HIGH SPEED CRAFT MOTION ANALYSIS – IMPACT COUNT INDEX (ICI)

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Abstract

High Speed Craft (HSC) operating at speed and over rough water can expose their occupants to a vibration exposure characterised by severe Repeated Shocks (RS).

The ability to describe and quantify the motion is essential but current methods (e.g. RMS, VDV) are considered to be of limited value in HSC environment. It is therefore desirable to have a simple but sensitive measure of RS exposure suited to the HSC environment.

To achieve this, the authors have used the technique of analysing impact magnitude and frequency and displaying the results in the form of an Impact Count (IC) histogram.

The IC is then used to derive an Impact Count Index (ICI), which is simply the percentage of the total number of shocks below a given threshold.

The IC and ICI were used to analyse the results of the testing of two HSC seats known to have different shock mitigation characteristics.

The IC graph clearly indicated differences in shock mitigation performance.

The ICI was more sensitive that the VDV and the frequency-weighted RMS for discriminating between seat performance. It is therefore proposed that the IC and ICI be used for the description and analysis of HSC motion.

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1. Introduction

High Speed Craft (HSC) operating at speed and over rough water can expose occupants to a motion characterised by a sequence of severe and distinct Repeated Shocks (RS). The ability to describe and quantify the motion is essential, but current assessment methods (e.g. the frequency-weighted RMS, or wRMS, and the VDV) are either inappropriate to the high crest factor of the HSC environment, or involve calculations unfamiliar to HSC operators, presenting obstacles when entering into a dialogue on RS and Whole Body Vibration (WBV) mitigation. It is desirable to have a simple but sensitive and informative measure of RS exposure better suited to the to the HSC shock and vibration environment.

2. Methods

Two military HSC ran side-by-side for three hours in a sea-state 2-3 at 40 knots. One of the HSC was fitted with standard In-service fixed seats, the second HSC was fitted with a commercial-off-the-shelf suspension seat. The motion of the HSC was measured using a bespoke system with the following characteristics:

- 3 axis floor mounted accelerometer (Seika B3), rigidly mounted directly under seat.
- Single axis (vertical) seat pan mounted accelerometer (Seika B3) conforming to SAE J1013:1992
- 50g measurement range accelerometer, 10,000g over range capability
- Multi channel digital 16 bit recorder with PC card (Embla A10).
- Seat occupancy pressure pad.
- External weather-proof event mark button.

The data was recorded with the following characteristics:

- Recorded continuously for whole trial run
- 16 bit signal resolution
- 2 kHz sample rate.
- Real time digital filtering and storage at 200Hz
- Measurement bandwidth: DC to 90Hz flat.

A technique of analysing impact magnitude and frequency was used, with and the results displayed in the form of an Impact Count (IC) histogram, displaying frequency of occurrence against the peak (frequency weighted or band-limited) amplitude of each individual shock. The IC is subsequently used to derive an Impact Count Index (ICI) which provides the ability to set objective exposure thresholds.

The main characteristic of boat motion during an HSC transit, even in calm sea-states (<2), was the presence of frequent, high magnitude, vertical shocks (Bass *et al.*, 2005; King and Holmes, 2005; Dobbins *et al.*, 2006). Existing methods of quantifying these shocks have inherent limitations when used in the context of an HSC transit (Sandover, 1998). Peak acceleration values can be important, but the wRMS (W_k) and VDV do not indicate the number of shocks and their individual magnitudes.

The analysis technique used to produce the IC and ICI was as follows:

The vertical accelerations recorded at the deck and at the seat pan during the transit were replayed through commercial signal analysis equipment. When the presence of a shock was detected, the peak acceleration was assigned to one of a series of 'bins', each of which covered a narrow range of peak acceleration values. Preliminary work showed that a suitable range for each bin was 0.2 g. For example, any shock having a peak vertical acceleration in the range 1.0000 to 1.1999 g was assigned to bin 1; shocks in the range 1.2000 to 1.3999 g were assigned to bin 2; etc. This process continued until the vibration and shock signal from the whole of the transit had been analysed. The result was a cumulative sum of impacts – the IC – being in each bin. The result was then plotted graphically as a series of impact counts (on the y-axis) for each bin (on the x-axis). For ease of reading, each bin was labelled not with the range of acceleration that it covered, but the acceleration value of the start of its range. Thus Bin 1 is labelled 0.5g; Bin 2. 0.7g; etc. Experience showed that depending on the sea-state, some low-magnitude bins tended to record general boat motion that was not a true shock. Therefore, the lower bins were discarded and the x-axis begins at a higher acceleration of 1.6g.

