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Methodology for Evaluating Fleet Protection of New Vehicle Designs: Application to Lightweight Vehicle Designs

Appendices

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16. Abstract

The National Crash Analysis Center (NCAC) has developed a systems modeling approach to assess real-world safety of vehicle designs in a virtual environment. This effort was to support NHTSA's research for assessing the effects of future vehicle design on safety, in particular, future lightweight vehicle designs. The approach includes estimating the real-world level of safety in a vehicle for its own occupants (self-protection) and for the occupants in vehicles with which it collides (partner protection). This approach will be referred to as EFP—Evaluating Fleet Protection—in this report. EFP is particularly useful for assessing innovative and new designs, and has the potential of becoming a powerful tool to study countermeasure strategies to improve and set priorities for both pre-crash and integrated safety and crashworthiness. As an initial implementation, EFP was applied to drivers in frontal crashes where the systems modeling was driven by finite element structural and rigid body occupant modeling, and real world crash and full-scale test data; however, the EFP approach can be extended to all crash modes and occupants.

EFP was applied to assess frontal crash safety performance of engineering models of concept lightweight vehicle designs developed in projects by the California Air Resources Board (CARB), Environmental Protection Agency (EPA), and National Highway Traffic Safety Administration as part of the Corporate Average Fuel Economy (CAFE) research efforts.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 APPENDIX 1: FE MODEL DEVELOPMENT

1.1 NCAC FEM Development

The National Crash Analysis Cemter (NCAC) is the only independent center in the world to develop, maintain, and make publicly available a large number of verified and validated vehicle finite element models, noting that the auto industry models are not available to researchers for proprietary reasons. Also, the NCAC is the first center to conceive and implement this daunting task of reverse engineering a complete vehicle model for crash simulations. The models of auto manufacturers are developed primarily from their available computer-aided design (CAD) drawings, and not through a reverse engineering process. Consequently, the NCAC models may be different than those of the OEM, but this approach is the best attempt to model the vehicles in production.

Vehicle model development at the NCAC involves several steps starting with first reverse engineering the structures and all mechanical components. Reverse engineering includes disassembling all vehicle parts and components, digitizing vehicle surfaces and components, automatic entry of geometric data in CAD models, meshing all parts, providing the necessary connectivities, and a host of FE pre-processing for subsequent computer crash analysis. Additionally, material thickness measurements are taken and specimen and component testing are performed for material characterizations. This information is required for finite element modeling. Vehicle models are validated by component, body-in-white, and full scale crash testing when applicable.

The methodology involves complete procedures from the early stages of reverse engineering through model generation, model verification, model size reduction, optimization, and validation for intended crash applications.

1.2 NCAC FEM Validation

Computer model validation has been the subject of several complex studies over many years. The NCAC engineers and other researchers have contributed to this topic in the past, through the Transportation Research Board's (TRB) applied mechanics subcommittees and other technical venues (see Section 1.6 for references). At present, there are some general agreements in the crashworthiness community concerning comparisons of deformation (displacement and rotation) plots, acceleration and force time histories during a crash, and capturing of crash peaks and their correct timing, among other techniques.

Traditionally, the accuracy and fidelity of simulations are studied in the following three stages:

1. Crash deformation and collapse modes in the high impact regions;
2. Time history records at different locations; and
3. Energy absorption by the different components.

In the first stage, global and local component deformations from the simulations are visually compared to images captured with high speed cameras from the test. Deformation plots from the simulation and test are set side by side and the response of the whole structure, as well as key components, is compared at different stages of the impact event. In the second stage, time history curves, such as acceleration, velocity, displacement, forces, etc., from the simulation are overlaid with the corresponding test data. The curves are compared visually in terms of number of peaks, magnitude and timing, and pulse duration. The final stage of the validation consists of examining the energies from the simulations. The global energies (total, kinetic, internal, sliding, hourglass, etc.) as well as the component energies from the simulation are checked to ensure that the conservation of energy condition is satisfied and no discrepancies are observed in the results.

Over the years, several methods have been developed to compare time history curves and establish an objective rating method to assist researchers in improving the validation of computer models. The methods can also be used to express the quality of the simulation results with a score, or rating. Rating makes it possible to quantify user requirements (e.g., “the model should score higher than 80%”). It is not trivial, however, to express the accuracy or the quality of a model with just one number. The general concept is to consider the model valid if the difference between the test data and simulation results falls within the differences between repeated tests. The first challenge is to quantify the variation in repeated tests. This difference depends on the type of test. Coupon tests are very repeatable and the variations are minimal. The differences between repeated tests become more significant for component testing. Increased differences are observed in full-scale crash testing where the behavior is dynamic and highly non-linear. The second challenge arises when comparing test and simulation curves. Several algorithms have been developed to quantify the differences between two curves (based on relative absolute difference, least square difference, area differences, area moment differences, etc.).

1.3 Twisk Objective Rating Method

One of the rating methods developed by Twisk et al. of TNO is described below [14]. Three scalar scores are calculated for each signal: (1) the **peak amplitude**, which can be positive or negative in sign; (2) the **timing of the peak amplitude**, relative to the start of the time history; and (3) the **weighted correlation (shape) for the entire signal** (WIFac).

Each individual score as well as the aggregated score can range in value from 0 to 1, where 0 indicates no correlation, and 1 indicates a perfect correlation. Anything over **0.6** has been generally accepted to be a good representation of the experiment.

For the calculation of the first two scalars, the following expression called the Factor Method (FM) is used:

$$\mathrm{crit} = \frac{\max\left(0, \exp \cdot \mathrm{sim}\right)}{\max\left(\exp^2, \mathrm{sim}^2\right)}$$

The WIFac calculates a scalar score for each point using the Factor Method calculation, and performs a weighted summation of all individual scores. The weight factors are the squared values of the data points, which means that smaller time history values contribute less to the WIFac score than large values:

$$crit = 1 - \sqrt{\frac{\sum \max\left(f[n]^2, g[n]^2\right) \cdot \left(1 - \frac{\max(0, f[n] \cdot g[n])}{\max\left(f[n]^2, g[n]^2\right)}\right)^2}{\sum \max\left(f[n]^2, g[n]^2\right)}}$$

Where:

f[n] = experimental data time history, point n.

g[n] = simulation data time history, point n.

To derive aggregate scores from individual scalar scores, the Root Mean Square (RMS) Addition is used. The RMS Addition method is defined by the following formula:

$$comb = 1 - \sqrt{\frac{\sum (W \cdot (1 - crit)^2)}{\sum W}}$$

In this formula, W is the weight factors for the individual criteria. The weight factors can be used to emphasize certain aspects of the model. For example, predicting the peak amplitude of a time history correctly can be made more important than predicting the peak timing or the WIFac.

As an example, this method is applied to the Ford Explorer model developed at the NCAC. The simulation results were compared to a NHTSA NCAP test and the criteria for peak amplitude, timing of the peak amplitude, and shape of the signal were calculated. These three criteria were then equally weighted to get a combined rating.

The peak criteria for the seat cross member acceleration was over 80 percent, however the timing and the shape criteria were in the 60th percentile range. The engine top and bottom accelerations had a combined rating of over 75 percent. The Ford Explorer model scored high rating values and the model can be considered applicable in the range of the NCAP test speed and impact condition. Any other impact configuration has to be compared to an equivalent experiment before accepting the model validity.

The global deformation of the vehicle structure looks very similar between simulation and experiment. The A-pillar deformation compares well, but the frame rail deformation is exaggerated in the simulation (Figure 1-1). After closely investigating the deformation modes and the rail design, NCAC researchers discovered that the rail reinforcement was not added in the early vehicle production. The NCAP test vehicle was one of the earlier production models and hence did not have this structural reinforcement. Consequently the deformation mode and acceleration response after 30 ms were different between the experiment and simulation.

Extreme care has to be taken when using the rating methods. The global and local deformation modes are equally important and should be examined before accepting the rating of the model. It is possible in some cases to get a good rating for one or more of the criteria, while the deformation modes may not match. Figure 1-2 compares the simulation results to the test results for this case and shows the corresponding objective rating for peak value, timing of the peak value, shape of the curve, and a weighted combined rating.

Figure 1-1 – Ford Explorer FEM Structure and Comparison Test

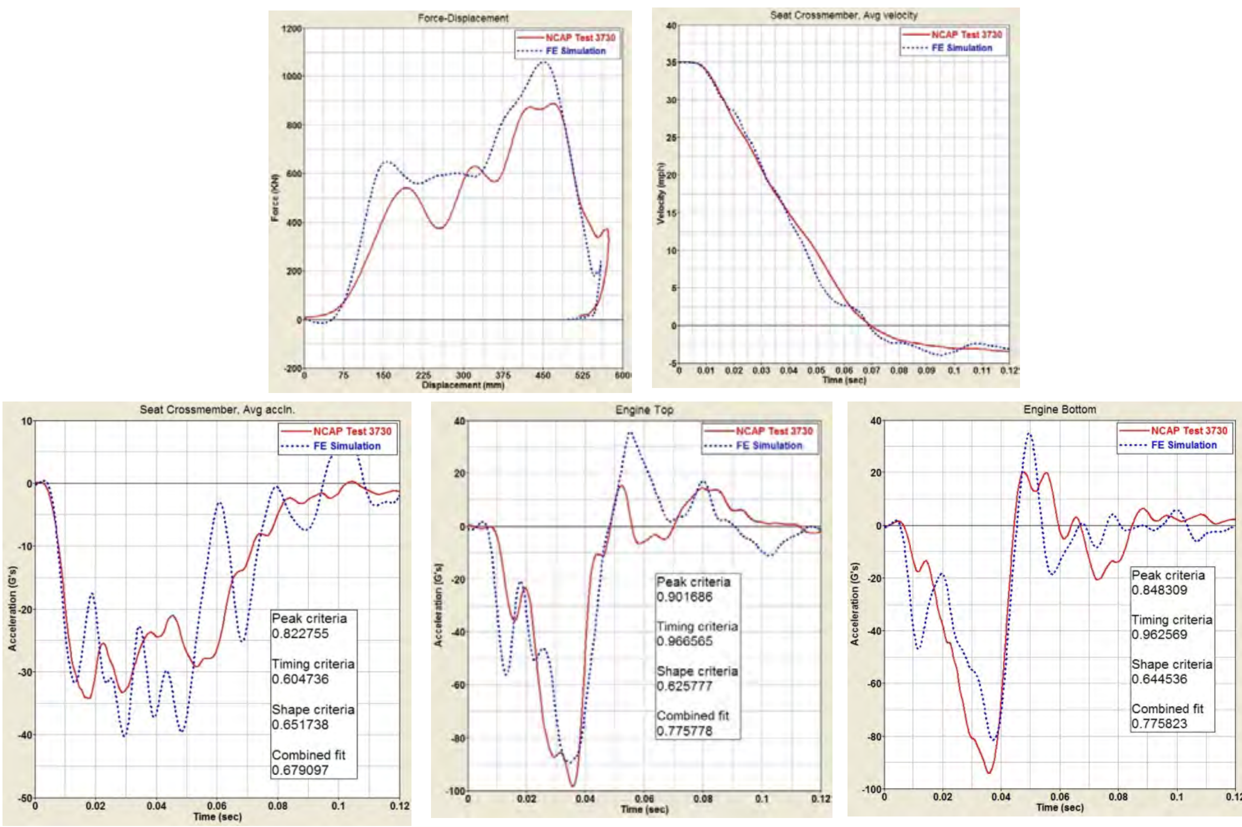

Figure 1-2 – Ford Explorer Validation and Objective Rating

1.4 ANOVA and MPC Objective Rating Criteria

More recently, another method for comparing two curves was developed as part of NCHRP 22-24 project, “Guidelines for Verification and Validation of Crash Simulations Used in Roadside Safety Applications” [15-16]. In this method two metrics, ANOVA and Geers MPC, are used to assess how close the simulation curves are to the test. If the criteria from both metrics are satisfied, the simulation curve is considered similar to the test. For the ANOVA metric, the average relative residual ($\bar{e}^r$) and the standard deviation of the residuals (σ^r) between the two curves are computed as follows:

$$\bar{e}^r = \frac{\sum_{i=1}^{n}(m_i - c_i)}{m_{\max}} \cdot \frac{1}{n}$$

$$\sigma^r = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(m_i - c_i - \bar{e}^r)^2}$$

Where m_i is the measured (test) data, c_i is the computed (simulation) data, and n is the number of points in the curves. The simulation and test curves are considered similar if the average relative residual is less than 5 percent and the standard deviation of the residuals is less than 20 percent. These percentages were derived from repeated rigid pole tests.

In the Geers MPC metric, three components: the magnitude (M_G), phase (P_G), and combined magnitude-phase (C_G), are used to compare simulation and test curves. These components are computed as follows:

$$M_G = \sqrt{\left[\frac{\sum_{i=1}^{N} c_i^2}{\sum_{i=1}^{N} m_i^2}\right]} - 1$$

$$P_G = 1 - \left[\frac{\sum_{i=1}^{N} m_i c_i}{\sqrt{\sum_{i=1}^{N} m_i^2 \sum_{i=1}^{N} c_i^2}}\right]$$

$$C_G = \sqrt{M_G^2 + P_G^{\ 2}}$$

The curves from the simulation and test are considered similar if the M, P, and C values are less than 40. An example using this approach was applied to compare simulation results from the Silverado pickup model to a full-scale frontal NCAP test. Figure 1-3 and Figure 1-4 show a sample of these comparisons.

For this project the Geers MPC and ANOVA metrics developed as part of NCHRP 22-24 were used as the quantitative measures to assess model validation for the four FEM surrogates of the fleet. The Roadside Safety Verification and Validation Program (RSVVP) was used to generate the metrics. The Sprague-Geers MPC metrics were used to quantify the similarity of the test and simulation curve shapes and the ANOVA metric was used to evaluate the residual error. It is worth noting that the Geers MPC metric acceptance criteria were developed for roadside safety applications where the tests typically involve longer duration complex impact sequences with more variability then the NHTSA vehicle crash tests, for example NCAP, being considered for the FE model validation. In the future, developing acceptance criteria for NHTSA type crash tests would be more pertinent and applicable to vehicle FE model validation efforts.

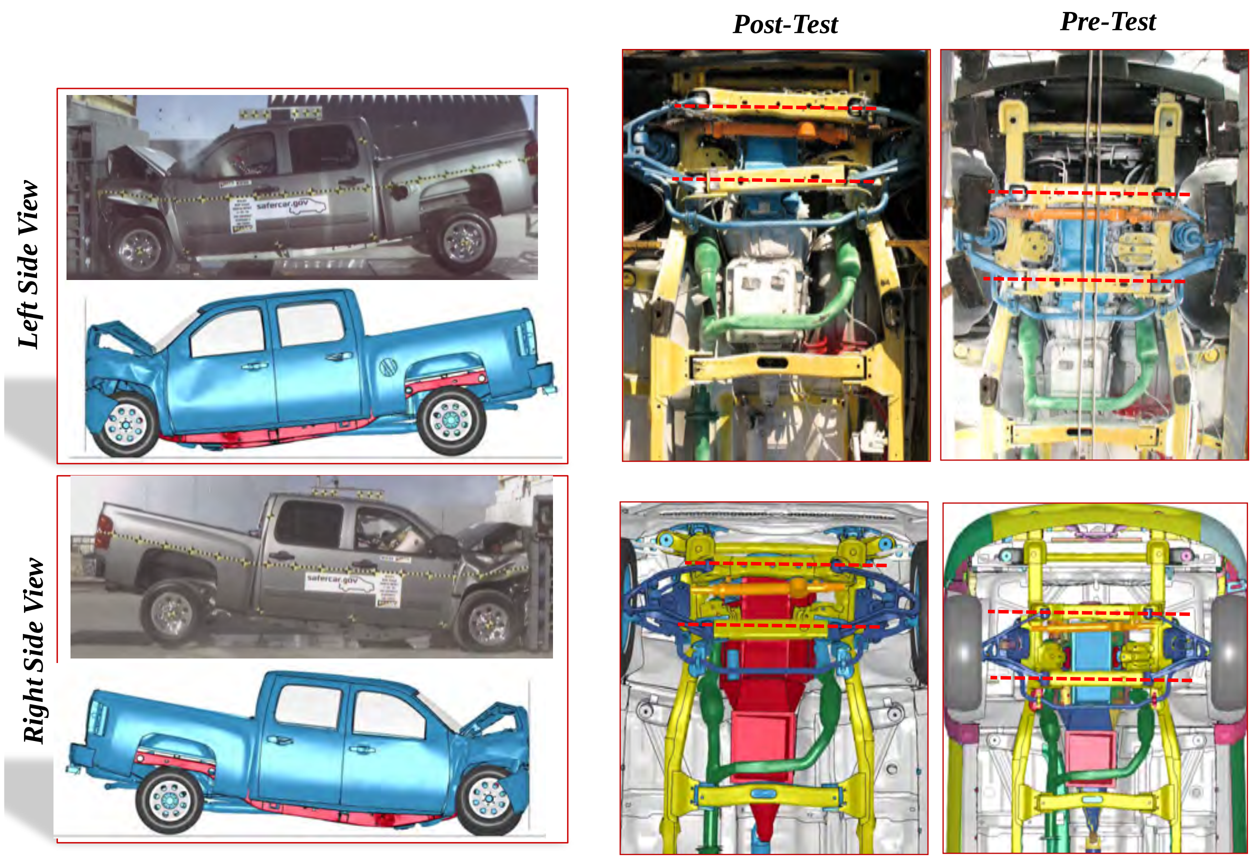

Figure 1-3 – Silverado Model Simulation Crash Deformation Profiles Comparison to NCAP Test

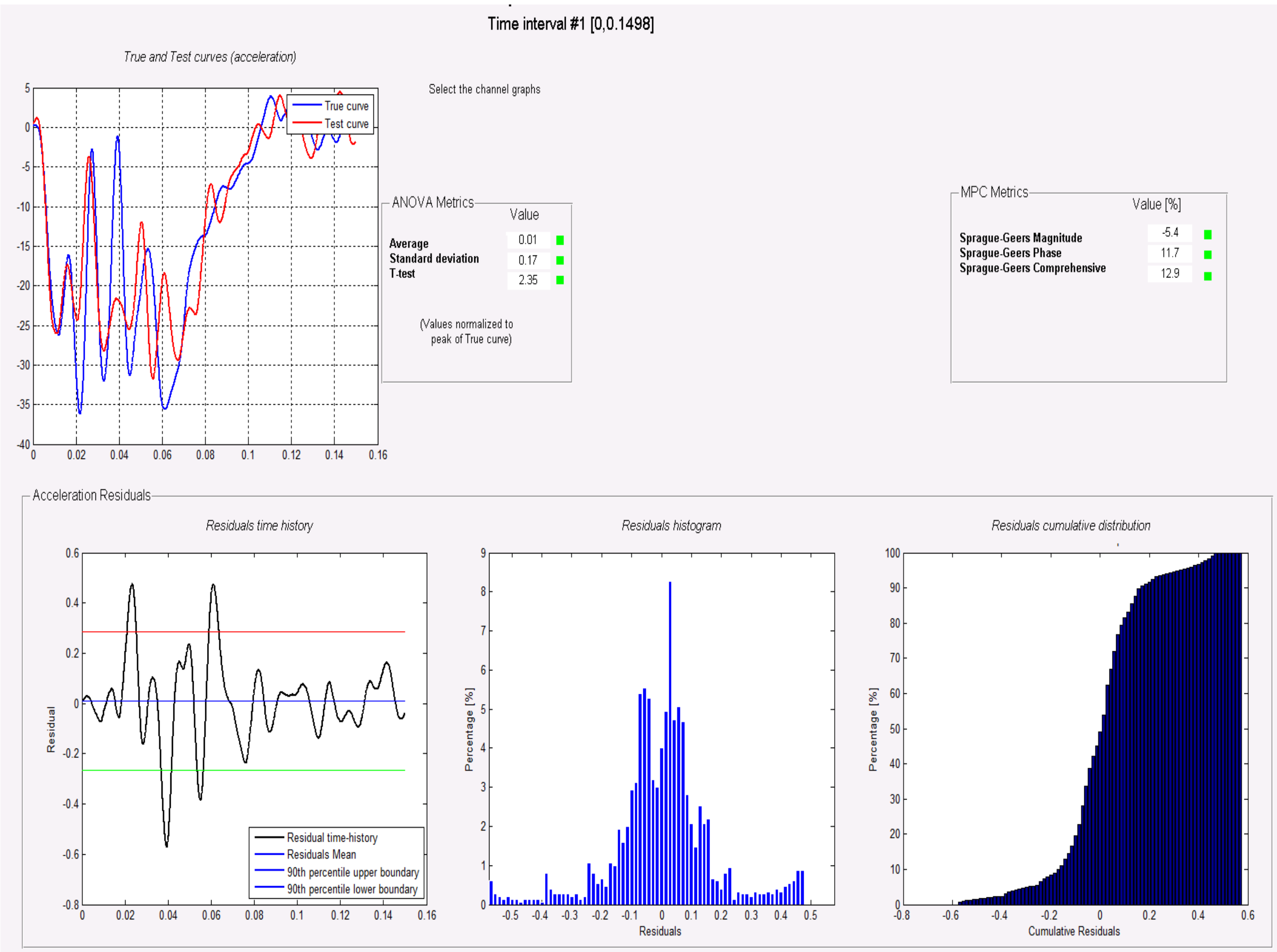

Figure 1-4 – NCHRP 15-22 ANOVA and MPC Metric - Silverado Compartment Acceleration Time History Example

1.5 Other Macro Level Objective Rating Methods

On a macro level, average occupant compartment accelerations/decelerations were compared between the test and the simulation. The crash pulse is further divided in two phases: 0-30 ms and 31 ms to the time of maximum crush. The average accelerations are calculated for these two phases in the crash pulse. A comparison between the test results and the simulation results were conducted. Other structural responses like toe-board intrusions, knee bolster area intrusions, and steering column and instrument panel movements during the crash, when modeled and available in the FEM, were also compared.

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2 APPENDIX 2: EXTENDED VALIDATION OF THE FINITE ELEMENT MODEL FOR THE 2002 FORD EXPLORER SPORT UTILITY VEHICLE

2.1 Introduction

A finite element (FE) model of a 2002 Ford Explorer was developed by NCAC at The George Washington University under contract with the Federal Highway Administration. This model was developed through reverse engineering and was intended for use in a variety of impact scenarios to support FHWA and National Highway Traffic Safety Administration research.

2.2 Model Building

A 2002 Ford Explorer (VIN: 1FMDU72KX3UA60597) was disassembled and each part was scanned to define its geometry, measured for thickness, and classified by material type. Material data was obtained through coupon testing, when possible. Standard material types were assigned for any parts for which no test data were available. The exterior and interior of the final vehicle model are shown in Figure 2-1 and a summary of the FE model components is provided in Table 2-1. The vehicle interior includes the instrument panel, full front row seats, and rear seat structure. The steering wheel, door trim, and rear seat cushions are not included in the model.

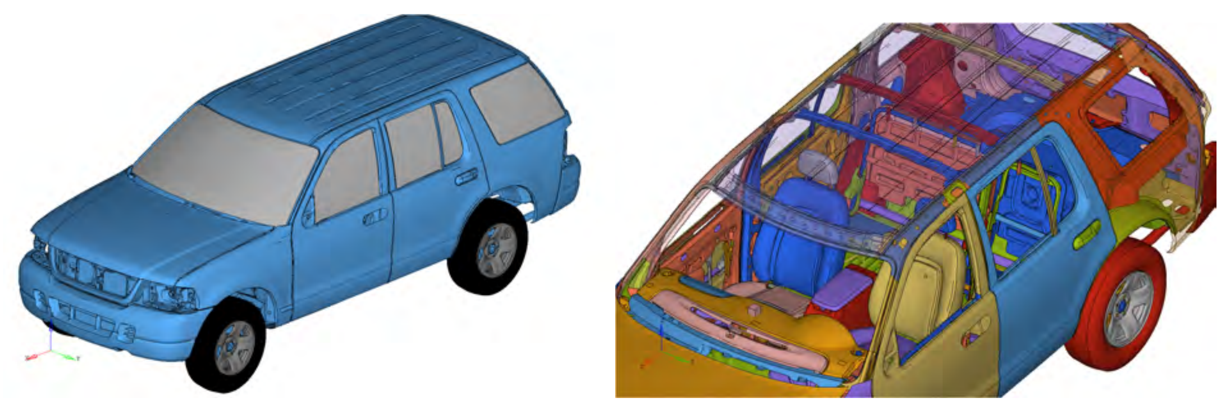


Figure 2-1 – Ford Explorer FE model exterior and interior views

Table 2-1 – Ford Explorer FE model summary

Number of Parts	923	Beam Element Connections	
Number of Nodes	724,628	Nodal Rigid Body Connections	2,102
Number of Shells	680,288	Extra Node Set Connections	132
Number of Beams	185	Rigid Body Connections	7
Number of Solids	33,690	Spotweld Connections	6,842
Total Number of Elements	714,205	Joint Connections	54

Accelerometers were included in the model to compare simulation results with test data. Figure 2-2 shows the locations of some of the most commonly used accelerometers for model validation.

Figure 2-2 – Accelerometer locations in FE model

Details about the modeling and the outcome of the initial validation efforts are documented in "Development and Validation of a Finite Element Model for the 2002 Ford Explorer" NCAC 2008-T-004 [1]. This document describes the additional validation efforts that were undertaken to enhance the Explorer FE model and assess its robustness for various types of impacts. These efforts were conducted by the NCAC in support of the NHTSA study "Investigate Self and Partner Protection of New Vehicle Designs Using Structural Modeling," TOPR No. 16 under DTFH61-09-D-00001.

2.3 Initial Model Validation

The FE model was initially verified to assure that it was a complete and accurate representation of the actual vehicle. The focus of the initial validation was the comparison of the simulation of the NCAP frontal test with actual data from NHTSA Tests 3730 and 5034 for a comparable vehicle [2,3]. A comparison of the vehicles used for the simulation and two NCAP tests is shown in Table 2-2. In addition to these comparisons, it is notable that the Explorer for Test 5034 was a used vehicle and had accumulated 70,974 miles.

Table 2-2 – Comparison of vehicle characteristics for FE model and two NCAP test vehicles

	FE Simulation	NCAP Test 3730	NCAP Test 5034
Unloaded Vehicle Weight (UVW)	2024.6 kg	2040 kg	2010.5 kg
Dummy Weight (2 per test)	151 kg (2x75.5 kg)	152 kg (2x76 kg)	129 kg (76+53 kg)
Cargo Weight	71 kg	131 kg	123.8 kg
As Tested Weight (ATW)	2246.6 kg	2323 kg	2263.3 kg
Model Year	2003	2002	2002
Drive Train	4WD	4WD	4WD
Engine Type	4.0 L V6	4.0 L V6	4.0 L V8
Testing Agency	NCAC	KARCO (CA)	TRC (OH)

The post-crash images show the extent of the deformation (Figure 2-3). The simulation and two tests exhibited similar vehicle kinematics. These similarities can also be observed in the vehicle acceleration, measured at the left and right rear seat cross-members (Figure 2-4). The Roadside Safety Verification and Validation Program (RSVVP) was used to generate objective measures of how well the simulation follows the test data [4]. The Sprague-Geers MPC metrics were used to quantify the similarity of the test and simulation curve shapes and the ANOVA metric was used to evaluate the residual error. The acceptance criteria for the Sprague-Geers metrics are a difference of less than 40 percent in magnitude, phase, or comprehensive (the square root of the sum of the squares of M and P). The acceptance criteria for the ANOVA metric are an average residual error of less than 5 percent and a standard deviation of the residual errors of less than 20 percent. When the values fall under these acceptance criteria, the simulation can be said to have good correlation with the test, with any deviations in the data attributable to random experimental error. These objective rating metrics for the left and right rear seat accelerations compared to Test 3730 are summarized in Table 2-3. It is worth noting that the acceptance criteria in RSVVP were developed for roadside safety applications where tests typically involve longer duration complex impact sequences with more variability than the NHTSA vehicle crash tests being considered for the FE model validation. In the future, developing acceptance criteria for NHTSA type crash test would be more pertinent and applicable to vehicle FE model validation efforts.

Figure 2-3 – Comparison of global deformation for Explorer in NCAP frontal simulation (top), Test 3730 (middle), and Test 5034 (bottom)

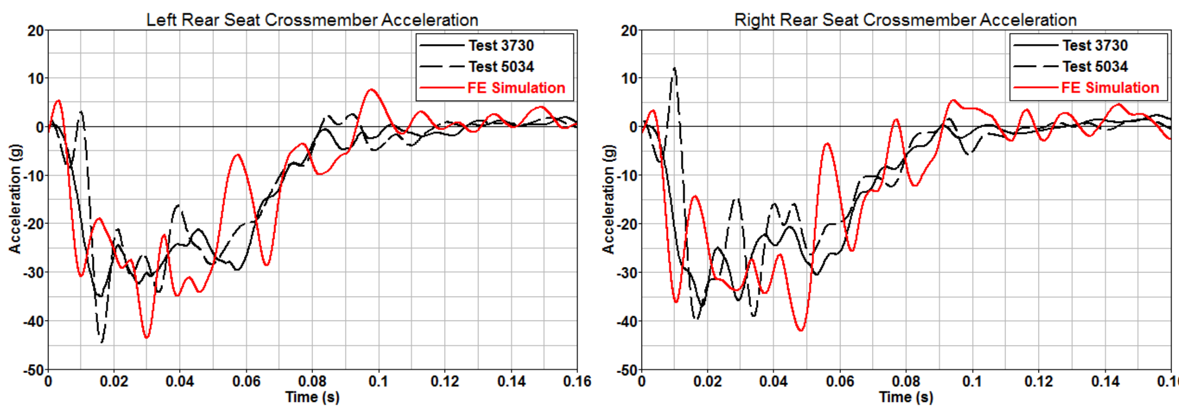


Figure 2-4 – Comparison of left and right rear seat crossmember accelerations for tests and simulation

Table 2-3 – Objective rating criteria for left and right rear seat accelerations

		Left Rear Seat Acceleration		Right Rear Seat Acceleration	
		Value (%)	Pass?	Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	4.7	Y	4.4	Y
	Phase	13.9	Y	13.4	Y
	Comprehensive	14.6	Y	14.1	Y
ANOVA Metric	Average	1	Y	0.4	Y
	Standard Deviation	18.6	Y	17.2	Y

The response of the engine during the crash event was captured through two accelerometers. Both the engine top and bottom accelerations in the simulation closely tracked the engine response in the two tests, as shown in Figure 2-5 and quantified in Table 2-4.

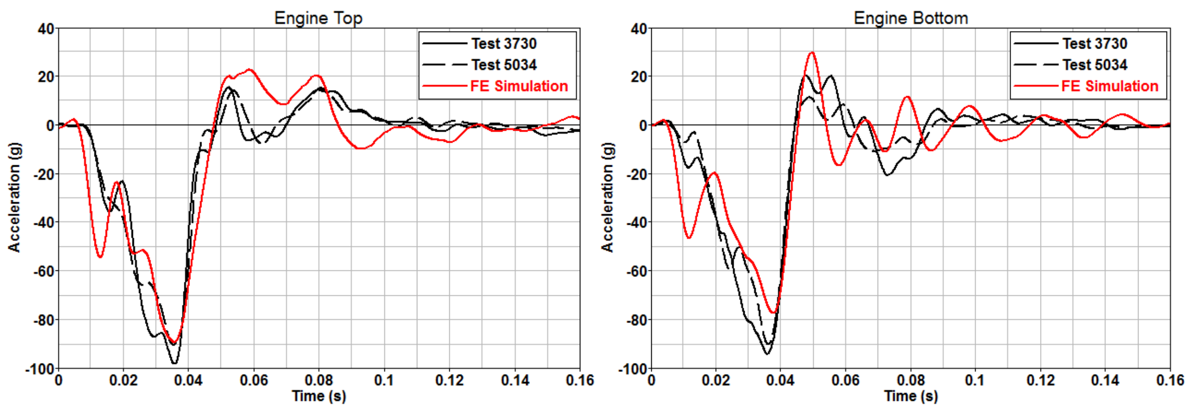


Figure 2-5 – Comparison of engine top and bottom accelerations for tests and simulation

Table 2-4 – Objective rating criteria for engine top and bottom accelerations

		Engine Top Acceleration		Engine Bottom Acceleration	
		Value (%)	Pass?	Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	1.1	Y	-14.3	Y
	Phase	13.7	Y	14.4	Y
	Comprehensive	13.7	Y	20.3	Y
ANOVA Metric	Average	0.5	Y	0.5	Y
	Standard Deviation	11.2	Y	11.8	Y

The simulation and test forces were compared, again showing that the simulation results were very similar to the test results (Figure 2-6 and Table 2-5). The peak timing and values for the total force were closely matched, and force-displacement curves showed that the simulated and test vehicles were of similar stiffness.

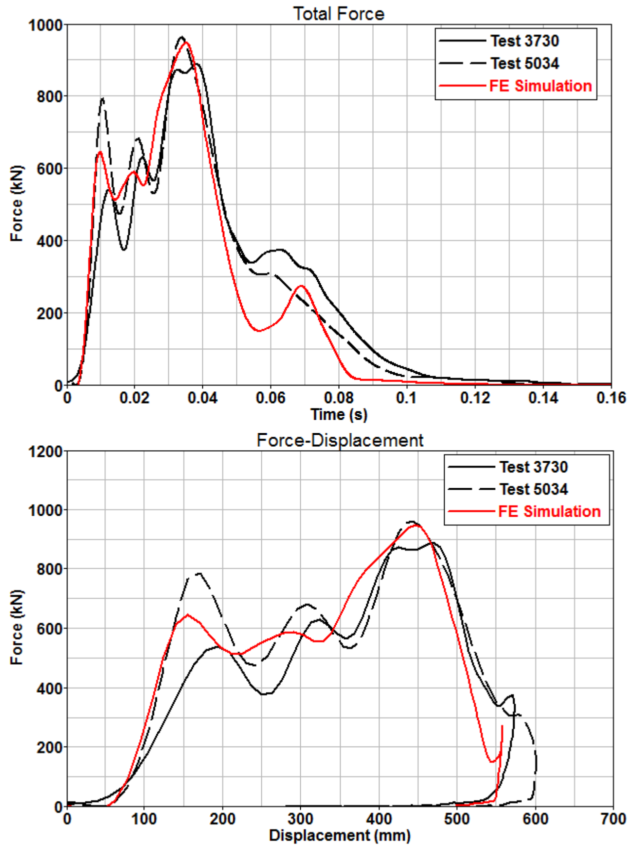
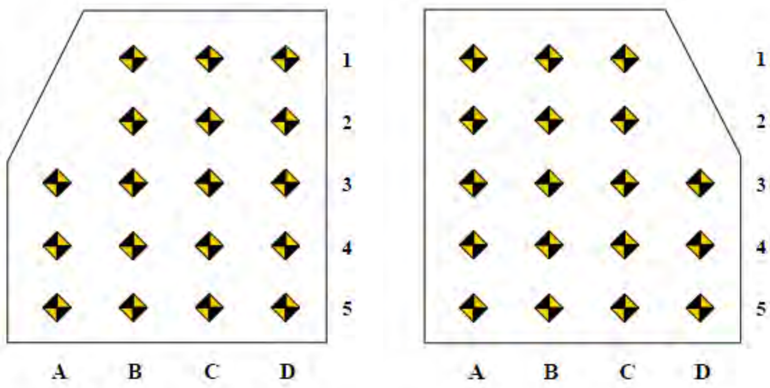


Figure 2-6 – Comparison of total wall force (left) and force-displacement (right) for tests and simulation

Table 2-5 – Objective rating criteria for total wall force

		Total Wall Force	
		Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	-1.8	Y
	Phase	8.2	Y
	Comprehensive	8.4	Y
ANOVA Metric	Average	-2.9	Y
	Standard Deviation	8.9	Y

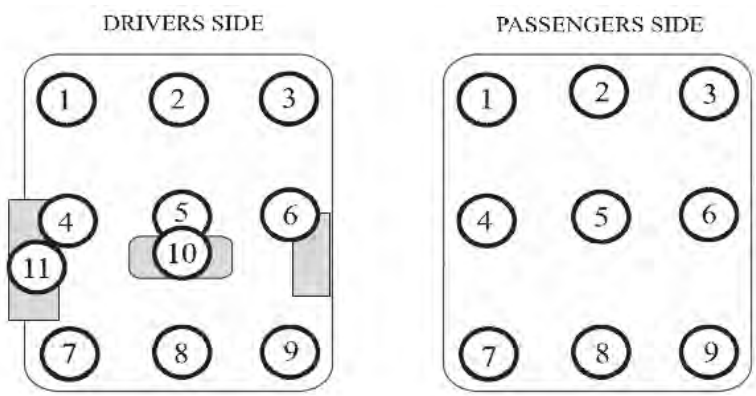
Lastly, intrusion data was compared. Matching the vehicle pulse was the most important factor in the validation, so the intrusion comparison was performed primarily for informational purposes and did not result in any changes to the FE model in order to better match the test data. Comparisons of the intrusion measurements for each test to the simulation, as well as diagrams showing the intrusion measurement locations, are provided in Figure 2-7 and Figure 2-8. The reference line for the FE simulation intrusion measurements was selected to be forward of the rear bumper at the cargo area floor pan. The additional intrusion observed on the passenger side of the FE vehicle compared to the driver side was caused by the difference in the buckling modes between the two sides of the vehicle. This vehicle was not previously validated to the compartment intrusions and no further changes were made to this model following the intrusion data analysis.



	Driver	
	Test # 3730	FE Simulation
Measurement Location	X-Axis Values	X-Axis Values
	mm	mm
A3	-13	-22.5
B1	-59	-44.4
C1	-66	-58.4
D1	-86	-57.4

	Passenger	
	Test # 3730	FE Simulation
Measurement Location	X-Axis Values	X-Axis Values
	mm	mm
A1	-3	-80.9
B1	3	-84.2
C1	6	-72.7
D3	-1	-19.4

Figure 2-7 – Intrusion comparison between Test 3730 and simulation for driver side and passenger side



	Driver	
	Test # 5034	FE Simulation
Measurement Location	X-Axis Values	X-Axis Values
	mm	mm
1	-27	-44.4
2	-54	-58.4
3	-54	-57.4
4	-11	-23.8
5	-11	-25.3
6	-45	-27.8

	Passenger	
	Test # 5034	FE Simulation
Measurement Location	X-Axis Values	X-Axis Values
	mm	mm
1	-57	-80.9
2	-48	-84.2
3	-27	-72.7
4	-35	-21.6
5	-12	-20.1
6	-5	-20

Figure 2-8 – Intrusion comparison between Test 5034 and simulation for driver side and passenger side

All of the above comparisons led to the conclusion that the FE model of the Ford Explorer is a valid representation of the physical vehicle. More information on the NCAP validation can be found in NCAP Report 2008-T-004 [1].

2.4 Additional Model Validations

The Explorer FE model was further validated by comparisons to additional tests where crash data was available. These comparisons included a Canadian rigid wall impact, a side impact test, and an offset deformable barrier test. These impacts were simulated to determine if the model would yield similar results as the physical test. The results of these additional comparisons are described in the following sections. The primary validation was done with the NCAP frontal test and no further changes were made to the model as a result of these additional comparisons.

2.4.1 CMVSS 212/301

The Ford Explorer model was simulated in a full frontal impact with a rigid wall at 30 mph and the results were compared to Canada Motor Vehicle Safety Standard (CMVSS) 212/301 Test 4690 [5]. A comparison of the vehicles used in the FE simulation and physical tests is presented in Table 2-6.

Similar deformation was observed in the test and simulation (Figure 2-9). The accelerations for the left and right rear seat crossmembers were found to be within an acceptable deviation from the test responses (Figure 2-10 and Table 2-7).

Table 2-6 – Comparison of vehicle characteristics for FE model and CMVSS Test 4690

	FE Simulation	**CMVSS 212/301 Test 4690**
Unloaded Vehicle Weight (UVW)	2024.6 kg	2044.3 kg
Dummy Weight	151 kg (2 x 75.5 kg)	(2 x HIII 5%, 2 x HIII 6y.o., 1 x HIII 3 y.o.)
Cargo Weight	71 kg	-
As Tested Weight (ATW)	2246.6 kg	2389.1 kg
Model Year	2003	2003
Drive Train	4WD	4WD
Engine Type	4.0 L V6	4.0 L V6
Testing Agency	NCAC	PMG (Canada)

Figure 2-9 – Post-crash images of Explorer after CMVSS 212/301 impact in test and simulation

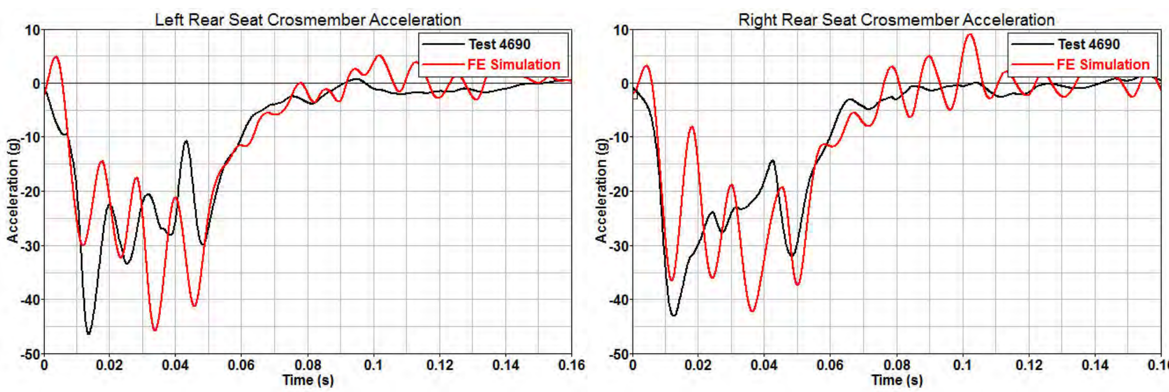


Figure 2-10 – Left and right rear seat crossmember accelerations for CMVSS 212/301 test and simulation

Table 2-7 – Objective rating criteria for left and right rear seat accelerations

		Left Rear Seat Acceleration		**Right Rear Seat Acceleration**	
		Value (%)	Pass?	Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	5.6	Y	5.6	Y
	Phase	14.8	Y	14.2	Y
	Comprehensive	15.8	Y	15.2	Y
ANOVA Metric	Average	1.5	Y	1.2	Y
	Standard Deviation	13.7	Y	14.4	Y

The engine top and bottom accelerations were also compared between the test and simulation. Figure 2-11 shows acceptable correlation between the test and simulation data. This acceptability of the simulation data compared to the test data is quantified in Table 2-8.

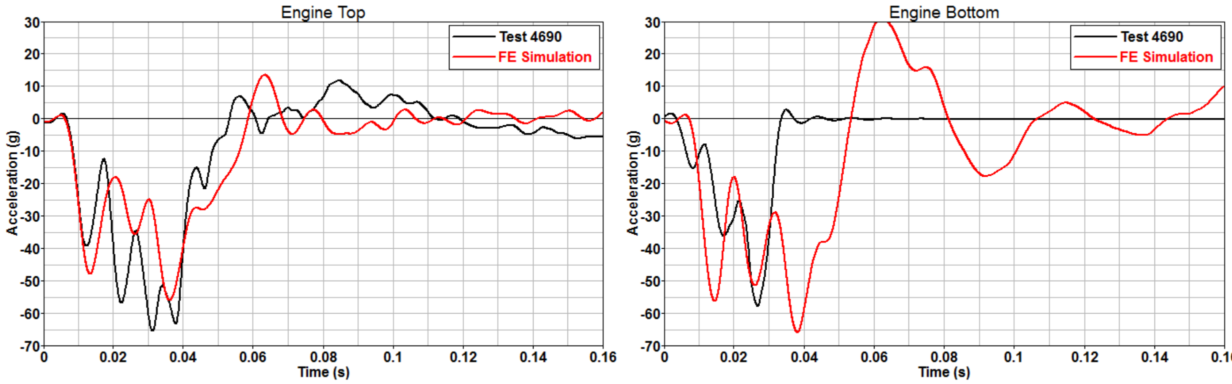


Figure 2-11 – Engine top and bottom accelerations for CMVSS 212/301 test and simulation

Table 2-8 – Objective rating criteria for engine top and bottom accelerations

		Engine Top Acceleration		Engine Bottom Acceleration	
		Value (%)	Pass?	Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	-13.2	Y	83.5	N
	Phase	17.8	Y	30.6	Y
	Comprehensive	22.1	Y	89	N
ANOVA Metric	Average	0.9	Y	-6.2	N
	Standard Deviation	15.3	Y	31.5	Y

2.4.2 NCAP Side Impact

The Explorer model was run under NCAP side impact conditions and the results were compared to NCAP Test 4087 [6]. A comparison of the vehicle characteristics for the test and simulation is presented in Table 2-9. The struck side acceleration measured at the left B-pillar is shown in Figure 2-12. Table 2-10 shows that the simulation passed the objective rating criteria for the left B-pillar acceleration data.

Table 2-9 – Comparison of vehicle characteristics for FE model and side NCAP test no. 4087

	FE Simulation	SNCAP Test 4087
Unloaded Vehicle Weight (UVW)	2024.6 kg	2009.5 kg
Dummy Weight	151 kg (2 x 75.5 kg)	161.5 kg (2 x 80.75 kg)
Cargo Weight	71 kg	126.9 kg
As Tested Weight (ATW)	2246.6 kg	2297.9 kg
Model Year	2003	2002
Drive Train	4WD	4WD
Engine Type	4.0 L V6	4.0 L V6
Testing Agency	NCAC	MGA (WI)

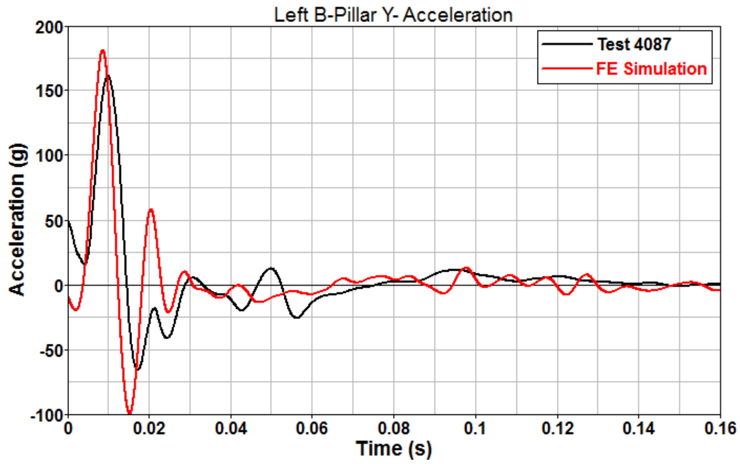


Figure 2-12 – Left B-pillar Y acceleration for side NCAP test and simulation

Table 2-10 – Objective rating criteria for left B-pillar Y acceleration

		Left B-pillar Acceleration	
		Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	3.1	Y
	Phase	25.2	Y
	Comprehensive	25.4	Y
ANOVA Metric	Average	-0.6	Y
	Standard Deviation	13.7	Y

The post-test deformation is shown in Figure 2-13. The discrepancy in the deformation profiles can be better observed through the intrusion profiles shown in Figure 2-14. This difference was due to the way the door latch was modeled in the simulation. In the physical test, the front door on the struck side of the vehicle did not separate from the body at the hinges, but the door opened at the latch during the crash event. The rear door on the struck side did not separate from the body at either the hinges or latches. The doors on the far side did not open either during the event. The FE model, however, does not incorporate failure for the latches and did not capture the observed front door behavior.

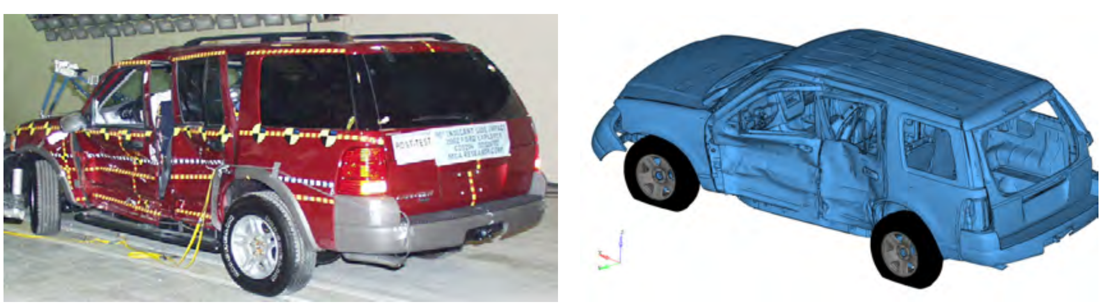


Figure 2-13 – Comparison of post-crash deformation between the side NCAP test and simulation

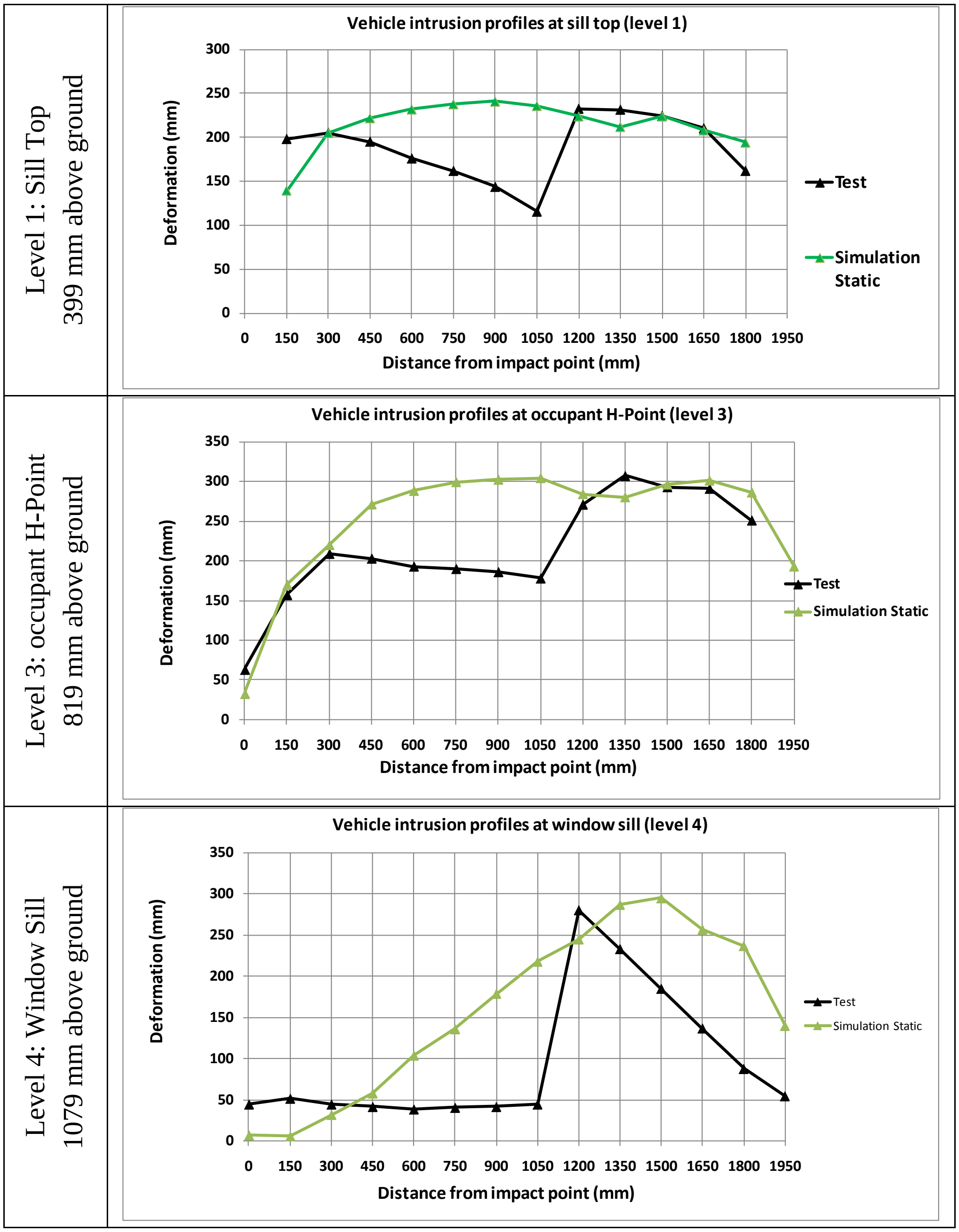


Figure 2-14 – Intrusion on levels 1, 3, and 4 after NCAP side impact

2.4.3 IIHS Offset Deformable Barrier

The model was run under the IIHS offset deformable barrier (ODB) crash test protocol, in which the vehicle strikes a deformable barrier at 40 mph with a 40% overlap on the driver side, and compared to data from IIHS Test CEF0125 [7]. A comparison of the test and simulation vehicle characteristics and deformation is shown in Table 2-11 and Figure 2-15. The acceleration and velocity plots for the simulation closely matched those of the test (Figure 2-16 and Table 2-12).

Table 2-11 – Comparison of vehicle characteristics for FE model and IIHS Test CEF0125

	FE Simulation	IIHS Test CEF 0125
Unloaded Vehicle Weight (UVW)	2024.6 kg	2046 kg
Dummy Weight	151 kg (2 x 75.5 kg)	~ 76 kg
Cargo Weight	71 kg	~ 26 kg
As Tested Weight (ATW)	2246.6 kg	2148 kg
Model Year	2003	2002
Drive Train	4WD	4WD
Engine Type	4.0 L V6	4.0 L V6
Testing Agency	NCAC	IIHS (VA)

Figure 2-15 – Comparison of post-impact deformation for IIHS ODB test

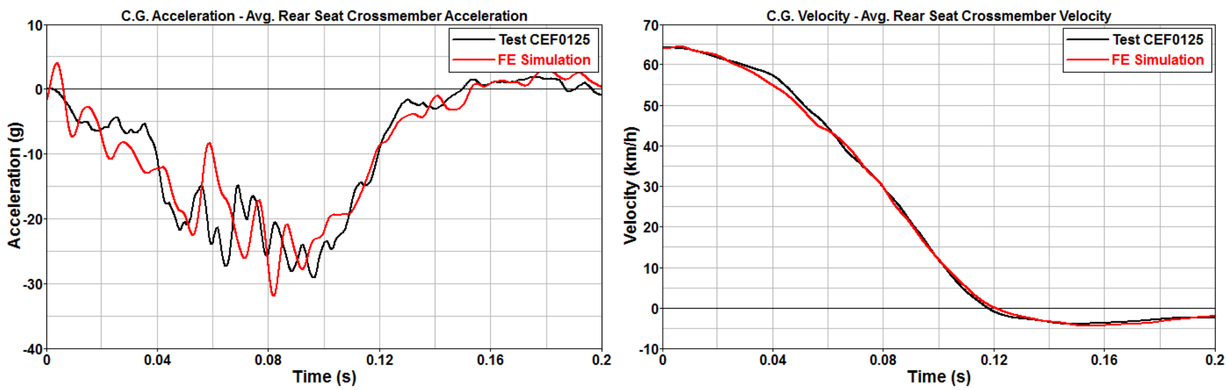


Figure 2-16 – Vehicle acceleration (left) and velocity (right) profiles of the test and simulation for the IIHS ODB test

Table 2-12 – Objective rating criteria for vehicle CG acceleration

		Vehicle CG Acceleration	
		Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	-2.1	Y
	Phase	9	Y
	Comprehensive	9.2	Y
ANOVA Metric	Average	0.2	Y
	Standard Deviation	13.1	Y

2.5 Model Robustness

The FE model was checked for robustness by running the model through a severe crash simulation with large deformation. The centerline pole simulation at 35 mph was selected for the robustness check. When the model was run under these crash conditions, a negative volume error occurred and the simulation was unable to complete. To correct this error, the model was updated, including changing the radiator fan axle material property from elastic to elasto-plastic and adding a contact interior for the bumper foam. The updated model was run again in the centerline pole impact condition and the results are shown in Figure 2-17 and Figure 2-18.

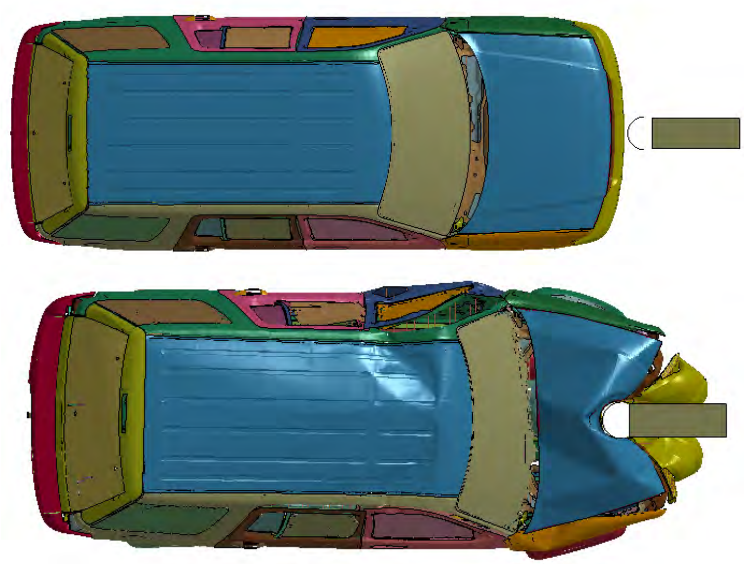


Figure 2-17 – Pre- and post-crash images of the Explorer for the centerline pole robustness simulation

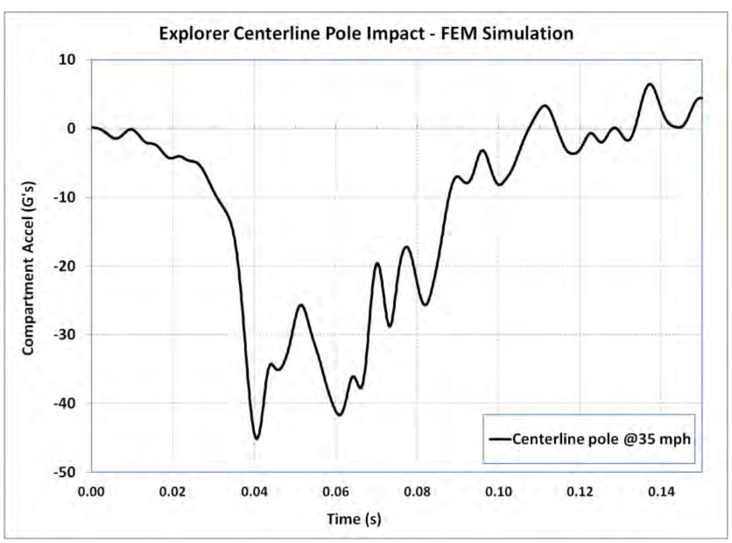


Figure 2-18 – Explorer compartment acceleration for the centerline pole robustness simulation

2.6 Varying Speed Trend Analysis

Several more simulations were run with the Ford Explorer FE model to verify that the model was providing consistent trends for different crash scenarios. The NCAP rigid wall, IIHS offset deformable barrier, and centerline pole simulations were run and the results were compared between low and high speeds within the same crash configuration to confirm that the vehicle responses were valid in the physical realm.

2.6.1 NCAP Rigid Wall

The NCAP rigid wall simulation was run at 25 mph and 35 mph. The pre- and post-crash images and resulting compartment accelerations are shown in Figure 2-19 and Figure 2-20. These runs verified that the higher speed impact yielded a slightly more severe crash pulse than the lower speed impact.

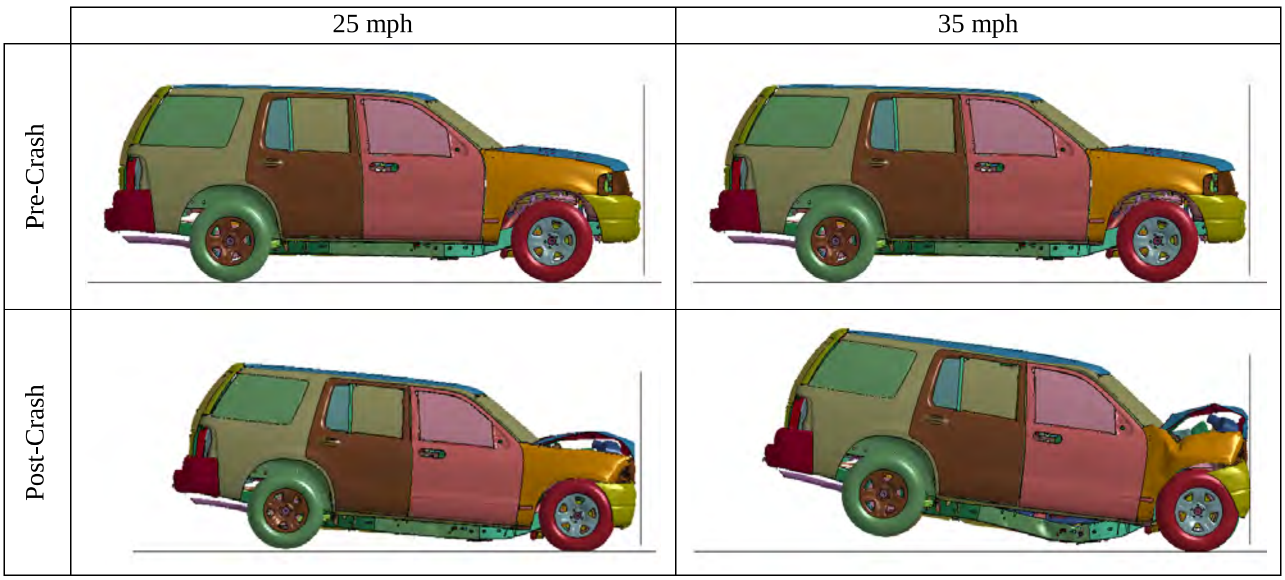


Figure 2-19 – Pre- and post-crash images of the Explorer for the full frontal impact at 25 mph and 35 mph

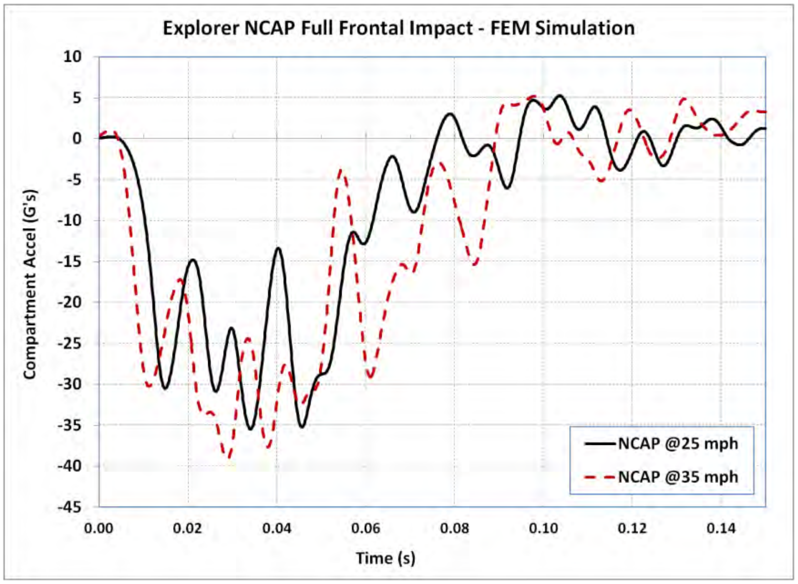


Figure 2-20 – Explorer compartment accelerations for NCAP frontal verification simulations

2.6.2 IIHS Offset Deformable Barrier

The IIHS ODB simulation was run at 25 mph and 40 mph. The pre- and post-crash images and resulting CG and left rear accelerometer outputs are shown in Figure 2-21 and Figure 2-22. These runs verified that the higher speed impact yielded higher compartment accelerations than the lower speed impact.

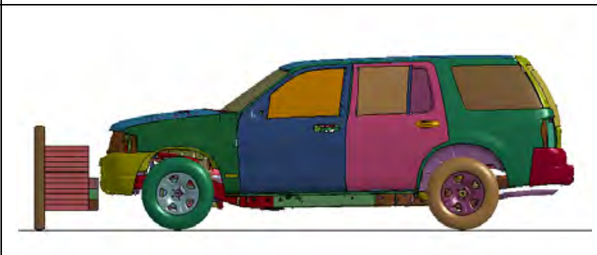
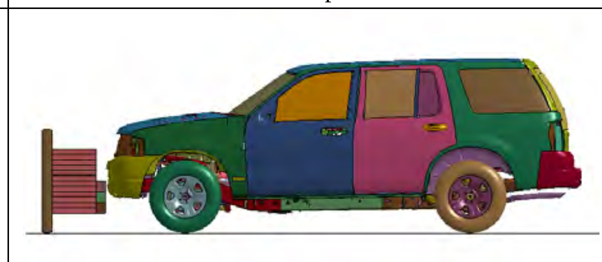
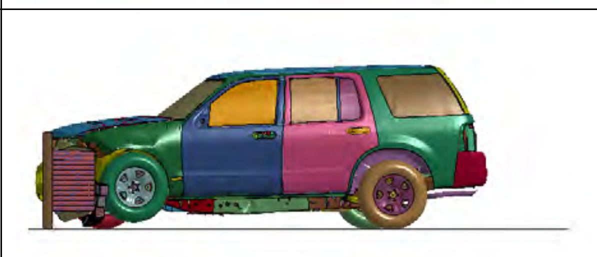
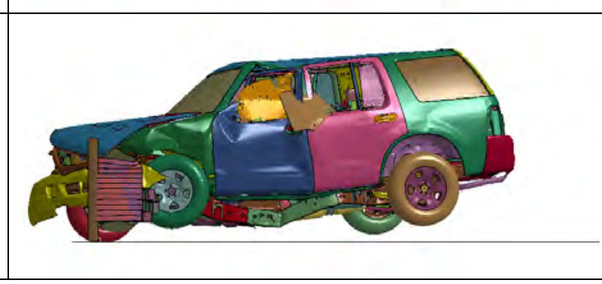
	25 mph	40 mph
Pre-Crash		
Post-Crash		

Figure 2-21 – Pre- and post-crash images of the Explorer for the IIHS ODB impact at 25 mph and 40 mph

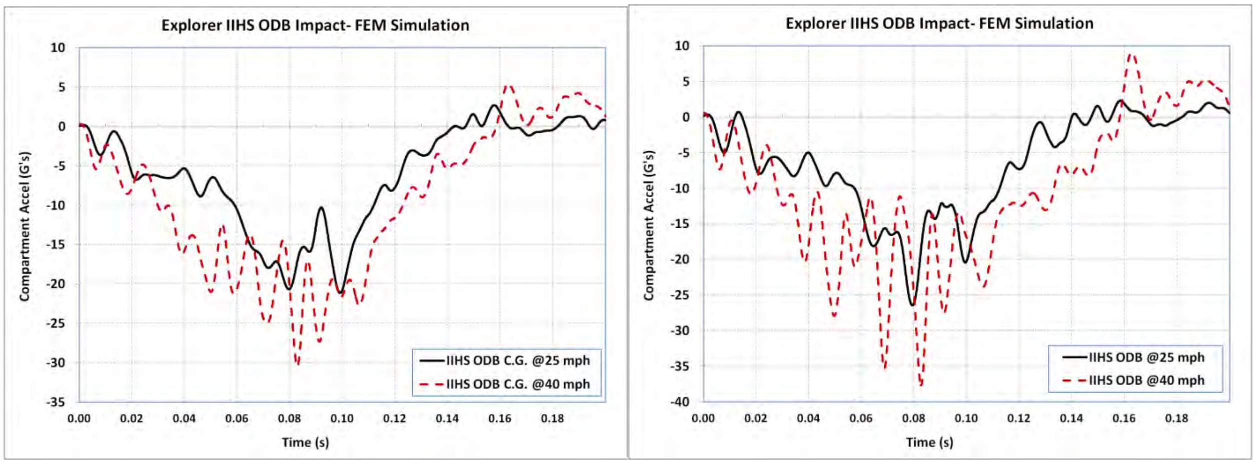


Figure 2-22 – Explorer CG (left) and left rear (right) accelerometer outputs for IIHS ODB verification simulations

2.6.3 Centerline Pole

The centerline pole simulation was run at 25 mph and 35 mph. The pre- and post-crash images and resulting compartment accelerations are shown in Figure 2-23 and Figure 2-24. These runs verified that the higher speed impact yielded a more severe crash pulse than the lower speed impact.

