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Assessment of the whole body vibration exposure and the dynamic seat comfort in passenger aircraft

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ABSTRACT

This paper describes the study performed to investigate and assess the whole body vibration (WBV) and the dynamic seat comfort of aircraft seats under three different flight conditions. The WBV exposures were assessed based on the international standard ISO-2631-1 (1997) and the British Standard BS-6841 (1987). The seat effective amplitude transmissibility (SEAT) value was then calculated and used as a measure of comfort. Three different methods were used to calculate the SEAT value; these methods include using average weighted vibration (A_w), vibration dose values (*VDV*) and using the transmissibility data. The experiments were performed using a multi-axis shaker table simulating takeoff, landing and cruise through turbulence vibration levels. The vibration levels were modeled closely to recordings obtained onboard an actual aircraft during flight. The effect of passenger weight and cushion material on the vibration transmissibility are also discussed.

Relevance to Industry: One of the customer's top priorities when looking to travel in an airplane is comfort. Assessing the WBV exposure and the dynamic seat comfort on passenger aircraft seats in laboratory will allow for better development of aircraft seats at much lower costs which, in turn, will provide the customer with high quality products.

1. Introduction

Passenger comfort is an important factor as air travel has become a common mode of transportation. In many transportation systems, more specifically aircrafts, vibration is transmitted to the passengers through the seat (Wei and Griffin, 1998). Many studies have been performed to predict the whole body vibration (WBV), seat transmissibility and dynamic seat comfort for varies vehicles; such as WBV exposures of bus drivers (Thamsuwan et al., 2013) and WBV exposures by motorcycle riders (Chen et al., 2009). However, little effort has been expended in the evaluation of WBV exposures and dynamic seat comfort in aircrafts.

Seat comfort can be divided into two categories; static comfort and dynamic comfort (Ebe and Griffin, 2000; Shen and Vértiz, 1997). Static comfort represents how comfortable the seat is without the effect of external forces and vibration. Whereas, dynamic comfort deals with the overall seat comfort; this includes external forces and their effects on a subject. Moreover, a seat that is comfortable statically in non-moving applications may have poor dynamic characteristics that make it uncomfortable when the vehicle is moving. Furthermore, comfort is primarily felt by the human body during a dynamic process rather than a static process (Yusof, 2005).

Dynamic seat comfort is generally defined by the transmissibility. The transmission of vibration associated with a dynamic system is governed by the frequency content, the direction of the input motion and the characteristics of the seat from which the vibration exposure is received (Nahvi, 2009). Vibration within 12 Hz affects the whole human body whilst vibrations above 12 Hz have local effects (Hostens and Ramon, 2003). Low-frequency vibrations between (2 and 20 Hz) can put the body in resonance which can cause eventual muscle fatigue and discomfort (Hostens and Ramon, 2003).

Human responses to WBV can be assessed by two main standards; the British standards BS 6841 (1987) and the international standards ISO 2631 (1997) (Nahvi, 2009; Paddan and Griffin, 2002). The BS-6841 considers a frequency range of 0.5 and 80 Hz, and recommends measuring four axes of vibrations on the seat (fore-aft, lateral and vertical vibration on seat surface and fore-aft on backrest) and to combine them to assess the vibration severity

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(Nahvi, 2009; Paddan and Griffin, 2002). The ISO 2631 suggests that vibration measurements be taken in three translational axes on the seat surface, however the axes with the greatest intensity is used to estimate vibration severity (Nahvi, 2009; Paddan and Griffin, 2002). Though the BS 6841 recommends combining the four axes of vibrations, only the vertical vibration on the seat surface will be investigated in this paper because the vertical component has the most dominate and greatest vibration severity.

