Frontal Impacts on Omnidirectional Seating Orientations of the GHBMC M50-O: Informing New Sled Conditions for ADS

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I. INTRODUCTION

The transition toward Automated Driving Systems (ADS) is enabling flexible cabin configurations, such as rear-facing and highly reclined seating. However, unconventional configurations and high recline angles exacerbate critical safety risks, particularly magnifying submarining tendencies and seat belt constraints. Current research by US-based AVOK [1], RCCADS [2], OSU [3] and ENOP [4] is investigating these challenges at speeds up to 56 km/h. Simulation studies suggest that rear-facing seating orientation is the safest, whereas side-facing and rear-oblique-facing seating orientations significantly increase injury risks during a frontal impact [5-6]. To address gaps in simulation literature, specifically the reliance on rigid seatbacks and upper-body kinematics, this study utilises a deformable seatback and maximum effective plastic strain (MEPS) analysis. The objective is to quantify structural damage in finite element (FE) human body model (HBM) simulations and identify the worst-case seating orientations during a frontal impact, providing a technical basis for developing new sled conditions for future ADS experimental research.

II. METHODS

Occupant response was evaluated using an LS-DYNA v11.1 simulation matrix across eight seating directions (0° to 315° at 45° intervals) (Fig. 1) and two recline angles (25° and 45°) at a 56 km/h frontal delta V. The GHBMC M50-O v6.2 FE HBM was integrated into a NHTSA Honda Accord FE seat model converted to an All-Belts-to-Seat configuration, ensuring consistent restraint geometry regardless of orientation. The modified FE seat model serves only for preliminary comparative assessments across seating directions, as it has not been structurally validated for high-speed rear or lateral loading. The restraint system incorporated a 2 kN pretensioner and 4 kN load limiter on the shoulder belt [5, 6]. The relative severity of various seating orientations was assessed using MEPS data derived from GHBMC simulations. The strain data were normalised on a 0–1 scale for each body region, with the normalisation performed across the eight set simulations per recline angle to capture the full range of response for each body region (Eq. 1). The normalised strain values (normMEPS) for each body region were squared to capture the exponential rise of mortality risk relative to injury severity, and subsequently scaled by established regression coefficients [7-8] to weight each region's contribution to overall survival. The weighted squared strains per body region were summed for each recline angle to determine a severity index for each seating orientation (Eq. 2). This study evaluates cumulative physiological burden using a mean severity index averaged across the 25° and 45° recline angles, allowing for efficient identification of worst case seating orientations.

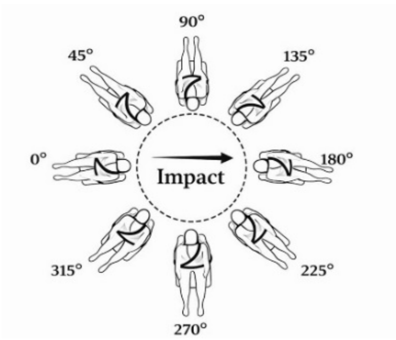

Fig. 1. Different seating orientations in the study

$$\mathrm{normMEPS}_{\mathrm{region,orientation}} = \frac{MEPS_{region,orientation} - Min\ MEPS_{region}}{Max\ MEPS_{region} - Min\ MEPS_{region}} \quad (Eq.1)$$

$$Severity\ index = \sum w_{region} * normMEPS^{2}_{\mathrm{region,orientation}} \quad (Eq.2)$$

$w_{head} = 0.65, w_{neck} = 0.28, w_{chest} = 0.42, w_{T-spine} = 0.18, w_{L-spine} = 0.18, w_{pelvis} = 0.35,\ w_{femur} = 0.12, w_{tibia} = 0.12$ [7, 8]

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III. INITIAL FINDINGS

The ranking of seating orientations based on the mean severity index identified the 135° seating orientation as the most critical condition (Fig. 2). With a cumulative physiological burden of approximately 0.9, this orientation was primarily driven by high weighted squared strains in the head and chest regions, which together accounted for over 60% of the total index. The 315° and 45° orientations followed as the next most severe; however, while 135° was dominated by upper-body loading, 315° showed a more distributed injury profile with significant contributions from the neck, spine, and pelvis. Conversely, the 225° orientation emerged as the least severe condition, with a total index score below 0.3. As shown in Fig. 2, while the 180° (rear-facing) orientation showed lower diversity in regional loading, its high head-strain contribution resulted in a higher severity ranking than the more distributed 225° case.