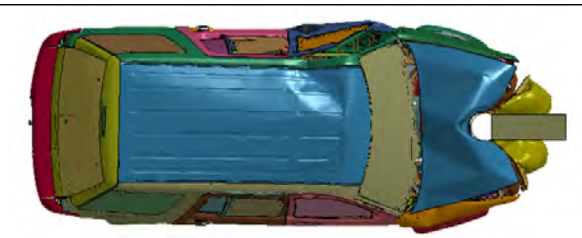
	25 mph	35 mph
Pre-Crash		
Post-Crash		

Figure 2-23 – Pre- and post-crash images of the Explorer for the centerline pole impact at 25 mph and 35 mph

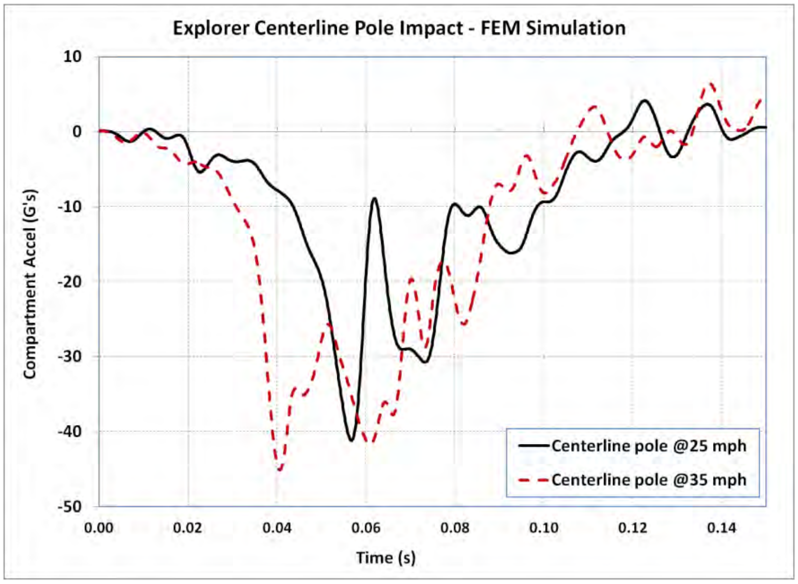


Figure 2-24 – Explorer compartment accelerations for centerline pole verification tests

2.7 Summary and Conclusions

A finite element model of the 2002 Ford Explorer sport utility vehicle was created using a reverse engineering process by the NCAC under contract to the FHWA. This vehicle was modeled to support NHTSA and FHWA research efforts.

The model was initially validated by comparison to images and data derived from the NHTSA NCAP tests, which involved frontal impact into a rigid wall at 35 mph. Comparisons of data from the tests and the model included:

- View of side deformations,
- Acceleration and velocity changes for the rear seat crossmember,
- Accelerations of the top and bottom of the engine,
- Total forces over time,
- Force displacement plots, and
- Driver and passenger side intrusion.

Vehicle kinematics and the accelerometer output data were compared and the simulation results showed overall good correlation with the physical test results.

This model was further verified against CMVSS 212/301 frontal impact, NCAP side impact, and IIHS offset deformable barrier frontal test configurations. The simulation results compared well to data from these tests, further demonstrating the validity of the Explorer model.

A robustness study was conducted to confirm that the model would be stable under crash conditions with severe deformation as in centerline pole impacts. This study revealed that the model was unstable, so several changes were made to the model to improve its robustness.

A consistency study confirmed that the model would yield reasonable results between high and low speed tests for rigid wall, offset deformable barriers, and centerline pole crash configurations. As expected, the high speed impacts resulted in greater vehicle deformation and higher compartment accelerations.

This model development process has proven the FE model of the Ford Explorer to be robust and applicable for the study of a variety of crash scenarios.

2.8 Acknowledgements

The authors wish to acknowledge the Federal Highway Administration and NHTSA of the U.S. Department of Transportation for supporting these modeling and simulation efforts.

2.9 References

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2. KARCO Engineering, "Final Report of New Car Assessment Program Testing of a 2002 Ford Explorer XLT 4WD SUV," NHTSA Test No. 3730, August 2001.
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4. Ray, M.L., et al; "Guidelines for Verification and Validation of Crash Simulations Used in Roadside Safety Applications," Report from NCHRP Project 22-24, TRB, Washington, DC, 2010.
5. PMG Technologies, "Compliance Frontal Impact CMVSS 212/301: Ford Explorer 2003," NHTSA Test No. 4690, February 2003.
6. MGA Research Corporation, "Final Report of FMVSS 214D Indicant Compliance Side Impact Test of a 2002/Ford/Explorer/SUV," NHTSA Test No. 4087, February 2002.
7. Insurance Institute for Highway Safety, "Crash Test Report: 2002 Ford Explorer," IIHS Test CEF0125, November 2001.

3 APPENDIX 3: EXTENDED VALIDATION OF THE FINITE ELEMENT MODEL FOR THE 2007 CHEVROLET SILVERADO PICKUP TRUCK

3.1 Introduction

In March 2007, the National Crash Analysis Center began development of a finite element (FE) model of the 2007 Chevy Silverado 1500 2WD under contract with the Federal Highway Administration (FHWA). This vehicle was selected for modeling to serve a variety of NHTSA and FHWA research needs. The vehicle is a 2298 kg, 4-door crew cab, short box, pickup truck with a 4.8 liter, V8 engine and an automatic 4-speed transmission.

This model was initially validated against NCAP test results and a series of component and full-scale tests. This document reviews the initial development and validation of the Chevy Silverado FE model and describes the subsequent updates to the model, including the extended validation and robustness comparisons of the updated model that were undertaken.

3.2 Model Building

The FE model of the 2007 Chevy Silverado was developed through the reverse engineering process. The vehicle was disassembled and each part was cataloged, scanned, measured, and classified by material type. Each part was meshed to create an accurate computer model representing the data gathered in the disassembly, including geometry and material properties. The final model is shown in Figure 3-1. Table 3-1 provides the breakdown of parts, nodes, and elements.

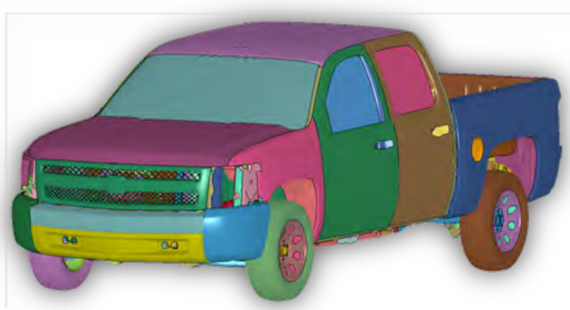


Figure 3-1 – Chevy Silverado FE model

Table 3-1 – Summary of Silverado FE model characteristics

Number of Parts	719	Beam Element Connections	2,825
Number of Nodes	979,488	Nodal Rigid Body Connections	696
Number of Shells	907,067	Extra Node Set Connections	56
Number of Beams	3,113	Rigid Body Connections	4
Number of Solids	53,281	Spotweld Connections	7,126
Total Number of Elements	963,482	Joint Connections	40

Material data and properties were obtained through coupon testing. Standard material types were assigned to any parts for which no test data were available. Further details of the model development are documented in NCAC 2009-T-005 [1].

3.3 Initial Validation

Because the Silverado model would initially be used for roadside hardware testing, it was important to validate the suspension system performance. The suspension system was initially validated using comparisons of inertial properties and suspension response tests. The inertial properties of the vehicle to be modeled were measured at a lab that specializes in testing. The comparisons of measured inertial properties and those reflected in the model indicated that the mass and geometry of the model were accurate (Table 3-2).

Table 3-2 – Comparison of inertial properties of the actual vehicle and FE model

	Actual Vehicle	FE Model
Weight, kg	2,337	2,270
Pitch inertia, kg-m^2	6,155	6,028
Yaw inertia, kg-m^2	6,453	6,490
Roll inertia, kg-m^2	1,051	1,050
Vehicle CG height, in	27.96	28.64

The initial FE model was validated against NCAP Test 5877 to determine if deformations and accelerations reflected test data. The correlations were considered good so it was concluded that the model was a good representation of the vehicle and it was released for public use. More information on the initial validations can be found in NCAC Reports 2009-T-005, 2009-W-005, and 2009-R-004 [1, 2, 3]. This document describes the additional validation efforts that were undertaken to enhance the Silverado FE model and assess its robustness for various types of impacts. These efforts were conducted by NCAC in support of the National Highway Traffic Safety Administration study “Investigate Self and Partner Protection of New Vehicle Designs Using Structural Modeling,” TOPR No. 16 under DTFH61-09-D-00001.

3.4 Extended Validation

The Silverado FE model was subsequently updated to include the interior components and make it possible to use the model for occupant risk analyses. For example, the FE model was updated to include the lower beam, upper inner support, upper outer support, joint enforcements, and vertical enforcements for the driver and passenger sides. The additional door components are shown in Figure 3-2 and Figure 3-3.

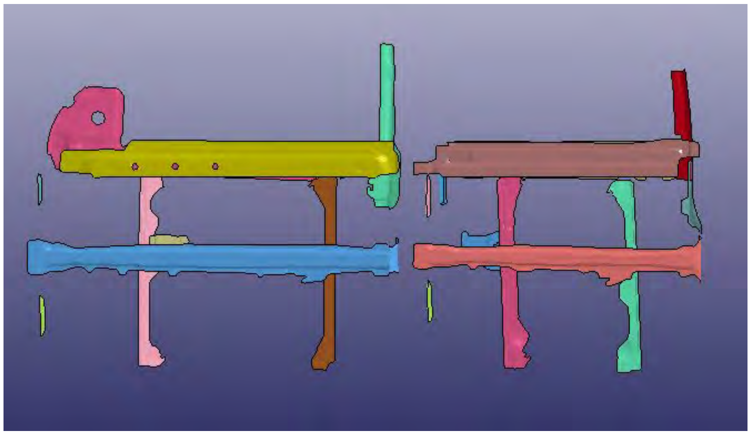


Figure 3-2 – Door components added to the driver side of the vehicle

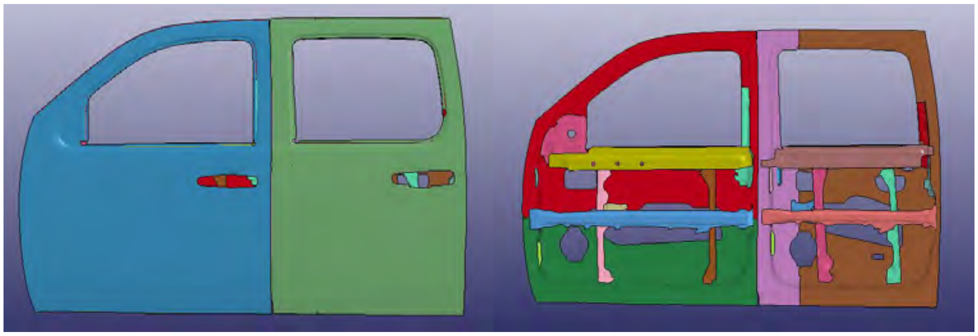


Figure 3-3 – Driver side doors showing placement of additional interior components relative to outer and inner panels

Accelerometers in the vehicle model were used to compare simulation data to test data. The locations of the accelerometers used in this study are shown in Figure 3-4.

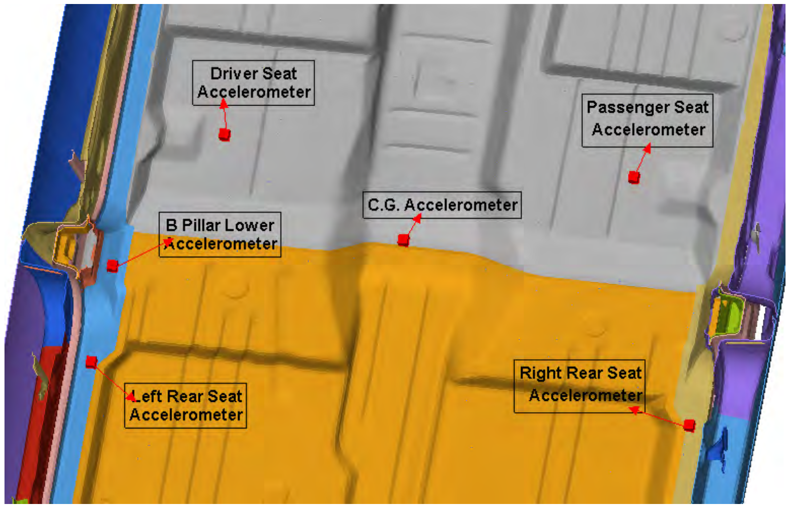


Figure 3-4 – Accelerometer locations for comparison to test data

The updated FE model of the Chevy Silverado was compared again to the results from the full frontal impact into a rigid barrier at 35 mph from NCAP Test 5877 [4]. A comparison of the vehicle characteristics of the FE model and test vehicle is shown in Table 3-3.

Table 3-3 – Comparison of vehicle characteristics of FE model and NCAP Test 5877

	FE Model	**NCAP Test 5877**
Weight (kg)	2622	2622
Engine Type	4.8 L V8	4.8 L V8
Tire size	P245/70R17	P245/70R17
Attitude (mm) As delivered	F – 1016	F – 929
	R – 1043	R – 1002
Wheelbase (mm)	3660	3664
CG (mm) rearward of front wheel C/L	1670	1664
Body Style	4-door crew cab	4-door crew cab

The simulation yielded similar vehicle kinematics and deformation, as shown in Figure 3-5. Figure 3-6 compares the left and right rear sill accelerations of the test and simulation. These graphs indicate good correlation between the test and simulation. The RSVVP was used to generate objective measures of how well the simulation follows the test data [5]. The Sprague-Geers MPC metrics were used to quantify the similarity of the test and simulation curve shapes and the ANOVA metric was used to evaluate the residual error. The acceptance criteria for the Sprague-Geers metrics are a difference of less than 40 percent in magnitude, phase, or comprehensive (the square root of the sum of the squares of M and P). The acceptance criteria for the ANOVA metric are an average residual error of less than 5 percent and a standard deviation of the residual errors of less than 20 percent. When the values fall under these acceptance criteria, the simulation can be said to have good correlation with the test, with any deviations in the data attributable to random experimental error. These objective rating metrics for the left and right rear sill accelerations compared to Test 5877 are summarized in Table 3-4. It is worth noting that the acceptance criteria in RSVVP were developed for roadside safety applications where tests typically involve longer duration complex impact sequences with more variability than the NHTSA vehicle crash tests being considered for the FE model validation. In the future, developing acceptance criteria for NHTSA type crash test would be more pertinent and applicable to vehicle FE model validation efforts.

Figure 3-5 – Side view of vehicle and model after NCAP crash

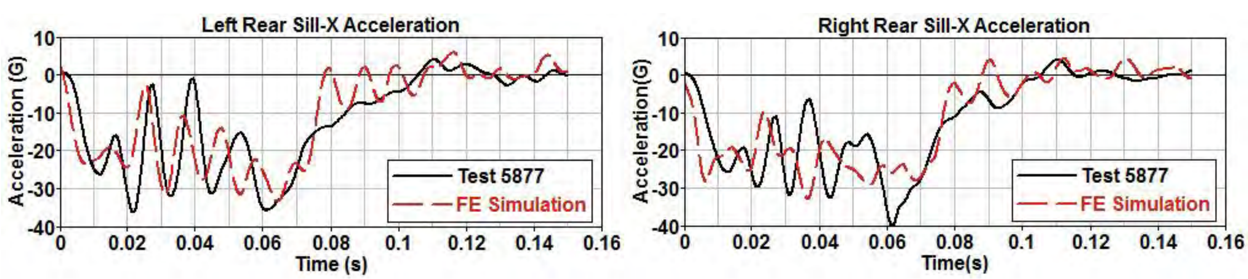


Figure 3-6 – Comparison of left and right rear sill X accelerations for test and simulation

Table 3-4 – Objective rating criteria for left and right rear sill accelerations

		Left Rear Sill Acceleration		Right Rear Sill Acceleration	
		Value (%)	Pass?	Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	-0.7	Y	0.2	Y
	Phase	10.8	Y	12.9	Y
	Comprehensive	10.8	Y	12.9	Y
ANOVA Metric	Average	2.6	Y	2	Y
	Standard Deviation	15.5	Y	16.9	Y

The left and right rear sill velocities were also compared, showing a velocity change of 62 km/h, versus the test, which showed a velocity change of 65 km/h (Figure 3-7). The velocity profiles were similar for both the left and right rear sill, indicating a symmetric response, as expected of a full frontal impact.

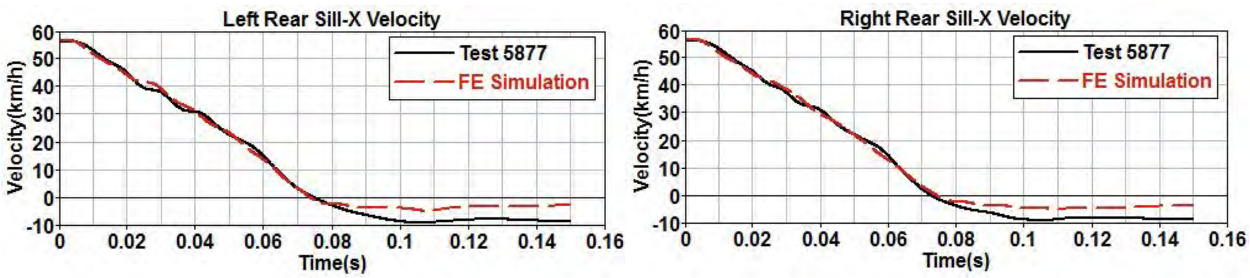


Figure 3-7 – Comparison of left and right rear sill X velocities for test and simulation

The total wall force and force-displacement data from the test and simulation are shown in Figure 3-8 and the RSSVP acceptance criteria are shown in Table 3-5.

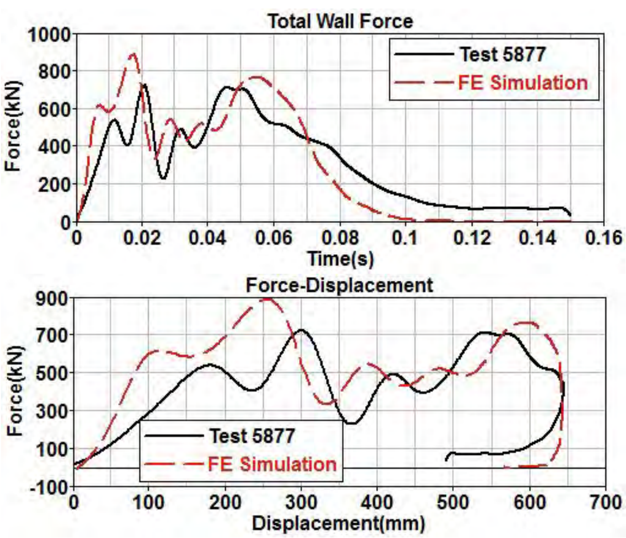


Figure 3-8 – Total wall force (left) and force-displacement (right) data for the test versus simulation

Table 3-5 – Objective rating criteria for total wall force

		Total Wall force	
		Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	12.1	Y
	Phase	11.7	Y
	Comprehensive	16.8	Y
ANOVA Metric	Average	-3.5	Y
	Standard Deviation	18	Y

Matching the vehicle pulse was the most important factor in this validation, but since intrusion data was available, these were compared as well. This comparison was performed primarily for informational purposes and is shown in Table 3-6 and Table 3-7. The results show reasonable correlation to observed intrusions.

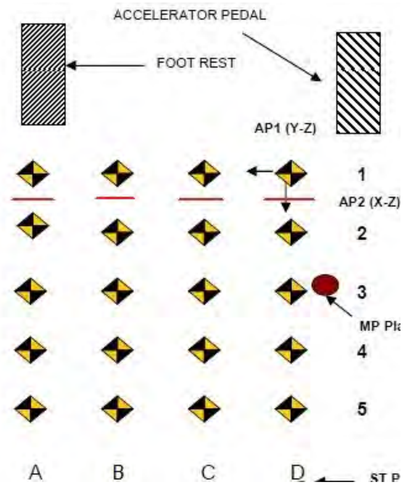


Figure 3-9 – Diagram of the intrusion measurement points for the driver side floor pan

Table 3-6 – Driver side intrusion, measured across row 1

Points	Test 5877 (mm)	FE Simulation (mm)
A1	-4	-5
B1	-8	-5
C1	-10	-9
D1	-8	-29

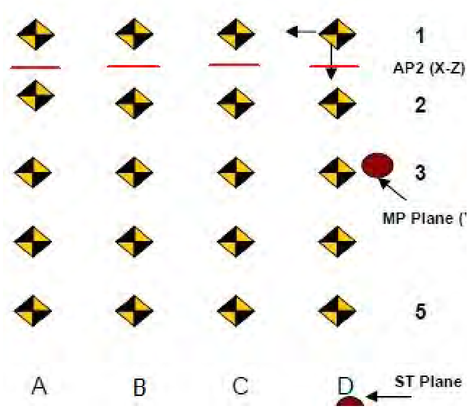


Figure 3-10 – Diagram of the intrusion measurements points for the passenger side floor pan

Table 3-7 – Passenger side intrusion, measured across row 1

Points	Test 5877 (mm)	FE Simulation (mm)
A1	-15	-24
B1	-15	-33
C1	-9	-31
D1	-4	-6

3.5 Additional Model Validation

The Silverado FE model was validated against additional tests involving the Silverado where crash data was available. These included comparison to an NCAP side impact test and an IIHS offset deformable barrier test. These simulations were run to verify that the model would yield similar results as the physical test for different types of impacts. The comparisons are described in the following sections.

3.5.1 NCAP Side Impact

The Silverado model was run under NCAP side impact conditions and the results were compared to NCAP Test 6185 [6]. The post-impact pictures of the test and simulation show similar deformation profiles (Figure 3-11). The amount of intrusion was consistently greater in the test than in the simulation (Figure 3-12), but the simulation followed a similar intrusion profile at each intrusion level as the test.

Figure 3-11 – Comparison of deformation post-impact for NCAP side impact test

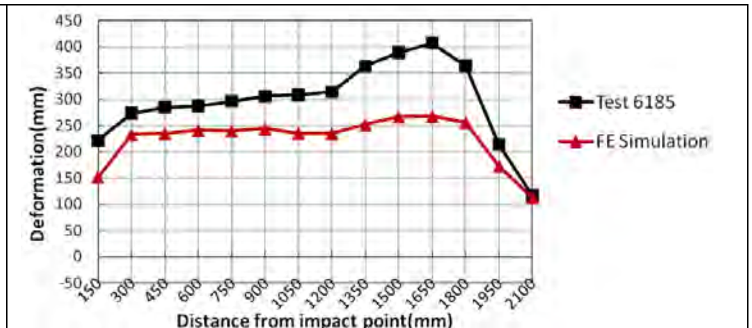
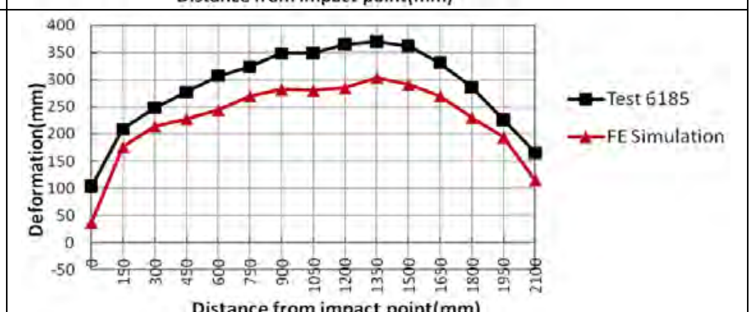
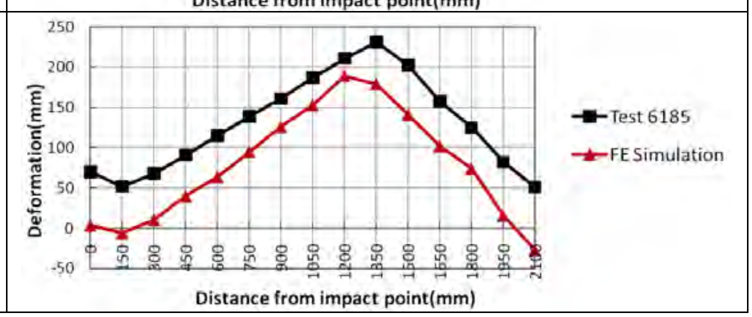
Level 1: Sill Top 406 mm above ground	
Level 3: occupant H-Point 851 mm above ground	
Level 4: Window Sill 1171 mm above ground	

Figure 3-12 – Intrusion on levels 1, 3, and 4 after NCAP side impact

The simulation was able to closely match the shape and peaks of the B pillar accelerations, as shown in Figure 3-13. This simulation proved that the Chevy Silverado FE model is robust and can be run in a side impact configuration with good correlation to test data.

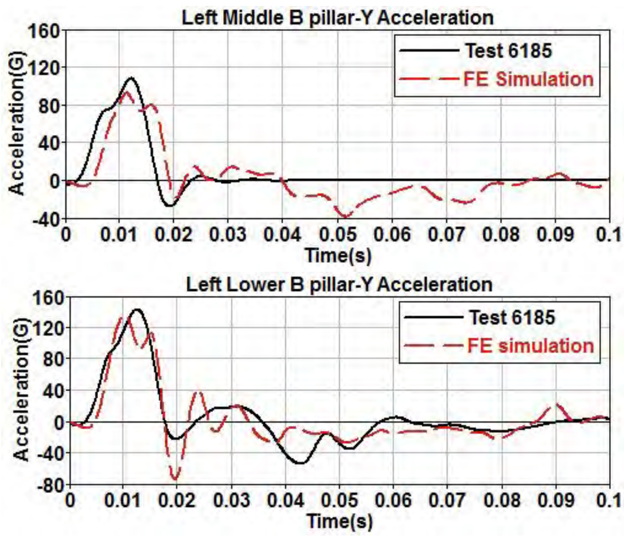


Figure 3-13 – Comparison of middle and lower B pillar accelerations for test and simulation

3.5.2 IIHS Offset Deformable Barrier

The model was run under the IIHS offset deformable barrier (ODB) crash test protocol, in which the vehicle strikes a deformable barrier at 40 mph with a 40 percent overlap on the driver side. A comparison of IIHS Test CEF0825 and the simulation vehicle characteristics and deformation are shown in Table 3-8 and Figure 3-14 [7]. The acceleration and velocity plots for the simulation reasonably matched those of the test (Figure 3-15 and Table 3-9).

Table 3-8 – Comparison of vehicle characteristics of FE model and IIHS Test CEF0825

	FE Model	**IIHS Test CEF0825**
Weight (kg)	2,622	2,454
Engine Type	4.8 L V8	5.3 L V8
Wheelbase (mm)	3660	3656
CG (mm) rearward of front wheel C/L	1670	1555
Body Style	4-door crew cab	4-door crew cab

Figure 3-14 – Comparison of post-impact deformation for IIHS ODB test

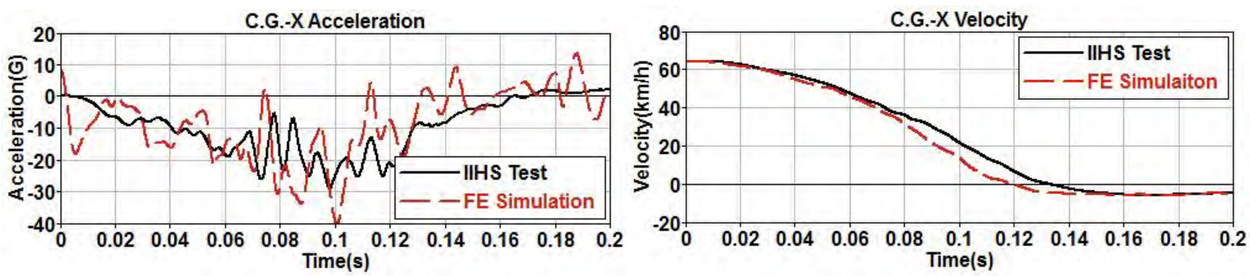


Figure 3-15 – Acceleration (left) and velocity (right) profiles of the test and simulation, measured at the vehicle CG

Table 3-9 – Objective rating criteria for vehicle CG

		Total Wall Force	
		Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	13.1	Y
	Phase	14.2	Y
	Comprehensive	19.3	Y
ANOVA Metric	Average	-0.7	Y
	Standard Deviation	21.5	Y

3.6 Model Robustness

The FE model was checked for robustness by running the model through a severe crash simulation with large deformation. The centerline pole simulation at 35 mph was selected for the robustness check. Pre- and post-crash images are shown in Figure 3-16 and the vehicle pulse is shown in Figure 3-17. No computation errors were encountered when running this simulation, proving the robustness of the model.

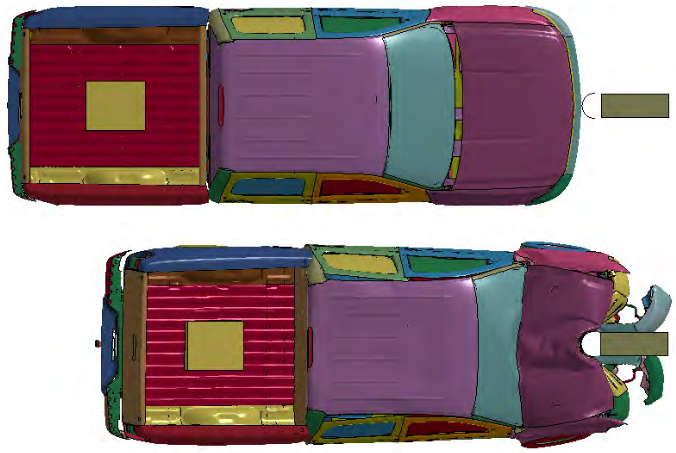


Figure 3-16 – Pre- and post-crash images of the Silverado for the centerline pole simulation at 35 mph

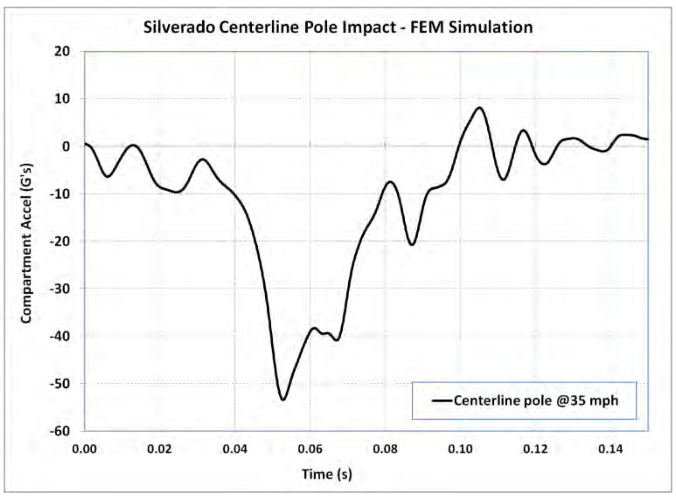


Figure 3-17 – Silverado compartment acceleration for the centerline pole simulation at 35 mph

3.7 Varying Speed Trend Analysis

Several more simulations were run with the Chevy Silverado FE model to verify that the model was showing the expected trends for different crash configurations under varying speeds. The NCAP rigid wall, IIHS offset deformable barrier, and centerline pole simulations were run and the results were compared between low and high speeds within the same crash configuration to confirm that the vehicle responses were valid in the physical realm.

3.7.1 NCAP Rigid Wall

The NCAP rigid wall simulation was run at 25 mph and 35 mph. The pre- and post-crash images and resulting compartment accelerations are shown in Figure 3-18 and Figure 3-19. These runs verified that the higher speed impact yielded a more severe crash pulse than the lower speed impact.

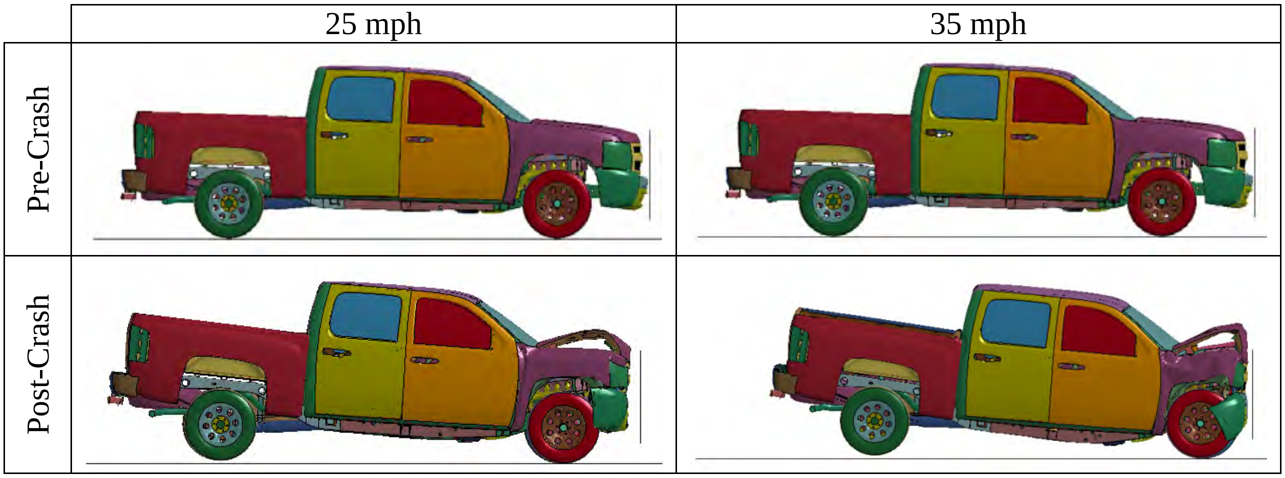


Figure 3-18 – Pre- and post-crash images of the Silverado for the full frontal impact at 25 mph and 35 mph

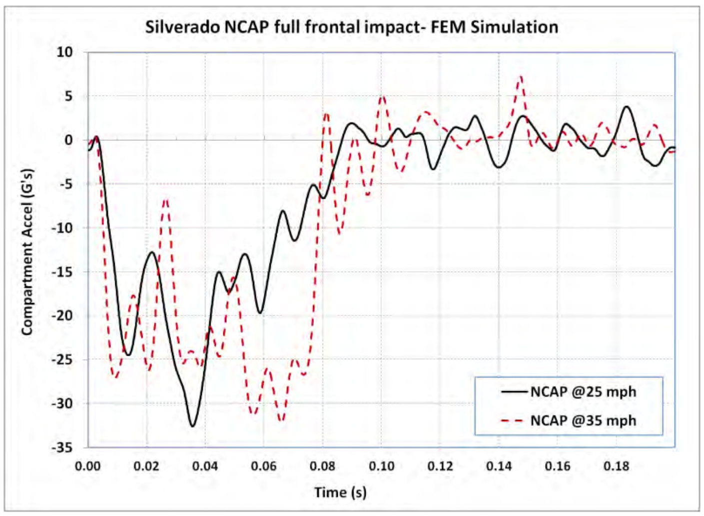


Figure 3-19 – Silverado compartment accelerations for NCAP frontal verification simulations

3.7.2 IIHS Offset Deformable Barrier

The IIHS ODB simulation was run at 25 mph and 40 mph. The pre- and post-crash images and resulting CG and left rear accelerometer outputs are shown in Figure 3-20 and Figure 3-21. These runs verified that the higher speed impact yielded higher compartment accelerations than the lower speed impact.

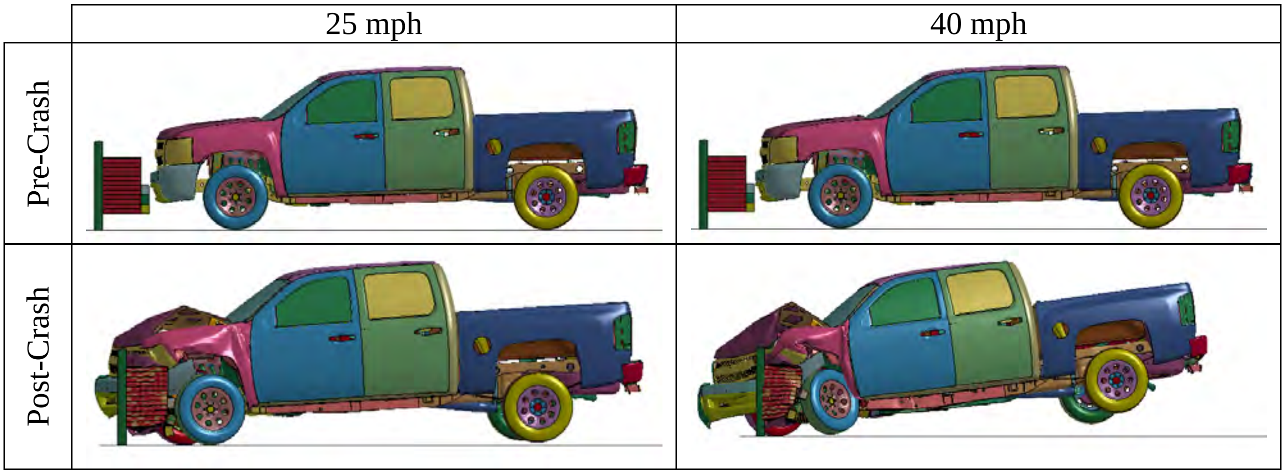


Figure 3-20 – Pre- and post-crash images of the Silverado for the IIHS ODB impact at 25 mph and 40 mph

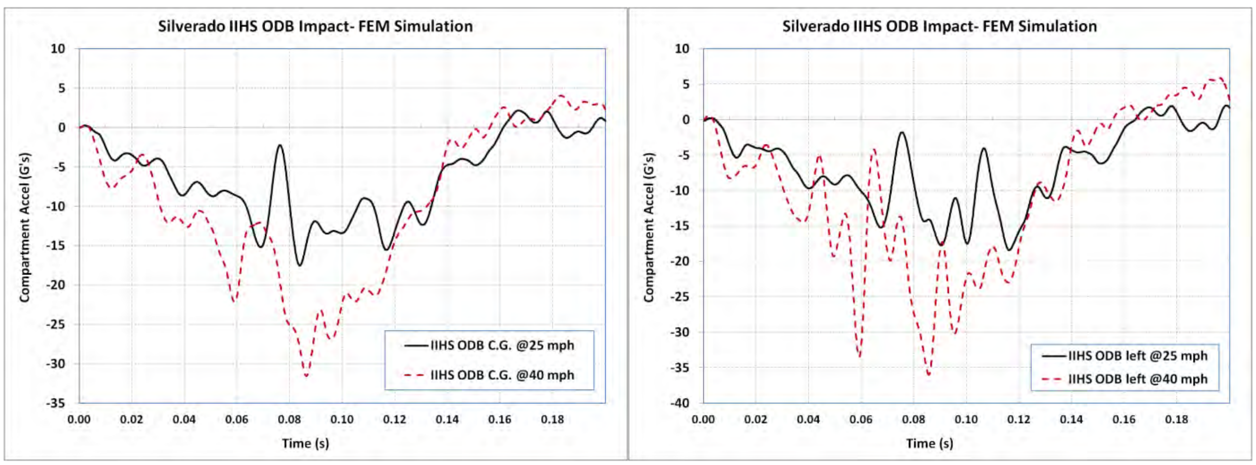


Figure 3-21 – Silverado CG (left) and left rear (right) accelerometer outputs for IIHS ODB verification simulations

3.7.3 Centerline Pole

The centerline pole simulation was run at 25 mph and 35 mph. The pre- and post-crash images and resulting compartment accelerations are shown in Figure 3-22 and Figure 3-23. These runs verified that the higher speed impact yielded a more severe crash pulse than the lower speed impact.

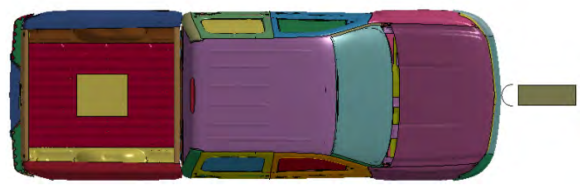
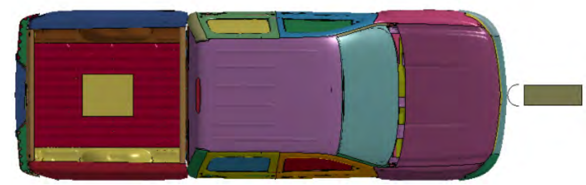
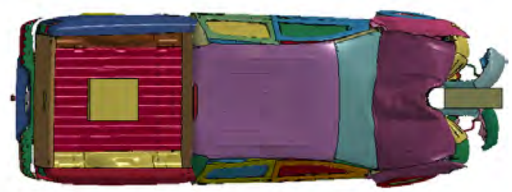
	25 mph	35 mph
Pre-Crash		
Post-Crash		

Figure 3-22 – Pre- and post-crash images of the Silverado for the centerline pole impact at 25 mph and 35 mph

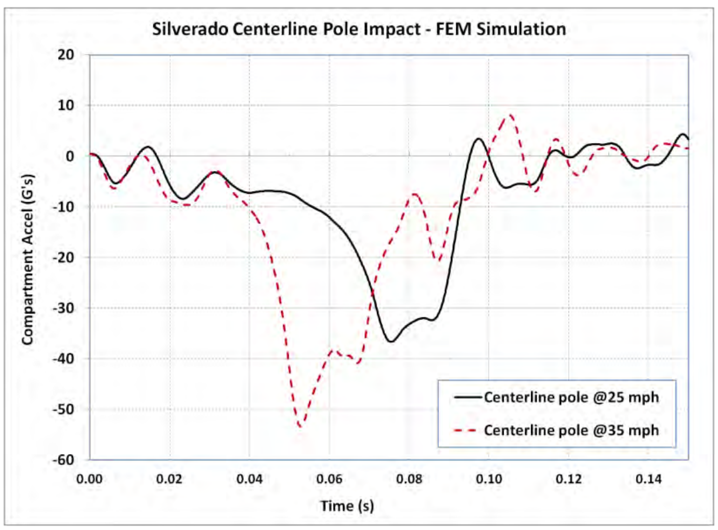


Figure 3-23 – Silverado compartment accelerations for centerline pole verification tests

3.8 Summary and Conclusions

A finite element model of the 2007 Chevrolet Silverado quad-cab pickup truck was created using a reverse engineering process by the NCAC under contract to the FHWA. This vehicle was modeled to support NHTSA and FHWA research efforts.

The model was initially validated by comparison to images and data derived from the NHTSA NCAP test, which involved frontal impact into a rigid wall at 35 mph. Comparisons of data from the test and the model included:

- View of side deformations,
- Acceleration and velocity changes for the rear sill,

- Total forces over time, and
- Force displacement plots.

Vehicle kinematics and the accelerometer output data were compared and the simulation results showed overall good correlation with the physical test results. This comparison was supplemented with comparison to inertial and suspension response data that compared the vehicle before tear down to the FE model.

The model was updated to include interior door components and was subjected to an extended validation effort. This effort involved comparing data from other frontal tests to the simulated test with the updated model. The model was also successfully validated against a side impact test. The robustness of the model was demonstrated by simulations of a centerline pole impact and damage consistency comparisons for rigid wall, offset deformable barrier, and centerline pole impacts at varying speeds. The simulations executed without error in these runs and the results reflected the expected responses and consistency with varying parameters. This led to the conclusion that the model was robust across various impact scenarios.

This model development process has proven the FE model of the Chevy Silverado to be robust and applicable for the study of a variety of crash scenarios.

3.9 Acknowledgements

The authors wish to acknowledge the Federal Highway Administration and NHTSA of the U.S. Department of Transportation for supporting these modeling and simulation efforts.

3.10 References

1. NCAC, "Development and Validation of a Finite Element Model for a 2007 Chevy Silverado," NCAC 2009-T-005, prepared for FHWA, May 2009.
2. NCAC, "Modeling, Testing, and Validation of the 2007 Chevy Silverado Finite Element Model," NCAC 2009-W-005, Oct 2009.
3. NCAC, "Component and Full-Scale Tests of the 2007 Chevrolet Silverado Suspension System," NCAC 2009-R-004.
4. Karco Engineering, "Final Report of New Car Assessment Program Testing of a 2007 Chevrolet Silverado LT1 4-Door Truck," NHTSA Test No. 5877, November 2006.
5. Ray, M.L., et al; "Guidelines for Verification and Validation of Crash Simulations Used in Roadside Safety Applications," Report from NCHRP Project 22-24, TRB, Washington, DC, 2010.
6. Karco Engineering, "Final Report of Side Impact New Car Assessment Program Testing of a 2007 Chevrolet Silverado LT 4-Door Truck," NHTSA Test No. 6185, August 2007.
7. Insurance Institute for Highway Safety, "Crash Test Report: 2009 Chevrolet Silverado," IIHS Test CEF0825, December 2008.

4 APPENDIX 4: EXTENDED VALIDATION OF THE FINITE ELEMENT MODEL FOR THE 2001 FORD TAURUS PASSENGER SEDAN

4.1 Introduction

A finite element model of a 2001 Ford Taurus was developed at the National Crash Analysis Center of The George Washington University under contract with the Federal Highway Administration for studying and advancing vehicle and highway safety research. Reverse engineering methods were employed to build a detailed FE model suitable for different crash conditions. This model has been periodically updated and enhanced to include more detail and improve robustness. Details about the modeling and the outcome of the initial validation efforts are documented in "Development and Validation of a Finite Element Model for the 2001 Ford Taurus" NCAC 2008-T-005 [1]. This document describes the additional validation efforts that were undertaken to enhance the Taurus FE model and assess its robustness for various types of impacts. These efforts were conducted by the NCAC in support of the NHTSA study "Investigate Self and Partner Protection of New Vehicle Designs Using Structural Modeling," TOPR No. 16 under DTFH61-09-D-00001.

4.2 Model Building and Initial Validation

A 2001 Ford Taurus was disassembled and each part was scanned to define its geometry, measured for thickness, and classified by material type. Material data for the major structural components were obtained through coupon testing. Standard material types were assigned to any parts for which no test data were available. The final vehicle model is shown in Figure 4-1. Accelerometers in the vehicle model are used to compare simulation data to test data. The locations of the accelerometers used in this study are shown in Figure 4-2.

The FE model was initially verified to assure that it was a complete and accurate representation of the actual vehicle. The focus of the initial validation was the comparison of the simulation of the NCAP frontal wall impact with actual data from NHTSA Test 3248 for a comparable vehicle [2].

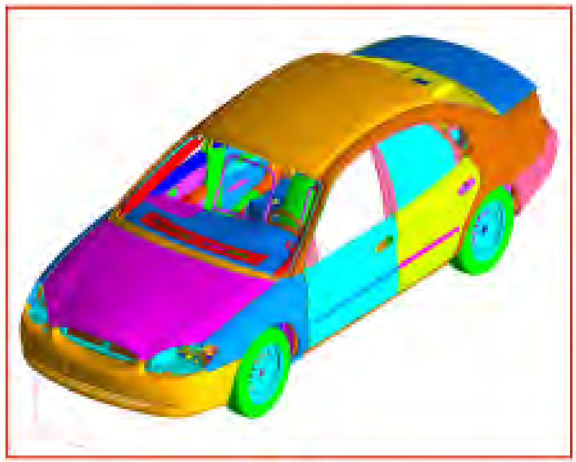


Figure 4-1 – 2001 Ford Taurus FE model

Figure 4-2 – Accelerometer locations for Ford Taurus FE model

4.3 Extended Model Validation

The vehicle model was updated to reduce the differences between the test and simulation pulses for full-frontal impacts and rigid pole impacts. In order to improve the correlation between the test and simulation pulses, the material properties were updated, primarily those of the subframe, and the element formulation was changed to fully integrate for some key components. The details of this updated model are shown in Table 4-1.

Table 4-1 – Ford Taurus FE model summary

Number of Parts	802	Nodal Rigid Body Connections	1,930
Number of Nodes	921,793	Extra Node Set Connections	53
Number of Shells	838,880	Rigid Body Connections	6
Number of Beams	10	Spotweld Connections	5,557
Number of Solids	134,449	Joint Connections	38
Total Number of Elements	973,351		

The Taurus FE model was validated against additional tests where crash data was available, including rigid wall, offset deformable barrier, moving deformable barrier, and offset rigid pole impacts. These simulations were run to verify that the model would yield similar results as the physical test. The primary validation was done with the NCAP frontal test and no further changes were made to the model as a result of these additional comparisons.

4.3.1 NCAP Rigid Wall Test

The updated and enhanced Ford Taurus FE model was used to simulate an NCAP frontal crash into a rigid barrier at 35 mph, using LS-DYNA. Four full frontal NHTSA tests were available for validation of the Ford Taurus FE model, Tests 3248, 4150, 4776, and 5143 [2,3,4,5].

The overall global deformation pattern of the FE model was very similar to that of the NCAP test, as shown in Figure 4-3. Figure 4-4 compares the left and right rear seat cross member accelerations of the test and simulation, also indicating similar vehicle behavior between the test and simulation. The Roadside Safety Verification and Validation Program (RSVVP) was used to generate an objective measure of how well the simulation follows the test data [6]. The Sprague-Geers MPC metrics were used to quantify the similarity of the test and simulation curve shapes and the ANOVA metric was used to evaluate the residual error. The acceptance criteria for the Sprague-Geers metrics are a difference of less than 40 percent in magnitude, phase, or comprehensive (the square root of the sum of the squares of M and P). The acceptance criteria for the ANOVA metric are an average residual error of less than 5 percent and a standard deviation of the residual errors of less than 20 percent. When the values fall under these acceptance criteria, the simulation can be said to have good correlation with the test, with any deviations in the data attributable to random experimental error. These objective rating metrics for the left and right rear seat accelerations compared to Test 4776 are summarized in Table 4-2. It is worth noting that the acceptance criteria in RSVVP were developed for roadside safety applications where the tests typically involve longer duration complex impact sequences with more variability than the NHTSA vehicle crash tests being considered for the FE model validation. In the future, developing acceptance criteria for NHTSA type crash tests would be more pertinent and applicable to vehicle FE model validation efforts.

Figure 4-3 – Comparison of the global deformation for Taurus in NCAP test and simulation

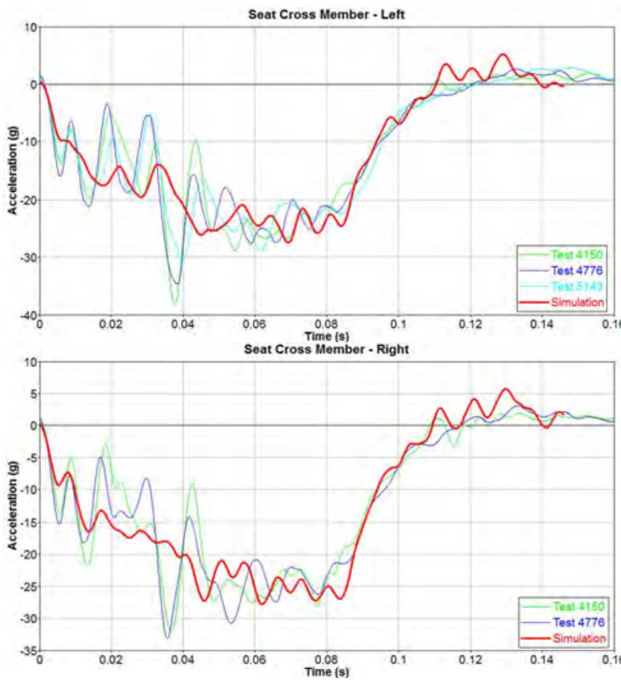


Figure 4-4 – Comparison of left and right rear seat cross member X accelerations for tests and simulation

Table 4-2 – Objective rating criteria for left and right rear seat cross member accelerations

		Left Rear Seat Acceleration		**Right Rear Seat Acceleration**	
		Value (%)	Pass?	Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	0.4	Y	0.6	Y
	Phase	7.7	Y	7.7	Y
	Comprehensive	7.7	Y	7.7	Y
ANOVA Metric	Average	0.4	Y	0.3	Y
	Standard Deviation	11.8	Y	12.4	Y

Lastly, the simulation and test forces were compared (Figure 4-5). The total wall force in the simulation closely matched that of the two tests. The similarity of the simulation and Test 4776 wall force curves is quantified in Table 4-3. Additionally, similar stiffness was observed in the FE model and test vehicles, as shown in the force-displacement plot.

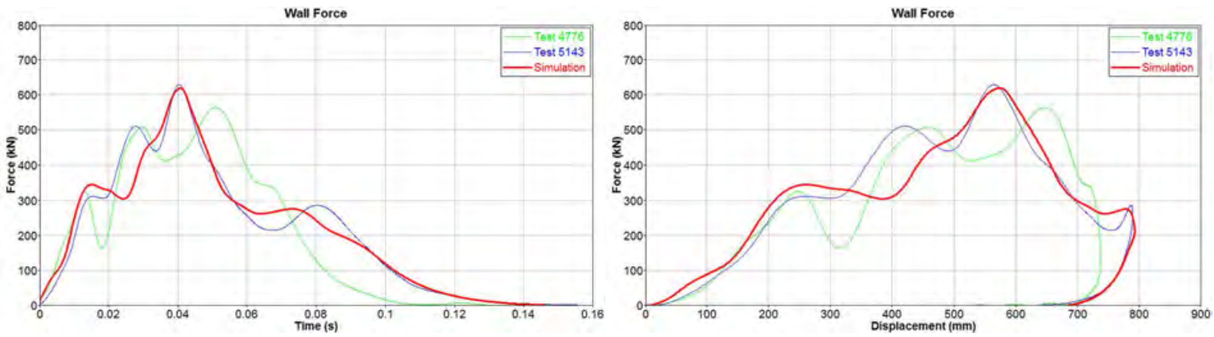


Figure 4-5 – Total wall force (left) and force-displacement (right) plots for the tests versus simulation

Table 4-3 – Objective rating criteria for total wall force

		Total Wall force	
		Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	-1.5	Y
	Phase	4.7	Y
	Comprehensive	4.9	Y
ANOVA Metric	Average	-0.1	Y
	Standard Deviation	6.4	Y

Matching the vehicle pulse was the most important factor in this validation. However, intrusion data was available, so these were compared as well. The intrusion measurements showed a good match between Test 4150 and the simulation on both the driver and passenger sides (Table 4-4 and Table 4-5).

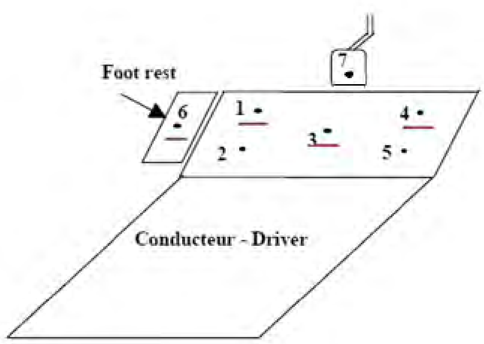


Figure 4-6 – Diagram of the intrusion measurement points for the driver side floor pan

Table 4-4 – Driver side intrusion

Item	Test 4150 (mm)	V 4d
1	-111	-117
3	-115	-123
4	-136	-158
6	-72	-66

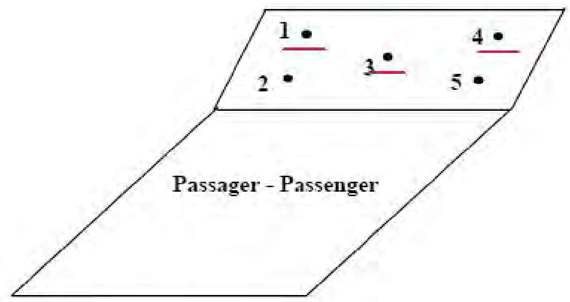


Figure 4-7 – Diagram of the intrusion measurements points for the passenger side floor pan

Table 4-5 – Passenger side intrusion

Item	Test 4150 (mm)	V4d
1	-143	-145
3	-122	-115
4	-123	-131

All of the data presented above validates the FE model of the Ford Taurus as a good representation of the physical vehicle.

4.3.2 Full Frontal Impact at 30 mph

The model was also verified against a full frontal impact into a rigid wall at 30 mph (NHTSA Tests 3150, 3224, 4134, 4135, and 4174) [7, 8, 9, 10, 11]. The overall global deformation pattern of the FE model was very similar to that of the NHTSA test, as shown in Figure 4-8. Figure 4-9 compares the left and right rear seat cross member accelerations of the test and simulation, also indicating similar vehicle behavior between the test and simulation (Table 4-6).

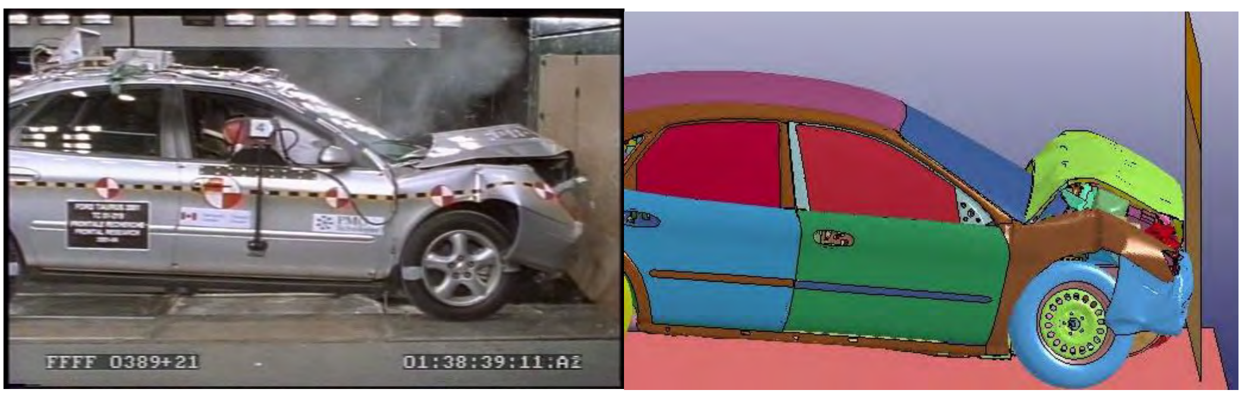


Figure 4-8 – Comparison of the global deformation for Taurus in 30 mph frontal test and simulation

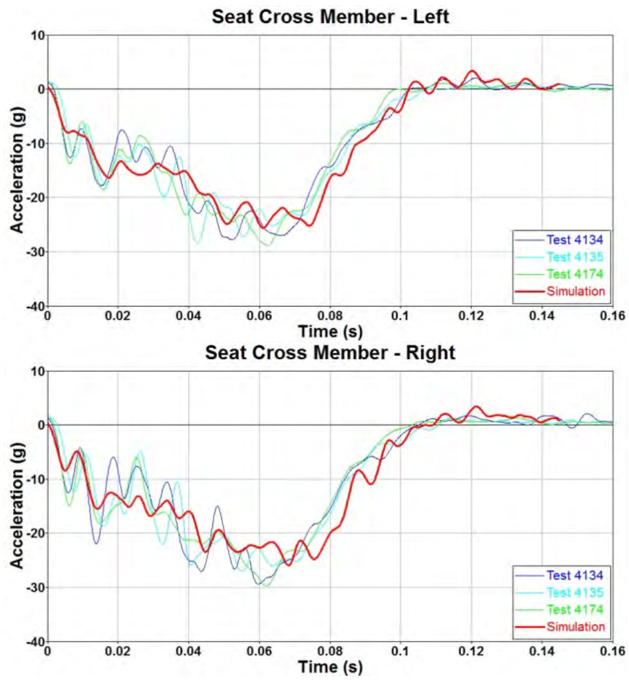


Figure 4-9 – Comparison of left and right rear seat cross member X accelerations for 30 mph tests and simulation

Table 4-6 – Objective rating criteria for left and right rear seat accelerations for 30 mph full frontal impact

		Left Rear Seat Acceleration		Right Rear Seat Acceleration	
		Value (%)	Pass?	Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	-1	Y	-2.1	Y
	Phase	6.3	Y	7.2	Y
	Comprehensive	6.3	Y	7.5	Y
ANOVA Metric	Average	0.2	Y	0.5	Y
	Standard Deviation	9.6	Y	11.9	Y

All of the data presented above further verified that the FE model of the Ford Taurus is a good representation of the physical vehicle.

4.3.3 IIHS Offset Deformable Barrier

The model was run under the IIHS offset deformable barrier (ODB) crash test protocol, in which the vehicle strikes a deformable barrier at 40 mph with a 40 percent overlap on the driver side. The simulation results were compared to IIHS Test CF00010 [12]. The overall vehicle deformation and pulse were similar between the test and simulation (Figure 4-10 and Figure 4-11). Table 4-7 summarizes the objective rating criteria for the simulation data compared to the test data.

Figure 4-10 – Comparison of post-impact deformation of IIHS ODB test

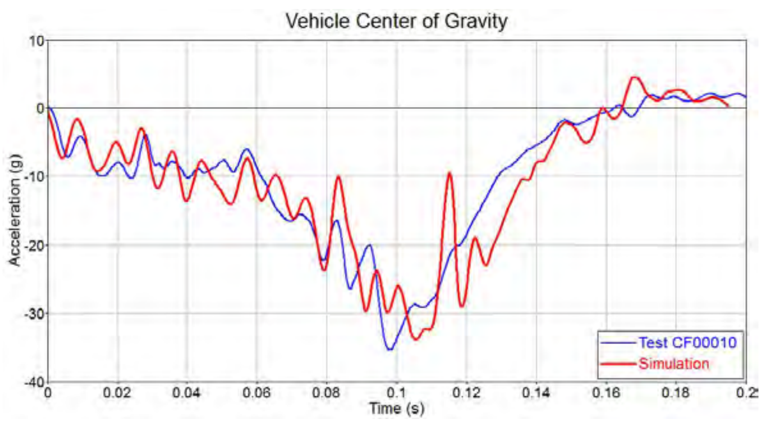


Figure 4-11 – Acceleration at the vehicle CG for the IIHS ODB test and simulation

Table 4-7 – Objective rating criteria for vehicle CG acceleration in the IIHS ODB simulation

		CG Acceleration	
		Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	3.2	Y
	Phase	8.6	Y
	Comprehensive	9.2	Y
ANOVA Metric	Average	-1.2	Y
	Standard Deviation	10.8	Y

The intrusion was also compared between the test and simulation (Figure 4-12). A quantitative comparison of the intrusion at four measurement points in the footwell area is shown in Table 4-8.

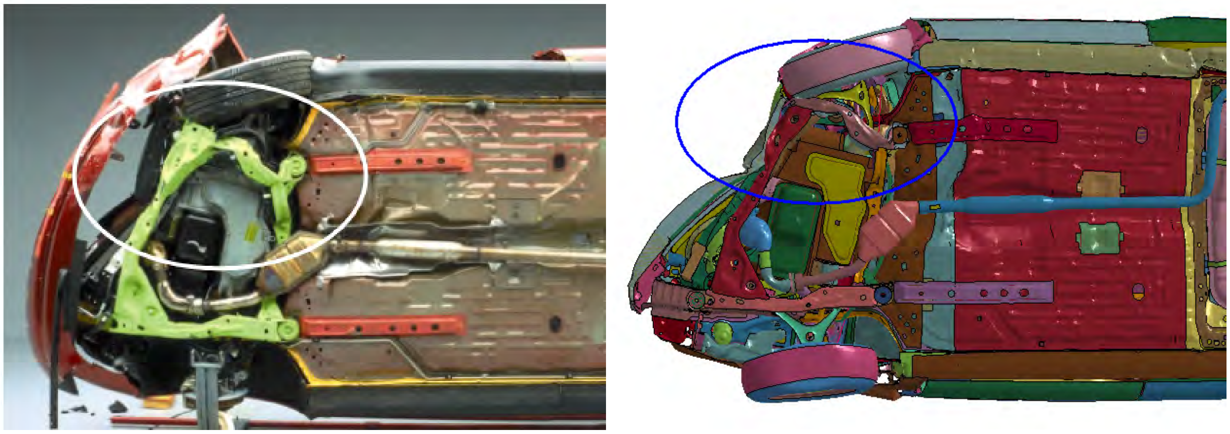


Figure 4-12 – Post-crash footwell intrusion comparison

Table 4-8 – Comparison of footwell intrusion between IIHS test and simulation

Location	IIHS test(mm)	Simulation(mm)
Footrest	-70	-105
Left toepan	-110	-166
Center toepan	-120	-161
Right toepan	-120	-156

4.3.4 MDB Side Impact

The Ford Taurus model was run in a side impact with a moving deformable barrier (MDB). The MDB had an initial velocity of 38.2 mph and was crabbed at a 27° angle. The Taurus was stationary and positioned at a 63° angle from the MDB's axis of forward motion. The simulation set up is illustrated in Figure 4-13.

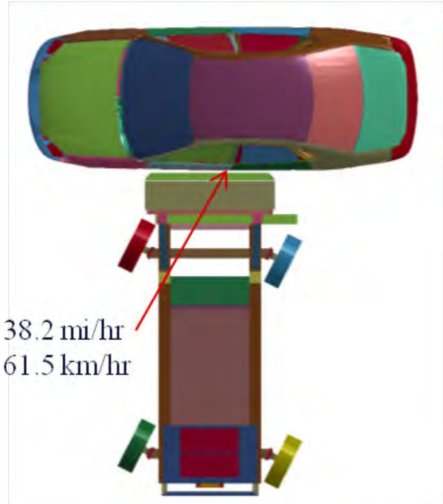


Figure 4-13 – Diagram of the MDB side impact test set up

The simulation results were compared to data from NHTSA Test 3263 [13]. The post-crash deformation profiles and vehicle accelerations show reasonable correlation (Figure 4-14, Figure 4-15, and Figure 4-16).

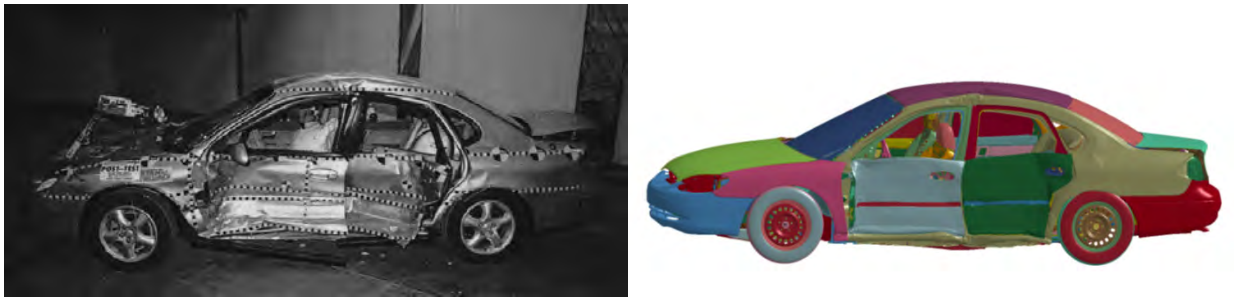


Figure 4-14 – Post-crash deformation of Taurus in side impact

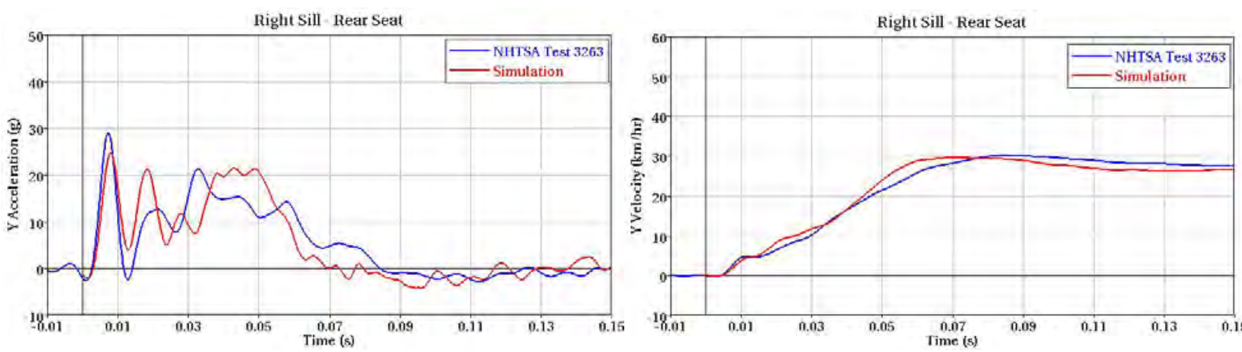


Figure 4-15 – Overall acceleration and velocity of the vehicle as captured by the right rear seat accelerometer

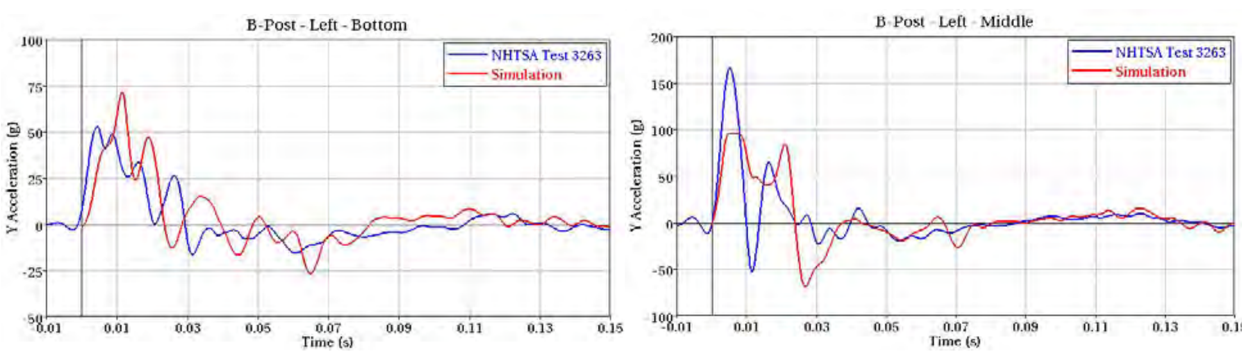


Figure 4-16 – Intrusion acceleration as measured at the bottom and middle of the struck side B-pillar

The intrusion was measured at three levels—sill top, occupant h-point, and window sill—in order to quantify the deformation profile and compare the test and simulation (Figure 4-17). The measurements showed acceptable correlation between the test and simulation. The difference in the rear section of the vehicle is associated with the fact that the rear door bent during the impact, which did not occur in the simulation because the door lock was modeled as a rigid connection.

