Transportation Synthesis Report

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Enhancing Ergonomics for Snowplow Drivers

Prepared for
The Clear Roads Technical Advisory Committee

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Transportation Synthesis Reports are brief summaries of currently available information on topics of interest to technical staff in departments of transportation. Online and print sources for TSRs include NCHRP and other TRB programs, AASHTO, the research and practices of transportation agencies, and related academic and industry research. Internet hyperlinks in TSRs are active at the time of publication, but changes on the host server can make them obsolete.

Request for Report

Snowplow drivers are sometimes required to drive and operate their equipment for many hours with little or no opportunity to take a break, stretch or relax for more than a few minutes. Drivers attest to the painful conditions they experience when the mental stress of driving is coupled with its physical demands. To date, very limited research has been conducted in the area of ergonomics and snowplow operation. Clear Roads, a winter maintenance pooled fund research project involving seven state DOTs, was interested in acquiring practical knowledge on the topic, and requested a review of literature and practices pertaining to ergonomics for snowplow operators.

Summary

We located a number of technologies, research studies and resources for guidance that address ergonomics issues relevant to snowplow drivers.

Technology

- Monroe Electro-Hydraulics Plow Control Systems include a variety of operator-friendly products incorporating ergonomic design and seat-mounted, fingertip control.
- Force America's CommandAll Controller Model MPJ is designed to integrate plow, hoist and spreader control and up to eight auxiliary functions into an ergonomic, single-hand control system, allowing the driver to perform multiple tasks.
- Maddock's Grader Stick is a unique, single-lever control system that allows operators to easily perform multiple blade movements simultaneously.
- Sears Seating Atlas Series truck seats incorporate leading edge ergonomic design features found in suspension seats today.

Research and Development

- Results from an Iowa DOT survey of the state's snowplow drivers suggests the need to improve equipment performance in a number of areas including cab environment (noise level, seats, size of the environment, and windshield visibility).
- Researchers use a single-axle test rig to evaluate the comfort of an air-inflated seat cushion designed for truck seats compared to a common foam cushion. The air-inflated cushion provides more driving comfort by improving pressure distribution between the seat cushion and the driver.
- An article from Theoretical Issues in Ergonomics Science reviews a transactional model of driver stress and fatigue and its ergonomic application to designing vehicle systems for "stress-tolerance," and concludes with guidelines for design to minimize safety problems associated with stress and fatigue.
- A newly-patented "ergonomic snowplow control system" would incorporate all plow functions into a fingertip switch pad conveniently mounted near the driver. The device would mitigate hand strain and be comfortable to use during extended operations.

Resources

- Atlas Ergonomics provides a service that identifies the proper, in-cab adjustments for individual truck drivers, and prints the information on a laminated card that drivers carry with them for reference.
- A pamphlet available from Occupation Health Clinics for Ontario Workers provides information concerning the ergonomic risks of driving and provides suggestions for keeping drivers healthy. Topics addressed include the hazards of long-term sitting and of whole-body vibration.

Technology

Plow Control Systems
Monroe Electro-Hydraulics
http://www.monroetruck.com/Pdf/PlowCtrls.pdf#search='ergonomic%20snow%20plow%20controls'
This site introduces a variety of operator-friendly control products incorporating ergonomic design and seat-mounted, fingertip control, including switch panels, and joysticks used for proportional (feathering) control of hydraulic-powered devices – hoist, plow, wing, blade etc.

Snow & Ice Control
Trailer/Body Builders Magazine, Sept. 1, 2003
http://trailer-bodybuilders.com/mag/trucks_snow_ice_control_2/
Scroll to: MPJ lets one hand control multiple tasks
Force America's CommandAll Controller Model MPJ is a fully proportional control for medium- and heavy-duty snow removal equipment. The MPJ controller design integrates plow, hoist and spreader control and up to eight auxiliary functions into an ergonomic, single-hand control system allowing the driver to perform multiple tasks. Integrating up to four programmable mini-proportional joysticks into a single stick design, the MPJ can control up to nine simultaneous functions without the use of mode menu selections.

Joy-stick control for motor grader functions
Better Roads Top New Products 2002: Motor Graders
http://www.betterroads.com/articles/hotprods02.htm
http://www.maddockcorp.com/GraderStick.html
Maddock's Grader Stick is a unique single-lever control system that operates all of the grader's blade functions plus front-wheel tilt and can be added to most motor graders. It provides the operator with proportional fine control ability to the lift/lower and swing functions of the blade, and adds single-hand straight up and straight down blade control. The operator is also easily able to perform multiple blade movements simultaneously.

Sears Seating
Atlas S 35 Heavy Duty Work Truck Seat
http://www.industrialseats.com/pgr.asp?pgrID=80&categoryID=20
Sears Seating Atlas Series truck seats incorporate leading edge ergonomic design features found in suspension seats today. Development of the Atlas included measuring and interviewing 193 volunteer truck drivers.

Research and Development

Winter Equipment Committee's Survey of Equipment Operators – Field Report
Iowa Department of Transportation Office of Maintenance and Director's Staff Division
August 2005
(A copy of the report is attached)
The Winter Equipment Committee, with support from the Office of Maintenance, surveyed all equipment operators in April 2005 as part of an effort to review the performance of equipment being used by Iowa DOT. Findings are presented by overall equipment performance areas addressed in the survey, ranked by the reported need for improvement. The top five areas were cab environment, truck liquid systems, wings, front plow and spreader, with cab environment ranked first: nearly 30 percent of drivers said this area needed improvement. Results in each of the areas were broken out by the age of equipment. An "Impact" column reports whether the age of the equipment appeared to have significantly impacted the ratings.

*** Cab Environment ***

% Needs Improvement			Age		
			1999 & Older	**2000 & Newer**	**Impact?**
29.9%	**Cab Environment**		37.7%	17.4%	Yes
	% Needs Work				
	36.5%	Noise Level	46.3%	19.9%	Yes
	33.0%	Size of Cab Environment	39.9%	20.5%	Yes
	26.4%	Seats	34.2%	12.3%	Yes
	24.2%	Windshield Visibility	28.5%	16.8%	Yes

The results confirmed the committee's belief that age of equipment played a role in how items in this area were rated. It was decided that identified problems should be dealt with through new purchases -- the committee will look at results for newer cabs to guide this effort.

Evaluation of an Alternative Seating Technology for Truck Seats
Seigler, M and Ahmadian, M.: Heavy Vehicle Systems / Intl. Journal of Vehicle Design; Vol. 10, Issue 3; 2003; pages 188-208
(A copy of the report is attached)
In this study, the comfort of an air-inflated seat cushion designed for truck seats was compared with a common foam cushion. Using a single-axis test rig, each cushion type was evaluated under both transient and steady-state conditions over a 12-hour period (in four-hour intervals) measuring the effects of long-term sitting. The tests indicated a greater stiffening of the foam over time and higher-pressure concentrations at the bony prominences compared to the air-inflated cushion. Objective measures recommended by past studies were used to evaluate the dynamic properties of the two cushions. Two new techniques, seat pressure distribution and area pressure change, were also formulated to highlight the relative dynamics between different types of seat cushions and their effect on driver comfort. Results from the tests demonstrate that the air-inflated seat cushion provides more driving comfort by improving pressure distribution between the seat cushion and the driver.

Towards a transactional ergonomics for driver stress and fatigue
Matthews, G.: Theoretical Issues in Ergonomics Science; Vol. 3, No. 2; April 1, 2002; pages 195-211(17)
Abstract available at IngentaConnect:
http://www.ingentaconnect.com/search/article?title=driver+ergonomics&title_type=tka&year_from=2001&year_to=2006&database=1&pageSize=20&index=9
This article reviews a transactional model of driver stress and fatigue, and its ergonomic application to designing vehicle systems for "stress-tolerance." Disturbances of subjective state are controlled by cognitive stress processes of appraisal and coping. Both personality factors and situational stressors may elicit maladaptive patterns of cognition that generate subjective stress symptoms, elicit potentially dangerous coping strategies, and interfere with information-processing and attention to the task at hand. Studies using a driving simulator have explored the behavioral consequences of several qualitatively different forms of "stress" that can be loosely labeled as anxiety, anger and fatigue. Implications of the model for design are reviewed, focusing on road engineering, in-car systems, and automation of vehicle functions. A transactional analysis focuses on evaluation of the cognitions produced by vehicle systems, problems of distraction and overload, and maintaining active task involvement. The article concludes with guidelines for design to minimize safety problems associated with stress and fatigue.

