Human Body Models as Design Requirements to Prevent Injury for Onboard Personnel in High-Speed Boat Operations.

Karin Brolin, Victor Alvarez, Emanuel Klasén, Matteo Perrone, Linus Fagerberg

I. INTRODUCTION

Personnel onboard high-speed boats are exposed to injury-inducing impacts due to slamming [1]. There is a need to define hull exposure limits to ensure personnel safety, as well as design requirements that can help minimise the risk of injuries by optimising equipment and boat design. Hull accelerations during high-speed boat slamming vary significantly depending on boat speed and sea state (wave height) but can reach peak values above 25 g within as little as 5-20 ms [2-3]. It is crucial that onboard personnel retain full physical functionality and mission readiness despite slamming impacts, regardless of whether they are standing, sitting, or lying down.

II. METHODS

To study the effect of high-speed boat slamming on injury risk for onboard personnel, we used numerical human body models in finite element (FE) simulations with LS-DYNA (ANSYS/LS-Dyna, ANSYS Inc., USA). The detailed Global Human Body Model Consortium-owned GHBMC model, representing the 50th percentile male (licensed from Elemance Ltd, USA). FE models of generic floors, seats, and bunks were created in LS-PrePost (ANSYS/LS-Dyna, ANSYS Inc., USA). Material properties were parametrised to examine how it would influence the human response. Additionally, a bucket seat was modelled with geometry from the Ullman Daytona Crew and compared to the generic seat configurations. The GHBMC model was positioned on the floor, seat, and bunk in standing, sitting, and lying postures, respectively (Fig. 1), using the preprocessor Ansa (BETA CAE Systems SA, Greece). For seats, three sitting postures were studied, each in two different seat suspension configurations and with two different seat foams.

A simplified acceleration pulse (peak 20 g, rise-time 10 ms), representative of severe hull movement during slamming, was applied as a boundary condition to the floor, seat, and bunk insertions. The resulting kinematics, along with predicted fracture, brain and internal organ injury risks, were analysed according to the GHBMC manual.

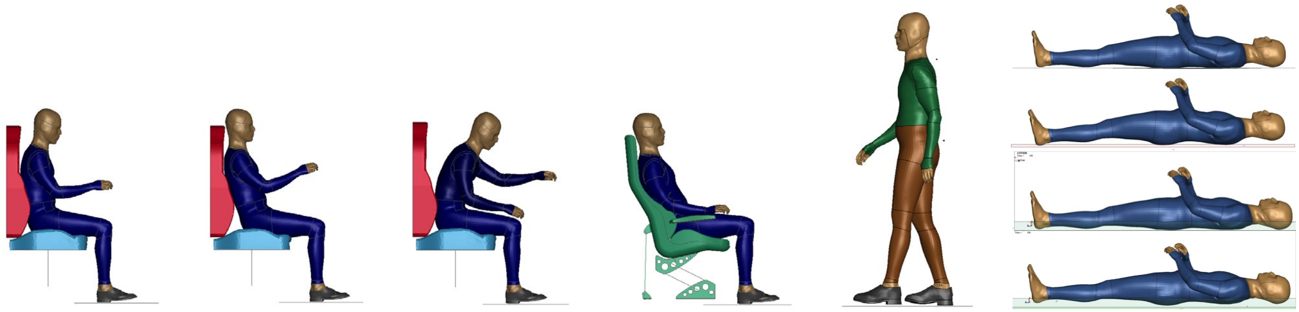

Fig. 1. GHBMC M50 positioned in generic seat, bucket seat, standing and supine on different surfaces.

III. INITIAL FINDINGS

For the sitting postures, pelvic acceleration varied in terms of both peak and shape. Altering seat suspension characteristics reduced the peak pelvic acceleration caused by unfavourable sitting postures (Fig. 2). This also had beneficial effects on the propagation of acceleration along the spine to the head, reducing the risk of brain injury (using BRIC). Softer seat pan foam was found to increase the risk of brain injury compared to stiffer foam. The bucket seat, however, exhibited the lowest brain injury risk, with the risk ranging from 16% to 28% of the brain injury risks predicted for the other configurations. Sitting posture influenced the lower limb fractures, which were

K. Brolin (e-mail: karin.brolin@lightness.eu) is a Docent in Computational Impact Biomechanics and consultant, V Alvarez and L Fagerberg are consultants with Lightness by Design, Stockholm, Sweden. E. Klausen is naval architect and M Perrone is researcher at The Swedish Defence Materiel Administration (FMV), Stockholm, Sweden.

predicted in some configurations, suggesting that footrest design could improve injury outcomes.

