Influence of Anthropometry on 5th Percentile Female Human Body Model Kinematics in a Frontal Sled Loading Scenario

Alex Kalmar-Gonzalo, Seth H. Mischo, F. Scott Gayzik

I. INTRODUCTION

Human Body Models (HBMs) are widely used in crash simulation to assess occupant response and evaluate injury mechanisms under controlled boundary conditions. These models are often developed to represent specific population percentiles; however, differences in anthropometric reference sources can lead to variation in mass distribution and body geometry, even among HBMs intended to represent the same demographic group. This variation may influence kinematic response, belt interaction, and loading patterns during crash events [1]. The present study focuses on two simplified 5th percentile female HBMs that differ in underlying anthropometry but are both nominally sized to match the same target population. One of these models, the F05 THOR (Test Device for Human Occupant Restraint)-Analogous Occupant, Simplified (F05 THAN-OS), was developed to replicate the component-level anthropometry of the 5th percentile female THOR ATD (Anthropometric Test Device) [2-3]. This design approach introduces targeted anthropometric changes that may influence the model's biofidelity in crash scenarios.

Lap-belt submarining, a phenomenon in which the lap belt slides over an occupant's anterior superior iliac spine (ASIS) into the abdomen, remains a challenging scenario to evaluate due to its sensitivity to occupant size, posture, and belt routing [4-5]. It is a known mechanism of serious abdominal and pelvic injury and is particularly relevant for small female occupants, who may be more susceptible due to reduced pelvic dimensions and inconsistent belt fit [6]. Using a frontal impact case specifically designed to induce submarining in small female occupants, this work investigates how anthropometric differences between the F05 THAN-OS and the baseline F05-OS affect occupant kinematics and simulation outcomes. The scope is limited to small female occupants due to the characteristics of the experimental dataset used for validation, which involved only small female post-mortem human subjects (PMHS). By isolating anthropometry as a variable, this study aims to provide insight into how changes in model construction can influence simulated outcomes in a submarining-prone loading condition.

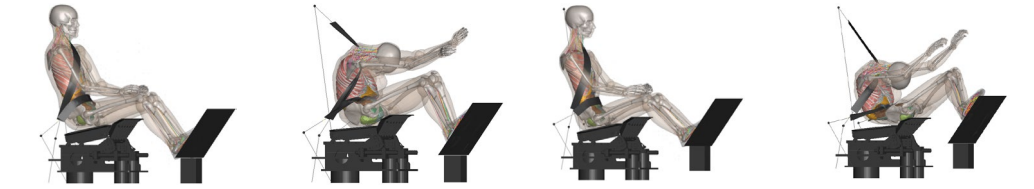
II. METHODS

A 5th Percentile Female Thor ANalogous Occupant, Simplified (F05 THAN-OS), which has previously been described in [3] has a mass of 47.6 kg, was compared to the 5th Percentile Female Occupant, Simplified (F05-OS), which has an initial mass of 53.8 kg, using a boundary condition derived from experimental data published in [6]. The referenced study details experimental tests using PMHS under three unique seating configurations across both high- and low-speed frontal impact pulses. This short communication will analyse the anthropometric differences of the two HBMs using seat configuration 2 as it was specifically designed to induce submarining in the experimental subjects. This high speed (54 km/h ΔV) frontal loading case incorporated independent shoulder and lap belts connected to strategically positioned anchorage points, decreased seat pan and anti-submarining ramp stiffnesses relative to the configuration designed to prevent submarining, a fuse loop in the lap-belt to dynamically introduce 40 mm of slack, and an initial forward pelvis displacement of 50 mm. The computational setup for this configuration, as applied to both the F05-OS and F05 THAN-OS models, is illustrated in Figure 1. Given the design intent of the experimental setup, submarining in the simulations was evaluated using a quantitative, geometry-based method. An algorithm was developed to track the position of the lap belt node nearest to the ASIS on each side of the pelvis. Submarining was considered to have occurred if this lap belt node translated posterior and superior to the most prominent ASIS node.