Ergonomic snowplow control system
United States Patent 6852934 B1
Feb 8, 2005
View patent information at http://www.freepatentsonline.com/6852934.html
As described by the inventor, this device incorporates all plow functions into a fingertip switch pad that would be conveniently mounted near the driver. There is no joystick. "The (switch pad) control system can be positioned so that the operator can have at his ready command, and without excessive movement of, or strain on, his hand, both the control system and another part of the vehicle's intrinsic controls such as the steering wheel or gearshift lever. The system may include an especially effective switch pad arrangement, making for ease of operation, and an optional resilient housing, making for surprisingly increased comfort especially in long-term operation. In typical, preferred embodiments, the control system is wireless and remote."

Resources

We Fit the Truck to the Driver
Atlas Ergonomics- services for commercial drivers
http://www.atlasergo.com/driversfit.htm
Atlas turns the complex demands of proper in-cab adjustments into a simple system of pictures, colors and numbers. For each driver, Atlas identifies all appropriate settings, based on his/her physical needs. Then Atlas provides each individual a simple laminated card with correct settings, and instructions on the knob or levers used to get there. Drivers can take the card from vehicle to vehicle, ensuring safety throughout the fleet, and reducing the need for additional assistance.

Schneider National Inc., a premier provider of transportation, logistics and related services, is working with Atlas Ergonomics to provide in-cab health and safety improvements for more than 12,000 drivers. A related June 2005 news article may be found at http://www.schneider.com/news/AtlasErgonReleaseFINAL.doc.html.

Ergonomics and Driving
Occupational Health Clinics for Ontario Workers Inc.
Revised 2005
http://www.ohcow.on.ca/resources/handbooks/ergonomics_driving/Ergonomics_And_Driving.pdf
This pamphlet provides information concerning the ergonomic risks of driving and provides suggestions for keeping drivers healthy. Topics addressed include the hazards of long-term sitting and of whole-body vibration. Safety tips include:

- If possible, the back of the driver's seat should be tilted at 110 degrees from the legs (that is, the seat pan) to reduce disc pressure and relax back muscles.
- The vehicle suspension system should be maintained in good working order to help mitigate whole-body vibration.
- A lumbar support should be used -- a properly-placed, rolled up towel can suffice.

Evaluation of an alternative seating technology for truck seats

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Abstract: A comprehensive comparison is provided between an air-inflated seat cushion designed for truck seats and a commonly used foam cushion. Using a single-axis test rig each cushion type is evaluated under both transient and steady-state conditions over a twelve-hour period – in four-hour intervals – measuring the effects of long-term sitting. The tests indicated a greater stiffening of the foam over time and higher-pressure concentrations at the bony prominences – as compared with the air-inflated cushion. Other objective methods used for evaluating the dynamic properties of the two seat cushions included those recommended by past studies, as well as new techniques that were developed based on previous research in the field of ride comfort. The new techniques, named Seat Pressure Distribution (SPD%) and Area Pressure Change (aPcrms) for the purpose of this study, are formulated to highlight the relative dynamics between different types of seat cushion, and their effect on driver comfort. The results show that the air-inflated seat cushion can provide significant improvements in pressure distribution between the seat cushion and the driver, therefore providing a more comfortable ride.

Keywords: air ride, heavy truck ride, air-inflated cushion, foam cushion, ride comfort, seat comfort, seat cushion, truck seat.

Reference to this paper should be made as follows: Seigler, M. and Ahmadian, M. (2003) 'Evaluation of an alternative seating technology for truck seats', *Heavy Vehicle Systems,* A Series of the *Int. J. of Vehicle Design*, Vol. 10, No. 3, pp. 188–208.

Notation

A	contact area
$aPcrms$	area pressure change rate (rms)
f	frequency
G_{ff}	floor acceleration power spectra
G_{ss}	seat acceleration power spectra
n	number of nonzero cell elements
P	contact pressure
$Pcrms$	pressure change rate (rms)

P_m	mean contact pressure
r	pressure range
SEAT%	seat effective amplitude transmissibility
SPD%	seat pressure distribution
T	total time period
W	pressure weighting factor
W_z	vertical seat vibration weighting factor

1 Introduction

Drivers of commercial vehicles, particularly heavy trucks, are required to drive long and sometimes irregular hours. In the USA, the driving limit for truck drivers, as defined by the Federal Highway Administration Hours-of Service (HOS) regulations, is 10 hours. A recent study, however, reported that almost 20% of drivers reported that they 'always or often' exceed that limit (Transafety Reporter, 1998). With such long hours of seated activity it could be argued that the most important part of the truck driver's working environment is the truck seat.

Yet only recently has the design of the truck seat been significantly improved. Improvements have emphasised bolster design to increase stability, and adjustments to backrest angle, contouring, and seat height to promote good posture. Also, the development of the air-ride system has made the seat capable of absorbing vibration transferred from the road surface to the driver. Outside of posture improvements, however, no significant advancements have been made to the seat cushion. Truck seat cushions have almost always been constructed of urethane foam with a polyester top-coated cloth. Foam cushions are the most widely used seat cushions because they offer the advantages of being low cost and lightweight. However, a common problem with foam seat cushions is that they degrade over time and the foam becomes denser, providing less cushioning. Alternative technologies, such as air-inflated seat cushions, have been proposed as replacements for foam cushions in order to eliminate their shortcomings. Evaluating these new technologies, however, requires methods for comparing the ride comfort characteristics of different types of seat cushion.

Recently, there has been a great deal of research devoted to finding objective measures for predicting the subjective perception of seat comfort. The problem is that the vast majority of objective measures used for evaluating comfort were created based on the comparison of different seat designs with similar types of seat cushions that are widely used in the automotive industry, i.e. urethane foam cushions. The dynamics of air-inflated seat cushions is very different from that of foam cushions in terms of their interface with the human body. There is therefore a need for alternative methods of evaluation that can effectively assess the dynamics at the interface between the cushion and the human body.

In this study we compare the comfort characteristics of two different different types of seat cushion design for truck seats – namely a standard foam seat cushion and an air-inflated seat cushion. Current research in the field of dynamic seat comfort has proposed several objective measures for comparing seat cushions. These objective measures are implemented to highlight the differences between cushion types. Furthermore, two objective measures are introduced and implemented as new methods for comparing different classes of seat cushions for truck seats, particularly air-inflated seat cushions and foam seat cushions.

2 Test setup

The tests were performed using a vertical-axis test rig, shown in Figure 1, which was designed to provide a controlled environment for evaluating properties of seats and seat cushions. It is recognized that fore and aft motions are significant in evaluating seat ride comfort (Gillespie, 1985). However such considerations fall beyond the scope of this investigation. The rig consists of a primary support structure and a mobile frame that moves in the vertical direction on a set of roller bearings to allow for low friction movement. A flat plate, called the 'floor,' is mounted onto the mobile frame to support the truck seat. The truck seat – equipped with a seat suspension (or air-ride) – conforms to US Federal Motor Vehicle Safety Standards for heavy truck seats, and is typical of most truck seats found in heavy commercial vehicles in the United States. A hydraulic actuator is mounted below the floor to simulate the dynamics at the seat under driving conditions.