For the standing GHBMC model, ankle and knee injuries were predicted for both configurations. No internal injuries were predicted in any of the standing GHBMC models. For the supine GHBMC model, fractures and soft tissue injuries, including brain and spleen injuries, were predicted in two out of four configurations. Only one bunk configuration did not predict any injuries.

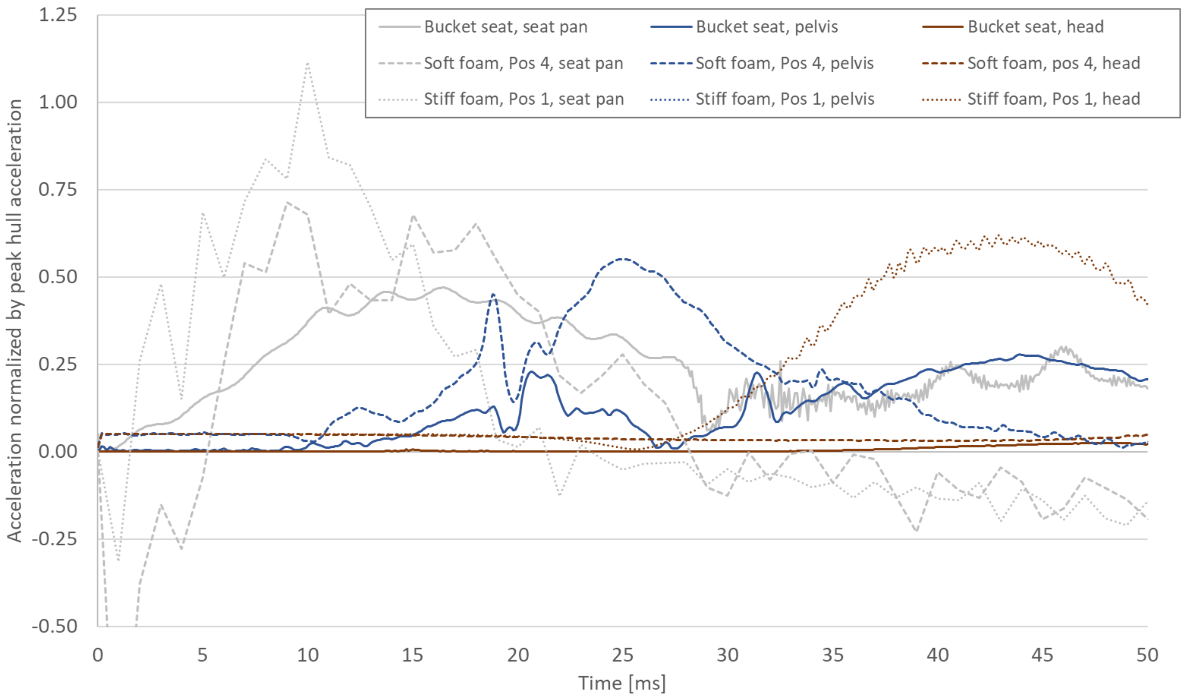

Fig. 2. Acceleration curves measured at the head, the pelvis and the seat pan for three seat configurations.

IV. DISCUSSION

The GHBMC model was successfully used to simulate the human impact response during an extreme slamming event. We were able to study how injury risk varied in different sitting, standing, and supine configurations. This demonstrates that human body models can be used as design requirements, to prevent injuries for onboard personnel experiencing high-speed boat slamming or similar impact events.

Ankle and knee injuries may not be considered severe according to AIS but could limit physical functionality and reduce mission readiness. Our results indicated that floor characteristics and seat footrest can be designed to reduce or eliminate the risk of these injuries, as well as assess the risks associated with existing floor designs. Future work should focus on identifying floor characteristics associated with injury prevention.

The supine GHBMC model could represent either a resting crew member or an injured individual who needs to be transported to a safe harbour for medical attention. Fast and safe evacuation of injured personnel may in the future be done with autonomous high-speed boats, especially in military settings. Our results indicate that it is feasible to protect a supine crew member during extreme high-speed boat slamming by setting bunk or stretcher design requirements based on human body models. This needs to be further investigated and the risk versus benefit of boat speed for different sea states can be explored, as well as bunk and mattress design.

A major limitation of this study was the simplified acceleration pulse used to represent extreme slamming impacts. The influence of acceleration pulse shape and magnitude on the injury risk predicted for the different floor, seat and bunk configurations needs to be further explored. Also, there could be an effect from preceding slamming impacts as the human body is already in motion when the extreme slamming impact occurs. It is tempting to combine multi body dynamics of longer events with multiple slamming impacts with FE simulations using anatomically detailed human body models.

V. REFERENCES

[1] Ullman J *et al.*, Clin Orthop Relat Res, 2022.
[2] Ullman J *et al.*, High Speed Vessels, 2020.
[3] Razola M *et al.*, Ocean Engineering, 2016.