

# Tackling human impact exposure on high-speed boats

There is still much confusion regarding what is actually safe and what can prove dangerous when it comes to whole body vibration and human impact exposure aboard high-speed, slamming-prone craft. Johan Ullman of High Speed Boat Operation Professionals (HSBO Pro) demystifies the debate, providing a practical overview of the actual risks involved and highlighting some of the shortcomings in the current directives

**H**uman impact exposure and resulting crew injuries are increasingly capturing attention among professional operators, naval architects and boatbuilders. As marine technology evolves and boats are pushed to go faster and faster, both vessel hulls and mariners are subject to increasing levels of strain, subsequently limiting the operational envelope.

Currently, this is still a relatively young field of research, where relevant data can be scarce. The rules and legislation being created are rarely based on scientific evidence, which makes it even more important for naval architects and boatbuilders to understand and solve these problems themselves (see Box, p36).

Boatbuilders and naval architects should be encouraged to design and build boats that do not only comply with legislation, but provide the best possible work environment on board.

This paper explains what is relevant to know and understand, to build safer and more comfortable boats.

## Design aspects

Let us consider the most important aspects to prevent injuries caused by impact exposure.

Hull design is crucial and the trade-offs between top speed, ride quality and stability is an eternal challenge.

Good cockpit design is very important in order to optimise the work environment for the crew. This does not constitute



Lab testing alone is no substitute for slamming data gleaned from sea trials



High-speed vessel hulls are being put under increasing amounts of strain – as are their personnel

any trade-off, as the human-factors optimisation normally saves cabin space and sometimes even weight.

The need for suspension seats, mitigating human impact exposure, is no longer controversial.

New technical solutions are brought forth on a regular basis. This makes it necessary to understand what works in real life, and how it works.

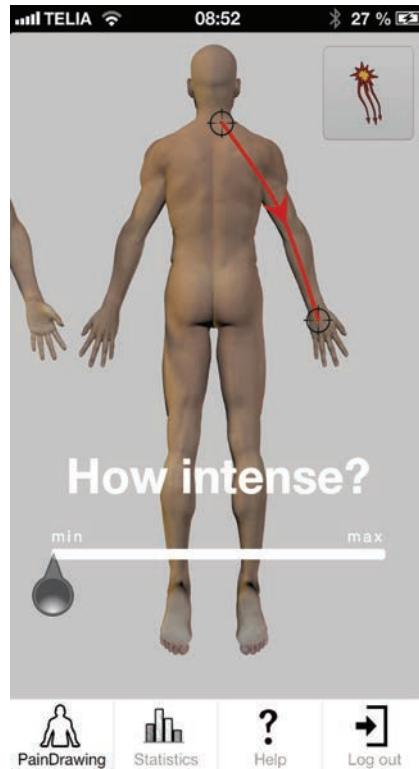
The basic demands are:

- No bottoming out (the term for when suspension systems violently reach the end of their stroke, exceeding their design limitations). Suspension seats bottoming out have been shown to multiply high hull impact loads by more than three times on the human body
- The best possible energy absorption, over the full spectrum, from small vibrations up to very high peak impacts
- Optimal postures. The shape of the spine is crucial under exposure to vibration and even more so under impact. When keeping the S-shaped form of spine, naturally maintained in standing, the spine is less susceptible to injury than when seated in a traditional posture with the Spine in a C-shape
- Lateral impact absorption – this reduces the risk of spinal injury, high as well as low, and reduces the risk of ejection when boats slip and trip. Even professional boats seem to be involved in 'slip trip and flip' accidents more frequently now

It is worth noting that, when seeking to prevent physical fatigue, caused by severe impact exposure, the above points are equally valid considerations. First of all, they help to reduce impact exposure. Over time they can also bring benefits such as increased crew comfort, the ability to relax, the feeling of safety and the ability to maintain a proper posture during all operations.

### Measuring 'dangerous' exposure

The level of impact that the human body can be exposed to without sustaining injury is highly individual. It is not possible to say when an impact of 4g, 8g or 10g will cause injury. Several factors influence the risk of injury; for example, the number of



The free PainDrawing app can be utilised to measure, quantify and register pains experienced by crew members

impacts, peak levels, duration of exposure, individuals' medical conditions, and so on. Work is ongoing to establish what levels of exposure are safe as opposed to dangerous.

Pain is the only measurable physiologic parameter that can be justified to use as an indicator of incipient injury. That is actually what pain is for. The sole reason it exists is to tell us what is harmful.

