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RESEARCH RESULTS
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# FINITE ELEMENT ANALYSIS OF APTA PASSENGER RAIL 8G INJURY SEAT TEST


## SUMMARY

The Federal Railroad Administration (FRA) sponsored researchers at the Volpe Center to perform finite element analyses (FEA) of 8g dynamic crash tests using a commuter rail 2-passenger seat design with different sized Hybrid-III anthropomorphic test devices (ATDs) including: (1) 50th percentile male (H3-50M), (2) 5th percentile female (H3-5F), and (3) 95th percentile male (H3-95M). The researchers based the simulations on compliance tests (see Figure 1) conducted per the American Public Transportation Association (APTA) safety standard APTA PR-CS-S-016-99 – Passenger Seats in Passenger Rail Cars [1].

Figure 1. Pre-test Photo of APTA Seat Standard Test with the Commuter Rail 2-passenger Seat

The researchers performed this study to address concerns from government stakeholders on the occupant protection of passengers outside of the size range currently specified in the APTA seat standard. The simulation results indicate that smaller occupants may experience more serious injuries in a forward-facing seating configuration due to having increased secondary impact velocities and lower masses as well as not being able to tolerate higher contact forces without injury.


## BACKGROUND

Passenger seats in commuter rail trains are subject to the safety requirements described in the APTA seat standard. This standard requires seats to be tested in simulated collision conditions with instrumented ATDs to evaluate the seat integrity, human injury performance, and occupant compartmentalization.

The standard requires three dynamic sled tests with ATDs:

1. Forward-facing human injury test with instrumented H3-50M ATDs
2. Rear-facing human injury test with instrumented H3-50M ATDs
3. Forward-facing structural integrity test with uninstrumented H3-95M ATDs

The standard also requires static strength tests for seat components, lateral and vertical seat attachment tests, and flame and smoke emission tests.

The analyses described here compare the human injury results from a simulated APTA forward-facing passenger rail seat test with different sized occupants, i.e., medium male, small female, and large male. The APTA seat standard only prescribes human injury requirements for medium-sized males. While the forward-facing structural integrity test uses H3-95M ATDs, these ATDs are not required to be instrumented so human injury results are not available for comparison with H3-50M ATDs.

## OBJECTIVES

The objectives of the analysis were to compare the human injury results from simulations of the APTA seat standard forward-facing human injury seat test with different sized occupants including a 50th percentile male, 5th percentile female, and 95th percentile male, and to assess whether injury criteria requirements in addition to those for the H3-50M should be considered for inclusion in the APTA seat standard.

## METHODS

Volpe researchers created an LS-DYNA FE model of a 2-person commuter rail seat based on design data provided by the manufacturer. The material properties specified in the model were based on publicly available information and samples were not extracted from the seat for mechanical characterization. The researchers used the following versions of the publicly available ATD models from Livermore Software Technology Corporation: (1) H3-50M detailed version released on February 2, 2017; (2) H3-5F detailed version released on February 2, 2017; and (3) H3-95M detailed version released on December 14, 2015.

The team analyzed row-to-row (R2R) sled test data shared by the manufacturer and open-bay (OB) sled test data sponsored by FRA [2]. They performed a limited study on model validation of the seat using sled test results including R2R forward- and rear-facing injury, R2R forward-facing structural integrity, and OB forward-facing injury tests. Researchers found that sled test models were sensitive to the exact positioning of the ATDs and only were able to achieve a median agreement error of 19 percent across the injury criteria. Since ATD positioning information necessary for detailed modeling was not recorded during the compliance tests, the researchers did not refine the model to achieve better model agreement.

Figure 3 shows the FE model of the forward-facing seat human injury test with two rows of 2-passenger seats and two H3-50M ATDs seated in the rear row. The researchers removed the seat-back and seat-bottom foam cushions from the model to reduce the simulation runtime and improve the stability for parametric analyses, but the ATDs were positioned as if the cushions were present.

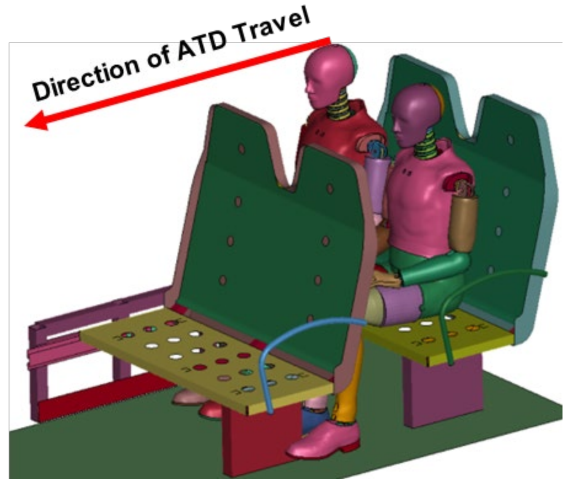


**Figure 2. FE Model of Forward-facing Seat Injury Test Immediately Prior to Impact**

The actual dynamic tests used a pneumatic accelerator sled system in which the ATDs were initially at rest. The sled was then rapidly pushed backwards, resulting in the ATDs moving forward relative to the sled and impacting the seat in front of them.

Figure 4 shows the 8g crash pulse used in each simulation. Researchers selected the crash pulse from the commuter rail seat compliance tests because it was in the middle of the range of severity. The selected crash pulse resulted in a maximum change in velocity of 10.99 m/s (24.58 mph) which is 12 percent above the APTA seat standard minimum of 9.81 m/s (21.95 mph).