3. Results

The motion of the HSC, described in the traditional terms of wRMS and VDV is shown in Table 1. The IC was used to analyse the results of the on-water testing of two HSC seats known to have different shock isolation characteristics.

Table 1. The Whole Body Vibration motion (W_k) of the High Speed Craft seats

		WBV		
		wRMS ($m.s^{-2}$)	**Crest Factor**	**VDV** ($m.s^{-1.75}$)
HSC: Fixed Seat	**Deck:**	2.00	24.0	39.9
	Fixed seat	1.93	25.1	36.8
HSC: Susp. Seat	**Deck:**	1.98	31.8	41.7
	Susp. seat	1.99	15.8	33.8

EU PAD WBV:

- RMS – EAV = 0.5 $m.s^{-2}$, ELV = 1.15 $m.s^{-2}$.
- VDV – EAV = 9.1 $m.s^{1.75}$, ELV = 21 $m.s^{1.75}$.

The impacts measured on the decks of both HSC are shown in Figure 1.

It can be seen that the motion experienced by the craft are similar, particularly above 3g.

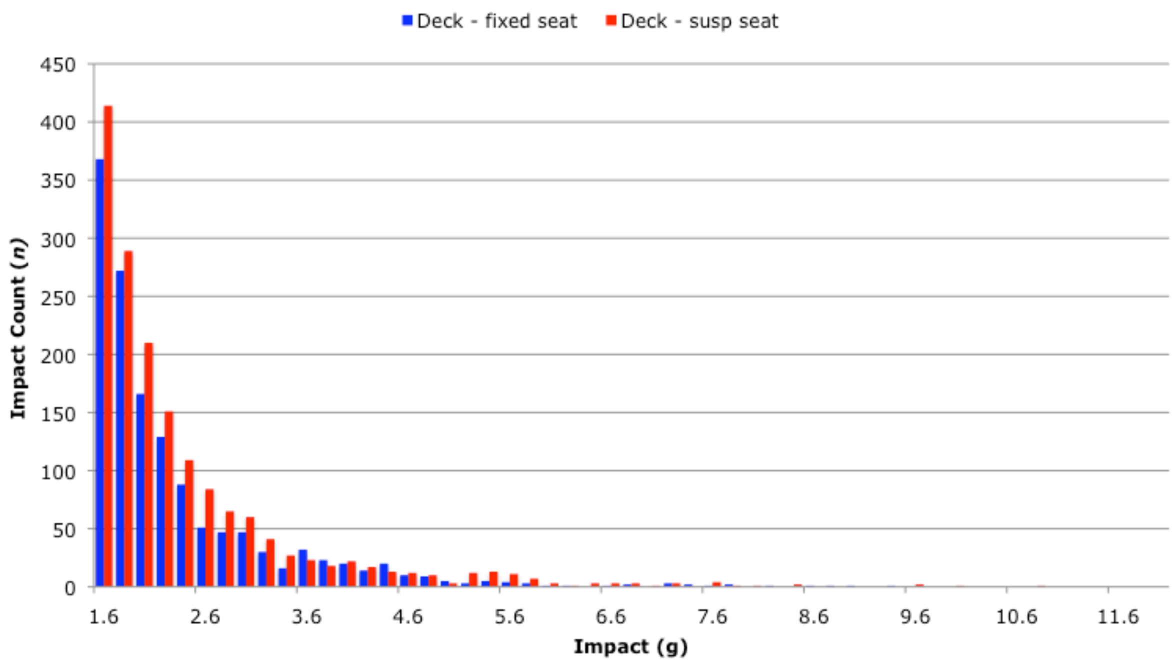

Figure 1. Impact Count graph of the HSC decks.

The IC graph for the HSC deck and the fixed seat is shown in Figure 2. It can be seen that above 2g the IC of the deck and seat are very similar.