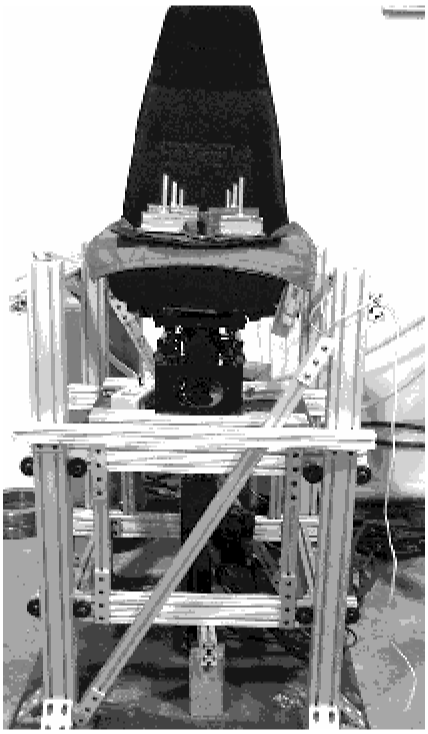

Figure 1 *Single-axis seat testing rig.*

Two types of truck seat cushion were used in the study. The first seat cushion, meant to characterise seat cushions most commonly used in the trucking industry, was a urethane-based foam cushion. The second experimental cushion used was an air-inflated seat cushion – shown in Figure 2 – which consists of interconnected air cells allowing for airflow between adjacent cells. The air-inflated cushion is based on the application of Pascal's law, which implies that a confined fluid will transmit applied pressure uniformly (Goonetilleke and Eng, 1994).

Figure 2 *Experimental air-inflated seat cushion partially covered.*

2.1 Data acquisition

Acceleration measurements are made at the floor, base, and seat of the test rig. Referring to Figure 3, the terminology is as follows:

Seat: vertical measurements made on top of the seat cushion at the interface between the indentor and the seat cushion.

Base: vertical measurements made at the base of the seat on the frame that is directly below the seat cushion.

Floor: vertical measurements made at the interface of the seat attachment to the vehicle structure; commonly, the truck floor.

As shown in Figure 4, the acceleration signals are passed through an 8-pole, 6-zero elliptic low-pass filter. For current experiments, the cut-off frequency was set at 15 Hz. A dSPACE Autobox provides digital signal processing of the transducer and actuator signals. These signals are then digitally converted and stored in a personal computer.

Dynamic interface pressure was measured using the Tekscan Body Pressure Measurement System (BPMS). Pressure distribution mapping was performed using a thin flexible resistive-based sensor pad featuring a 42 by 48 array of individual 0.16 in^2 pressure-sensing elements, or 'cells'.

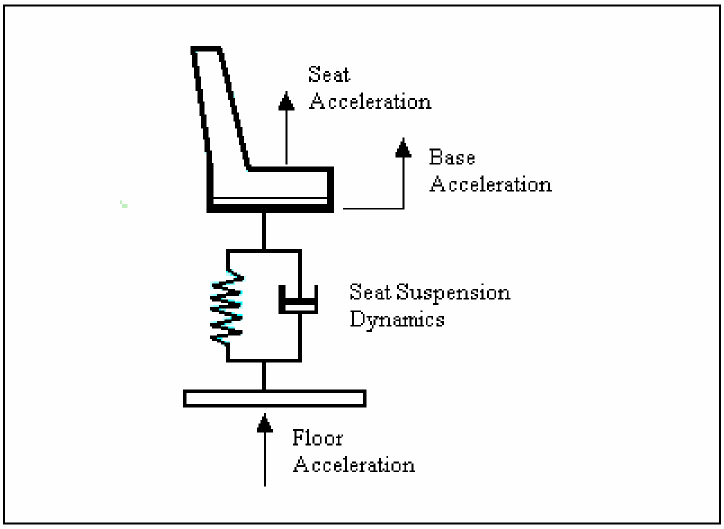

Figure 3 *Terminology for seat cushion testing.*

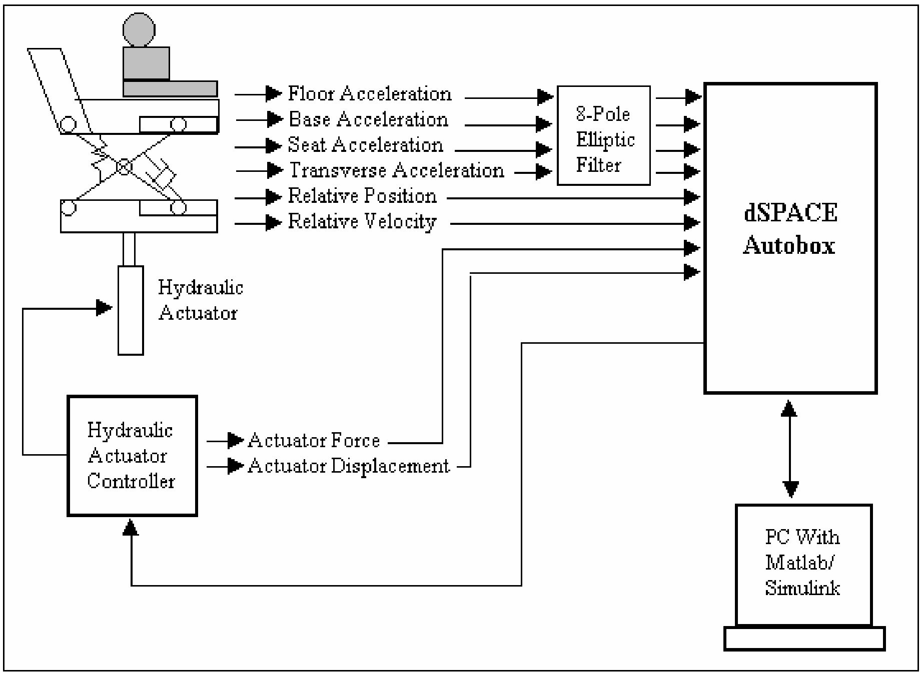

Figure 4 *Data acquisition setup.*

2.2 Cushion loading indentor (CLI)

To alleviate some of the inherent repeatability problems involved in road testing with human subjects, the tests were performed with a cushion loading indentor (CLI) that was designed and built by the Advanced Vehicle Dynamics Laboratory of Virginia Tech for the purpose of this study. The indentor, shown in Figure 5, enabled us to adequately simulate variable pressure distribution, similar to what would be attained by a seated person, in a repeatable manner. The indentor system consists of the five components, highlighted in Figure 5 and listed below:

1. a 0.5mm thin layer of neoprene,
2. a human buttocks shaped polyurethane plastic mould,
3. a soft weighting system,
4. a base plate with loading rings, and
5. 3.5 × 5 inch weights for variable loading capability.

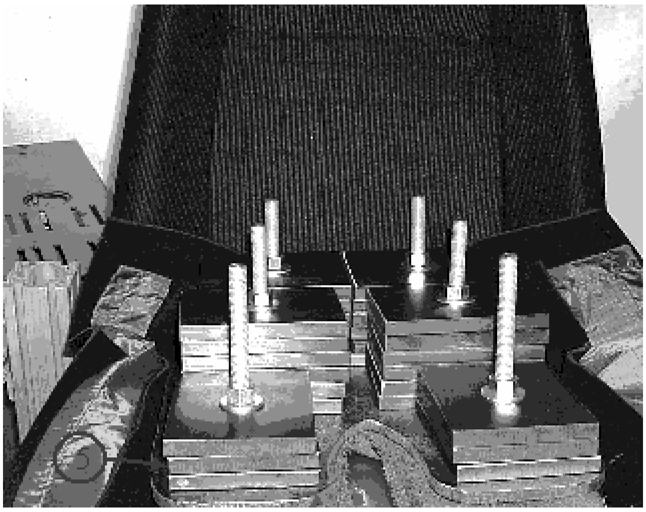

Figure 5 *Cushion loading indentor (CLI) positioned on truck seat.*

The mould was made of a 30-durometer polyurethane based material (Poly 75-30) developed by Polytek Development Corporation. The material was chosen for its compliance to different types of seat cushions. The mould was constructed by pouring the Poly 75-30 into a negative mould created from an average of eighty 200 lb seated men. The addition of the neoprene layer was used specifically to simulate the resiliency of human tissue.

