Development and Validation of a 2009 Toyota Venza MADYMO Frontal Occupant Model

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This working paper summarizes recent efforts and findings derived from NCAC research. It is intended to solicit feedback on the approach, scenarios analyzed, findings, interpretations, and implications for practice reported by the research team. Please forward comments or questions to the authors noted above. These efforts will ultimately be documented and made available to advance research efforts related to this topic and guidance for practice.

ABSTRACT
A rigid body model of a driver was developed in MADYMO to predict occupant injury risks in a 2009 Toyota Venza for the Hybrid III 50th percentile male dummy. This model was validated against frontal crash data from regulatory tests.
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INTRODUCTION
A frontal MADYMO model of a driver in a 2009 Toyota Venza was developed in support of the National Highway Traffic Safety Administration (NHTSA) study, “Investigate Self and Partner Protection of New Vehicle Designs Using Structural Modeling,” TOPR No. 16 under DTFH61-09-D-00001. An FE model of the Toyota Venza was previously developed as part of an Environmental Protection Agency (EPA) study on light weight vehicles. This FE model was used in simulated crashes with other vehicles and objects. The FE simulation results were used as inputs for the frontal MADYMO occupant model, which was developed to assess occupant injury risk.

To develop the MADYMO model, a generic model year (MY) 2011 small car was obtained from a restraint manufacturer. This generic model was used as a foundation for the Venza occupant model. This foundation model was modified to reflect data and measurements from the crash test report in order to make it more representative of a Toyota Venza. The Venza occupant model was validated against frontal crash test data for a frontal NCAP test.

MODEL DEVELOPMENT
The baseline Venza occupant model was based on the generic occupant model, test reports, vehicle measurements, and component specifications. The baseline MADYMO model is shown in Figure 1. The generic MADYMO model was customized with Venza dimensions and restraint characteristics. Occupant compartment components such as toe pan, floor, A-B pillars and windshield geometry were exported from the LS-DYNA Venza baseline model shown in Figure 2.
The resulting Venza MADYMO occupant model is shown in Figure 3. The occupant seating position was modified to match the clearance dimensions in NHTSA test reports. For the MADYMO simulations the FEM vehicle crash pulse, toe pan, floor, and A-B pillar intrusions were also generated from the LS-DYNA simulations and then imported into the MADYMO occupant model. The occupant models used prescribed structural motions extracted from the LS-DYNA results for the toe pan, floor, windshield, and A-B pillar intrusions.

The airbag and seat belt characteristics used generic specifications, with adjustments to the load limiting and pretension characteristics. A shoulder belt load limiter of 4000N was added to the model. The model used a generic FE model airbag, not a Venza vehicle airbag model. The “5-30” rule was used to estimate the firing time from the FE crash pulse and the firing time came to 18 ms. The Venza occupant model is currently being improved for a follow on study and will be reported on with more extensive
MODEL VALIDATION

The following naming convention was used for the plots discussed in this section: crash test outputs are labeled “Test”, MADYMO simulations using the crash test pulse are labeled “Simulation”, and MADYMO simulations using the FE vehicle simulation pulse are labeled “FE Simulation”.

The Venza baseline occupant model with the Hybrid III 50th percentile male dummy was evaluated against available full frontal crash data, NHTSA test number 6601. Two simulations were run—one using the crash test pulse with no intrusion and one using the FE pulse from the LS-DYNA full vehicle simulation with intrusion. The difference between the crash test pulse and the FE pulse is shown in Figure 4. To ensure that the FE crash pulse results from this study were consistent with the data presented in the EPA Venza baseline report, a snapshot of the crash pulse output from the final EPA Venza baseline report is shown in Figure 5. As it can be seen in Figure 4, the duration of the FE simulation crash pulse was shorter than that of the test crash pulse. The peak G’s and their timings are similar in both events. The crash pulse comparison indicates that the FE simulation crash pulse is not a perfect match for the test data. The simulation results should not be used as a direct prediction of occupant safety performance. However, the trends observed in simulation results can still be used. For this study, the change in simulation results between the baseline and lightweight vehicle designs should still provide insight for guiding research priorities for lightweight vehicles.

