PROFESSIONAL BOATBUILDER

The magazine for those working in design, construction, and repair

NUMBER 142
APRIL/MAY
2013
$5.95 U.S.

MEASURING IMPACT EXPOSURE
THE HYBRID CONUNDRUM
COMPOSITE WEIGHT
BRUCE KIRBY

JAAKKO PITKÄJÄRVI/COURTESY BOOMERANGER BOATS

Practical Impact-Exposure Testing

Taking measures required under the European Union's 2002 Vibration Directive, Boomeranger Boats, a builder of specialized high-speed RIBs in Finland, tests two models of shock-mitigating seats to determine which will best reduce whole-body impacts on boat operators.

Text by Jussi Mannerberg
Photographs and illustrations courtesy Boomeranger Boats

Above—*Built in Finland, the 31.2' (9.5m), 6,614-lb (3,000-kg) Boomeranger Special Ops C-3500 open RIB, powered by twin 300-hp Mercury Verado outboards, is designed for high-speed commercial or government service. As such, the boat is subject to the European Union's directive limiting worker exposure to impacts and vibrations. It requires adoption of the best available shock-mitigating technology to protect crews working in extreme marine environments.*

Editor's Note: Professional BoatBuilder *has devoted significant editorial space in recent issues to exploring the efforts of naval architects and engineers to model and understand the slamming and impact accelerations that fast planing boats and their crews are exposed to. "Analyzing Accelerations" Parts 1 and 2 appeared in PBB Nos. 140 and 141, respectively. Those articles detailed what we know about the specifics of seakeeping in high-speed craft, what we should be able to model during the design phase, and what tests and data would help designers better predict vertical accelerations over a range of speeds and sea states.*

The following article is a practical account of how a designer and builder of high-speed professional-grade RIBs addresses vertical accelerations in its existing models. Its author, boatbuilder Jussi Mannerberg, tells how the company he manages, Boomeranger Boats (Loviisa, Finland), measures slamming loads on hulls and assesses impact exposure of professional boat crews to meet the requirements of the European Union's Vibration Directive. This article is based on a similar paper Mannerberg presented at the 2012 High Speed Boat Operations Forum in Göteborg, Sweden.

—Aaron Porter

Boomeranger Boats Oy has built professional high-speed rigid inflatable boats (RIBs) since 1991. In the last two years, we've seen an increasing number of potential buyers inquiring whether the boats comply

JAAKKO PITKÄJÄRVI/COURTESY BOOMERANGER BOATS

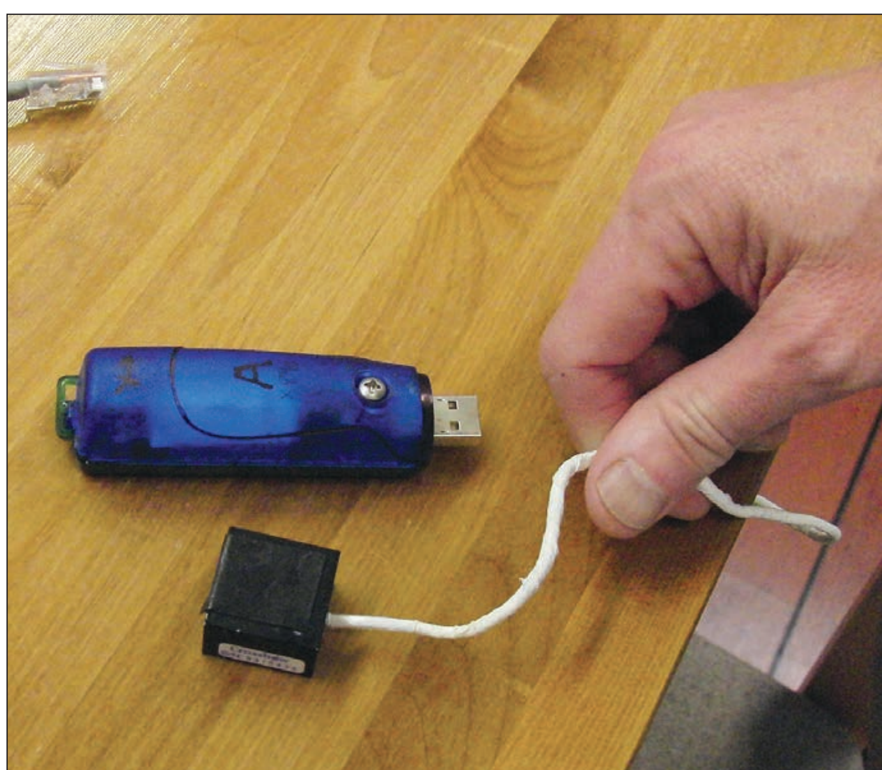
Designers at Boomeranger tested two models of shock-mitigating seats to determine which better dampened the vertical and lateral accelerations crews are likely to be exposed to in high-speed, rough-water operations. The seats were installed in the forward position ahead of the helm station, and the crew riding in them were monitored as the boat was run through a variety of maneuvers in different wind and sea states.