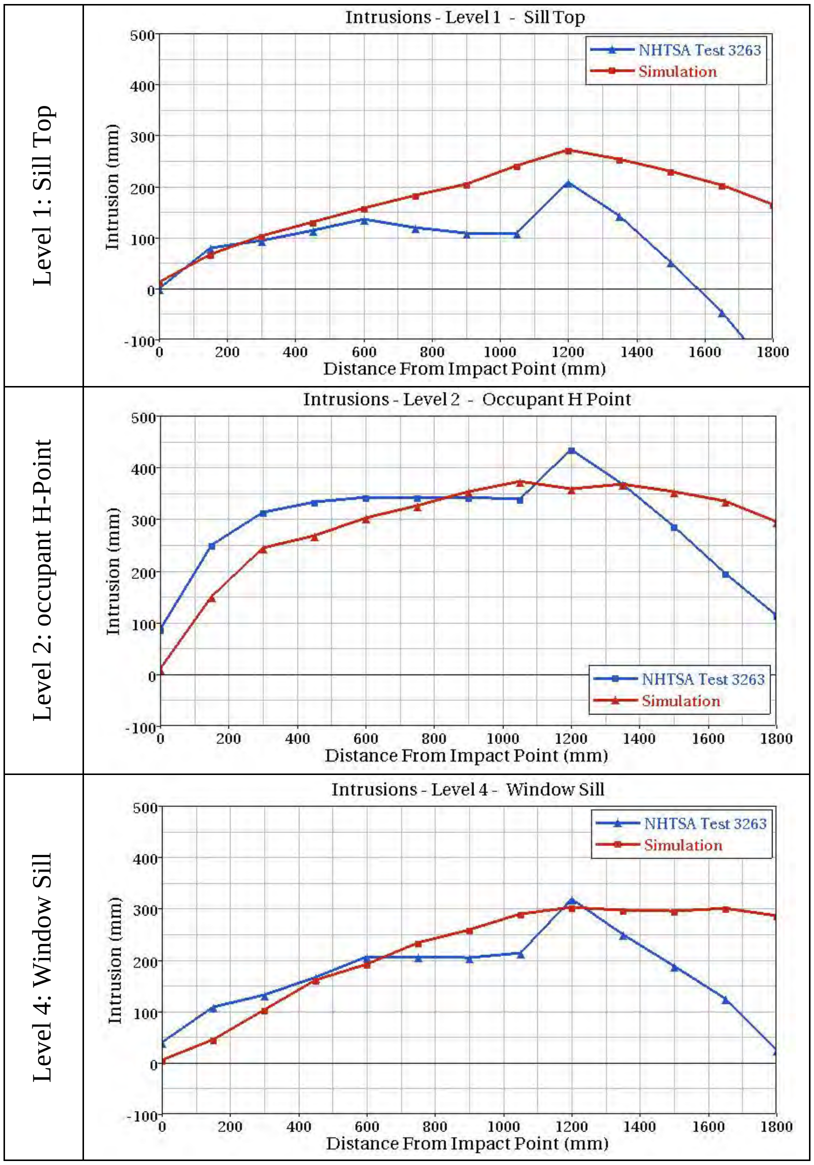


Figure 4-17 – Intrusion measured at three levels after side impact

4.3.5 Offset Rigid Pole at 35 mph

The Taurus FE model was run in an offset impact with a rigid 10” pole at 35 mph. The pole was offset 15 percent (27.7 cm) to the left of the vehicle centerline. Post-impact pictures and vehicle motion are shown in Figure 4-18 and Figure 4-19 for IIHS Test CF05001 and the simulation [14]. Due to the fact that failure was not incorporated in the model, specifically for the engine mounts, the simulation results do not capture the response seen in the tests.

Figure 4-18 – Post-crash images of the Taurus in an offset rigid pole impact

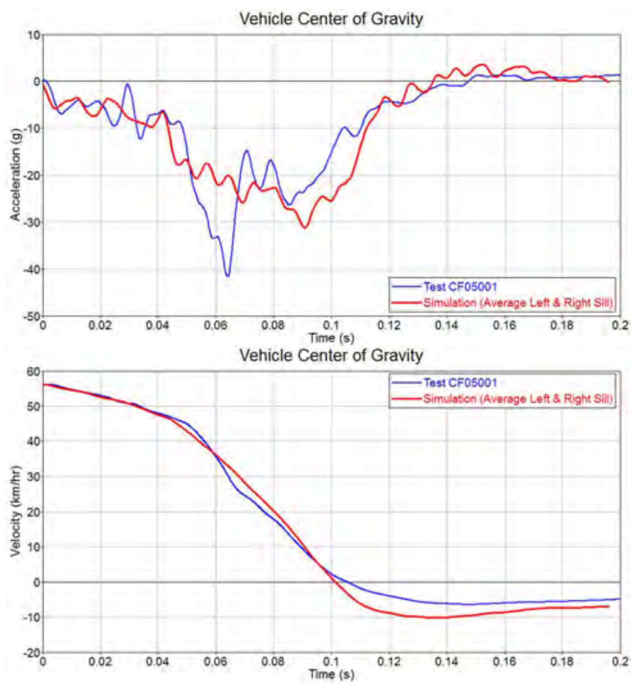


Figure 4-19 – Taurus acceleration and velocity measured at the vehicle CG

4.3.6 Offset Rigid Pole at 40 mph

The Taurus FE model was run in an offset impact with a rigid 10" pole at 40 mph. The pole was offset 16 percent (30.5 cm) to the left of the vehicle centerline. Post-impact pictures and vehicle motion are shown in Figure 4-20 and Figure 4-21 for the IIHS Test CF05002 and the simulation [15].

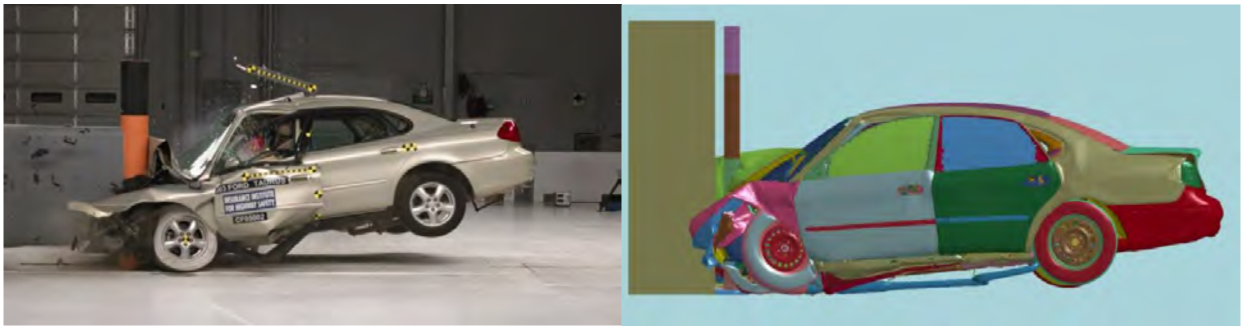


Figure 4-20 – Post-crash images of the Taurus in an offset rigid pole impact

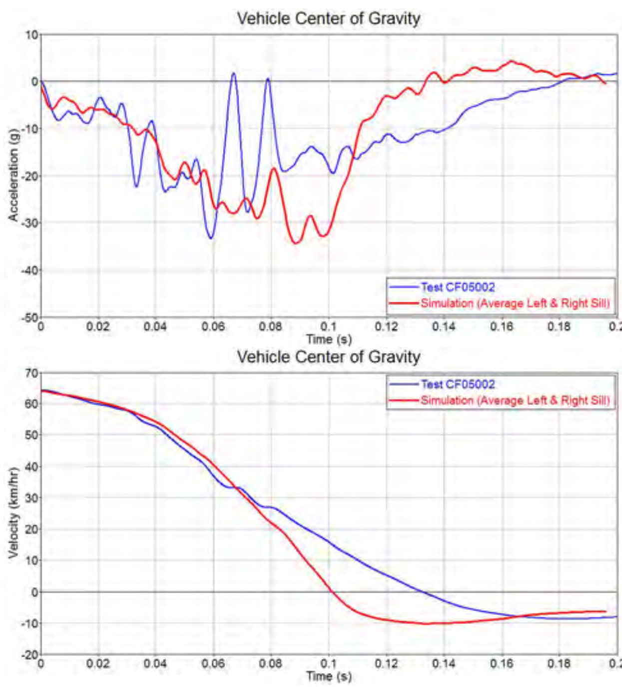


Figure 4-21 – Taurus acceleration and velocity measured at the vehicle CG

4.4 Model Robustness

The FE model of the Ford Taurus was run in several different crash configurations to confirm that the simulations would run to completion with no computational errors. The centerline pole impact at 35 mph was selected for one of the robustness runs, as it is a severe, high speed crash with large, localized deformation. This crash condition would test the robustness of the FE model. Additionally, the Taurus model was tested for robustness in full frontal and 40 percent offset impacts with the 2007 Chevrolet Silverado FE model.

4.4.1 Centerline Pole at 35 mph

The centerline pole simulation was run with the Ford Taurus at an impact speed of 35 mph. The model was proven to be robust, as no errors were encountered and the simulation ran to completion. The preand post-crash images showing the severity of the deformation is shown in Figure 4-22 and the vehicle acceleration is shown in Figure 4-23.

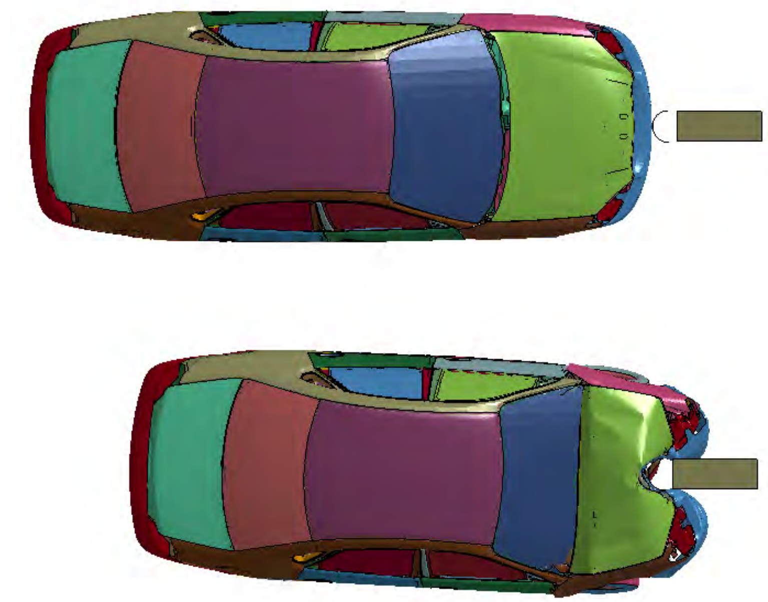


Figure 4-22 – Pre- and post-crash images of the Taurus for the centerline pole robustness simulation

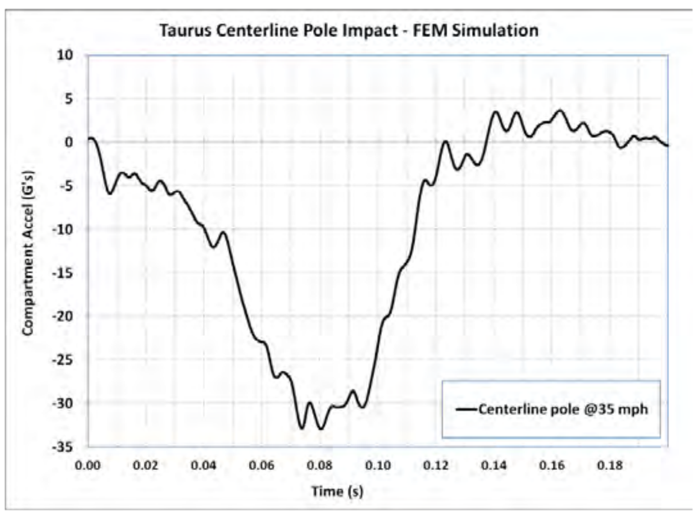


Figure 4-23 – Compartment acceleration of Taurus in centerline pole impact at 35 mph

4.4.2 Full Frontal Impact Into Silverado

The Taurus was run into the Chevy Silverado pickup truck in a full frontal impact at 35 mph. This simulation ran to completion with no errors. The extent of the deformation is shown in Figure 4-24 and the vehicle pulse is shown in Figure 4-25. The accelerations for the right rear seat and left rear seat are similar, showing a symmetrical impact as expected of a full frontal crash.

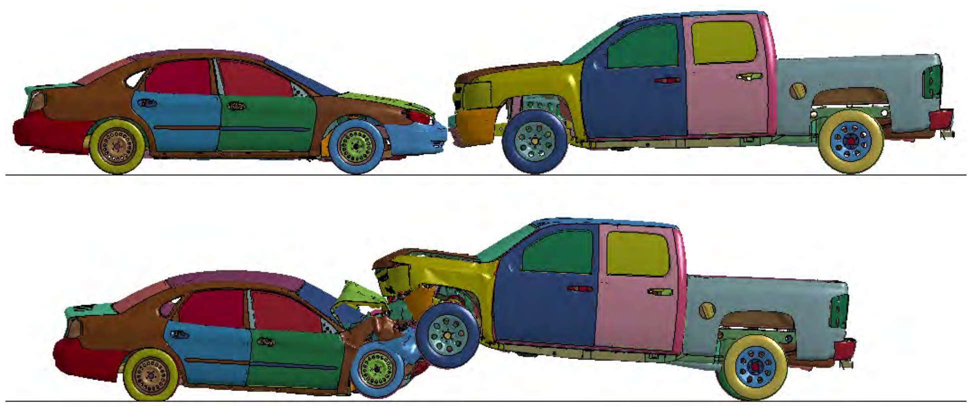


Figure 4-24 – Pre- and post-crash images of the Taurus striking the Silverado with 100 percent overlap

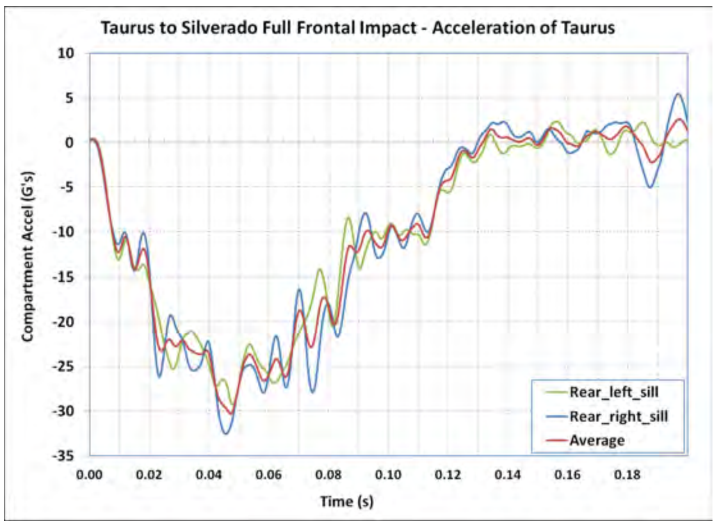


Figure 4-25 – Compartment acceleration of Taurus in full frontal impact with Silverado

4.4.3 Offset Impact Into Silverado

The Taurus model was run into the Silverado model at 35 mph with a 40 percent overlap. This simulation ran to completion with no errors, showing the robustness of the Taurus FE model. The deformation of the Taurus is shown in Figure 4-26 and the vehicle pulse is shown in Figure 4-27. The acceleration of the left rear seat was greater than that of the right rear seat, as expected in an offset crash on the driver side of the vehicle.

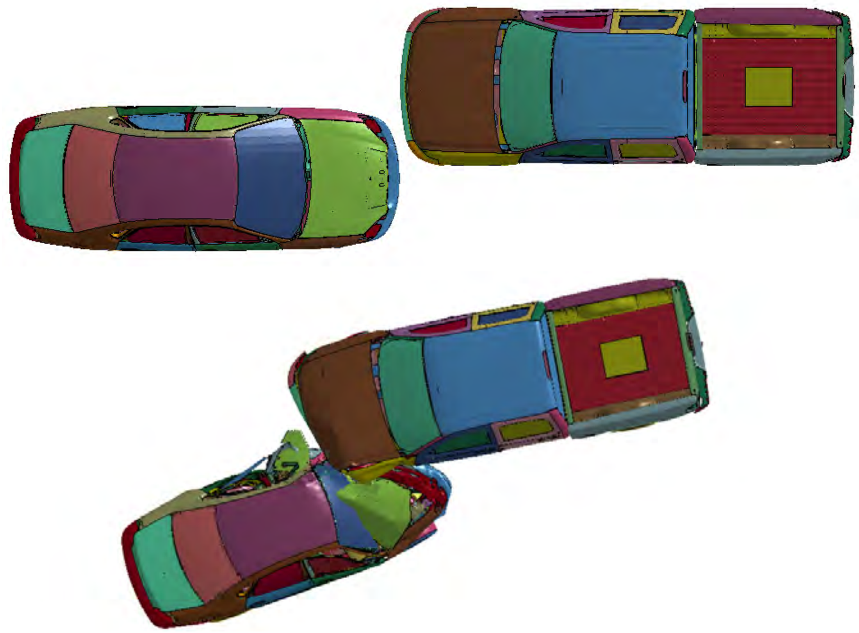


Figure 4-26 – Pre- and post-crash images of the Taurus striking the Silverado with 40 percent overlap

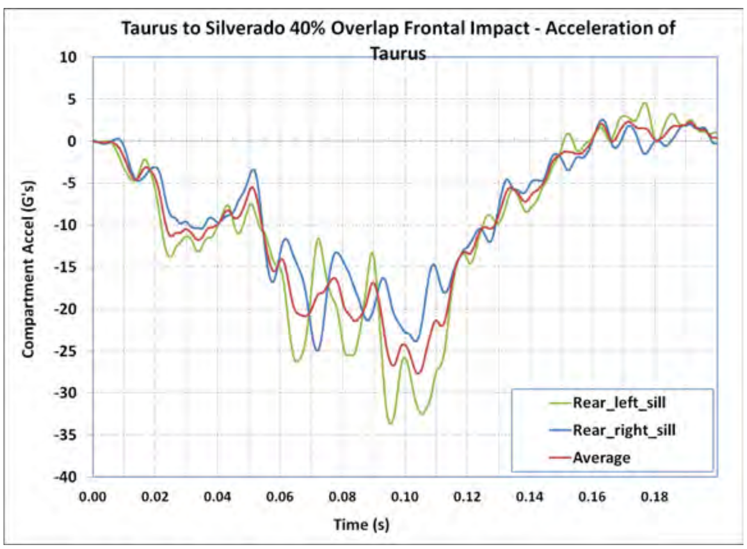


Figure 4-27 – Compartment acceleration of Taurus in 40 percent offset impact with Silverado

4.5 Varying Speed Trend Analysis

Several more simulations were run with the Ford Taurus FE model to verify that the model was showing the expected trends in different crash configurations. The NCAP rigid wall, IIHS offset deformable barrier, and centerline pole simulations were run and the results were compared between low and high speeds within the same crash configuration to confirm that the vehicle responses were valid in the physical realm.

4.5.1 NCAP Rigid Wall

The NCAP rigid wall simulation was run at 25 mph and 35 mph. The pre- and post-crash images and resulting compartment accelerations are shown in Figure 4-28 and Figure 4-29. These runs verified that the higher speed impact yielded a more severe crash pulse than the lower speed impact.

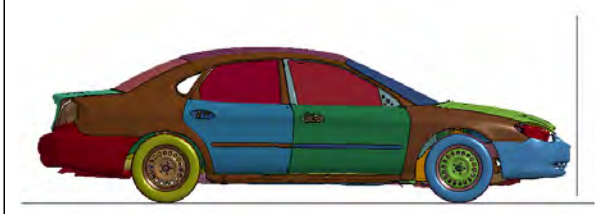
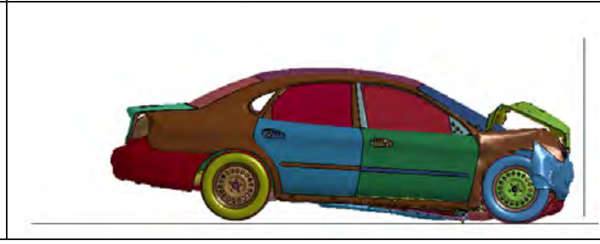
	25 mph	35 mph
Pre-Crash		
Post-Crash		

Figure 4-28 – Pre- and post-crash images of the Taurus for the full frontal impact at 25 mph and 35 mph

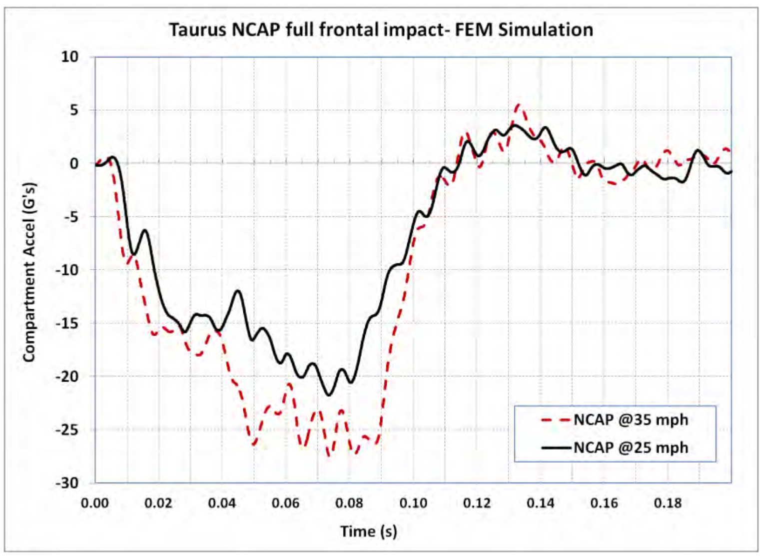


Figure 4-29 – Taurus compartment accelerations for NCAP frontal verification simulations

4.5.2 IIHS Offset Deformable Barrier

The IIHS ODB simulation was run at 25 mph and 40 mph. The pre- and post-crash images and resulting C.G. and left rear accelerometer outputs are shown in Figure 4-30 and Figure 4-31. These runs verified that the higher speed impact yielded higher compartment accelerations than the lower speed impact.

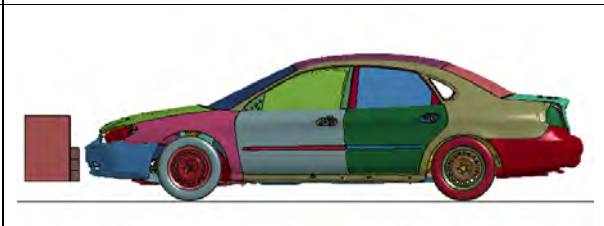
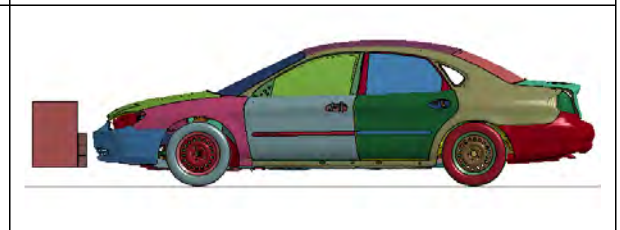
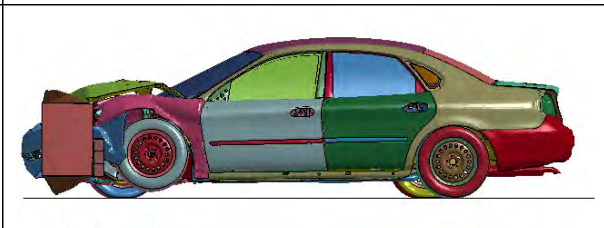
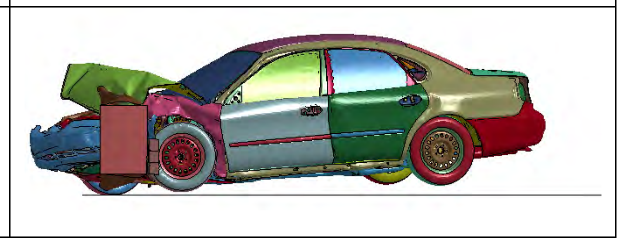
	25 mph	40 mph
Pre-Crash		
Post-Crash		

Figure 4-30 – Pre- and post-crash images of the Taurus for the IIHS ODB impact at 25 mph and 40 mph

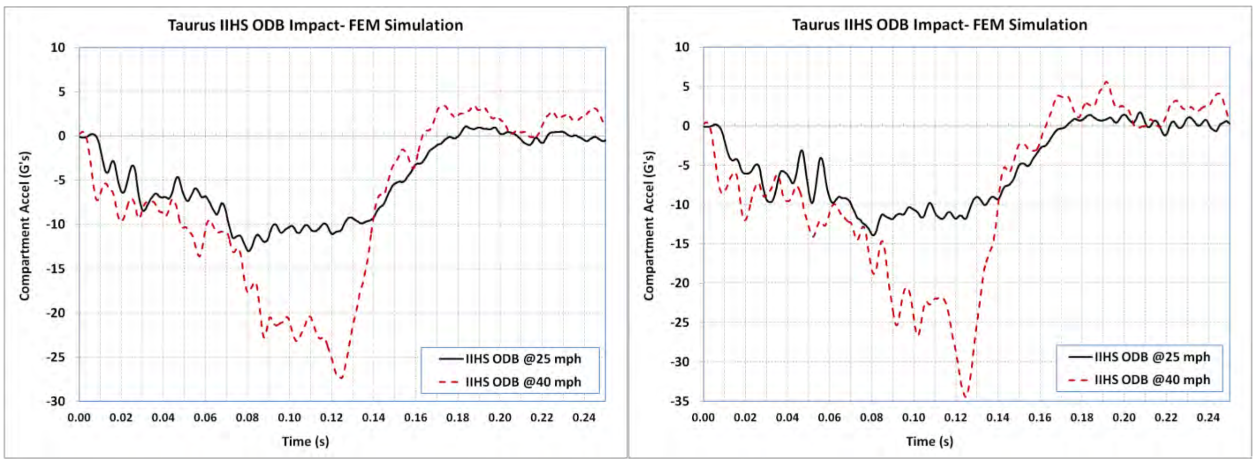


Figure 4-31 – Taurus CG (left) and left rear (right) accelerometer outputs for IIHS ODB verification simulations

4.5.3 Centerline Pole

The centerline pole simulation was run at 25 mph and 35 mph. The pre- and post-crash images and resulting compartment accelerations are shown in Figure 4-32 and Figure 4-33. These runs verified that the higher speed impact yielded a more severe crash pulse than the lower speed impact.

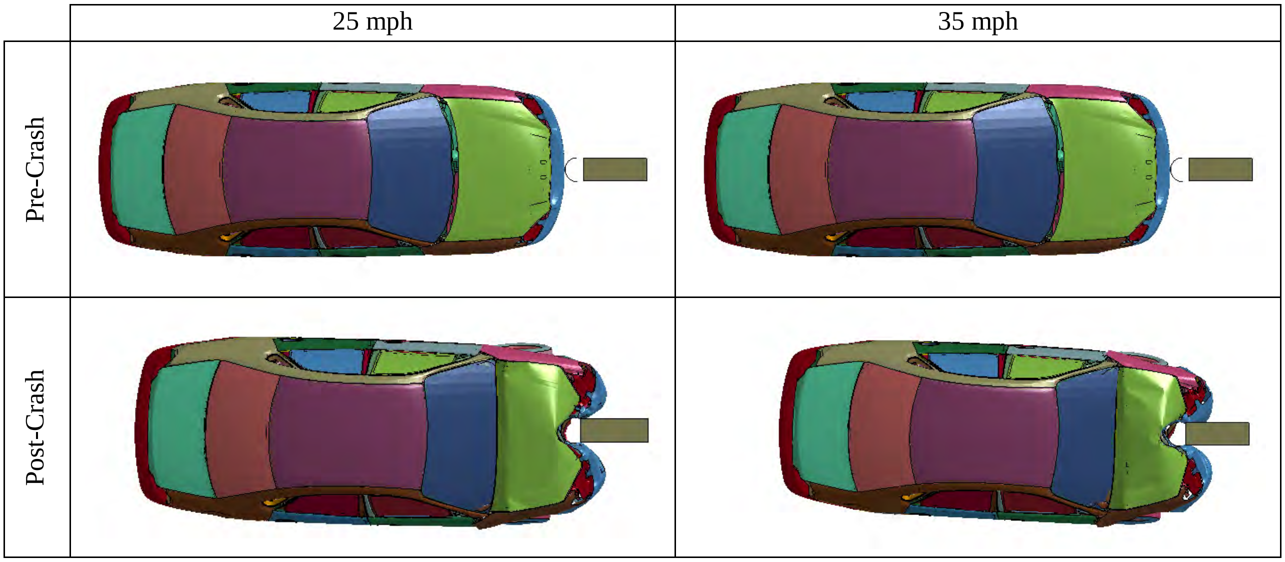


Figure 4-32 – Pre- and post-crash images of the Taurus for the centerline pole impact at 25 mph and 35 mph

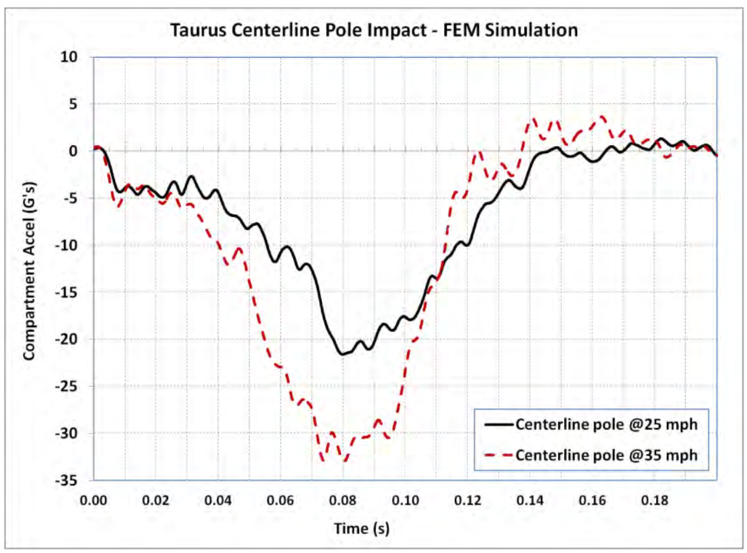


Figure 4-33 – Taurus compartment accelerations for centerline pole verification tests

4.6 Summary and Conclusions

A finite element model of the 2001 Ford Taurus passenger sedan was created using a reverse engineering process by the NCAC under contract to the FHWA. This vehicle was modeled to support NHTSA and FHWA research efforts.

The model was initially validated by comparison to images and data derived from the NHTSA NCAP tests, which involved frontal impact into a rigid wall at 35 mph. Comparisons of data from the tests and the model included:

- View of side deformations,
- Acceleration and velocity changes for the rear seat cross member,
- Accelerations of the top and bottom of the engine,

- Total forces over time, and
- Force displacement plots.

Vehicle kinematics and the accelerometer output data were compared and the simulation results showed overall good correlation with the physical test results.

Additional validation efforts were undertaken using data available from other crash tests, including full frontal wall, offset deformable barrier, moving deformable barrier, and offset rigid pole impacts. Simulation results compared well to data from these tests to determine the validity of the enhanced model. Robustness checks were also undertaken to demonstrate model performance in simulations of centerline pole impacts and full frontal collisions into a Chevrolet Silverado. The model provided viable representations in these large deformation crash events. The capabilities of the model were also checked by comparing the response trends for rigid wall, offset deformable barrier, and centerline pole impacts at varying speeds. The simulations executed without error in these runs and the results reflected the expected responses and consistency with varying parameters. This led to the conclusion that the model was robust across various impact scenarios.

This model development and validation process has proven the FE model of the Ford Taurus to be robust and applicable for the study of a variety of crash scenarios.

4.7 Acknowledgements

The authors wish to acknowledge the Federal Highway Administration and National Highway Traffic Safety Administration of the U.S. Department of Transportation for supporting these modeling and simulation efforts.

4.8 References

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5. Transportation Research Center, “2004 Ford Taurus 4-door into a Flat Frontal Barrier,” NHTSA Test No. 5143, August 2004.
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15. Insurance Institute for Highway Safety, “R&D Crash Test Report – High Speed Pole Test: 2003 Ford Taurus,” IIHS Test No. CF05002, August 2005.

5 APPENDIX 5: EXTENDED VALIDATION OF THE FINITE ELEMENT MODEL FOR THE 2010 TOYOTA YARIS PASSENGER SEDAN

5.1 Background

A finite element (FE) model based on a 2010 Toyota Yaris passenger sedan was developed through the process of reverse engineering at the National Crash Analysis Center of The George Washington University . These efforts were conducted under a contract with the Federal Highway Administration . This model will become part of the array of FE models developed to support crash simulation. The model was validated against the NHTSA frontal New Car Assessment Program (NCAP) test for the corresponding vehicle. This vehicle was selected for modeling to reflect current automotive designs and technology advancements for an important segment of the vehicle fleet. This model is expected to support current and future NHTSA research related to occupant risk and vehicle compatibility as well as FHWA barrier crash evaluation, research, and development efforts. This vehicle conforms to the Manual for the Assessment of Safety Hardware (MASH) requirements for an 1100C test vehicle [1].

5.2 Modeling Summary

A production 2010 Toyota Yaris four-door passenger sedan was purchased as the basis for the model [VIN JTDBT4K37A4067025]. The reverse engineering process systematically disassembled the vehicle part by part. Each part was cataloged, scanned to define its geometry, measured for thicknesses, and classified by material type. All data was entered into a computer file and then each part was meshed to create a computer representation for finite element modeling that reflected all of the structural and mechanical features in digital form.

Parts were broken down into elements such that critical features were represented consistent with the implications of element size on simulation processing times. Material data for the major structural components was obtained through coupon testing from samples taken from vehicle parts. From the material testing, appropriate stress and strain values were determined to include in the model for the analysis of crush behavior in crash simulation.

A representation of the resulting FE model in comparison to the actual vehicle is shown in Figure 5-1. This detailed FE model was constructed to include full functional capabilities of the suspension and steering subsystems (Figure 5-2), details of the inner door components (Figure 5-3), and coarse representations of the interior components (Figure 5-4). Table 2-1 summarizes the final FE model properties.

Figure 5-1 – Actual and FE model of a 2010 Toyota Yaris sedan

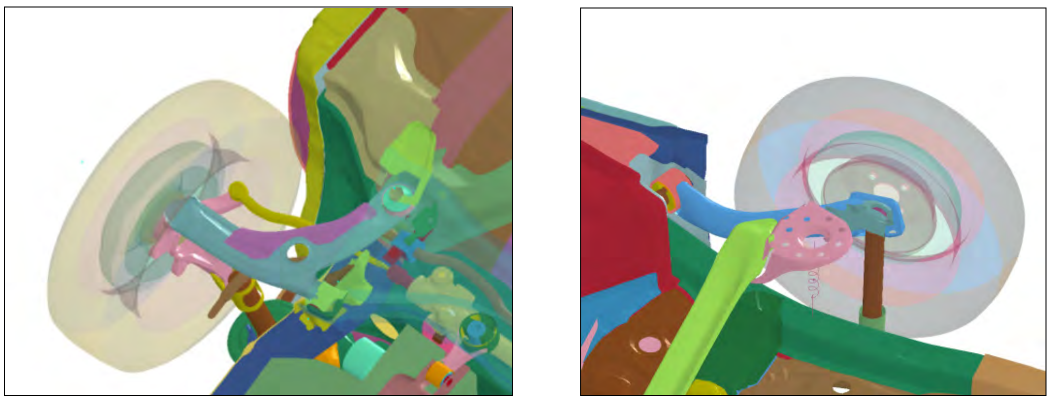


Figure 5-2 – Details of the front (left) and rear (right) steering and suspension subsystems

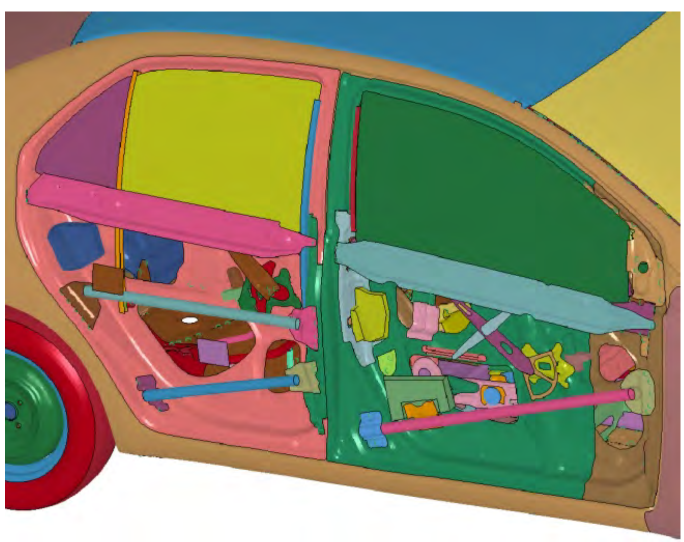


Figure 5-3 – Details of the inner door components

Figure 5-4 – Coarse representations of structural interior components

Table 5-1 – Toyota Yaris FE model summary

Number of Parts	917	Beam Element Connections	4,425
Number of Nodes	1,480,422	Nodal Rigid Body Connections	727
Number of Shells	1,250,424	Extra Node Set Connections	20
Number of Beams	4,738	Rigid Body Connections	2
Number of Solids	258,887	Spotweld Connections	4,107
Total Number of Elements	1,514,068	Joint Connections	39

Details about the model and the outcome of the initial validation efforts are documented in “Development and Validation of a Finite Element Model for a 2010 Toyota Yaris Sedan” NCAC 2011-T-001 [2]. This document describes the additional validation efforts that were undertaken to assess the robustness of the Yaris FE model for various types of impacts. These efforts were conducted by NCAC in support of the NHTSA study “Investigate Self and Partner Protection of New Vehicle Designs Using Structural Modeling,” TOPR No. 16 under DTFH61-09-D-00001.

5.3 Initial Model Validation

The FE model was initially verified and validated in several ways to assure that it was an accurate representation of the actual vehicle. These efforts included checks for completeness of elements and adequacy of connection details. The mass, moments of inertia, and center of gravity (CG) locations of the actual vehicle, as measured at the SEAS, Inc. lab, and FE model were compared. The results are shown in Table 5-2. The weight; pitch, roll, and yaw inertias; and x, y, and z coordinates for the CG were found to be similar and within acceptable limits.

Table 5-2 – Actual vehicle and FE model mass, inertia, and CG comparisons based upon data from testing at SEAS, Inc.

	Actual Vehicle	FE Model
Weight, kg	1078	1100
Pitch inertia, kg-m^2	1498	1566
Yaw inertia, kg-m^2	1647	1739
Roll inertia, kg-m^2	388	395
Vehicle CG X, mm	1022	1004
Vehicle CG Y, mm	-8.3	-4.4
Vehicle CG Z, mm	558	569

The focus of the initial validation was the comparison of the simulation of the NCAP frontal wall impact with actual data from NHTSA Tests 5677 and 6221 for a comparable vehicle [3, 4]. For this simulation, accelerometers were positioned in the same locations as the NCAP test (Figure 5-5). The most commonly benchmarked accelerometers for NCAP performance are the left rear seat, right rear seat, and engine top and bottom. The left rear seat and right rear seat accelerometers are used to measure the deceleration response and velocity of the vehicle cabin in the wall impact.

Location	Node ID
Left Seat	319812
Right Seat	319820
Engine Top	319828
Engine Bottom	319836

Figure 5-5 – Accelerometer locations in FE model

Table 5-3 provides specific data for key parameters of the FE model and the vehicle used in the NCAP tests. It is easily noted that all were very similar. More information on the NCAP test vehicle, like vehicle weight distribution, vehicle attitude, center of gravity (CG) location, and fuel tank capacity, are published in the NHTSA test reports.

Table 5-3 – Comparison of vehicle characteristics for FE model and two NCAP test vehicles

	FE Model	Test 5677	Test 6221
Weight (kg)	1263	1271	1245
Engine Type	1.5L V4	1.5L V4	1.5L V4
Tire size	P185/60R15	P185/60R15	P185/60R15
Attitude (mm) (As delivered)	F – 668	F – 673	F – 675
	R – 673	R – 680	R – 673
Wheelbase (mm)	2538	2551	2463
CG (mm) Rear of front wheel C/L	1035	999	976
Body Style	4 Door Sedan	4 Door Sedan	3 Door Liftback

The overall global deformation pattern of the FE model was very similar to that of the NCAP test, as shown in Figure 5-6. Figure 5-7 compares the left and right rear seat accelerations of the test and simulation, also indicating similar vehicle behavior between the test and simulation. The Roadside Safety Verification and Validation Program (RSVVP) was used to generate objective measures of how well the simulation follows the test data [5]. The Sprague-Geers MPC metrics were used to quantify the similarity of the test and simulation curve shapes and the ANOVA metric was used to evaluate the residual error. The acceptance criteria for the Sprague-Geers metrics are a difference of less than 40 percent in magnitude, phase, or comprehensive (the square root of the sum of the squares of M and P). The acceptance criteria for the ANOVA metric are an average residual error of less than 5 percent and a standard deviation of the residual errors of less than 20 percent. When the values fall under these acceptance criteria, the simulation can be said to have good correlation with the test, with any deviations in the data attributable to random experimental error. These objective rating metrics for the left and right rear seat accelerations compared to Test 5677 are summarized in Table 5-4. It is worth noting that the acceptance criteria in RSVVP were developed for roadside safety applications where tests typically involve longer duration complex impact sequences with more variability than the NHTSA vehicle crash tests being considered for the FE model validation. In the future, developing acceptance criteria for NHTSA type crash test would be more pertinent and applicable to vehicle FE model validation efforts.

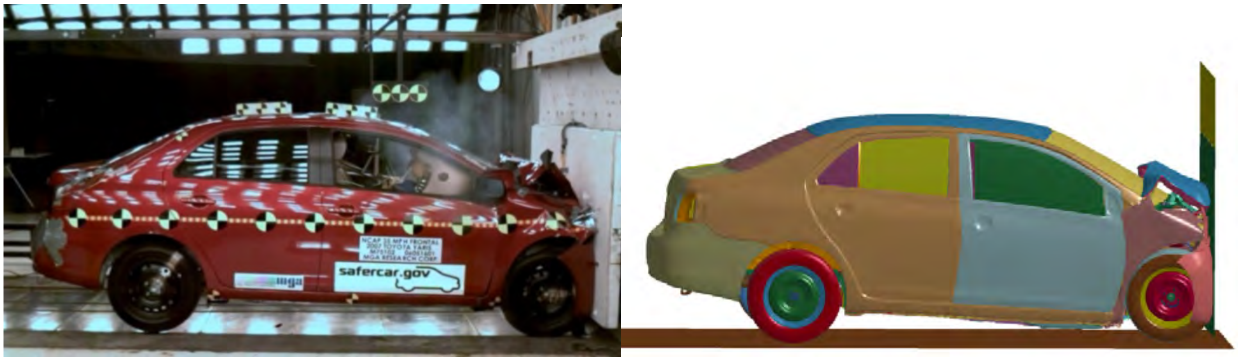


Figure 5-6 – Comparison of the global deformation for Yaris in NCAP Test 5677 and simulation

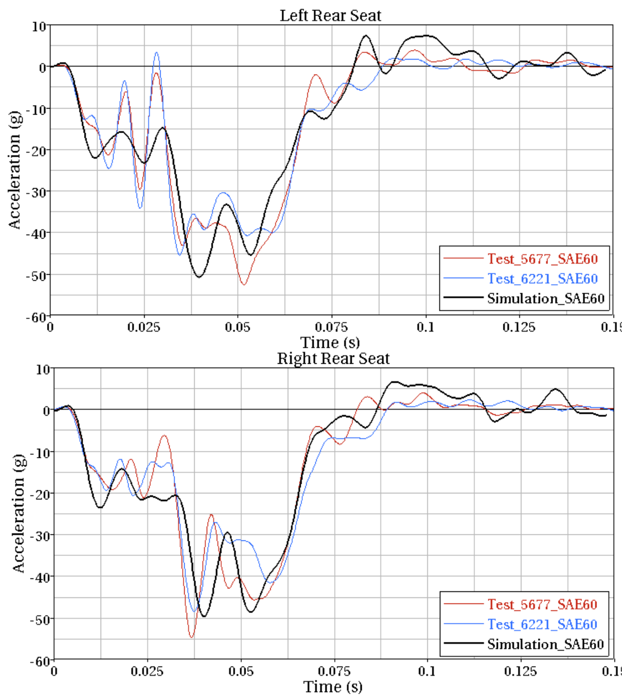


Figure 5-7 – Comparison of left and right rear seat X accelerations for tests and simulation

Table 5-4 – Objective rating criteria for left and right rear seat accelerations

		Left Rear Seat Acceleration		Right Rear Seat Acceleration	
		Value (%)	Pass?	Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	-2.7	Y	0.7	Y
	Phase	8.4	Y	9.3	Y
	Comprehensive	8.8	Y	9.3	Y
ANOVA Metric	Average	0.6	Y	0.1	Y
	Standard Deviation	10.1	Y	10.6	Y

The response of the engine during the crash event was captured through two accelerometers. Both the engine top and bottom accelerations in the simulation closely tracked the engine response in the two tests, as shown in Figure 5-8. The objective rating metrics for the engine top acceleration compared to Test 5677 are shown in Table 5-5.

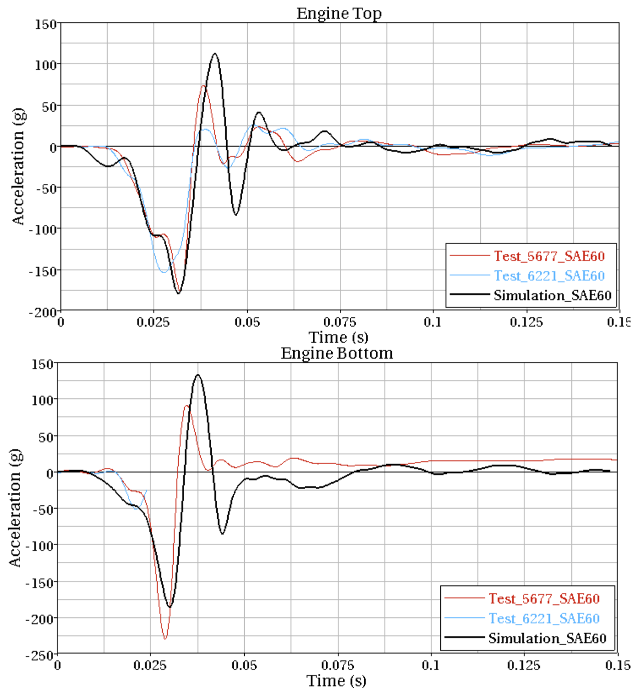


Figure 5-8 – Comparison of engine top and bottom accelerations for tests and simulation

Table 5-5 – Objective rating criteria for engine top acceleration

		Engine Top Acceleration	
		Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	17.7	Y
	Phase	16	Y
	Comprehensive	23.9	Y
ANOVA Metric	Average	-0.2	Y
	Standard Deviation	12.6	Y

Lastly, the simulation and test forces were compared (Figure 5-9). The total wall force in the simulation closely matched that of the two tests. The simulation showed slightly higher maximum force, but also showed similar peak timing and impact duration. The similarity of the simulation and Test 5677 wall force curves is quantified in Table 5-6. Additionally, similar stiffness was observed in the FE model and test vehicles, as shown in the force-displacement plot.

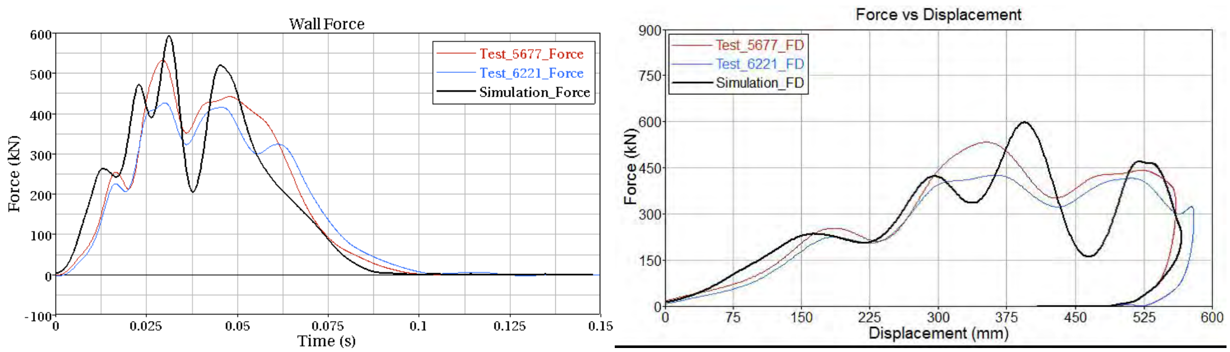


Figure 5-9 – Total wall force (left) and force-displacement (right) plots for the tests versus simulation

Table 5-6 – Objective rating criteria for total wall force

		Total Wall Force	
		Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	-1.2	Y
	Phase	8.2	Y
	Comprehensive	8.3	Y
ANOVA Metric	Average	-0.7	Y
	Standard Deviation	11.2	Y

All of the data presented above validates the FE model of the Toyota Yaris as a good representation of the physical vehicle. More information on the NCAP validation can be found in NCAP Report 2011-T-001 [2].

5.4 Additional Model Validations

The Yaris FE model was further validated by comparisons to additional tests where crash data was available. These comparisons included a 25 mph full frontal and offset deformable barrier impact. These impacts were simulated to determine if the model would yield similar results as the physical test. The results of these additional comparisons are described in the following sections.

5.4.1 Full Frontal Impact at 25 mph

The model was verified against a full frontal impact into a rigid wall at 25 mph (NHTSA Test 6069) [6]. A comparison of the test and simulation vehicles is shown in Table 5-7.

The overall global deformation pattern of the FE model was very similar to that of the NHTSA test, as shown in Figure 5-10. Figure 5-11 compares the left and right rear seat accelerations of the test and simulation, also indicating similar vehicle behavior between the test and simulation. Table 5-8 summarizes the statistical comparison of the data from the simulation and the test, noting that it passed the objective criteria.

Table 5-7 – Comparison of vehicle characteristics for FE model and NHTSA Test 6069 vehicle

	FE Model	Test 6069
Weight (kg)	1211	1212
Engine Type	1.5L V4	1.5L V4
Tire size	P185/60R15	P185/60R15
Attitude (mm) (As delivered)	F – 668	F – 673
	R – 673	R – 672
Wheelbase (mm)	2538	2550
Body Style	4 Door Sedan	4 Door Sedan

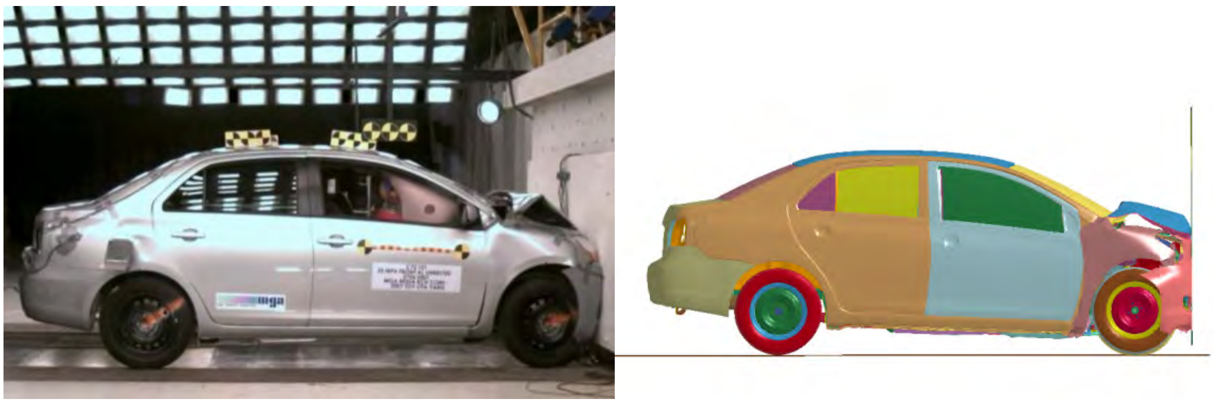


Figure 5-10 – Comparison of the global deformation for Yaris in NHTSA test no. 6069 and simulation

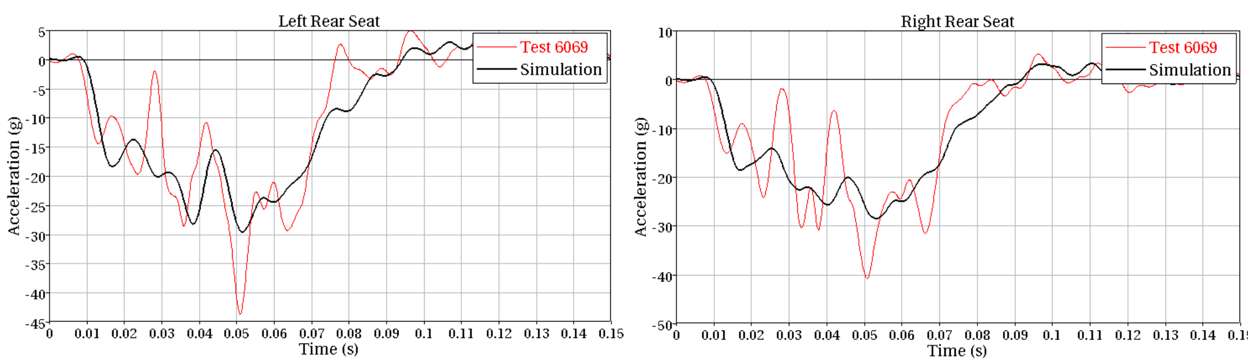


Figure 5-11 – Comparison of left and right rear seat X accelerations for NHTSA Test 6069 and simulation

Table 5-8 – Objective rating criteria for left and right rear seat accelerations for 25 mph full frontal impact

		Left Rear Seat Acceleration		Right Rear Seat Acceleration	
		Value (%)	Pass?	Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	-4	Y	-4.5	Y
	Phase	11.4	Y	12.4	Y
	Comprehensive	12	Y	13.2	Y
ANOVA Metric	Average	-0.7	Y	-0.4	Y
	Standard Deviation	11.3	Y	13.5	Y

The simulation and test forces were compared (Figure 5-12). The total wall force in the simulation closely matched that of the two tests (Table 5-9). The simulation showed slightly higher maximum force, but also showed similar peak timing and impact duration. Similar stiffness was observed in the FE model and test vehicles, as shown in the force-displacement plot.

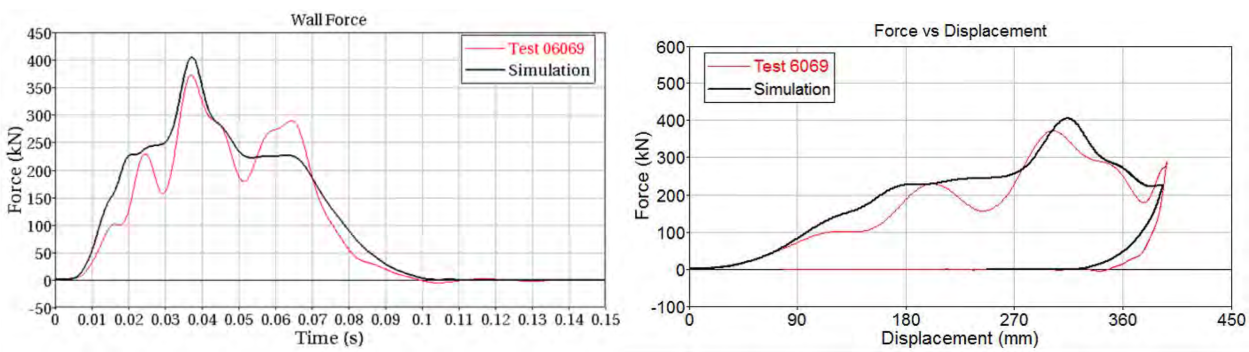


Figure 5-12 – Total wall force (left) and force-displacement (right) plots for NHTSA Test 6069 versus simulation

Table 5-9 – Objective rating criteria for total wall force for 25 mph full frontal impact

		Total Wall Force	
		Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	7.5	Y
	Phase	6.1	Y
	Comprehensive	9.7	Y
ANOVA Metric	Average	3.3	Y
	Standard Deviation	8.1	Y

All of the data presented above further indicated that the FE model of the Toyota Yaris is a good representation of the physical vehicle.

5.4.2 IIHS Offset Deformable Barrier

The model was run under the IIHS offset deformable barrier (ODB) crash test protocol, in which the vehicle strikes a deformable barrier at 40 mph with a 40 percent overlap on the driver side. The simulation results were compared to IIHS Test CEF0610 [7]. The overall vehicle deformation and pulse were similar between the test and simulation (Figure 5-13 and Figure 5-14). Table 5-10 summarizes the objective rating criteria for the simulation data compared to the test data.

Figure 5-13 – Comparison of post-impact deformation of IIHS ODB test

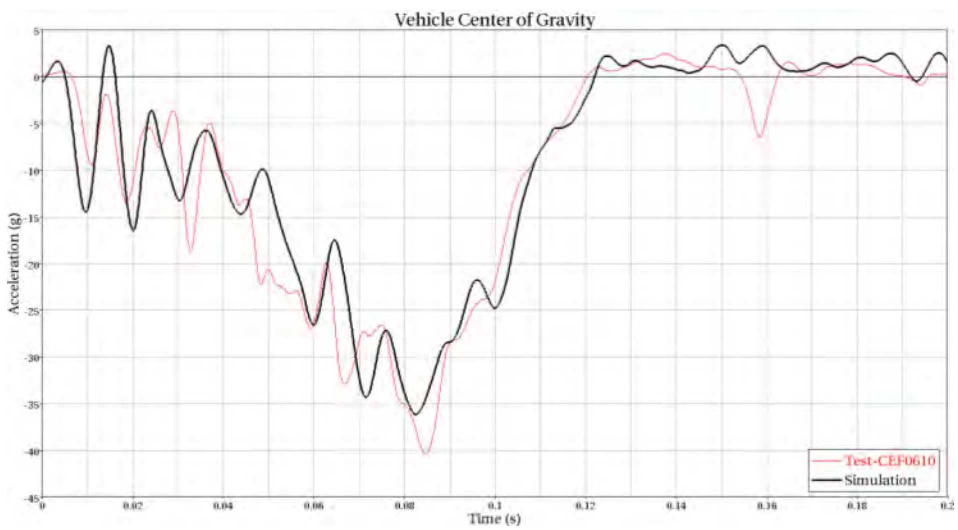


Figure 5-14 – Acceleration at the vehicle CG for the IIHS ODB test and simulation

Table 5-10 – Objective rating criteria for vehicle CG acceleration in the IIHS ODB simulation

		CG Acceleration	
		Value (%)	Pass?
Sprague-Geers MPC Metric	Magnitude	-5.4	Y
	Phase	7.7	Y
	Comprehensive	9.4	Y
ANOVA Metric	Average	2	Y
	Standard Deviation	9.2	Y

The intrusion was also compared between the test and simulation. The intrusion was measured at four places on the footwell, as shown in Figure 5-15. The comparison of the intrusion is shown in Table 5-11.

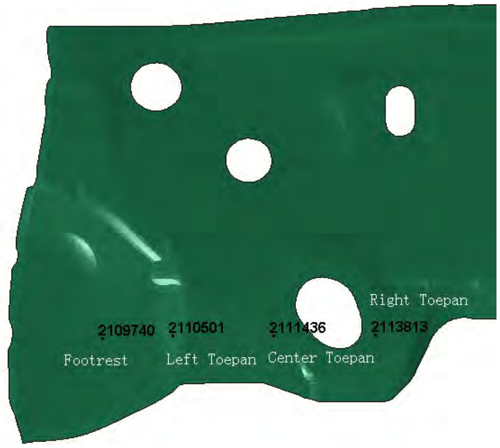


Figure 5-15 – Footwell intrusion measurement locations

Table 5-11 – Comparison of footwell intrusion between IIHS test and simulation

Location	IIHS test(mm)	Simulation(mm)
Footrest	-20	-85
Left toepan	-100	-118
Center toepan	-50	-101
Right toepan	-40	-75

5.5 Model Robustness

As further tests of the robustness of the FE model of the Toyota Yaris, several different crash configurations were run to confirm that the simulations would run to completion with no computational errors. These included centerline pole, full frontal and offset into the Silverado, and varying speed rigid wall impacts. Data for actual crashes of these types did not exist, so analytical comparisons were not possible. The results are presented in the following sections.

5.5.1 Centerline Pole Impact at 35 mph

The centerline pole impact at 35 mph was selected for one of the robustness runs, as it is a severe, high speed crash with large, localized deformation. This crash condition would test the robustness of the FE model. The centerline pole simulation was run with the Toyota Yaris at an impact speed of 35 mph. The model was proven to be robust, as no errors were encountered and the simulation ran to completion. The pre- and post-crash images showing the severity of the deformation is shown in Figure 5-16 and the vehicle acceleration is shown in Figure 5-17. These are consistent with expected results for this type of impact.

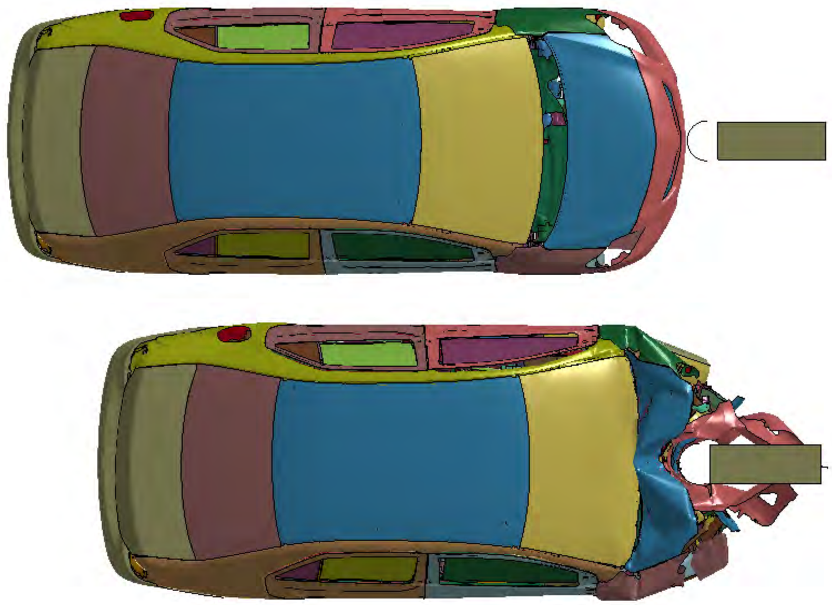


Figure 5-16 – Pre- and post-crash images of the Yaris for the centerline pole robustness simulation

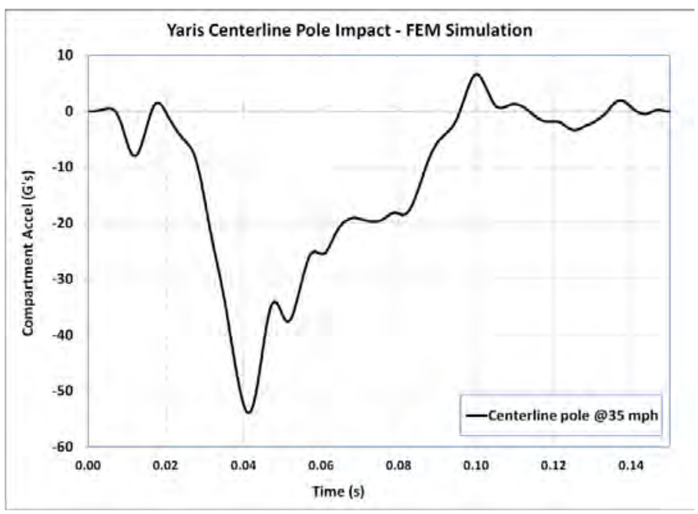


Figure 5-17 – Compartment acceleration of Yaris in centerline pole impact at 35 mph

5.5.2 Full Frontal Impact Into Silverado

Additionally, the Yaris model was tested for robustness in a head-on, full frontal impact with the 2007 Chevrolet Silverado FE model at 35 mph. This simulation ran to completion with no errors. The extent of the deformation is shown in Figure 5-18 and the vehicle pulse is shown in Figure 5-19. The accelerations for the right rear seat and left rear seat are similar, showing a symmetrical impact expected of a full frontal crash.

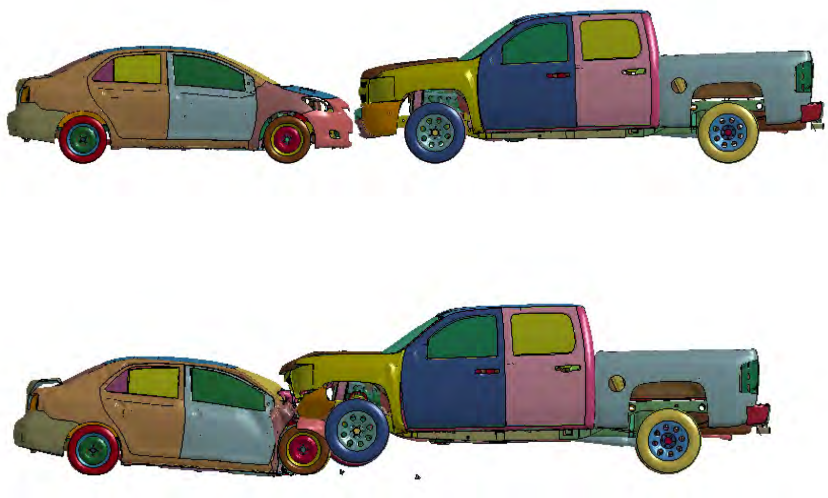


Figure 5-18 – Pre- and post-crash images of the Yaris striking the Silverado with 100 percent overlap

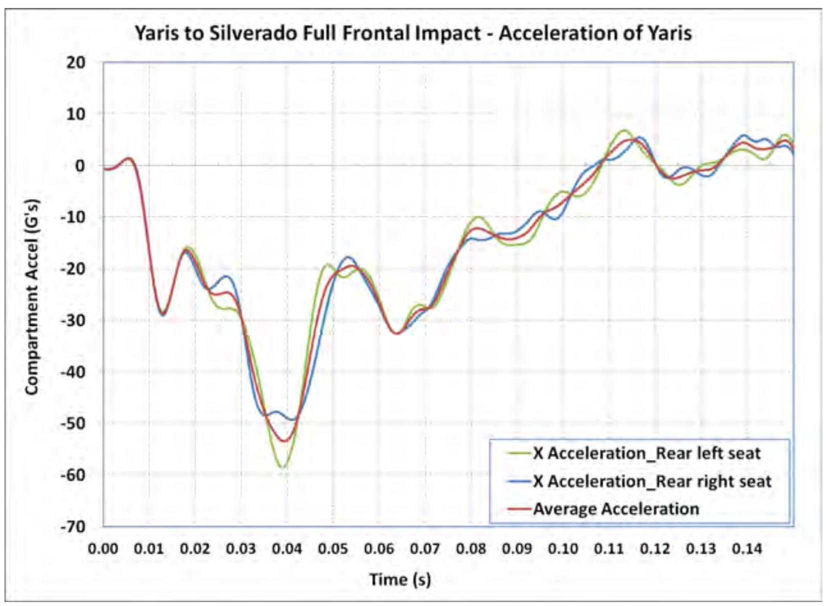


Figure 5-19 – Compartment acceleration of Yaris in full frontal impact with Silverado

5.5.3 Offset Impact Into Silverado

The Yaris model was run into the Silverado model at 35 mph with a 40 percent overlap. This simulation ran to completion with no errors, showing the robustness of the Yaris FE model. The deformation of the Yaris is shown in Figure 5-20 and the vehicle pulse is shown in Figure 5-21. The acceleration of the left rear seat was greater than that of the right rear seat, as expected in an offset crash on the driver side.

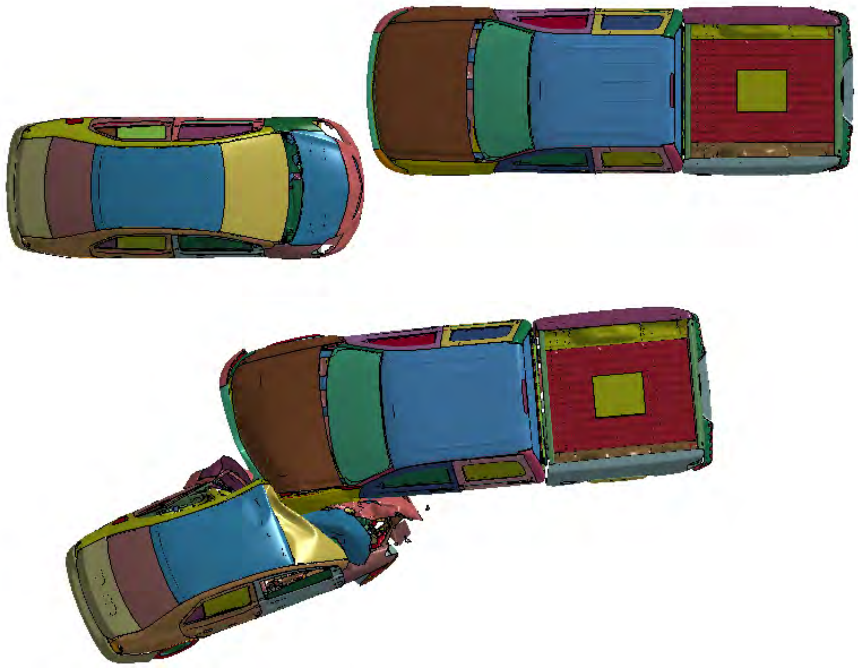


Figure 5-20 – Pre- and post-crash images of the Yaris striking the Silverado with 40 percent overlap

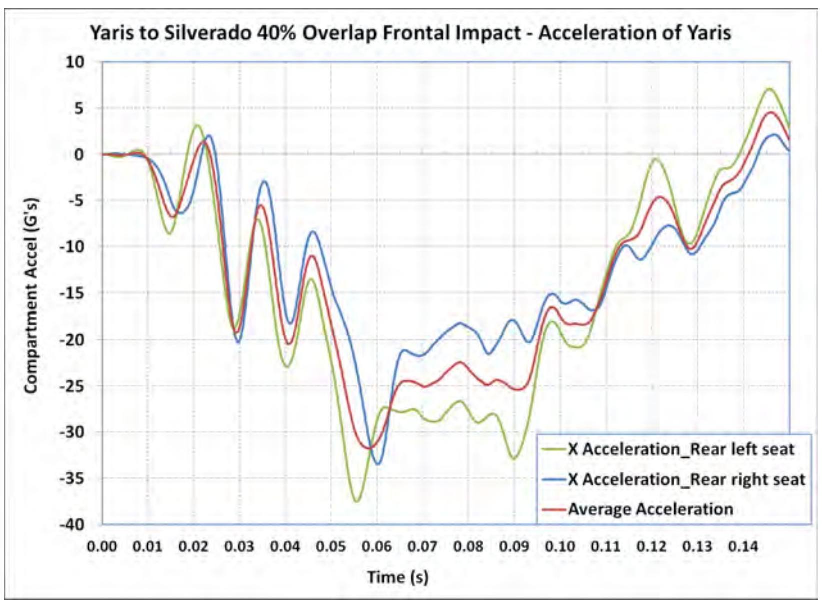


Figure 5-21 – Compartment acceleration of Yaris in 40 percent offset impact with Silverado

5.6 Varying Speed Trend Analysis

Additional simulations were run with the Toyota Yaris FE model to verify that the model would show consistent deformations for rigid wall, offset deformable barrier, and centerline pole impacts at varying speeds. The results were compared between low and high speeds within the same crash configuration to confirm that the vehicle responses were valid in the physical realm.

