

How Body Pressure Distribution Can Map Soldier Comfort

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ABSTRACT

Currently, when the Army studies ride quality and comfort, 6 Watts of absorbed power is commonly cited as a target. However, absorbed power is dependent upon vehicle speed and road roughness and does not fully describe the direct interaction between the occupant and the seat cushion. Recently, there has been a great deal of growth in Body Pressure Distribution (BPD) measurement technologies. This growth in technology allows for new perspectives in quantifying ride comfort. Up to this point, the Army has not capitalized on these new technologies and still heavily on absorbed power to quantify ride comfort. This paper explores how the Army has benefited from pressure mapping technologies to complement absorbed power in quantifying ride comfort of military vehicles.

INTRODUCTION

Over the past decade the ground vehicles of the United States Army have gone through many changes. Lately, there has been an influx of larger and heavier tactical vehicles such as the Mine Resistant Ambush Protected (MRAP) vehicles. As the name alludes, one of the primary design considerations of these vehicles is to keep Soldiers safe in the event of a mine blast. However, in the process of rapidly procuring these vehicles, some of them were designed with poor ride comfort due to stiff suspensions combined with uncomfortable seats. As a result, there have been many complaints from Soldiers in theater about the roughness of the ride and the comfort of the seats. This has prompted the Army to take an active role in determining how to test and quantify seat comfort.

In addition to rapid fielding, one could look to the Army's method for measuring comfort as another possible cause for uncomfortable seats. The Army currently relies heavily on Average Absorbed Power to describe ride quality and seat

comfort [1]. However, absorbed power is purely an acceleration based method comparable to ISO 2631, BS 6841 and VDI 2057 used by other industries and nations [2]. However, absorbed power, like other acceleration methods, is inadequate at distinguishing between different seat shapes.

Today, technologies allow for detailed Body Pressure Distribution (BPD) to describe comfort. BPD has been used by automotive companies for years but is not used widely in military applications. Just as acceleration methods have associated metrics like absorbed power, the BPD method also has metrics to help describe comfort. A few of the metrics used are pressure change rate root-mean-square (Pcrms), area pressure change root-mean-square (aPcrms) and seat pressure distribution (SPD%) [3, 4].

Recently, TARDEC has performed a number of tests to measure seat comfort and has been researching how these methods can help the Army improve current and future seats to be more comfortable. However, most studies published on ride comfort are done for automotive and commercial applications [5]. While there are similarities between the commercial and military applications, especially heavy and off-road trucks, the differences are vast. This paper will outline how the Army has benefited from the use of BPD technology as well as explain some of the limitations with applying current methods to military applications.

BACKGROUND

ABSORBED POWER

The absorbed power metric was developed in 1966 by the U.S. Army Tank-Automotive Command (TACOM) [1]. It describes human response to whole body vibration as it relates to ride comfort. In the frequency domain, absorbed power is calculated by,

$$AP = \sum_{i=0}^N K_i A_i^2 \text{ rms} \quad (1)$$

where K_i represents a conversion constant which is a function of the frequency i . The root mean square of the acceleration is $\frac{\text{Watts}}{A_i^2 \text{ rms}}$. The value K_i has units of $\frac{\text{ft/sec}^2}{\text{Watts}}$ which gives absorbed power units of Watts. In general, an absorbed power of 6 Watts is used as a rough upper human tolerance limit. However, drivers will travel beyond the 6 Watt limit if necessary.

PRESSURE CHANGE RATE ROOT-MEAN-SQUARE

In addition to measuring comfort by acceleration, pressure is also used to evaluate comfort. Pressure change rate root-mean-square (Pcrms), was commercially developed as a means of evaluating ride comfort with respect to transient vibrations by measuring pressure [3]. Pcrms is calculated as follows:

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

where T is total time and $P(t)$ is the dynamic pressure. Unlike absorbed power, there is no threshold value for Pcrms that determines what a comfortable seat is versus an uncomfortable seat. It is merely used to compare seats with similar materials. A lower Pcrms value implies the seat absorbs vibrations better than a seat with a higher Pcrms.

AREA PRESSURE CHANGE RATE

Using the Pcrms metric as a foundation, another metric, area pressure change rate (aPcrms) can be used to investigate seat comfort with respect to seat contact area [4]. This metric, developed by a University and a commercial partner, incorporates area in conjunction with a pressure weighting based on the “physiological effect of pressure” [4] and is defined as:

$$aPcrms = \sum_{i=1}^4 A(r_i) Pcrms(r_i) W(r_i) \quad (3)$$

where $A(r_i)$ is the total area that is within the pressure range shown in Table 1. Also, $W(r_i)$ is the weighting factor within the pressure range r_i . Similar to Pcrms, aPcrms does not have a threshold value for comfort and is used to compare seats. However, aPcrms is more appropriately used to investigate a particular event such as a harsh bump while Pcrms is used to describe the entire ride.

Table 1. Pressure Ranges and Weighting Factor Used in Calculating aPcrms [4]

Pressure range, r_i	Weighting Factor, $W(r_i)$
$r_1: 40 \leq p_m(n) < 60 \text{ mmHg}$	$W(r_1) = 1$
$r_2: 60 \leq p_m(n) < 80 \text{ mmHg}$	$W(r_2) = 2$
$r_3: 80 \leq p_m(n) < 100 \text{ mmHg}$	$W(r_3) = 3$
$r_4: > 100 \text{ mmHg}$	$W(r_4) = 4$

SEAT PRESSURE DISTRIBUTION

In addition to aPcrms, the University and commercial partner developed a calculation for the Seat Pressure Distribution (SPD%) [4]. The SPD% is a dimensionless quantity that relates the pressure of each cell to the average pressure to quantify how evenly the seat distributes the pressure of the occupant and is calculated as:

$$SPD\% = \frac{\sum_{i=1}^n (p_i - p_m)^2}{4np_m^2} \quad (4)$$

where p_i is the pressure of the i^{th} cell, p_m is the mean pressure, and n is the number of non-zero cells. The SPD% can be calculated from both static and dynamic riding conditions with the dynamic being calculated by averaging the value at each time step.

MILITARY ENVIRONMENT

Though commercial and military seat applications are similar in that they both hold an occupant stationary in a vehicle, they differ tremendously in the environment in which they operate. From a testing standpoint these differences can impact how the seats are tested and what design features must be focused on to make an accurate determination of the seat's comfort.

One major difference that must be accounted for is what is worn by the occupant. In military vehicles, Soldiers wear body armor as well as other gear such as a Fighting Load Carrier (FLC) vest and a hydration pack. In order for testing to be relevant, this equipment must be worn by the occupant for the duration of the test.



Figure 1. Example of gear worn by Soldiers (a) Individual Body Armor, (b) Hydration system and various FLC equipment