2.3 Input test signals

Input signals were chosen to accurately simulate real driving conditions for truck drivers. Three distinct input signals, shown in Figure 6, were used for testing. To evaluate the vibration characteristics of the seat and seat cushion, chirp and step signals were implemented; the chirp to efficiently excite multiple frequencies, and the 1-inch step to induce transient vibration. The chirp input is a linear swept-frequency signal from 0.5 to 10.5 Hz with starting amplitude of 0.75 inches and duration of 30 seconds. This signal is then fed through a 1.5 Hz low-pass filter to produce a decaying chirp signal. The application of a filter was necessary due to the physical limitations of the hydraulic actuation system.

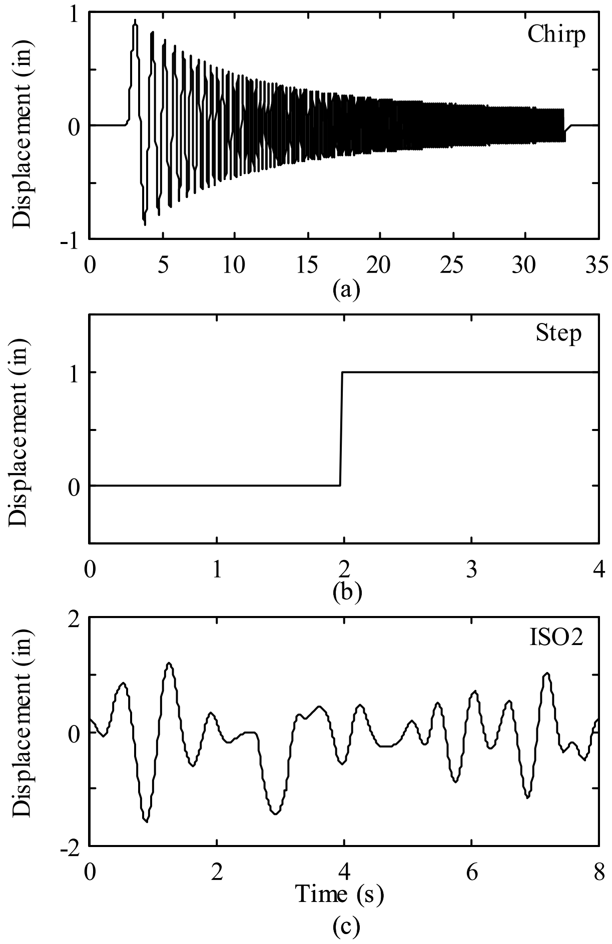

Figure 6 *Time traces of experimental input signals: (a) Chirp; (b) Step; (c) ISO2.*

For pressure measurements, the third input used was a broadband random excitation ISO2 signal. The ISO2 signal is defined by the ISO 7096 standard, and was chosen for use because of its low-frequency content typically experienced by heavy trucks (ISO 7096, 2000).

3 Evaluation methods

Objective measures for predicting the relative comfort of one seat compared to another can be divided into two categories: vibration analysis methods and interface pressure analysis methods due to the known consequences that vibration and pressure have on the human body. Vibration affects the human body by causing a person to contract muscles in an attempt to dampen vibration (Chaffin and Anderson). This ultimately results in discomfort and muscle fatigue. High pressure at bony prominences, such as the ischial tuberocities, can cause loss of blood and nutrient flow resulting in discomfort and possibly fatigue (Kumar *et al*., 1994). Others measures, including physiological and anthropomorphic measurements, have also proved influential, but are beyond the scope of the current study. This section presents some of the objective measures – representative of the latest methods in ride comfort research – used for quantitatively describing the differences between foam and air-inflated seat cushions.

It is important to note that this study makes no attempt to define comfort or to identify the causes of discomfort. This study is solely concerned with evaluating the performance of air-inflated seat cushions relative to the standard foam seat cushion and relies on previous research to provide the evaluation methods. The new comfort measures created for this study are also based on previous research.

3.1 Seat effective amplitude transmissibility (SEAT%)

A valuable method for comparing one seat to another is the objective measure of Seat Effective Amplitude Transmissibility (SEAT%), which is defined as

$$SEAT\% = \left[\frac{\int G_{ss}(f) W_z^2(f)\, df}{\int G_{ff}(f) W_z^2(f)\, df} \right]^{1/2} \times 100 \tag{1}$$

This method is a measure of the transmission of acceleration from the floor to the seat cushion where $G_{ss}(f)$ and $G_{ff}(f)$ are the seat and floor power spectra, respectively. The frequency dependent weighting factor $W_i(f)$, as defined in Table 1, is based on research of human discomfort (Griffin, 1996). The SEAT value may be considered the frequency-weighted percentage of vibration energy transferred from the floor to the seated person. That is, for a seat with no vibration suppression, the output seat acceleration would be the same as the input floor excitation resulting in a SEAT value of 100%. Decreasing values indicate a more comfortable seat.

Table 1 Frequency dependent weighting factors for calculating SEAT% (Chaffin and Anderson).

Frequency range	*Weighting factor*
$0.5 < f < 2.0$	$W_z(f) = 0.4$
$2.0 < f < 5.0$	$W_z(f) = f/5.00$
$5.0 < f < 16.0$	$W_z(f) = 1.00$
$16.0 < f < 80.0$	$W_z(f) = 16/f$

3.2 Pressure change rate (Pcrms)

Researchers at Daihatsu Motor Co, Ltd, when comparing three different types of foam seat, found that pressure change rate root-mean-square (Pcrms) was the most accurate measure for 'unpleasant sensations' due to transient vibrations (Uenishi *et al*., 2000). Pcrms is calculated as follows:

$$Pcrms = \left\{ \frac{1}{T} \int_0^T \left(\frac{dP(t)}{dt} \right)^2 dt \right\}^{1/2} \tag{2}$$

where *T* is the total time period and *P*(*t*) is the dynamic pressure. The research suggests that a lower pressure change rate will result in a more comfortable seat cushion. Similar to SEAT%, there is no threshold value that separates a comfortable seat from an uncomfortable one. Pcrms, however, can be used as an objective comparison for evaluating seat cushions.

3.3 Area pressure change rate (aPcrms)

There are inherent health issues with sitting for long periods of time. When sitting on a surface, the soft tissues can be compressed and deformed by the underlying skeletal structure (bony prominence), particularly at the ishcial tuberocities. At extreme pressures this creates an obstruction of the blood supply resulting in a deficiency of oxygen to tissue cells (Henderson *et al*., 1994). For this reason it is believed that the pressure distribution at the human/seat interface must be incorporated into any objective measurement of ride comfort. A new method that we suggest for comparing seat cushions using interface pressure measurements is Area Pressure Change Rate (aPcrms). The method is an adaptation of Pcrms to include the pressure distribution of the seated person.

$$aPcrms = \sum_{i=1}^{N} A(r_i) Pcrms(r_i) W(r_i) \tag{3}$$

For each of the *n* individual nonzero-pressure cells an average pressure, P_m, is calculated over the test run. Each contact area $A(r_i)$ is determined by calculating the total area of cells with average pressure within the specified pressure ranges, r_i. There are $N =$ 4 pressure ranges where r_i defines the *i*th pressure range. The pressure change rate, $Pcrms(r_i)$, is the average *Pcrms* of cells within each pressure range. A weighting factor, $W(r_i)$, is incorporated for each pressure range. The pressure ranges and weighting factors are defined in Table 2. Physically, *aPcrms* measures the ability of a seat cushion to limit the amount of pressure change and, at the same time, maintain a uniform pressure distribution.

The choosing of the pressure ranges and the corresponding weighting factors can be justified by considering that all living cells require adequate oxygen to survive. Loss of oxygen, due to applied pressure, over extended durations leads to tissue necrosis. The external pressure required to close blood capillaries at normal human arterial pressures is generally accepted as approximately 32 mmHg (Kosiac, 1961). For this reason, we approximate a lower threshold of pressure as 40 mmHg and assign the lowest weighting factor of $W(r_i)$ = 1. Interface pressures below this threshold value are of little concern due to the fact that blood flow is not restricted. Furthermore, during the process of experimentation it was found that 100 mmHg was near the upper limit of pressure measurement. For this reason, we consider any pressure above this threshold of 100 mmHg extremely undesirable; therefore it is given the largest weighting factor of $W(r_4)$ = 4. Pressures between these two extremes of 40 mmHg and 100 mmHg are divided into four pressure ranges incremented by 20 mmHg.