with the European Union Directive on Whole Body Impact and Vibration, a standard implemented to assure the health and safety of workers in E.U. member nations.

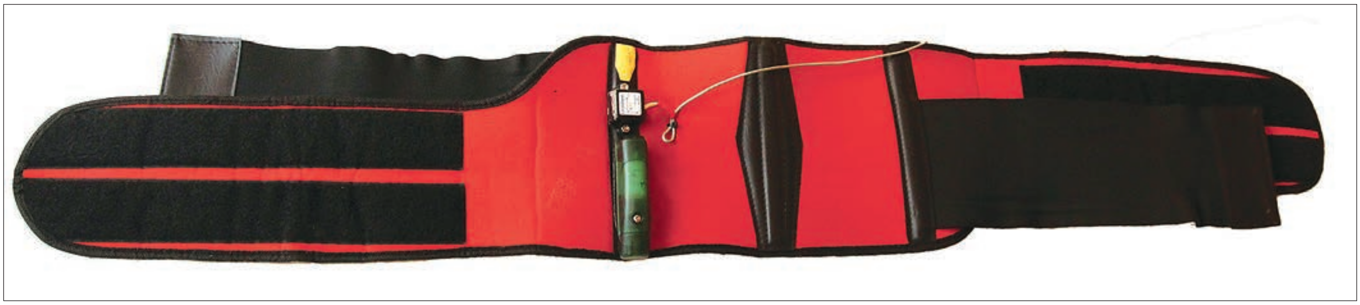
Designed to limit exposure to vibration in all workplaces, the directive specifies the responsibilities of employers to assess the risk and exposure to vibrations, plan and implement control measures, provide and maintain suitable work equipment, train workers about the risks, and monitor the effectiveness of risk controls. It specifies maximum daily exposure levels expressed as an eight-hour energy-equivalent frequency-weighted acceleration, or A(8), value. Most relevant to marine professionals is the whole-body vibration limit expressed as 21 m/s1.75. Every employer is responsible for assuring that employees are not exposed to impacts exceeding the limits. If exposure cannot be guaranteed to remain below the limits, exemptions from the directive can be granted, but only if the best available technologies to reduce shock exposure are employed. Summaries of the legislation identify sea and air transport as examples of workplaces where, despite protective measures, it may not be possible to always comply with the exposure limits.

In response to customer questions about the directive, Boomeranger conducted a scientific real-world study to:

• collect data on hull impacts in high seas to answer questions about possible compliance with the E.U. directive, and



Data were collected through multiple accelerometers and data loggers attached directly to the deck inside the console to measure hull impacts, and strapped to the crew to measure impacts transmitted up through the seats.



To measure the forces on the crew, the accelerometers were bound tightly to their torsos in kidney belts worn inside survival suits. The method has been validated against bone-anchored sensors and was found to be suitably accurate for impacts up to 16–20 Hz.

not to exceed the limits stated in the E.U. directive.

• Shock-mitigating seats can sufficiently reduce impact exposure on humans so it falls within the limits stated in the E.U. directive.

• All shock-mitigating boat seats reduce impact exposure on humans.

Our test platform was a boat from the standard Boomeranger product line—a 31.2′ (9.5m) Boomeranger Special Ops C-3500 open RIB powered by twin 300-hp Mercury Verado outboard engines; dry weight 6,614 lb (3,000 kg); deadrise 26°.

We tested two different types of shock-mitigating jockey-style seats featuring vertical as well as limited horizontal suspensions. The seats were mounted side by side in front of the pilot console, where the subjects could be seen by the pilot and copilot during transit.