Pain can be measured, quantified and registered. That has been done for decades. A new smartphone app has recently been launched for this purpose. PainDrawing can be downloaded for free ([www.paindrawing.com](http://www.paindrawing.com)). It is based on scientifically validated methods and optimised for ease of use, in order to reach maximum compliance.

By registering any development of pain over time and comparing it with impact exposure data, it should be possible to find out which levels of exposure cause pain and which do not.

### Suspension seat performance

True performance of suspension seats can only be tested at sea, where all kinds

of impacts, with various peak levels, directions, rise times and durations, are at hand. Because the input is stochastic, studies have to be controlled. This means that trials have to be done side-by-side with the same hull exposure input.

Seats tested should be mounted side by side, because the vertical impacts vary greatly from stern to bow. Hence only two or possibly three seats can be compared in each test set-up.

Crossover design should be used, meaning that, in order to compensate for individual differences in anatomy or reaction patterns, the subjects should ride in both seats.

What, then, are relevant factors to measure? Impacts on the human body should be measured, preferably as close as possible to the spine or pelvis, including both the number of impacts and their peak levels. Measuring of the seat does not give a good enough picture of human exposure.

The number of impacts surpassing 2.0g should be logged and plotted as histograms for each peak level of impact, segmented in 1.0g increments from 2.0g up to the highest impacts measured. This method makes it easy to visualise and compare impact exposure.

Subjective assessments of comfort/discomfort under impact also provide relevant information. This is because the human body has very sophisticated systems for registering discomfort, which is a relevant parameter. The standard method for subjective ratings is a simple one known as the Visual Analogue Scale (VAS).

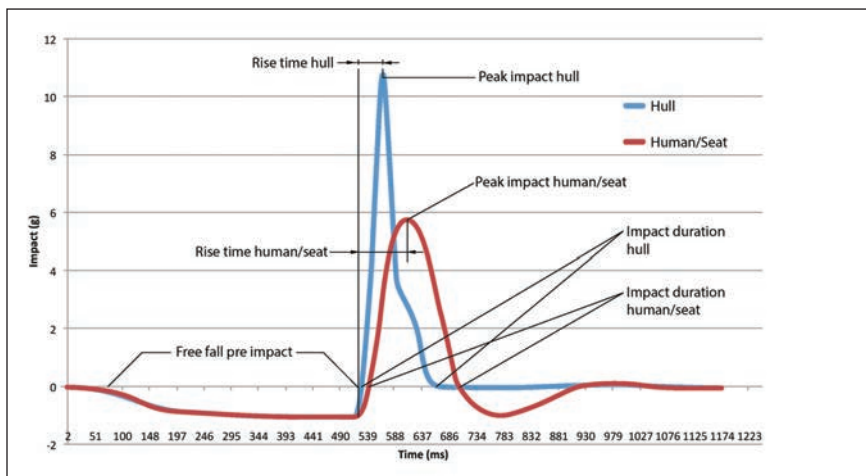
### Lab testing: a solution?

Currently, various methods for the standardised testing of suspension seats are being developed around the world. Boatbuilders and end users are demanding methods which evaluate the function of suspension seats in use and for future acquisitions.

Lab testing can be relevant: testing the performance of suspension mechanisms in standardised. Pure vertical test models can be used to identify non-functioning or poorly functioning technologies. However, it cannot be used for assessing actual performance in real operations and conditions.

Lab testing alone does not give sufficient information about different suspension seats' capacities to protect crew from dangerous exposure. Reasons for this include the facts that:

- The impact exposure at sea is so severe that people do get injured. Experiments exposing subjects to these levels of exposure is not possible, nor morally acceptable
- The impact exposure at sea is stochastic, and multidirectional
- Lateral forces acting on the spine are more dangerous than pure axial forces
- Human bodies react to impact with muscular reflexes, protecting and stabilising the body and absorbing energy
- The human body's reaction to impact exposure depends on a number of factors, such as: body posture; the



The typical shape of an impact on the hull and on a person in a functioning suspension seat

preceding moment of weightlessness; visual impressions; vestibular impressions; tactile feedback from the

hull, through arms and legs; training effects (conscious and non-conscious), etc. Without these effects, the exposure

## RINA-QinetiQ Maritime Innovation Award

Innovation is key to success in all sectors of the maritime industry, and such innovation will stem from the development of research carried out by engineers and scientists in universities and industry, pushing forward the boundaries of design, construction and operation of marine vessels and structures.