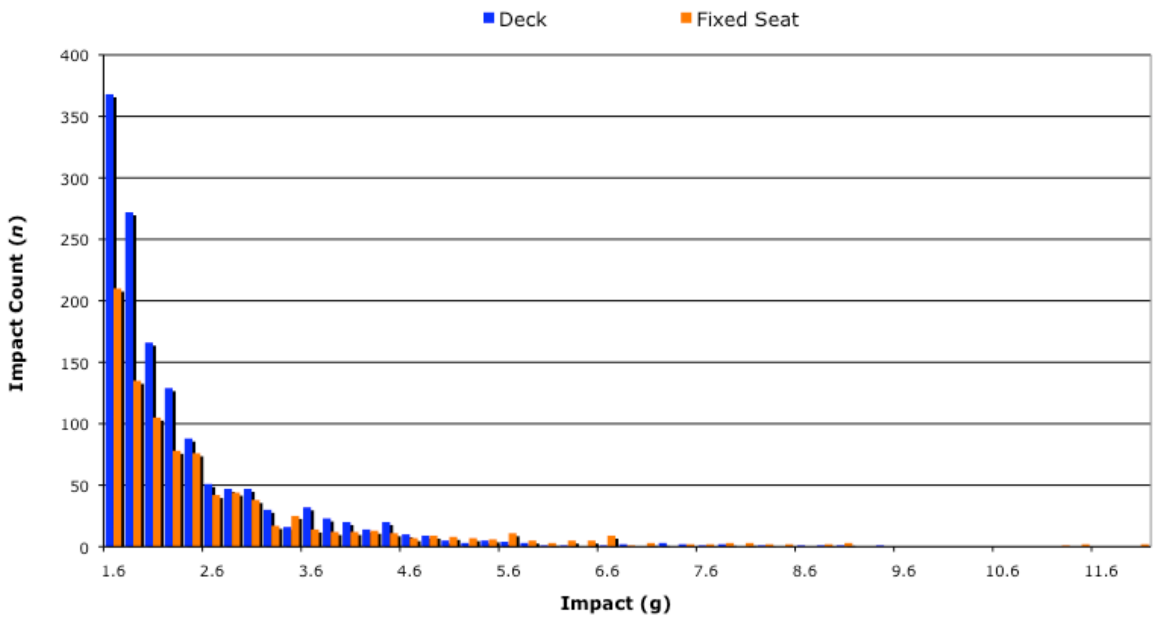

Figure 2. Impact Count graph of the HSC deck and fixed seat

The IC graph for the HSC deck and the suspension seat is shown in Figure 3. It can be seen that the suspension seat substantially reduces both the frequency and the magnitude of the impacts compared to the HSC deck.