Seat A was sent for Boomeranger's evaluation from a manufacturer who claimed its product would allow boats where resistance and shock-absorbing capacity were greatest.

Seat B, a model already installed on many Boomeranger boats, was equipped with a leaf-spring suspension and a nonadjustable damper. Height for this type of seat is adjusted by different-level footrests.

With both seats, subjects' feet rested on the deck during trials. Neither seat was fitted with handholds.

Our two test subjects, both male, were of similar size and stature—176–181 lbs (80–82 kg), 6′ (185cm) tall—and physically fit. During the trials they switched places, sitting in each seat through the full course of testing.

We relied on accelerometers to measure impacts, and employed two separate systems for recording accelerations on the boat hull and on the two subjects in the seats.

System 1 was an eight-channel Valitec data logger connected to two 3-axis ±10-g Crossbow accelerometers firmly attached to kidney belts worn by the subjects, and one single-axis ±25-g accelerometer taped to the deck. The Valitec system was fitted with an external push button on a wire, which triggered 10 seconds of recording each time it was actuated.

System 2 comprised three separate 3-axis Gulf Coast Data ±50-g accelerometers, each with its own built-in 2-Gb data logger and time recording. The subjects wore two of these accelerometers, and another one was fixed to the deck.

The accelerometers measuring deck impacts were affixed by double adhesive tape to the deck, inside the console about 3′ (1m) behind the two seats.

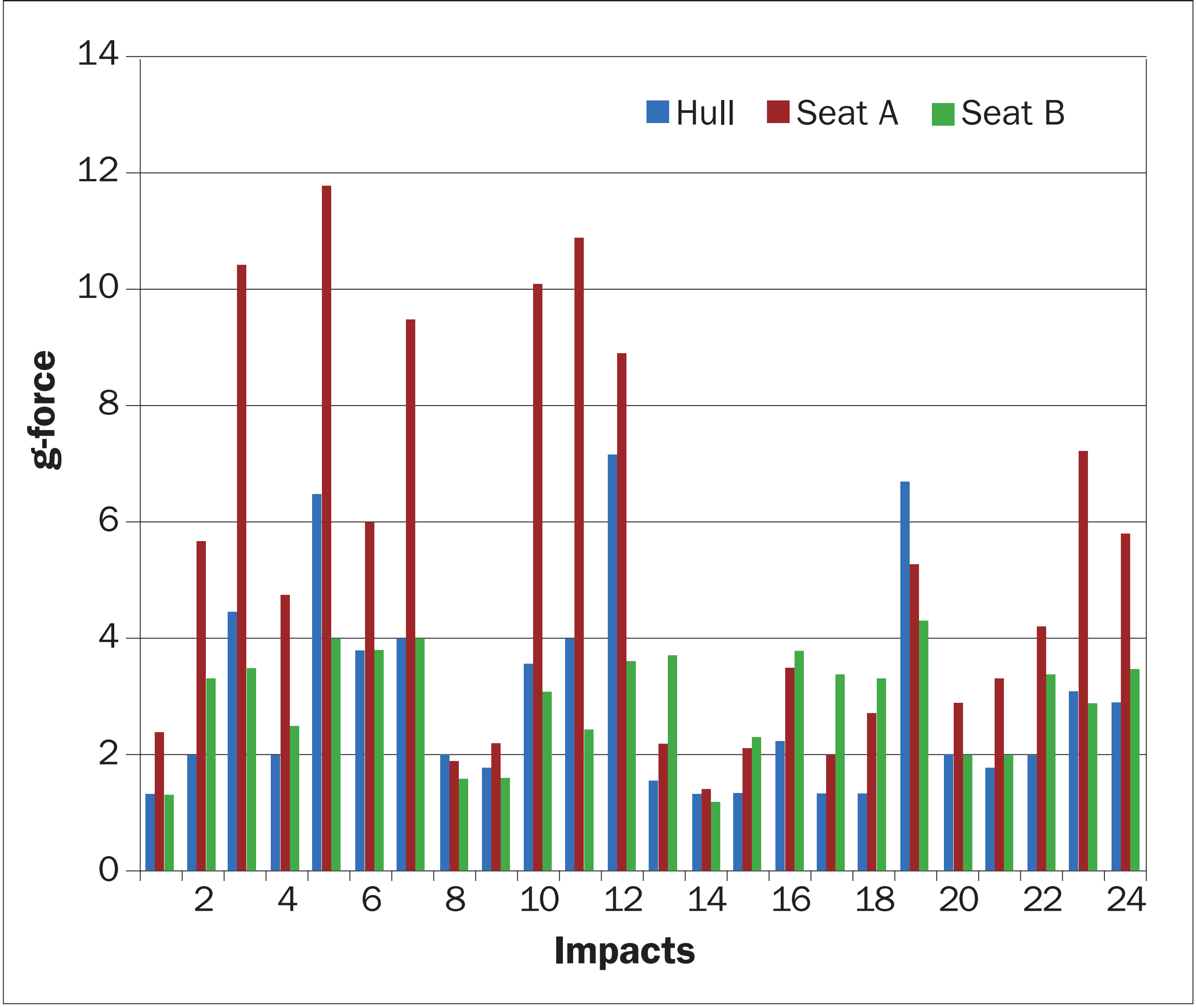
The accelerometers on the human test subjects were attached to kidney belts worn against their bodies, inside survival suits. This kidney-belt method has been validated against traditional methods with bone-anchored sensors and was found to give relevant data for impacts up to 16–20 Hz.

