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Human impact exposure on fast boats

Carl Magnus Ullman presents us with a walk-through guide to human impact exposure, with questions answered and myths dispelled.

Most boaters know that slamming at speeds in rough conditions can be dangerous. The topic of injury risks on slamming fast craft is still gaining increased recognition, even among leisure boat owners. This is not least due to media attention on a number of accidents where boat owners, as well as innocent paying passengers, have been injured in severe slam events.

Research is ongoing, mainly sponsored by military and coastguard agencies in various countries.

A number of standards exist, as well as different methods of boiling down exposure data to single-figure values. Hugo Montgomery-Swan asked me to clarify the subject and point out what is relevant to know and to understand.

First of all, acute injury does not come as a result of vibration, but as a result of impact. This is well known in the scientific community. So why has 'whole body vibration' come into this field? It is simply because there have been no standards regulating or limiting the exposure to impact. So the EU committee just had to use the closest ones they could find: ISO standards developed for lorries and forestry machines. Vibration is not good. Extensive exposure can cause problems over time, adding to aging of discs and cartilage, but this is not of great relevance for the risk of acute injury – especially not for leisure boating people.

Let's forget vibration, whole body vibration, WBV and similar acronyms and focus instead on impacts. The most severe injuries, seen as a result of bad slamming events, include fractures to vertebrae and extremities and rupture of intervertebral discs, even in the neck. Distortions are common but normally less serious.

How bad a slamming is acceptable?

A good rule of thumb is that anything that hurts is potentially dangerous. Pain will usually be the first indicator of an injury. It is wise not to accept travelling in HS craft in such a way that you experience severe discomfort or pain, regardless of whether this appears at 4g or 13g impacts. It is also dangerous to claim that certain wave conditions and directions are more dangerous than others. Injuries can occur regardless of wave direction, and the risk is proportional to the level of energy in the slam.

Standards

EU Directive 2002/44/EC

Does the EU directive apply? Yes – it is the law in all EU countries and applies to boats being operated professionally – as well as in tourist/joyride applications. It defines the maximum level of exposure you are allowed to subject employees or paying passengers to. These limit values are so strict that they are normally exceeded within minutes on an 8–10 m boat doing 35 knots in 0.7m waves. So when someone claims that, with this or that boat, or this or that seat, you will comply with the EU directive, it is just not true! It will only be true if you don't leave the dock on a windy day.

Derogations from the EU directive can be granted, but only on a national level, and only on the condition that all reasonable measures are taken to reduce the impact exposure. This includes, for example, using the proven best shock mitigation technologies available. The EU directive does not apply to privately used leisure boats.

ISO 2631

This is the original standard for whole body vibration. Not relevant.

ISO 2631:5

This is an updated version, with algorithms tweaked to give higher values, if there are a significant number of high-level impacts in the raw data. The problem is that it doesn't show much difference. Single severe impacts disappear completely. This standard should not, according to the authors, be used for anything producing impacts over 4g. Not relevant.

Annex 10 of 2000 HSC CODE, International Code of Safety for High-Speed Craft.

This annex is put in place to make sure crew and passenger seats, on boats and ferries, do not break or become detached from the deck, under collision or when running a ground. It has no bearing on the function or performance of suspension seats. The limits for structural failure are lower than the forces acting on HS boats under severe impact. It deals mainly with horizontal forces. Seats claimed to comply with this standard are known to have failed, with injured operators as a result.

MCA Marine Guidance Note MGN 436

This is a new document (Sept 2011) based on understanding of new research and technologies. The recommendations are relevant!

Terms and units used in the standards

RMS or Root Mean Square is defined as 'the square root of the arithmetic mean of the squares of a set of values, used as a measure of the typical magnitude of a set of numbers, regardless of their sign'. In this context, it is used as an average value of how much energy is transmitted through vibration over a period of time. It does not say anything about single impacts and is normally not affected by single impacts.

The beauty of today's new technology is that measuring impacts now is so easy that basically anyone can do it.