The Royal Institution of Naval Architects – QinetiQ Maritime Innovation Award seeks to encourage such innovation by recognising outstanding scientific or technological research in the areas of hydrodynamics, propulsion, structures and material which has the potential to make a significant improvement in the design, construction and operation of marine vessels and structures.

The Award is made annually to either an individual or an organisation, in any Country. Nominations for the Award may be made by any member of the global maritime community, and are judged by a panel of members of the Institution and QinetiQ. The Award will be announced at the Institution's Annual Dinner (tbc).

Nominations are now invited for the 2014 Maritime Innovation Award. Individuals may not nominate themselves, although employees may nominate their company or organisation.



**QinetiQ**

- Nominations may be up to **750 words** and should describe the research and its potential contribution to improving the design, construction and operation of maritime vessels and structures,
- Nominations may be forwarded online at [www.rina.org.uk/MaritimeInnovationAward](http://www.rina.org.uk/MaritimeInnovationAward) or by email to [MaritimeInnovationAward@rina.org.uk](mailto:MaritimeInnovationAward@rina.org.uk)
- Nominations should arrive at RINA Headquarters by **31 December 2014**
- Queries about the award should be forwarded to the Chief Executive at [hq@rina.org.uk](mailto:hq@rina.org.uk)

would cause more and more severe injuries. These reactions cannot be simulated in a lab situation

- Impacts at sea also vary in character depending on the weight of the hulls, dead rise and seakeeping.

Seat performance, and the capacity of seats to protect vessel occupants from dangerous impact exposure, can only be tested with live human occupants, on board, under actual exposure at sea.

The most efficient and scientifically prudent way to compare performance is in side-by-side testing, while measuring impacts on the bodies of the subjects seated in the seats.

Impact exposure varies significantly depending on where in the boat you make the measurements. As a rough rule of thumb, impact peak levels at the stern are half of those at the centre of gravity (COG). The forces in the bow can be twice as large as those at the COG, and half at the transom. Hence, comparisons should be done side-by-side at the same longitudinal position.

It is also important to gather subjective assessments from the test subjects. This is because there is a correlation between experienced pain and discomfort while exposed to impact and harmful exposure.

It is worth noting that standards

and regulations keep changing as knowledge expands.

The human body, however, hasn't changed much in the last 1,000 years and will keep reacting or failing in the same ways, when exposed to the same hardship.

This is why true injury prevention should be the main objective along with striving to comply with standards and regulations.

Impact Count and Impact Count Index (ICI) is a new way of presenting true exposure data. It presents the number of impacts and their peak values, as described above, and is and has good correlation with physical fatigue and subjective ratings. Its use is therefore recommended for scientific comparisons. *SBI*

## Common misconceptions regarding human impact exposure

There are many misconceptions as to what counts as 'relevant' guidance in protecting against human impact exposure. HSBO PRO lists 12 of these below

- 1) "Existing standards can prevent injuries"

All existing standards are based on differently tweaked mean values of vibrations, not impact exposure. Hence they can only give very rough indications of when it gets dangerous. They can probably be used to predict physical fatigue.

- 2) "The EU directive and its limits for allowed exposure is based on scientific evidence"

There is no scientific evidence to support the limits suggested in the EU directive. Similarly, there is no scientific data published to support any specific exposure as being 'safe' or 'dangerous', neither any to support any peak acceleration levels as being dangerous.

The main weakness with the EU directive is that it is based on vibrations, not on compression forces. The result of this is that you can be exposed to clearly dangerous impacts causing acute injury without surpassing the limits. You can also by far exceed the

allowed limits without being subject to dangerous exposure.

The EU directive can be used to project physical fatigue, which is one relevant factor, but not to define limits for safe impact exposure.

- 3) "Root mean square (RMS) values can be used to assess risks of acute injury"

RMS values cannot be used to calculate the compression forces in each impact. The compression forces depend on the peak value of each impact. Higher peak acceleration means higher compression forces.

The risks of acute injury also depend on the duration of the impact. Longer duration of the same compression force increases the risk of structural failures, such as fractures or disc ruptures.

- 4) "RMS values can be tweaked in different ways to be made useful to assess risks of acute injury"

There is no way in which RMS values can be tweaked to be useful to calculate the compression forces in each impact.

RMS values are mean values and 'hide' the peak values, even when tweaked with the different algorithms.

