Digital Twin to Assess Public Transit Safety in Frontal Crash

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I. INTRODUCTION

Epidemiological studies, full-scale crash tests and sled studies have suggested that for bus passengers in frontal collisions, contact with handrails attached to the adjacent seat can be a potential source of injury [1-4]. However, handrail interaction as a function of seat geometry, ATD stature and sled pulse has not been investigated in a systematic manner. Concomitantly, the limitations of current ATDs in the transit bus environment have been highlighted, including high thoracic spine stiffness and the inability to assess injury risk for direct impact on the neck [4].

To address the need for assessment of a wide variety of impact conditions and to provide an environment to assess alternate seat designs, a digital twin approach was undertaken. The approach comprised: a physical test buck constructed to reproduce ATD kinematics observed in full-scale crash tests [4]; a digital twin of the sled buck incorporating ATDs for verification and validation against the physical test data; and integration of the digital twin with detailed human body models (HBMs) to assess occupant response based on kinematics and injury risk.

II. METHODS

Sled testing

Forward-facing seats, vertical posts and seat anchorages were removed from the passenger section of a decommissioned New Flyer D40i bus (Fig. 1A) [4] and attached to a generic, configurable test buck (Fig. 1B). The test buck accommodated fore-aft and vertical adjustments of seat anchorage locations and fore-aft repositioning of vertical posts. Seat height and seat pitch in this series of tests were matched to those measured on the bus.

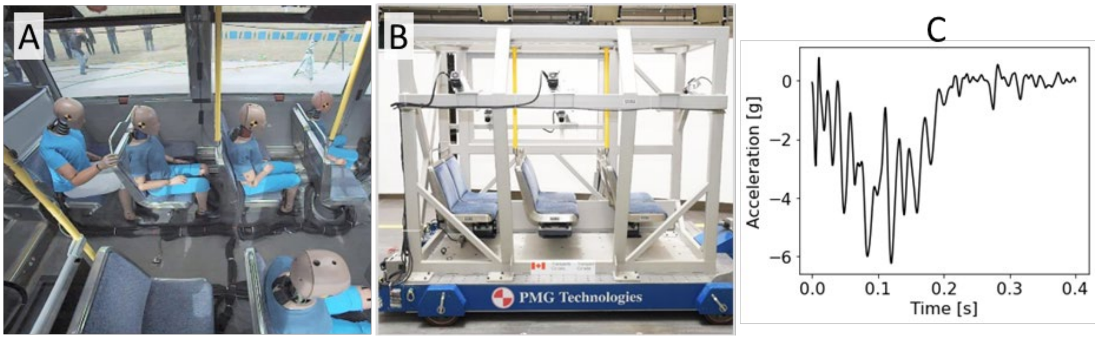

Fig. 1. (A) Inboard view showing part of the passenger compartment of a bus. (B) Side view of the test buck attached to the deceleration sled. (C) 6.5 g sled pulse.

Ten sled tests were conducted on a decelerative sled (MESSRING GmbH, Krailing, Germany). For brevity, this communication reports on the results of six tests, each of which was conducted with a 6.5 g pulse (Fig. 1C), the Hybrid-III 5th female (HIII$_5$) in the second-row seats, and the Hybrid-III 50th male (HIII$_{50}$) in the third-row seats. ATD posture (reclined or upright) and seat position (inboard or outboard) were varied between tests. The handrail height in front of the ATDs was 50 mm lower on the outboard seat than on the inboard seat. ATD positioning was recorded by a 3D metrology system (FaroArm, FARO, Lake Mary, Florida, US). ATD instrumentation included accelerometers at the head, chest and pelvis; potentiometer at the chest; load cells at the neck and femurs; and angular rate sensors at the head. Data were filtered as per SAE J211.

Digital Twin

The surfaces of the seats and anchorages were measured by a 3D metrology system (FaroArm). A FE model of the sled buck was created from the measured seat geometry, and simulations of the six sled tests were conducted with FE models of the HIII$_5$ and HIII$_{50}$. The positions of ATD models were matched to those of the physical ATDs using the measured pre-test positioning points. The predicted ATD responses of each simulation were compared to those of physical tests qualitatively and using CORA to validate the computational sled and occupant model. Next, two HBMs, the Global Human Body Models Consortium (GHBMC) average stature male (M50) and small stature female (F05), were integrated with the sled model to assess response and injury risk. The HBMs were repositioned to reproduce the ATD seating position and assessed for the inboard seat, upright posture sled case.

