External Biofidelity Evaluation of GHBMC M50-O V.6.1 Model in Deep Reclined Position

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I. INTRODUCTION

Current and future vehicle environments may allow occupants to adopt postures substantially different from the traditional upright seating position. For instance, in fully supervised driving modes, individuals may choose to rest or even sleep in a significantly reclined configuration. Current luxury vehicles also allow deep recline settings of the passenger seats. However, accident statistics indicate an increased risk of injury and mortality for occupants who are partially or fully reclined [1–2] in vehicles whose restraint systems were not designed for such positions. Moreover, conventional crash-test dummies are not validated for such postures and cannot accurately represent occupant behavior in highly reclined configurations. To address these limitations, Finite Element Human Body Models (FE HBMs) offer a valuable complementary approach.

FE HBMs are supposed to be more biofidelic than dummies [3] and enable detailed analysis of body segment mechanical responses and injury prediction [4]. As such, they represent a valuable tool for the optimisation of restraint systems in non-standard postures. Recent FE studies using HBM have shown that seat belt geometry and load-limiting strategies can influence the kinematics and injury risks on a reclined occupant during a whole-sequence frontal crash scenario [5]. For instance, the relationship between the risk of submarining with lap belt–pelvis interaction, seat geometry, and morphological variability was underlined [6].

Several recent test series using Post-Mortem Human Subjects (PMHS) in reclined postures [7–9] have provided data for kinematic validation and predictive capability of numerical models in these configurations. The present work aims to evaluate the behavior of the Global Human Body Model Consortium (GHBMC) 50th percentile male detailed occupant (M50-O) V.6.1 model in comparison with the reclined posture experiments conducted on PMHS by Baudrit *et al.* [7].

II. METHODS

The environment [7] was reproduced as an FE model. It consists of the semi-rigid seat developed by Uriot *et al.* [10], with an anti-submarining ramp twice as stiff and a rotation limited to 15°, and a backseat inclination of 58° with respect to the vertical axis. The four-point belt restraint system consisted of a lap belt equipped with two 3.5-kN load limiters, and a shoulder belt equipped with a 4-kN load limiter at the upper anchorage. As in [7], the frontal applied pulse reached a 36g peak over 85 ms, yielding a 14 m/s delta-V. It corresponds to a NCAP 56 km/h full-width crash of a small European car against a rigid wall, scaled down by 20%.

The GHBMC V.6.1 model was first positioned using a marionette method to reproduce an average posture of the three PMHS tested in the reclined configuration. Following that, the model was seated under gravity while constraining the pelvis so that the H-point of the GHBMC matched the average H-point coordinates of the PMHS. At this stage, no specific morphing of the GHBMC model toward individual PMHS anthropometry was performed.

In this paper, the HBM time-responses were compared to the PMHS time-responses in terms of head and pelvis kinematics, seat and footrest reaction forces, belt forces and seat plates rotations. The seat reaction forces were defined as the sum of the contact forces between the GHBMC model and the semi-rigid seat. The simulation was performed with erosion active for bone elements according to user's manual and was run using LS-DYNA version R.9.3.

III. INITIAL FINDINGS

The simulation reached normal termination. The comparison with the PMHS is shown in Fig. 1 for overall kinematics and in Fig. 2 for charts of the time-history responses. No submarining was observed for GHBMC model, which is consistent with the three PMHS test results. As with PMHS 745 and 746, the GHBMC remained in contact with the seat until the end of the impact. PMHS 744 pelvis moved outside the seat front edge. This is also the only PMHS which did not sustain pelvic fractures. Furthermore, the tests revealed a potential new spinal injury mechanism specific to deep reclined posture: compression-extension [7]. The corresponding "S-shaped" deformation pattern was reproduced in the GHBMC simulation (Fig. 1c).

The head kinematics of the GHBMC model fairly agrees in shape with the PMHS corridor and is close in peak: at 100ms, the head X-displacement is 630 mm for the GHBMC model, compared to values ranging from 645 mm

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to 745 mm in the PMHS tests. The pelvis kinematics response of the GHBMC model falls slightly outside the PMHS corridor but remains close to PMHS 745 and 746 responses, which stayed in contact with the seat (Fig. 2a, b).

Regarding belt forces, the GHBMC model shows good agreement with the PMHS tests and with the characteristics of the restraint system (Fig. 2c, d). In the unloading phase, the model exhibits a slightly faster decrease in belt force compared to the PMHS responses. A comparable trend is also found in the contact forces between the GHBMC model and the semi-rigid seat, indicating consistent global interactions. (Fig. 2e). However, the forces on the footrest remain nearly twice those measured in the tests (Fig. 2f).

