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Effects of body-borne equipment on occupant forces during a simulated helicopter crash

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ABSTRACT

Helicopter seats are designed to a specified mass range including equipment and can only provide limited energy absorbing protection within its designed energy absorbing capability. Over recent years, military occupants have been required to carry increasing amounts of equipment, which may affect the probability of injury during a crash. To investigate the effects of increasing equipment mass during a helicopter crash on injury, a linear 7-degree-of-freedom mass–spring–damper model is developed to simulate an occupant wearing body-borne equipment on a crashworthy helicopter seat. A fixed load energy absorption mechanism is also included in the model. To examine the effects of equipment attachment types, the mass bodies representing the equipment are attached with a spring and damper, with low and high stiffness values indicating loose and tight attachment respectively. Dimensional analysis shows that the maximum forces are proportional to the initial impact velocity prior to stroke. The results demonstrate that increasing the equipment mass reduces the seat's capability to absorb the total impact energy at higher initial impact velocities. The safe velocity, the velocity that prevents bottoming out, reduces from 10.2 m/s, for an occupant without equipment, to 7.4 m/s for an occupant with an equipment mass of 40 kg at the lower and upper torso and 2 kg at the head. When the equipment mass is 40 kg at the hip and at the upper torso and 2 kg at the head, a maximum increase on the underside of the pelvis of 173% is measured, providing an increased possibility of injury in the lumbar region. Increases of 321%, 889% and 335% on the maximum forces on the hip, upper torso and head respectively create the potential for contact injury at the hip, upper torso and head from equipment and more than a 50% chance of spinal injury. The results show that increasing equipment mass significantly increases the potential for injury at the lumbar, hip, upper torso and head.

Relevance to industry: Relevance to industry: Military pilots today are required to wear a vast amount of equipment, that exceeds the weight limit of crashworthy helicopter seats. This paper demonstrates the disastrous effects of wearing large amounts whilst seated on a crashworthy helicopter seat in a simulated helicopter crash.

1. Introduction

In a helicopter crash, a crashworthy seat is designed to absorb the energy through a stroking load limit mechanism. This mechanism allows the seat and the occupant to move at loads just under the humanly tolerable limit, over the maximum distance between the seat pan and the cabin floor (Coltman, 1994). The seat is designed in terms of a specified range of occupant mass and can only provide limited protection within its designed energy absorbing capability (Desjardins, 2003). Military Standard-58095A (1986) is the standard used for aircrew seat design. It sets the condition that a crashworthy seat must be designed to carry an occupant with 5 kg of equipment during a crash. Current body-borne equipment can exceed six times that depending on mission type (NAVAIR 13-1-6.7.2, 1999). If the increased mass causes the impact energy to be excessive, a phenomenon called bottoming out will occur at the end of stroke. Bottoming out occurs, because the stroke is initiated at lower acceleration and causes the seat to reach its full stroking distance before the total

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Abbreviations: DOF, degrees of freedom; ATD, anthropomorphic test device; EQM, equations of motion.

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impact energy is absorbed resulting in the occupant potentially experiencing a significantly higher impact load and increasing the likelihood of injury. The effect of weight on bottoming out occurring and the subsequent extreme loads experienced by an occupant are illustrated in a crash of a Sikorsky S-92A helicopter, where 17 passengers died of drowning. It was found that four seats bottomed out due to the weight of the individuals. All occupants on seats excluding those that bottomed out experienced inertial vertical load factors of between 5.3 g and 8.6 g, however, the individuals on seats that bottomed out experienced inertial vertical load factors that most likely exceeded 8.6 g (Transport Safety Board of Canada, 2009).

Lumped parameter models consider the human body as several concentrated masses connected by a spring and damper and are the simplest method to represent the human body (Liang and Chiang, 2006). A four-degree of freedom (DOF) model developed by Payne and Band (1971) was used in vertical vibrations for seated occupants and based on the one-DOF system developed earlier by Payne and Stech (1969), which used one mass body to represent the human body. Adding to that model, they added the viscera, the buttocks and a head to more accurately represent the specific mass bodies of the human body. The parameters of the model were selected by matching relevant available data from vertical drop tests and calculating the driving point impedance characteristics. Similarly, Wan and Schimmels (1995) developed a four-DOF model with the same mass bodies, however the viscera is attached to both the upper torso and lower torso. This model was considered in a literature review by Liang and Chiang (2006) to provide the greatest accuracy with experimental values in Boileau and Rakheja (1998) in seat to head transmissibility, driving point impedance and the apparent mass.