Data from System 1 were used to compare characteristics of the discrete impacts on the hull and the two subjects.

Data from System 2, recorded continuously, were used for calculating the Impact Count Index (ICI), and $S_{ed}(8)$—the human exposure for accumulated spine stress dose, normalized to an eight-hour exposure—to assess total impact exposure during transit.

Our measurement of hull impacts

Figure 1. Values for 24 Highest Impacts



Accelerometer readings of the 24 highest impacts were isolated from the broader data to focus on how two shock-mitigating seats handled them. Data reveal instances in which Seat A seemed to amplify the impacts delivered to the hull.

and the comparison of seats were focused on vertical accelerations. Lateral and longitudinal accelerations were monitored by the accelerometers on the subjects and on the deck with System 2.

In addition, two video cameras recorded the entire run. One camera recording in slow motion (300 frames per second) was positioned in the bow facing aft, and the other was attached to the console facing forward. Both cameras recorded movements of the subjects and the seats during the transit. Position, speed, and course were monitored by GPS.

During the test runs the wind was 17–26 knots from the southwest, and significant wave heights were from 3.3′ to 8.2′ (1m to 2.5m). The boat was driven at a variety of headings with speeds adjusted to what was considered safe for the subjects and comfortable by the crew.

Results

The maximum peak impact recorded on the deck/hull was 7.2 g (**Figure 1**).