Above: Royal Australian Navy RIB fully loaded with gear and crew (on heavier boats having softer peak impacts). Main: Deep-V hull displacing water effectively.

Applying RMS value limits, it is not dangerous to fall out of a window on the sixth floor, because, over a period of one minute, you have not received more energy exposure than you should be able to sustain …

VDV, or Vibration Dose Value, is a single-figure value for cumulative RMS values over an 8-hour or 16-hour period – and the same as above is true.

Crest factor is calculated by dividing peak values by therm value. So the more vibration, the lower the crest factor. It indicates, not the impact exposure, but the difference between the impacts and the vibration.

Sed8, defined as 'the human exposure for accumulated spine stress dose, normalized to an eight-hour exposure', is another single value unit, based on the ISO 2632:5 standard.

ICI, or Impact Count Index, is a straightforward way to measure impacts, counting them and recording what you measured – how high the impacts were and how many: the real impact exposure. The ICI method is easy to understand and to use in exposure studies.

Are any of these values linked to the risk of injury?

No. There are no experimental scientific data linking any of these values to definable injury risks. But there is one great difference. ICI presents the real exposure data, untampered with, which means that you can see how high the impacts actually were. It also has a good correlation with rating pain and discomfort. ICI is therefore better as a basis for future, more relevant standards. ICI has also been shown to correlate well with physical fatigue, which is assumed to increase the risks of injury.**(Fig. 3)**

What exposure limits are safe?

The simple answer is that no one knows. You can go out and get slammed beyond what is healthy and still stay within existing standards' limits if you just don't stay out too long, and you can easily exceed the limits, over time, without getting injured. The reason is that all the standards are based on algorithms, based on older algorithms, based on vibration dose measurements and comfort ratings done on lorry drivers in the 1960s.

These algorithms are based on RMS values and the new standards tweak these RMS values in ever more sophisticated ways, all in attempts to describe exposure during a day at sea, in one single figure. No one has yet come up with the idea of describing the impact on fighter aircraft pilots, ejecting with ejection seats, in terms of RMS values or whole body vibration. Impact levels there are comparable to the most extreme impacts we measure on HS craft (in the range of 20g).

Pain is the best indicator of impending injury. If it hurts – don't do it! If the slamming is really uncomfortable, it will, over time, wear down structures in your body that you want to keep intact for the future, like discs and knee cartilages.

How do I find out?

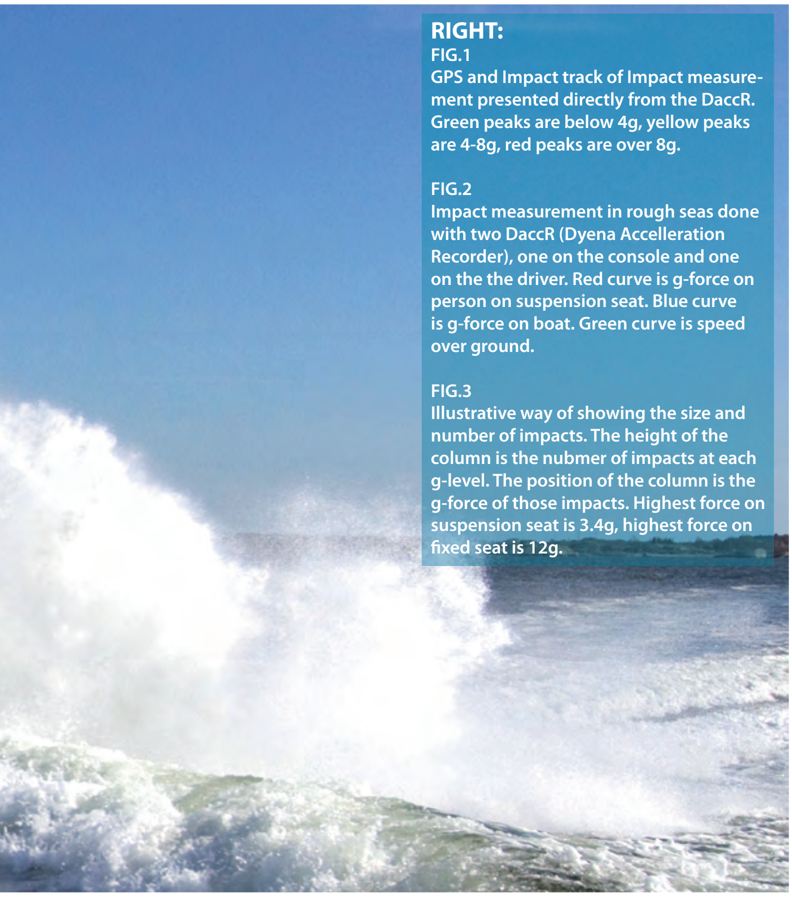
The beauty of today's new technology is that measuring impacts now is so easy that basically anyone can do it. New devices are available on the market, with user-friendly interfaces, built for the user not just for the scientist. **(Fig. 2)**