Finally, the rotation of the anti-submarining ramp (Fig. 2g) and seat pan (Fig. 2h) are also in agreement with the test data. However, for seat pan rotation, the simulation presents a slightly different profile during the rise to the peak. Specifically, the increase occurs as a single, continuous slope with a slower rotation rate, whereas in the PMHS the rise is characterised by two distinct phases: an initial, faster rotation followed by a short plateau.

Fig. 1 - (a) Lateral image of PMHS (respectively 745 and 746) in experimental testing from [7] at 68ms. (b) - Lateral image of the M50-O model at 68ms. (c) - View of the bones of the M50-O model at 68ms.

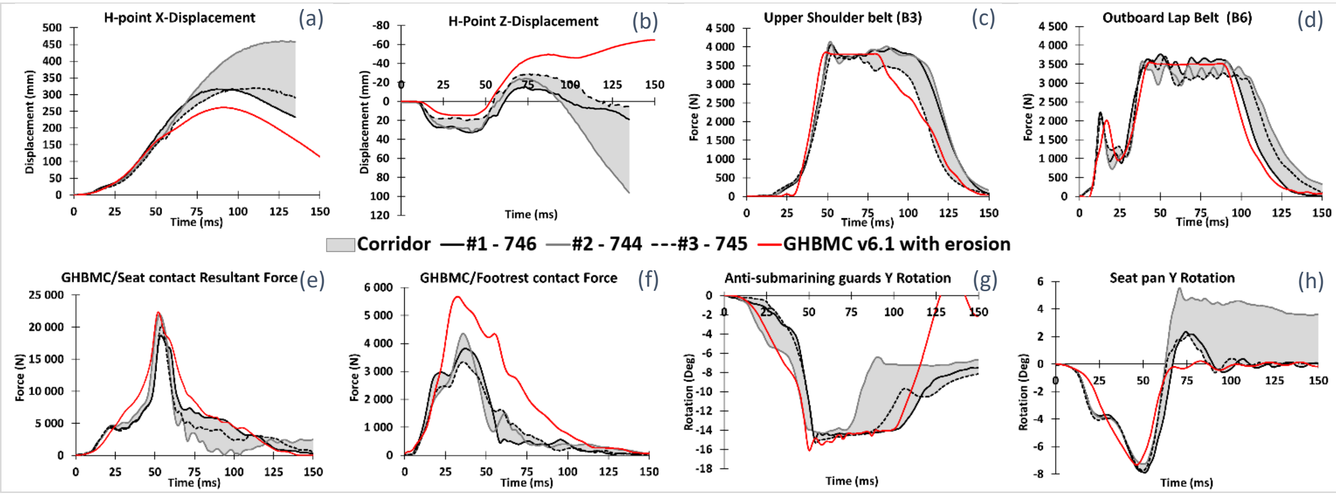

Fig. 2 – Comparative time-history responses

IV. DISCUSSION

The kinematics results are consistent with the PMHS tests even if the pelvis displacement is underestimated in the simulation. This may be explained by the occurrence of a pelvis fracture at approximately 52ms in the simulation, which could influence the observed kinematics. The model seat contact forces are in good agreement with the reference data.

The simulation revealed differences from the tests regarding the footrest forces and the seat pan rotational speed. These discrepancies may be attributed to differences in mass distribution between the GHBMC model and the PMHS. In particular, the PMHS had thinner and less muscular thighs due to their age, whereas the GHBMC is based on the scan of a young adult male. This may explain the higher footrest reaction forces exerted by the GHBMC, as well as the difference in the seat-pan rotation profile, assuming it is strongly influenced by the lap-belt forces transmitted through the legs to the seat surface. This could be confirmed in a further study by morphing the HBM to match the subject anthropometries.

These data could therefore support the development and validation of new compression/extension-based injury criteria, complementing the existing compression/flexion criteria [4]. Future work will therefore concentrate on assessing lumbar injury metrics to determine the model's predictive performance for this mechanism in deep reclined configurations.

V. REFERENCES

[1] Dissanaike *et al.*, J Trauma 2008. [2] McMurry *et al.*, Traffic Inj. Prev., 2018. [3] Tang *et al.*, Front. Bioeng. Biotechnol., 2023. [4] Tushak *et al.*, IRCOBI, 2023. [5] Östh *et al.*, IRCOBI, 2024. [6] Brynskog *et al.*, Front. Bioeng. Biotechnol., 2025. [7] Baudrit *et al.*, Stapp Car Crash J, 2022. [8] Richardson *et al.*, Stapp Car Crash J, 2020. [9] Lopez-Valdes *et al.*, IRCOBI, 2024. [10] Uriot *et al.*, Stapp Car Crash J, 2015.