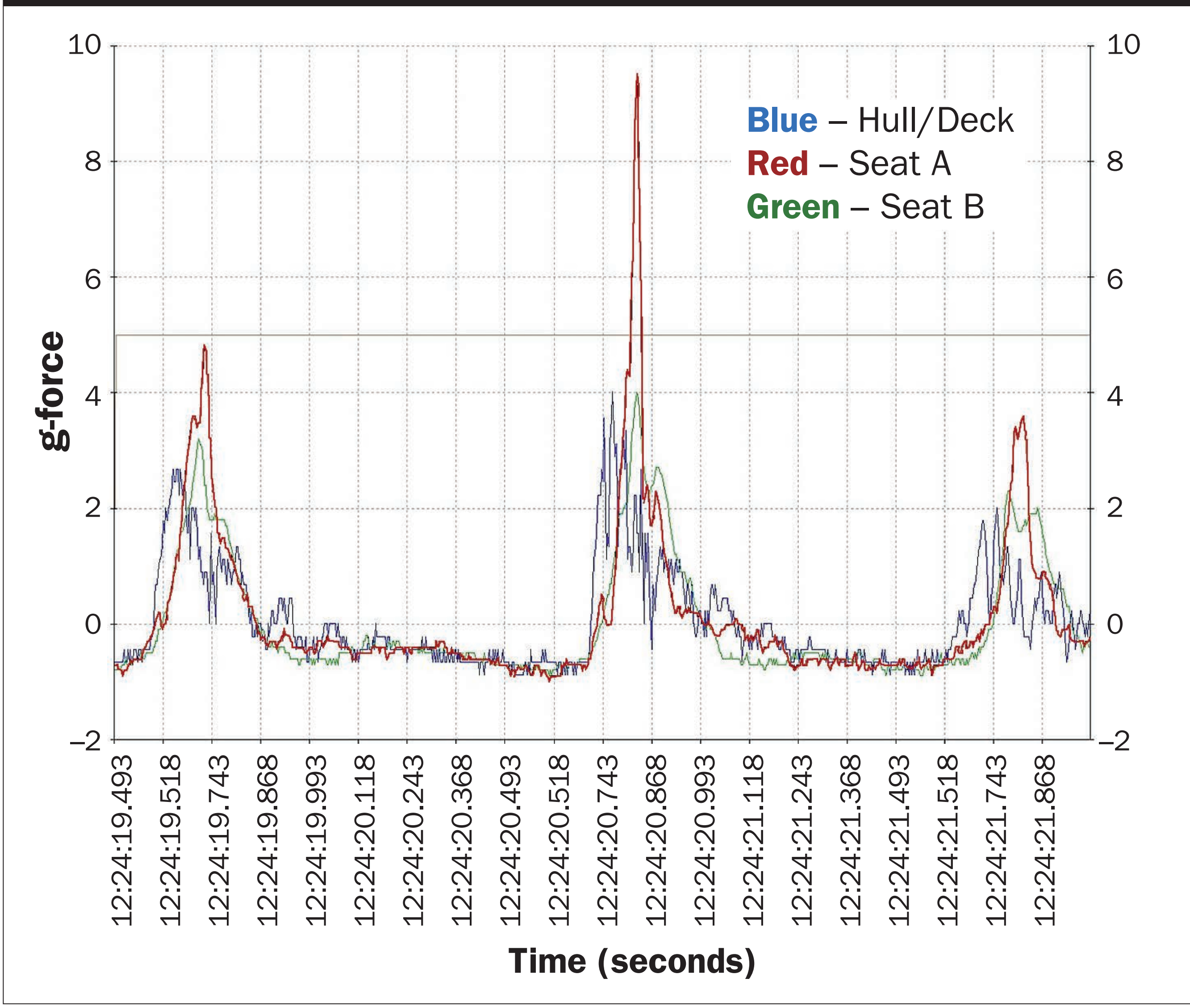
The $S_{ed}(8)$ value calculated from the hull-mounted accelerometers was 2.84 MPa. This is significantly lower than 4.7 MPa—the limit value suggested as acceptable by the U.S. Navy.

Vibration dose value (VDV)—a single figure derived from cumulative root-mean-square values over an eight-hour period—for the boat was 15.0 m/s1.75. This is lower than the daily exposure limit value of 21 m/s1.75, but higher than the daily exposure action value of 9.1 m/s1.75 stated in the E.U. directive.

Impacts measured were similar on both seats up to 1.6-g peak accelerations. In higher accelerations, Seat A showed more-severe impacts than Seat B (**Figures 2** and **3**).

On Seat A we recorded impacts as high as 11.8 g, the range limit for the accelerometer. And extrapolation of

Figure 2. Impact Data for 2.3-Second Test Interval



Overlaid data of a 2.3-second interval show that Seat A is already bottoming out and amplifying impacts at as little as 2 g.

data suggests impacts as high as 14–15 g. On Seat B, 4.0 g was the highest impact recorded.

Overlaying deck and seat data reveals that in the higher-peak deck impacts, Seat B significantly reduced impacts to the subject, while Seat A multiplied impacts up to a factor of three. In the lower range of deck peak impacts, up to 3 g, impacts on the subject in Seat B differed little from deck impacts, while the subject in Seat A repeatedly received significantly higher peak values than the deck impacts (**Figure 4**).

It is important to note that the deck accelerometers had to be fitted in a dry space, and hence were located about 3′ aft of the seats. This prevented relevant calculation of transfer functions, as impacts normally were higher forward than aft.

Our video recording verified that Seat A repeatedly bottomed out, causing subjects severe discomfort. This limited the top speed and the trial period, as continuing the test was considered unsafe. Although we limited the trial period to a total of 90 minutes, the data are sufficient to fulfill the objectives of the study.