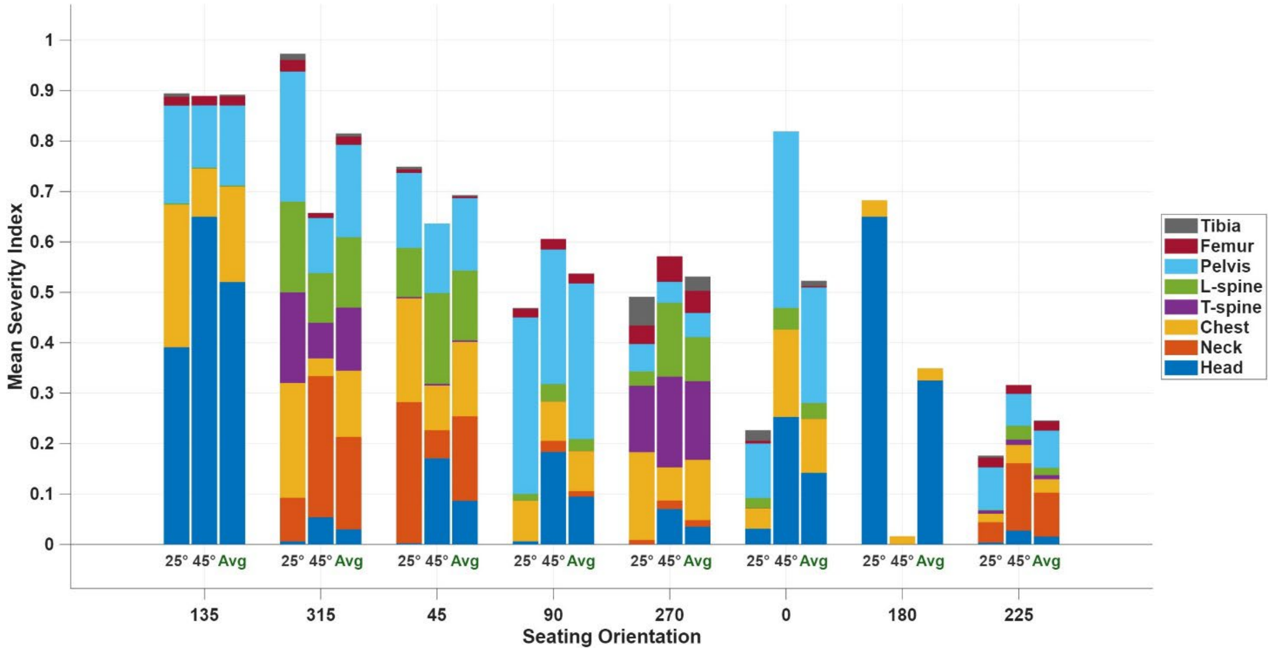

Fig. 2. Severity index for different seating orientations used in the study

IV. DISCUSSION

The elevation of the 135° and 315° seating orientations as the most severe condition—surpassing both forward-facing (0°) and rear-facing (180°) orientations, highlights the critical vulnerability of occupants to "out-of-position" kinematics during frontal impacts. While submarining is a known risk in 45° seatback recline of the 0° seating orientation [3, 9-11], the 315° oblique vector introduces complex lateral-longitudinal loading that causes disproportionately high spinal and pelvic strains. In contrast, the top-ranked 135° orientation shifts the burden to the upper body, showing a disproportionate increase in head and chest severity. While previous studies have investigated frontal-oblique loading [12-14], data from the current study suggests that the high cumulative burden in rear-oblique loading (e.g., 135° orientation) also warrants urgent consideration, as this orientation threatens the regions critical to survival – head and chest. These findings correlate with previous simulation studies using kinematics [5-6], while advancing the analysis by incorporating a direct injury-based perspective through this strain-based ranking. However, a notable discrepancy remains between simulations and experiments regarding the 180° orientation. While simulations suggest minimal severity, PMHS studies by Kang *et al.* [15-16] documented significant skeletal injuries, likely due to seatback interaction and ramping. This highlights a limitation in GHBMC biofidelity. Specifically, the model requires improved validation for spinal flexibility and more representative abdominal content motion, which drives inferior-superior rib loading during high-speed rear-facing frontal impacts [17-18]. Addressing these gaps could elevate the severity index for this direction, bringing it closer to the worst-case scenarios. Furthermore, as the previous studies [7-8] utilised a general hospital dataset lacking impact directionality, these weight factors may not be fully applicable to each seating orientation. Nevertheless, the elevated hazard of rear-oblique loading relative to pure rear loading, driven by asymmetrical torso rotation, highlights the value of standardised, high-severity ADS sled tests.

V. REFERENCES

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Expansion of Acronyms:
AVOK – Automated Vehicle Occupant Kinematics
RCCADS – Research Consortium for Crashworthiness in Automated Driving Systems
OSU – Ohio State University
ENOP – Enable New Occupant Seating Positions

NOTE: This report is published in the interest of advancing motor vehicle safety research. While the report may provide results from research or tests using specifically identified motor vehicle models, it is not intended to make conclusions about the safety performance or safety compliance of those motor vehicles, and no such conclusions should be drawn.