This means that you can measure the exposure you are subject to and get the data up on your own computer screen, presented as the number of impacts and the severity of each. You can even see where you got slammed and when**.(Fig. 1)**

What about limiting impact exposure?

Hull shape: Deeper V-shaped hulls slam more softly on the surface by displacing water more gradually.

Posture is important for good control of the boat and for withstanding impact exposure. A slouching, C-shaped spine is more vulnerable than a balanced S-shaped spine.



RIGHT:
FIG.1
GPS and Impact track of Impact measurement presented directly from the DaccR. Green peaks are below 4g, yellow peaks are 4-8g, red peaks are over 8g.

FIG.2
Impact measurement in rough seas done with two DaccR (Dyena Accelleration Recorder), one on the console and one on the the driver. Red curve is g-force on person on suspension seat. Blue curve is g-force on boat. Green curve is speed over ground.

FIG.3
Illustrative way of showing the size and number of impacts. The height of the column is the nubmer of impacts at each g-level. The position of the column is the g-force of those impacts. Highest force on suspension seat is 3.4g, highest force on fixed seat is 12g.

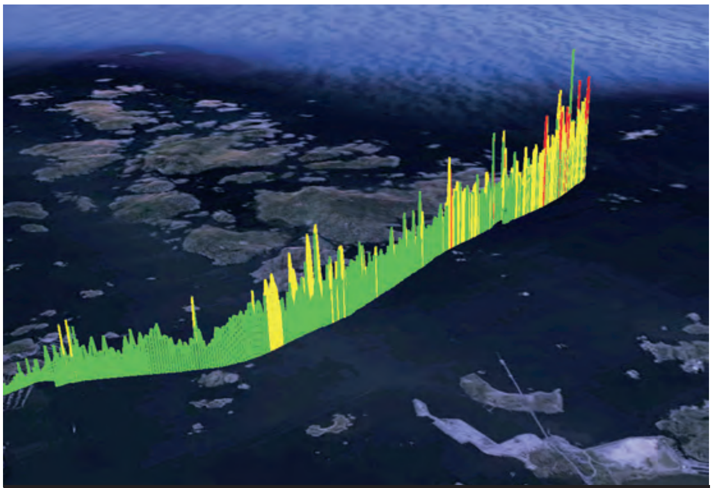


FIG.1

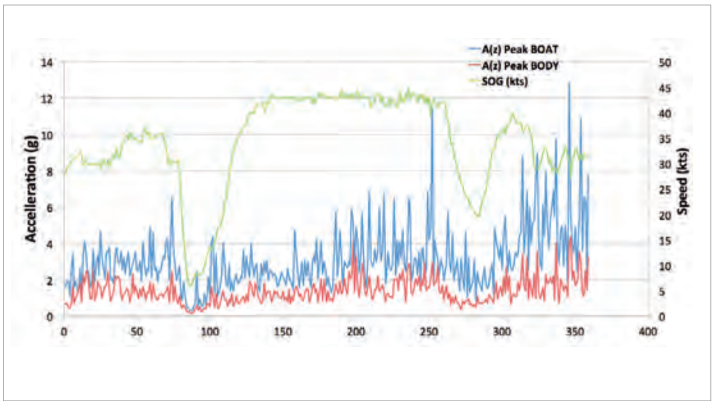


FIG. 2

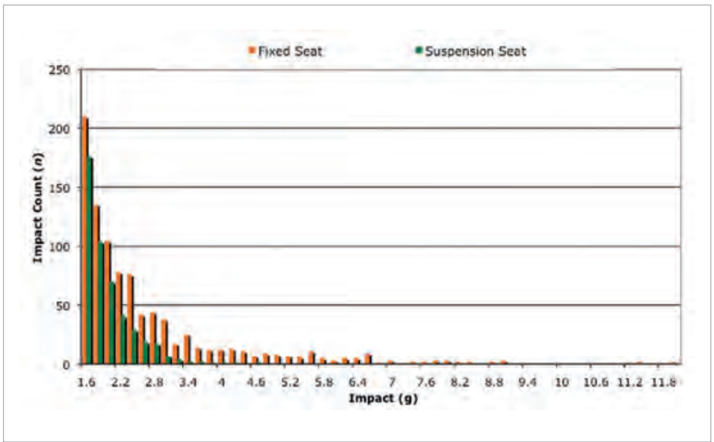


FIG. 3

A shallower deadrise gives higher speeds and harder slamming.

Boat displacement: A heavier boat has more mass to decelerate, which results in lower peak accelerations compared to a similar lighter platform.

Suspension seating is becoming standard worldwide, in order to reduce physical fatigue and injury risks, in agencies operating HS craft professionally.

It is worth knowing that the definition 'suspension seat' just indicates that there is some energy-absorbing element present. Some seats, marketed as 'shock mitigation' seats, have however been proven to actually multiply impacts on the human body, as they bottom out. Bottoming out is when the suspension travel is abruptly stopped by mechanically reaching the end of the stroke.

Posture is important for good control of the boat and for withstanding impact exposure. A slouching, C-shaped spine is more vulnerable than a balanced S-shaped spine. Feet on deck or on fixed footrests allow legs to absorb energy under impact and provide tactile feedback (see Fig. 3). Standing can produce impacts on the spine three times higher than those on the hull.