5.6.1 NCAP Rigid Wall

The NCAP rigid wall simulation was run at 25 mph and 35 mph. The pre- and post-crash images and resulting compartment accelerations are shown in Figure 5-22 and Figure 5-23. These runs verified that the higher speed impact yielded a more severe crash pulse than the lower speed impact.

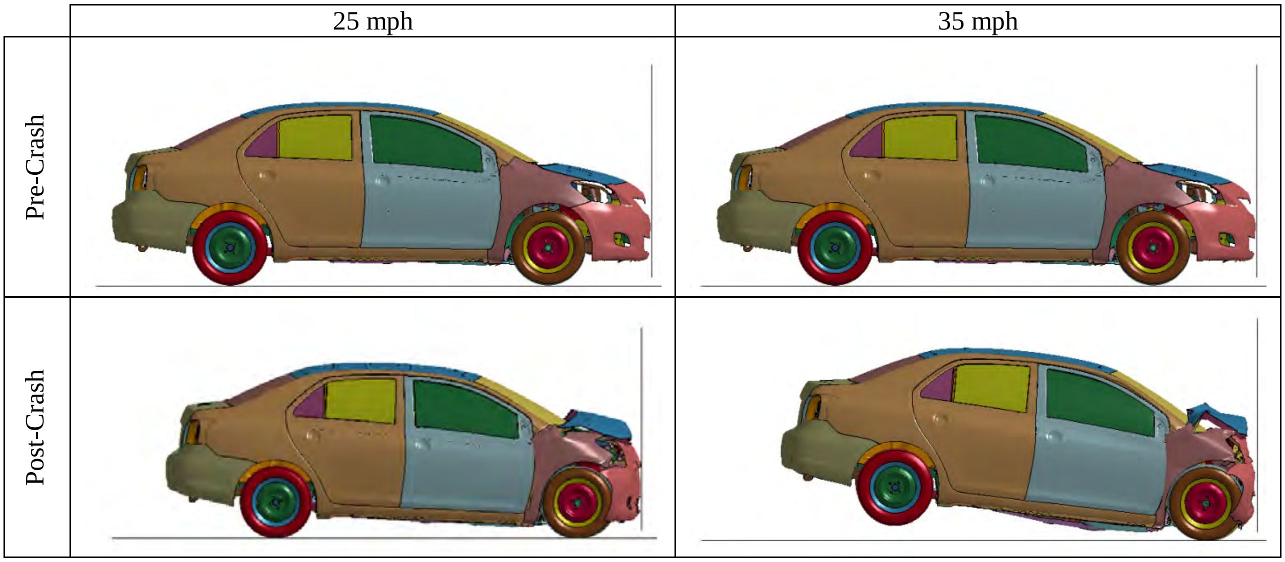


Figure 5-22 – Pre- and post-crash images of the Yaris for the full frontal impact at 25 mph and 35 mph

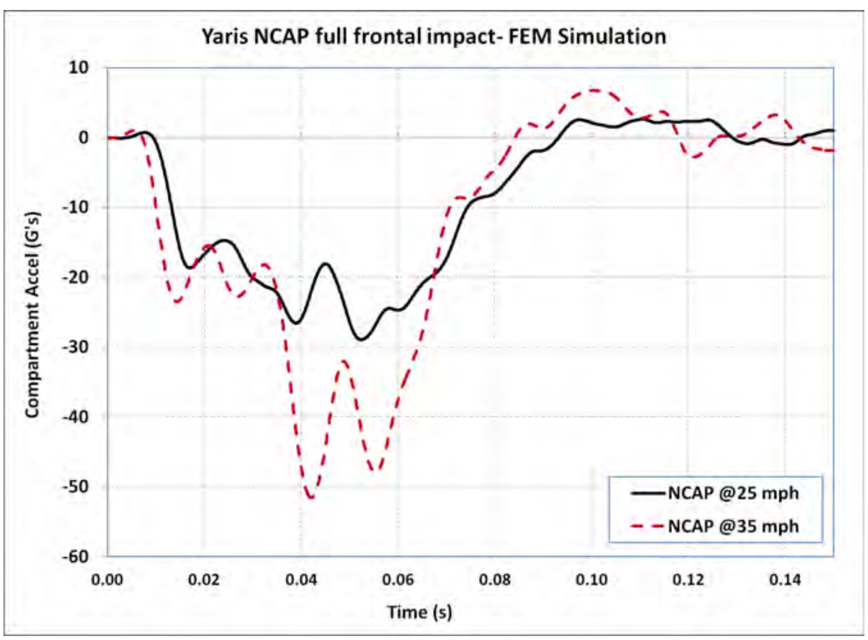


Figure 5-23 – Yaris compartment accelerations for NCAP frontal verification simulations

5.6.2 IIHS Offset Deformable Barrier

The IIHS ODB simulation was run at 25 mph and 40 mph. The pre- and post-crash images and resulting CG and left rear accelerometer outputs are shown in Figure 5-24 and Figure 5-25. These runs verified that the higher speed impact yielded higher compartment accelerations than the lower speed impact.

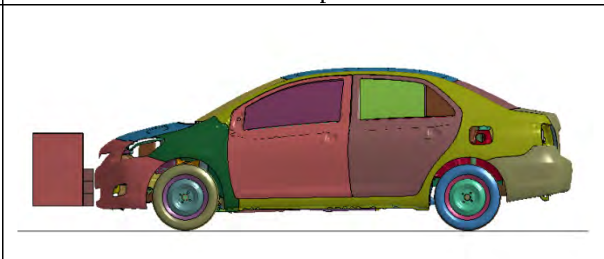
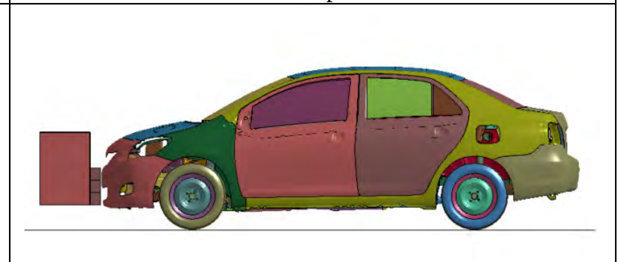
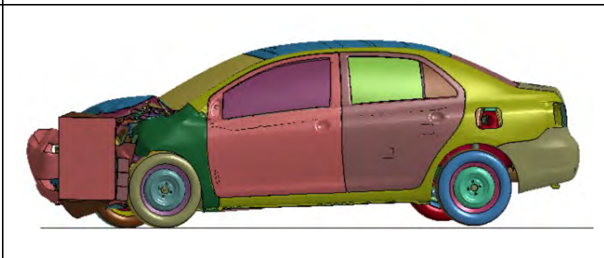
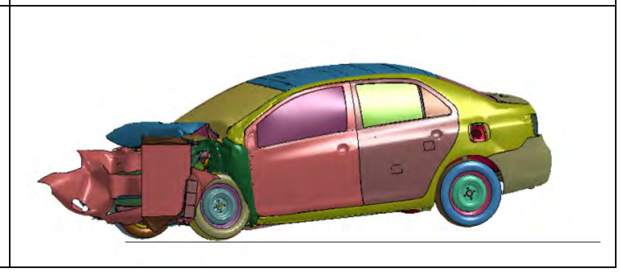
	25 mph	40 mph
Pre-Crash		
Post-Crash		

Figure 5-24 – Pre- and post-crash images of the Yaris for the IIHS ODB impact at 25 mph and 40 mph

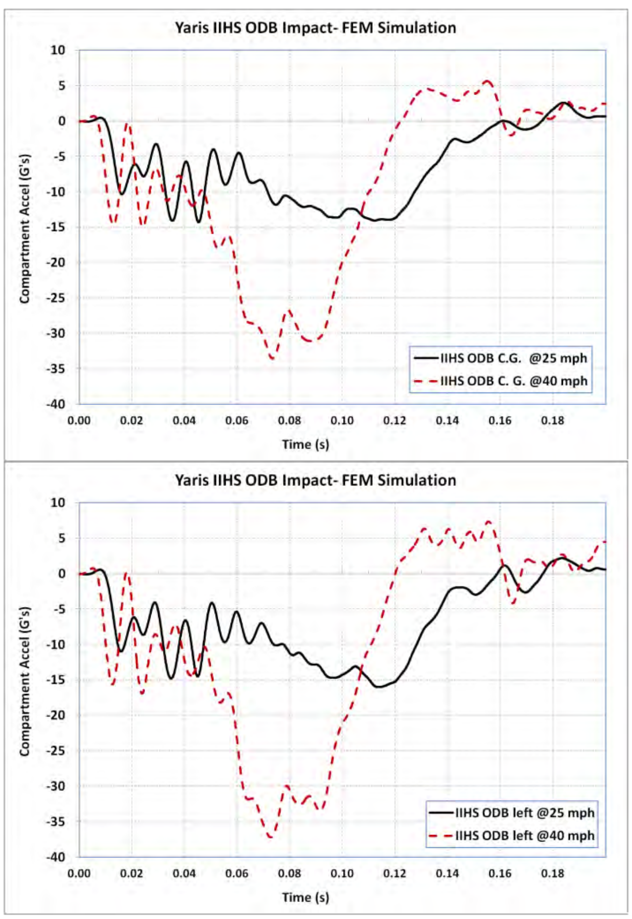


Figure 5-25 – Yaris CG (left) and left rear (right) accelerometer outputs for IIHS ODB verification simulations

5.6.3 Centerline Pole

The centerline pole simulation was run at 25 mph and 35 mph. The pre- and post-crash images and resulting compartment accelerations are shown in Figure 5-26 and Figure 5-27. These runs verified that the higher speed impact yielded a more severe crash pulse than the lower speed impact.

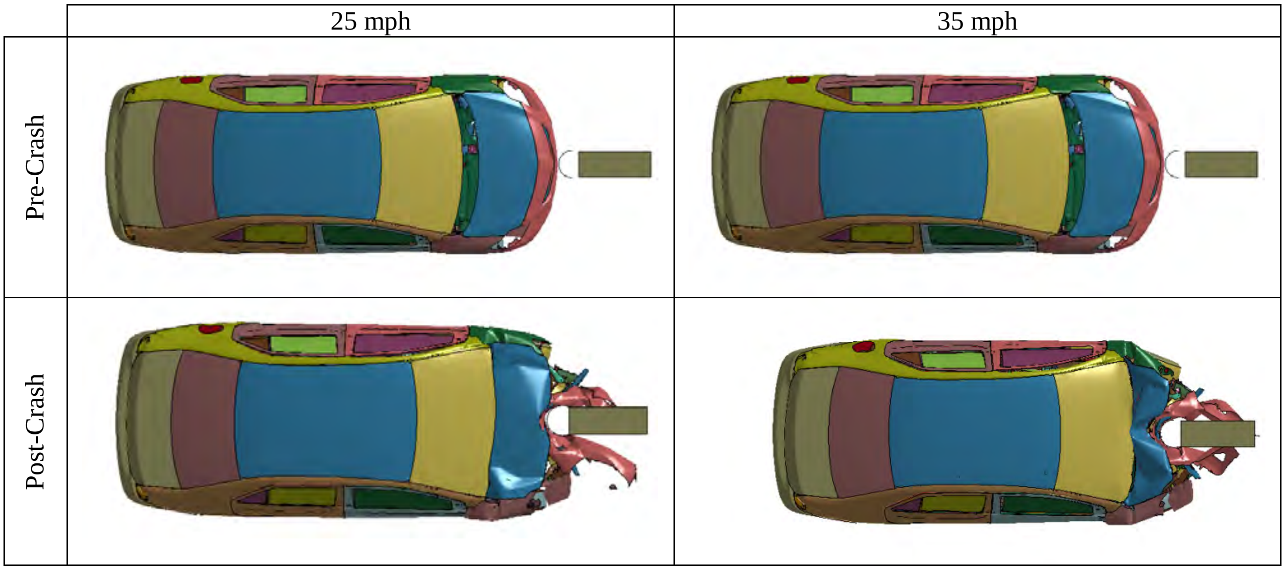


Figure 5-26 – Pre- and post-crash images of the Yaris for the centerline pole impact at 25 mph and 35 mph

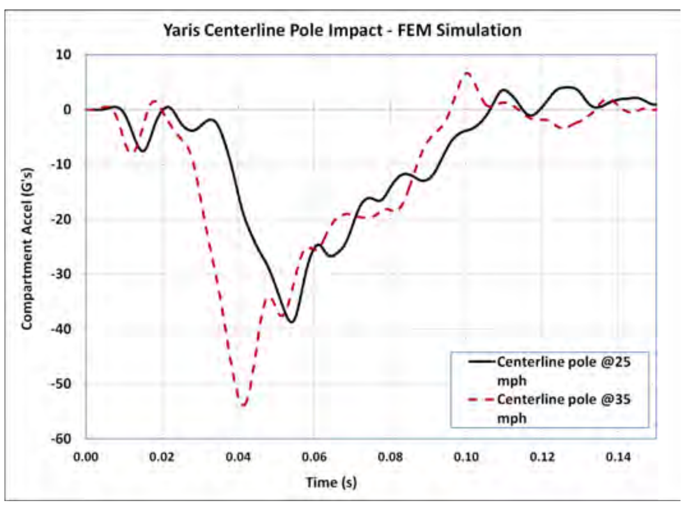


Figure 5-27 – Yaris compartment accelerations for centerline pole verification tests

5.7 Summary and Conclusions

A finite element model of the 2010 Toyota Yaris passenger sedan was created using a reverse engineering process by the NCAC under contract to the FHWA. This vehicle was modeled to support current and future NHTSA and FHWA research efforts. The modeling effort led to a detailed model that:

- Consisted of 1,514,068 elements,
- Represented the functions of the steering and suspension components,

- Included all interior door components, and
- Included partial vehicle interior components.

The model was initially validated by comparison to images and data derived from the NHTSA NCAP tests, which involved frontal impact into a rigid wall at 35 mph. Comparisons of data from the tests and the model included:

- View of side deformations,
- Acceleration and velocity changes for the rear seat cross member,
- Accelerations of the top and bottom of the engine,
- Total forces over time, and
- Force displacement plots.

Vehicle kinematics and the accelerometer output data were compared and the simulation results showed overall good correlation with the physical test results.

Extended validation efforts continued with comparisons to data from other full frontal wall and offset deformable barrier impacts. The simulation results compared well to data from these tests, further demonstrating the validity of the Yaris model. Finally, model robustness was demonstrated by additional simulations of centerline pole impacts, full frontal and offset impacts into a Chevrolet Silverado, and damage comparisons for impacts at varying speeds. The simulations executed without error in these runs and the results reflected the expected responses and consistency with varying parameters. The robustness study confirmed that the model was stable under several different crash configurations and speeds, including those where severe vehicle deformation occurs.

This model development process has proven the FE model of the Toyota Yaris to be robust and applicable for the study of a variety of crash scenarios.

5.8 Acknowledgements

The authors wish to acknowledge the Federal Highway Administration and National Highway Traffic Safety Administration of the U.S. Department of Transportation for supporting these modeling and simulation efforts.

5.9 References

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2. NCAC, "Development and Validation of a Finite Element Model for a 2010 Toyota Yaris Sedan" NCAC 2011-T-001, prepared for FHWA, Dec 2011.
3. MGA Research Corporation, "Final Report of New Car Assessment Program Testing of a 2007 Toyota Yaris," NHTSA Test No. 5677, June 2006.
4. MGA Research Corporation, "Final Report of a New Car Assessment Program Testing of a 2008 Toyota Yaris 3-Door Liftback," NHTSA Test No. 6221, November 2007.
5. Ray, M.L., et al; "Guidelines for Verification and Validation of Crash Simulations Used in Roadside Safety Applications," Report from NCHRP Project 22-24, TRB, Washington, DC, 2010.

6. MGA Research Corporation, “Final Report of FMVSS 208 Compliance Testing of a 2007 Toyota Yaris,” NHTSA Test No. 6069, August 2007.
7. Insurance Institute for Highway Safety, “Crash Test Report: 2007 Toyota Yaris,” IIHS Test CEF0610, December 2006.

6 APPENDIX 6: DEVELOPMENT AND VALIDATION OF A 2001 FORD TAURUS MADYMO FRONTAL OCCUPANT MODEL

6.1 Introduction

A frontal MADYMO model of a driver in a 2001 Ford Taurus was developed by the National Crash Analysis Center of the George Washington University in support of the NHTSA study, “Investigate Self and Partner Protection of New Vehicle Designs Using Structural Modeling,” TOPR No. 16 under DTFH61-09-D-00001. For this study, several different vehicle finite element (FE) models were developed, including the 2001 Ford Taurus, and run under different crash configurations in single vehicle and two vehicle crashes. The data from these FE models were used as inputs for the frontal MADYMO models that were developed to assess occupant injury risk.

To develop the MADYMO models, the NCAC obtained generic occupant models from restraint manufacturers, upon which the specific vehicle models would be built. For the 2001 Ford Taurus, a generic model year (MY) 2011 small car was used as a foundation. This foundation model was modified to reflect data and measurements from the crash test report in order to make it more representative of a Ford Taurus.

The Taurus occupant simulations were first validated against frontal crash test data. Then, the simulations were run in the same crash tests configurations, but using the pulses output by the LS-DYNA FE simulations. This check was performed to ensure that reasonable occupant responses would be observed once the FE simulation outputs were used in the occupant models. Lastly, the occupant model was run under several different crash configurations to confirm the stability and robustness of the model and to verify that reasonable occupant response trends would be observed. This paper serves as documentation of the above model development and validation processes.

6.2 Model Development

The first step in modifying the generic small car model was to set up the interior based on the available surface geometry from the FE model. The position of the seat and steering wheel were adjusted to conform to what would be found in the actual vehicle. Finite element representations of the toe pan and footrest were imported from the LS-DYNA model, allowing for the use of prescribed structural motion to capture the vehicle intrusion.

In addition to the generic vehicle environment, the NCAC also obtained the knee bolster stiffness functions and frontal interior plane geometry for the MY 2004 Taurus directly from Ford (Figure 6-1). These were used to further tailor the model to the Taurus geometry and characteristics. The contact characteristics for the knee bolster were especially important, as these would allow for more accurate femur loading in the occupant model.

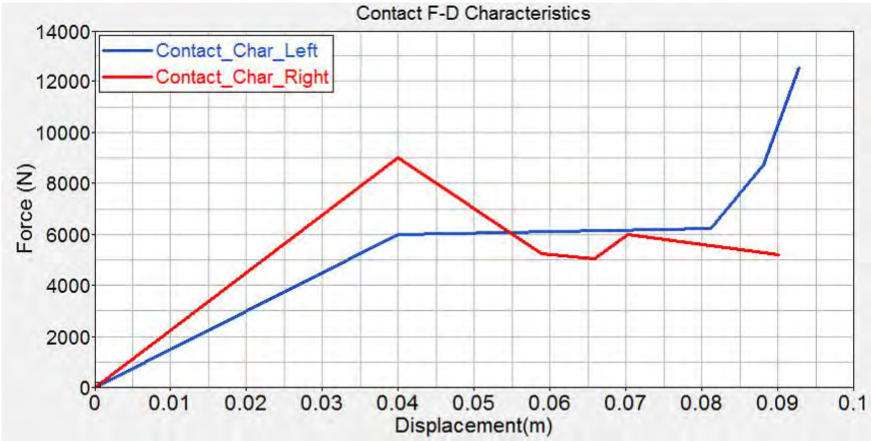

Figure 6-1 – Taurus knee bolster contact characteristic (supplied by Ford)

Next, dummy was positioned according to available test reports. The dummy positions for the 50th percentile male and 5th percentile female were based on NHTSA test nos. 4135 and 5143, respectively [1,2]. Measurements such as the seat back angle (degree), head to windshield (mm), nose to rim (mm), chest to dash (mm), steering wheel to chest (mm), rim to abdomen (mm), left knee to dash (mm), right knee to dash (mm), tibia angle (degree), and knee to knee (mm) were considered in positioning the dummies. The dummies were positioned to match as many of these measurements as possible (Figure 6-2). The model was also subject to visual inspection to ensure that the final position was physically reasonable.

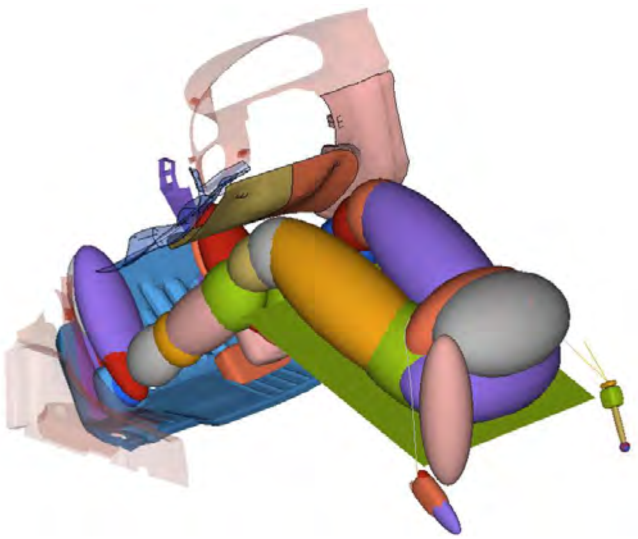

Figure 6-2 – Lower extremity positioning of the 50th percentile dummy in the Taurus occupant model

The final positions of the 50th percentile dummy and 5th percentile dummy are shown in Figure 9-1.

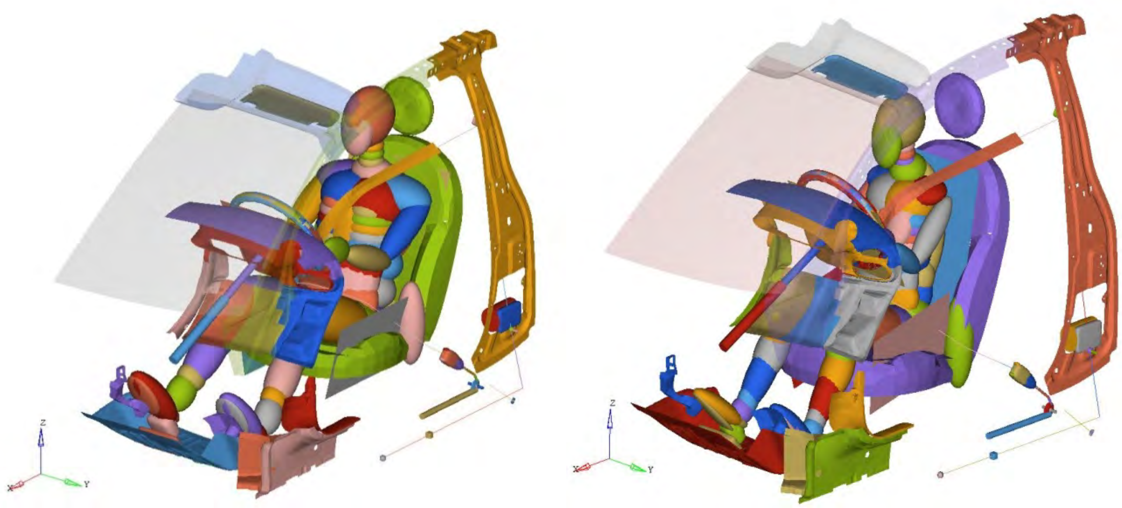

Figure 6-3 – Final position of 50th percentile (left) and 5th percentile (right) dummies in Taurus model

In addition to proper positioning, it was also important to effectively couple the dummy to the vehicle interior, specifically in the interaction of the foot with the footrest and floor. In the Taurus occupant model, the foot was not well-coupled to the floor, causing the heel to elastically bounce off the floor upon impact. To achieve tighter coupling of the foot to the floor, a "foot stop" was added to the floor, acting as a heel rest for the right foot (Figure 6-4). The addition of this foot stop allowed for more realistic lower extremity kinematics and closer correlation to test data.

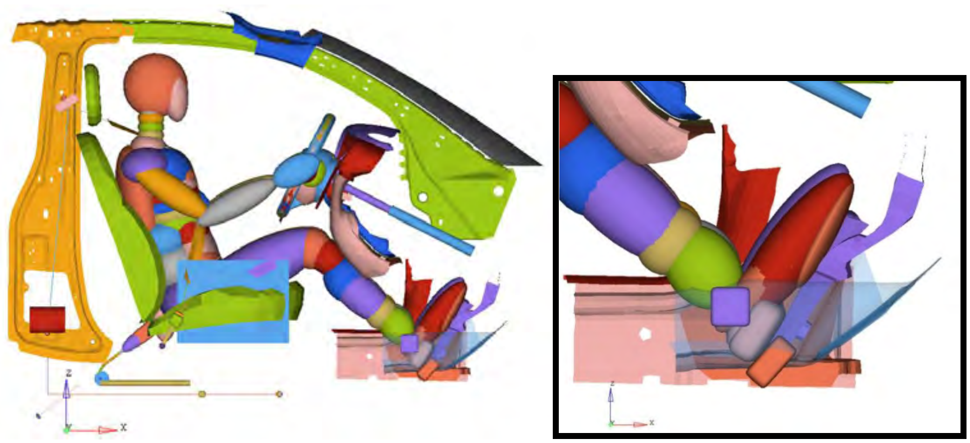

Figure 6-4 – Addition of Foot Stop to Taurus Occupant Model

The shoulder belt loads from the crash test data were analyzed to determine the air bag and pretensioner firing time, as shown in Figure 6-5. For NHTSA test no. 4135, the firing time was observed to be 24 ms.

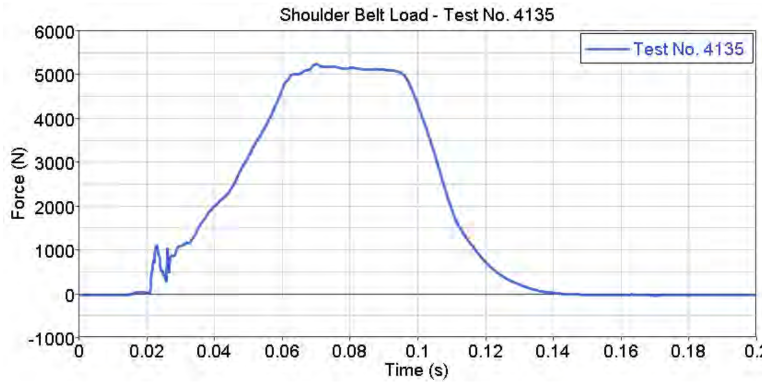

Figure 6-5 – Shoulder belt force for NHTSA test no. 4135

The firing time for this specific case was then used to determine a firing time rule that would be applicable to all crash speeds. The general guideline is for the "5-30" rule, i.e. 30 msec prior to 5" free motion travel of the occupant. The crash data was checked to verify that this vehicle conformed to the general guideline. The crash pulse from the test was double integrated to give the displacement time history, as shown in Figure 9-3. Five inches of displacement were observed at 54 ms, which confirmed that the 24 ms firing time matched the established "5-30" rule. For all simulations that were run in this study, the firing time was determined with this rule—30 ms less than the time at which 5 inches of displacement were observed.

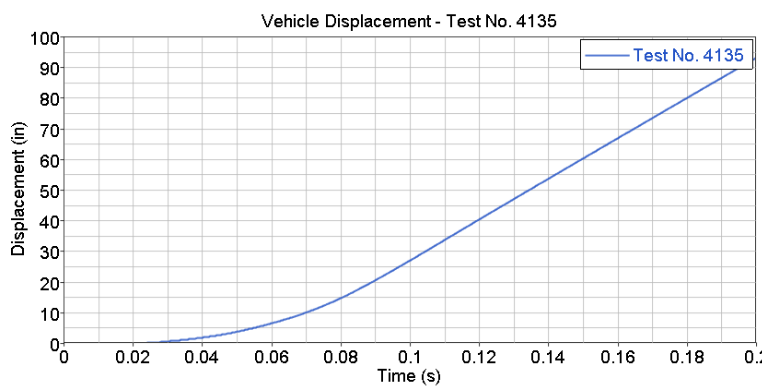

Figure 6-6 – Vehicle displacement time history for NHTSA test no. 4135

The restraint system was fine-tuned through an iterative process until the model output the expected occupant accelerations according to the crash test data. Through this process, the air bag vent size and pretensioner pull function were modified. In the generic model, the air bag vent size was 25 mm. However, in order to reduce the HIC numbers to match the test results, the vent size was increased to 30 mm, which softened the air bag.

The characteristics of the belt system were determined by the shoulder belt load data from the crash test. The pretensioner was located at the outboard side in the generic model, but this was moved to the inboard side for the Taurus model. The pretensioner pull function was adjusted in increments of 5 mm from 25 mm to 65 mm to determine the appropriate amount of pretensioning. The final pull function used in the model is shown in Figure 6-7.

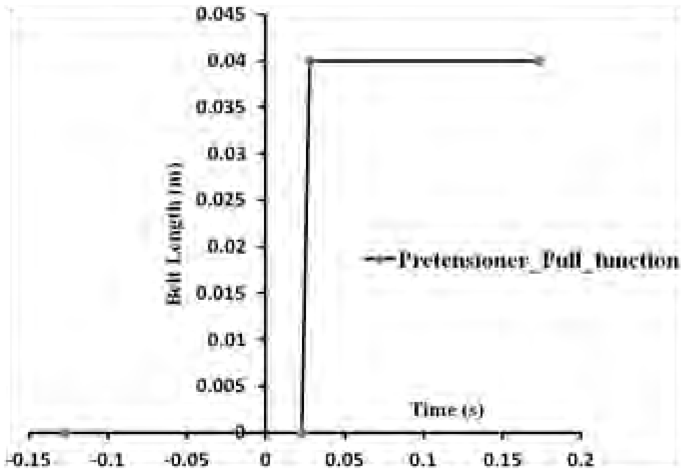

Figure 6-7 – Taurus pretensioner pull function

Lastly, the belt load data from the test showed that there was a load limiter at the shoulder belt. This was added, with load limiting set at 5000 N.

6.3 Model Validation

The Taurus occupant models with the 50th percentile male dummy and 5th percentile female dummy were validated against available full frontal crash data. The primary responses that were compared in this validation study are discussed in the following section.

6.3.1 Full Frontal 35 mph Validation: 50th Percentile Male Dummy

The 50th percentile occupant model seated in the Taurus was validated against NHTSA test no. 4776 [3]. Two simulations were run—one using the crash test pulse and one using the FE pulse from the LS-DYNA full vehicle simulation. The difference between the crash test pulse and the FE pulse is shown in Figure 9-5. The differences in the vehicle pulse led to a slight firing time discrepancy, causing the occupant responses in the FE pulse simulations to be delayed compared to the occupant responses in the test pulse simulations.

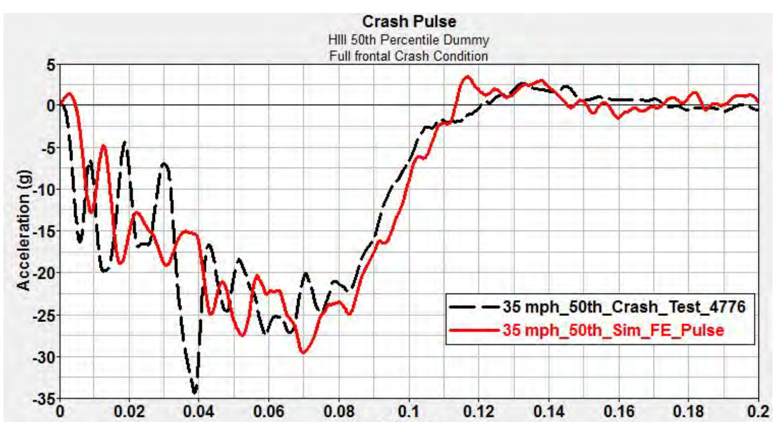

Figure 6-8 – Vehicle pulse comparison between test no. 4776 and FE simulation output

The shoulder belt loads for this test were not available, so only the lap belt forces were compared between the test and simulations (Figure 6-9).

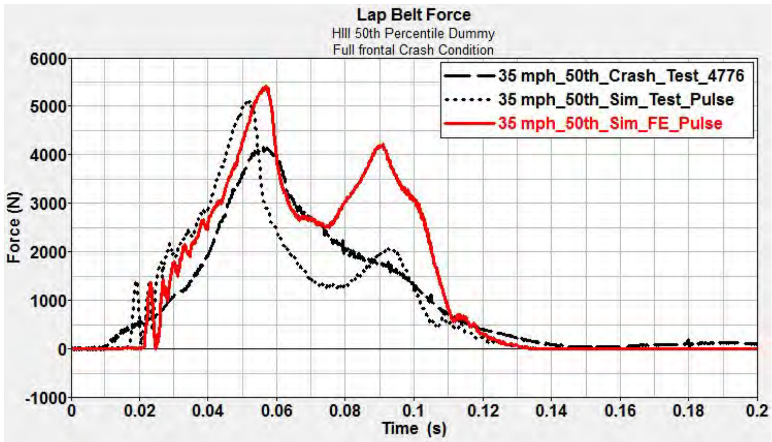

Figure 6-9 – Comparison of lap belt force from test and simulations for 35 mph full frontal impact

All of the outputs for the dummy model were compared to the available crash test data. However, only the chest deflection (Figure 9-7), head acceleration (Figure 9-8), neck tension (Figure 9-9), and femur forces (Figure 9-10) will be shown below, as these were the body regions of interest in the overall study.

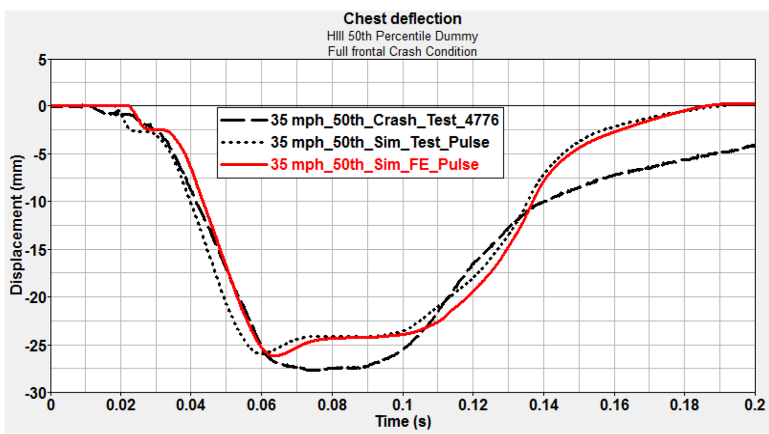

Figure 6-10 – Comparison of chest deflection from test and simulations for 35 mph full frontal impact

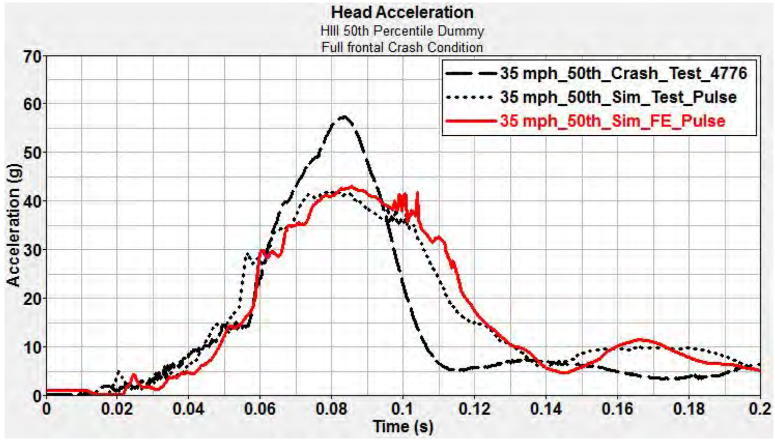

Figure 6-11 – Comparison of head acceleration from test and simulations for 35 mph full frontal impact

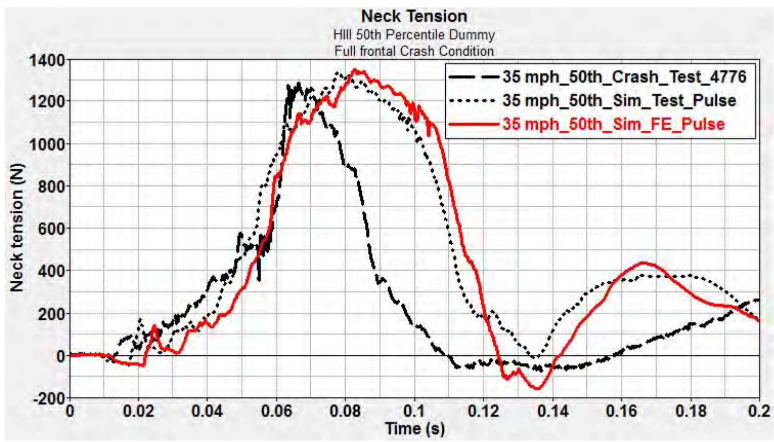

Figure 6-12 – Comparison of neck tension from test and simulations for 35 mph full frontal impact

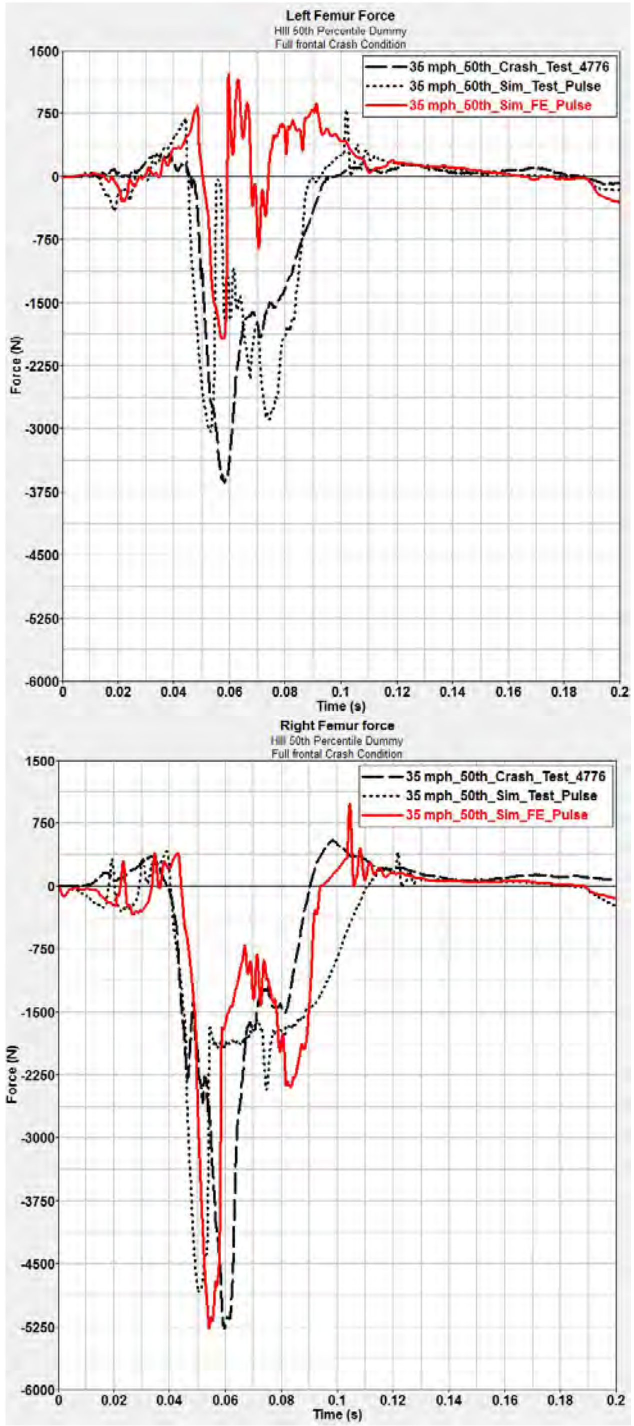

Figure 6-13 – Comparison of left and right femur forces from test and simulations for 35 mph full frontal impact

6.3.2 Full Frontal 30 mph Validation: 50th Percentile Male Dummy

The 50th percentile dummy model seated in the Taurus was also validated against NHTSA test no. 4135, a full frontal impact into a rigid barrier at 30 mph [1]. Three simulations were run for this crash configuration, one at 30 mph using the test pulse, one at 30 mph using the FE pulse, and one at 25 mph using the FE pulse (Figure 6-14). The 25 mph simulation was run to verify that the response was trending as expected, i.e., that the 25 mph impact would yield lower dummy responses than the 30 mph impact.

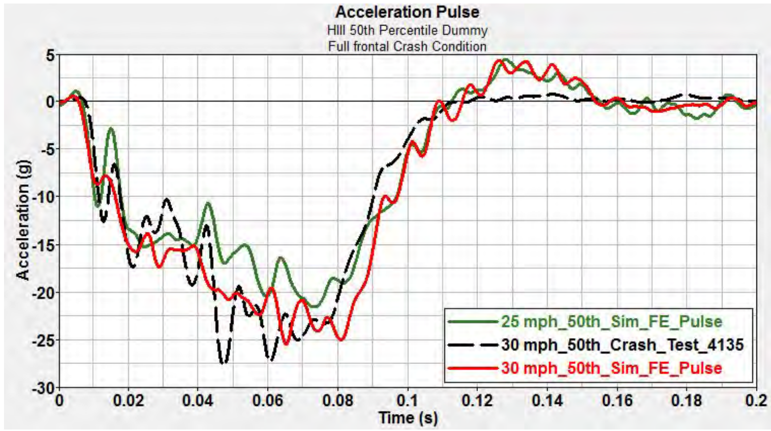

Figure 6-14 – Comparison of vehicle pulse from test and simulations for 30 mph full frontal impact

Both lap belt and shoulder belt data were available for comparison. Figure 6-15 shows that there was good correlation between the shoulder belt forces of the crash test versus the simulations. The addition of the load limiter in the simulation was crucial in matching the shoulder belt data and in getting occupant responses closer to the test.

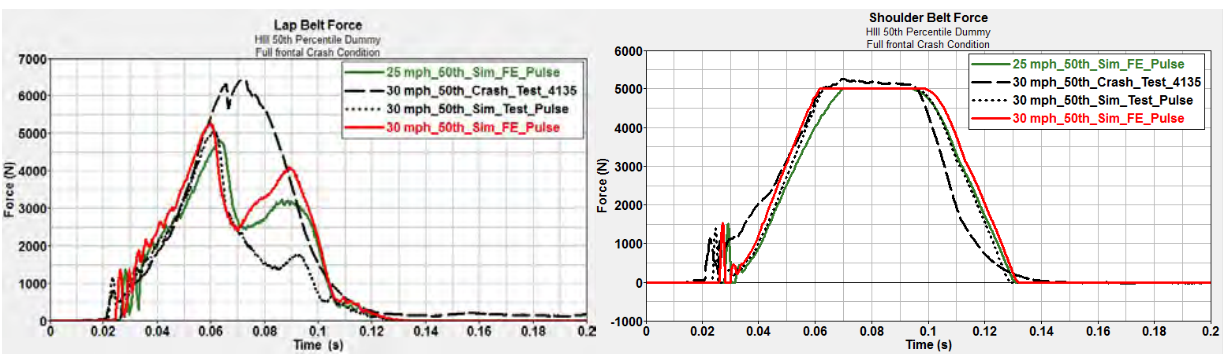

Figure 6-15 – Comparison of lap and shoulder belt forces from test and simulations for 30 mph full frontal impact

The chest deflection (Figure 6-16), head acceleration (Figure 6-17), neck tension (Figure 6-18), and femur loads (Figure 6-19) were also compared between the test and simulations, showing a reasonable match.

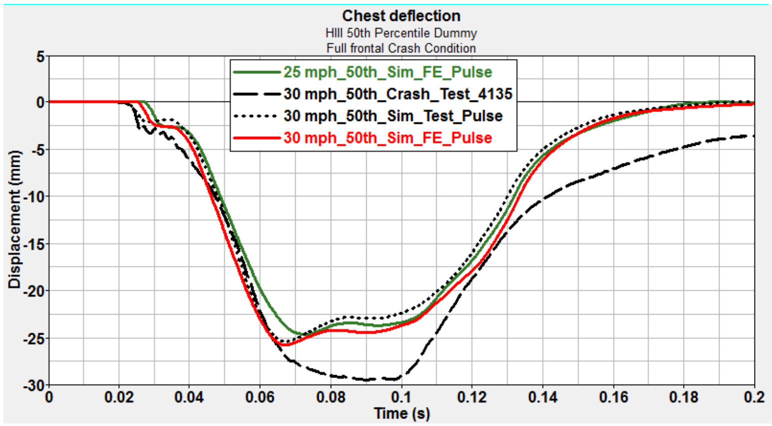

Figure 6-16 – Comparison of chest deflection from test and simulations for 30 mph full frontal impact

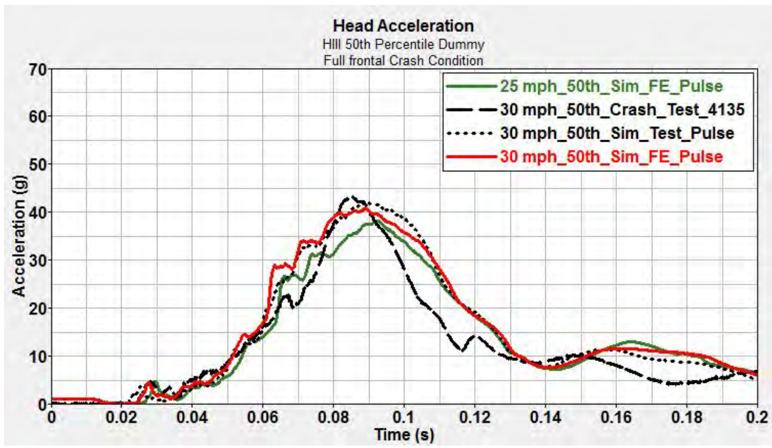

Figure 6-17 – Comparison of head acceleration from test and simulations for 30 mph full frontal impact

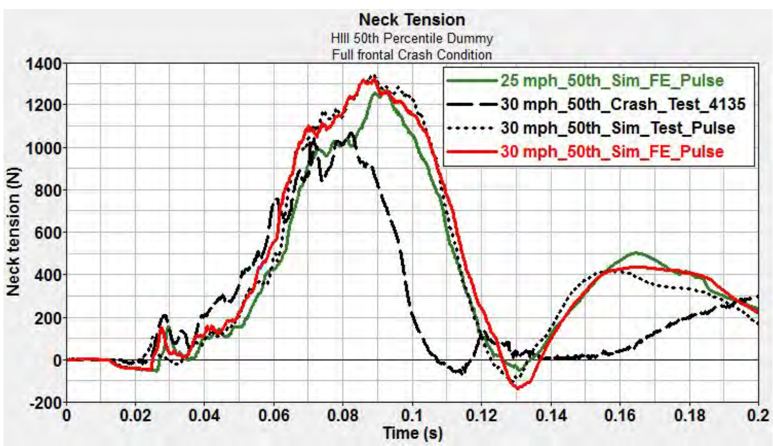

Figure 6-18 – Comparison of neck tension from test and simulations for 30 mph full frontal impact

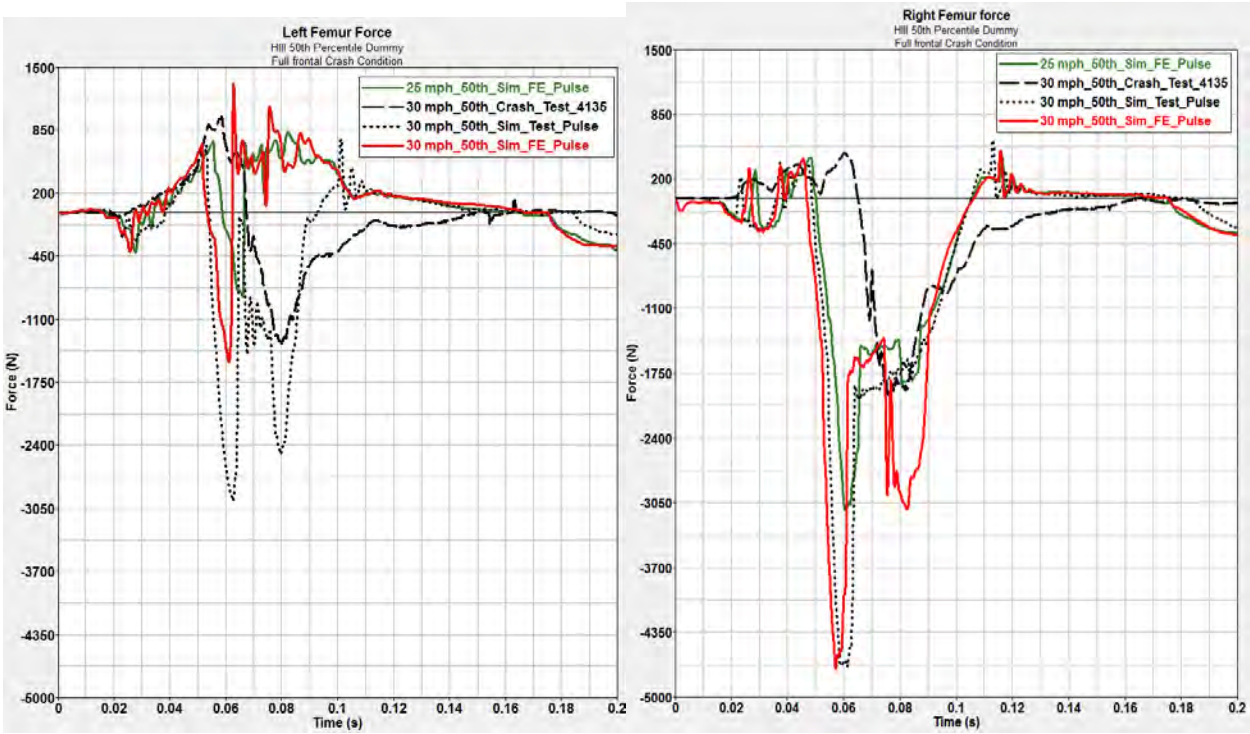

Figure 6-19 – Comparison of left and right femur forces from test and simulations for 30 mph full frontal impact

6.3.3 Offset Frontal 40 mph Validation: 50th Percentile Male Dummy

The 50th percentile male dummy model seated in the Taurus was validated against IIHS test no. CF00010, an offset frontal impact with a deformable barrier at 40 mph [4]. Two simulations were run—one with the test pulse and one with the FE pulse output from the LS-DYNA full vehicle simulation. A comparison of the crash test pulse and FE pulse is shown in Figure 9-16. For the offset crash configuration, all three linear accelerations were used to propel the vehicle in order to account for the yaw and pitch seen in the PSM of the toe pan and footrest.

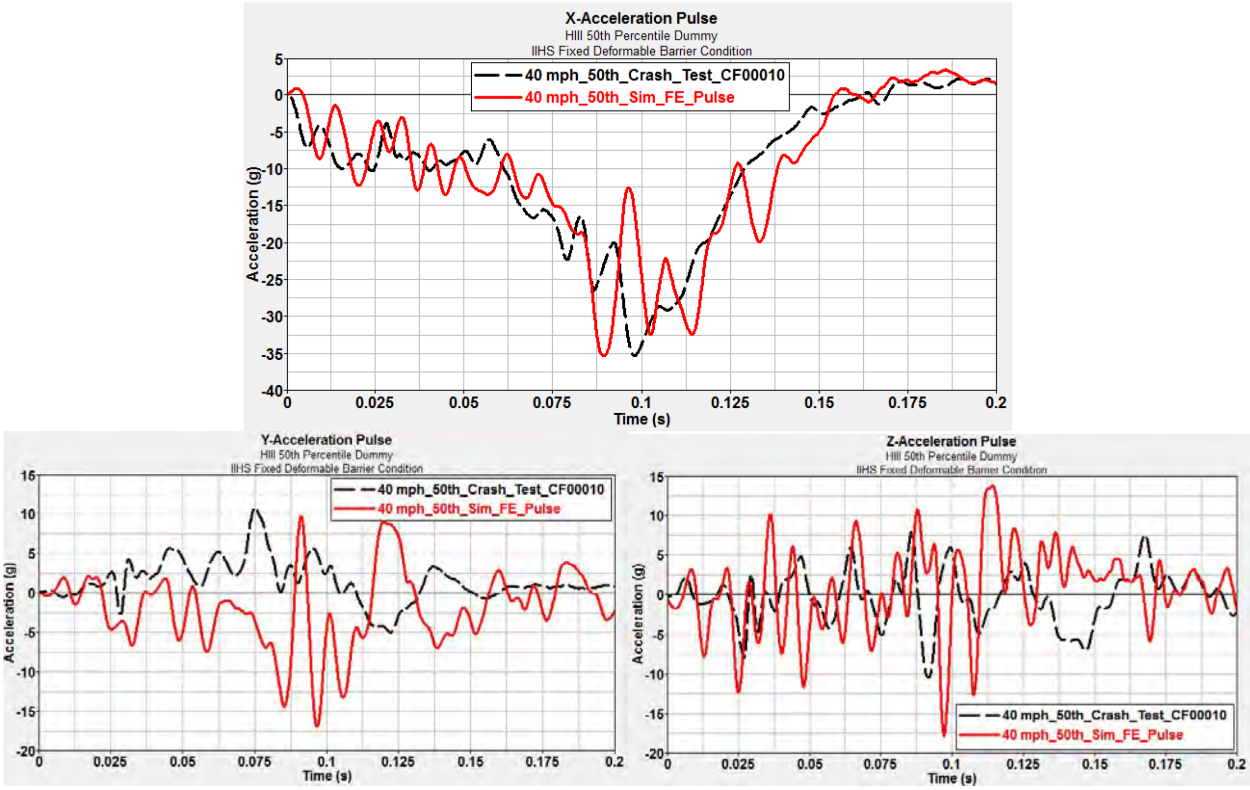

Figure 6-20 – Comparison of X, Y, and Z vehicle acceleration from test and simulation for 40 mph offset frontal impact

No belt data were available for this test. The chest deflection (Figure 9-17), head acceleration (Figure 9-18), neck tension (Figure 9-19), and femur forces (Figure 9-20) were compared between the test and simulations, showing reasonable correlation.

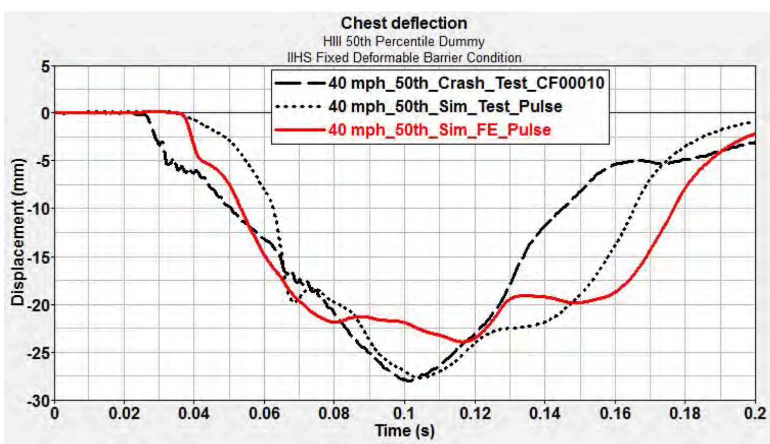

Figure 6-21 – Comparison of chest deflection from test and simulations for 40 mph offset frontal impact

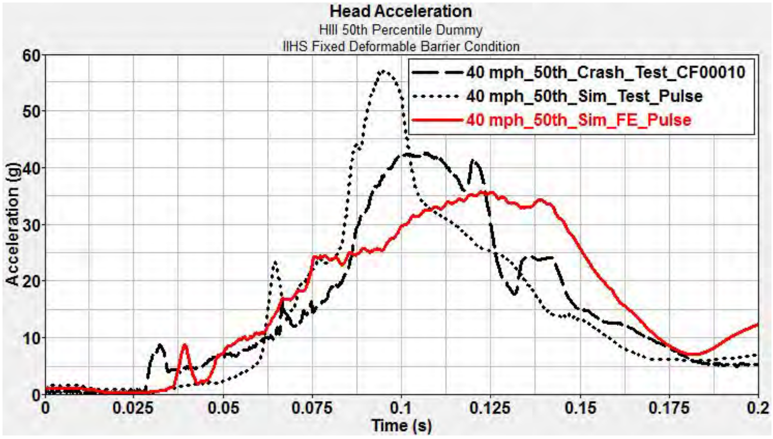

Figure 6-22 – Comparison of head acceleration from test and simulations for 40 mph offset frontal impact

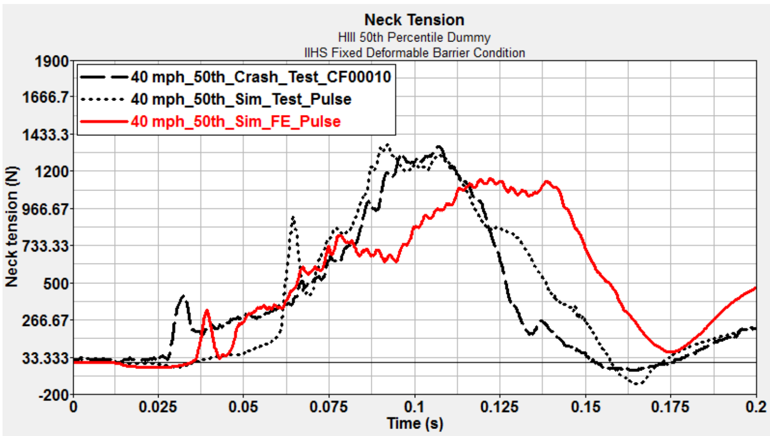

Figure 6-23 – Comparison of neck tension from test and simulations for 40 mph offset frontal impact

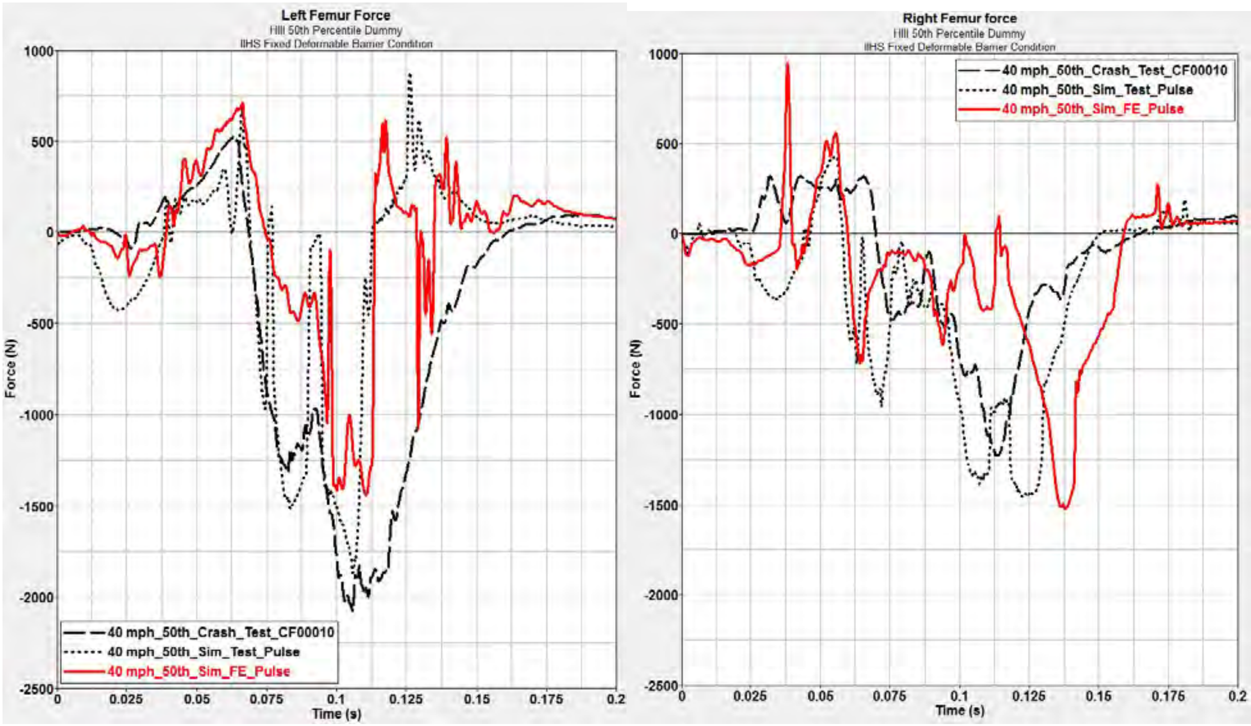

Figure 6-24 – Comparison of left and right femur forces from test and simulations for 40 mph offset frontal impact

6.3.4 Full Frontal 35 mph Validation: 5th Percentile Female Dummy

The 5th percentile female dummy model seated in the Taurus was validated against NHTSA test no. 5143, a full frontal impact into a rigid barrier at 35 mph [2]. Two simulations were run—one with the test pulse and one with the FE pulse output from the LS-DYNA full vehicle simulation. A comparison of the crash test pulse and FE pulse is shown in Figure 9-21. Belt load data were not available in the crash test report.

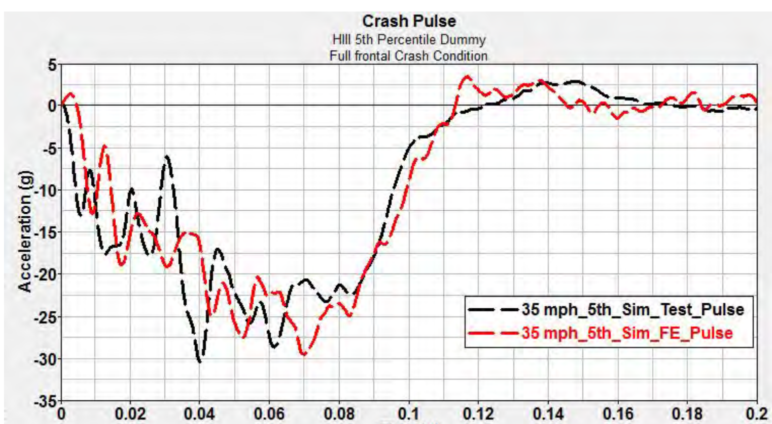

Figure 6-25 – Comparison of vehicle pulse from test and simulation for 35 mph full frontal impact

The chest deflection (Figure 9-22), head acceleration (Figure 9-23), neck tension (Figure 9-24), and femur forces (Figure 9-25) were compared between the test and simulations, showing reasonable correlation.

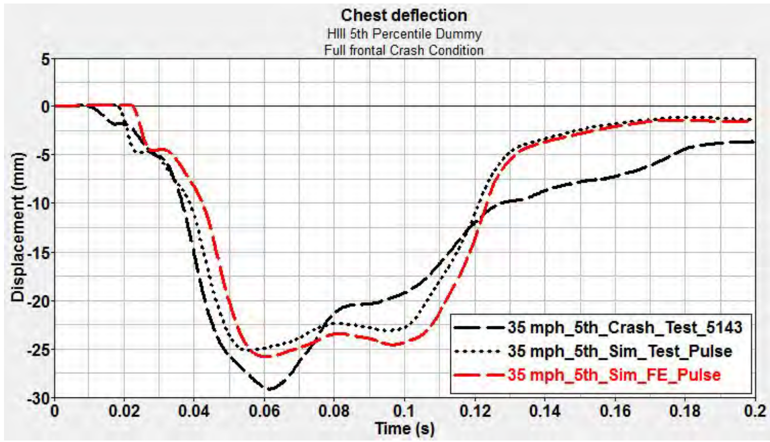

Figure 6-26 – Comparison of chest deflection from test and simulations for 35 mph full frontal impact

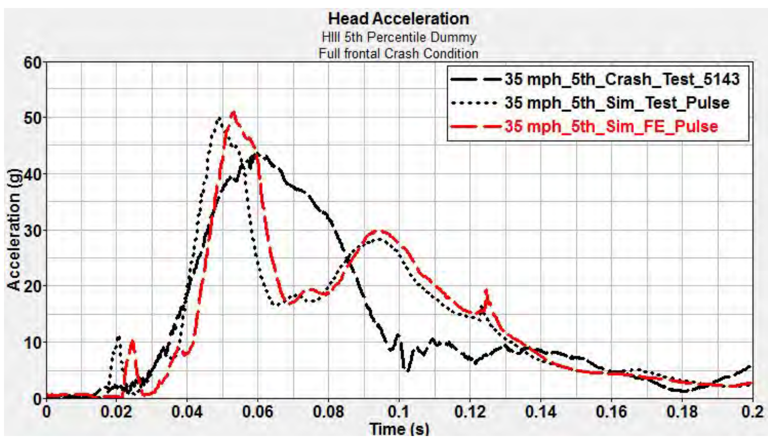

Figure 6-27 – Comparison of head acceleration from test and simulations for 35 mph full frontal impact

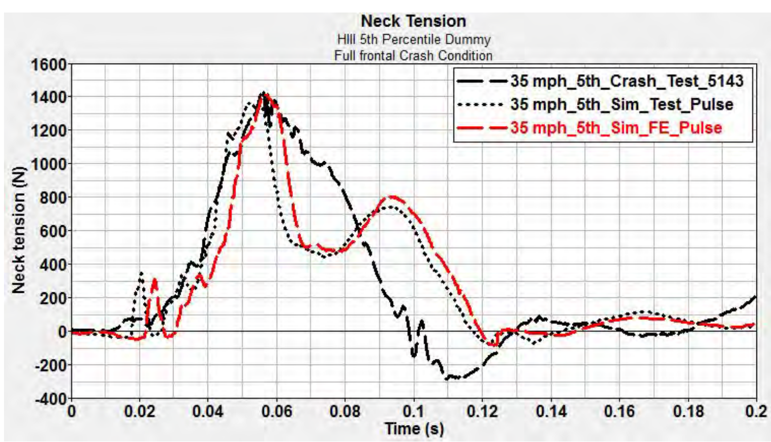

Figure 6-28 – Comparison of neck tension from test and simulations for 35 mph full frontal impact

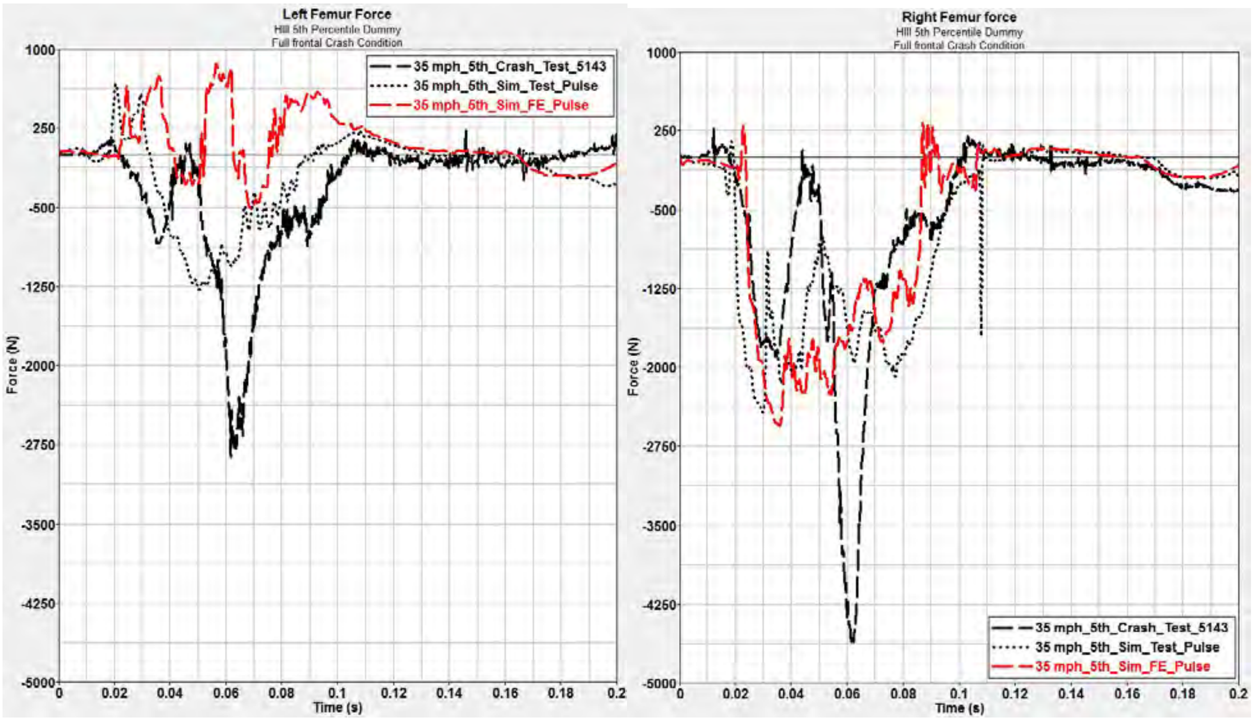

Figure 6-29 – Comparison of left and right femur forces from test and simulations for 35 mph full frontal impact

6.3.5 Full Frontal 30 mph Validation: 5th Percentile Female Dummy

The 5th percentile dummy model seated in the Taurus was also validated against NHTSA test no. 4174, a full frontal impact into a rigid barrier at 30 mph [5]. Three simulations were run for this crash configuration, one at 30 mph using the test pulse, one at 30 mph using the FE pulse, and one at 25 mph using the FE pulse (Figure 9-26). The 25 mph simulation was run to verify that the response was trending as expected, i.e., that the 25 mph impact would yield lower dummy responses than the 30 mph impact.