Some of the early investigations in this field conducted by (Varterasian and Thompson, 1977) have established a relationship between the measured vibration transmissibility and the human perception of it. More recently, (Van Niekerk et al., 2002) has investigated the use of the seat effective amplitude transmissibility (SEAT) value to assess the dynamic comfort in vehicles. SEAT is a measure used to determine a seat effective ability to dampen or in some cases amplify transmitted vibration to the user. The SEAT value was used evaluate the dynamic seat comfort by using the power spectral density (PSD) of the input vibrations at the seat base and the measured response vibrations at the seat surface. Another method investigated by (Nahvi, 2009; Thamsuwan et al., 2013) used to compute the SEAT value by using WBV exposure parameters from calculated average weighted vibration (*Aw*) and vibration dose values (*VDV*) on the seat surface and seat base. The current standards recommend that if the input base acceleration contains shocks, the *VDV* value should be used to determine the SEAT value (Nahvi et al., 2009).

Few investigations have been performed to evaluate the health effects associated with whole-body vibration (WBV) in aircrafts. For example, (Burström et al., 2006) conducted an experimental investigation to evaluate the health risks on cabin attendants during landing flight condition onboard of the Boeing 737–800. Burström et al. found that vibration loads are greater in the up and down (i.e. vertical) directions during landing. Moreover they observed that the whole body vibration exposure is more than 50% higher on the rear crew seats than that on the front crew seats. Burström et al. also reported that the vibration dose values measured on the crew seats are below the exposure limits described by the European Standards. However, Burström et al. concluded that there could be a risk for cabin attendants due to the exposure to multiple shocks. Therefore, efforts should be made to develop better seat cushions and seat backrests; as well as informing the attendants about the most suitable posture during landing to minimize adverse health effects. More recently, (Kåsin et al., 2011) examined the whole-body vibration (WBV) exposure in helicopters and its relation to low back pain. Six helicopters were tested and the average weighted acceleration values were measured during a continuous flight, split into 15 different operationally relevant maneuvers. Kåsin et al. found that the average weighted vibration value estimated during an 8-h working day was lower than the European Union and International Standards' bound of risk criteria. However, Kåsin et al. reported that, despite the vibration levels being low, helicopter pilots reported a high incidence of lower back pain which is possibly due to the helicopter pilots posture combined with WBV.

Although there have been extensive studies performed to assess the whole-body vibration (WBV) exposures and the dynamic seat comfort in many different vehicles, little has been investigated in passenger aircrafts. Moreover, most of the investigations that have been performed for aircrafts were mainly focused on assessing the occupants' exposure to vibration in terms of the health effects. Therefore, in this study, the main objective is to develop an experimental setup that can be used to evaluate the WBV exposure and the dynamic seat comfort in a passenger aircraft under three different flight conditions; taking into account the effect of passenger's weight and cushion material. The transmissibility at the seat surface is measured; and a comparison of the SEAT values using three different methods; the transmissibility data, average weighted vibration and vibration dose values are presented. The ability to perform these measurements in the laboratory allows for more research and development of aircraft seats at a much lower cost which, in turn, will provide the customers with high quality product at a much lower cost.

2. Methodology

2.1. Test cases

To assess the overall WBV exposure and the dynamic seat comfort in the economy class aircraft seat, different test case scenarios were performed under different flight conditions; takeoff, landing and cruise through turbulence. These test case scenarios include measuring the WBV exposure with a 150 lb (65 kg) dummy on the economy class seat surface. The economy class seat cushion was removed and a business class seat cushion was added to the economy class seat to investigate the effect of the business class cushion. A second identical dummy was then added alongside the first dummy to see if there is an effect in the WBV exposure and the dynamic seat comfort with a second passenger.

2.2. Experimental setup and calibration

The experiments are performed in the Automotive Center of Excellence (ACE) at the University of Ontario institute of Technology. ACE has a multi-axis shaker table (MAST) in hemi-anechoic chamber. The six axis inverted hexapod design allows for products to be tested for structural durability and the detection of noise and vibration in six dimensions. The shaker table is designed to operate up to 150 Hz with maximum displacement amplitude of ±150 mm. Fig. 1 shows the experimental setup employed in the ACE for the economy class seat.

The vibration signals received during three different flight conditions; takeoff, landing and cruise through turbulence, were used to excite the shaker table. Since the shaker table can only operate up to 150 Hz, it was important to measure the vibration

Fig. 1. Economy class setup.