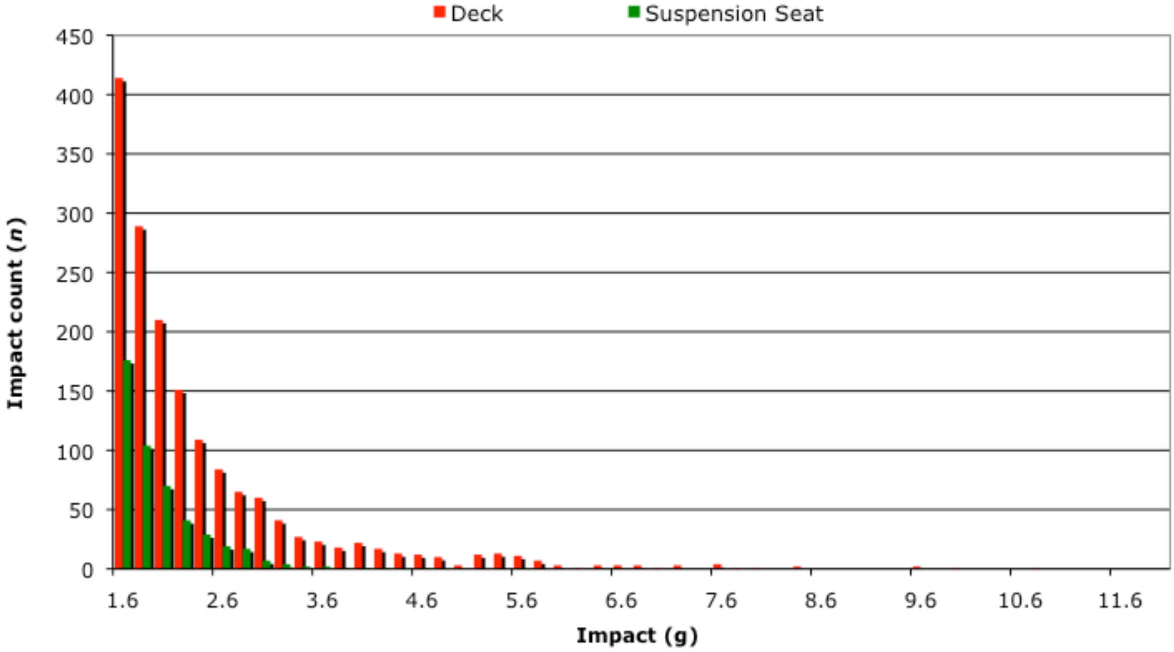

Figure 3. Impact Count graph of the HSC deck and suspension seat

The IC graph comparing the fixed seat and the suspension seat is shown in Figure 4. It can be seen that the suspension seat reduces both the frequency and the magnitude of the impacts compared to the fixed seat.

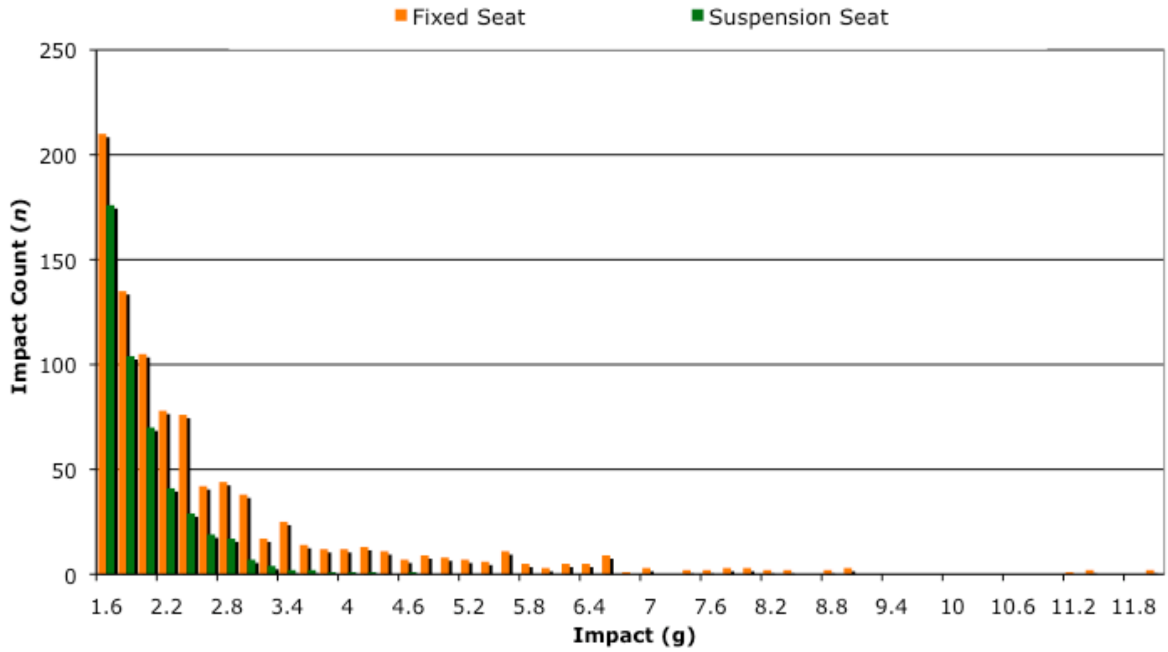

Figure 4. Impact Count graph of the fixed seat and suspension seat

The peak impact acceleration (the same as the peak values used to calculate the Crest Factor) was compared for the different seat types and the HSC decks. The comparisons, including % differences are shown in Table 2. The results show that the suspension seat reduced peak impact acceleration by 62% compared to the fixed seat and by 57% compared to the HSC deck.

Table 2. Comparisons of peak impact acceleration (ICI_{peak}) experienced on the HSC, the fixed seat and the suspension seat.

	HSC		
	Fixed-seat	**Susp-seat**	**% diff**
Deck	9.4g	10.8g	+ 14.9
Seat	12.0g	4.6g	- 62%
% diff	+ 28%	- 57%	

An alternative method of visualising the RS exposure is to use an accumulation of the impact count plotted against the magnitude of the impacts experienced. The data for the fixed and suspension seats are shown in Figure 5. This methodology provides an intuitive description of how the suspension seat reduces both the number and the magnitude of the impacts.