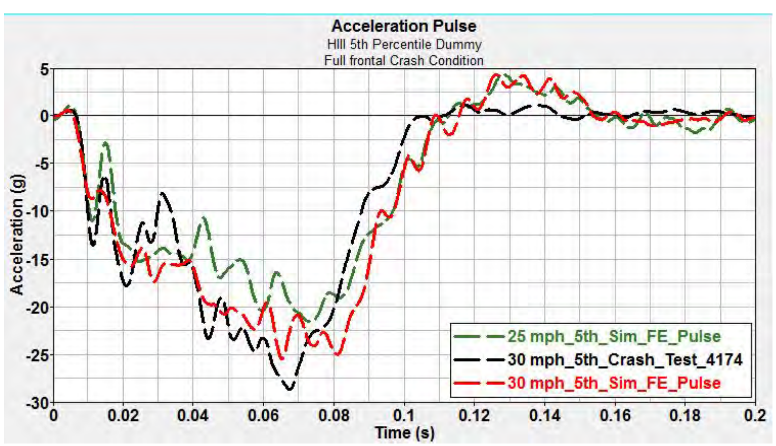

Figure 6-30 – Comparison of vehicle pulse from test and simulations for 30 mph full frontal impact

Both lap belt and shoulder belt data were available for comparison. Figure 9-27 compares the lap and shoulder belt forces of the crash test versus the simulations.

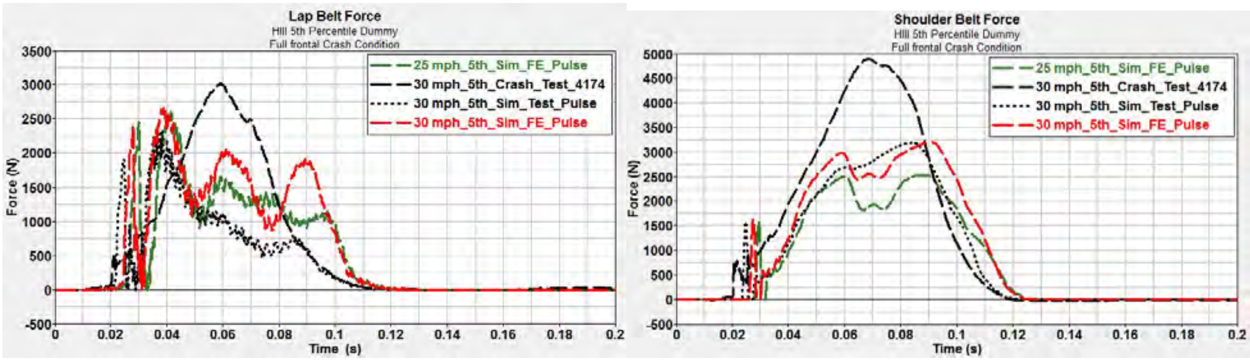

Figure 6-31 – Comparison of lap and shoulder belt forces from test and simulations for 30 mph full frontal impact

The chest deflection (Figure 9-28), head acceleration (Figure 9-29), neck tension (Figure 9-30), and femur loads (Figure 9-31) were also compared between the test and simulations, showing a reasonable match.

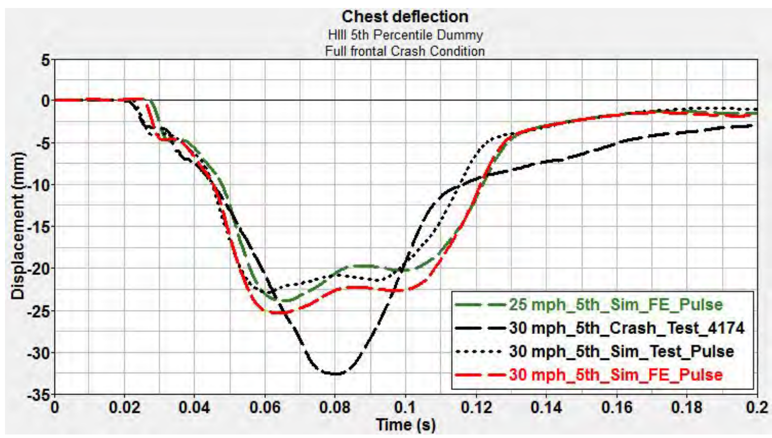

Figure 6-32 – Comparison of chest deflection from test and simulations for 30 mph full frontal impact

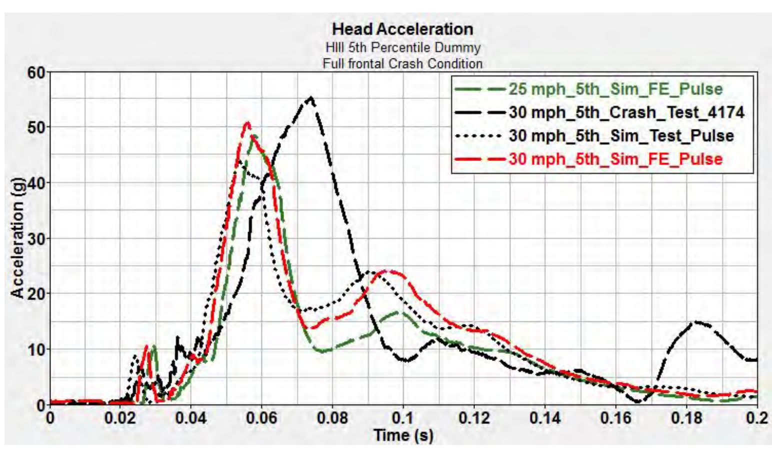

Figure 6-33 – Comparison of head acceleration from test and simulations for 30 mph full frontal impact

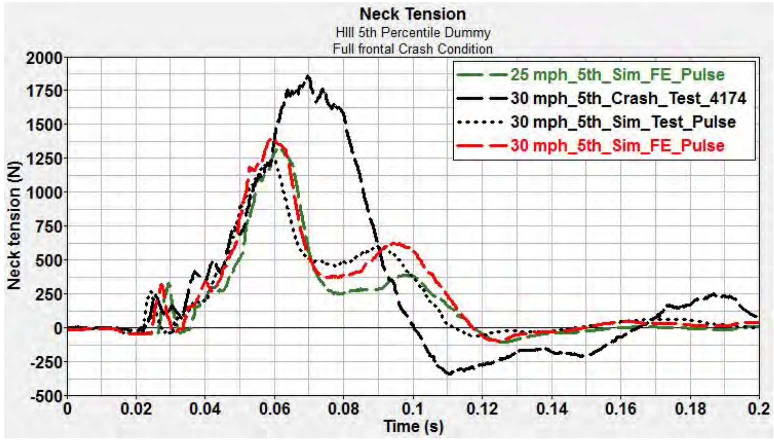

Figure 6-34 – Comparison of neck tension from test and simulations for 30 mph full frontal impact

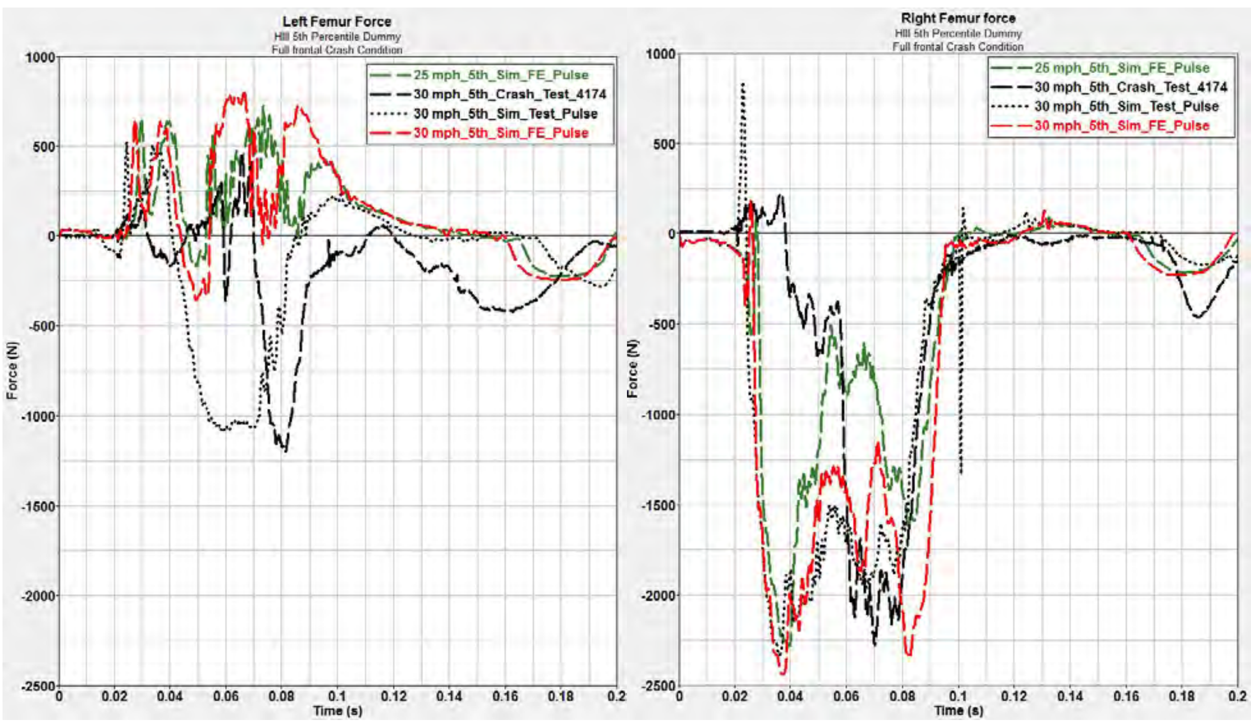

Figure 6-35 – Comparison of left and right femur forces from test and simulations for 30 mph full frontal impact

6.3.6 Validation Summary

The results from the validation study are summarized in Table 9-1 and Table 9-2 for the 50th percentile dummy and in Table 9-3 for the 5th percentile dummy.

Table 6-1 – 50th percentilepercentile dummy full frontal validation results

	H350/50th	NHTSA 25 mph 50th FE_pulse	NHTSA 30 mph 50th, Test#4135	NHTSA 30 mph 50th, Test_pulse	NHTSA 30 mph 50th, FE_pulse	NHTSA 35 mph 50th, Test#4776	NHTSA 35 mph 50th, Test_pulse	NHTSA 35 mph 50th FE_pulse
Response	**Formula**	**Simulation FE pulse Results**	**Crash Test Results (4135)**	**Simulation Test pulse Results**	**Simulation FE pulse Results**	**Crash Test Results (4776)**	**Simulation Test pulse Results**	**Simulation FE pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	117	154	156	145	316	159	165
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	228	226	308	294	511	327	347
neck tension (T)	**Upper Neck Fz Max**	1267	1066	1343	1321	1284	1333	1347
Chest deflection (mm)	**Max Deflection**	24	29	25	26	27.2	26	26
Chest acceleration (g)	**Max Acceleration**	35	35	41	40	42.9	41	41
Femur Load - Left (N)	**Max Compression force Fz**	871	1362	2970	1546	3640	3040	1926
Femur Load - Right (N)	**Max Compression force Fz**	3126	1980	4690	4720	5254	4846	5273
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.01%	0.05%	0.06%	0.04%	1.09%	0.06%	0.08%
chest deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	2.29%	4.17%	2.59%	2.93%	3.38%	2.93%	2.93%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	1.19%	0.61%	2.39%	2.42%	2.99%	2.55%	3.01%
neck tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.03%	0.02%	0.04%	0.04%	0.04%	0.04%	0.04%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.03	0.05	0.05	0.05	0.07	0.06	0.06

Table 6-2 – 50th percentilepercentile dummy offset frontal validation results

	H350/50th	IIHS 40 mph 50th Test	IIHS 40 mph 50th Test_pulse	IIHS 40 mph 50th FE_pulse
Response	**Formula**	**Crash Test Results (CF00010)**	**Simulation Test pulse Results**	**Simulation FE pulse Results**
HIC15	$HIC = \left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1)\right\}_{max}$	165	289	105
HIC36	$HIC = \left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1)\right\}_{max}$	338	398	236
neck tension (T)	**Upper Neck Fz Max**	1400	1368	1152
Chest deflection (mm)	**Max Deflection**	28	28	24
Chest acceleration (g)	**Max Acceleration**	43	33	30
Femur Load - Left (N)	**Max Compression force Fz**	2076	1867	1439
Femur Load - Right (N)	**Max Compression force Fz**	1230	1455	1522
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.08%	0.79%	0.01%
chest deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	3.72%	3.72%	2.20%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.65%	0.57%	0.43%
neck tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.05%	0.04%	0.03%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.04	0.05	0.03

Table 6-3 – 5th percentilepercentile dummy full frontal validation results

	H305/5th	NHTSA 25 mph 5th FE_pulse	NHTSA 30 mph 5th, Test#4174	NHTSA 30 mph 5th, Test_pulse	NHTSA 30 mph 5th, FE_pulse	NHTSA 35 mph 5th, Test#5143	NHTSA 35 mph 5th, Test_pulse	NHTSA 35 mph 5th FE_pulse
Response	**Formula**	**Simulation FE pulse Results**	**Crash Test Results (4174)**	**Simulation Test pulse Results**	**Simulation FE pulse Results**	**Crash Test Results (5143)**	**Simulation Test pulse Results**	**Simulation FE pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	159	275	131	182	166	175	185
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	163	283	136	188	318	181	192
neck tension (T)	**Upper Neck Fz Max**	1328	1850	1228	1392	1433	1366	1411
Chest deflection (mm)	**Max Deflection**	24	32	23	25	29	25	26
Chest acceleration (g)	**Max Acceleration**	34	42.7	38	39	37	40	42
Femur Load - Left (N)	**Max Compression force Fz**	223	1193	1083	353	2748	1287	514
Femur Load - Right (N)	**Max Compression force Fz**	2290	2280	2331	2437	4605	2428	2556
HIC15 Risk (AIS 3%)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.06%	0.66%	0.02%	0.12%	0.08%	0.10%	0.13%
chest deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def/0.817)^0.4612)))**	2.29%	5.78%	2.01%	2.59%	4.17%	2.59%	2.93%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.47941* max Femur /1000)) - 1/(1+EXP(4.9795))**	1.34%	1.33%	1.38%	1.48%	5.20%	1.47%	1.61%
neck tension (AIS3%)	**1/(1+EXP(10.958-3.77*NeckTension/1000))**	0.26%	1.83%	0.18%	0.33%	0.39%	0.30%	0.35%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.06	0.15	0.06	0.07	0.17	0.07	0.08

6.4 Model Verification and Robustness

Both the 50th percentile and 5th percentile simulations were run in a centerline pole impact at 25 mph and 35 mph. These simulations were performed to show that the model was stable and that the model would trend as expected. For the centerline pole impact, the X, Y, and Z vehicle linear accelerations from the LS-DYNA full vehicle simulations were used to drive the model (Figure 9-32).

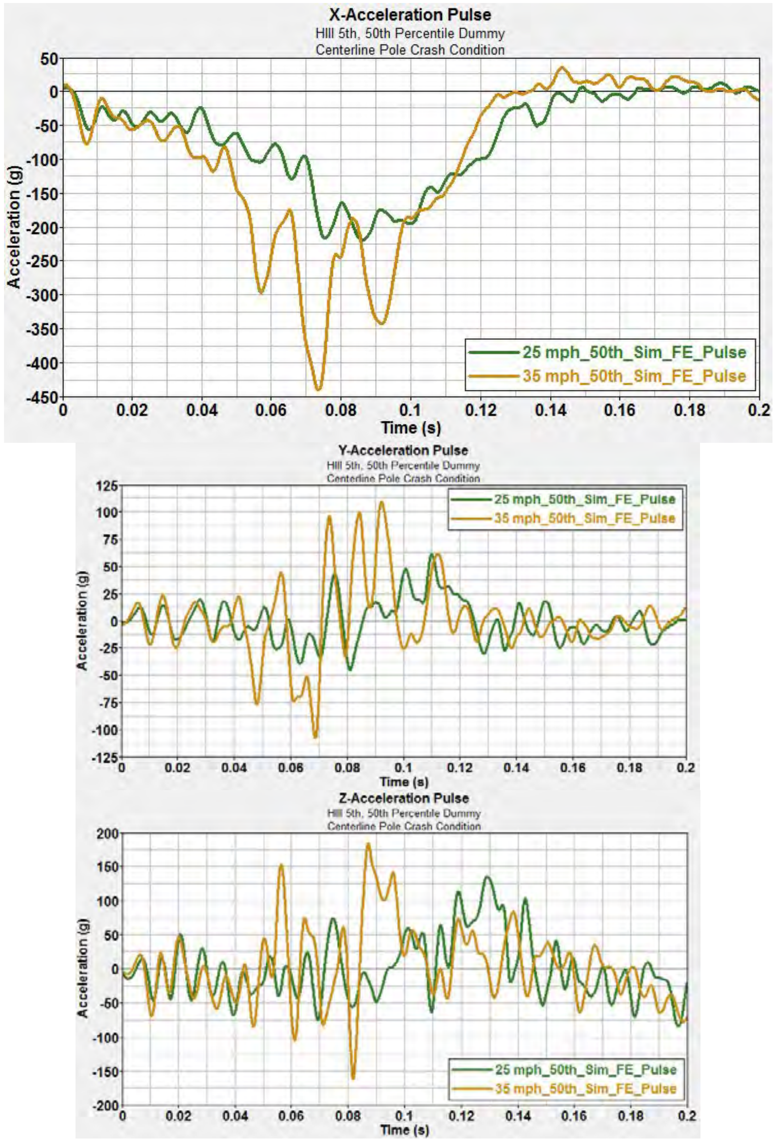

Figure 6-36 – Comparison of X, Y, and Z vehicle accelerations from 25 mph and 35 mph centerline pole impacts

The simulations were also run in offset frontal impacts into a deformable barrier at 25 mph and 40 mph. For this crash configuration, the X, Y, and Z linear accelerations from the LS-DYNA full vehicle simulations were used to drive the model (Figure 9-33).

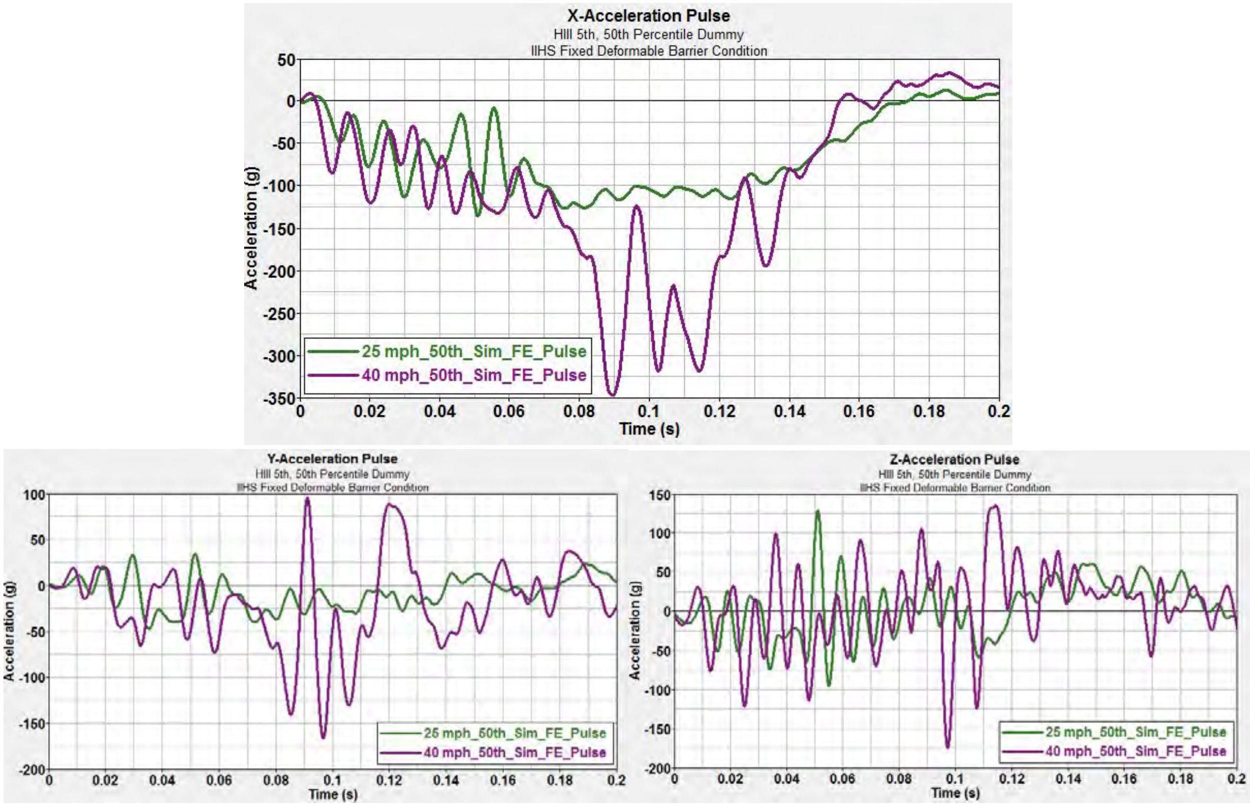

Figure 6-37 – Comparison of X, Y, and Z vehicle accelerations from 25 mph and 40 mph offset frontal impacts

The results for the 50th percentile dummy and 5th percentile dummy for these verification and robustness runs are shown in Table 9-4 and Table 9-5. These results show the expected trends, with higher injury risk corresponding to the higher speed impact and lower injury risk corresponding to the lower speed impact.

Table 6-4 – Comparison of injury results for 50th percentile dummy for verification and robustness simulations

	H350/50th	**Centerline pole 25 mph 50th**	**Centerline pole 35 mph 50th**	**IIHS 25 mph 50th**	**IIHS 40 mph 50th**
Response	**Formula**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	78	212	25	105
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	153	380	43	236
Neck Tension (T)	**Upper Neck Fz Max**	905	1233	621	1152
Chest deflection (mm)	**Max deflection**	23	28	19	24
Chest acceleration (g)	**Max acceleration**	27	43	18	30
Femur Load - Left (N)	**Max Compression force Fz**	745	1588	288	1439
Femur Load - Right (N)	**Max Compression force Fz**	1276	3477	610	1522
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.00%	0.23%	0.00%	0.01%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	2.01%	3.72%	1.21%	2.20%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.35%	1.41%	0.15%	0.43%
Neck Tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.01%	0.03%	0.01%	0.03%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.02	0.05	0.01	0.03

Table 6-5 – Comparison of injury results for 5th percentile dummy for verification and robustness simulations

	H305/5th	Centerline pole 25 mph 5th	Centerline pole 35 mph 5th	IIHS 25 mph 5th	IIHS 40 mph 5th
Response	**Formula**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1)\right\}_{max}$	171	188	125	155
HIC36	$HIC = \left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1)\right\}_{max}$	181	206	135	258
Neck Tension (T)	**Upper Neck Fz Max**	1596	1552	893	1399
Chest deflection (mm)	**Max deflection**	22	26	23	23
Chest acceleration (g)	**Max acceleration**	26	39	32	29
Femur Load - Left (N)	**Max Compression force Fz**	562	1049	942	1550
Femur Load - Right (N)	**Max Compression force Fz**	1571	2442	568	2093
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.09%	0.14%	0.02%	0.06%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def/0.817)^0.4612)))**	3.28%	5.67%	3.78%	3.78%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.47941* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.76%	1.49%	0.39%	1.16%
Neck Tension (AIS3%)	**1/(1+EXP(10.958-3.77*NeckTension/1000))**	0.71%	0.60%	0.05%	0.34%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.05	0.08	0.04	0.05

6.5 Summary and Conclusions

The models of the 50th percentile dummy and 5th percentile dummy seated in the Taurus were validated against available crash data from regulatory and consumer information tests. Further verification and robustness simulations run under varying crash conditions confirmed that the model was stable. Low and high speeds were run under the same impact configuration, confirming that the model yielded the expected trends in that the higher speed simulations led to greater injury than the lower speed simulations.

6.6 Acknowledgements

The authors wish to acknowledge the Federal Highway Administration and National Highway Traffic Safety Administration of the U.S. Department of Transportation for supporting these modeling and simulation efforts.

6.7 References

1. PMG Technologies Test and Research Centre, “Compliance Frontal Impact CMVSS 208/212/301: Ford Taurus 2000,” NHTSA Test No. 4135, August 2000.
2. Transportation Research Center Inc., “2004 Ford Taurus 4-door into a Flat Frontal Barrier,” NHTSA Test No. 5143, August 2004.
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5. PMG Technologies Test and Research Centre, “Joint TC/NHTSA Frontal Airbags Research Tests: Ford Taurus 2001,” NHTSA Test No. 4174, April 2001.

7 APPENDIX 7: DEVELOPMENT AND VALIDATION OF A HONDA ACCORD MADYMO FRONTAL OCCUPANT MODEL

7.1 Introduction

A frontal MADYMO model of a driver in a Honda Accord was developed by the National Crash Analysis Center of the George Washington University in support of the NHTSA study, “Investigate Self and Partner Protection of New Vehicle Designs Using Structural Modeling,” TOPR No. 16 under DTFH61-09-D-00001. For this study, several different vehicle finite element (FE) models were developed, including the Honda Accord, and run under different crash configurations in single vehicle and two vehicle crashes. The data from these FE models were used as inputs for the frontal MADYMO models that were developed to assess occupant injury risk.

To develop the MADYMO models, the NCAC obtained generic occupant models from restraint manufacturers, upon which the specific vehicle models would be built. For the Honda Accord, a generic model year (MY) 2011 small car was used as a foundation. This foundation model was modified to reflect data and measurements from the crash test report in order to make it more representative of a Honda Accord.

The Accord occupant simulations were first validated against frontal crash test data. Then, the simulations were run in the same crash tests configurations, but using the pulses output by the LS-DYNA FE simulations. This check was performed to ensure that reasonable occupant responses would be observed once the FE simulation outputs were used in the occupant models. Lastly, the occupant model was run under several different crash configurations to confirm the stability and robustness of the model and to verify that reasonable occupant response trends would be observed. This paper serves as documentation of the above model development and validation processes.

7.2 Model Development

The first step in modifying the MY 2011 small car model was to set up the interior based on the available surface geometry from the FE model. The FE model did not include the vehicle interior, but did include the toe pan area, floor steering wheel, and side panel, as shown in Figure 7-1.

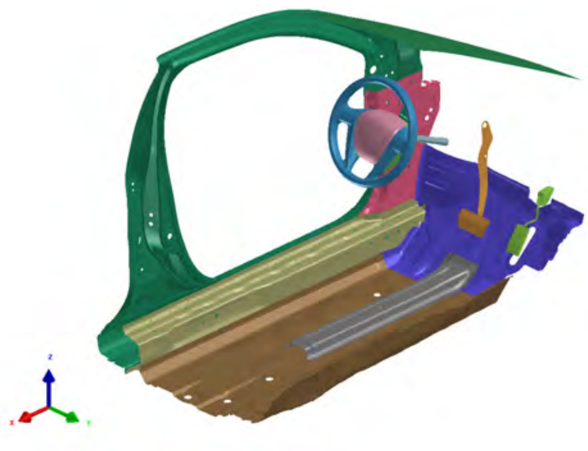

Figure 7-1 – Structural FE parts from LS-DYNA model

The NCAC was able to locate an appropriate model year Accord and digitize the data for the dashboard, A-pillar, knee bolster, accelerator pedal, brake pedal, roof, seat back, seat bottom, and steering wheel, as shown in Figure 7-2.

Figure 7-2 – Digitized Honda Accord components

The elements from the FE vehicle model and the additional digitized Accord data were imported into the generic MADYMO model. The FE components were used as a reference to adjust the positioning of the interior of the MADYMO model (Figure 7-3). The dash panel of the generic model was repositioned to match the digitized data from the physical vehicle. Additionally, the steering column and driver air bag were also moved suing the steering column joint. The seat was also positioned based on the digitized data.

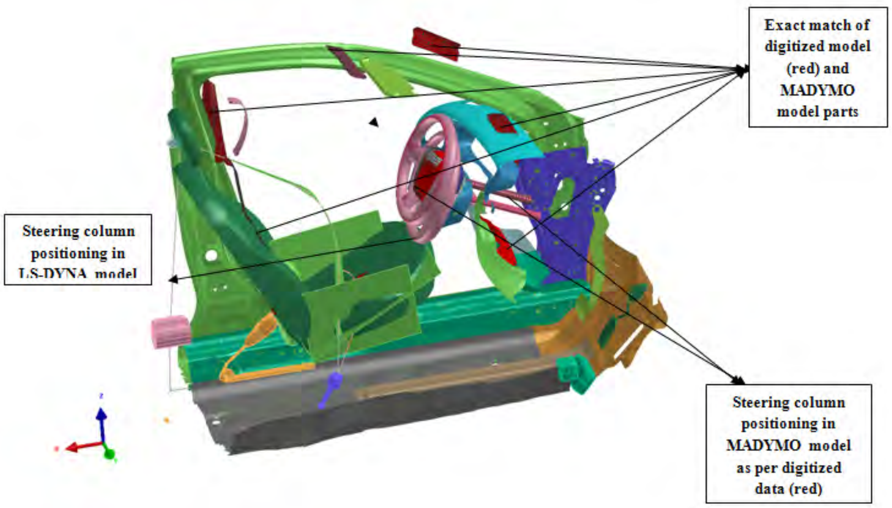

Figure 7-3 – Overlay of the LS-DYNA data, digitized data, and MADYMO model

Finite element representations of the toe pan and footrest were imported from the LS-DYNA model, allowing for the use of prescribed structural motion to capture the vehicle intrusion.

Next, dummy was positioned according to available test reports. The dummy positions for the 50th percentile male and 5th percentile female were based on NHTSA test nos. 7078 and 6481, respectively [1,2]. For the 50th percentile dummy in the offset configuration, IIHS test no. CEF1003 was used for the dummy positioning [3]. Measurements such as the seat back angle (degree), head to windshield (mm), nose to rim (mm), chest to dash (mm), steering wheel to chest (mm), rim to abdomen (mm), left knee to dash (mm), right knee to dash (mm), tibia angle (degree), and knee to knee (mm) were considered in positioning the dummies. The dummies were positioned to match as many of these measurements as possible. The model was also subject to visual inspection to ensure that the final position was physically reasonable. The final positions of the 50th percentile dummy and 5th percentile dummy are shown inFigure 7-4.

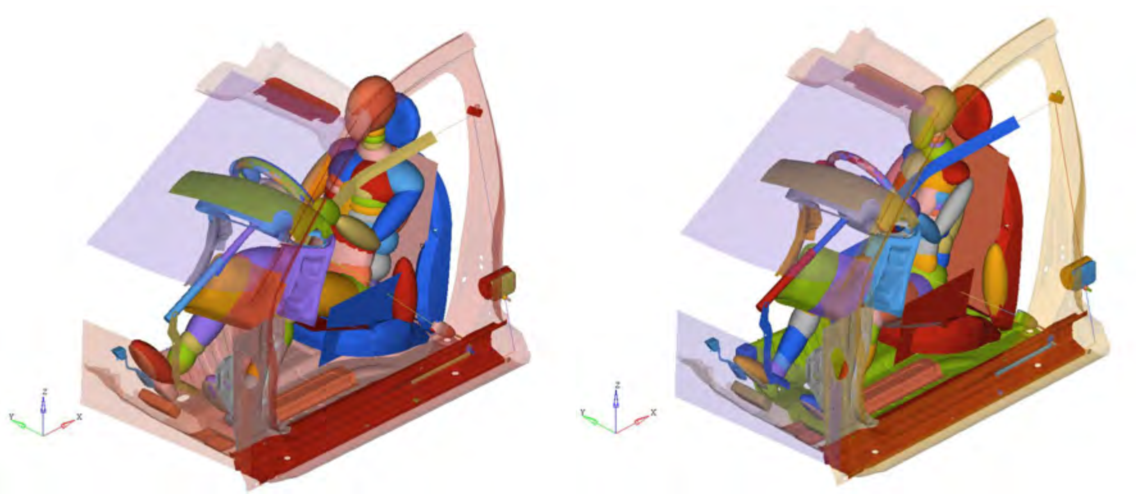

Figure 7-4 – Final position of 50th percentile (left) and 5th percentile (right) dummies in Accord model

The shoulder belt loads from the crash test data were analyzed to determine the air bag and pretensioner firing time, as shown in Figure 7-5. For NHTSA test no. 7078, the firing time was observed to be 17 ms.

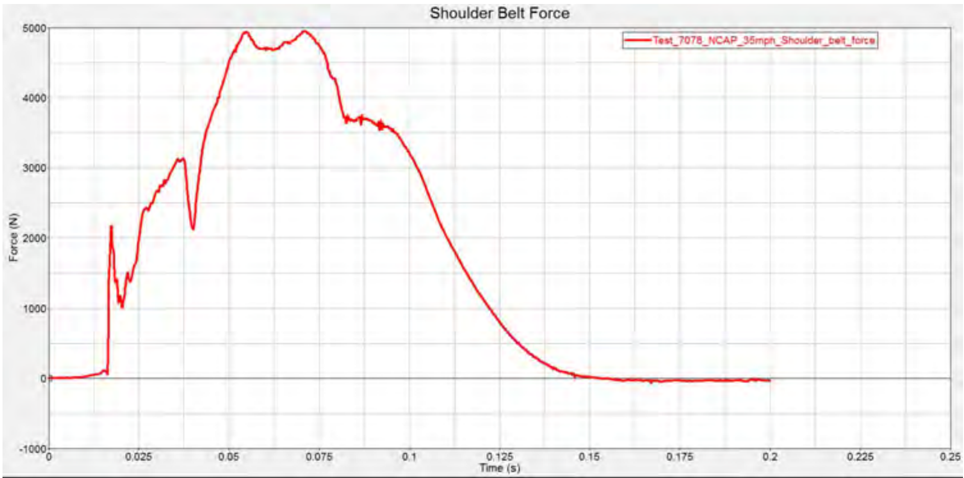

Figure 7-5 – Shoulder belt force for NHTSA test no. 7078

The firing time for this specific case was then used to determine a firing time rule that would be applicable to all crash speeds. The general guideline is for the "5-30" rule, but the crash data was checked to verify that this vehicle conformed to the general guideline. The crash pulse from the test was double integrated to give the displacement time history, as shown in Figure 7-6. Five inches of displacement were observed at 46.5 ms, which confirmed that the 34 ms firing time matched the established "5-30" rule. For all simulations that were run in this study, the firing time was determined with this rule—30 ms less than the time at which 5 inches of displacement were observed.

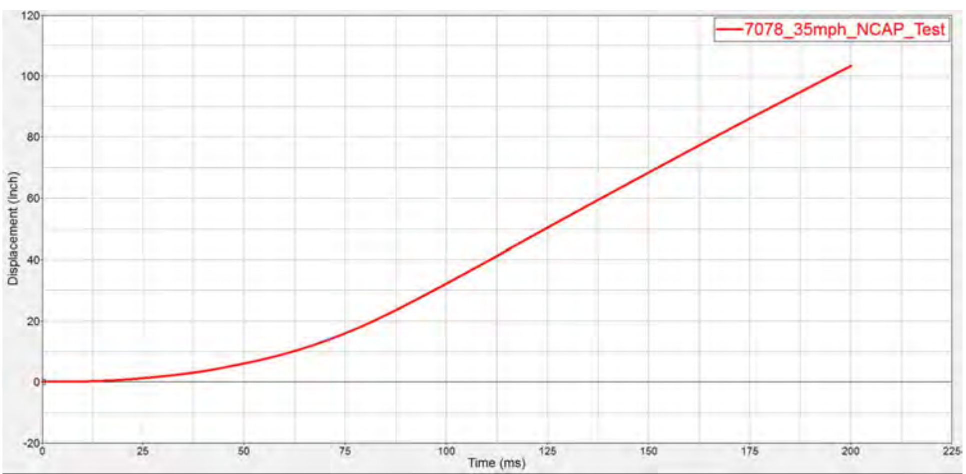

Figure 7-6 – Vehicle displacement time history for NHTSA test no. 4135

The restraint system was fine-tuned through an iterative process until the model output the expected occupant accelerations according to the crash test data. Through this process, the air bag vent size and pretensioner pull function were modified. In the foundation model, the air bag vent size was 25 mm. However, in order to reduce the HIC numbers to match the test results, the vent size was increased to 30 mm, which softened the air bag.

The characteristics of the belt system were determined by the belt load data from the crash test. Two pretensioners were used in this model—one at the inboard side of the lap belt and another located at the shoulder belt retractor. The pretensioner pull function was adjusted in an iterative process to determine the appropriate amount of pretensioning. The final pull function used in the model is shown in Figure 7-7.

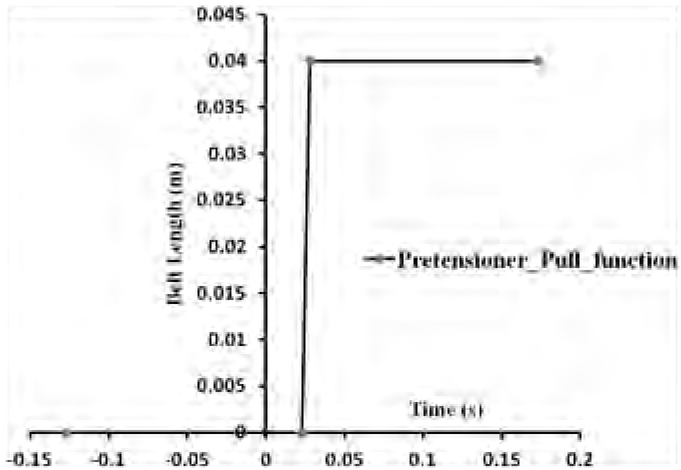

Figure 7-7 – Accord pretensioner pull function

Lastly, the belt load data from the test showed that there was a dual phase load limiter in the vehicle. To model this belt behavior, the retractor spool function was modified using reasonable lower and upper limits of this function (Figure 7-8). The model was adjusted within these limits until an appropriate match with the belt load test data was achieved.

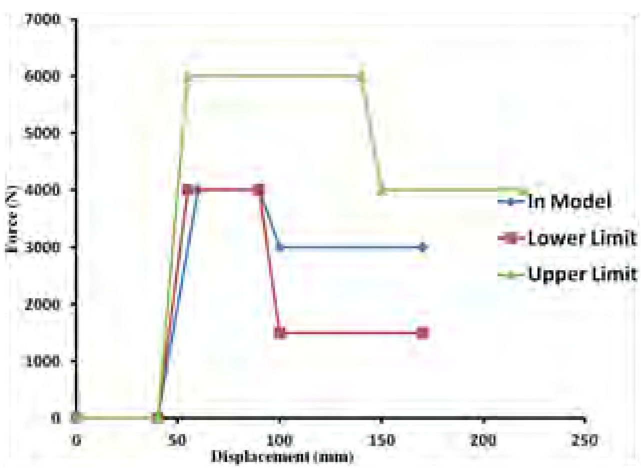

Figure 7-8 – Retractor spool function

7.3 Model Validation

The Accord occupant models with the 50th percentile male dummy and 5th percentile female dummy were validated against available full frontal crash data. The primary responses that were compared in this validation study are discussed in the following section.

7.3.1 Full Frontal 35 mph Validation: 50th Percentile Male Dummy

The 50th percentile occupant model seated in the Accord was validated against NHTSA test no. 7078, a full frontal impact into a rigid barrier at 35 mph [1]. Three simulations were run for this crash configuration, one at 35 mph using the test pulse, one at 35 mph using the FE pulse, and one at 25 mph using the FE pulse (Figure 7-9). The 25 mph simulation was run as a check to make sure that the response was trending as expected, i.e., that the 25 mph impact would yield lower dummy responses than the 35 mph impact.

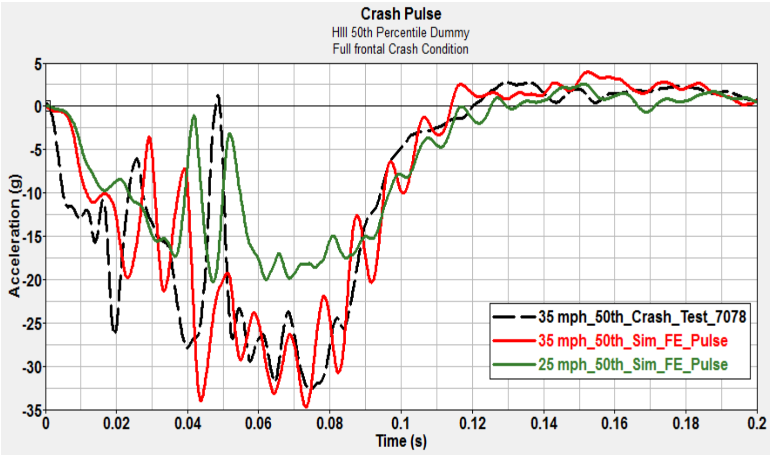

Figure 7-9 – Vehicle pulse comparison between test no. 7078 and FE simulation outputs

The lap and shoulder belt loads were compared between the test and simulations (Figure 7-10).

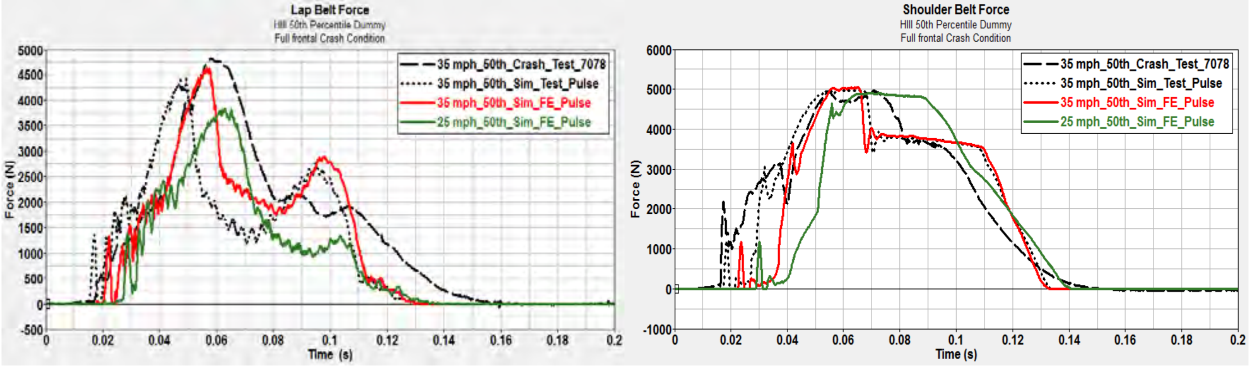

Figure 7-10 – Comparison of lap and shoulder belt forces from test and simulations for full frontal impact

All of the outputs for the dummy model were compared to the available crash test data. However, only the chest deflection (Figure 7-11), head acceleration (Figure 7-12), neck tension (Figure 7-13), and femur forces (Figure 7-14) will be shown below, as these were the body regions of interest in the overall study.

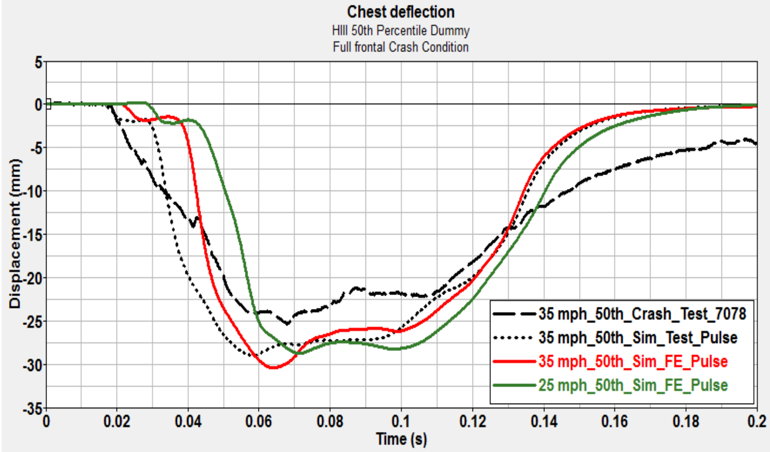

Figure 7-11 – Comparison of chest deflection from test and simulations for full frontal impact

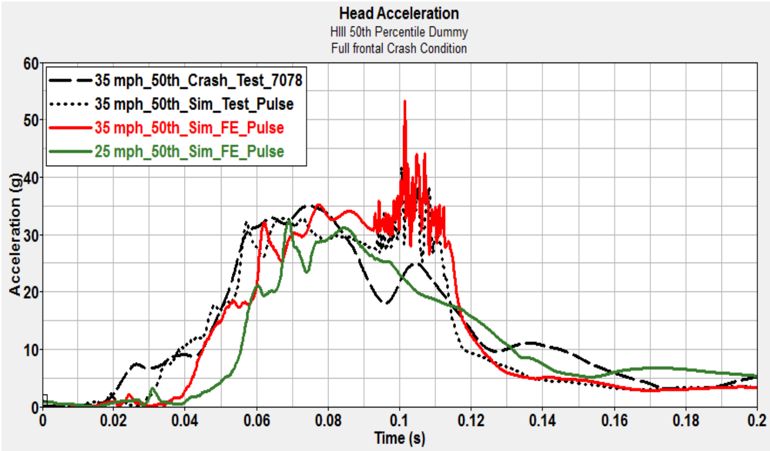

Figure 7-12 – Comparison of head acceleration from test and simulations for full frontal impact

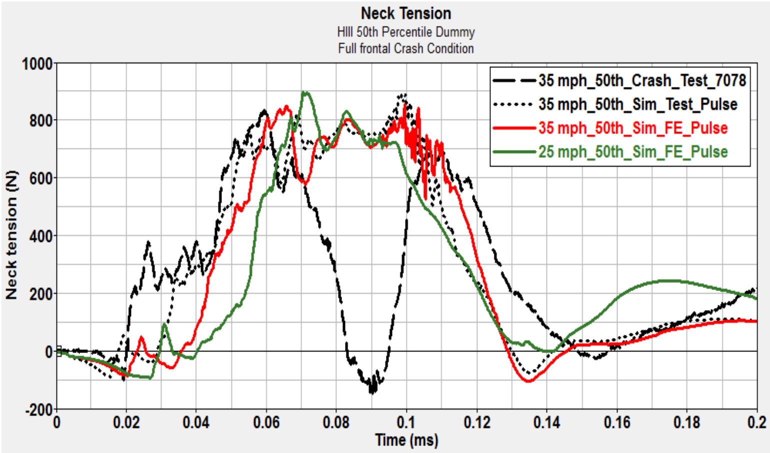

Figure 7-13 – Comparison of neck tension from test and simulations for full frontal impact

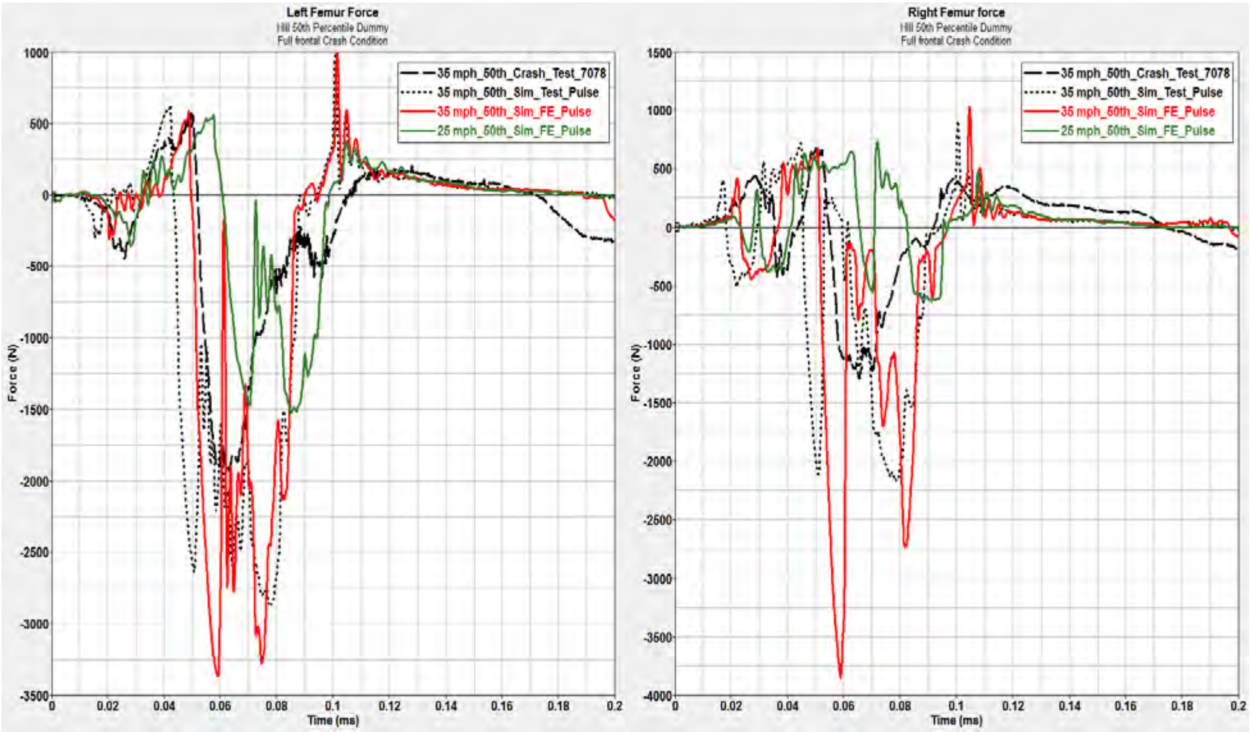

Figure 7-14 – Comparison of left and right femur forces from test and simulations for full frontal impact

7.3.2 Offset Frontal 40 mph Validation: 50th Percentile Male Dummy

The 50th percentile male dummy model seated in the Accord was validated against IIHS test no. CEF1003, an offset frontal impact with a deformable barrier at 40 mph [3]. Three simulations were run for this crash configuration, one at 40 mph using the test pulse, one at 40 mph using the FE pulse, and one at 25 mph using the FE pulse (Figure 7-15). For the offset crash configuration, all three linear accelerations were used to propel the vehicle in order to account for the yaw and pitch seen in the PSM of the toe pan and footrest. The 25 mph simulation was run as a check to make sure that the response was trending as expected, i.e., that the 25 mph impact would yield lower dummy responses than the 40 mph impact.

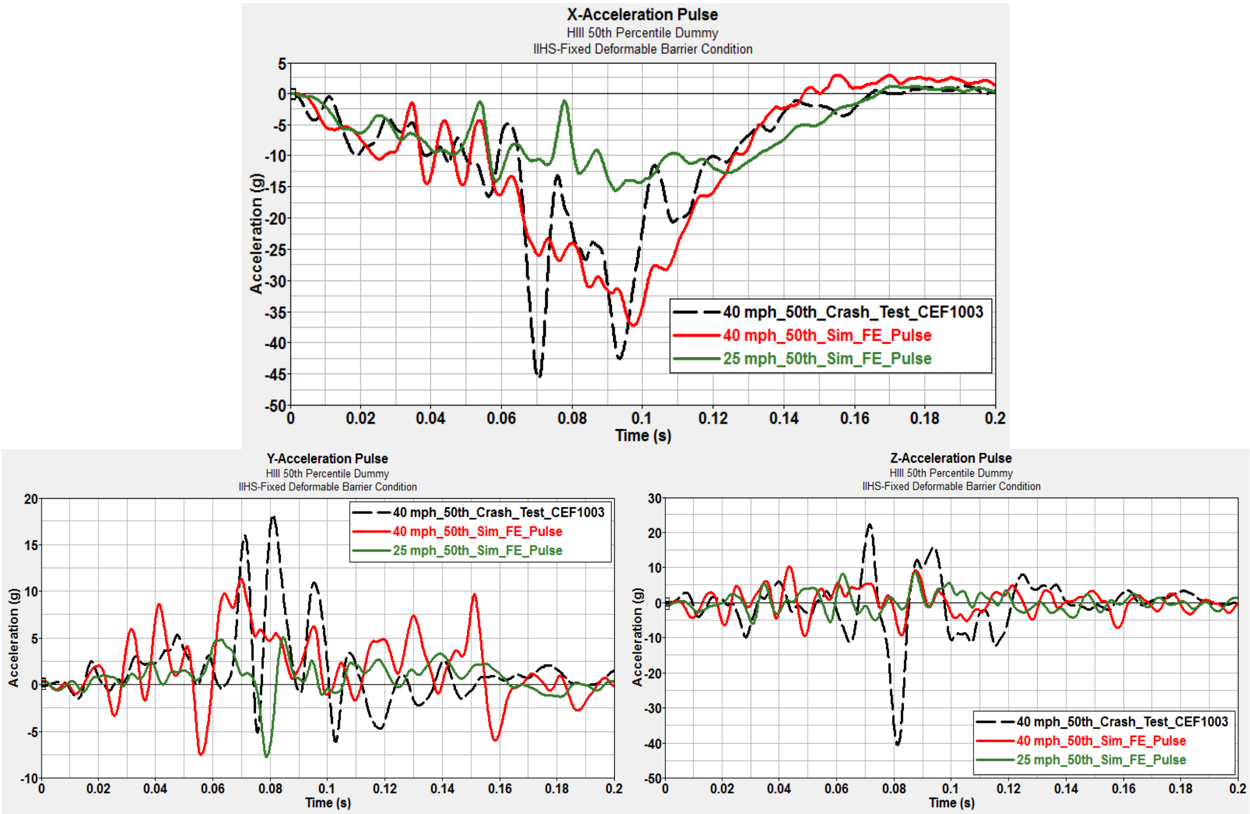

Figure 7-15 – Comparison of X, Y, and Z vehicle acceleration from test and simulations for offset frontal impact

No belt data were available for this test. The chest deflection (Figure 7-16), head acceleration (Figure 7-17), neck tension (Figure 7-18), and femur forces (Figure 7-19) were compared between the test and simulations, showing reasonable correlation.

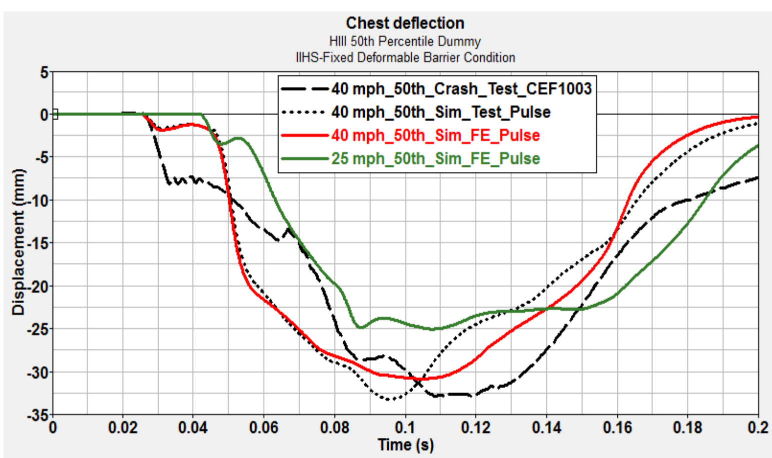

Figure 7-16 – Comparison of chest deflection from test and simulations for offset frontal impact

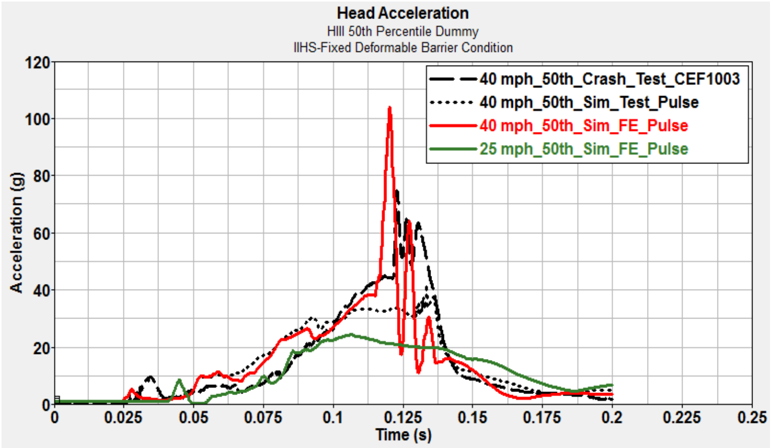

Figure 7-17 – Comparison of head acceleration from test and simulations for offset frontal impact

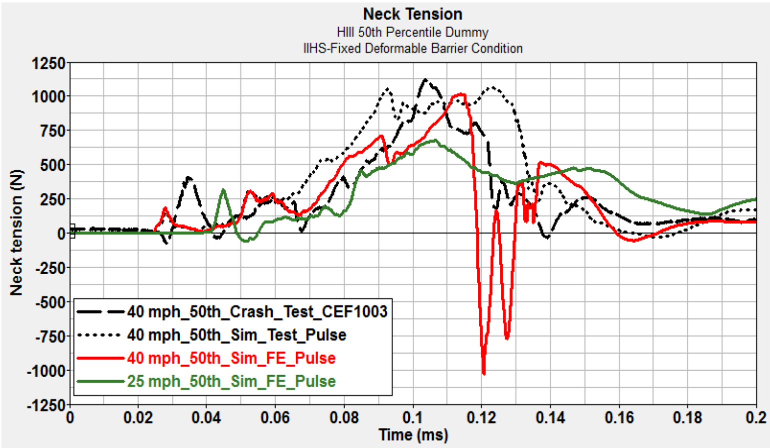

Figure 7-18 – Comparison of neck tension from test and simulations for offset frontal impact

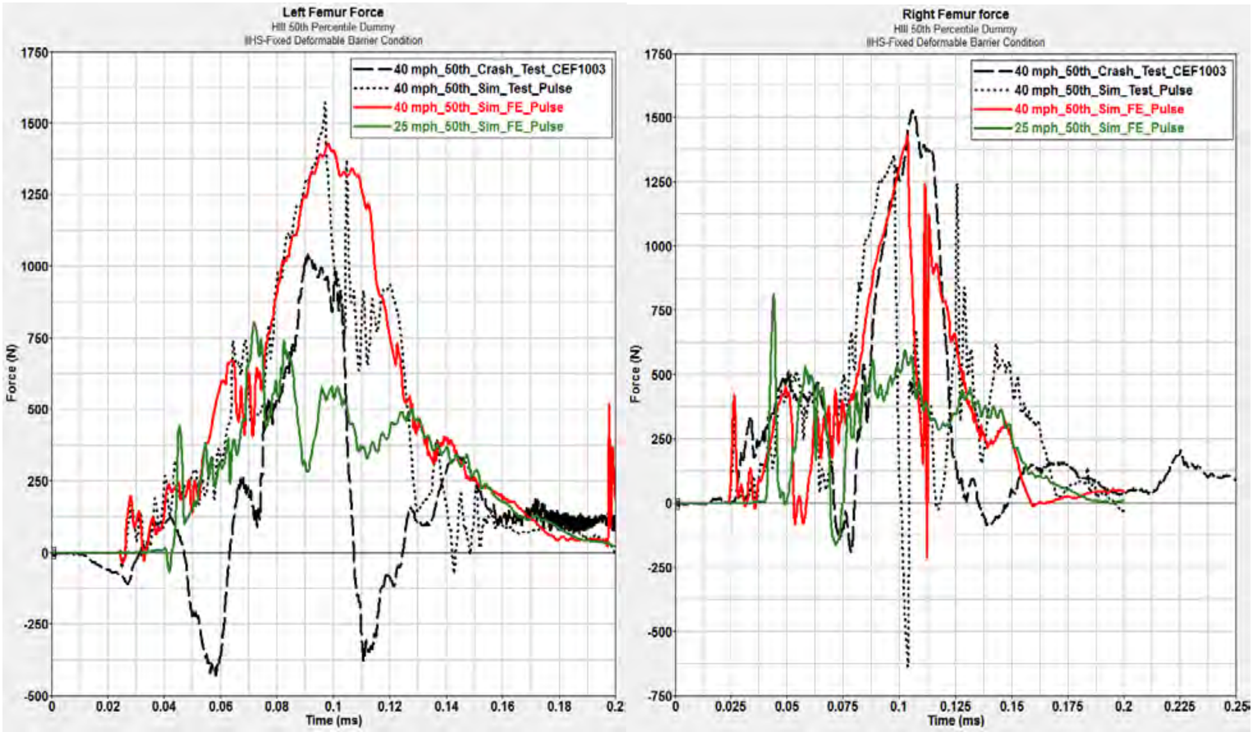

Figure 7-19 – Comparison of left and right femur forces from test and simulations for offset frontal impact

7.3.3 Full Frontal 25 mph Validation: 5th Percentile Female Dummy

The 5th percentile female dummy model seated in the Accord was verified against NHTSA test no. 6481, a full frontal impact into a rigid barrier at 25 mph with an unbelted occupant [2]. Three simulations were run—one with the test pulse with a belted occupant and two with the FE pulse output from the LS-DYNA full vehicle simulation, unbelted and belted. It important to note the Accord in test no. 6481 had a 3.5 L engine while the Accord FE model was developed to match the 35 mph test, no. 7078, which had the smaller v-4, 2.4 L engine. A comparison of the crash test pulse and FE pulse is shown in Figure 9-21. The 25 mph FE pulse had a similar width and reasonable g levels as compared with the 35 mph crash test pulse shown in Figure 9-5. However, the larger v-6 3.5 L engine takes out more of the available crush and results in higher g levels and an earlier and narrower pulse in the 25 mph crash test pulse, as shown in Figure 7-20. Because the occupant was unbelted, belt load data were not available in the crash test report.

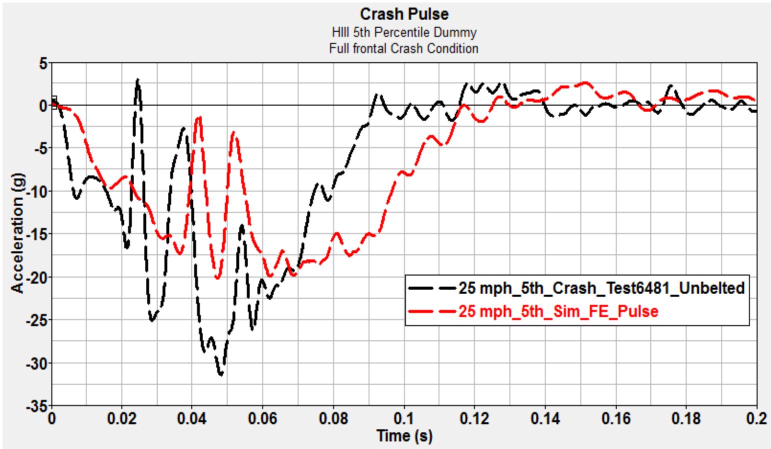

Figure 7-20 – Comparison of vehicle pulse from test and simulation for 25 mph full frontal impact

The chest deflection (Figure 7-21), head acceleration (Figure 7-22), neck tension (Figure 7-23), and femur forces (Figure 7-24) were compared between the test and simulations, showing reasonable correlation.

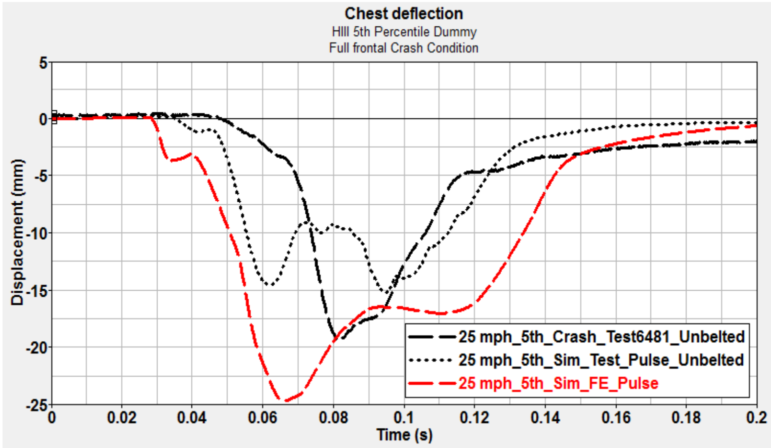

Figure 7-21 – Comparison of chest deflection from test and simulations for 25 mph full frontal impact

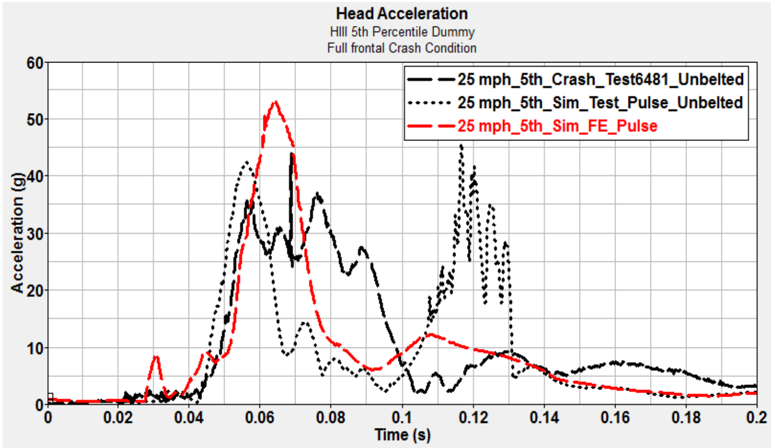

Figure 7-22 – Comparison of head acceleration from test and simulations for 25 mph full frontal impact

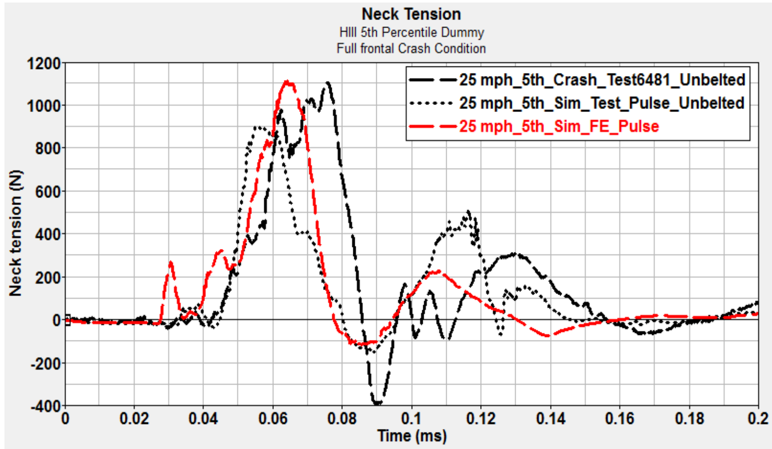

Figure 7-23 – Comparison of neck tension from test and simulations for 25 mph full frontal impact

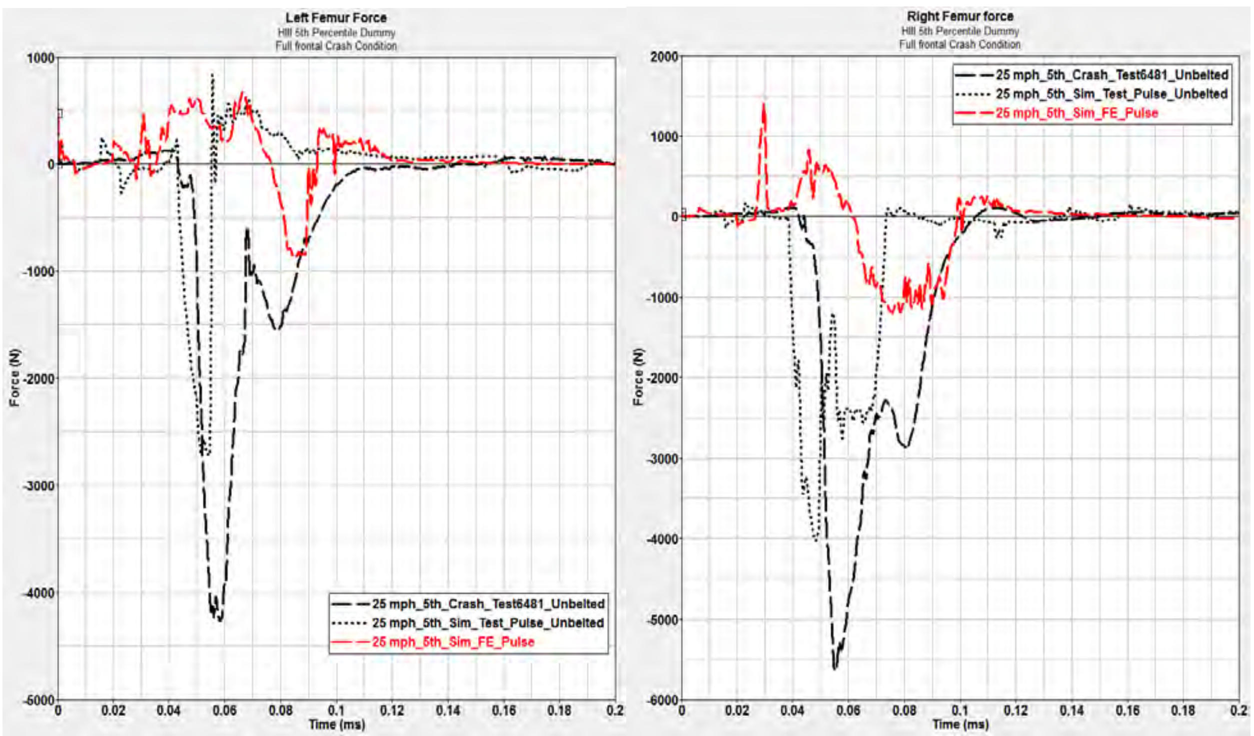

Figure 7-24 – Comparison of left and right femur forces from test and simulations for 25 mph full frontal impact

7.3.4 Full Frontal 35 mph Validation: 5th Percentile Female Dummy

The 5th percentile dummy model seated in the Accord was also run in a full frontal impact into a rigid barrier at 35 mph. No regulatory or consumer information crash tests were available with the 5th percentile dummy in this configuration, so the test pulse from NHTSA test no. 7078 (which involved a 50th percentile dummy) was used to drive this simulation [1]. This was checked against a simulation in which the FE pulse was used to ensure that the FE pulse was reasonably representative of the test pulse. A comparison of these pulses is shown in Figure 7-25.