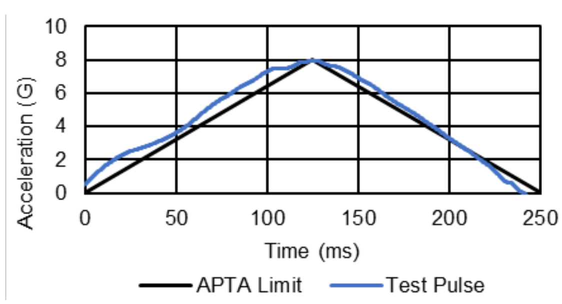


**Figure 3. Crash Pulse**

Table 1 shows the injury assessment reference values (IARVs) or performance limits for each type of ATD. All the IARVs were originally specified for automotive frontal crash protection. The researchers used IARVs for a 50th percentile male from the APTA seat standard, but they are originally from 49 CFR 571.208 S6. The researchers used IARVs for a 5th percentile female from 49 CFR 571.208 S15.3. Since IARVs for a 95th percentile male are not specified in 49 CFR 571.208, researchers used recommended values published in 1999 by Eppinger et al. [3].

**Table 1. Injury Assessment Reference Values**

| Criterion | H3-50M | H3-5F | H3-95M |
|---|---|---|---|
| Head Injury Criterion (HIC15) | 700 | 700 | 700 |
| Neck Injury Criterion (Nij) | 1 | 1 | 1 |
| Neck Axial Tension | 4.17 kN | 2.62 kN | N/A† |
| Neck Axial Compression | 4.00 kN | 2.52 kN | N/A† |
| Chest Acceleration, 3 ms | 60g | 60g | 55g |
| Femur Axial Load | 10.00 kN | 6.805 kN | 12.70 kN |

† The researchers could not find well established neck tension or compression IARVs for a 95th percentile male in the literature.

The parameters used to compute the neck injury criteria (Nij) for each ATD differed in that the 95th percentile male ATD was less likely to exceed the Nij limit than the 5th percentile female ATD, even though the peak neck loads and moments experienced were larger than those of the 5th percentile female ATD. Generally, the larger the ATD, the larger the force/moment tolerance. The Nij parameters for each ATD can be found in the IARV sources noted above.

## RESULTS

The human injury FEA results presented in this section are normalized by the IARVs in Table 1. Results greater than 1 would not meet the selected performance requirement, and values close to 0 indicate a very low likelihood of human injury. Figure 5 shows the normalized head injury criterion over a 15 ms clip (HIC15), Nij, neck axial tension, and neck axial compression normalized peak values from the ATDs. Results are not shown for the neck axial loads from the H3-95M because the researchers could not find an appropriate IARV for a 95th percentile male. Head and neck injury results were generally closer to the limit for the 5th percentile female.

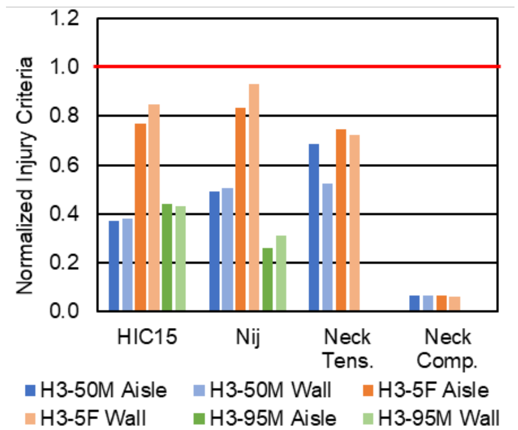


**Figure 4. Head and Neck Injury FEA Results**

Figure 6 shows normalized resultant chest acceleration over a 3 ms clip and femur axial load normalized peak values from the ATDs. The femur results indicate a slightly higher risk of leg injury for the 5th percentile female, but the disparity was not as large as observed in the head and neck results.

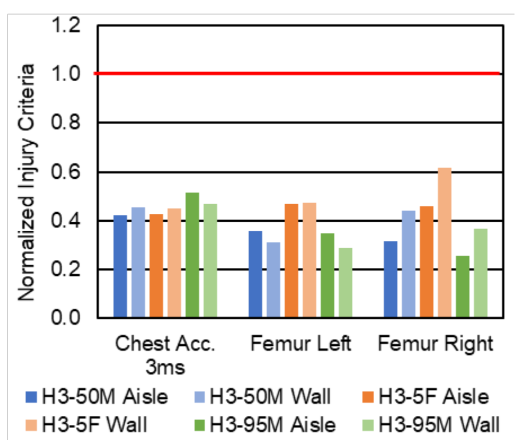


**Figure 5. Chest and Leg Injury FEA Results**

## CONCLUSIONS

Researchers used FEA to preliminarily compare the risk of human injury for 50th percentile males, 5th percentile females, and 95th percentile males in passenger rail impacts with forward-facing seats. The results indicate that 5th percentile females may be at a higher risk of head and neck injury based on HIC15 and Nij results.

## FUTURE ACTION

Further study of passenger rail accident data is necessary to see if there are trends in human injury for different sized passengers. However, passenger rail accidents are rare, so this data may not be readily available. Because the FE model from the study was not fully validated, the researchers recommend that actual sled tests be used to compare human injury results from the H3-50M, H3-5F, and H3-95M ATDs.

## REFERENCES

[1] American Public Transportation Association (March, 2021). APTA PR-CS-S-016-99, Rev. 3 - Standard for Passenger Seats in Passenger Railcars. Washington, D.C.

[2] Federal Railroad Administration (2023). Dynamic Crash Testing of Open-Bay Seats (Report No. RR 21-01). FRA.

[3] Eppinger, R., et al. (November 1999). Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems - II. NHTSA.

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## KEYWORDS

Crashworthiness, dynamic sled testing, ATDs, rail passenger safety, secondary impacts, finite element analysis

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