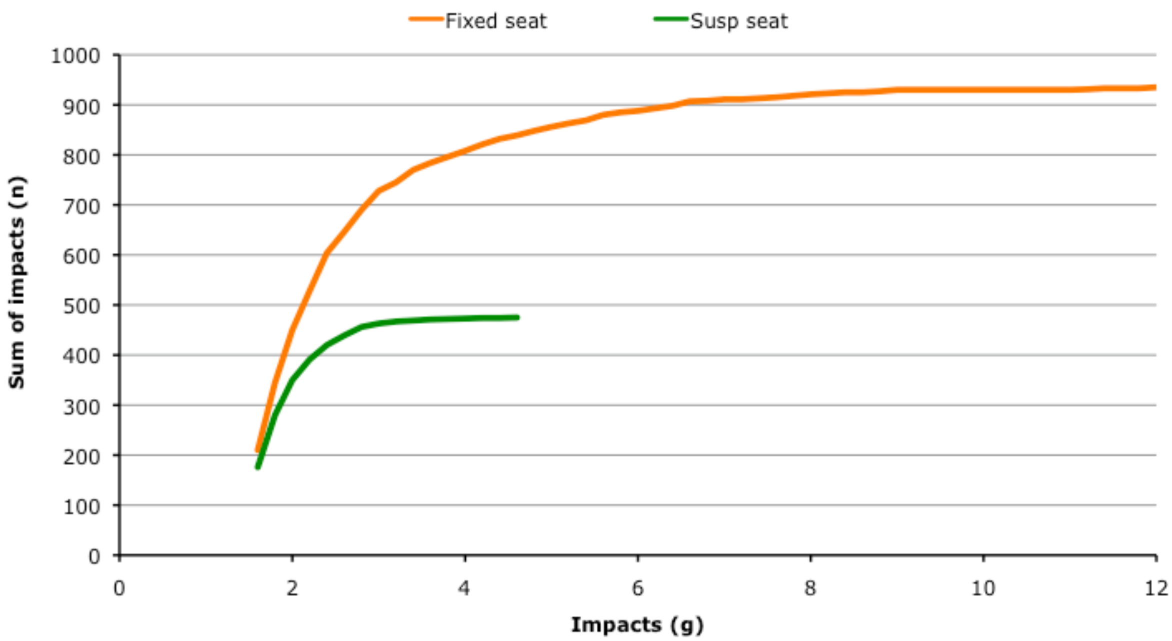

Figure 5. A comparison of the HSC seat types using the sum of the impacts.

Further analysis of the accumulated impact count data was conducted by plot the number of impacts with a peak acceleration of less than a specified value as a percentage of the total impact count. This methodology provides the ability to define exposure criteria that may be used to intuitively evaluate and limit exposure to RS. The example shown in Figure 6 and Table 3 illustrates the fixed and suspension seat data along with ICI criteria of 95% ($ICI_{95\%}$) and 99% ($ICI_{99\%}$) of the total impact count.

