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Effect of body-borne equipment on injury of military pilots and aircrew during a simulated helicopter crash

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ABSTRACT

Military helicopter pilots are expected to wear a variety of items of body-borne equipment during flight so as to be prepared for any situation that may arise in combat. Helicopter seats are designed to a specified weight range for an occupant with equipment. This paper investigates how distributing the equipment on the body affects injury potential during a helicopter crash. A finite element model representing a helicopter seat with a fully deformable 50th percentile Hybrid III carrying equipment was developed. The model was subjected to a standard military certification crash test. Various equipment configurations were investigated and analysed to determine its influence on the risk of injury. It was found that placing the equipment low on the torso, i.e. near the thighs, not only reduces the likelihood of injury in the lumbar, spinal region but also provides favourable results in neck and head injury risk when compared to other configurations investigated. In contrast, placing equipment high on the torso, i.e. close to the chin, increases the lumbar load and implicitly, the risk of head injury. A statistical analysis is carried out using the Wilcoxon Signed Rank Test to deliver probability of loads experienced within a certain interval. This study recommends an equipment configuration that improves survivability for an occupant seated on a fixed load energy absorbing seat which is subjected to Military Standard 58095A Test 4.

1. Introduction

Combat environments have evolved over the years, placing troops in a number of new and different combat situations. This has directly led to the advancement in military personnel equipment to ensure that troops are prepared for any new scenarios. When those personnel are flying in helicopters, equipment is placed on the body not only with an emphasis on easy accessibility but also an even distribution of the load during flight to minimise cumulative loading. Helmet loads during simulated day and night flights have been studied comprehensively (Forde et al., 2011; Navy upgrading its aircrew, 2013). However, understanding the load distribution on other parts of the body and how it affects injury criteria in a helicopter crash is largely unknown. The majority of equipment carried by personnel is placed inside a primary survival gear carrier (PSGC), which sits over the top of the flight suit and the body armour on the upper torso. Inside the PSGC are placed the medical supply kit, ammunition, air bottle, radio, flashlight, survival knife and emergency signal mirror and other equipment as demonstrated in Fig. 1. Equipment weight varies, normally in the range 5 kg–30 kg, depending on what is considered essential to a specific mission (13-1-6.7-2 Aircrew, 2007). Australian Defence Personnel, use a Modular Lightweight Load Carrying Vest (MOLLE), which allows them to position pouches carrying equipment at any position, they prefer.

Keywordsabbreviation: PSGC, Primary Survival Gear Carrier; JSSG, Joint Service Specification Guide; VPS, Virtual Performance Solutions; ATD, Anthropomorphic Test Device; FTSS, First Technology Safety Solutions; COG, Centre of Gravity; NIJ, Neck Injury Criteria; NTE, Neck Tension/Extension; NTF, Neck Tension/Flexion; NCE, Neck Compression/Extension; NCF, Neck Compression/Flexion; HIC15, Head Injury Criteria.

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In a helicopter crash, where the seat undergoes vertical loading, the design of a crashworthy seat requires that it is able to absorb the energy through a stroking load limit mechanism. This mechanism allows the seat and the occupant to move at loads that are just under the humanly tolerable limit, and over the maximum distance between the seat pan and the cabin floor. The seat is designed in terms of a specified range of occupant mass and can provide limited protection only within its designed energy absorbing capability (Desjardins, 2003). If the equipment causes the mass to increase outside the design range, a phenomenon called bottoming out will occur at the end of the stroke. Bottoming out occurs because the seat reaches its full stroking distance before the total impact energy is absorbed, resulting in the potential for a more extreme impact load and increasing the likelihood of injury. How the additional mass effects bottoming out is illustrated in a crash of a Sikorsky S-92 helicopter in which four seats bottomed-out (Transportation Safety Board of Canada (2009)). In this case, the initial vertical load factors experienced most likely exceeded 8.6 g, the seats designed limit, but were within the human tolerable limit. The primary cause of death in this situation was drowning. If this impact was to occur on land, it could be assumed that the passengers would have most likely survived with a bottoming-out load this low.