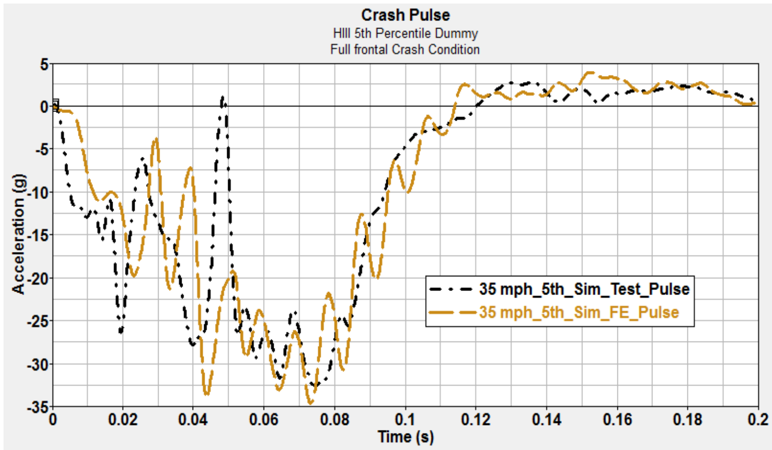

Figure 7-25 – Comparison of vehicle pulse from test and simulation for 35 mph full frontal impact

Figure 7-26 compares the lap and shoulder belt forces of the crash test versus the simulations.

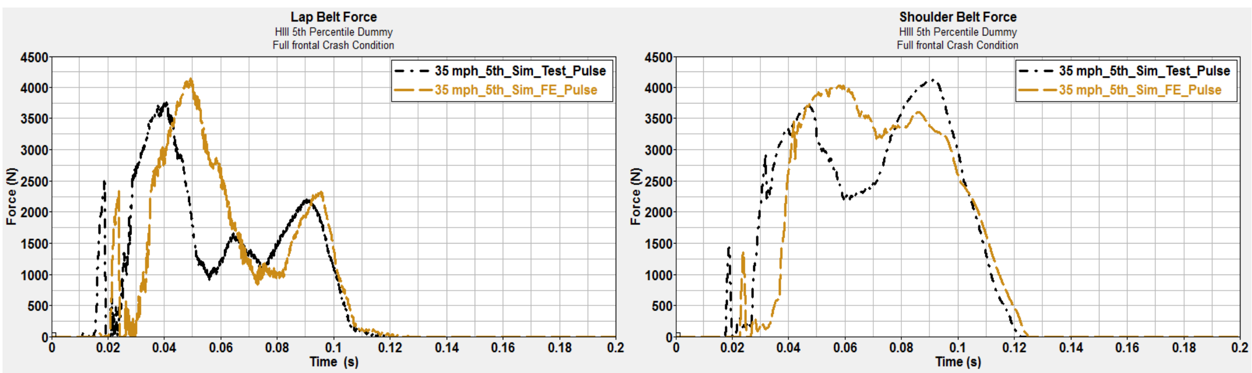

Figure 7-26 – Comparison of lap and shoulder belt forces from two simulations for 35 mph full frontal impact

The chest deflection (Figure 7-27), head acceleration (Figure 7-28), neck tension (Figure 7-29), and femur loads (Figure 7-30) were also compared between the simulations, showing a reasonable match.

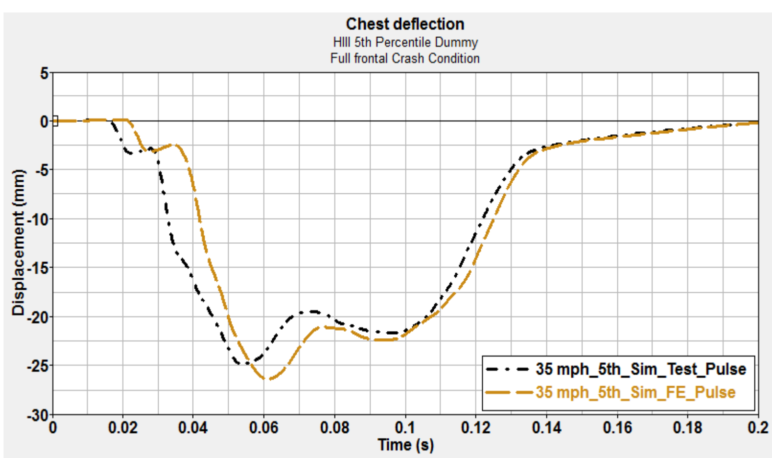

Figure 7-27 – Comparison of chest deflection from two simulations for 35 mph full frontal impact

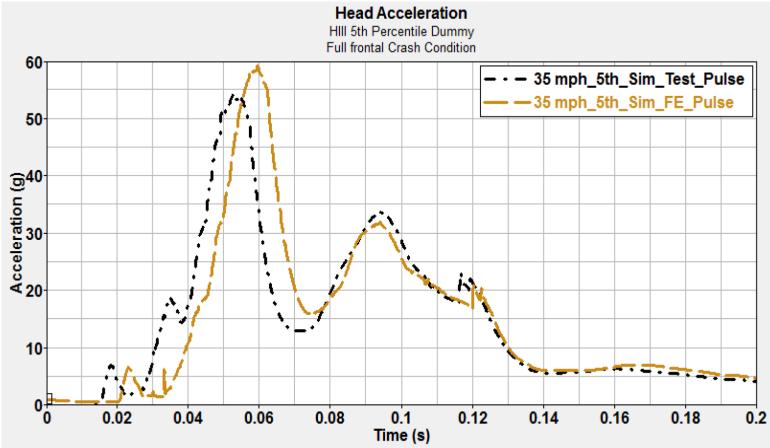

Figure 7-28 – Comparison of head acceleration from two simulations for 35 mph full frontal impact

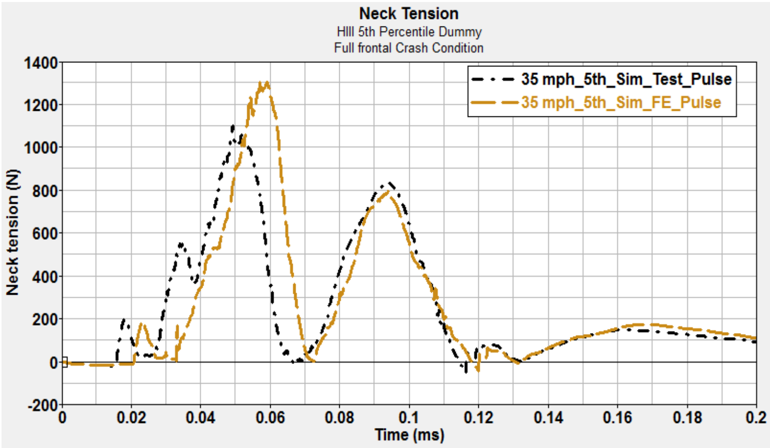

Figure 7-29 – Comparison of neck tension from two simulations for 35 mph full frontal impact

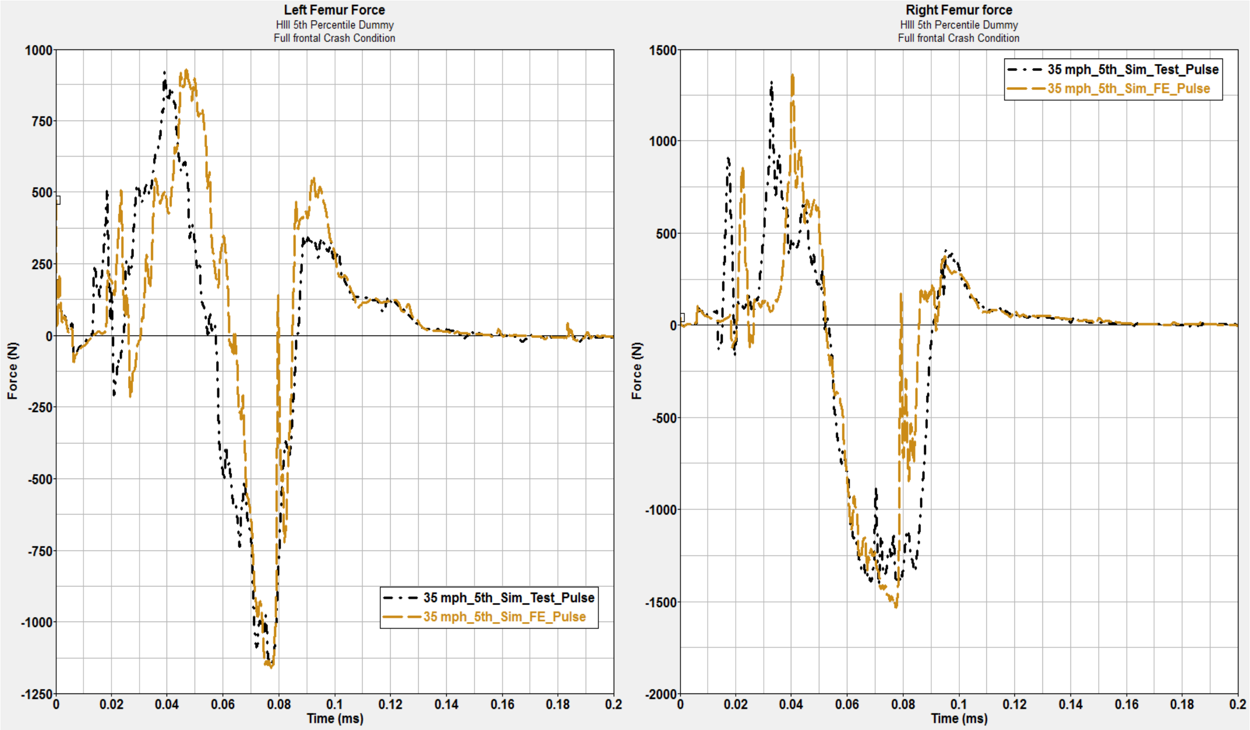

Figure 7-30 – Comparison of left and right femur forces from two simulations for 35 mph full frontal impact

7.3.5 Validation Summary

The results from the validation study are summarized in Table 7-1 and Table 7-2 for the 50th percentile dummy and in Table 7-3 for the 5th percentile dummy.

Table 7-1 – 50th percentilepercentile dummy full frontal validation results

	H350/50th	NCAP 25 mph 50th FE Pulse	NHTSA 35 mph 50th Test_Pulse _7078	NHTSA 35 mph 50th Test_Pulse _7078	NCAP 35 mph 50th FE Pulse
Response	**Formula**	**Simulation FE Pulse Results**	**Crash Test Results (7078)**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	68	98	88	106
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	139	200	187	233
Neck Tension (T)	**Upper Neck Fz Max**	895	841	887	851
Chest deflection (mm)	**Max Deflection**	29	25	29	30
Chest acceleration (g)	**Max Acceleration**	29	34	33	37
Femur Load - Left (N)	**Max Compression force Fz**	1524	1929	2880	3366
Femur Load - Right (N)	**Max Compression force Fz**	627	1293	2160	3851
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.00%	0.01%	0.00%	0.01%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	4.17%	2.69%	4.17%	4.66%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.43%	0.59%	1.05%	1.67%
Neck Tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.01%	0.01%	0.01%	0.01%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.05	0.03	0.05	0.06

Table 7-2 – 50th percentilepercentile dummy offset frontal validation results

	H350/50th	IIHS 40 mph 50th	IIHS 40 mph 50th Test Pulse	IIHS 40mph 50th FE Pulse
Response	**Formula**	**Crash Test Results (CEF1003)**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	334	94	331
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	500	220	387
Neck Tension (T)	**Upper Neck Fz Max**	1120	1058	1011
Chest deflection (mm)	**Max Deflection**	32	33	30
Chest acceleration (g)	**Max Acceleration**	40	31	37
Femur Load - Left (N)	**Max Compression force Fz**	430	74	38
Femur Load - Right (N)	**Max Compression force Fz**	193	638	212
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	1.33%	0.00%	1.29%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	5.78%	6.41%	4.66%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.10%	0.16%	0.05%
Neck Tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.02%	0.02%	0.02%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.07	0.07	0.06

Table 7-3 – 5th percentilepercentile dummy full frontal validation results

	H305/5th	NHTSA 25 mph 5th Test_pulse _6481 Unbelted	NHTSA 25 mph 5th Test_pulse _6481 Unbelted	NCAP 25mph 5th FE Pulse Belted	NHTSA 35 mph 5th Test_pulse _7078	NCAP 35mph 5th FE Pulse
Response	**Formula**	**Crash Test Results**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	78	97	200	224	263
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	165	100	206	231	273
Neck Tension (T)	**Upper Neck Fz Max**	1102	895	1126	1098	1306
Chest deflection (mm)	**Max Deflection**	19	15	25	25	26
Chest acceleration (g)	**Max Acceleration**	43	36	43	39	46
Femur Load - Left (N)	**Max Compression force Fz**	4265	2714	862	1146	1167
Femur Load - Right (N)	**Max Compression force Fz**	5637	4034	1203	1408	1531
HIC15 Risk (AIS 3%)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.00%	0.01%	0.18%	0.29%	0.55%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def/0.817)^0.4612)))**	1.16%	0.62%	4.97%	2.59%	5.67%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.47941*max Femur /1000)) - 1/(1+EXP(4.9795))**	8.62%	3.86%	0.53%	0.65%	0.73%
Neck Tension (AIS3%)	**1/(1+EXP(10.958-3.77*NeckTension/1000))**	0.02%	0.01%	0.12%	0.02%	0.24%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.10	0.04	0.06	0.04	0.07

7.4 Model Verification and Robustness

Both the 50th percentile and 5th percentile simulations were run in a centerline pole impact at 25 mph and 35 mph. These simulations were performed to show that the model was stable and that the model would trend as expected. For the centerline pole impact, the X, Y, and Z vehicle linear accelerations from the LS-DYNA full vehicle simulations were used to drive the model (Figure 7-31).

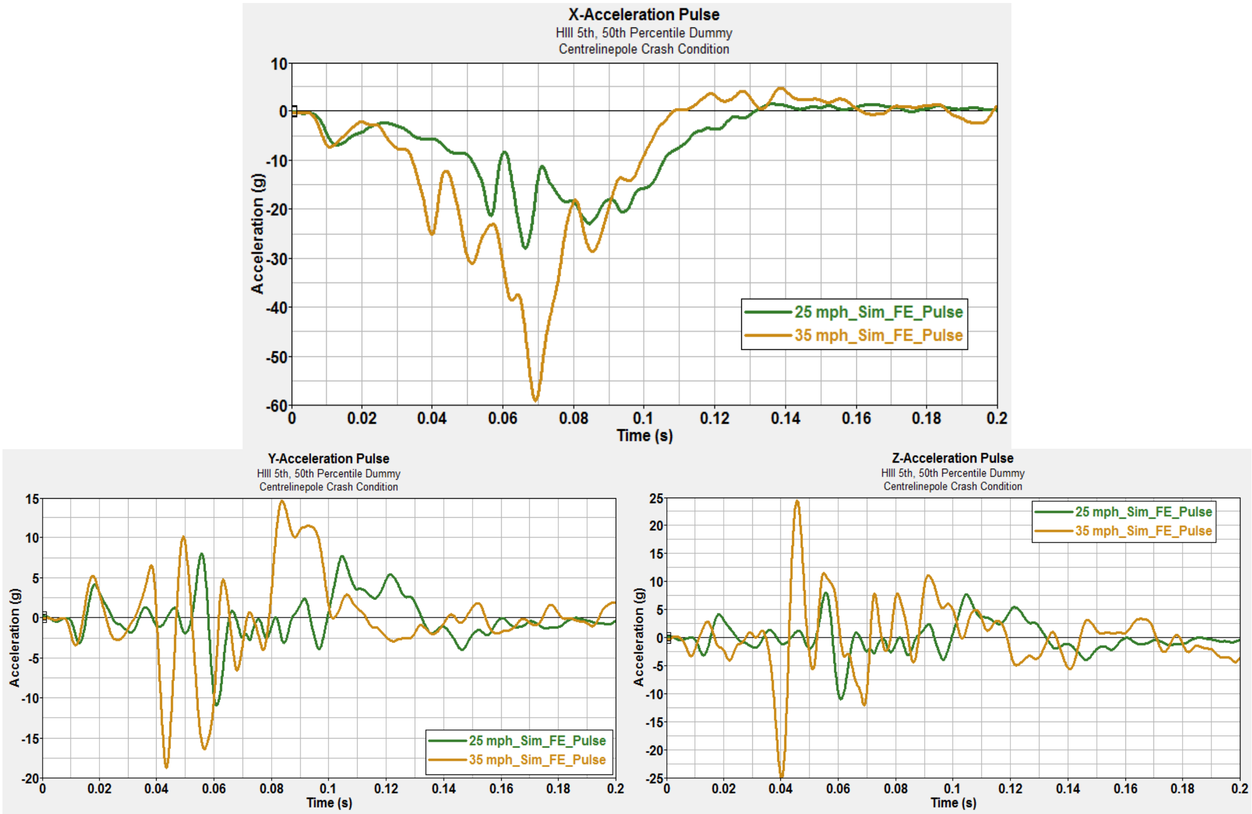

Figure 7-31 – Comparison of X, Y, and Z vehicle accelerations from 25 mph and 35 mph centerline pole impacts

The simulations were also run in offset frontal impacts into a deformable barrier at 25 mph and 40 mph. For this crash configuration, the X, Y, and Z linear accelerations from the LS-DYNA full vehicle simulations were used to drive the model (Figure 7-32).

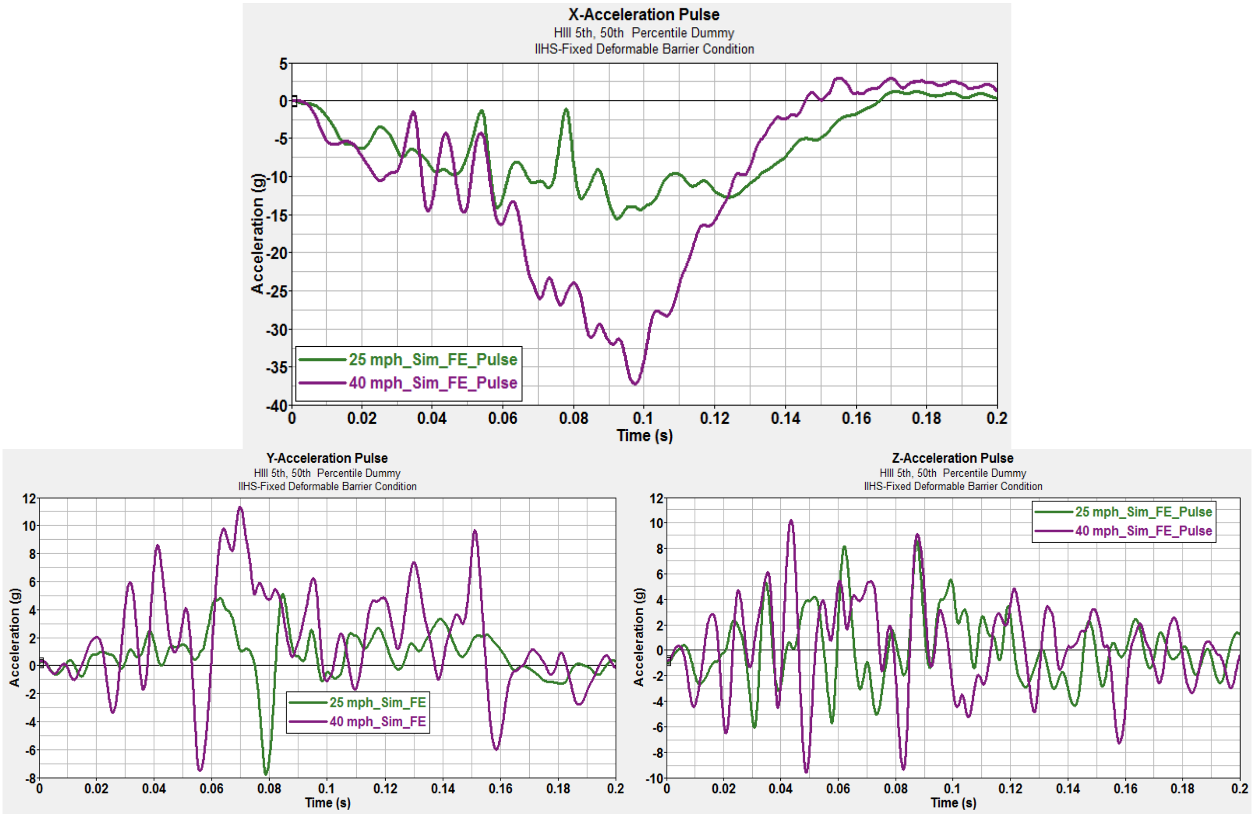

Figure 7-32 – Comparison of X, Y, and Z vehicle accelerations from 25 mph and 40 mph offset frontal impacts

The results for the 50th percentile dummy and 5th percentile dummy for these verification and robustness runs are shown in Table 7-4 and Table 7-5. These results show the expected trends, with higher injury risk corresponding to the higher speed impact and lower injury risk corresponding to the lower speed impact.

Table 7-4 – Comparison of injury results for 50th percentile dummy for verification and robustness simulations

	H350/50th	Centerline pole 25 mph 50th	Centerline pole 35 mph 50th	IIHS 25 mph 50th	IIHS 40 mph 50th
Response	**Formula**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	54	226	38	331
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	112	418	83	387
Neck Tension (T)	**Upper Neck Fz Max**	813	1007	679	1011
Chest deflection (mm)	**Max deflection**	29	34	25	30
Chest acceleration (g)	**Max acceleration**	33	50	29	37
Femur Load - Left (N)	**Max Compression force Fz**	19	1338	67	38
Femur Load - Right (N)	**Max Compression force Fz**	0	3246	163	212
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.00%	0.30%	0.00%	1.29%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	4.17%	7.10%	2.59%	5%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.00%	1.26%	0.04%	0.05%
Neck Tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.01%	0.02%	0.01%	0.02%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.04	0.09	0.03	0.06

Table 7-5 – Comparison of injury results for 5th percentile dummy for verification and robustness simulations

	H305/5th	Centerline pole 25 mph 5th	Centerline pole 35 mph 5th	IIHS 25 mph 5th	IIHS 40 mph 5th
Response	**Formula**	**Simulation FE Results**	**Simulation FE Results**	**Simulation FE Results**	**Simulation FE Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	181	324	125	335
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	191	365	135	478
Neck Tension (T)	**Upper Neck Fz Max**	1226	1470	893	1614
Chest deflection (mm)	**Max deflection**	25	28	23	21
Chest acceleration (g)	**Max acceleration**	48	60	32	37
Femur Load - Left (N)	**Max Compression force Fz**	979	1420	942	1800
Femur Load - Right (N)	**Max Compression force Fz**	1025	3467	568	1001
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.12%	1.19%	0.02%	1.34%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def/0.817)^0.4612)))**	4.97%	7.29%	3.78%	2.83%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.47941* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.43%	2.81%	0.39%	0.92%
Neck Tension (AIS3%)	**1/(1+EXP(10.958-3.77*NeckTension/1000))**	0.18%	0.44%	0.05%	0.76%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.06	0.11	0.04	0.06

7.5 Summary and Conclusions

The models of the 50th percentile dummy and 5th percentile dummy seated in the Accord were validated against available crash data from regulatory and consumer information tests. Further verification and robustness simulations run under varying crash conditions confirmed that the model was stable. Low and high speeds were run under the same impact configuration, confirming that the model yielded the expected trends in that the higher speed simulations led to greater injury than the lower speed simulations.

7.6 Acknowledgements

The authors wish to acknowledge the Federal Highway Administration and National Highway Traffic Safety Administration of the U.S. Department of Transportation for supporting these modeling and simulation efforts.

7.7 References

1. MGA Research Corporation, "Final Report of New Car Assessment Program Frontal Impact Testing of 2011 Honda Accord LX 4-Dr Sedan," NHTSA Test No. 7078, October 2010.
2. MGA Research Corporation, "Final Report of FMVSS 208 Compliance Testing of a 2008 Honda Accord," NHTSA Test No. 6481, November 2008.
3. Insurance Institute for Highway Safety, "Crash Test Report: 2010 Honda Accord Crosstour," IIHS Test CEF1003, June 2010.

8 APPENDIX 8: DEVELOPMENT AND VALIDATION OF A 2009 TOYOTA VENZA MADYMO FRONTAL OCCUPANT MODEL

8.1 Introduction

A frontal MADYMO model of a driver in a 2009 Toyota Venza was developed in support of the 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.

8.2 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 8-1. 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 8-2.

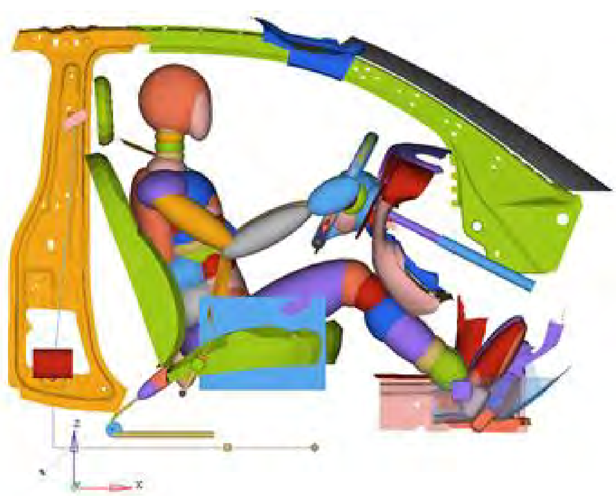

Figure 8-1 – Generic MADYMO Occupant Model

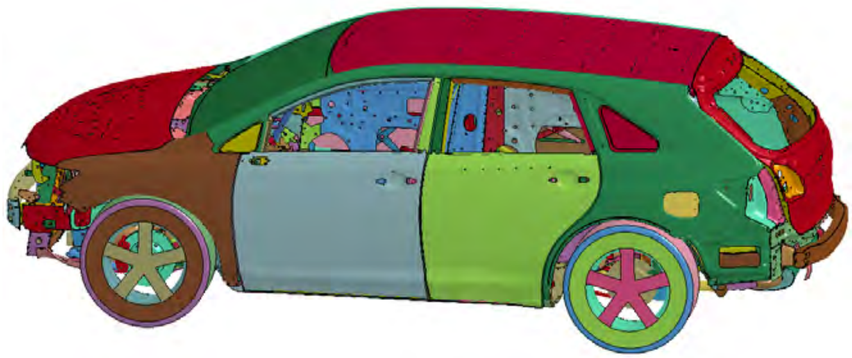

Figure 8-2 – Venza Baseline FE Model

The resulting Venza MADYMO occupant model is shown in Figure 8-3. 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.

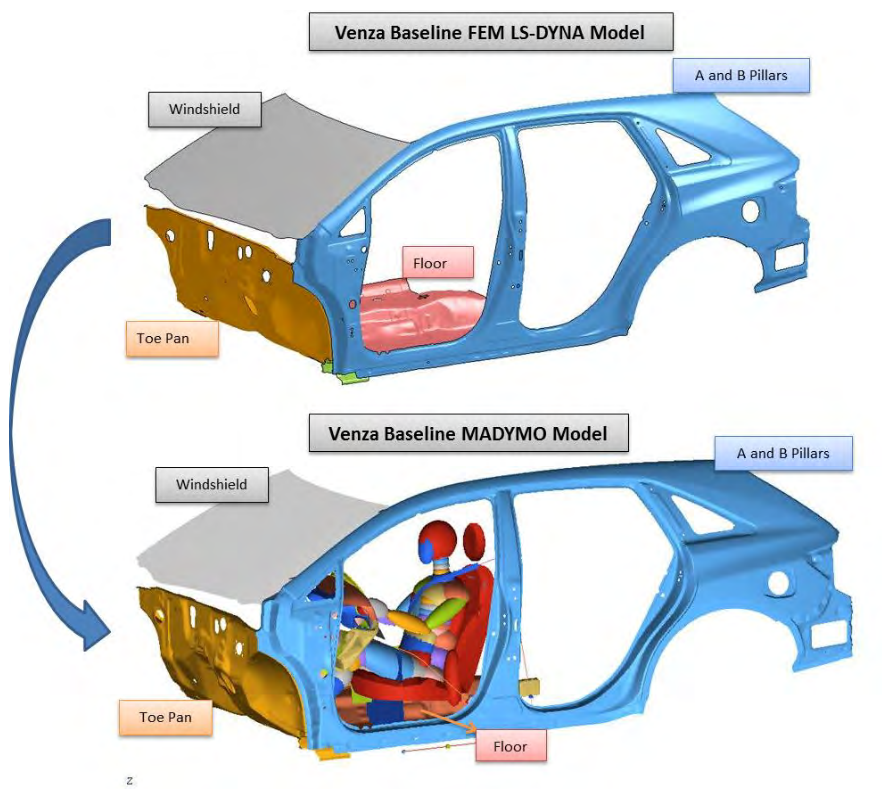

Figure 8-3 – Venza baseline MADYMO occupant Model

The air bag 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 air bag, not a Venza vehicle air bag 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 documentation of the model validation.

8.3 Model Validation

The following naming convention was used for the 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 8-4. 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[1] is shown in Figure 8-5. As it can be seen in Figure 8-4, 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.

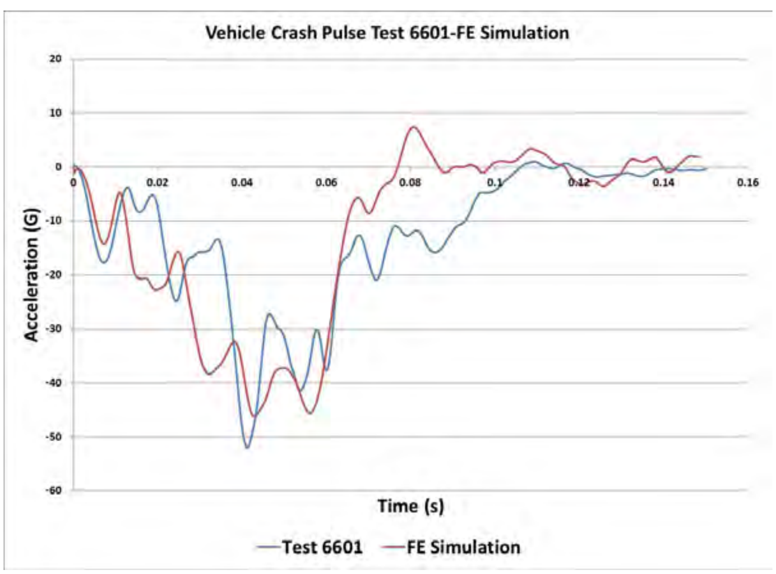

Figure 8-4 – Vehicle ccrash pulse comparison between Test 6601 and FE simulation

[1] http://www.epa.gov/oms/climate/documents/420r12026.pdf

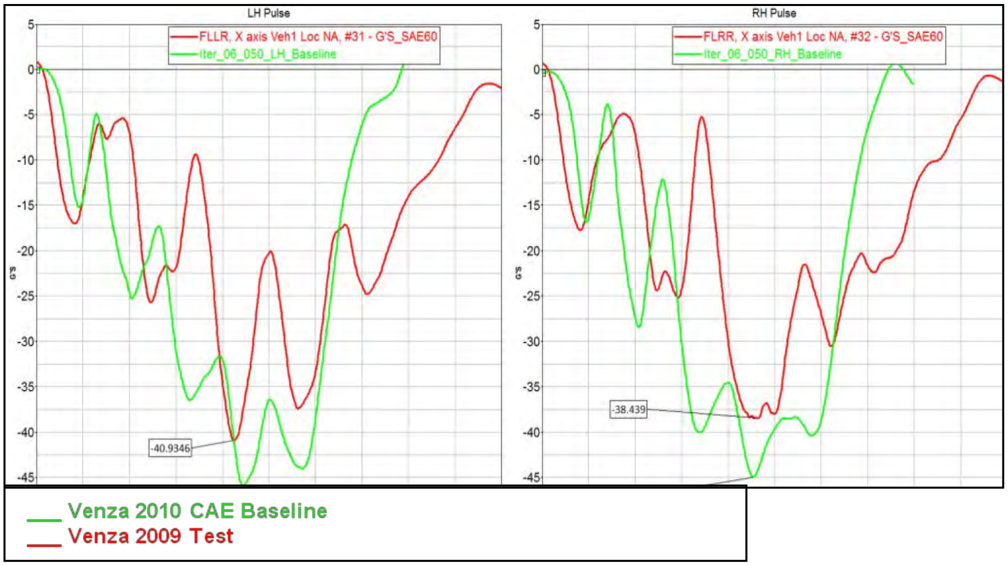

Figure 8-5 – Body pulse: CAE baseline model vs. test

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 8-6 and Figure 8-7 show the shoulder and lap belt forces for the test and both MADYMO simulations.

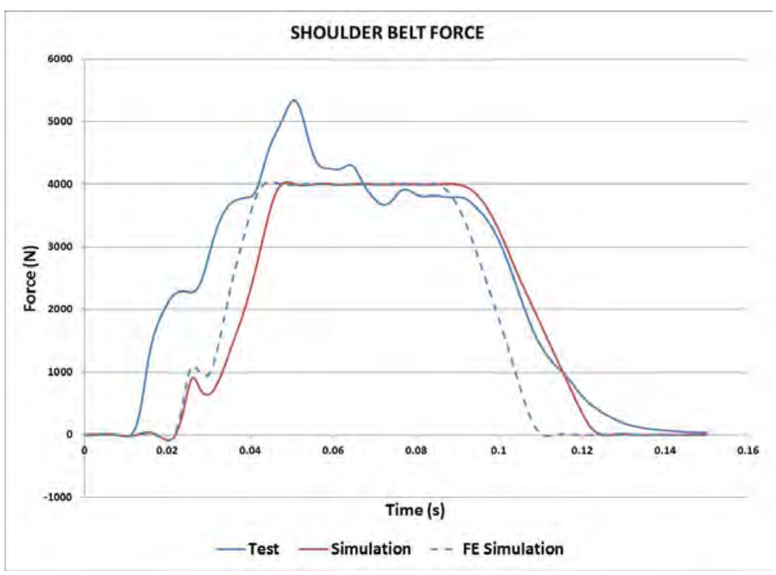

Figure 8-6 – Comparison of shoulder belt force from Test 6601 and Simulation

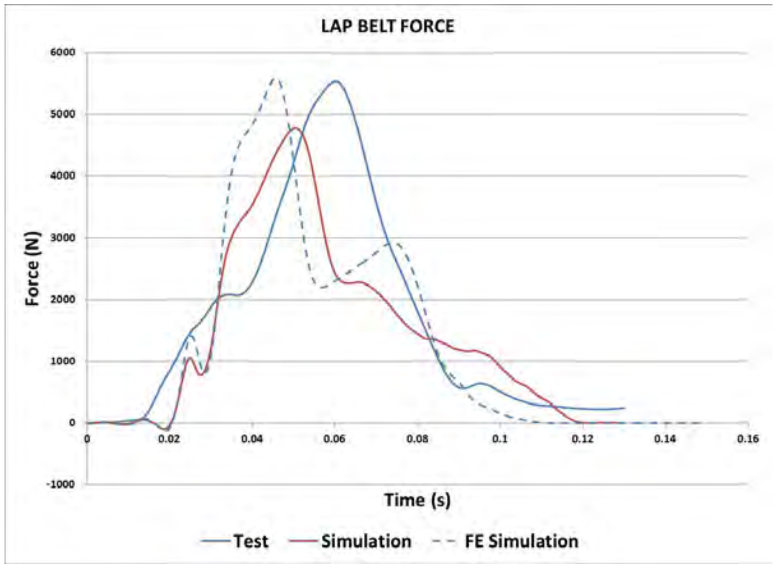

Figure 8-7 – Comparison of lap belt force from Test 6601 and simulation

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 8-8). The occupant's head kinematics at the peak of the resultant acceleration is shown in Figure 8-9. 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 air bag and not the one from the test, the head-air bag interaction forces of the test and simulation are different, which leads to different peak and timing of the head resultant acceleration.

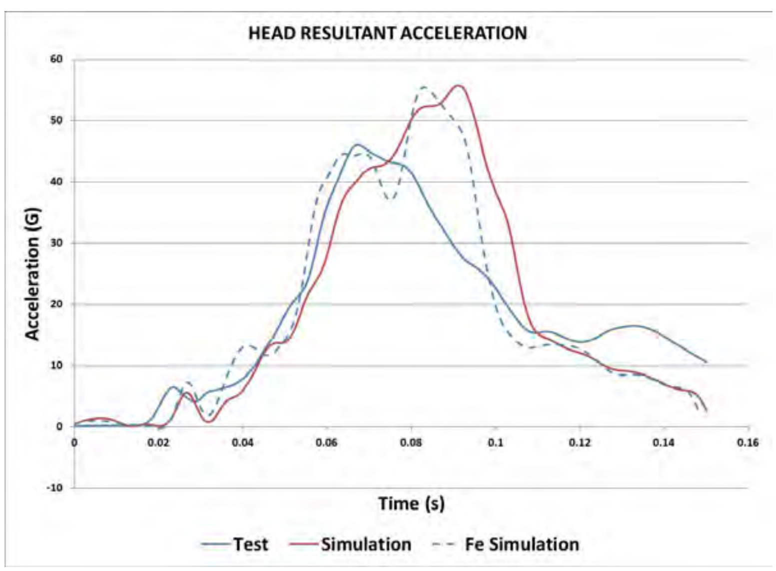

Figure 8-8 – Comparison of head acceleration for Test 6601 and simulation

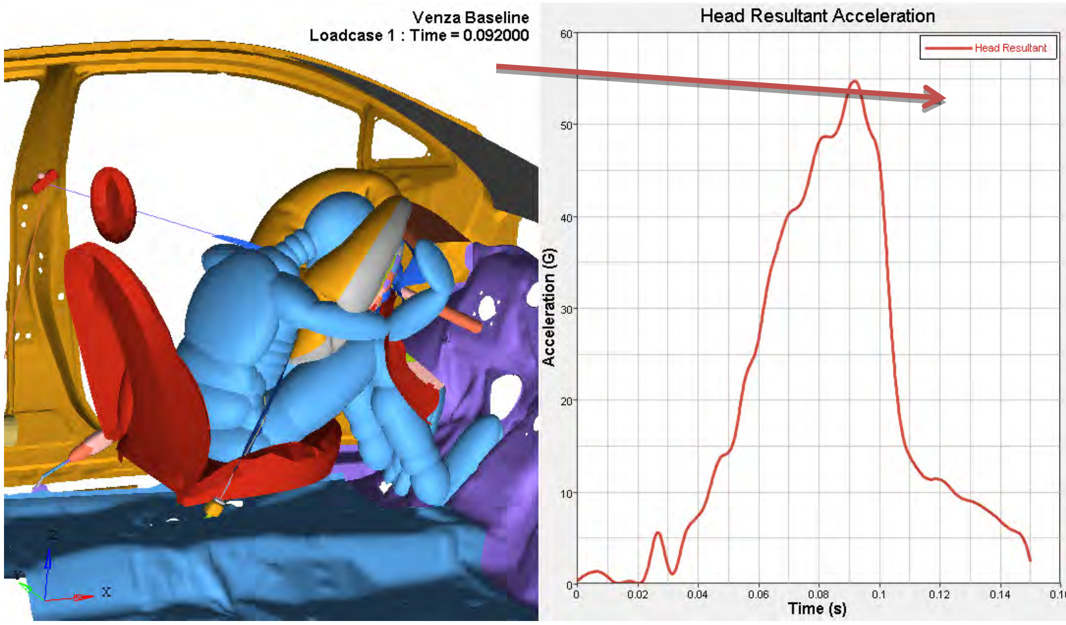

Figure 8-9 – Head kinematics for Venza baseline model at peak acceleration time

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 8-10). 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 8-14 and Figure 8-15) that peaked at 50 milliseconds lead to higher pelvis accelerations (Figure 8-11), which in turn lead to higher peak chest acceleration.

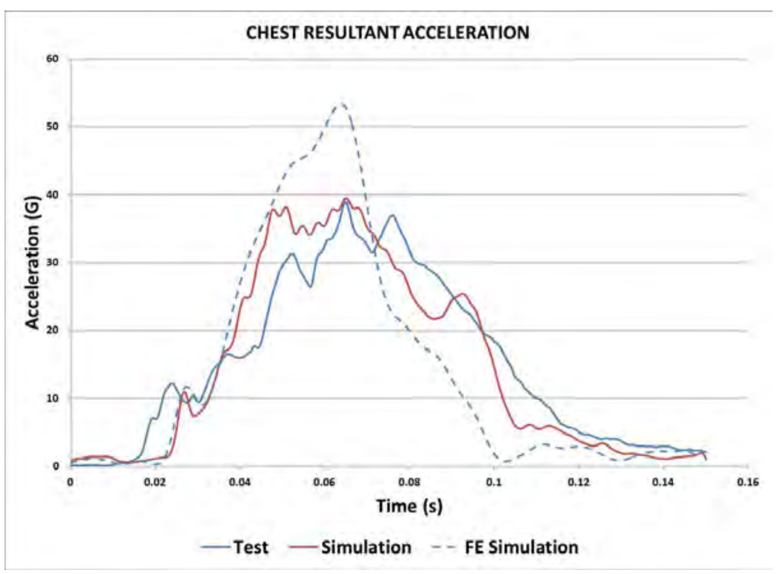

Figure 8-10 – Comparison of chest acceleration from test 6601 and simulation

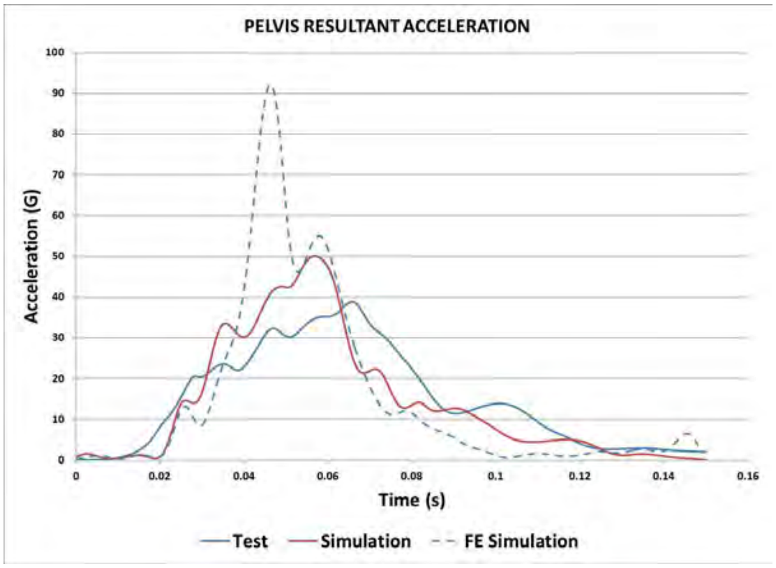

Figure 8-11 – Comparison of pelvis acceleration from Test 6601 and simulation

The chest deflection plots for both MADYMO simulations fall within the general shape of the test output, as shown in Figure 8-12.

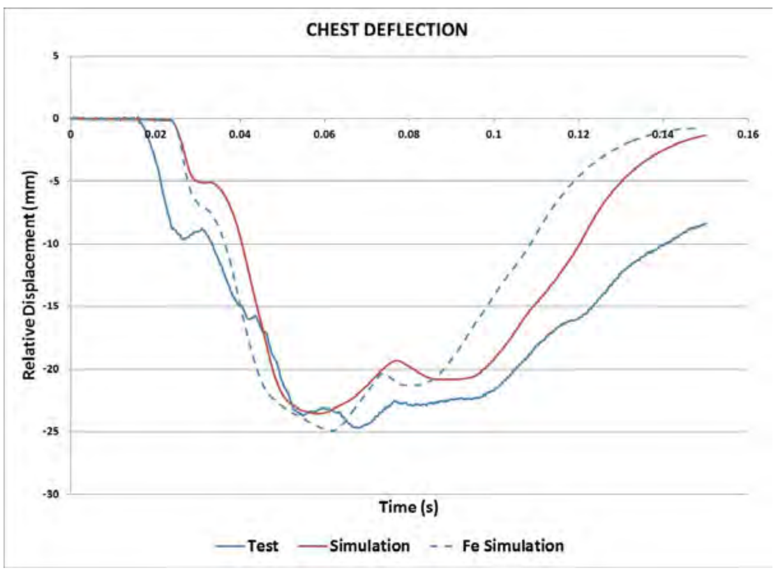

Figure 8-12 – Comparison of chest deflection from Test 6601 and simulation

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 8-13). From the occupant kinematics shown in Figure 8-9, it can be seen that there was contact between the head and air bag 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 air bag 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.

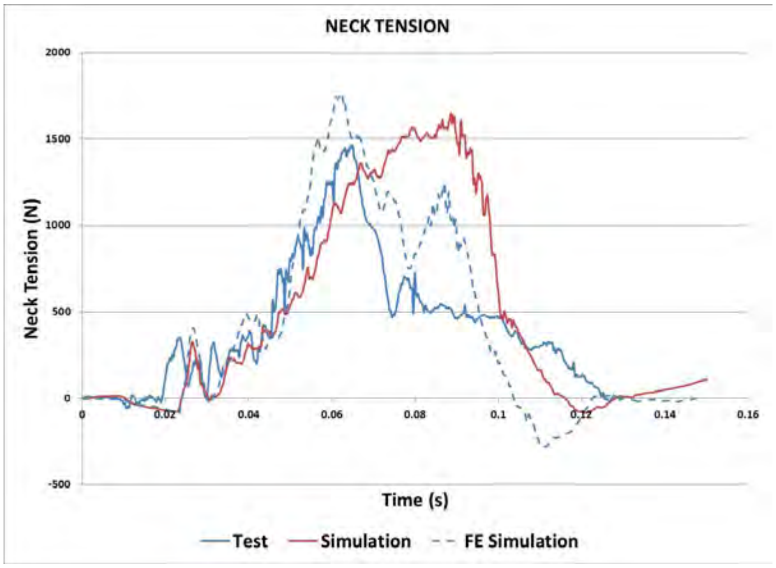

Figure 8-13 – Comparison of neck tension from Test 6601 and simulation

The left and right femur load comparisons for the test and simulations are shown in Figure 8-14 and Figure 8-15. The Venza baseline MADYMO model did not model the knee air bags 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.

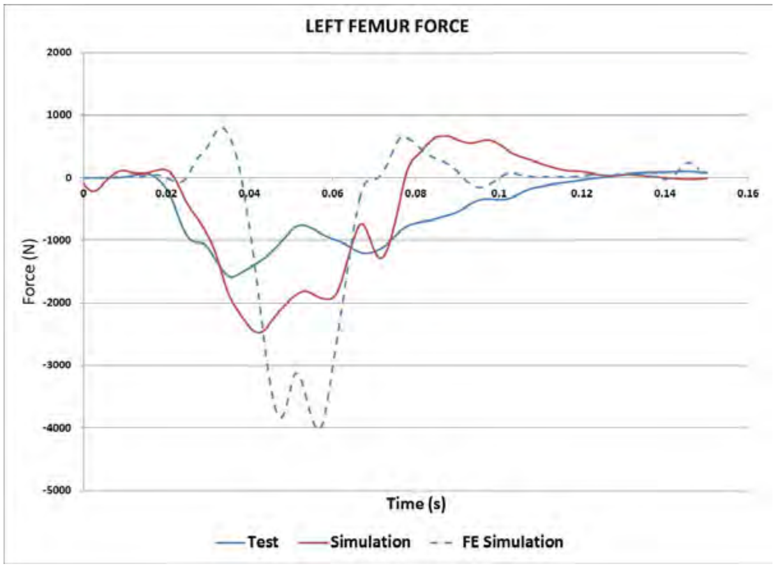

Figure 8-14 – Comparison of left femur force from test and simulation

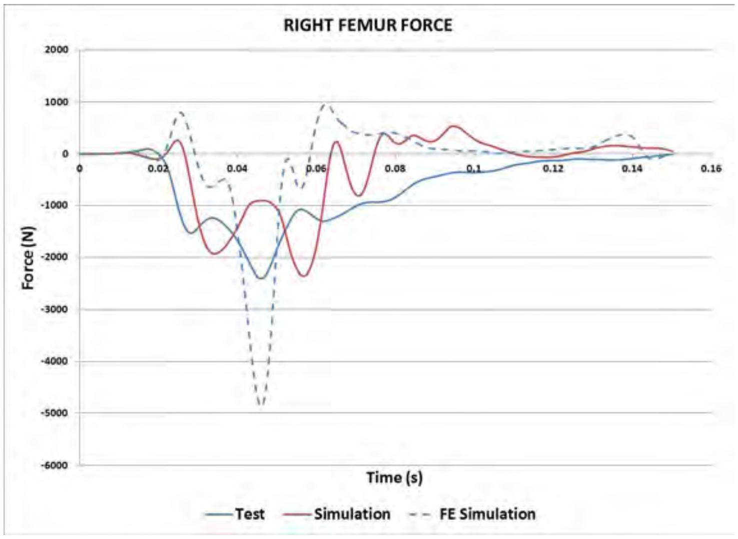

Figure 8-15 – Comparison of right femur force from test and simulation

8.4 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 8-1. 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 air bags present in the vehicle helped mitigate the femur loads.

Table 8-1 – Occupant Injury Results

NCAP	HIC 15	Chest 3MS (Gs)	Chest Deflection (mm)	Neck Tension (N)	Femur Left Load (N)	Femur Right Load (N)
Test 6601	339	36	25	1460	1667	2549
MADYMO Simulation using test crash pulse	302	38	23	1650	2549	2365
MADYMO Simulation using FE pulse	242	53	25	1768	4225	4970

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.

8.5 Acknowledgements

The authors wish to acknowledge the Federal Highway Administration and National Highway Traffic Safety Administration of the U.S. Department of Transportation for supporting these modeling and simulation efforts.

9 APPENDIX 9: DEVELOPMENT AND VALIDATION OF A TOYOTA YARIS MADYMO FRONTAL OCCUPANT MODEL

9.1 Introduction

A frontal MADYMO model of a driver in a Toyota Yaris was developed by the National Crash Analysis Center of the George Washington University in support of the NHTSA study, “Investigate Self and Partner Protection of New Vehicle Designs Using Structural Modeling,” TOPR No. 16 under DTFH61-09-D-00001. For this study, several different vehicle finite element (FE) models were developed, including the Toyota Yaris, and run under different crash configurations in single vehicle and two vehicle crashes. The data from these FE models were used as inputs for the frontal MADYMO models that were developed to assess occupant injury risk.

To develop the MADYMO models, the NCAC obtained generic occupant models from restraint manufacturers, upon which the specific vehicle models would be built. For the Toyota Yaris, a generic model year (MY) 20011 small car was used as a foundation. 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 Yaris.

The Yaris occupant simulations were first validated against frontal crash test data. Then, the simulations were run in the same crash tests configurations, but using the pulses output by the LS-DYNA FE simulations. This check was performed to ensure that reasonable occupant responses would be observed once the FE simulation outputs were used in the occupant models. Lastly, the occupant model was run under several different crash configurations to confirm the stability and robustness of the model and to verify that reasonable occupant response trends would be observed. This paper serves as documentation of the above model development and validation processes.

9.2 Model Development

The first step in modifying the MY 2011 small car model was to position the dummy according to available test reports. The dummy positions for the 50th percentile male and 5th percentile female were based on NHTSA test nos. 6221 and 6069, respectively [1,2]. For the offset frontal configuration, IIHS test no. CEF0610 was used to position the 50th percentile dummy [3]. The same dummy positioning for the 5th percentile dummy was used in both the full frontal and offset frontal crash configurations. Measurements such as the seat back angle (deg), head to windshield (mm), nose to rim (mm), chest to dash (mm), steering wheel to chest (mm), rim to abdomen (mm), left knee to dash (mm), right knee to dash (mm), tibia angle (deg), and knee to knee (mm) were considered in positioning the dummies. The dummies were positioned to match as many of these measurements as possible. The model was also subject to visual inspection to ensure that the final position was physically reasonable. The final positions of the 50th percentile dummy and 5th percentile dummy are shown in Figure 9-1.

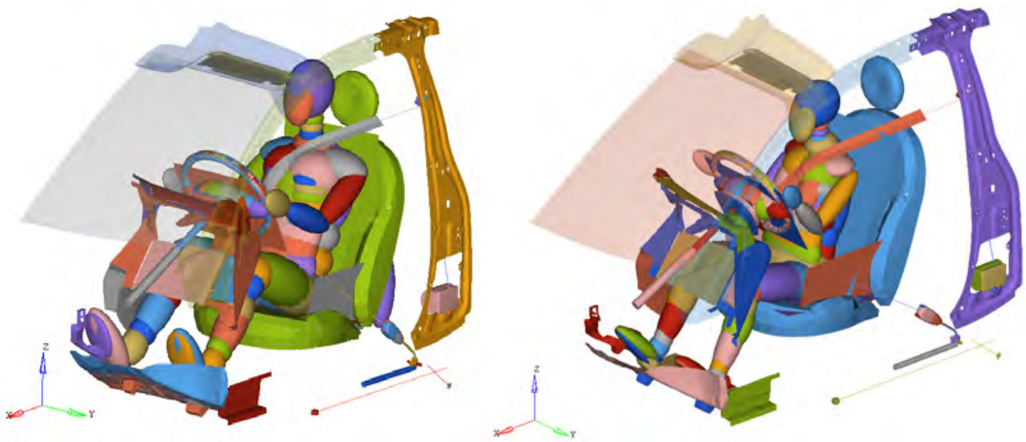

Figure 9-1 – Final position of 50th percentile (left) and 5th percentile (right) dummies in Yaris full frontal model

The shoulder belt loads from the crash test data were analyzed to determine the air bag and pretensioner firing time. For NHTSA test no. 5677, the firing time was observed to be 20 ms (Figure 9-2) [4].

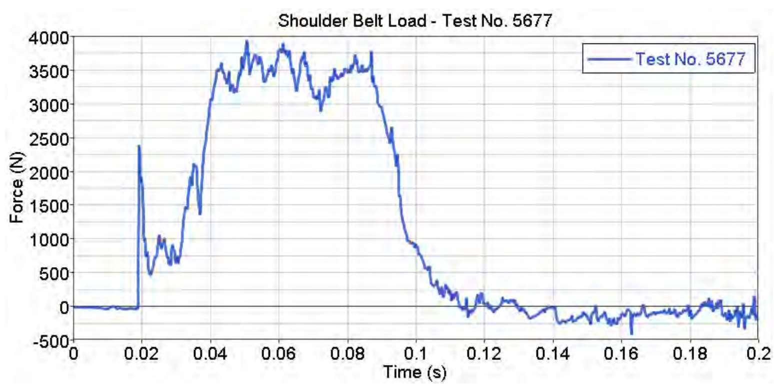

Figure 9-2 – Shoulder belt force for NHTSA test no. 5677

The firing time for this specific case was then used to determine a firing time rule that would be applicable to all crash speeds. The general guideline for determining firing time is to use the 5-30 rule, but the crash data showed that the firing time for this vehicle did not conform to the general guideline. The crash pulse from the test was double integrated to give the displacement time history, as shown in Figure 9-3. Seven inches of displacement were observed at 50 ms, which would correspond to a 7-30 rule. For all simulations that were run in this study, the firing time was determined with this rule—30 ms less than the time at which 7 inches of displacement were observed.

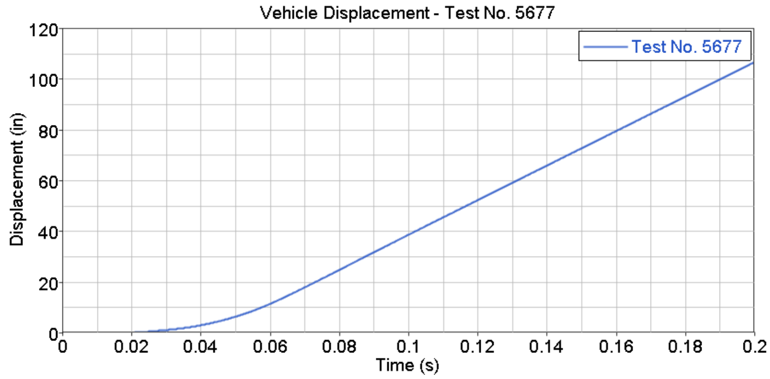

Figure 9-3 – Vehicle displacement time history for NHTSA test no. 5677

The restraint system was fine-tuned through an iterative process until the model output the expected occupant accelerations according to the crash test data. All simulations were run with an air bag vent size of 30 mm. The shoulder belt characteristics were modified to match the belt load data from NHTSA test no. 6221 [1]. The belt characteristics were changed as described below and as indicated in Figure 9-4.

1. The retractor system was tuned according to the test shoulder belt load. The first peak at 15 ms was controlled with a generic pretensioner function.
2. The dip after the first peak was controlled by changing the amount of belt payout during pretensioning.
3. The slope of the shoulder belt force was controlled with a retractor spooling function.
4. Digressive load limiting was added to the model.

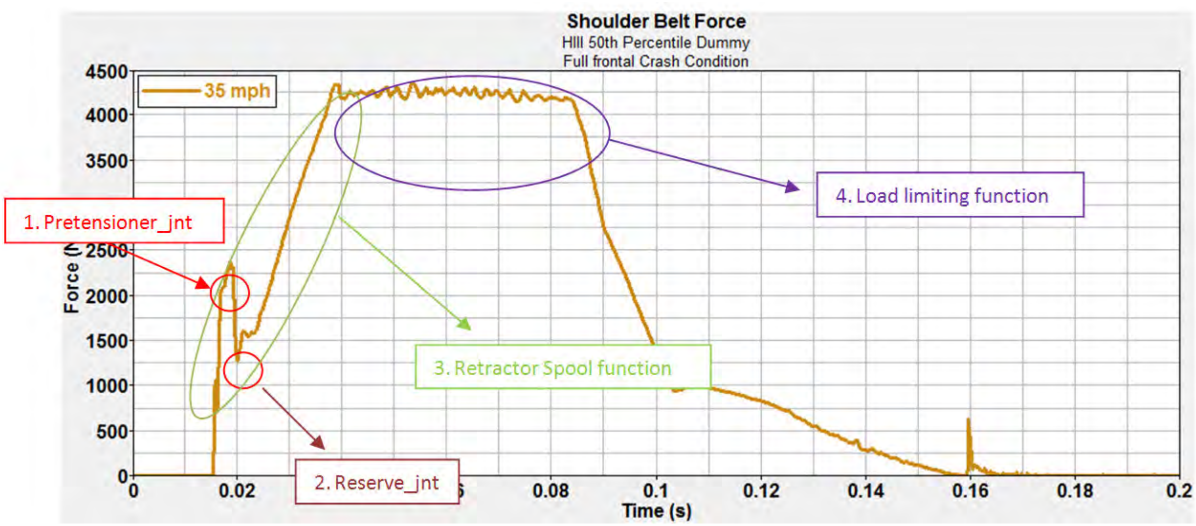

Figure 9-4 – Yaris shoulder belt force

9.3 Model Validation

The Yaris occupant models with the 50th percentile male dummy and 5th percentile female dummy were validated against available full frontal crash data. The primary responses that were compared in this validation study are discussed in the following section.

9.3.1 Full Frontal 35 mph Validation: 50th Percentile Male Dummy

The 50th percentile occupant model seated in the Yaris was validated against NHTSA test no. 6221, a full frontal impact into a rigid barrier at 35 mph [1]. Two simulations were run for this crash configuration, one at 35 mph using the test pulse and one at 35 mph using the FE pulse (Figure 9-5).

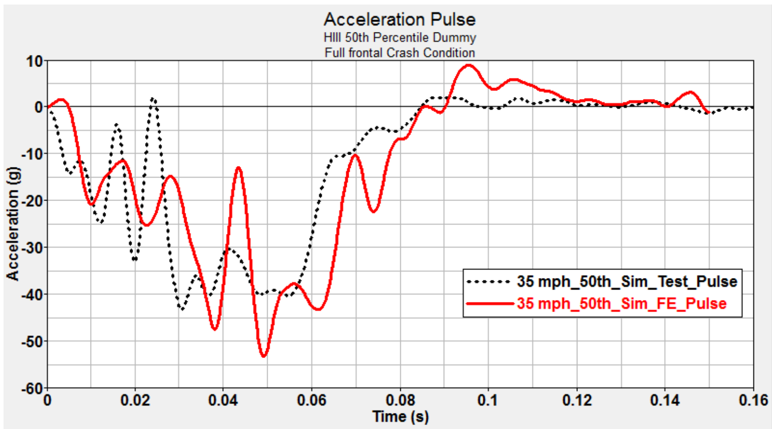

Figure 9-5 – Vehicle pulse comparison between test no. 6221 and FE simulation output

The lap and shoulder belt forces from the simulations were compared to the test data, as shown in Figure 9-6.

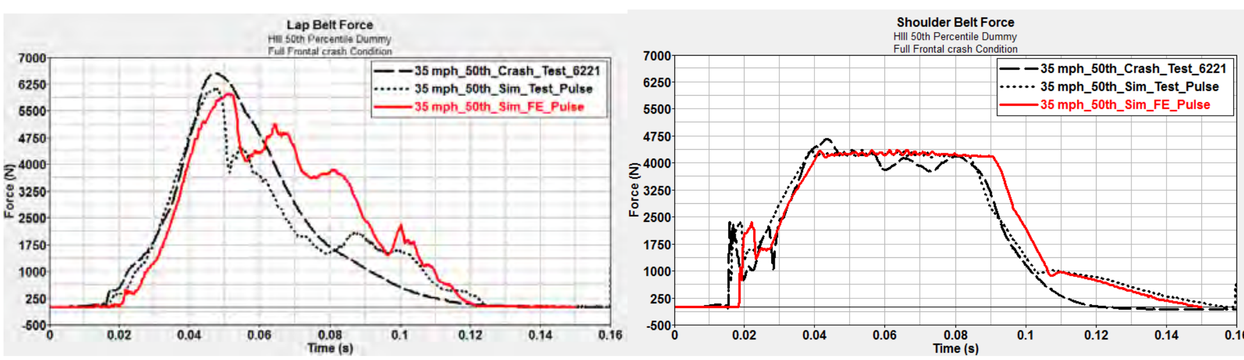

Figure 9-6 – Lap and shoulder belt forces from test and simulations for 35 mph full frontal impact

All of the outputs for the dummy model were compared to the available crash test data. However, only the chest deflection (Figure 9-7), head acceleration (Figure 9-8), neck tension (Figure 9-9), and femur forces (Figure 9-10) will be shown below, as these were the body regions of interest in the overall study.

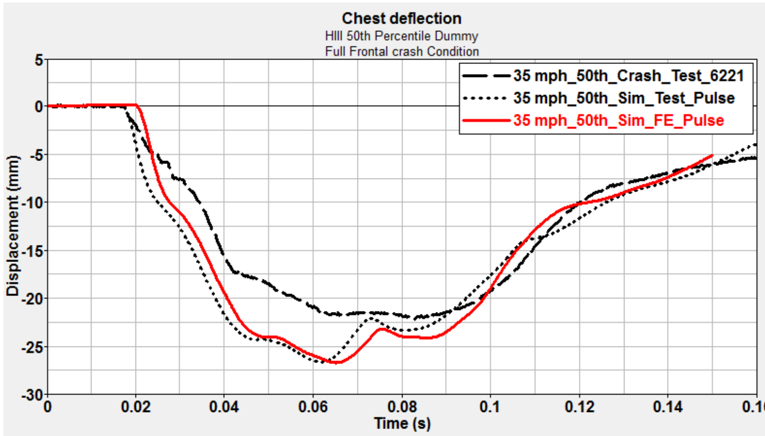

Figure 9-7 – Comparison of chest deflection from test and simulations for 35 mph full frontal impact

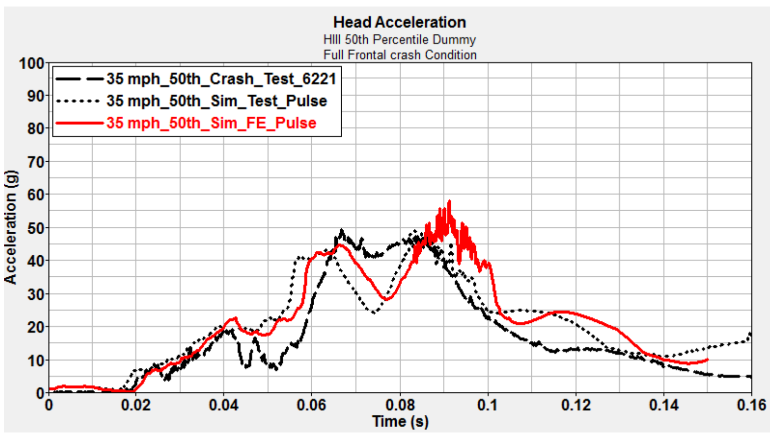

Figure 9-8 – Comparison of head acceleration from test and simulations for 35 mph full frontal impact

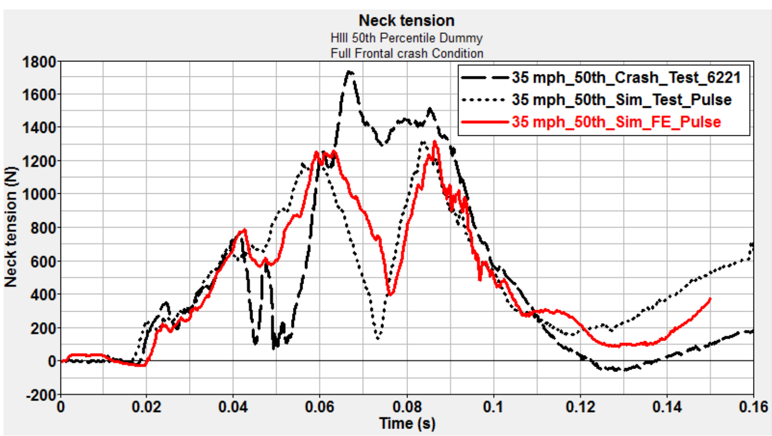

Figure 9-9 – Comparison of neck tension from test and simulations for 35 mph full frontal impact

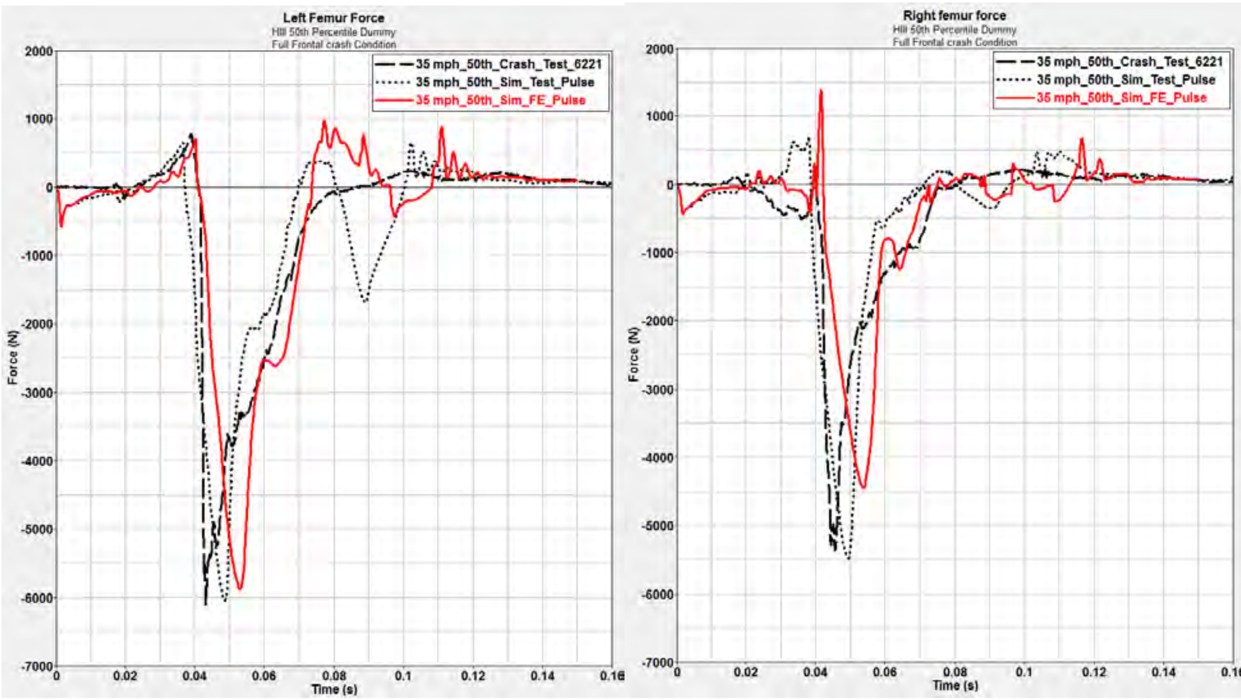

Figure 9-10 – Comparison of left and right femur forces from test and simulations for 35 mph full frontal impact

9.3.2 Full Frontal 25 mph Validation: 50th Percentile Male Dummy

The 50th percentile dummy model seated in the Yaris was also run in a full frontal impact into a rigid barrier at 25 mph. No regulatory or consumer information crash tests were available with the 50th percentile dummy in this configuration, so the test pulse from NHTSA test no. 6069 (which involved a 5th percentile dummy) was used to drive this simulation [2]. This was checked against a simulation in which the FE pulse was used to ensure that the FE pulse was reasonably representative of the test pulse.