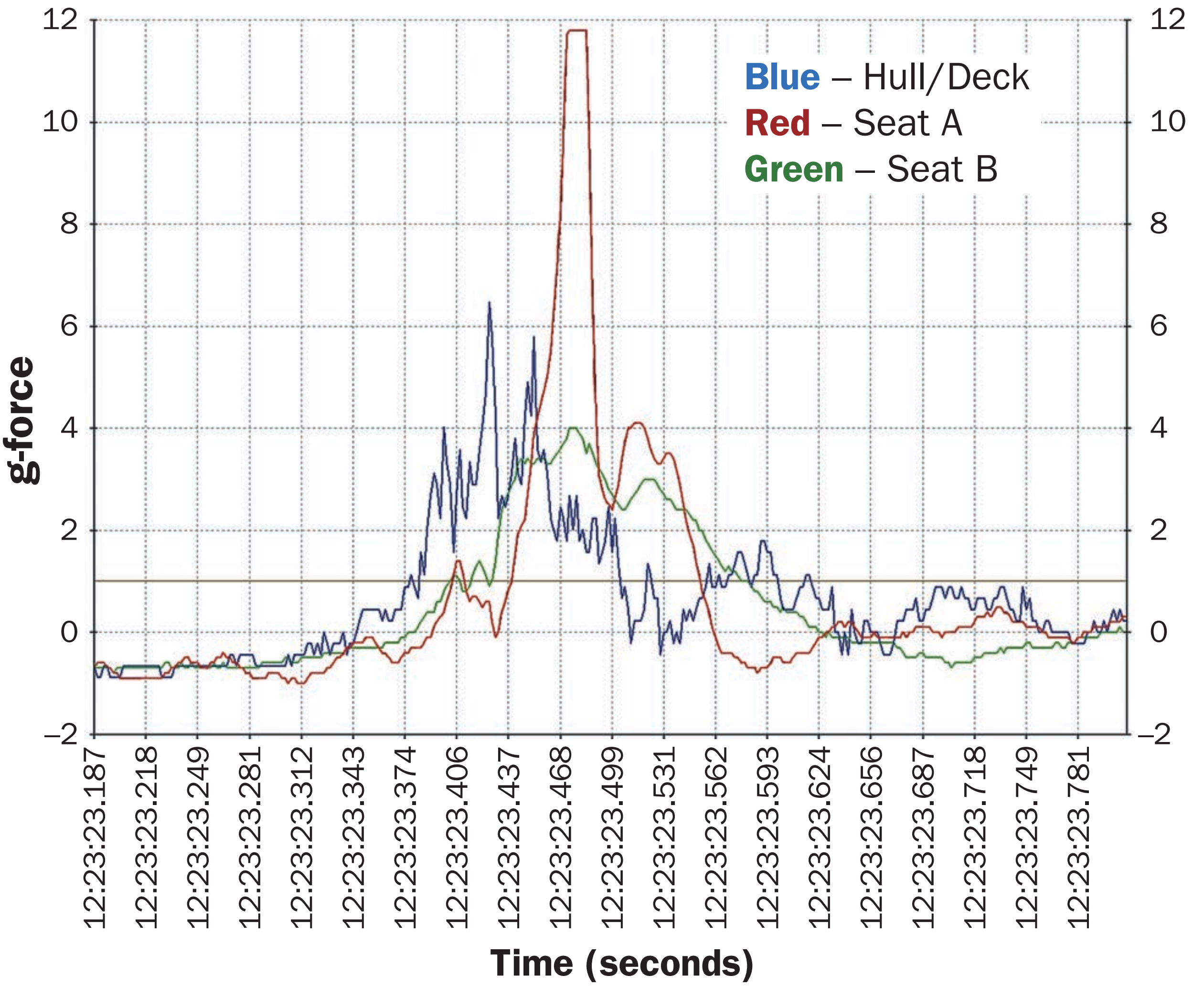
Relative to our hypotheses, the tests revealed:

- Impact exposure on board high-speed boats cannot under normal operating conditions be guaranteed to stay within the limits stated in the E.U. directive.
- Impact exposure on humans can be reduced by the use of shock-mitigation seats, but is *not* guaranteed to fall within the limits stated in the E.U. directive.
- *Not* all shock-mitigating boat seats reduce impact exposure on humans.