Table 2 Pressure ranges and weighting factors used in calculating aPcrms.

Pressure range, r_i	*Weighting factor, $W(r_i)$*
r_1: $40 \le P_m(n) < 60$ mmHg	$W(r_1) = 1$
r_2: $60 \le P_m(n) < 80$ mmHg	$W(r_2) = 2$
r_3: $80 \le P_m(n) < 100$ mmHg	$W(r_3) = 3$
r_4: $P_m(n) > 100$ mmHg	$W(r_4) = 4$

The weighting factors for the aPcrms calculation were chosen as a starting point. The effect of varying applied pressure levels on human tissue is not well known, at least not to the level of knowledge that we have for how vibration affects the human body. Knowledge of such weighting factors requires subjective research to determine the level of discomfort associated with each pressure range. For this reason, we have chosen a simple approach by dividing the ranges into relatively small increments of 20 mmHg and separating them by a linearly increasing weighting scale. The aPcrms value accounts for the pressure distribution, contact area, and the rate of change of pressure across the seated area. A smaller aPcrms value is thought to result in less discomfort.

3.4 Seat pressure distribution (SPD%)

Research in seat comfort has established a positive relationship between uniform pressure distribution and perceived comfort (Milivojevich *et al*., 2000). Furthermore, lower pressures are always more desirable in terms of long-term tissue integrity. Since a uniform pressure alleviates high concentrated pressure, we assume that a more uniform distribution is better in terms of comfort. One way of quantitatively measuring the ability of a seat cushion to uniformly distribute pressure is with seat pressure distribution (SPD%), defined as:

$$SPD\% = \frac{\sum_{i=1}^{n}\left(P_i - P_m\right)^2}{4nP_m^2} \times 100 \qquad (4)$$

This method is used in conjunction with a body pressure mapping system where n is the total number of nonzero cell elements, P_{i} is the pressure at the ith cell, and P_{m} is the mean pressure of the n elements. A lower percentage value describes a more uniformly distributed seat cushion. For a perfectly uniformly distributed seat cushion each pressure

P_i would be equal to the mean pressure P_m resulting in a value of zero. Note that SPD% can be used for both static and dynamic environments. A dynamic SPD% calculation uses the average pressure from each individual pressure-sensing element over a test run. Furthermore, a time trace of SPD% can be examined to determine the ability of the seat cushion to maintain uniform pressure.

4 Experimental results

The results are divided into two categories: (1) the vibration results taken from acceleration measurements, and (2) pressure distribution measurements from the BPMS. The vibration results are used to evaluate the damping characteristics of the two seat cushion types, and to examine any dynamic degradation over time. The pressure distribution maps are used to evaluate the dynamics of each seat cushion at the interface with the CLI.

The tests were conducted over a twelve-hour period to characterise the effects of long-term seating, similar to what a truck driver would experience during extended-duration driving. Furthermore, the tests were performed multiple times to establish reproducibility. The results shown are a representative sample of these multiple experiments.

4.1 Vibration analysis

To examine the stiffening effects of each seat cushion over time, a chirp test was conducted in four-hour intervals over a period of twelve hours. The results were that both seat cushions displayed stiffening over time that was revealed by an increase in natural frequency. Figures 7 and 8, respectively, show the cushion transmissibility of both seat cushions with increased time along with the corresponding resonant frequency for each four-hour test. The seat cushions displayed almost identical resonant frequency and magnitude values for the initial test at hour 0. The foam cushion, however, displayed slightly more stiffening over time, revealed in the shift in natural frequency. These results are more clearly shown in Figure 9. Figure 9 also shows that the resonant frequency of the foam cushion does not appear to level off, even within the twelve-hour test frame. In fact, the foam cushion exhibits a trend of further stiffening even after twelve hours.

To evaluate the damping properties of each seat configuration, the step response was evaluated as shown in Figure 10. A step input simulates common road disturbances such as sudden changes in road elevation. The step response of a given system is a valuable method for evaluating the damping properties of the system. Damping can be thought of as the ability of a seat cushion to quickly reduce vibrations from a transient input to zero.

From Figure 10, the step response of the two seat configurations offered little difference between the two seats, in terms of their peak response and settling time. This indicates that the air-inflated cushion that we tested has a comparable damping characteristic to the foam cushion that was used in the study.

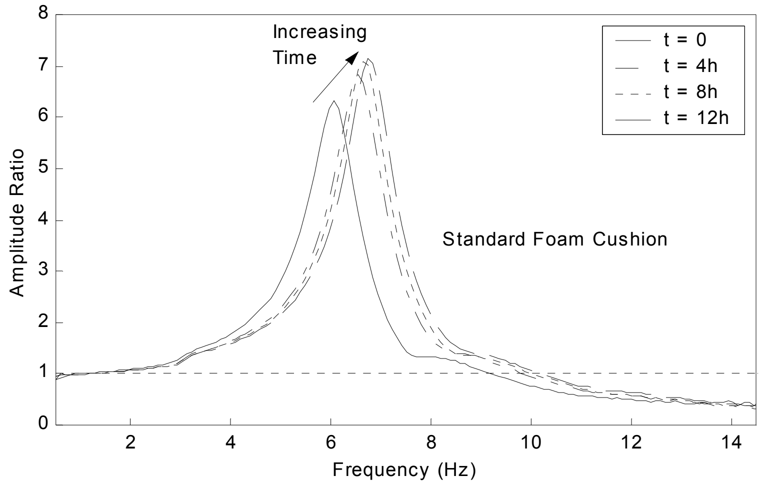

Figure 7 *Vertical cushion transmissibility (seat acceleration divided by base acceleration) for the standard foam cushion.*

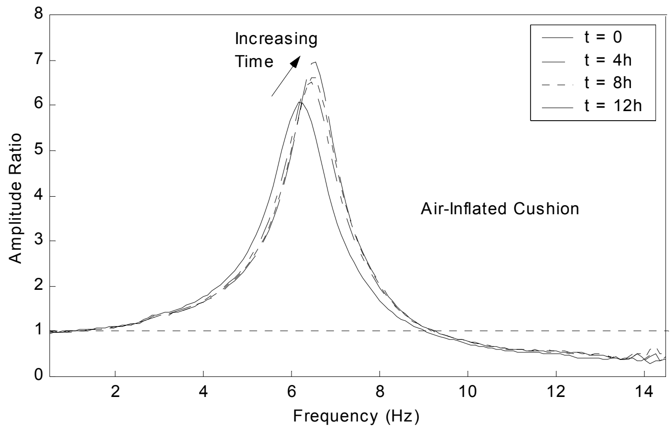

Figure 8 *Vertical cushion transmissibility (seat acceleration divided by base acceleration) for the air-inflated seat cushion.*