Injury from helicopter crashes can occur from a number of sources including inertial forces from excessive acceleration, blunt impact and direct contact with the vehicle, and exposure to environmental conditions such as a post-crash fire (Pellettiere et al., 2011). According to a survey that reviewed 156 US Army aviation accidents from 1983 to 2005, head/neck injury was the largest frequency with 87%, followed by injury to the spine/pelvis (83%) and to the heart/aorta (46%) (Barth and Balcena, 2010). Another review of mishap data was collected in which 917 A-B Department of Defense rotorcraft mishaps were studied covering 3800 occupant exposures. It was noted that in the Army data, the majority of fatalities had injuries to the chest, head and neck while those with only major injuries had a prevalence of upper and lower extremity injuries (Mapes et al., 2008).

Injury measurement guidelines are defined by the Federal Aviation Authority (FAA) for civil aircraft (Code of Federal Regulations) and in the Joint Service Specification Guide (JSSG) for the United States Department of Defence (DoD JSSG-2010-7, 1998). These guidelines propose a tolerance level, developed through physical testing or analysis to provide limits of human tolerance, which provides a criterion for measuring injury risk. The major areas of injury defined in these guides are related to the lumbar spine, chest, neck and head. Aircraft passenger and crew seats must complete defined dynamic tests including drop tower tests and sled tests in order to be certified. Drop tower tests use a pulse generator such as a honeycomb sandwich panel to mimic the deceleration characteristics of the cabin floor relative to the seat when it is dropped from a predetermined height to reach the intended velocity (Chiba et al., 2014; Polanco and Littell, 2011). Sled tests apply the pulse directly to the bottom of the seat in a similar way via a propulsion method (such as bungy cords) to propel the seat to the desired velocity, which is then decelerated by the impact of honeycomb sandwich panels or hydraulic compression.

Fig. 1. An aircrew survival vest used by helicopter pilots (Navy upgrading its aircrew, 2013).

Experimental crash testing of human test subjects or crash test dummies at injury causing loads provides the ultimate validation of design effectiveness for injury risk reduction. Such methods can be ethically unsuitable or simply commercially unavailable for multiple tests. A complimentary method of analysing injury criterion of an occupant in a vertical impact crash is using crash software that utilises the explicit finite element method. For analysing a wide range of scenarios, this method is more cost effective, more time optimal, and allows detailed examination of performance not always in real life testing. Various studies have analysed seated dummies and their responses in a simulated vertical crash, with models that can vary from very simple rigid body models to very complex and detailed deformable models. Richards & Sieveka (Richards and Sieveka, 2011) modelled a UH-60 Blackhawk pilot seat. In this model, a generic floor mounted seat with rear struts supporting two guide tubes and a simple bucket were utilised and a spring device resisting the motion represented the fixed load energy absorption device. A more complex seat model for an agricultural aircraft was developed where an energy-absorbing device was modelled in LS-DYNA (Mathys and Ferguson, 2012). During the stroke, the seat slides downwards along the rails and crush the energy absorbing tubes against the fixed collars. Both studies used representative dummy models that allowed them to analyse injury during a simulated vertical crash.

A number of studies have been completed on seated dummies in landmine blasts, underwater shock and injury from aviation helmet neck loading and load carriage during walking. Further studies have been completed on the functional performance of a soldier in full chemical and biological protection. (Cheng et al., 2010; Mathys and Ferguson, 2012; Pal et al., 2014; Malapane and Shaba, 2001). However, research is limited on the effects of body-borne equipment on injury in a helicopter crash. Richards & Sieveka (Richards and Sieveka, 2011) completed a preliminary analysis of the effect of personnel equipment on injury during a helicopter crash. They used an ellipsoid Hybrid III Anthropomorphic Test Device (ATD) with a rigid lumped mass located at the centre of the sternum to represent equipment. The authors found that the lumbar load increased by at least 19% for a 50th percentile aviator to a maximum of 60%. Only the influence of one rigid upper torso equipment mass on lumbar load was considered in this study, as the major focus was the effect of various energy absorption devices used by helicopter seat manufacturers. The study concluded that lumbar load will increase with added upper torso mass. It also recommended the need for more thorough analysis including the effect of various mass properties of equipment and location to determine their influence on the major injury criteria defined by the FAA and in the JSSG. Another study completed by Aggromito et al., 2014 used a 7-degree of freedom (DOF) mass spring damper analytical model to analyse a human during a simulated helicopter crash and found that increasing equipment mass has negative effects on the onset of bottoming-out, and the forces experienced at the pelvis, upper torso and head. Both studies were limited in their analysis, indicating the need for a three-dimensional analysis. To analyse the effect of equipment on the forces on a seated person in greater detail, equipment needs to be located at a variety of locations on the body.