Conclusions

The test boat produced impact values lower than expected and lower than peak values previously measured in similar conditions on boats of similar size. However, the boat can, even with a skilled driver operating in

Figure 3. Highest Impact, in Seat A



Overlay of the highest recorded impact suggests that the crew member in Seat A was subjected to more than 12 g. Note that the limit for the accelerometer was 11.5 g, thus the flat peak of the graph. Extrapolation of the graph indicates a peak in excess of 14 g.

normal operating conditions, produce impact exposure that may exceed the limit values in the E.U. directive.

To achieve relevant comparative data, further testing of hull performance should be done in controlled studies with reference hulls measured simultaneously, running parallel in side-by-side trials.

As for the seats tested, at lower speeds and hull impacts up to about 2 g, there was no significant difference in the shock absorption between the two models. Peak values also differed little from peak values on the hull. At hull impact levels from 3 g and above, Seat A repeatedly amplified the impacts, with recorded levels as much as three times higher than those measured from the hull. The best explanation of this phenomenon is that Seat A bottomed out at higher impact levels. At deck impacts in excess of 2 g, Seat B reduced impacts more than Seat A. Indeed, the higher the hull impact, the greater the difference between the two seats.

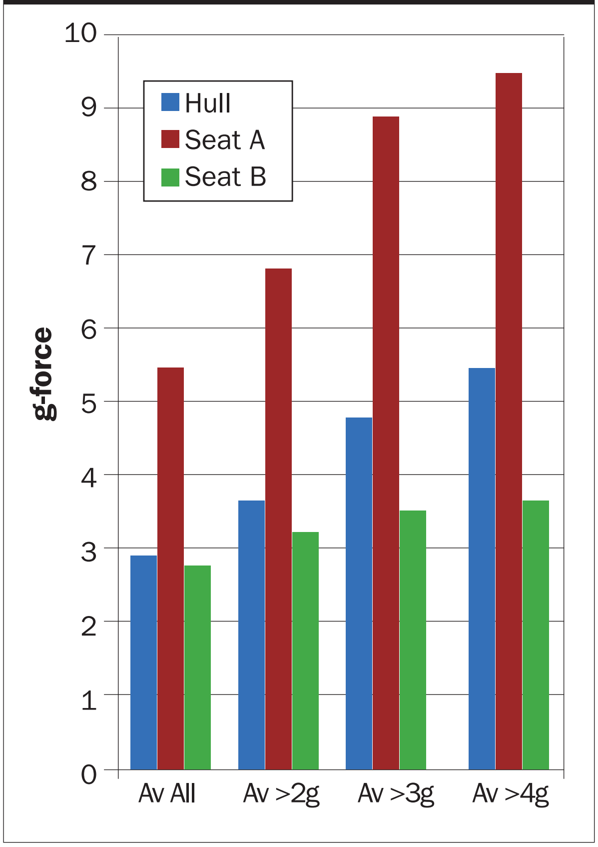
In the highest registered accelerations, Seat B reduced impact levels by 50%.

Practical Implications and Recommendations

At Boomeranger, we found our test hull produced low impact levels compared to similar vessels measured in other studies. However, even with the best available hulls, exposure to subjects running at speed in rough sea conditions will most probably exceed the limits. This makes it necessary for employers of crew in high-performance boats to supply some proof that they have selected the most efficient suspension seats available to minimize impact exposure. And, of

Comparing mean peak values for the entire data set to those for impacts greater than 2 g, 3 g, and 4 g confirms that the differences in seat performance were amplified in rougher conditions.

Figure 4. Mean Peak Values for Impacts Above 2g, 3g, and 4g



course, those employers may reasonably look to the boatbuilders and seat manufacturers to assure them that they can meet the letter of the directive.

In practical terms, we can demonstrate to our customers the likely deck impacts of our boat running in specific sea conditions, and the performance of two different shock-mitigating seats. Our tests revealed that, in some conditions, Seat A amplifies impacts and hence increases risk of injury. It cannot be considered to fill the criteria for best proven technology. Conversely, Seat B has been shown to significantly reduce impact exposure and can thus be reasonably expected to fill the demand for the best available means to reduce impact. PBB

***About the Author:** Finnish naval architect Jussi Mannerberg is a graduate of the Yacht Design Program of the Southampton (United Kingdom) Solent University. With a background in designing sail and power boats, he is the CEO of Boomeranger Boats, a builder specializing in high-speed craft for military and government service, in Loviisa, Finland.*