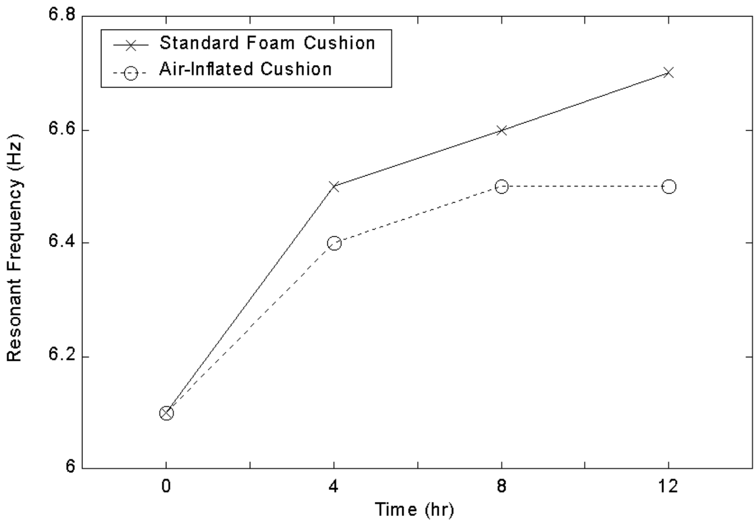

Figure 9 *Change in resonant frequency over time.*

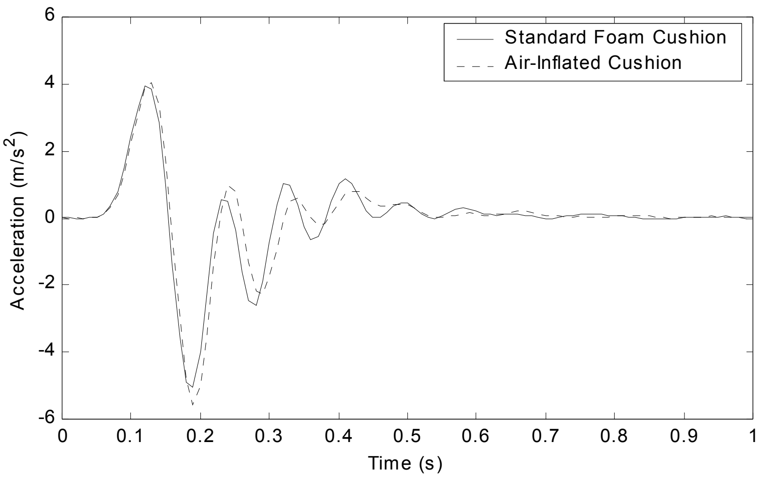

Figure 10 *Vertical seat acceleration response to a 1-inch step input.*

In terms of the metric SEAT%, the results shown in Figure 11 indicate that the air-inflated seat cushion is only 6% better than the foam cushion. The small difference between the two seats can be attributed to the fact that SEAT% is based on acceleration measurements on the seat, which are strongly dominated by the seat suspension. This can be seen in Figure 12, which shows that seat cushions have very little effect on the resonant frequency or on the frequency at which isolation occurs. The seat suspension absorbs most of the gross input vibration from the floor and the dynamics of the seat cushions are comparatively negligible. As intuitively may be apparent, for seats with soft suspensions – such as the one that we used in this study – the vibrations measurements on the seat cushion are strongly influenced by the seat suspension, and the seat cushion plays only a minor role in those measurements. Therefore, using acceleration on the seat cushion alone does not allow for assessing the dynamic effect of the seat cushion on what is perceived by the driver; or more precisely, the dynamic interface between the cushion and the seated person. This indicates that a metric such as SEAT% may not be suitable for comparing different classes of cushions, although it would be quite valid for studying seats with different types of suspensions. As such, we resort to other metrics, namely those that are based on the pressure distribution on the seat cushion, which will be discussed next.

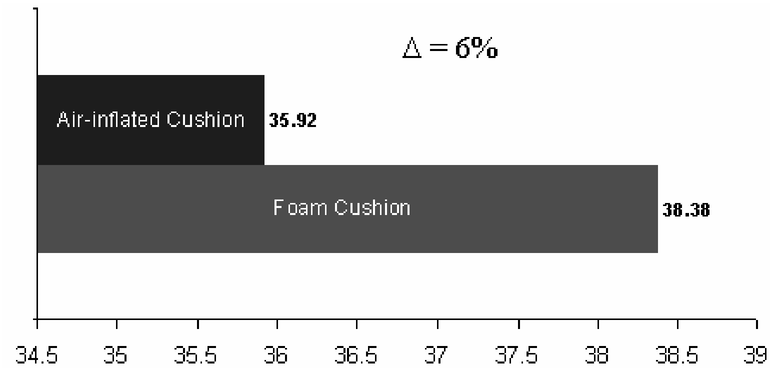

Figure 11 *SEAT% for air-inflated and foam seat cushions.*

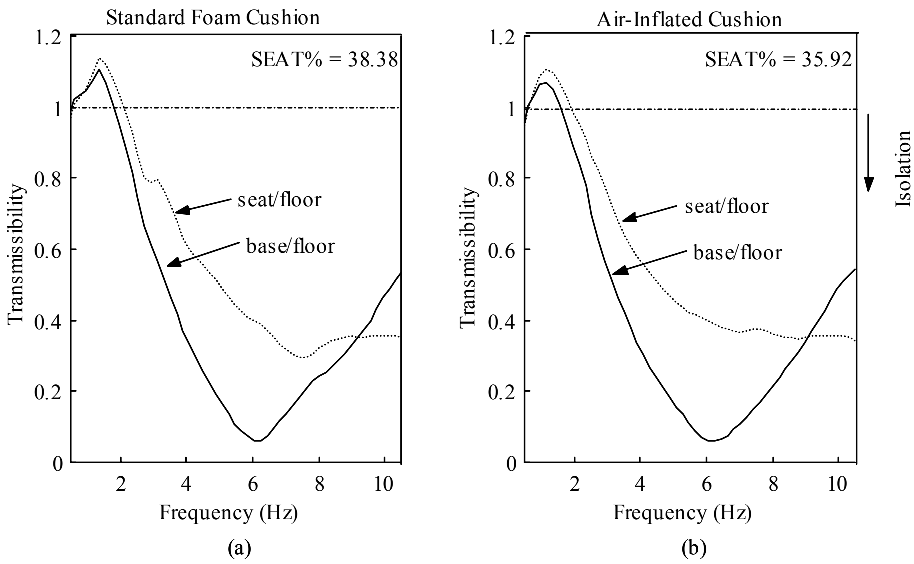

Figure 12 *Vertical transmissibility (base acceleration divided by floor acceleration and seat acceleration divided by floor acceleration); (a) standard foam cushion; (b) air-inflated cushion.*

4.2 Pressure distribution analysis

The following analysis includes a comparison of the pressure distribution between the seat cushion and the cushion loading indenter (CLI), as well as the following three measures that were discussed earlier:

SPD%
Pcrms
aPcrms.

Pressure distribution maps, shown in Figure 13, demonstrate a fundamental difference between a foam and air-inflated cushion. The foam cushion shows areas of high pressure not found in the air-inflated cushion pressure distribution profile. The air-inflated cushion demonstrates the ability to more uniformly distribute the applied load. The lower pressures are also, in part, due to increased contact area. The relative pressure distributions can be compared quantitatively using the static *SPD%* values, which shows that the air-inflated cushion yields an approximately 50% more uniformly distributed pressure distribution than the foam cushion.

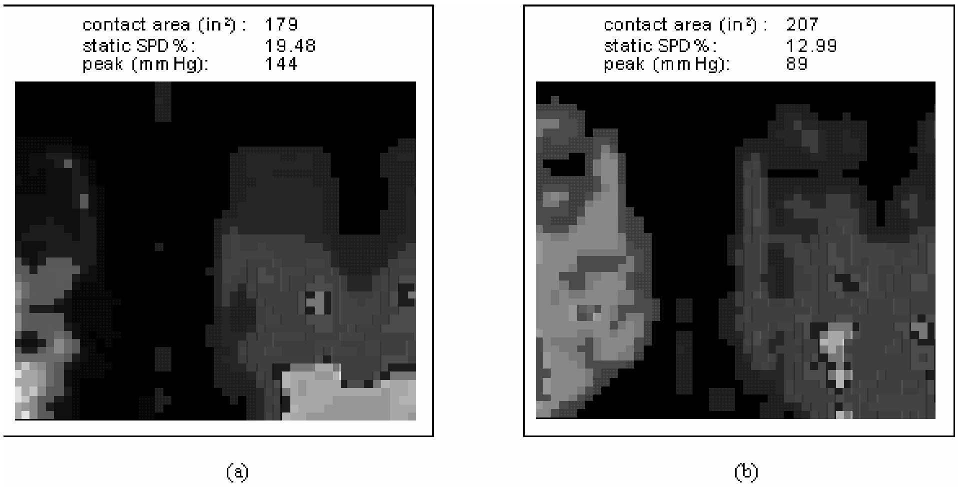

Figure 13 *Static interface pressure distribution; (a) standard foam cushion; (b) air-inflated cushion.*

From previous vibration analysis, there was an increase in cushion stiffness over time. These effects and how they correspond to ride comfort, however, were not evident from Figures 7 and 8. An analysis of pressure occurrence over time shows that the increase in cushion stiffness results in higher interface pressures, as shown in Figures 14 and 15. These figures present a histogram of the average pressures for each cell for the entire test cycle, in six pressure bands. The results directly correlate to the cushion-stiffening effect and show the consequence of cushion stiffening over time on what the driver would feel.