Simulations were developed through the HBM for Virtual Testing framework and executed with a total runtime of 170 ms on LS-DYNA R12.2.1, using the Wake Forest School of Medicine Demon Cluster, which runs on 64 cores with 96 GB of ram. Ten kinematic and kinetic response metrics were extracted using Python-based post-processing scripts. These included shoulder belt forces, lap belt forces, H-point X-displacement, pelvis rotation about the Y-axis, seat pan reaction forces in the X- and Z-directions, and accelerations of the T4 vertebral body

F. S. Gayzik (e-mail:sgayzik@wakehealth.edu; tel: 336-702-9177) is a Professor, Alex Kalmar-Gonzalo is a PhD student in Biomedical Engineering, S. H. Mischo is a PhD student in Biomedical Engineering, all at Wake Forest School of Medicine (WF-SOM) in Winston-Salem, USA. Disclosure: F. S. Gayzik is a member of Elemance, LLC, which provides academic and commercial licenses for GHBMC-owned HBMs.

and pelvis. Time-history outputs for each model were left unscaled and unweighted, and were compared directly to individual experimental traces from the study [6]. CORrelation and Analysis (CORA) scores were calculated for each metric to quantify the level of agreement between the model predictions and experimental data. The CORA scores taken from each model were averaged and compared to understand how the models comprehensively compared to experimental data.



a.) GHBMC F05-OS at t = 0 b.) GHBMC F05-OS at Peak Pelvis Rotation c.) GHBMC F05 THAN-OS at t = 0 d.) GHBMC F05 THAN-OS at Peak Pelvis Rotation

Fig. 1. Seat configuration 2 [6] for both HBMs. Models are shown at the time of peak pelvis rotation.

III. INITIAL FINDINGS

CORA scores were calculated for ten kinematic and kinetic metrics to evaluate the dynamic response of the HBMs throughout the simulation. These metrics captured key aspects of occupant motion and loading, enabling a direct comparison between model predictions and experimental data. The individual CORA scores for each metric were cross-plotted between the GHBMC F05-OS and GHBMC F05 THAN-OS models, as shown in Figure 2, to visualise the relative performance of each model and highlight which outputs had greater CORA scores as compared to experimental results. The average CORA score across all 10 metrics was 0.601 for the GHBMC F05-OS and 0.787 for the GHBMC F05 THAN-OS, indicating a stronger overall agreement with experimental data for the THOR-analogous model. This suggests that the component-level anthropometry adopted from the ATD counterpart may better represent the PMHS subjects from this study. Additionally, submarining was accurately detected in simulations using both models indicating that each exhibited behaviour consistent with that observed in the experimental subjects.

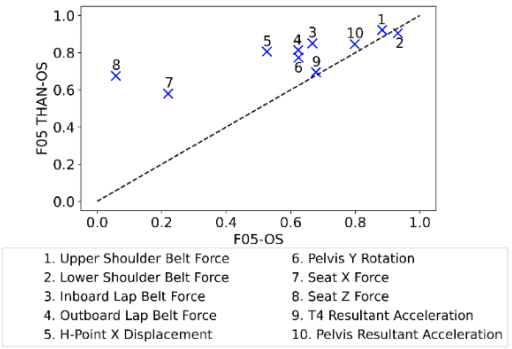


Fig. 2. Cross-plotted CORA scores for the F05-OS and F05 THAN-OS HBMs

IV. DISCUSSION

The CORA scores indicate that the F05 THAN-OS model produced responses more consistent with experimental data, as evidenced by the majority of cross-plotted scores favouring the F05 THAN-OS over the F05-OS. One contributing factor may be the mass difference between the two models: the F05 THAN-OS has a total mass approximately 6.2 kg lower than that of the F05-OS, aligning more closely with the average subject mass of 45 kg in the experimental study cohort. This improved anthropometric match likely contributed to the increased fidelity in model response. The observed differences in biofidelity can be attributed to the variations in component-level anthropometry between the models, which appear to influence occupant kinematics and loading in submarining-prone scenarios. Similar trends have also been noted in the other two seating configurations from the dataset, which have been run as part of this ongoing work. Future work will focus on expanding this comparison by simulating the F05 THAN-OS and the THOR finite element (FE) models in matched boundary conditions derived from experimental tests performed with the THOR ATD. This will allow for a direct assessment of the similarities and differences in kinematic and kinetic behaviour between the THAN-OS and its counterpart.

V. ACKNOWLEDGEMENTS

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