Suspended decks and cockpits have been around for years but have not, until now, been proven to function well in practice. Some with limited travel absorb high frequencies, which is good. Others also impair the tactile feedback and balance input, thus making the operator unable to feel what the boat is doing.

Soft deck materials are more comfortable to walk on and do absorb some of the high frequencies in the impacts, but not the high levels of energy in the impacts. The amount of energy possible to absorb is proportional to the length of the suspension travel. This is just the laws of physics. Just as it is more comfortable and healthier to run in jogging shoes than in deck shoes, it can be nice to have a soft layer on the deck. A good stable pair of Nikes might be just as good. Jogging shoes also distribute pressure on the foot optimised to different load zones. Deck shoes, especially the Docksides type, are great for sailing, but not on slamming high-speed boats.

Sitting on a RIB tube is dangerous. It can function as a pneumatic catapult when absorbing energy over 2m of tube and pushing it up into your spine.

Lateral/oblique impacts are more dangerous than pure axial ones, as the spine is better optimised to withstand the latter.

Driving watching professional boat racing with monohull boats is enlightening. You can see that extreme race boats can normally be kept on top of the waves without much change in attitude for each wave, when the wave pattern is right. The worst slams are produced when you hit the front of a wave with the entire hull at once.

Conclusion

In the end, it is all down to a good hull shape, proper equipment, good seamanship and skills. Even with the best hull shape and the best seats in the world, a reckless driver can cause injuries to innocent passengers on board.

Even the most skilled drivers sometimes find themselves and their boats in unexpected situations where accidents and injuries occur. Research and development continues in the effort to protect people.

For references, listed standards and recommendations for further reading see: www.hsbopro.com.

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