Three simulations were run for this crash configuration, one at 25 mph using the test pulse, one at 25 mph using the FE pulse, and one at 30 mph using the FE pulse (Figure 9-11). The 30 mph simulation was run to verify that the response was trending as expected, i.e., that the 30 mph impact would yield higher dummy responses than the 25 mph impact.

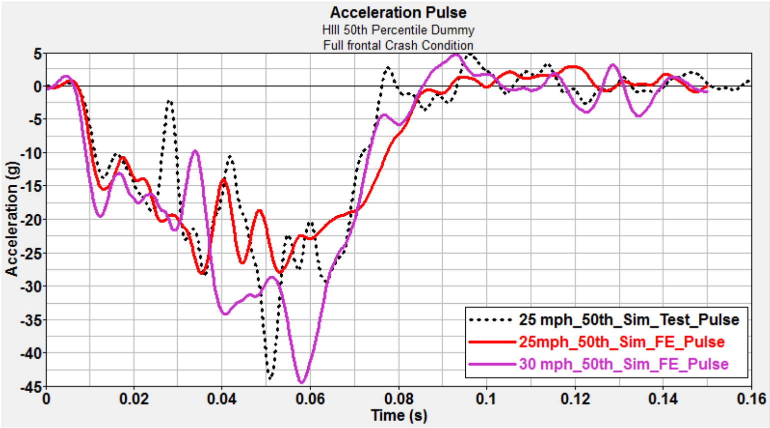

Figure 9-11 – Vehicle pulse comparison between test no. 6069 and FE simulation outputs

The chest deflection (Figure 9-12), head acceleration (Figure 9-13), neck tension (Figure 9-14), and femur forces (Figure 9-15) were compared between the three simulations.

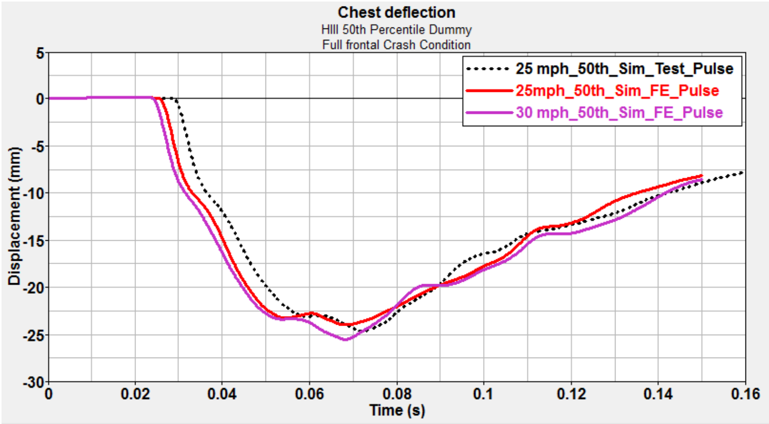

Figure 9-12 – Comparison of chest deflection from three simulations for full frontal impact

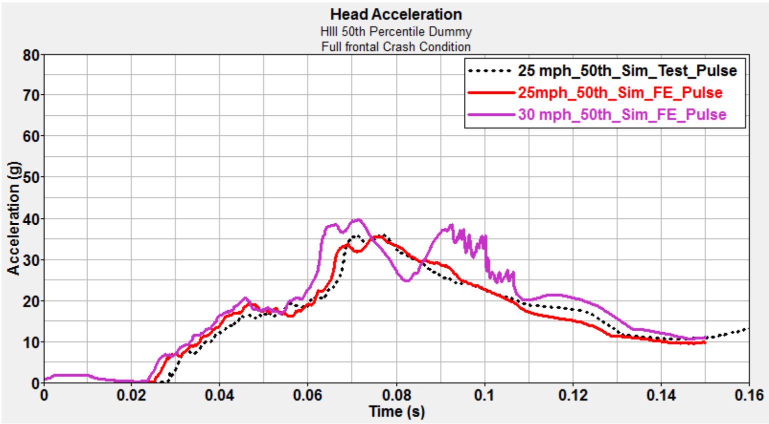

Figure 9-13 – Comparison of head acceleration from three simulations for full frontal impact

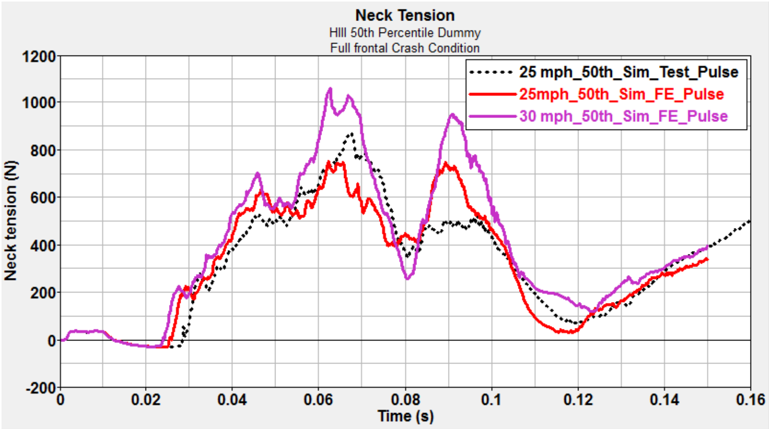

Figure 9-14 – Comparison of neck tension from three simulations for full frontal impact

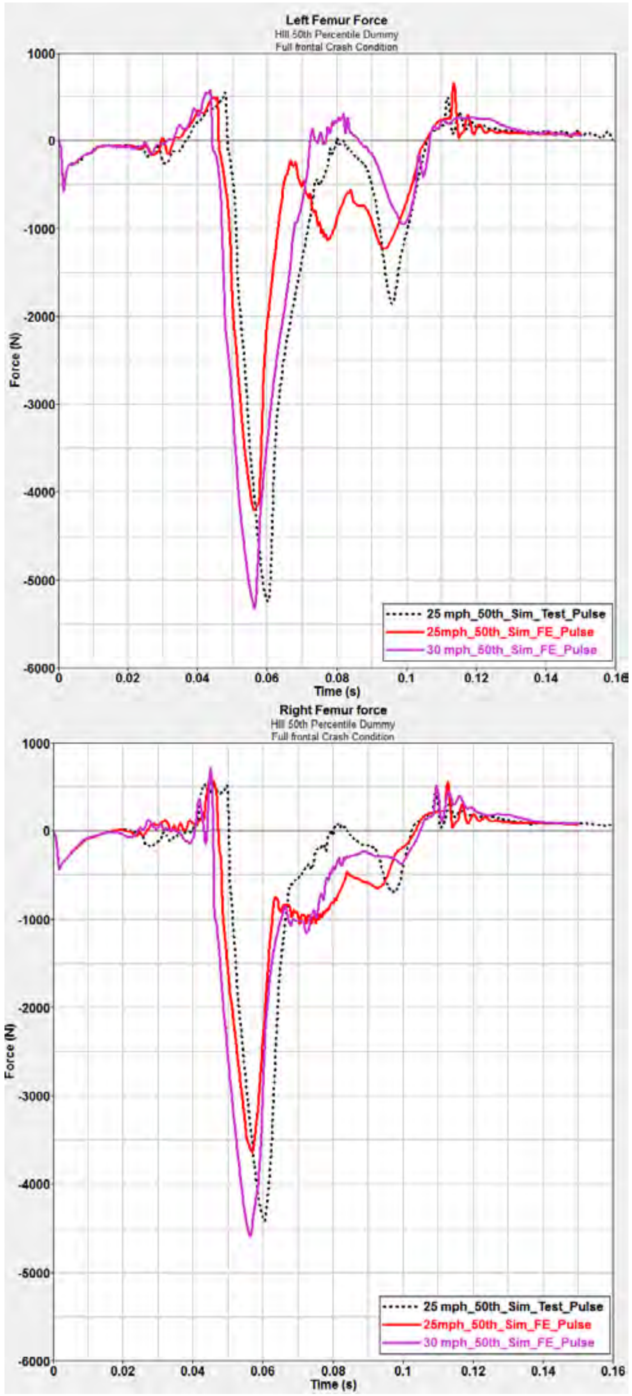

Figure 9-15 – Comparison of left and right femur forces from three simulations for full frontal impact

9.3.3 Offset Frontal 40 mph Validation: 50th Percentile Male Dummy

The 50th percentile male dummy model seated in the Yaris was validated against IIHS test no. CEF0610, an offset frontal impact with a deformable barrier at 40 mph [3]. Three simulations were run for this crash configuration, one using the test pulse at 40 mph, one using the FE pulse at 40 mph, and one using the FE pulse at 25 mph (Figure 9-16). For the offset crash configuration, all three linear accelerations were used to drive the simulation.

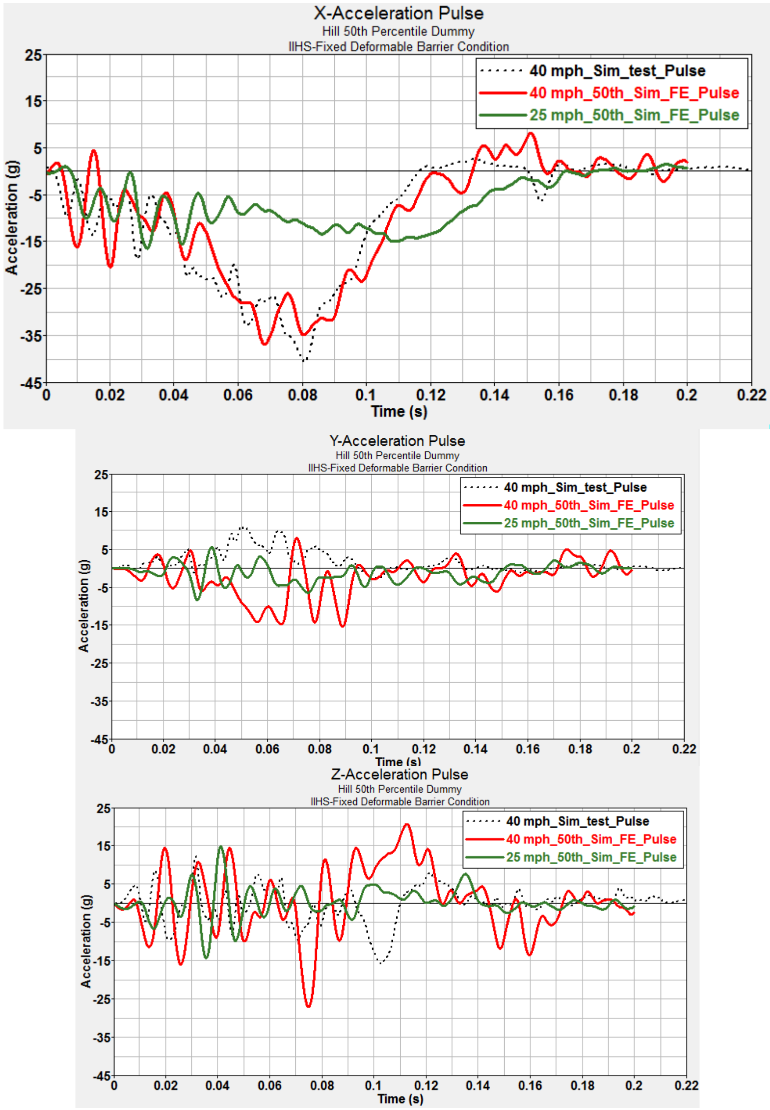

Figure 9-16 – Comparison of X, Y, and Z vehicle acceleration from test and simulations for offset frontal impact

No belt data were available for this test. The chest deflection (Figure 9-17), head acceleration (Figure 9-18), neck tension (Figure 9-19), and femur forces (Figure 9-20) were compared between the test and simulations, showing reasonable correlation.

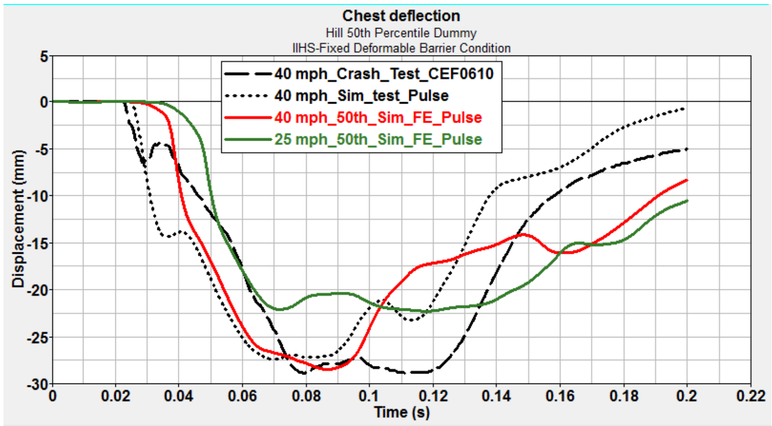

Figure 9-17 – Comparison of chest deflection from test and simulations for offset frontal impact

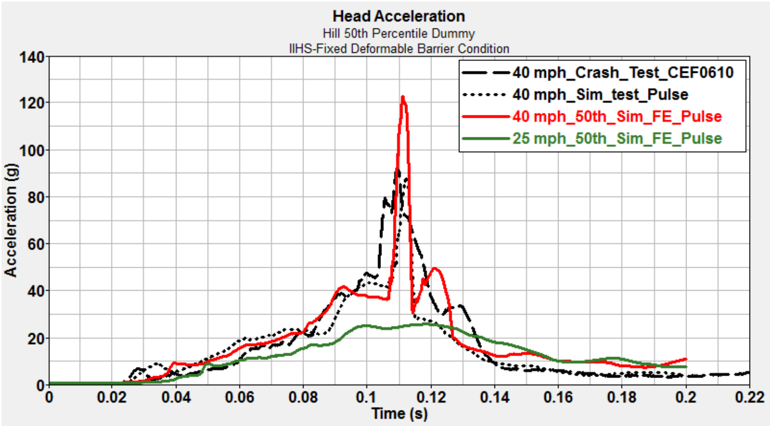

Figure 9-18 – Comparison of head acceleration from test and simulations for offset frontal impact

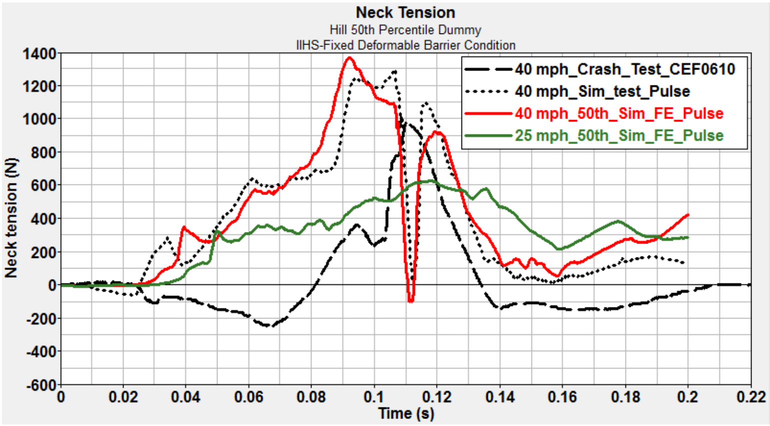

Figure 9-19 – Comparison of neck tension from test and simulations for offset frontal impact

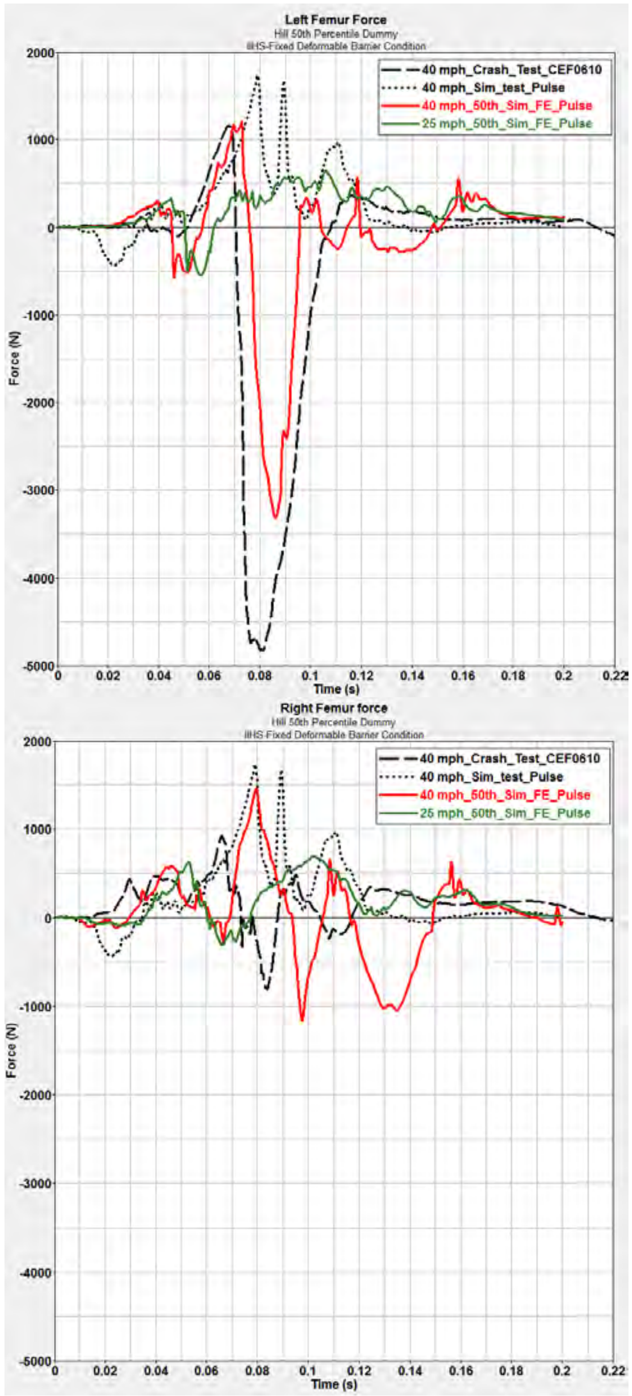

Figure 9-20 – Comparison of left and right femur forces from test and simulations for offset frontal impact

9.3.4 Full Frontal 25 mph Validation: 5th Percentile Female Dummy

An unbelted 5th percentile female dummy model seated in the Yaris was validated against NHTSA test no. 6069, a full frontal impact into a rigid barrier at 25 mph [2]. One simulation was run using the pulse from the crash test, shown in Figure 9-21.

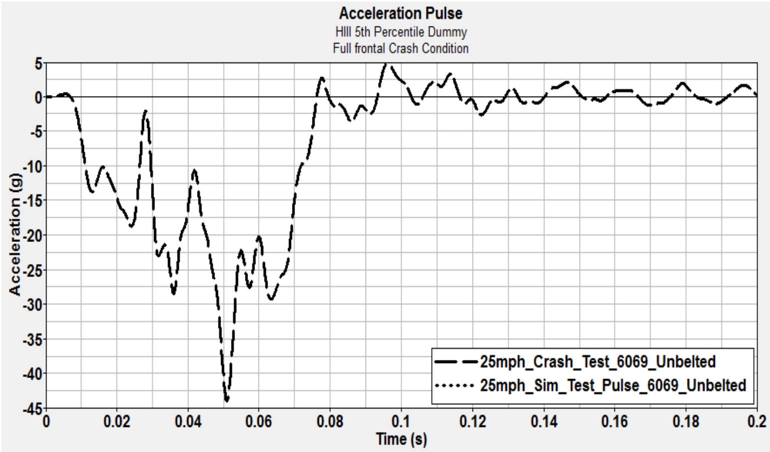

Figure 9-21 – Yaris 25 mph full frontal impact crash pulse

Belt forces were not compared in these simulations because the test involved an unbelted occupant. The chest deflection (Figure 9-22), head acceleration (Figure 9-23), neck tension (Figure 9-24), and femur forces (Figure 9-25) were compared between the test and simulations, showing reasonable correlation.

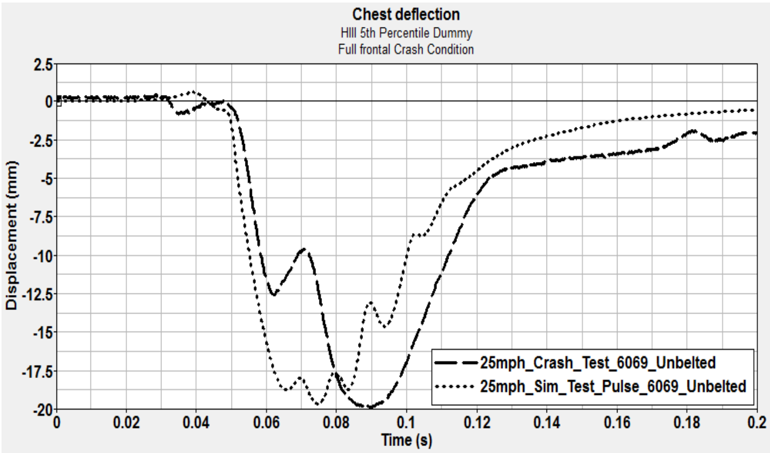

Figure 9-22 – Comparison of chest deflection from test and simulations for full frontal impact

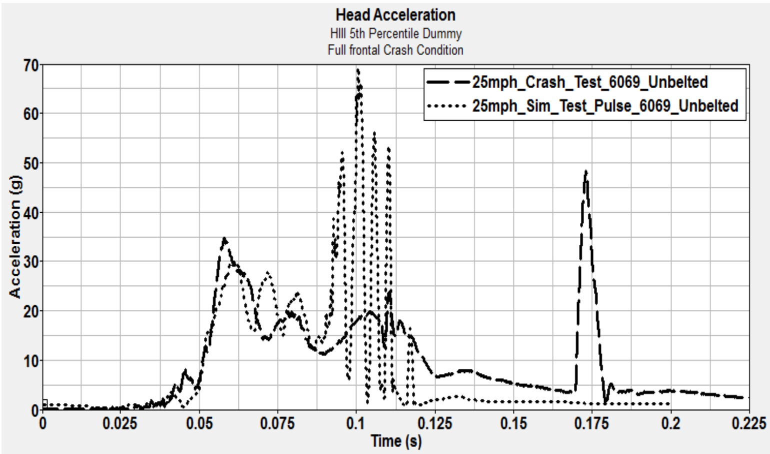

Figure 9-23 – Comparison of head acceleration from test and simulations for full frontal impact

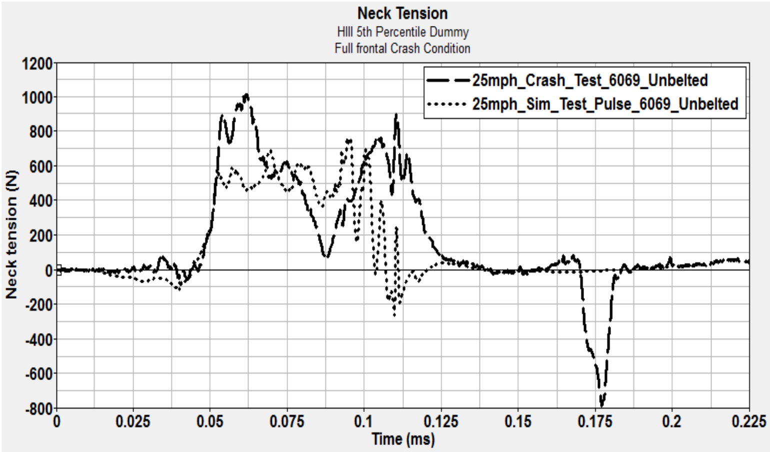

Figure 9-24 – Comparison of neck tension from test and simulations for full frontal impact

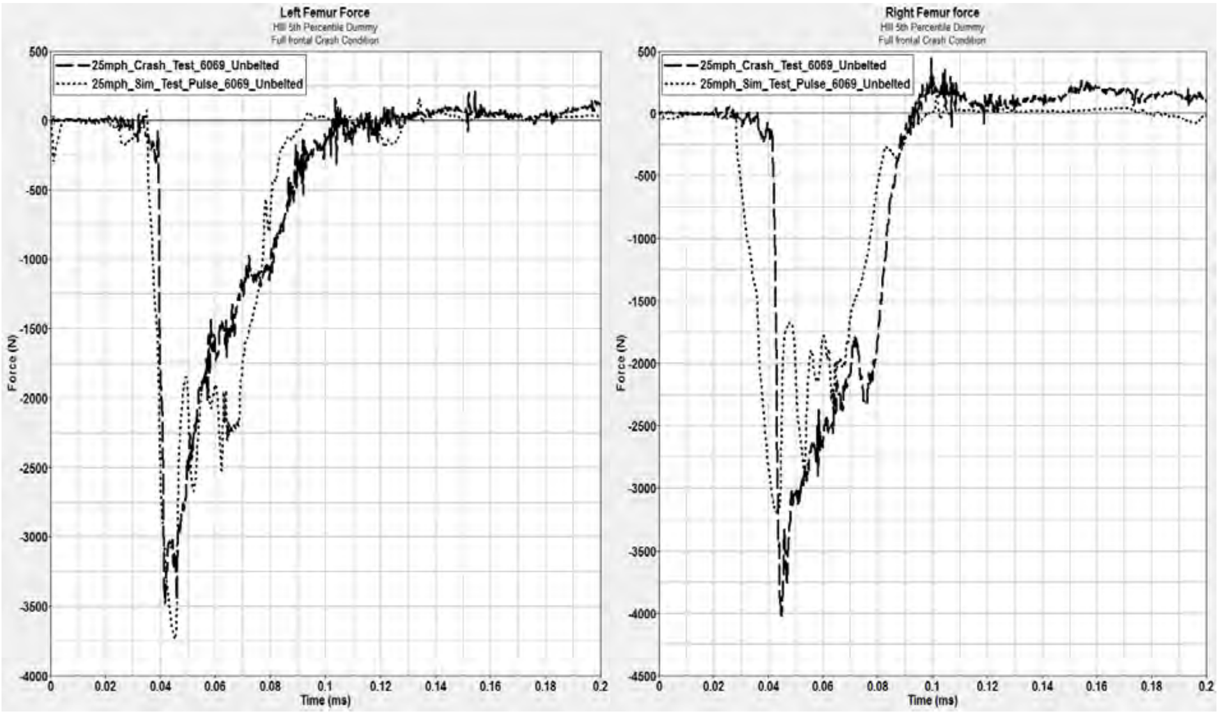

Figure 9-25 – Comparison of left and right femur forces from test and simulations for full frontal impact

9.3.5 Full Frontal 35 mph Validation: 5th Percentile Female Dummy

The 5th percentile dummy model seated in the Yaris was also run in a full frontal impact into a rigid barrier at 35 mph. No regulatory or consumer information crash tests were available with the 5th percentile dummy in this configuration, so the test pulse from NHTSA test no. 6221 (which involved a 50th percentile dummy) was used to drive this simulation [1]. This was checked against a simulation in which the FE pulse was used to ensure that the FE pulse was reasonably representative of the test pulse. A third simulation was run at 30 mph using the FE pulse to confirm that the lower speed would lead to lower injury. A comparison of these pulses is shown in Figure 9-26.

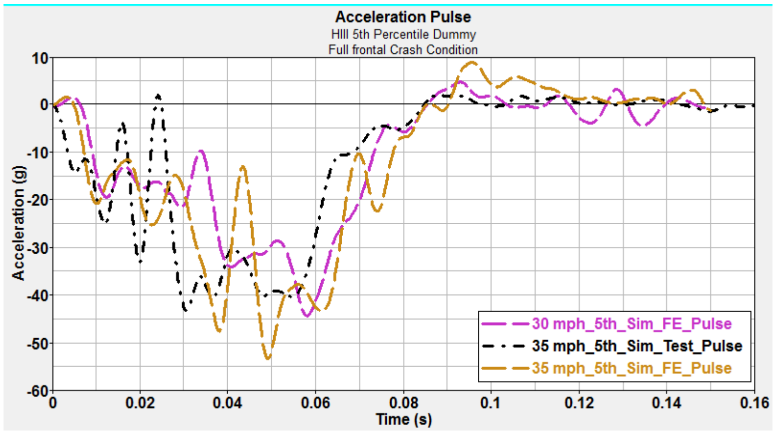

Figure 9-26 – Comparison of vehicle pulse from test and simulation for full frontal impact

Figure 9-27 compares the lap and shoulder belt forces of the three simulations.

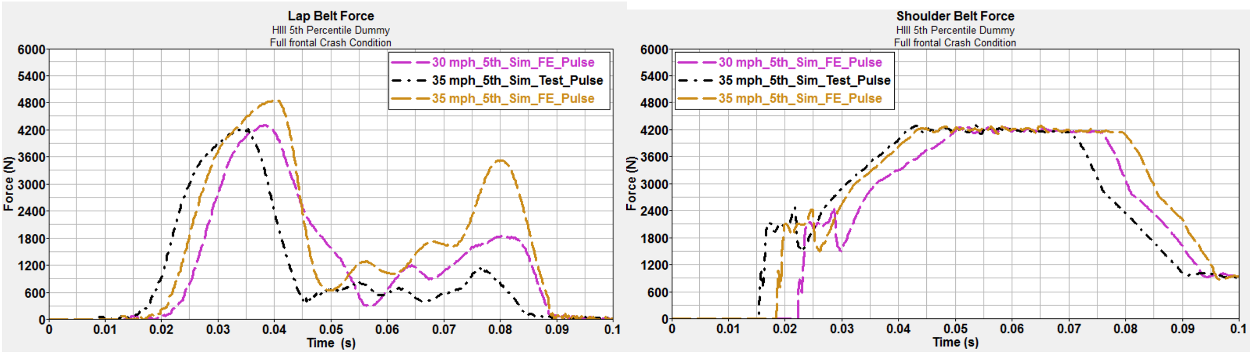

Figure 9-27 – Comparison of lap and shoulder belt forces from two simulations for full frontal impact

The chest deflection (Figure 9-28), head acceleration (Figure 9-29), neck tension (Figure 9-30), and femur loads (Figure 9-31) were also compared between the simulations, showing a reasonable match.

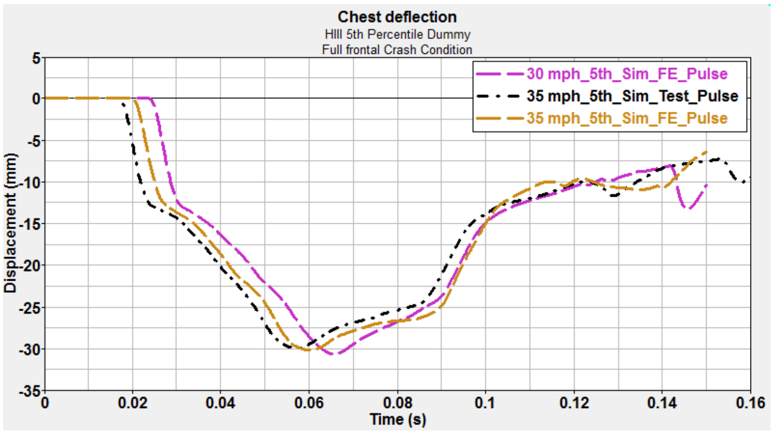

Figure 9-28 – Comparison of chest deflection from two simulations for full frontal impact

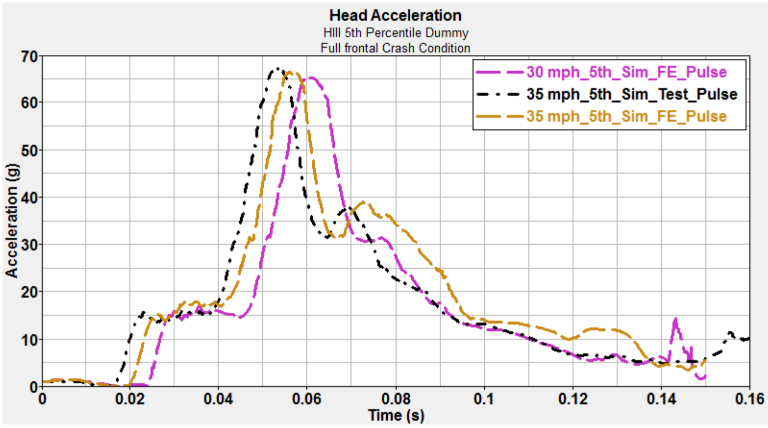

Figure 9-29 – Comparison of head acceleration from two simulations for full frontal impact

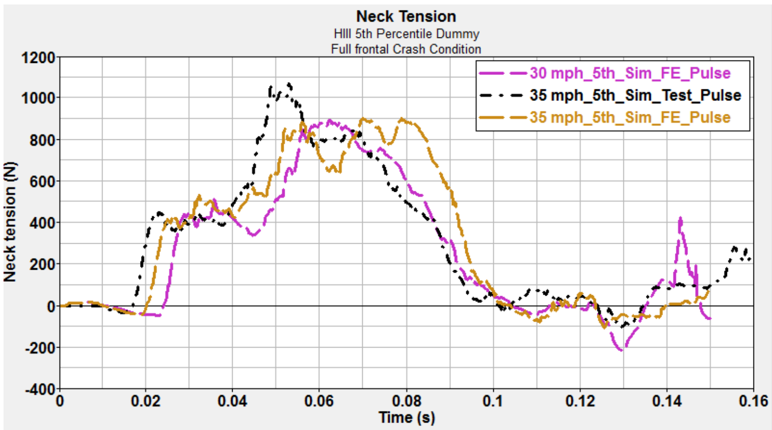

Figure 9-30 – Comparison of neck tension from two simulations for full frontal impact

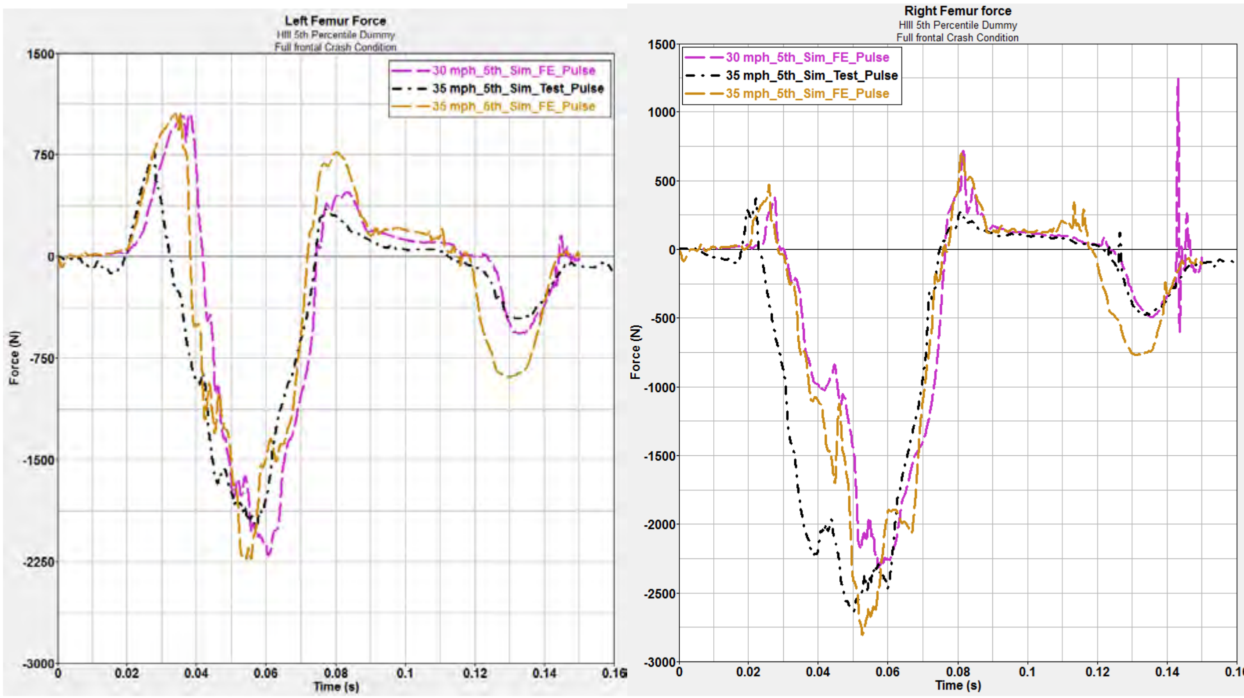

Figure 9-31 – Comparison of left and right femur forces from two simulations for full frontal impact

9.3.6 Validation Summary

The results from the validation study are summarized in Table 9-1 and Table 9-2 for the 50th percentile dummy and in Table 9-3 for the 5th percentile dummy.

Table 9-1 – 50th percentilepercentile dummy full frontal validation results

	H350/50th	NHTSA 25 mph 50th FE_pulse	NHTSA 25 mph 50th Test_Pulse _6069	NHTSA 30 mph 50th, FE_Pulse	NHTSA 35 mph, 50th Test_Pulse _6221	NHTSA 35 mph 50th Test_Pulse _6221	NHTSA 35 mph 50th FE_pulse
Response	**Formula**	**Simulation FE Pulse Results**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**	**Crash Test Results (6221)**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	98	101	122	195.33	170	222
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	177	165	237	389.589	313	385
Neck Tension (T)	**Upper Neck Fz Max**	749	874	1060	1733.27	1323	1314
Chest deflection (mm)	**Max Deflection**	24	25	26	22.206	27	27
Chest acceleration (g)	**Max Acceleration**	37	38	43	43.023	46	47
Femur Load - Left (N)	**Max Compression force Fz**	4202	5239	5321	6034.737	6045	5882
Femur Load - Right (N)	**Max Compression force Fz**	3636	4411	4591	5326.779	5479	4446
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.01%	0.0%	0.0%	0.2%	0.1%	0.28%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	2.27%	3%	3%	2%	3%	3.31%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	1.95%	2.97%	3.07%	4.00%	4.02%	3.79%
Neck Tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.01%	0.01%	0.0%	0.1%	0.0%	0.04%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.04	0.06	0.06	0.06	0.07	0.07

Table 9-2 – 50th percentilepercentile dummy offset frontal validation results

	H350/50th	IIHS test data	IIHS 40 mph 50th Test results	IIHS 40 mph 50th	IIHS 25 mph 50th
Response	**Formula**	**Crash Test Results CEF0610**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	628	321	545	49
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	704	389	623	109
Neck Tension (T)	**Upper Neck Fz Max**	979	1293	1367	628
Chest deflection (mm)	**Max Deflection**	29	27	28	22
Chest acceleration (g)	**Max Acceleration**	53	37	41	21
Femur Load - Left (N)	**Max Compression force Fz**	4825	5386	3309	549
Femur Load - Right (N)	**Max Compression force Fz**	804	432	1161	305
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	8.62%	1.16%	5.99%	0.00%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	4%	3.31%	3.93%	1.83%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	2.53%	3.15%	1.30%	0.13%
Neck Tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.02%	0.04%	0.04%	0.01%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.15	0.07	0.11	0.02

Table 9-3 – 5th percentilepercentile dummy full frontal validation results

	H305/5th	NHTSA 25 mph 5th FE Pulse Belted	NHTSA 25 mph 5th Test_pulse _6069 Unbelted	NHTSA 30 mph 5th FE Pulse Belted	NHTSA 35 mph 5th FE Pulse Belted	NHTSA 35 mph 5th FE Pulse Belted
Response	**Formula**	**Simulation FE Pulse Results**	**Crash Test Results**	**Simulation FE Pulse Results**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	326.903	57.885	349.033	345	327.755
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	332.213	69.754	381.469	416	435.6
Neck Tension (T)	**Upper Neck Fz Max**	897.945	1009.47	890.514	1065	897.848
Chest deflection (mm)	**Max Deflection**	29.7817	19.853	30.6405	30	30.18
Chest acceleration (g)	**Max Acceleration**	44.7366	37.478	52.9996	55	57.2942
Femur Load - Left (N)	**Max Compression force Fz**	1857.32	3488.183	2206.09	1999	2235.33
Femur Load - Right (N)	**Max Compression force Fz**	1637.41	4006.009	2314.38	2633	2806.35
HIC15 Risk (AIS 3%)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	1.23%	0.0%	1.5%	1.5%	1.24%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def/0.817)^0.4612)))**	9.02%	2%	10%	9%	9.44%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.47941*max Femur /1000)) - 1/(1+EXP(4.9795))**	0.96%	3.80%	1.36%	1.69%	1.89%
Neck Tension (AIS3%)	**1/(1+EXP(10.958-3.77*NeckTension/1000))**	0.05%	0.1%	0.0%	0.1%	0.05%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.11	0.06	0.13	0.12	0.12

9.4 Model Verification and Robustness

Both the 50th percentile and 5th percentile simulations were run in a centerline pole impact at 25 mph and 35 mph. These simulations were performed to show that the model was stable and that the model would trend as expected. For the centerline pole impact, the X, Y, and Z vehicle linear accelerations from the LS-DYNA full vehicle simulations were used to drive the model (Figure 9-32).

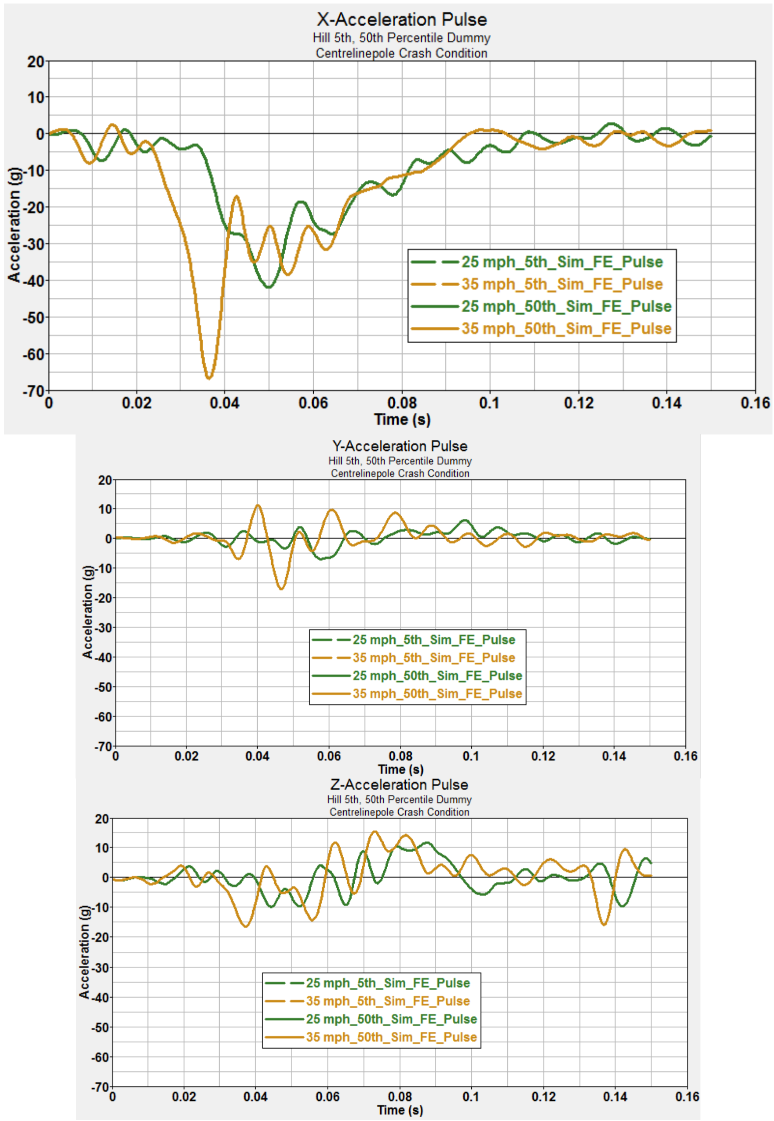

Figure 9-32 – Comparison of X, Y, and Z vehicle accelerations from 25 mph and 35 mph centerline pole impacts

The simulations were also run in offset frontal impacts into a deformable barrier at 25 mph and 40 mph. For this crash configuration, the X, Y, and Z linear accelerations from the LS-DYNA full vehicle simulations were used to drive the model (Figure 9-33).

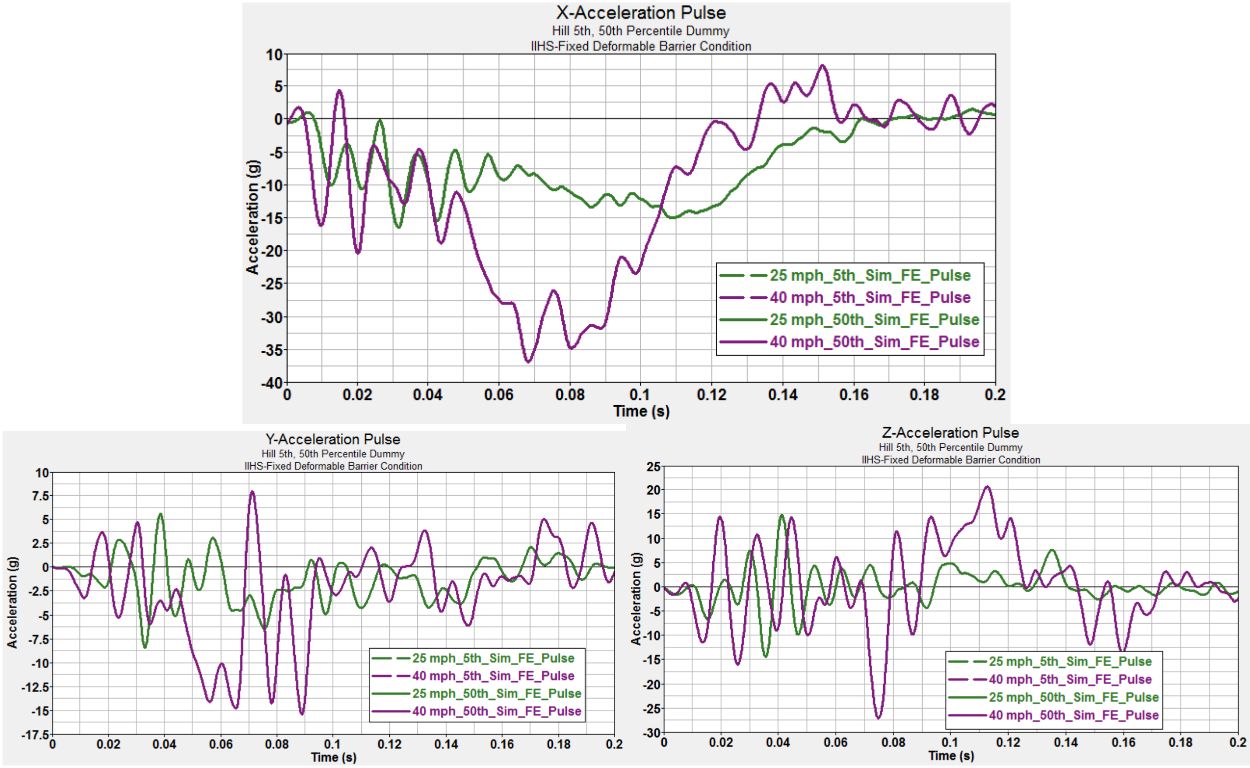

Figure 9-33 – Comparison of X, Y, and Z vehicle accelerations from 25 mph and 40 mph offset frontal impacts

The results for the 50th percentile dummy and 5th percentile dummy for these verification and robustness runs are shown in Table 9-4 and Table 9-5. These results show the expected trends, with higher injury risk corresponding to the higher speed impact and lower injury risk corresponding to the lower speed impact.

Table 9-4 – Comparison of injury results for 50th percentile dummy for verification and robustness simulations

	H350/50th	Centerline pole 25 mph 50th	Centerline pole 35 mph 50th	IIHS 25 mph 50th	IIHS 40 mph 50th
Response	**Formula**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	82.2773	196.694	49	545
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	155.221	273.516	109	623
Neck Tension (T)	**Upper Neck Fz Max**	938.304	1438.7	628	1367
Chest deflection (mm)	**Max deflection**	24.9383	27.1531	22	28
Chest acceleration (g)	**Max acceleration**	37.8794	48.0477	21	41
Femur Load - Left (N)	**Max Compression force Fz**	6302.5	7436.2	549	3309
Femur Load - Right (N)	**Max Compression force Fz**	2756.65	3955.82	305	1161
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.00%	0.17%	0.00%	5.99%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	2.57%	3.37%	1.83%	3.93%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	4.41%	6.52%	0.13%	1.30%
Neck Tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.02%	0.05%	0.01%	0.04%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.07	0.10	0.02	0.11

Table 9-5 – Comparison of injury results for 5th percentile dummy for verification and robustness simulations

	H305/5th	Centerline pole 25 mph 5th	Centerline pole 35 mph 5th	IIHS 25 mph 5th	IIHS 40 mph 5th
Response	**Formula**	**Simulation FE Results**	**Simulation FE Results**	**Simulation FE Results**	**Simulation FE Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	283.929	296.593	156.545	292.529
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	290.608	329.478	165.842	368.094
Neck Tension (T)	**Upper Neck Fz Max**	1126.35	1256.01	921.908	1200.12
Chest deflection (mm)	**Max deflection**	28.766	30.5633	22.2487	27.9647
Chest acceleration (g)	**Max acceleration**	42.9836	51.7551	24.095	44.8203
Femur Load - Left (N)	**Max Compression force Fz**	1072.01	2605.53	918.334	1885.97
Femur Load - Right (N)	**Max Compression force Fz**	1642.65	2747.06	1076.48	1235.75
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.74%	0.87%	0.06%	0.83%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def/0.817)^0.4612)))**	8.00%	9.86%	3.40%	7.26%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.47941* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.81%	1.82%	0.46%	0.99%
Neck Tension (AIS3%)	**1/(1+EXP(10.958-3.77*NeckTension/1000))**	0.12%	0.20%	0.06%	0.16%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.10	0.12	0.04	0.09

9.5 Summary and Conclusions

The models of the 50th percentile dummy and 5th percentile dummy seated in the Yaris were validated against available crash data from regulatory and consumer information tests. Further verification and robustness simulations run under varying crash conditions confirmed that the model was stable. Low and high speeds were run under the same impact configuration, confirming that the model yielded the expected trends in that the higher speed simulations led to greater injury than the lower speed simulations.

9.6 Acknowledgements

The authors wish to acknowledge the Federal Highway Administration and National Highway Traffic Safety Administration of the U.S. Department of Transportation for supporting these modeling and simulation efforts.

9.7 References

1. MGA Research Corporation, “Final Report of New Car Assessment Program Testing of a 2008 Toyota Yaris 3-Door Liftback,” NHTSA Test No. 6221, November 2007.
2. MGA Research Corporation, “Final Report of FMVSS 208 Compliance Testing of a 2007 Toyota Yaris,” NHTSA Test No. 6069, August 2007.
3. Insurance Institute for Highway Safety, “Crash Test Report: 2007 Toyota Yaris,” IIHS Test CEF0610, December 2006.
4. MGA Research Corporation, “Final Report of New Car Assessment Program Testing of a 2007 Toyota Yaris,” NHTSA Test No. 5677, June 2006.

10 APPENDIX 10: DEVELOPMENT AND VALIDATION OF A FORD EXPLORER MADYMO FRONTAL OCCUPANT MODEL

10.1 Introduction

A frontal MADYMO model of a driver in a Ford Explorer was developed by the National Crash Analysis Center of the George Washington University in support of the NHTSA study, “Investigate Self and Partner Protection of New Vehicle Designs Using Structural Modeling,” TOPR No. 16 under DTFH61-09-D-00001. For this study, several different vehicle finite element (FE) models were developed, including the Ford Explorer, and run under different crash configurations in single vehicle and two vehicle crashes. The data from these FE models were used as inputs for the frontal MADYMO models that were developed to assess occupant injury risk.

To develop the MADYMO models, the NCAC obtained generic occupant models from restraint manufacturers, upon which the specific vehicle models would be built. For the Ford Explorer, a generic model year (MY) 2006 sport utility vehicle (SUV) was used as a foundation. This foundation model was modified to reflect data and measurements from the crash test report in order to make it more representative of a Ford Explorer.

The Explorer occupant simulations were first validated against frontal crash test data. Then, the simulations were run in the same crash tests configurations, but using the pulses output by the LS-DYNA FE simulations. This check was performed to ensure that reasonable occupant responses would be observed once the FE simulation outputs were used in the occupant models. Lastly, the occupant model was run under several different crash configurations to confirm the stability and robustness of the model and to verify that reasonable occupant response trends would be observed. This paper serves as documentation of the above model development and validation processes.

10.2 Model Development

The first step in modifying the generic MY 2006 SUV model was to position the dummy according to available test reports. The dummy positions for the 50th percentile male and 5th percentile female were based on NHTSA test nos. 3730 and 4690, respectively [1,2]. Measurements such as the seat back angle (degree), head to windshield (mm), nose to rim (mm), chest to dash (mm), steering wheel to chest (mm), rim to abdomen (mm), left knee to dash (mm), right knee to dash (mm), tibia angle (degree), and knee to knee (mm) were considered in positioning the dummies. The dummies were positioned to match as many of these measurements as possible. The model was also subject to visual inspection to ensure that the final position was physically reasonable. The final positions of the 50th percentile dummy and 5th percentile dummy are shown in Figure 10-1.

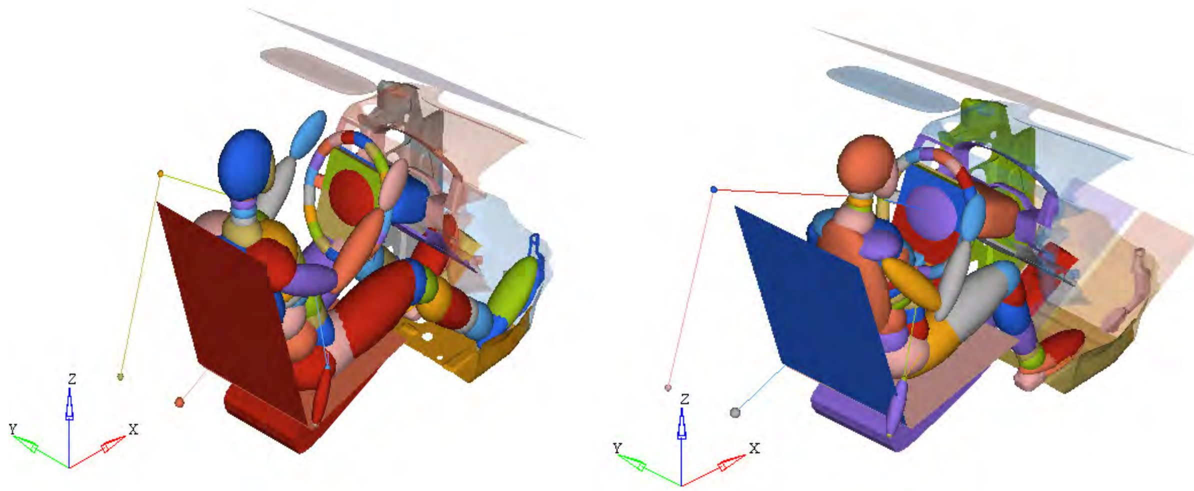

Figure 10-1 – Final position of 50th percentile (left) and 5th percentile (right) dummies in Explorer model

The general guideline for determining firing time is to use the "5-30" rule, but the crash data showed that the firing time for this vehicle did not conform to the general guideline. In order to get good correlation between the test and simulation for the 35 mph full frontal crash condition, a firing time of 14 ms was necessary. This firing time corresponded to a "7-30" rule, as 7 inches of displacement were observed at 44 ms in the crash test (Figure 10-2). For all simulations that were run in this study, the firing time was determined with this rule—30 ms less than the time at which 7 inches of displacement were observed.

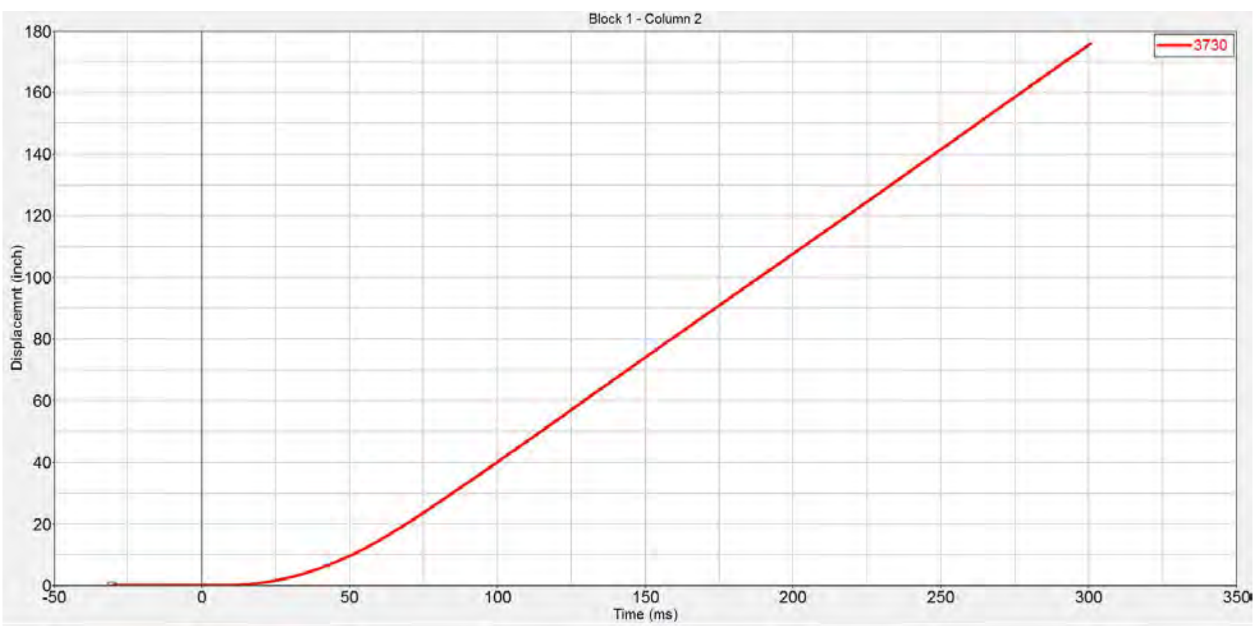

Figure 10-2 – Vehicle displacement time history for NHTSA test no. 3730

The restraint system was fine-tuned through an iterative process until the model output the expected occupant accelerations according to the crash test data. Through this process of refining the model, it was determined that it was necessary to include a more modern air bag in the model. The NCAC had previously acquired a generic MY 2009 pickup truck model and replaced the air bag in the Explorer model with the air bag from this newer model.

10.3 Model Validation

The Explorer occupant models with the 50th percentile male dummy and 5th percentile female dummy were validated against available full frontal crash data. The primary responses that were compared in this validation study are discussed in the following section.

10.3.1 Full Frontal 35 mph Validation: 50th Percentile Male Dummy

The 50th percentile occupant model seated in the Explorer was validated against NHTSA test no. 3730, a full frontal impact into a rigid barrier at 35 mph [1]. Two simulations were run for this crash configuration, one at 35 mph using the test pulse and one at 35 mph using the FE pulse (Figure 10-3).

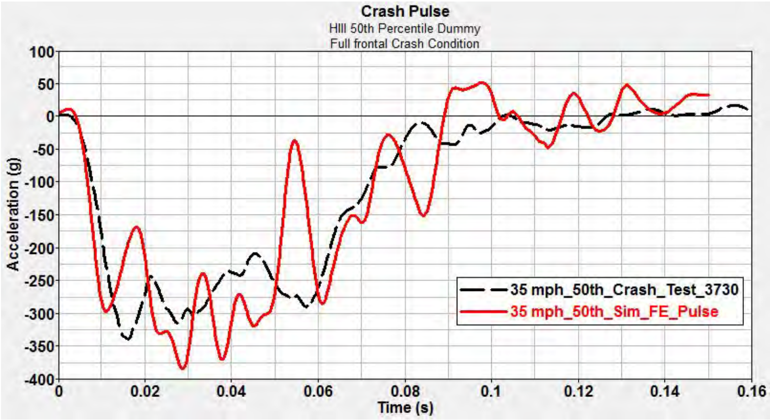

Figure 10-3 – Vehicle pulse comparison between test no. 3730 and FE simulation output

No lap or shoulder belt data were available for this test. All of the outputs for the dummy model were compared to the available crash test data. However, only the chest deflection (Figure 10-4), head acceleration (Figure 10-5), neck tension (Figure 10-6), and femur forces (Figure 10-7) will be shown below, as these were the body regions of interest in the overall study.

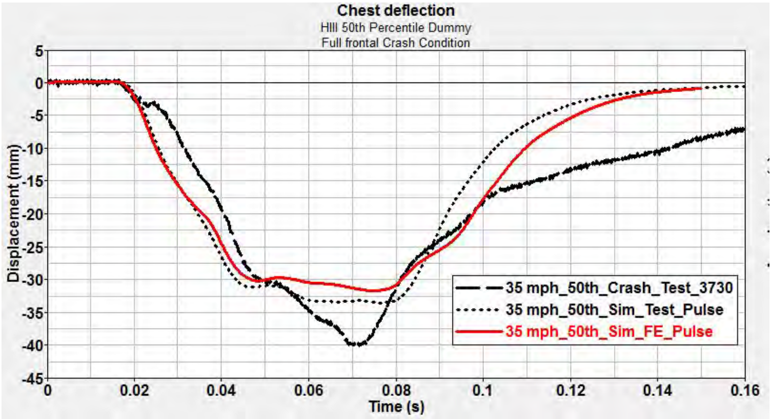

Figure 10-4 – Comparison of chest deflection from test and simulations for full frontal impact

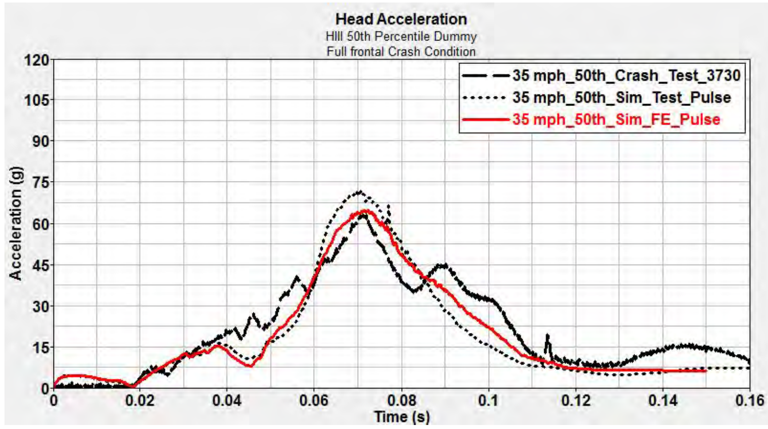

Figure 10-5 – Comparison of head acceleration from test and simulations for full frontal impact

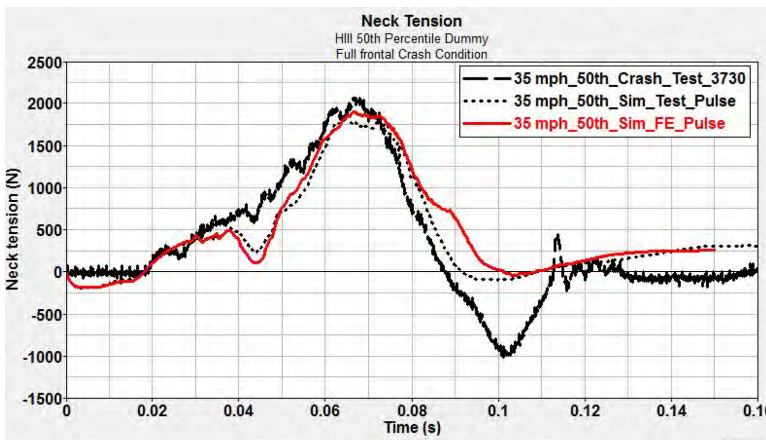

Figure 10-6 – Comparison of neck tension from test and simulations for full frontal impact

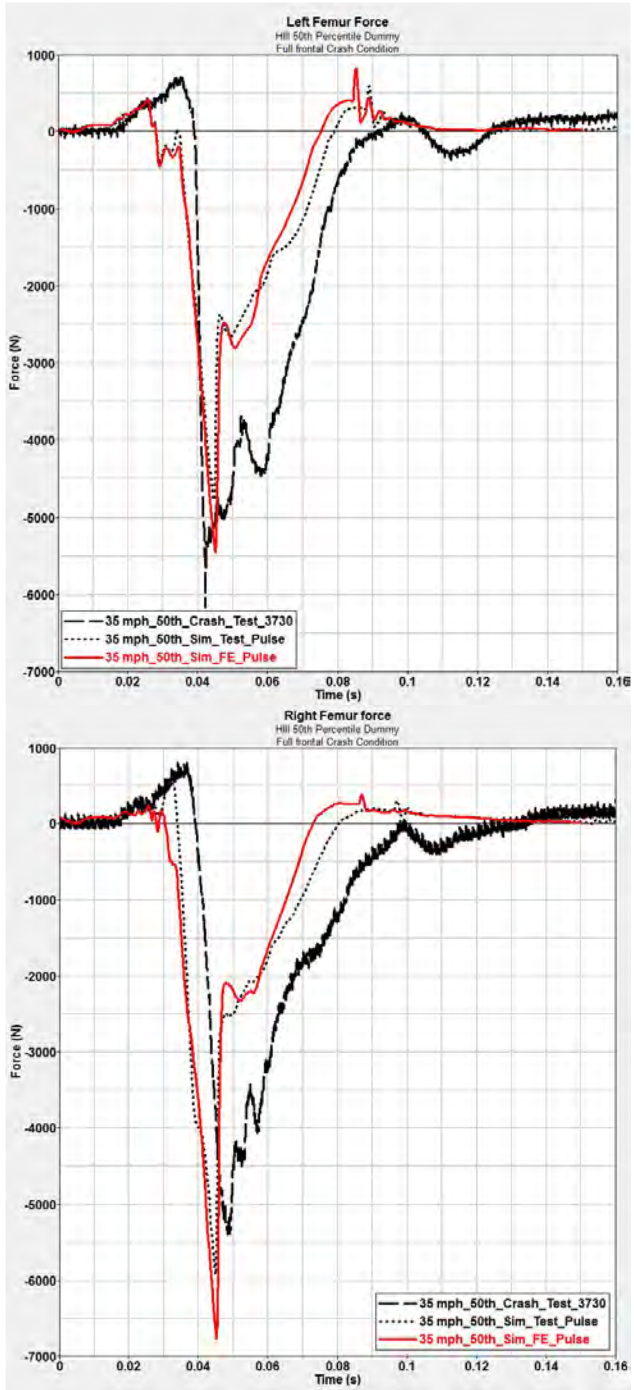

Figure 10-7 – Comparison of left and right femur forces from test and simulations for full frontal impact

10.3.2 Full Frontal 30 mph Validation: 50th Percentile Male Dummy

The 50th percentile dummy model seated in the Explorer was also run in a full frontal impact into a rigid barrier at 30 mph. No regulatory or consumer information crash tests were available with the 50th percentile dummy in this configuration, so the test pulse from NHTSA test no. 4690 (which involved a 5th percentile dummy) was used to drive this simulation [2]. This was checked against a simulation in which the FE pulse was used to ensure that the FE pulse was reasonably representative of the test pulse.

Three simulations were run for this crash configuration, one at 30 mph using the test pulse, one at 30 mph using the FE pulse, and one at 25 mph using the FE pulse (Figure 10-8). The 25 mph simulation was run to verify that the response was trending as expected, i.e., that the 25 mph impact would yield lower dummy responses than the 30 mph impact.

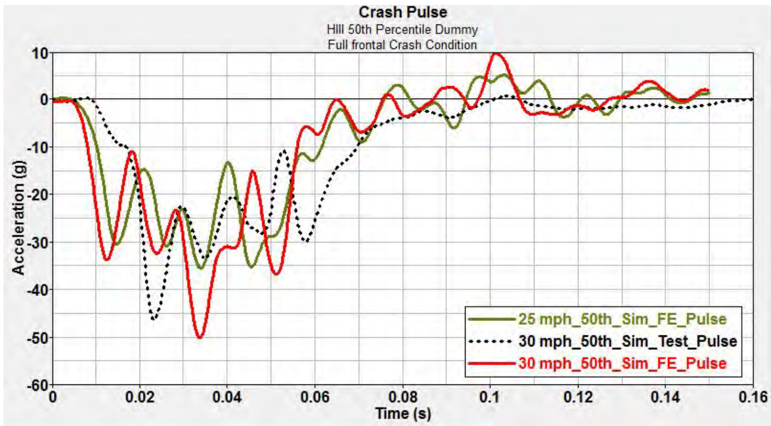

Figure 10-8 – Vehicle pulse comparison between test no. 4690 and FE simulation outputs

The chest deflection (Figure 10-9), head acceleration (Figure 10-10), neck tension (Figure 10-11), and femur forces (Figure 10-12) were compared between the three simulations.

