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A study on the modeling and analysis of a helicopter's occupant seat belt for crashworthiness †

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Abstract

In this paper, a method of modeling a seat belt on a crew seat during a dynamic seat testing was studied. The body segments of the occupant were modeled with joints that consisted of various stiffness, damping, and friction. Three types of seat belt restraint systems were investigated and an analysis on the injury assessment of the helicopter's crew under a drop impact was conducted. The effectiveness of the seat belt system for crashworthiness and safety was likewise evaluated. From the impact analysis results, it was determined that the head, neck, and spine of the crew body can be easily damaged in the vertical direction more than the longitudinal direction. Based on the verified model, the human body's behavior was studied using three point restraint systems. The displacement and injury level of the 12-point restraint system was the smallest.

Keywords: Crashworthiness; Drop impact; Human body impact; Musculoskeletal model

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1. Introduction

Military aircraft commonly consists of an escape seat and a controller to control the escape system for occupant survivability [1]. Thoroughly understanding how a human responds in an impulsive environment is essential to prevent injuries [2, 3]. Many improvements have been accomplished through various studies and analyses, and these results have been applied to new aircraft designs [4].

From 1955 to 1965, a popular approach to the determination of an aircraft's structural crash design capability was to perform full-scale crash tests. Tests of this nature are extremely expensive, particularly when the test article increases in size, such as in current wide-body jets. In addition to cost, the test conditions are not repeatable. The 1970s witnessed significant advances in the computer modeling of nonlinear crash dynamic behavior, both at the substructure and airframe level [5]. A full-scale crash test of the Sikorsky ACAP flight test helicopter was performed at the Impact Dynamics Research Facility of the NASA Langley Research Center in June 1999. The purpose of the test was to generate experimental data for correlation with a nonlinear, explicit transient dynamic crash simulation developed using the MSC Dytran finite element code. For the test the helicopter was outfitted with two crew members, two troop seats, and four anthropomorphic test dummies [5]. In this paper, three restraint scenarios are considered: 5, 7, and 12-point restraint systems.

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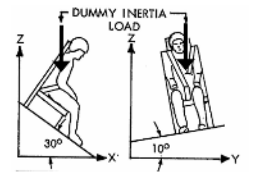
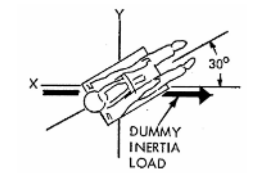
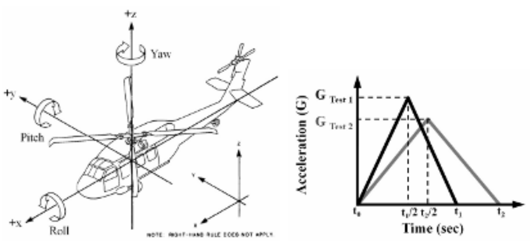
2. Crash environment

2.1 Requirements of seat design

The conditions of performance requirement for military helicopter seats were defined by JSSG-2010-7 [1]. These conditions consist of a static load test and a dynamic load test. Figure 1 shows the cockpit seat design and the static load test [1]. Table 1 shows the dynamic test parameters for military rotary-wing aircraft. Working with a 50 %tile of human model crew (male), we considered the following: human body: 77.3 kg, clothes: 14 kg, helmet: 1.5 kg, shoes: 1.9 kg, and total mass: 81.1 kg.m

Table 1. Dynamic test parameters for military rotary-wing aircraft (MIL-S-58095) [1].

Test condition and seat orientation					
Test 1: Downward, Forward, and Lateral Loads			Test 2: Forward and Lateral Loads		
					
Pitch	Roll	Yaw	Pitch	Roll	Yaw
-30	10	0	0	0	-30
Test pulse required					
Parameter	Limits	Parameter	Limits		
t0 sec t1 sec GTest 1	0.000 0.061 48	t0 sec t2 sec GTest 2	0.000 0.100 30		



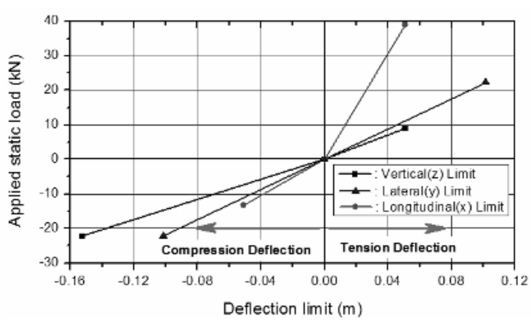


Fig. 1. Cockpit seat design and static load test [1].