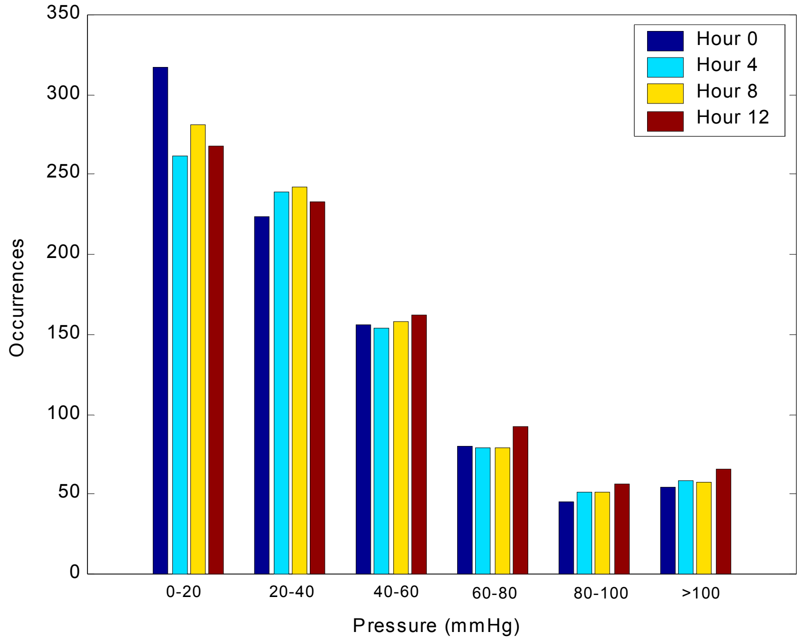

Figure 14 *Pressure occurrences from hour 0 through hour 12 (foam cushion).*

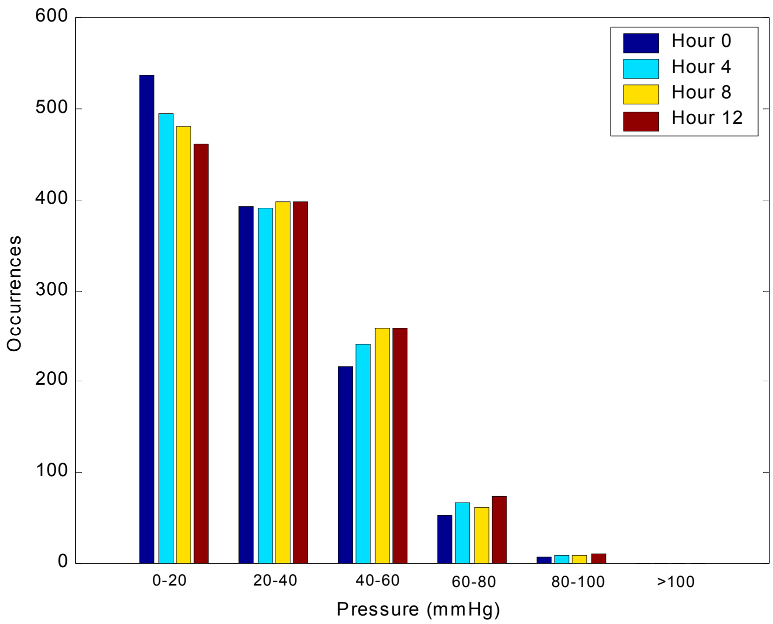

Figure 15 *Pressure occurrences from hour 0 through hour 12 (air-inflated cushion).*

Both seat cushions show a shift of pressure distributions from the lower band to the higher bands. The foam cushion, however, exhibits a more significant shift to the 80 – 100 and >100 mmHg pressure ranges. Pressure shifts for the air-inflated seat cushion are mostly confined to the 40 – 60 mmHg pressure ranges. It is important in terms of tissue health to limit pressure exposure above 60 mmHg. Research has established 60 mmHg as a threshold pressure at which tissue ischemia is likely to occur after 1 hour of exposure (Bar, 1989). It is worth noting that there is an inverse relationship between seated interface pressure and the time to develop tissue damage (Goonetilleke, 1998).

Figure 16 shows the dynamic SPD% of both seat cushion types and Figure 17 displays the averaged SPD% over the entire 8-second test run of the ISO2 input signal. As with the static case, the air-inflated seat cushion displays more evenly distributed pressure. Also, the distribution remains relatively constant compared with the high changes associated with the foam cushion. The mean value of the SPD% for the entire run indicates a 36% improvement resulting from the air-inflated cushion, as compared to the foam cushion.

Figure 18 shows the pressure change rate of the two cushions, as measured by the Pcrms values. Figure 19 compares Pcrms for each cushion type. The results show a smaller Pcrms for the air-inflated cushions than the foam cushion. The percent difference between the two cushions (i.e. 8%), however, is smaller than what we observed earlier with SPD% and what aPcrms will indicate in results that we will discuss next. This smaller difference is due to the fact that Pcrms is ultimately a measure of the rate of change of pressure on the cushion and is most suitable for assessing discomfort due to transient vibration (Uenishi *et al*., 2000). The results in Figure 19 indicate that the rate of change of pressure is slightly lower for the air-inflated cushion.

