighters like supersonic cruise and super-agility airplanes has created greater demands on the protective capacities of a partial pressure suit (PPS), which leads to an increasing conflict between its function and efficiency (Færevik and Eidsmo Reinertsen, 2003; Murray et al., 2011; Rudnjanin et al., 2006). The integration of protective functions, such as compensation, anti-gravity, anti-penetration and cold-resistance intensifies, may affect the impact of a PPS on pilot's efficiency (Albery and Chelette, 1998; Alexander and Laubach, 1973; Zhang, 1999). Therefore, ergonomics research on PPSs has been focused on effectively ensuring the efficiency of a PPS without reducing its protective capacities.

So far there have been only a few ergonomics studies on PPSs, and no ergonomic evaluation index system has been developed. However, a PPS is only one kind of protective suit and thus the study of PPSs can also use the experiences developed for other types of protective suits for reference (Abramov et al., 2005; Aghazadeh and Rajulu, 2006; Chang et al., 2007; Havenith and Heus, 2004; Huck, 1988; Liu et al., 1998; O'Hearn et al., 2005; White et al., 1994). Ergonomics research on protective suits can be divided into three main categories: subjective investigation, objective testing and numerical simulation. Among them, subjective investigation is the most traditional. It is carried out by analysing questionnaires and the subjective reflections of the subjects. White et al. (1994) studied the influence of U.S. Air Force Advanced Technology Anti-G Suits (ATAGS) and U.S. Navy Enhanced Anti-G Lower Ensembles (EAGLE) on pilots' operating performance by questionnaire. Based on the results, they improved the functions of the protective suit. Subjective investigation is easy to carry out, but is subject to both subject and contextual bias, which makes the data less precise. With the development of technology, ergonomic studies of protective suits have transformed from qualitative analysis to quantitative studies. Objective ergonomics research falls into two categories: human mechanics (flexibility, power, etc.) and manipulation performance. Adams and Keyserling (1993) and Coca et al. (2008) studied the effect of protective suits on the flexibility of wearers by using a goniometer and a flexometer to collect data on range of motion. However, the precision of this method can be influenced by the variability of operators collecting the data. O'Hearn et al. (2005) analysed the impact of Army cold winter clothing on soldiers' agility and gait characteristics by applying a three-dimensional video-based motion capture system, which can record human moving trajectory and achieve data on range of motion and gait characteristics. Albery and Chelette (1998) designed an experiment in which subjects tracked a simulated "bogey" aircraft on a visual

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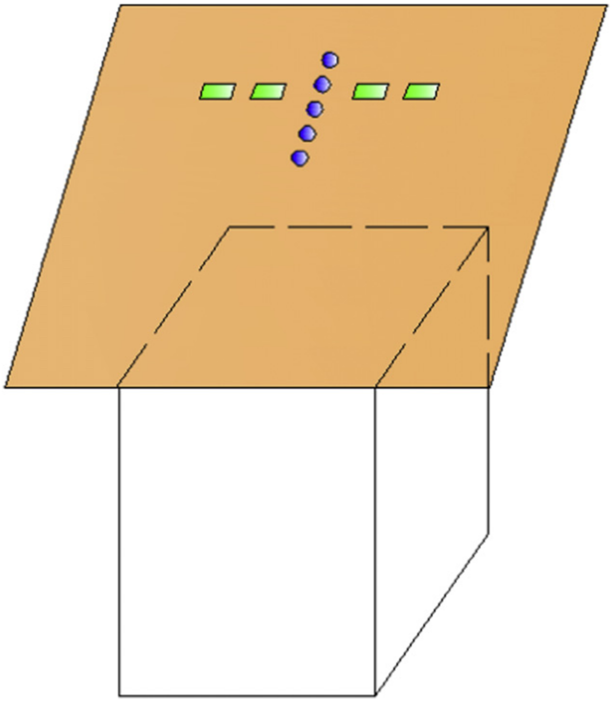

Fig. 1. Target-pointing board.

display and performed a secondary task to test the effect of G suit type on cognitive performance and found that more advanced protective systems not only allowed longer G endurance, but provided adequate support for maintained cognitive performance throughout the extended exposure. Moreover, advances in computer technology have enabled numerical simulation to be used in ergonomics studies of protective suits. This method studies the ergonomics of protective suit by using a digital human model and a personal protective equipment model. Kozycki (1998) and Kozycki and Gordon (2002) developed a modelling and simulation approach to examine the encumbrance of helicopter aircrew clothing and equipment. He compared the results of the simulation with that of a three-dimensional motion capture system and proved the feasibility of his numerical simulation method. However, this method is a work in progress and needs to be improved. Although there have been many investigations on the ergonomics of protective suits, systemic ergonomics evaluations and indices system of protective suits, considering body mechanics, the vehicle and the environment, has not been studied so far.

The aim of this study was to develop an ergonomics evaluation and indices system for PPSs based on the analysis of pilot motion range, operational performance and operational strength. The research on range of motion, including joints' moving angles, accessible domain, etc. while pilots were performing various operating tasks, was measured by a three-dimensional video-based motion capture system. Operational performance was judged by performance of specific flight tasks. Operational strength was assessed by measuring the power provided by the hands and feet. Based on the results, this work established a system for evaluating PPSs ergonomic design and for testing improvements. It also provides a reference for mission planning and the man-machine interface design of airplane cockpits.

2. Methods

2.1. Subjects

A total of twenty-one Chinese male undergraduate students with an average age of 23.14 years (range 21–25) were enrolled in this study. The average height and weight were 169.48 cm (range 165–175 cm) and 62.52 kg (range 56–77 kg) respectively. The subjects were all right-hand dominant and were chosen carefully to ensure that their body-sizes met the requirements of a PPS (Hu et al., 2008). All subjects had knowledge of PPSs and flight missions. Their physical condition met the experimental requirements, including no physical disability or limitations and no case histories of heart and lung problems. They were also informed beforehand of the purpose of the study, the nature of the test conditions, the experimental procedures, and the risks associated with the study. Before testing, all subjects were trained to a given criterion of performance and to be familiar with the experimental tasks.

2.2. Apparatus

The apparatus used in this study included a three-dimensional video-based motion capture system, a target-pointing board, a hand dynamometer, and a step-tread apparatus. The three-dimensional video-based motion capture system (VICON460) is composed of six video cameras with a sampling frequency of 120 Hz, and corresponding accessories. This system was used to

Fig. 2. Step-tread apparatus.