2.2 Cushion modeling of seat

The comfort characteristics of automotive seats are strongly related to various seat design factors and their static and dynamic properties, including vibration attenuation characteristic and pressure distribution at the human seat interface. The widely used polyurethane foam cushions possess highly nonlinear visco-elastic properties. The energy restoring and dissipation properties of such cushions are strongly dependent upon the subject's posture and physical characteristics and the magnitude and frequency of vibration excitation [5]. Figure 2 shows a pilot seat with six degree of freedoms.

3. Crew modeling and analytical results of human behavior

3.1 Injury criterion

Currently, military crash-resistant seating systems for rotary-wing and light fixed-wing aircraft are evaluated against criteria established by a NASA memorandum published by Eiband, entitled "Human Tolerance to Rapidly Applied Accelerations: A Summary of the Literature." These criteria were published in 1959 and were based on human and animal test data. Much of the data were collected for a variety of full-torso restraints as well as head restraints in some cases.

3.1.1 Head injury criterion

With recent advances in automotive crash safety, the National Highway Traffic Safety Administration (NHTSA) has promulgated several injury criteria that

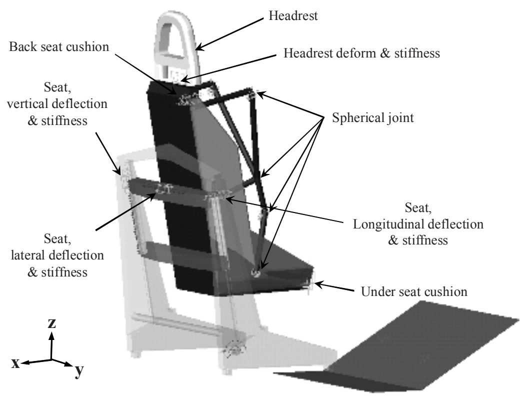


Fig. 2. Crew seat with six degree of freedoms.

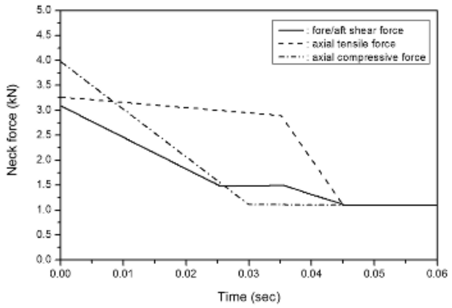


Fig. 3. Injury assessment curves of Hybrid Ш-type adult dummies [1].

could also have applications to military crash safety [5]. Foremost among these criteria is the head injury criterion (HIC). The HIC duration should be limited to 15 milliseconds or less to calculate the HIC value for a given head acceleration-time history. HIC values are required under 1113 at 5 %tile small female, 1000 at 50 %tile midsize male, and 957 at 95 %tile large male. HIC is defined as follows:

$$HIC = (t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\,dt\right]^{2.5}_{\max} \quad (1)$$

where t_1 and t_2 are the initial and final times (in seconds) of the interval, respectively, during which HIC attains a maximum value and acceleration is measured in g's.

3.1.2 Neck injury limit value

Fig. 3 summarizes injury assessment reference values (IARVs) for Hybrid Ш-type adult dummies [1]. According to IARV, flexion bending moment was 190 Nm and extension bending moment was 57 Nm. For axial neck compression serious injury did not occur under 1.1 KN, even though the load was endured for a long time.

3.2 Restraint system

A computer model of the helicopter occupant was developed through the commercial software LifeMOD [2] using a seated Hybrid Ш (1750 mm, 77.3 kg), which is generated in 19 segments. Cervical vertebra consisted of one part in LifeMOD that was transfigured into seven parts in order to observe specific cervical vertebra behavior. Fig. 4 shows an analytical model with a seat, a human body, and a restraint system. The human body model consisted of 25 segments and 24 joints. The mass of the helmet was added to the concentrated mass of the head.