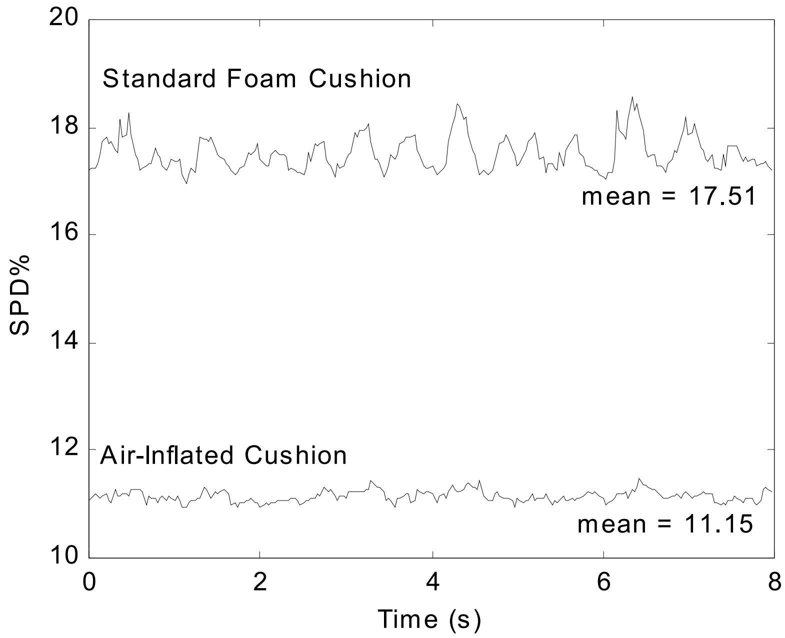

Figure 16 *Comparison of dynamic seat percent pressure distribution (SEAT%).*

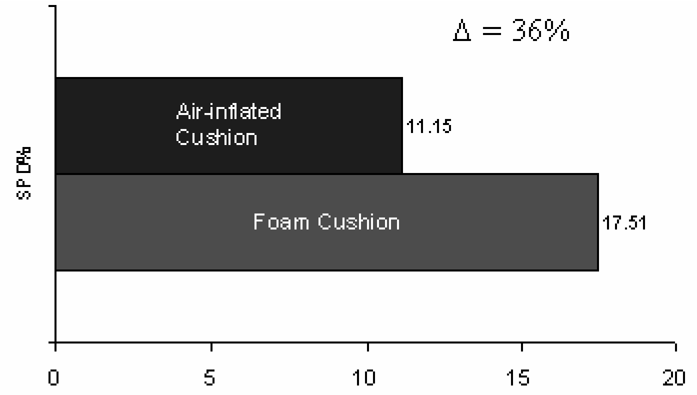

Figure 17 *Comparison of averaged dynamic SPD%.*

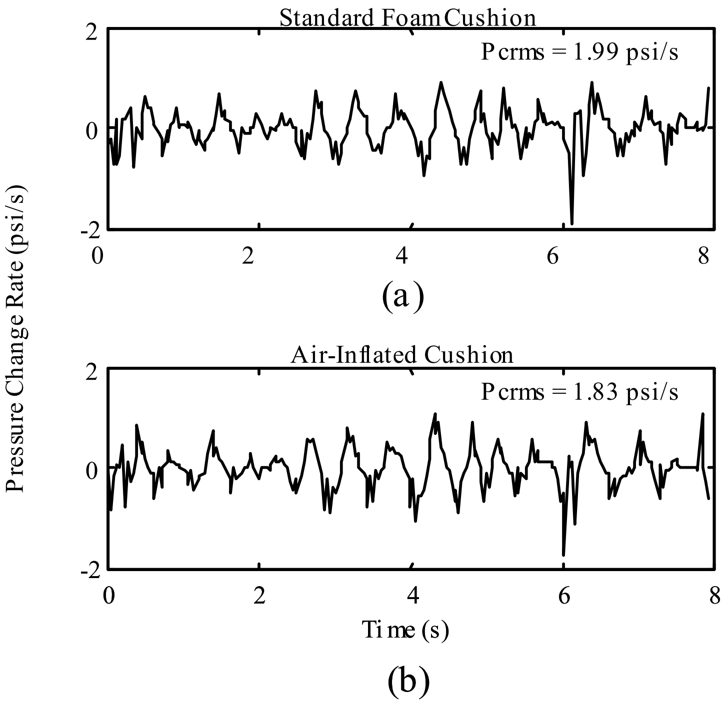

Figure 18 *Comparison of pressure change rate; (a) foam cushion; (b) air-inflated cushion.*

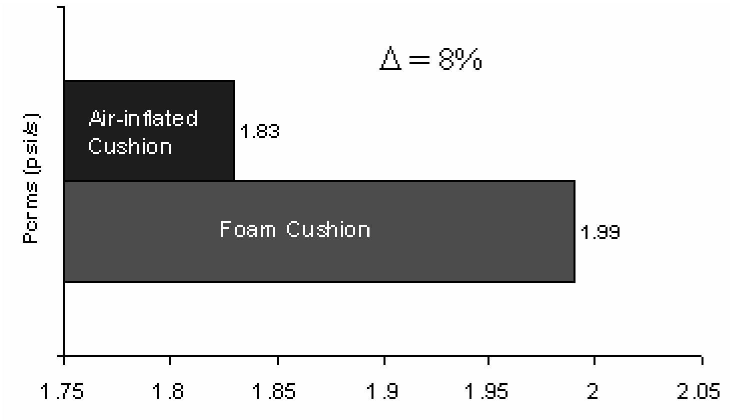

Figure 19 *Comparsion of Pcrms for foam and air-inflated cushion.*

The last measure that is used for comparing the two cushions is aPcrms, which was described earlier. The aPcrms accounts for both the pressure change and the pressure distribution across the seated area. The results shown in Figure 20 indicate that the air-inflated cushion yields a much more favourable dynamic performance, by as much as 58%.

The subjective field-testing that has been conducted in an on-going study shows a direct correlation between the aPcrms numbers and ride comfort. The results of that study show that the lower the aPcrms value, the higher the seat cushion is rated in subjective evaluations of comfort. It is recognised that the ultimate value of aPcrms is dependent on the correlation of subjective and objective data.

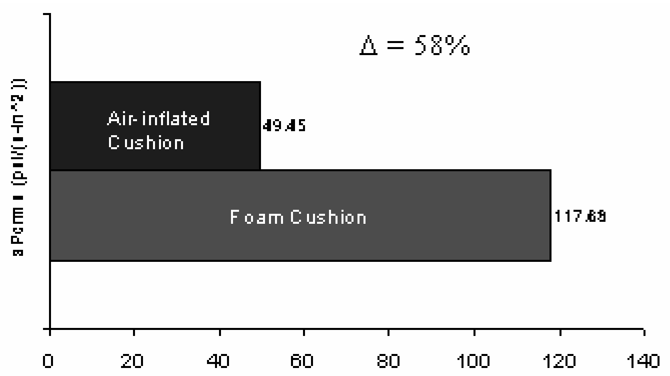

Figure 20 *Comparison of aPcrms between foam and air-inflated cushion.*

5 Conclusions

A comprehensive comparison between an air-inflated seat cushion designed for truck seats and a commonly used foam cushion was provided in order to highlight the differences in the dynamic properties of the two cushions and how they could affect driver comfort. A single axis test rig, specially designed and built for truck seat testing, was used to conduct the tests necessary for comparing the dynamic performance of the cushions. Different types of test were used to evaluate various aspects of each type of cushion; in terms of their response to narrow-band (single frequency) dynamics, broadband input of the type that is commonly used in trucking industry for testing seats, and a step input for assessing the damping characteristics of each cushion. The tests were conducted over a twelve-hour period – in four-hour intervals – in order to measure the changes that occur at the seat cushion over time and assess how these changes can affect the metrics that are used for evaluating the cushions.

The tests indicated a greater stiffening of the foam cushion over time, as compared with the air-inflated cushion. Furthermore, pressure measurements at the seat showed higher-pressure concentrations for the foam cushion at the bony prominences of the seated person – namely, the ischial regions – as compared to the air-inflated cushion. The air-inflated cushion exhibited a much more evenly distributed pressure map between the cushion and the test object, and it provided lower pressures at the ischials. Based on past studies, this is expected to contribute to more driver comfort, for both short hauls and extended driving ranges.

A series of tests aimed at evaluating the damping properties of each cushion showed both cushions to have nearly identical damping properties. The damping property is important for settling the bouncing up and down on the cushion that can occur during driving, due to large motions across the seat suspension. This indicates that air-inflated cushions can provide more comfort to the driver without causing any more bouncing up and down on the seat.

Other methods used for evaluating the dynamic properties of the two seat cushions included those recommended by studies in the past, as well as new techniques that were developed specifically for this study. The new techniques, named SPD% and aPcrms, were formulated such that they can best highlight the dynamic differences between dissimilar types of seat cushions, and their effect on driver comfort. The results, summarised in Figure 21, show that the air-inflated seat cushion provides significant improvements in pressure distribution between the seat cushion and the driver, therefore providing a more comfortable ride.

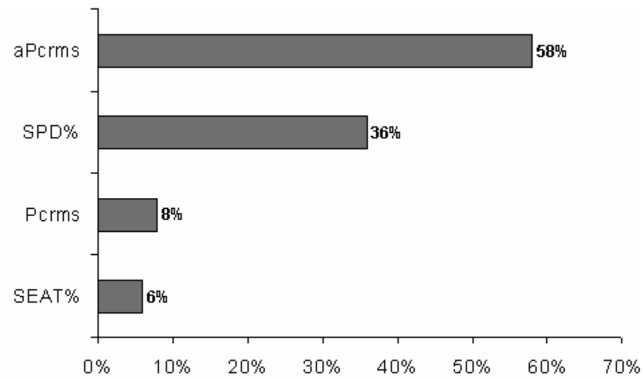

Figure 21 *Percent improvement offered by an air-inflated seat cushion in comparison with a foam cushion, using different metrics.*

Acknowledgements

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