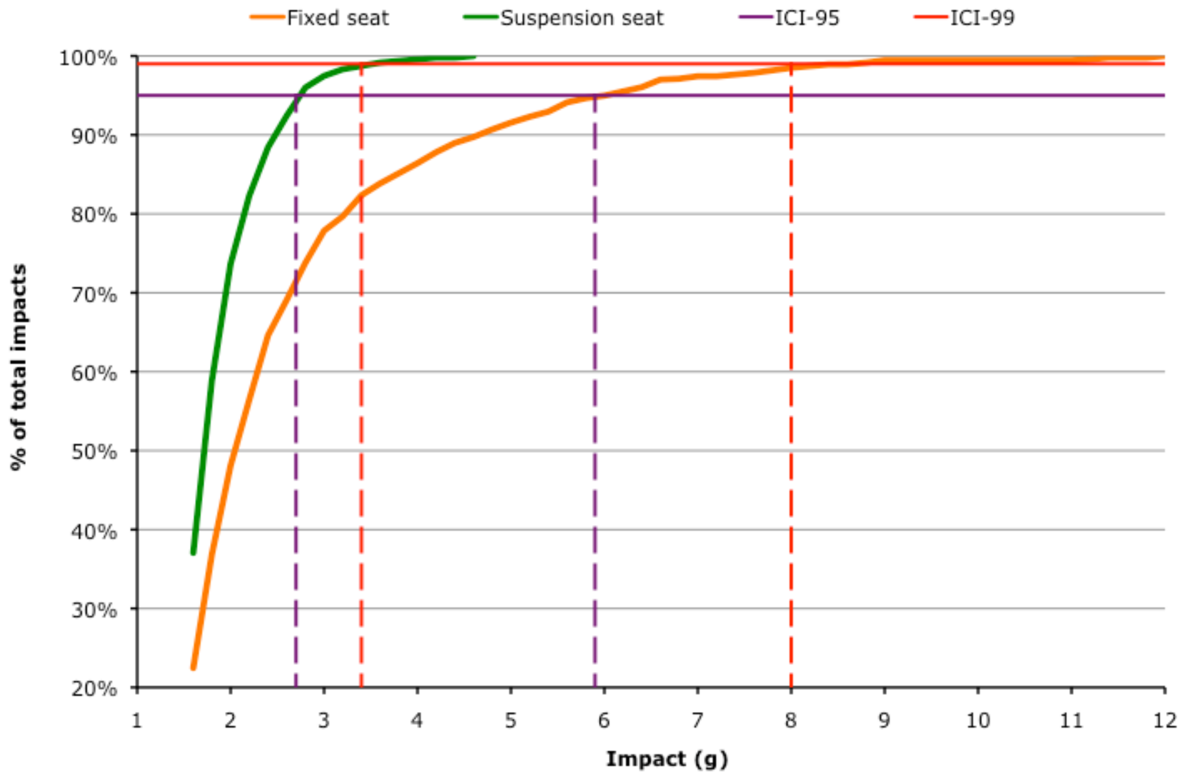

Figure 6. A comparison of the seat types using the sum of the impacts described as a percentage of the total number of impacts. The Impact Count Index for the 95% and 99% criteria are indicated demonstrating how the ICI can be used to provide a measure against which a system can be evaluated.

Table 3. The 95% and 99% and peak Impact Count Index (ICI) values for the fixed and suspension seats.

	Fixed Seat	**Suspension Seat**	**% Difference**
$ICI_{95\%}$	5.8g	2.7g	53%
$ICI_{99\%}$	8.0g	3.4g	58%
ICI_{peak}	12.0g	4.6g	62%

4. Discussion

The IC was found to clearly demonstrate differences in shock mitigation performance between the two seat types. The ICI was found to be more sensitive than both the VDV and the wRMS, as a measure for discriminating between seat performance. The ICI expressed as a proportion of the total count is inherently more robust than the crest factor, which is reliant on a single instantaneous acceleration measurement. The ability of the ICI to set an intuitive exposure limit makes the analysis technique a valuable tool for HSC sector stakeholders. For example, a 3.5g $ICI_{99\%}$ exposure limit could be specified. In this case, the suspension seat would have an acceptable exposure profile but the fixed seat would be unacceptable. This concept is shown graphically in Figure 7.