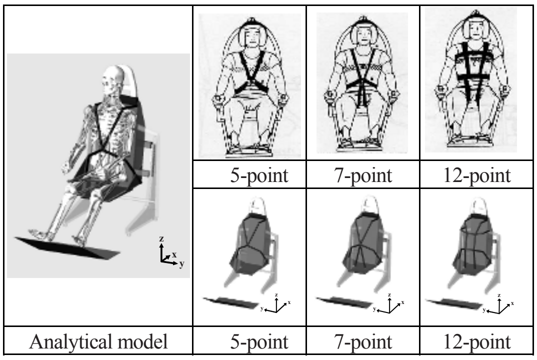
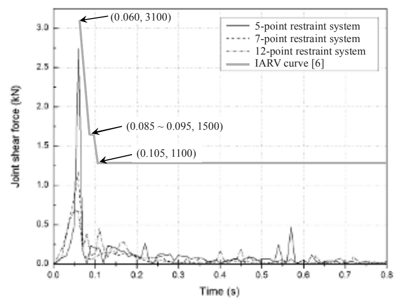
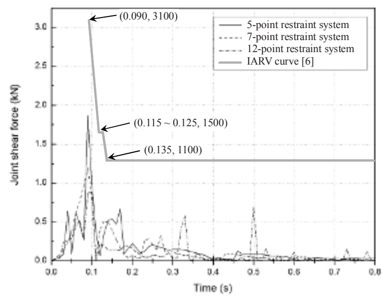


Fig. 4. Analytical model and three typical restraint systems [5].



(a) Test 1



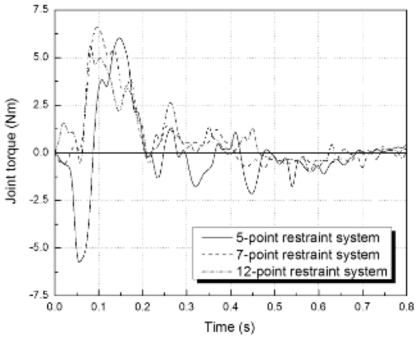
(b) Test 2

Fig. 5. Absolute joint shear force history for three restraint systems.

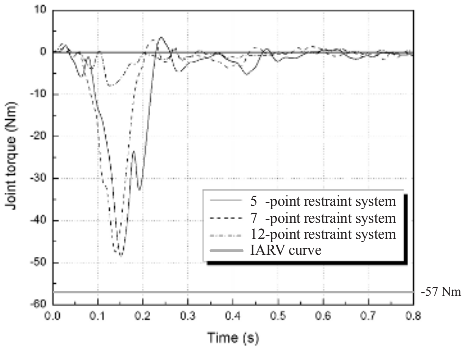
In this paper, three restraint scenarios are considered; 5, 7, and 12-point restraint systems. Fig. 5 shows the three typical restraint systems [5]. The seat motion assumed a rigid-body motion.

3.3 Analytical results of human behavior

Figs. 5 (a) and (b) show the absolute joint shear force history of test 1 and test 2 for the three restraint systems, respectively. Figs. 6(a) and (b) show the neck joint torque history of test 1 and test 2 for the three restraint systems, respectively.



(a) Test 1



(b) Test 2

Fig. 6. Joint torque history of neck for three restraint systems.

4. Conclusions

An analysis on the injury assessment of a helicopter's crew under a drop impact was conducted. The effectiveness of the seat belt system for crashworthiness and safety was evaluated. The conclusions are described as follows:

1) From the impact analysis results, it was determined that the head, neck, and spine of the crew body can be easily damaged in the vertical direction more than the longitudinal direction.
2) Based on the verified model, the human body's behavior was studied using three point restraint systems. The displacement and injury level of the 12-point restraint system was the smallest.

A developed musculoskeletal dynamic model can be applied to biomechanics, kinetics, medical science, and gait analysis.

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