III. INITIAL FINDINGS

In each sled test, the physical ATDs translated forward until the knees contacted the seatback, the torso pitched forward, and the ATDs contacted the forward handrail. The point of contact between the ATD and handrail was dependent on handrail height and ATD stature. When seated outboard (low handrail height), the neck of the $HIII_5$ and the upper chest of the $HIII_{50}$ contacted the handrail. When seated inboard (high handrail height, Fig. 2), the chin of the $HIII_5$ and the neck of the $HIII_{50}$ contacted the handrail.

The simulated motions of the ATD models were in good agreement with the physical tests (Fig. 2). CORA ratings averaged across all test conditions were 0.812 for the $HIII_{50}$ and 0.685 for the $HIII_5$. The M50 and F05 HBMs predicted increased forward displacement of the upper spine and neck relative to the ATD models (Fig. 3), associated with increased thoracic spine flexion. This flexion led to contact between the face and the top of the seatback for the HBMs (Fig. 3). Another notable difference was that the F05 contacted the handrail at the lower neck, whereas the $HIII_5$ model contacted the handrail at the chin (Fig. 2).

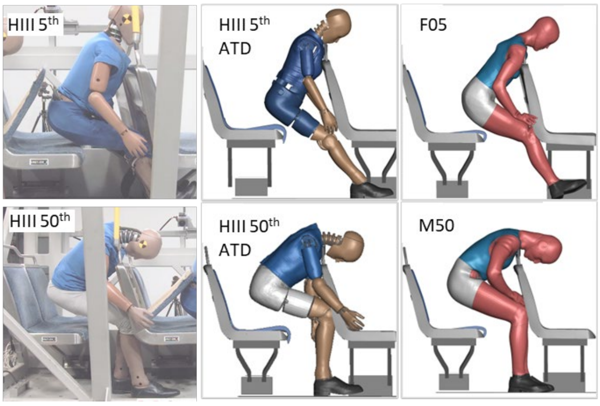

Fig. 2. (Top) Comparison of the physical $HIII_5$, $HIII_5$ FE model and F05 model at the time of handrail contact.
(Bottom) Comparison of the physical HIII-50, HIII-50 model and M50 model at the time of handrail contact.

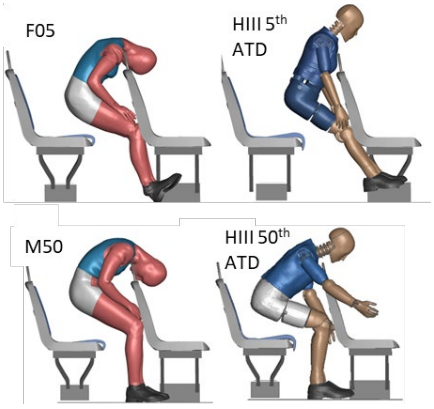

Fig. 3. (Top) Comparison of the F05 to the $HIII_5$ model. (Bottom) Comparison of the M50 to the $HIII_{50}$ model.

IV. DISCUSSION

A series of physical tests was conducted with the sled buck incorporating ATDs and simulated with the corresponding digital twin to describe, for one seat design, how ATD stature and handrail height can influence the interaction between the ATD and the handrail. ATD motions and contact points with the handrail observed in sled tests were qualitatively similar to those reported for full-scale bus crashes [4]. Unlike physical ATDs, ATD models and HBMs can measure additional neck kinetics and kinematics responses occurring from impact on the forward handrail. HBM simulations can additionally reveal test conditions for which ATD limitations influence interaction with the handrail. This sled buck design serves as a baseline reference for the integration of numerical and physical tools to advance safety countermeasures in transit buses and emerging vehicle configurations.

V. REFERENCES

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[2] Olivares, G., *et al.*, *ESV*, 2009.
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