A number of studies have been completed on seated occupants in landmine blasts, underwater shock and injury from aviation helmet neck loading (Wang and Bird, 2000; Zong and Lam, 2002; Dong and Lu, 2012; Mathys and Ferguson, 2012). However, research is limited on the effects of body-borne equipment on injury in a helicopter crash. Richards and Sieveka (2011) developed a model using the software MADYMO to investigate lumbar loads with increasing equipment mass. The occupant was modelled as an ellipsoid Hybrid III Anthropomorphic Test Device (ATD) with a rigid mass on the upper torso to represent equipment. The addition of 30 lb of equipment mass resulted in a predicted 61% increase in lumbar load. Only the influence of rigid upper torso equipment mass on lumbar load was considered. Furthermore, the effect of equipment attachment types on loading and loading paths was not considered in Richards and Sieveka (2011).

To be able to fully analyse the effect of body-borne equipment on the forces on an occupant, equipment needs to be located at the hip, upper torso and head and attachment types need to be examined to investigate the influence on the loads.

The objective of this study is to determine the forces as a result of increasing the equipment mass on an occupant seated on a crashworthy seat during a helicopter crash. A four-DOF occupant model is used to represent a seated occupant. Equations were devised to represent the force control of a crashworthy seat utilising a fixed load energy absorption (FLEA) device. Equipment was attached at the hip, upper torso and head with a spring and damper, and the spring coefficient was varied to examine the effects of loose and tight attachment types on the forces and loading paths on the occupant. Using a simple numerical procedure with a transient analysis, the model was solved by the Fourth-Order Runge–Kutta method in MATLAB used in the ODE45 function.

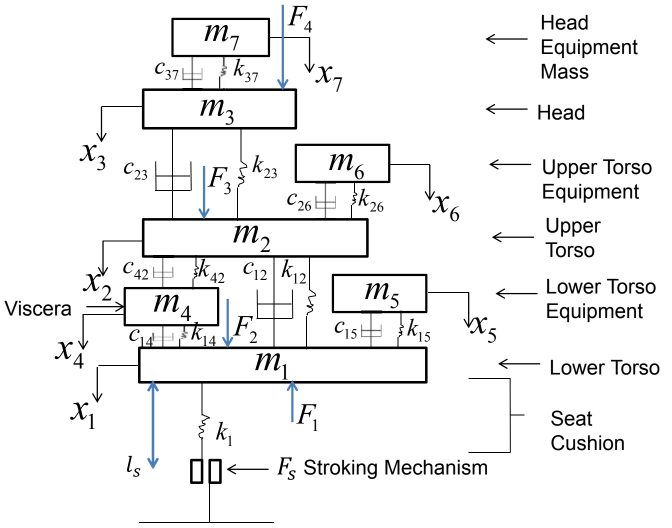

Fig. 1. Occupant model with equipment attached.

2. Biodynamic occupant model with equipment

2.1. Occupant model

The occupant model is a four-DOF mass–spring–damper model that closely replicates that proposed by Payne and Band (1971) and Wan and Schimmels (1995), see Fig. 1. The occupant is represented by 4 mass bodies, the lower torso (m_1), upper torso (m_2), head (m_3) and viscera (m_4). The spring coefficient is represented by k and the damping coefficient by c. The subscript values following the spring and damping coefficients are used to represent the masses it connects. For example, k_{12} joins m_1 with m_2. The viscera is identified as one of the most important subsystems, when excited in the sitting position as under the influence of longitudinal vibration the abdominal mass vibrates in and out of the thoracic cage. A spring and damper characterizes the spinal column and connects the upper torso to the lower torso. To accurately calculate spinal response and the force from the helmet on the head, the upper torso and the head are considered as two mass bodies also connected by a spring and a damper. The pelvis and the seat are identified as one mass body and is the major difference from the model in Wan and Schimmels (1995), with the seat cushion represented as a spring with non-linear characteristics. The mass, stiffness and damping properties were determined from the models proposed by Payne and Band (1971) and Wan and Schimmels (1995). The occupant has an effective mass of 62.5 kg which is based on a 50th percentile male occupant. The model parameters are presented in Table 1.

Table 1
Occupant parameters.

Item	Location	Value
m_1 (kg)	Lower torso	35
m_2 (kg)	Upper torso	17.5
m_3 (kg)	Head	4.5
m_4 (kg)	Viscera	5.5
k_{12} (kN/m)	Lower torso–Upper torso	150
k_{14} (kN/m)	Lower torso–Viscera	2
k_{23} (kN/m)	Upper torso–Head and neck	160
k_{42} (kN/m)	Viscera–Upper torso	12.5
c_{12} (kN s/m)	Lower torso–Upper torso	0.81
c_{14} (kN s/m)	Lower torso–Viscera	0.05
c_{23} (kN s/m)	Upper torso–Head and neck	0.424
c_{42} (kN s/m)	Viscera–Upper torso	0.131