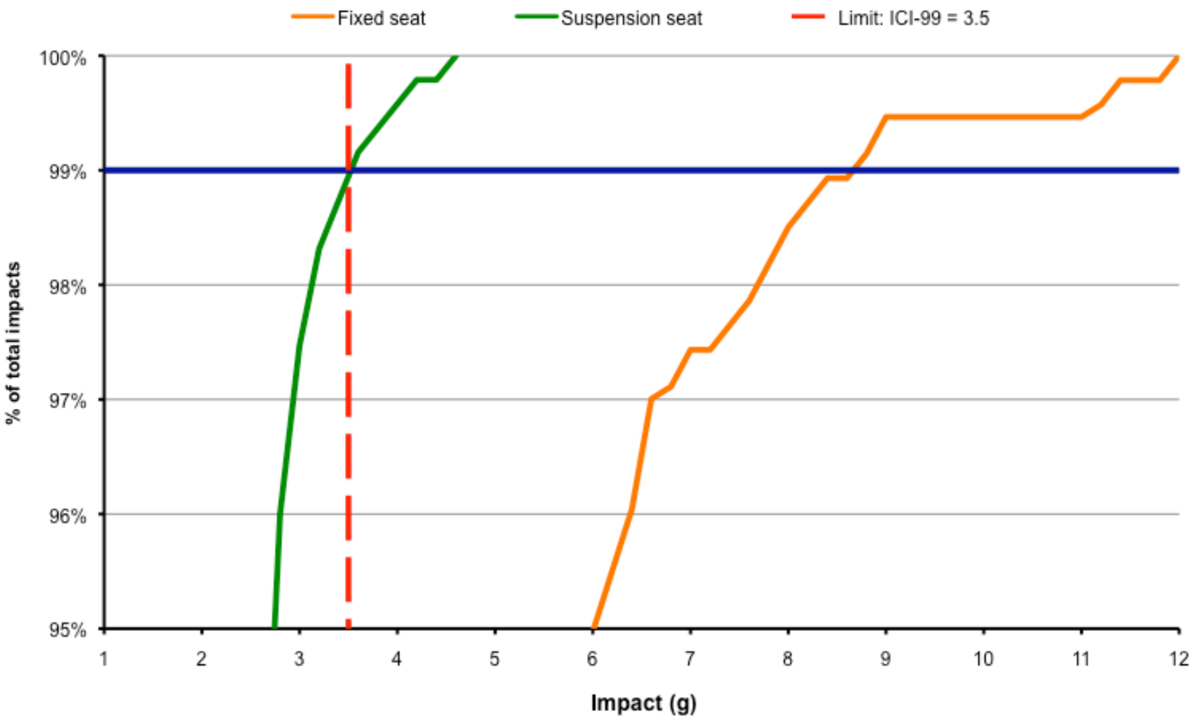

Figure 7. A graphical demonstration of the use of a 99% Impact Count Index exposure limit of 3.5g used as an acceptance criteria for a HSC suspension seat.

The IC/ICI was calculated using unweighted but band-limited acceleration measurements rather than specific comfort weightings (e.g. W_k) This approach was taken as HSC operators may perceive HSC motion differently from a more general population exposed to lower amplitude motions less distinctive time domain characteristics (e.g. Dobbins *et al.* 2008).

5. Conclusion

The IC and ICI analysis methods provide an intuitive method for analysing the effect of shock mitigation methodologies, e.g. suspension seats, in HSC. Feedback from HSC operators has been positive for the use of the IC/ICI technique over traditional shock and vibration analysis methods as it provides an intuitive method of analysing HSC RS data. Further work is ongoing to link the IC/ICI analysis methodology to indices of Motion Induced Fatigue (MIF) (Myers *et al.* 2008) and acute and chronic musculoskeletal injury. It is therefore proposed that the IC and ICI analysis methods be used for the description and analysis of HSC motion, in addition to traditional vibration methods, for quantifying RS and WBV exposure.

6. References

Bass, C., R. Salzar, A. Ziemba, S. Lucas and R. Peterson (2005). The Modeling and Measurement of Humans in High Speed Planing Boats Under Repeated Impacts. *Proceedings of the 2005 International Research Council on Biomechanics of Impact Conference.* Prague, Czech Republic: 397-410.

Dobbins, T., Myers, S. and Hill, J. (2006) Multi-axis shocks during high speed marine craft transits. *Conference proceedings: 41st UK Group Meeting on Human Response to Vibration, Farnborough, UK.*

Dobbins, T., Myers, S., Dyson, R., Gunston, T., Pierce, E., Blankenship, J. and LaBrecque J. (2008) Discrepancies between the perceived discomfort of experienced high speed craft operators and current standards. *Conference proceedings: 43rd UK Group Meeting on Human Response to Vibration, Leicester, UK.*

International Organization for Standardization (1997). Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements, ISO 2631-1:1997, International Organization for Standardization.

King, S. and S. Holmes (2005). Assessment and evaluation of suspension seats on reducing human vibration exposure in Rigid Inflatable Boats. Farnborough, QinetiQ Ltd.

Myers, S., Dobbins T., King, S., Hall, B., Gunston, T., Holmes, S. and Dyson, R. (2008) The effectiveness of shock mitigating technology in reducing motion induced fatigue in small high speed craft. Conference proceedings, International Maritime Conference, Pacific 2008. Sydney, Australia.

Society of Automotive Engineers (1992). Measurement of whole body vibration of the seated operator of off-highway work machines. SAE J1013, Society of Automotive Engineers.

Sandover J. (1998) The fatigue approach to vibration and health: is it a practical and viable way of predicting the effects on people ? Journal of Sound and Vibration, Vol. 215(4), pp. 699-721.