- 5) "Natural resonance frequency of lumbar spine specimens ( $\approx 5\text{Hz}$ ) indicate dangerous frequencies for impact exposure."

There is no scientific evidence that resonance in the spine after singular impacts has any relevance for the risk of structural failure of vertebrae or discs. Exposure to continuous vibration at frequencies around 5Hz is believed to contribute to structural fatigue but that is not relevant for exposure to impacts occurring once per second or less.

- 6) "Frequencies over 10 - 30 Hz in impacts, have no mechanical effect on anatomical structures"

There is no scientific evidence to support this, nor any to justify filtering out higher frequencies measured on the human body. Structural vibration in higher frequencies is however a confounding factor and can give false high values for hull impact.

It is worth noting that the human body in itself functions as a Low Pass filter, absorbing higher frequencies especially in the soft tissues.

7) *“Acceleration rise time is not relevant”*

Rise time (the duration of the increase from 0 to peak), AKA ‘jerk factor’, is highly relevant. The faster the onset (change of acceleration), the more severe the compression forces.

For example: when the rise time is ≈ 1 second, the entire body is basically accelerated homogeneously and relative displacement is negligible. When rise time is just 0.02 seconds, a shockwave travels up the spine. This can cause relative displacement (compression) and, potentially, injuries.

8) *“Adjustability is an important feature for suspension seats”*

There is no scientific evidence to support that adjustable suspensions are safer than progressive suspensions. Compliance is a practical issue and several anecdotal reports exist, indicating that adjustment of suspension is no more common than height adjustment of the backrests in office chairs, which is well known to be very close to zero.

9) *“Height adjustability reduces risk of injury”*

Height adjustability of boat seats is seen as a requirement in some tender specifications. This rarely comes with an explanation of whether taller individuals should be seated higher or lower.

It is important that operators have good visibility of the sea and instruments and that postures are not compromised by geometrical constraints. It is also important to feel the boat’s motion with your feet. There is very rarely any need to change the height of the seat pan.

10) *“Lateral supports prevent injuries”*

There is no scientific evidence to support that lateral supports for the torso prevent injuries.

There is, however, good reason to believe that lateral supports for the torso sometimes prevent ejections.

**The directives currently in place**

Several standards for human impact exposure exist, though none of these are based on scientific evidence. They are all based on RMS and differ from each other in how the RMS data is processed by algorithms, resulting in some differences depending on the number of registered impacts.

Different choices and treatment of input values and varying designs of algorithms result in some differences in output data depending on the impacts received.

The most commonly used and referenced are:

- European Union Directive 2002/ 44/EC, which is now law in all EU countries. It stipulates allowed levels of vibration that passengers and crew can be exposed to. The EU directive states limit for allowable exposure to mean values of ‘whole body vibration’, not on exposure to impact
- ISO 2631-5, “Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 5”. The ISO 2631-5 is based on mean values of vibrations, but algorithms have been added give higher values when single impacts are recorded. This standard only applies to impact levels lower than 4g, and has no scientifically proven correlation to any injury risks. This makes it irrelevant for most high-speed craft
- Annex 10 of 2000 HSC CODE, International Code of Safety for High-Speed Craft, is a structural guideline aimed at ensuring that seats and other components fitted on a craft will not come loose in case of collisions. The standard includes stress-testing procedures for components and fittings. This standard does not concern the exposure of humans, and the impact levels for testing are lower than the forces normally measured on high-speed craft
- MGN 436, UK Maritime and Coastguard Agency, Marine Guidance Note, is a recently published document that is relevant for human exposure

In other cases, high lateral supports can cause excessive lateral deflection of the neck, causing neck injuries. Several ejection accidents have occurred in recent years, normally caused by ‘slip, trip and flip’ events. Some of these have resulted in lethal injuries. There is also good reason to believe that straddle support for the thighs can reduce risk of ejection.

11) *“Soft deck materials can reduce risk of back injuries”*

No scientific evidence supports this statement. However, soft deck materials can absorb high frequency components in impacts. This increases comfort and most probably has a protective effect

on cartilages in wrists, knees and hips when standing.

To some extent even shock absorbing soles, as found in jogging shoes, will have a similar effect.

12) *“Standing up will protect the body under impact”*

Standing up puts your spine in a better position than traditional sitting. This is good, but not sufficient. Standing up can actually multiply impact levels on the human body by up to three times those measured on the deck.

The effects of high impact on straight or almost-straight legs can be enough to cause severe injury. **SBI**