![Vehicle Crash Pulse Test 6601-FE Simulation](image)

Figure 4. Vehicle Crash Pulse Comparison between Test 6601 and FE Simulation

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In terms of restraint systems, the 2009 Toyota Venza from the NCAP test number 6601 had both driver and passenger force limiters dual stage 5000-4000N. For the 2011 Venza model (used for the FE baseline vehicle modeling) both driver and passenger force limiters are single stage 4000N. All the MADYMO simulations for the lightweight vehicle project used a shoulder belt load limiter of 4000N. Figure 6 and Figure 7 show the shoulder and lap belt forces for the test and both MADYMO simulations.
All of the outputs for the dummy model were compared to the available crash test data.

The peak head resultant acceleration for the MADYMO simulation using the test crash pulse occurs later in the crash than as shown in the test data (Figure 8). The occupant’s head kinematics at the peak of the resultant acceleration is shown in Figure 9. The difference in the timing of when the shoulder belt engages (0.01s for Test 6601 and 0.02s for the MADYMO simulation) explains why there is a delay in the simulation peak head acceleration. Also, since the MADYMO model used a generic airbag and not the one from the test, the head-airbag interaction forces of the test and simulation are different, which leads to different peak and timing of the head resultant acceleration.
The chest resultant accelerations for the test and the MADYMO simulation using the test crash pulse are very similar in peak magnitude as well as duration of pulse (Figure 10). For the MADYMO simulation using the FE vehicle crash pulses, the peak chest acceleration is higher than the other two cases. The MADYMO simulation using the FE crash pulse included intrusion being modeled based on the LS-DYNA simulations. The high femur loads (Figure 14 and Figure 15) that peaked at 50 milliseconds lead to higher pelvis accelerations (Figure 11), which in turn lead to higher peak chest acceleration.
The chest deflection plots for both MADYMO simulations fall within the general shape of the test output, as shown in Figure 12.

The neck tension for the MADYMO simulation using the test crash pulse closely followed the neck tension from the test for the first 70 milliseconds of the event (Figure 13). From the occupant kinematics shown in Figure 9, it can be seen that there was contact between the head and airbag at 90 milliseconds, which indicates why the neck tension in the MADYMO simulation did not decrease in the second part of the crash event, as it did for the crash test. For the MADYMO simulation in which the FE simulation crash pulse was used, due to compartment intrusions and the different knee-pelvis-chest kinematics of the occupant, the duration of the chest to airbag contact was shorter (indicated by the duration of the chest resultant acceleration). The neck tension resulting from the MADYMO simulation using the FE crash data looked very realistic and closer to the test results.
The left and right femur load comparisons for the test and simulations are shown in Figure 14 and Figure 15. The Venza baseline MADYMO model did not model the knee airbags that were present in the physical test 6601. Therefore both left and right femur loads had higher values in the simulation than in the test. For the MADYMO simulation in which the FE crash pulse was used and compartment intrusions were included in the modeling, the femur loads were even higher. This shows that the intrusion drove the FE simulation femur loads significantly higher than in the test.
SUMMARY AND CONCLUSIONS
A MADYMO rigid body model of a frontal Toyota Venza occupant model with a Hybrid III 50th percentile male driver was developed to predict occupant injury risks for the occupant. This model was evaluated against frontal crash data from regulatory tests. The model was built based on a generic MADYMO Hybrid III 50th percentile occupant model. Two simulations were run, one using the vehicle crash test data from the NCAP test number 6601 and one using the FE vehicle crash pulse resulted from the LS-DYNA Venza FE baseline rigid wall simulation. The results from the MADYMO model evaluation and the test results are summarized in Table 1. While the chest and head predictions were reasonable, the femur predictions for the MADYMO simulation using the FE crash pulse were not as reliable as the head and chest results. The MADYMO model using the FE crash pulse input, included the toe pan, floor, windshield, and A-and B-pillar intrusions of the Venza FE model. The femur loads were driven by the intrusion. Also, for test 6601, the knee airbags present in the vehicle helped mitigate the femur loads.

<table>
<thead>
<tr>
<th>Test 6601</th>
<th>MADYMO Simulation using test crash pulse</th>
<th>MADYMO Simulation using FE pulse</th>
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<tr>
<td>HIC 15</td>
<td>Chest 3MS (Gs)</td>
<td>Neck Tension (N)</td>
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<tr>
<td>339</td>
<td>36</td>
<td>1460</td>
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The purpose of this analysis was to develop a baseline Venza MADYMO occupant model with results that represent reasonably the small SUV class of vehicles, making it feasible for this model to be used in a fleet modeling study. The baseline occupant injury results are used as reference points in understanding trends in injury results/risks for the lightweight vehicle modeling project.
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FOR MORE INFORMATION
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