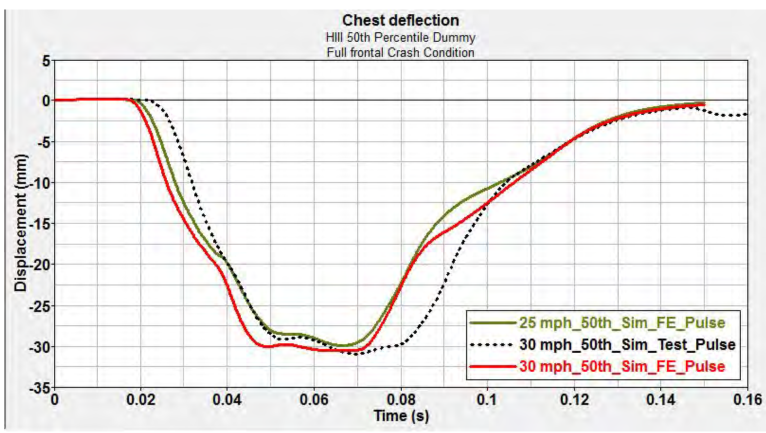

Figure 10-9 – Comparison of chest deflection from three simulations for full frontal impact

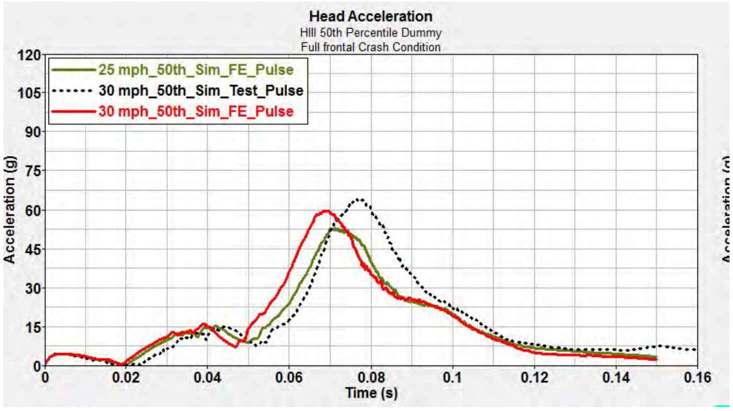

Figure 10-10 – Comparison of head acceleration from three simulations for full frontal impact

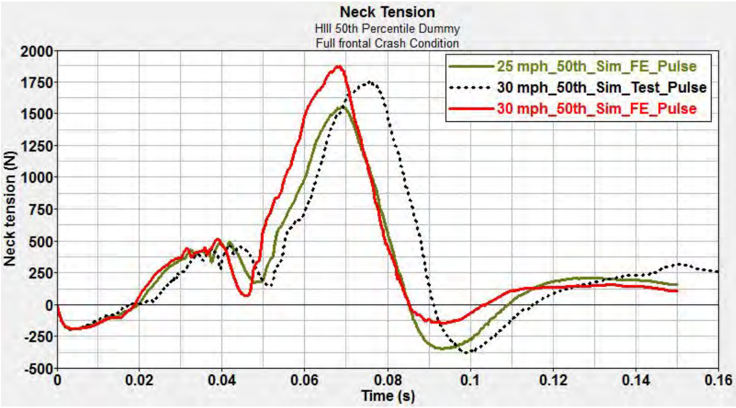

Figure 10-11 – Comparison of neck tension from three simulations for full frontal impact

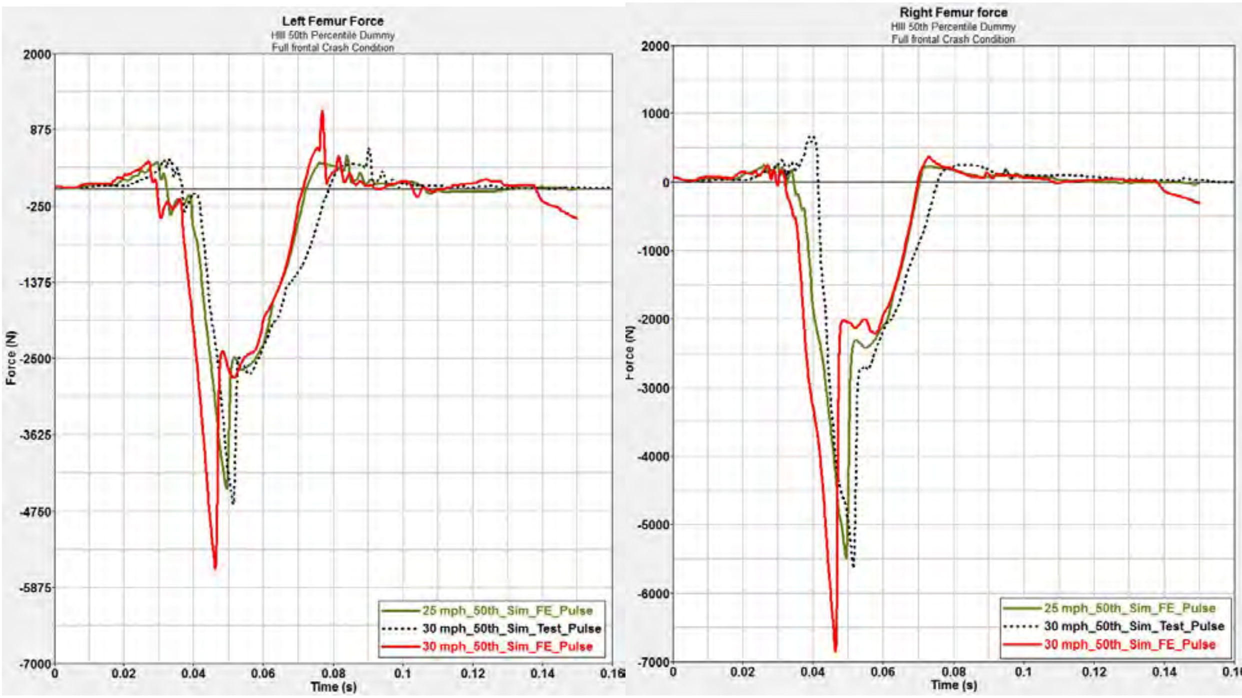

Figure 10-12 – Comparison of left and right femur forces from three simulations for full frontal impact

10.3.3 Offset Frontal 40 mph Validation: 50th Percentile Male Dummy

The 50th percentile male dummy model seated in the Explorer was validated against IIHS test no. CEF0125, an offset frontal impact with a deformable barrier at 40 mph [3]. Two simulations were run for this crash configuration, one using the test pulse and one using the FE pulse (Figure 10-13). For the offset crash configuration, all three linear accelerations were used to drive the simulation.

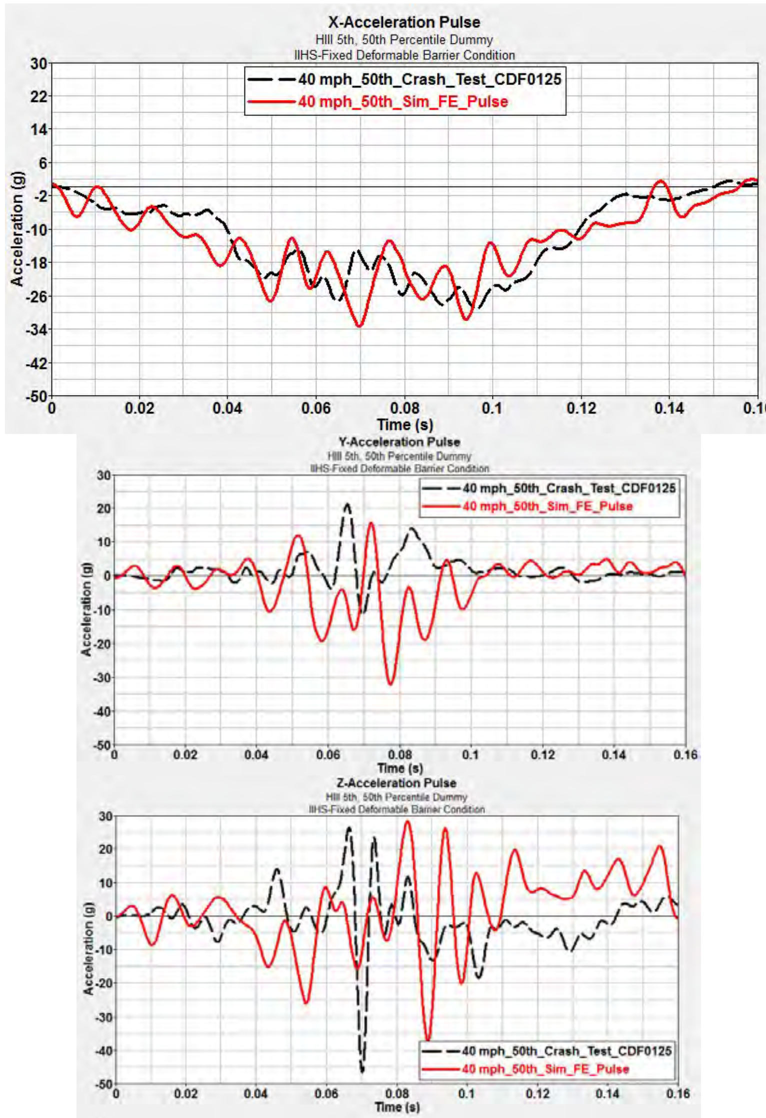

Figure 10-13 – Comparison of X, Y, and Z vehicle acceleration from test and simulations for offset frontal impact

No belt data were available for this test. The chest deflection (Figure 10-14), head acceleration (Figure 10-15), neck tension (Figure 10-16), and femur forces (Figure 10-17) were compared between the test and simulations, showing reasonable correlation.

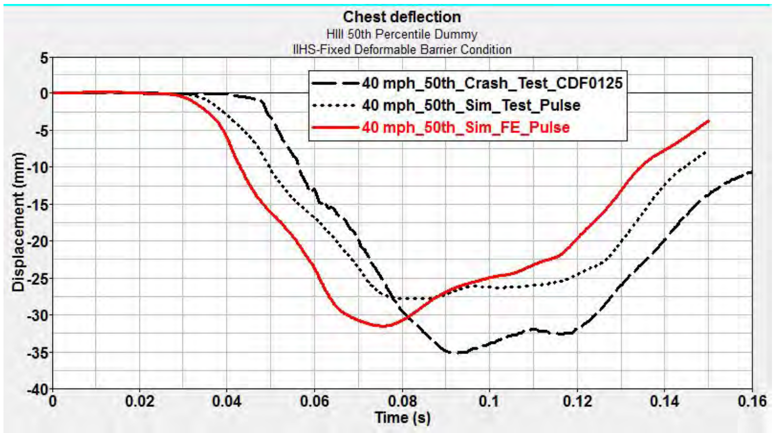

Figure 10-14 – Comparison of chest deflection from test and simulations for offset frontal impact

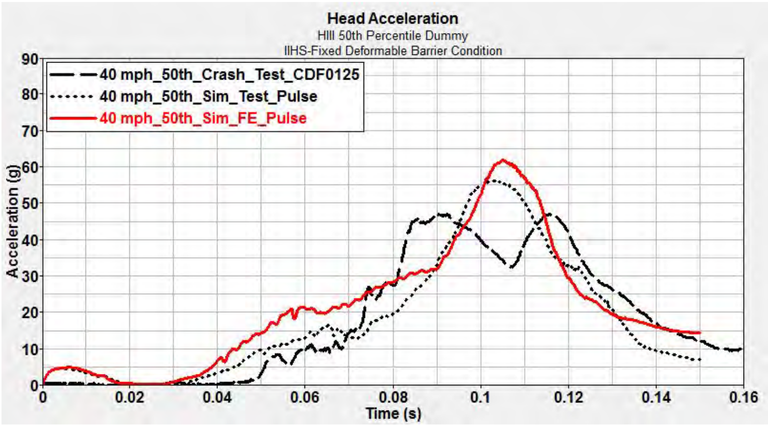

Figure 10-15 – Comparison of head acceleration from test and simulations for offset frontal impact

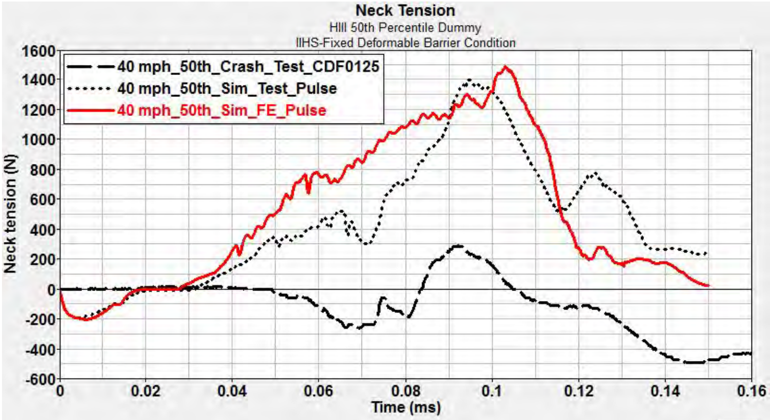

Figure 10-16 – Comparison of neck tension from test and simulations for offset frontal impact

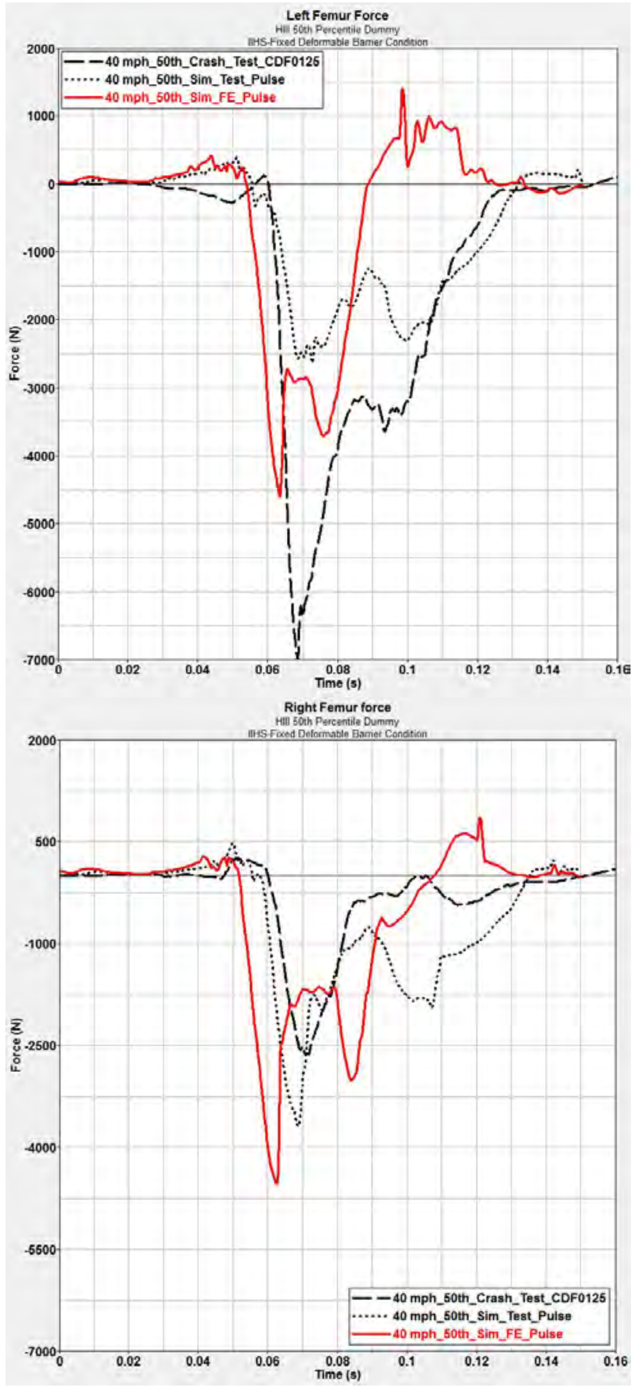

Figure 10-17 – Comparison of left and right femur forces from test and simulations for offset frontal impact

10.3.4 Full Frontal 30 mph Validation: 5th Percentile Female Dummy

The 5th percentile female dummy model seated in the Explorer was validated against NHTSA test no. 4690, a full frontal impact into a rigid barrier at 30 mph [2]. Three simulations were run—one with the test pulse at 30 mph and two with the FE pulse output from the LS-DYNA full vehicle simulation at 25 mph and 30 mph. A comparison of the crash test pulse and FE pulse is shown in Figure 10-18. The 25 mph simulation was run to verify that the response was trending as expected, i.e., that the 25 mph impact would yield lower dummy responses than the 30 mph impact.

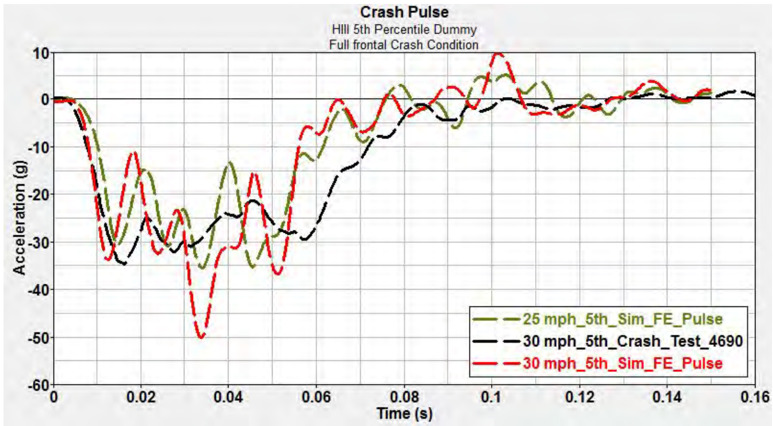

Figure 10-18 – Comparison of vehicle pulse from test and simulation for full frontal impact

Belt forces were not compared in these simulations because the test data was not available. The chest deflection (Figure 10-19), head acceleration (Figure 10-20), neck tension (Figure 10-21), and femur forces (Figure 10-22) were compared between the test and simulations, showing reasonable correlation.

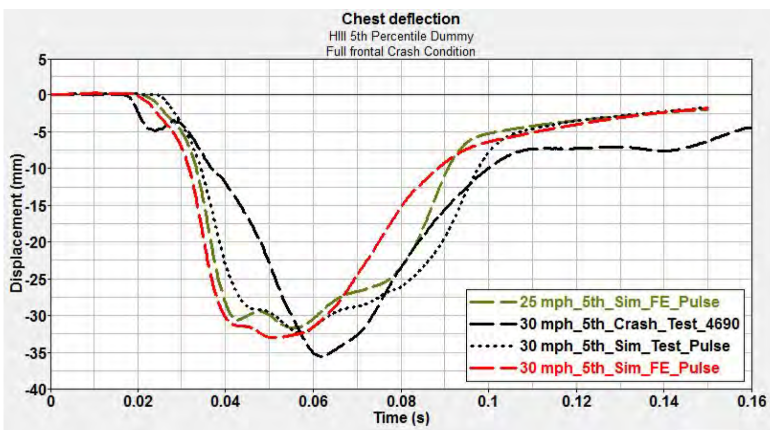

Figure 10-19 – Comparison of chest deflection from test and simulations for full frontal impact

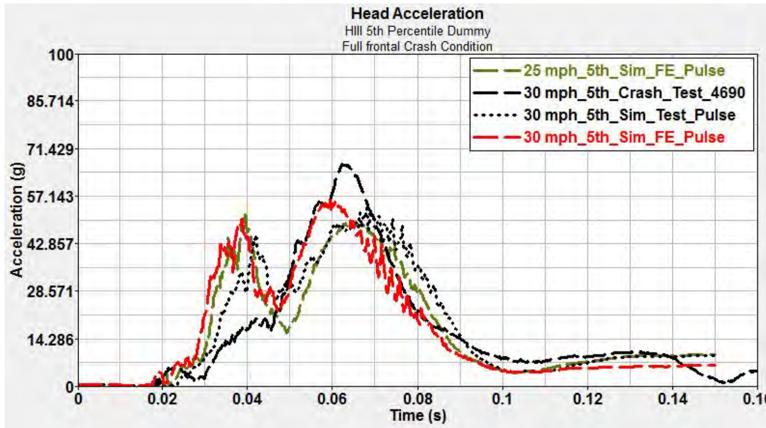

Figure 10-20 – Comparison of head acceleration from test and simulations for full frontal impact

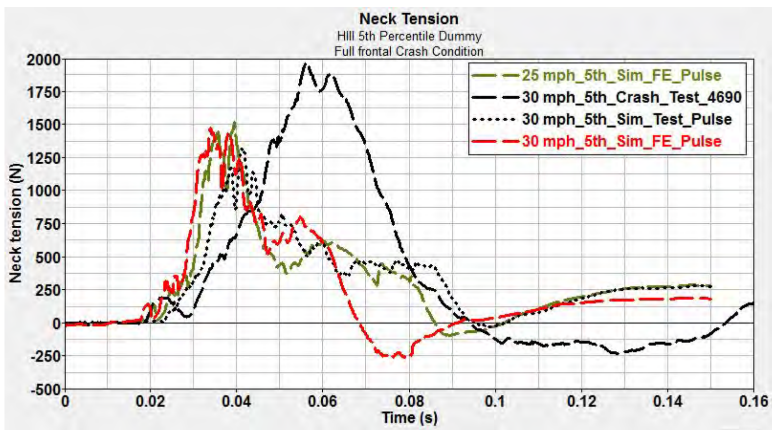

Figure 10-21 – Comparison of neck tension from test and simulations for full frontal impact

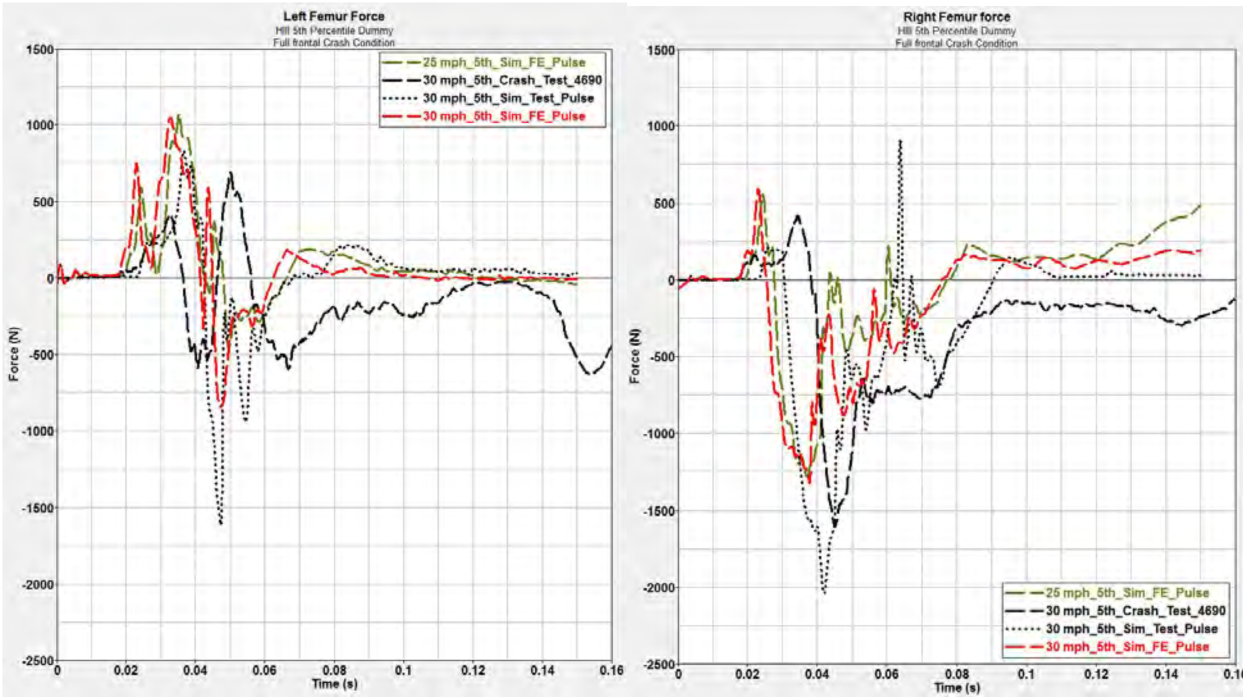

Figure 10-22 – Comparison of left and right femur forces from test and simulations for full frontal impact

10.3.5 Full Frontal 35 mph Validation: 5th Percentile Female Dummy

The 5th percentile dummy model seated in the Explorer was also run in a full frontal impact into a rigid barrier at 35 mph. No regulatory or consumer information crash tests were available with the 5th percentile dummy in this configuration, so the test pulse from NHTSA test no. 3730 (which involved a 50th percentile dummy) was used to drive this simulation [1]. This was checked against a simulation in which the FE pulse was used to ensure that the FE pulse was reasonably representative of the test pulse. A comparison of these pulses is shown in Figure 10-23.

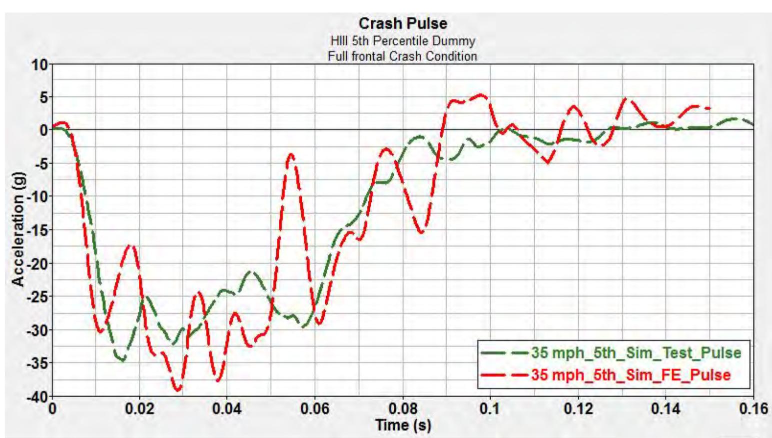

Figure 10-23 – Comparison of vehicle pulse from test and simulation for 35 mph full frontal impact

Figure 10-24 compares the lap and shoulder belt forces of the two simulations.

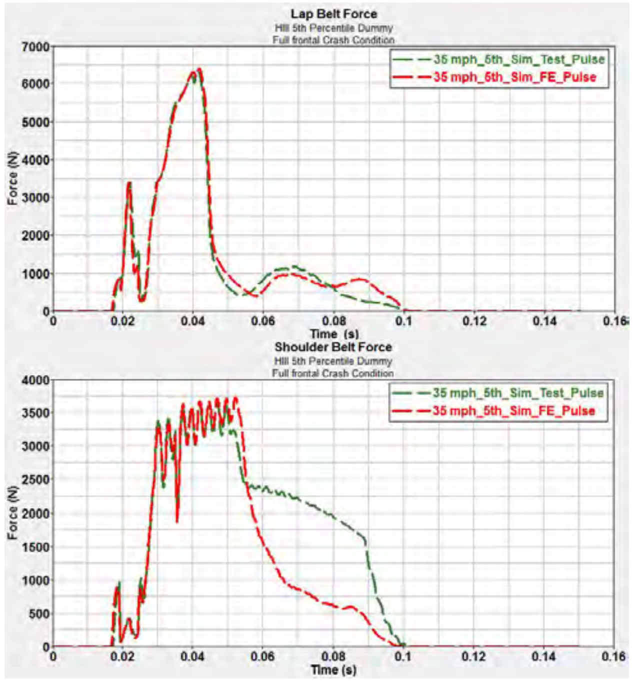

Figure 10-24 – Comparison of lap and shoulder belt forces from two simulations for 35 mph full frontal impact

The chest deflection (Figure 10-25), head acceleration (Figure 10-26), neck tension (Figure 10-27), and femur loads (Figure 10-28) were also compared between the simulations, showing a reasonable match.

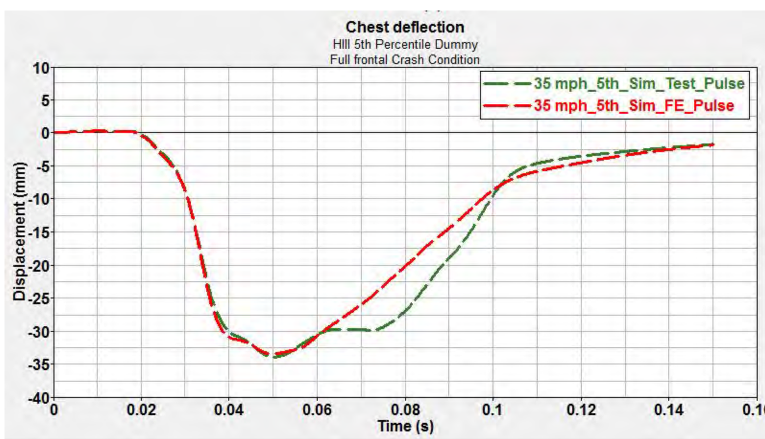

Figure 10-25 – Comparison of chest deflection from two simulations for 35 mph full frontal impact

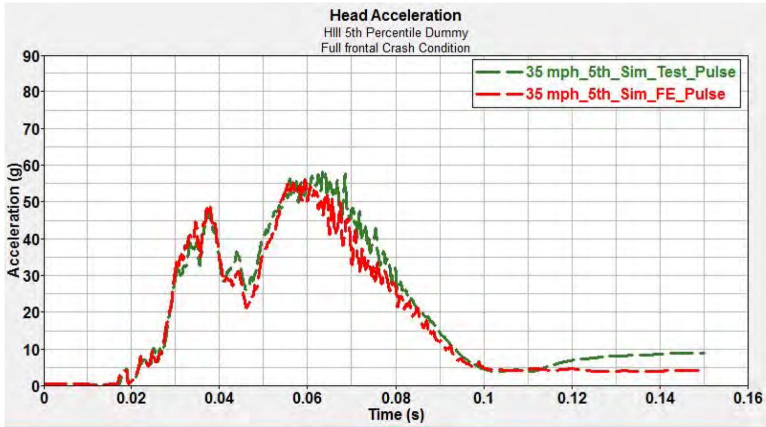

Figure 10-26 – Comparison of head acceleration from two simulations for 35 mph full frontal impact

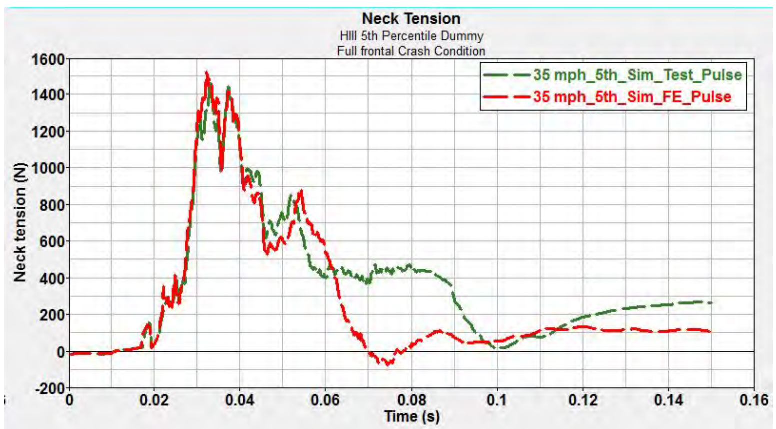

Figure 10-27 – Comparison of neck tension from two simulations for 35 mph full frontal impact

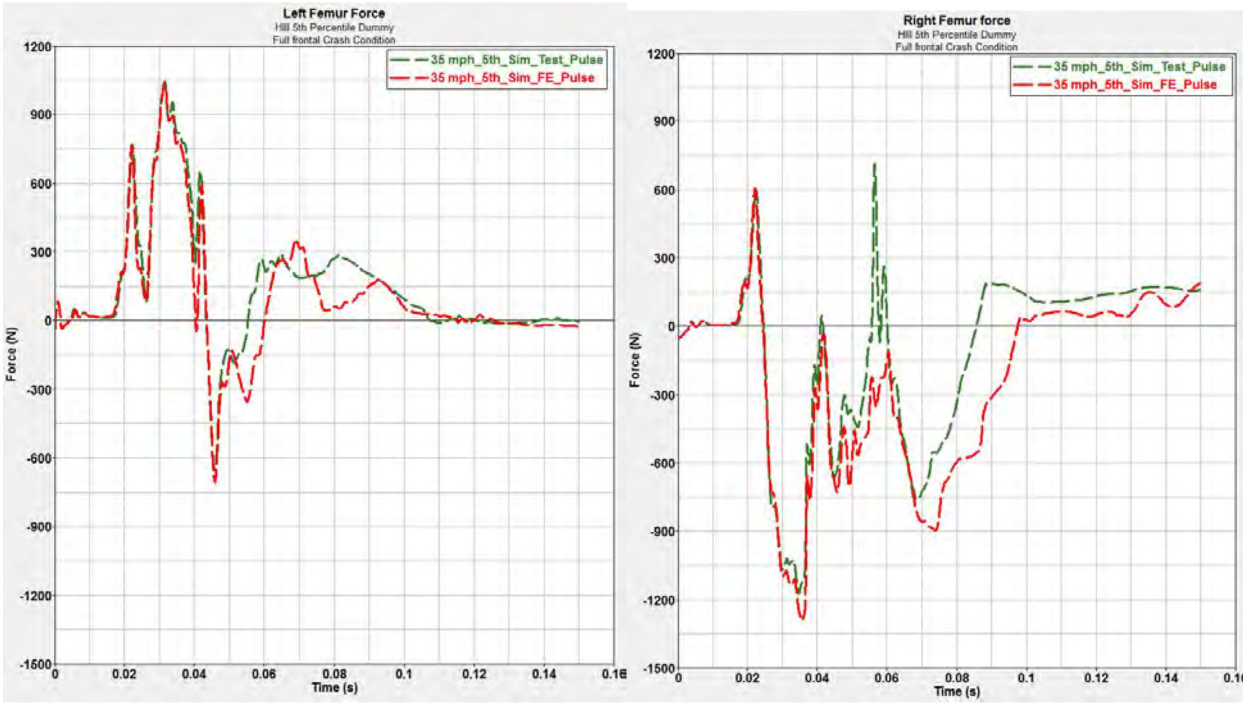

Figure 10-28 – Comparison of left and right femur forces from two simulations for 35 mph full frontal impact

10.3.6 Validation Summary

The results from the validation study are summarized in Table 10-1 and Table 10-2 for the 50th percentile dummy and in Table 10-3 for the 5th percentile dummy.

Table 10-1 – 50th percentilepercentile dummy full frontal validation results

	H350/50th	NHTSA 25 mph 50th FE_pulse	NHTSA 30 mph 50th Test_Pulse _4690	NHTSA 30 mph 50th, FE_Pulse	NHTSA 35 mph, 50th Test_Pulse _3730	NHTSA 35 mph 50th Test_Pulse _3730	NHTSA 35 mph 50th FE_pulse
Response	**Formula**	**Simulation FE Pulse Results**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**	**Crash Test Results (3730)**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	240	384	310	324	533	419
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	293	467	371	519	681	602
Neck Tension (T)	**Upper Neck Fz Max**	1553	1743	1873	2062	1781	1903
Chest deflection (mm)	**Max Deflection**	30	31	30.5	40	33.5	31.7
Chest acceleration (g)	**Max Acceleration**	43	42	47	47.5	45	47.5
Femur Load - Left (N)	**Max Compression force Fz**	4419	4649	5607	5809	4785	5453
Femur Load - Right (N)	**Max Compression force Fz**	5492	5579	6846	5338	5919	6769
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.39%	2.1%	1.0%	1.2%	5.6%	2.80%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	4.61%	5%	5%	12%	7%	5.60%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	3.27%	3.38%	5.34%	3.69%	3.84%	5.20%
Neck Tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.07%	0.1%	0.1%	0.2%	0.1%	0.16%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.08	0.10	0.11	0.17	0.15	0.13

Table 10-2 – 50th percentilepercentile dummy offset frontal validation results

	H350/50th	IIHS test data	IIHS 40 mph 50th Test results	IIHS 40 mph 50th
Response	**Formula**	**Crash Test Results CEF0125**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1)\right\}_{max}$	202	314	369
HIC36	$HIC = \left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1)\right\}_{max}$	413	459	499
Neck Tension (T)	**Upper Neck Fz Max**	1900	1399	1485
Chest deflection (mm)	**Max Deflection**	35	28	31
Chest acceleration (g)	**Max Acceleration**	39	37	36
Femur Load - Left (N)	**Max Compression force Fz**	7000	2636	4610
Femur Load - Right (N)	**Max Compression force Fz**	2600	3687	4539
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.19%	1.07%	1.86%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	8%	3.72%	4.97%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	5.63%	1.55%	2.32%
Neck Tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.16%	0.05%	0.06%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.13	0.06	0.09

Table 10-3 – 5th percentilepercentile dummy full frontal validation results

	H305/5th	NHTSA 25 mph 5th FE_pulse	NHTSA 30 mph 5th, Test#4690	NHTSA 30 mph 5th Test_pulse _4690	NHTSA 30 mph 5th, FE_Pulse	NHTSA 35 mph 5th Test_pulse _3730	NHTSA 35 mph 5th FE_pulse
Response	**Formula**	**Simulation FE Pulse Results**	**Crash Test Results (4690)**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**	**Simulation Test Pulse Results**	**Simulation FE Pulse Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	213	396	309	264	471	267
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	297	490	430	395	608	399
Neck Tension (T)	**Upper Neck Fz Max**	1514	1964	985	1473	996	1520
Chest deflection (mm)	**Max Deflection**	31.6	36	37	33	41.4	33.3
Chest acceleration (g)	**Max Acceleration**	52	56.2	51.2	62	52.3	62
Femur Load - Left (N)	**Max Compression force Fz**	459	625	1376	844	680	707
Femur Load - Right (N)	**Max Compression force Fz**	1280	1609	2240	1320	1283.4	1289
HIC15 Risk (AIS 3%)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.24%	2.3%	1.0%	0.6%	4.0%	0.59%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def/0.817)^0.4612)))**	11.07%	17%	19%	13%	28%	13.28%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.47941* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.57%	0.78%	1.29%	0.60%	0.57%	0.58%
Neck Tension (AIS3%)	**1/(1+EXP(10.958-3.77*NeckTension/1000))**	0.52%	2.8%	0.1%	0.4%	0.1%	0.53%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.12	0.22	0.21	0.14	0.31	0.15

10.4 Model Verification and Robustness

Both the 50th percentile and 5th percentile simulations were run in a centerline pole impact at 25 mph and 35 mph. These simulations were performed to show that the model was stable and that the model would trend as expected. For the centerline pole impact, the X, Y, and Z vehicle linear accelerations from the LS-DYNA full vehicle simulations were used to drive the model (Figure 10-29).

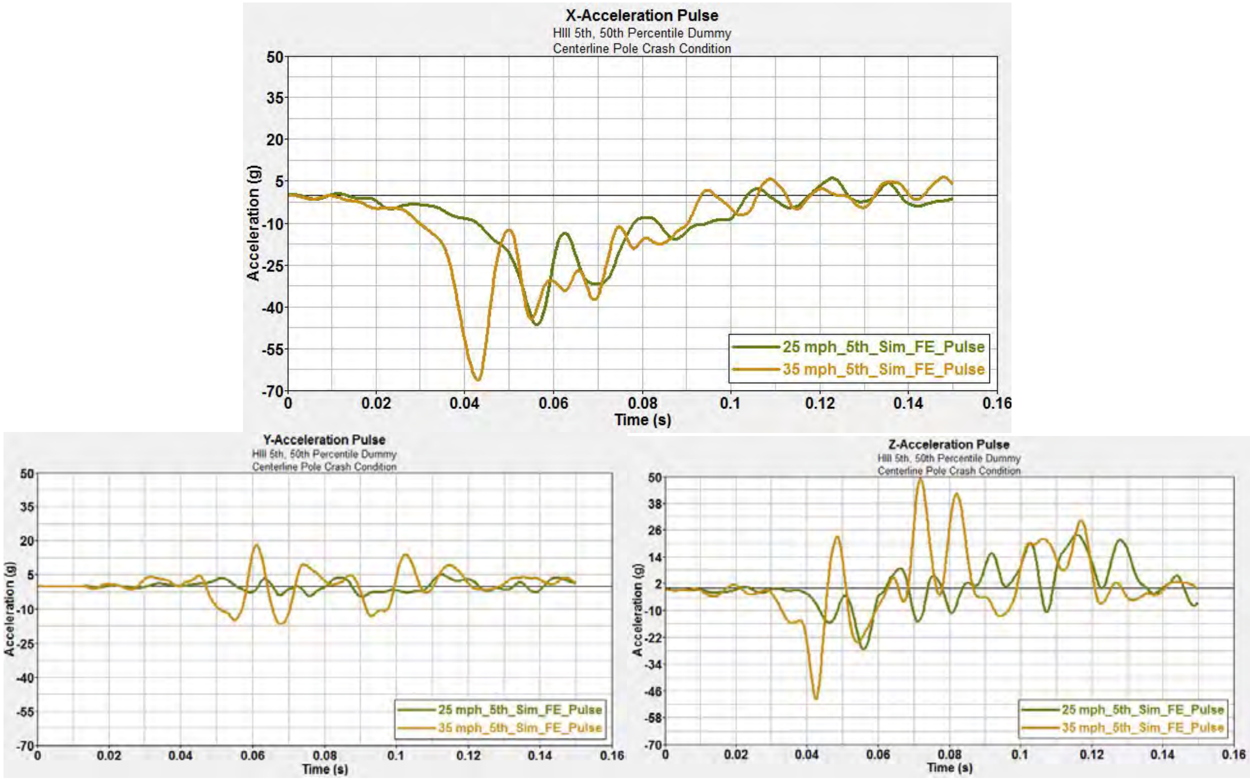

Figure 10-29 – Comparison of X, Y, and Z vehicle accelerations from 25 mph and 35 mph centerline pole impacts

The simulations were also run in offset frontal impacts into a deformable barrier at 25 mph and 40 mph. For this crash configuration, the X, Y, and Z linear accelerations from the LS-DYNA full vehicle simulations were used to drive the model (Figure 10-30).

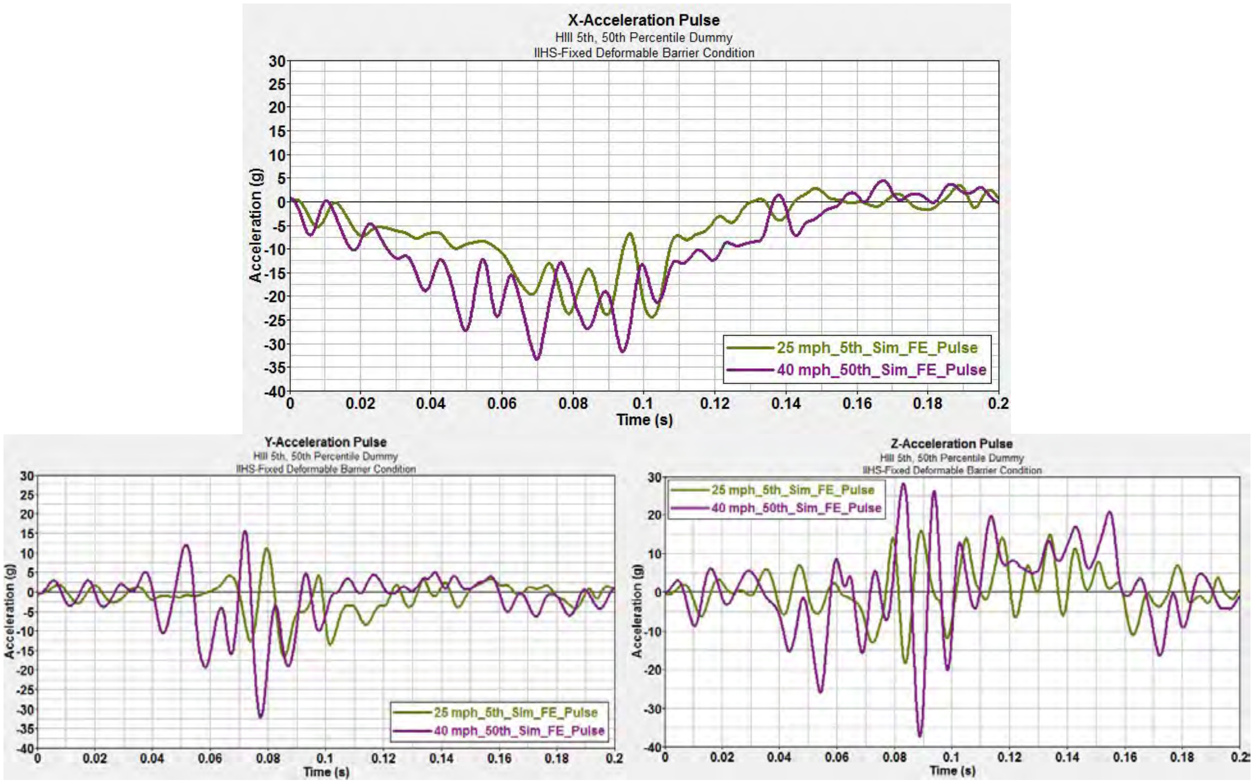

Figure 10-30 – Comparison of X, Y, and Z vehicle accelerations from 25 mph and 40 mph offset frontal impacts

The results for the 50th percentile dummy and 5th percentile dummy for these verification and robustness runs are shown in Table 10-4 and Table 10-5. These results show the expected trends, with higher injury risk corresponding to the higher speed impact and lower injury risk corresponding to the lower speed impact.

Table 10-4 – Comparison of injury results for 50th percentile dummy for verification and robustness simulations

	H350/50th	Centerline pole 25 mph 50th	Centerline pole 35 mph 50th	IIHS 25 mph 50th	IIHS 40 mph 50th
Response	**Formula**	**Simulation Results**	**Simulation Results**	**Simulation Results**	**Simulation Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	78	212	25	105
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	153	380	43	236
Neck Tension (T)	**Upper Neck Fz Max**	905	1233	621	1152
Chest deflection (mm)	**Max deflection**	23	28	19	24
Chest acceleration (g)	**Max acceleration**	27	43	18	30
Femur Load - Left (N)	**Max Compression force Fz**	745	1588	288	1439
Femur Load - Right (N)	**Max Compression force Fz**	1276	3477	610	1522
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.00%	0.23%	0.00%	0.01%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	2.01%	3.72%	1.21%	2.20%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.35%	1.41%	0.15%	0.43%
Neck Tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.01%	0.03%	0.01%	0.03%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.02	0.05	0.01	0.03

Table 10-5 – Comparison of injury results for 5th percentile dummy for verification and robustness simulations

	H305/5th	Centerline pole 25 mph 5th	Centerline pole 35 mph 5th	IIHS 25 mph 5th	IIHS 40 mph 5th
Response	**Formula**	**Simulation Results**	**Simulation Results**	**Simulation Results**	**Simulation Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	171	188	125	155
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	181	206	135	258
Neck Tension (T)	**Upper Neck Fz Max**	1596	1552	893	1399
Chest deflection (mm)	**Max deflection**	22	26	23	23
Chest acceleration (g)	**Max acceleration**	26	39	32	29
Femur Load - Left (N)	**Max Compression force Fz**	562	1049	942	1550
Femur Load - Right (N)	**Max Compression force Fz**	1571	2442	568	2093
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.09%	0.14%	0.02%	0.06%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def/0.817)^0.4612)))**	3.28%	5.67%	3.78%	3.78%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.47941* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.76%	1.49%	0.39%	1.16%
Neck Tension (AIS3%)	**1/(1+EXP(10.958-3.77*NeckTension/1000))**	0.71%	0.60%	0.05%	0.34%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.05	0.08	0.04	0.05

10.5 Summary and Conclusions

The models of the 50th percentile dummy and 5th percentile dummy seated in the Explorer were validated against available crash data from regulatory and consumer information tests. Further verification and robustness simulations run under varying crash conditions confirmed that the model was stable. Low and high speeds were run under the same impact configuration, confirming that the model yielded the expected trends in that the higher speed simulations led to greater injury than the lower speed simulations.

10.6 Acknowledgements

The authors wish to acknowledge the Federal Highway Administration and National Highway Traffic Safety Administration of the U.S. Department of Transportation for supporting these modeling and simulation efforts.

10.7 References

1. KARCO Engineering, “Final Report of New Car Assessment Program Testing of a 2002 Ford Explorer XLT 4WD SUV,” NHTSA Test No. 3730, August 2001.
2. PMG Technologies Test and Research Centre, “Compliance Frontal Impact CMVSS 212/301: Ford Explorer 2003,” NHTSA Test No. 4690, February 2003.
3. Insurance Institute for Highway Safety, “Crash Test Report: 2002 Ford Explorer,” IIHS Test CEF0125, December 2001.

11 APPENDIX 11: DEVELOPMENT AND VALIDATION OF A CHEVROLET SILVERADO MADYMO FRONTAL OCCUPANT MODEL – INTERIM DOCUMENTATION

11.1 Introduction

A frontal MADYMO model of a driver in a Chevrolet Silverado was developed by the National Crash Analysis Center of the George Washington University in support of the NHTSA study, "Investigate Self and Partner Protection of New Vehicle Designs Using Structural Modeling," TOPR No. 16 under DTFH61-09-D-00001. For this study, several different vehicle finite element (FE) models were developed, including the Chevy Silverado, and run under different crash configurations in single vehicle and two vehicle crashes. The data from these FE models were used as inputs for the frontal MADYMO models that were developed to assess occupant injury risk.

To develop the MADYMO models, the NCAC obtained generic occupant models from restraint manufacturers, upon which the specific vehicle models would be built. For the Chevy Silverado, a generic model year (MY) 2009 pickup truck was used as a foundation. This foundation model was modified to reflect data and measurements from the crash test report in order to make it more representative of a Chevy Silverado.

The Silverado occupant simulations were first validated against frontal impact crash test data. Then, the simulations were run in the same crash tests configurations, but using the pulses output by the LS-DYNA FE simulations. This check was performed to ensure that reasonable occupant responses would be observed once the FE simulation outputs were used in the occupant models. Lastly, the occupant model was run under several different crash configurations to confirm the stability and robustness of the model and to verify that reasonable occupant response trends would be observed. This paper serves as documentation of the above model development and validation processes.

11.2 Model Development

The first step in modifying the generic MY 2009 pickup truck model was to position the dummy according to available test reports. The dummy position for the 50th percentile male was based on test no. 5877 for the full frontal crash configuration and test no. CEF0825 for the offset frontal crash configuration [1,2]. The dummy position for the 5th percentile female was based on test no. 6277 for both the full frontal and offset frontal crash configurations [3]. Measurements such as the seat back angle (degree), head to windshield (mm), nose to rim (mm), chest to dash (mm), steering wheel to chest (mm), rim to abdomen (mm), left knee to dash (mm), right knee to dash (mm), tibia angle (degree), and knee to knee (mm) were considered in positioning the dummies. The dummies were positioned to match as many of these measurements as possible. The model was also subject to visual inspection to ensure that the final position was physically reasonable. The final positions of the 50th percentile dummy and 5th percentile dummy in the full frontal condition are shown in Figure 11-1.

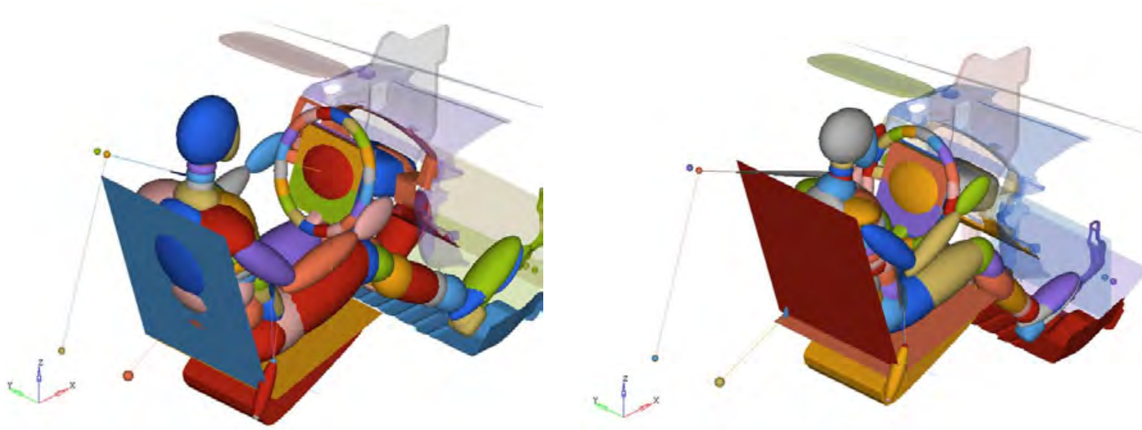

Figure 11-1 – Final position of 50th percentile (left) and 5th percentile (right) dummies in Silverado model

NHTSA test no. 5907 was used to determine the firing time guideline for the Silverado model [4]. The general guideline for determining firing time is to use the "5-30" rule, but the crash data showed that the firing time for this vehicle did not conform to the general guideline. The shoulder belt data showed a firing time of 18 ms (Figure 11-2). To derive the firing time rule, the vehicle displacement time history was used to determine the displacement at 48 ms, which would be the 18 ms firing time plus 30 ms. Thus, a "6-30" rule was determined, as 6 inches of displacement were observed at 48 ms in the crash test (Figure 11-3). For all simulations that were run in this study, the firing time was determined with this rule—30 ms less than the time at which 6 inches of displacement were observed.

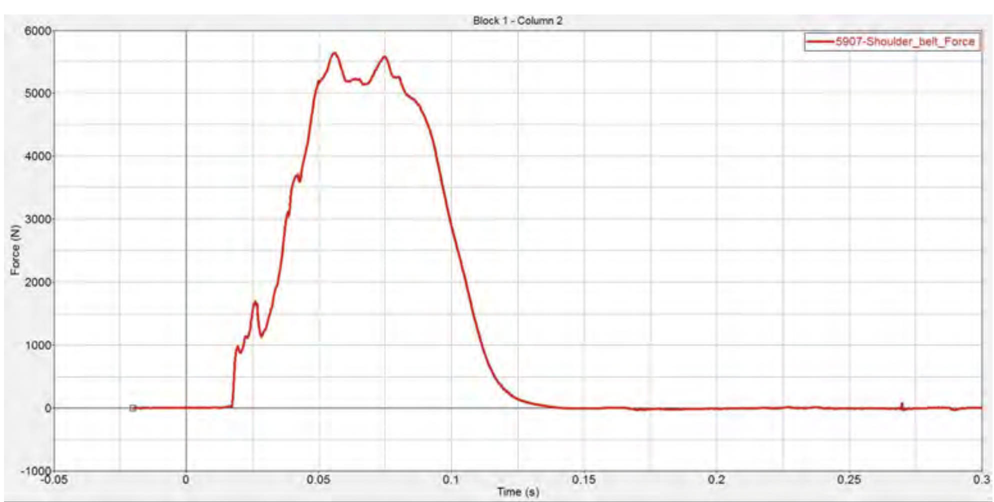

Figure 11-2 – Shoulder belt force for NHTSA test no. 5907

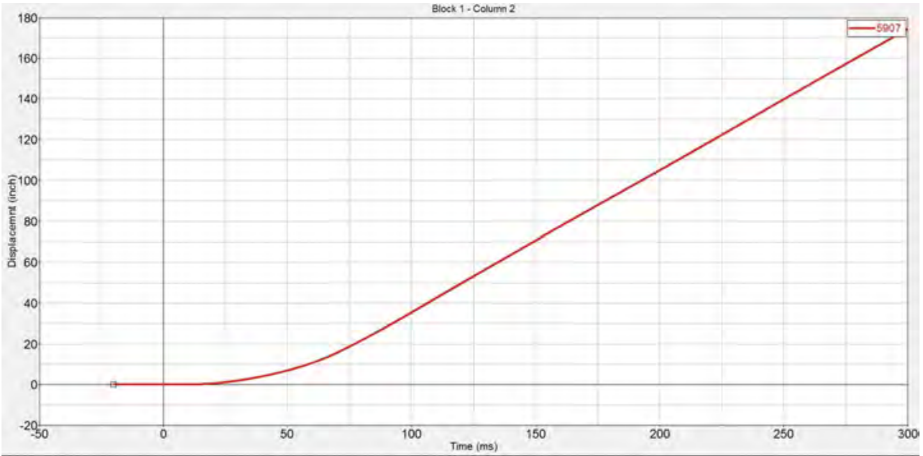

Figure 11-3 – Vehicle displacement time history for NHTSA test no. 5907

In order to account for the vehicle intrusion, planes were created in the MADYMO environment to represent the footrest, accelerometer pedal, and instrument panel. Motion was applied to these planes using the output data from the full vehicle FE simulations.

11.3 Model Validation

The Silverado occupant models with the 50th percentile male dummy and 5th percentile female dummy were validated against available full frontal crash data. The primary responses that were compared in this validation study are discussed in the following section.

11.3.1 Full Frontal 35 mph Validation: 50th Percentile Male Dummy

The 50th percentile occupant model seated in the Silverado was validated against NHTSA test no. 5877, a full frontal impact into a rigid barrier at 35 mph [1]. Two simulations were run for this crash configuration, one at 35 mph using the test pulse and one at 35 mph using the FE pulse (Figure 11-4).

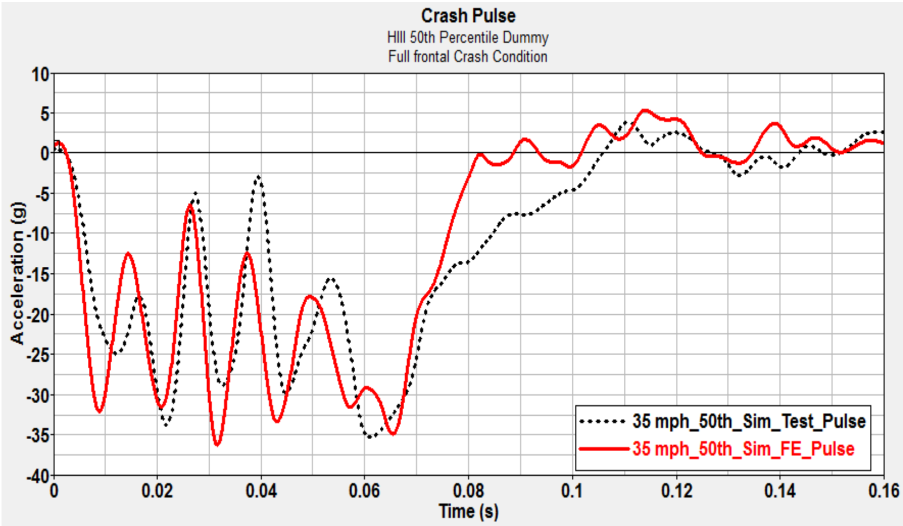

Figure 11-4 – Vehicle pulse comparison between test no. 5877 and FE simulation output

A comparison of the lap and shoulder belt forces shows good correlation between the test and both simulations (Figure 11-5).

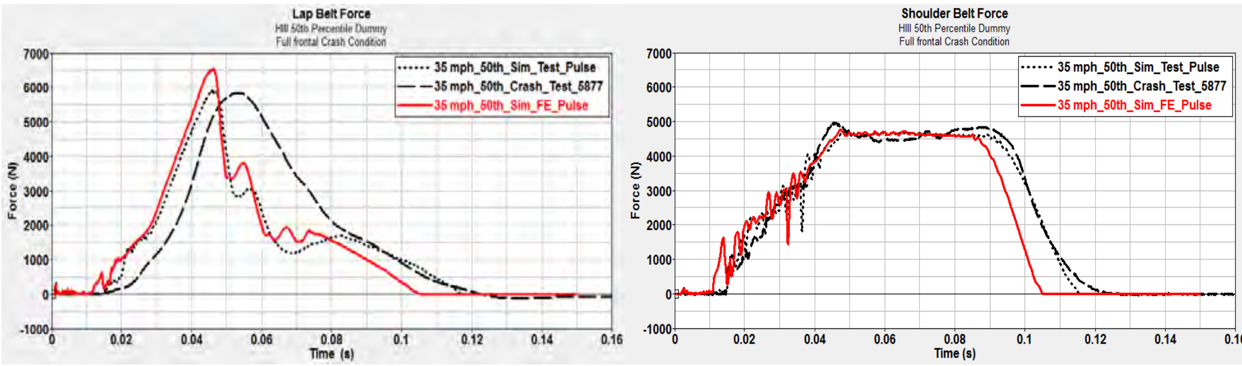

Figure 11-5 – Comparison of lap (left) and shoulder (right) belt forces between test and simulations

All of the outputs for the dummy model were compared to the available crash test data. However, only the chest deflection (Figure 11-6), head acceleration (Figure 11-7), neck tension (Figure 11-8), and femur forces (Figure 11-9) will be shown below, as these were the body regions of interest in the overall study.

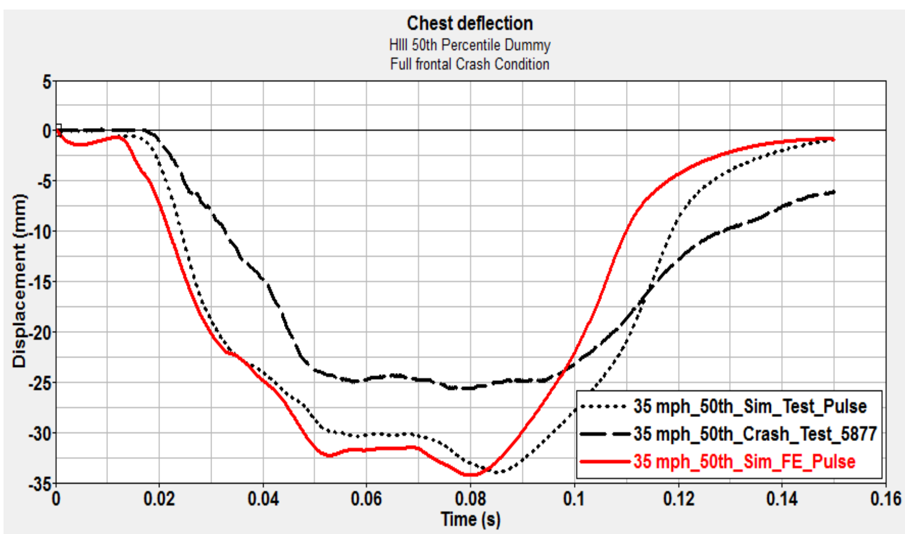

Figure 11-6 – Comparison of chest deflection from test and simulations for full frontal impact

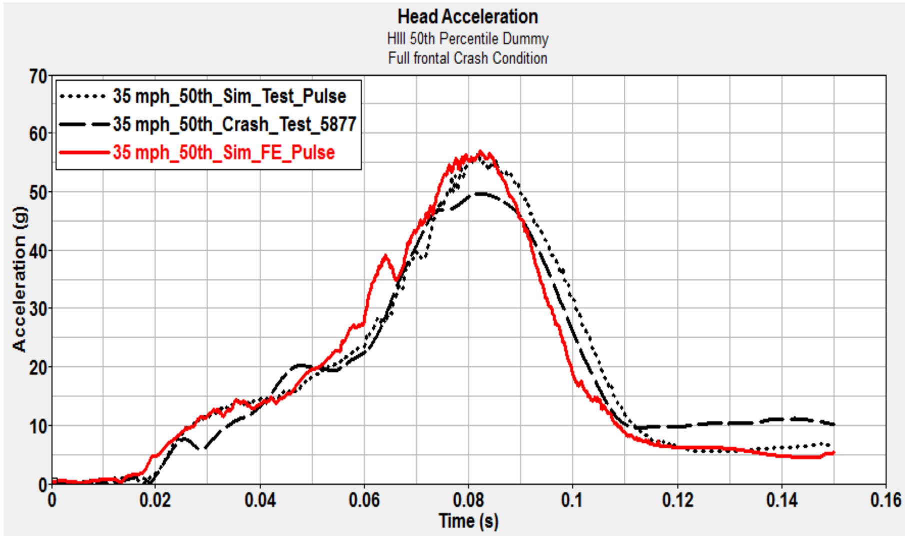

Figure 11-7 – Comparison of head acceleration from test and simulations for full frontal impact

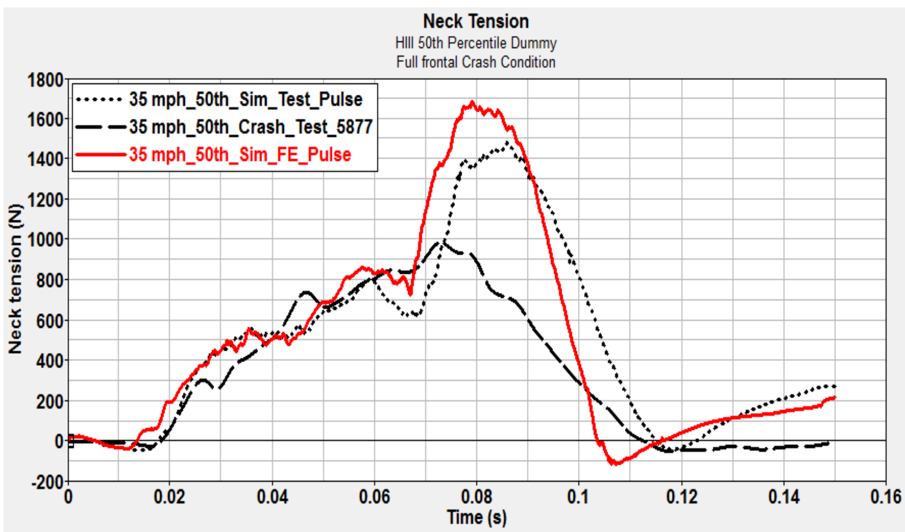

Figure 11-8 – Comparison of neck tension from test and simulations for full frontal impact

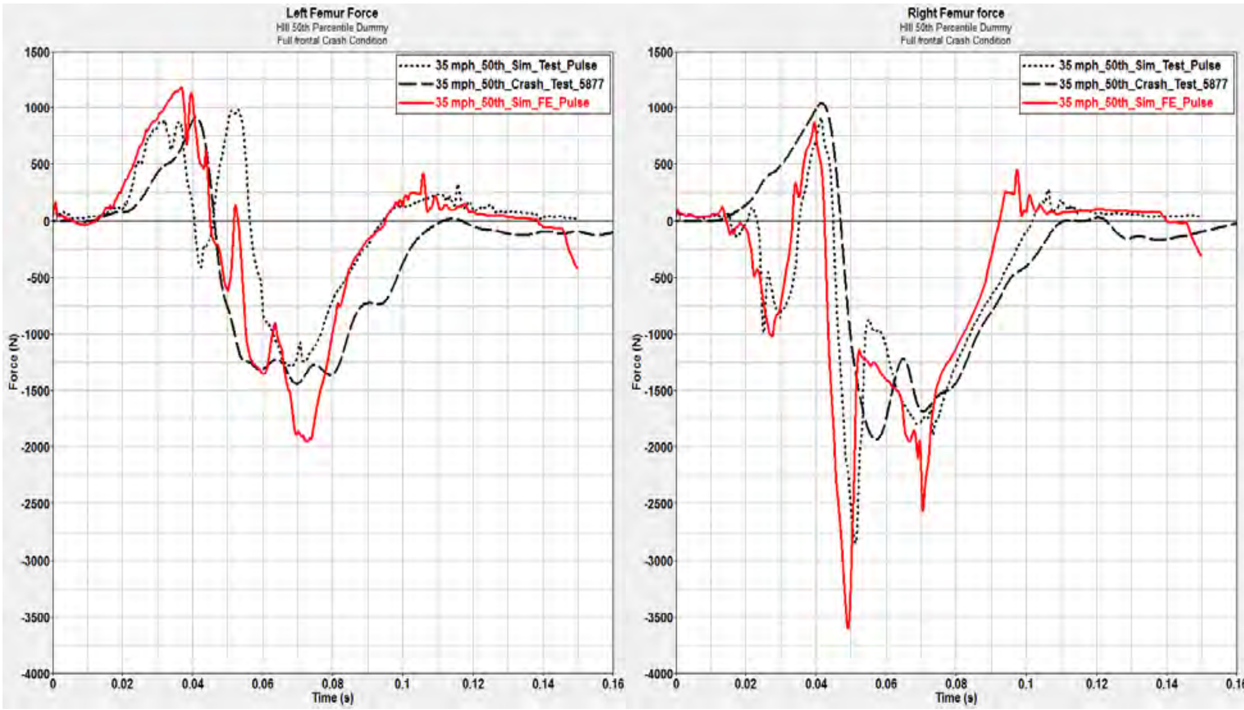

Figure 11-9 – Comparison of left and right femur forces from test and simulations for full frontal impact

11.3.2 Offset Frontal 40 mph Validation: 50th Percentile Male Dummy

The 50th percentile male dummy model seated in the Silverado was validated against IIHS test no. CEF0825, an offset frontal impact with a deformable barrier at 40 mph [2]. Two simulations were run for this crash configuration, one using the test pulse and one using the FE pulse (Figure 11-10). For the offset crash configuration, all three linear accelerations were used to drive the simulation.

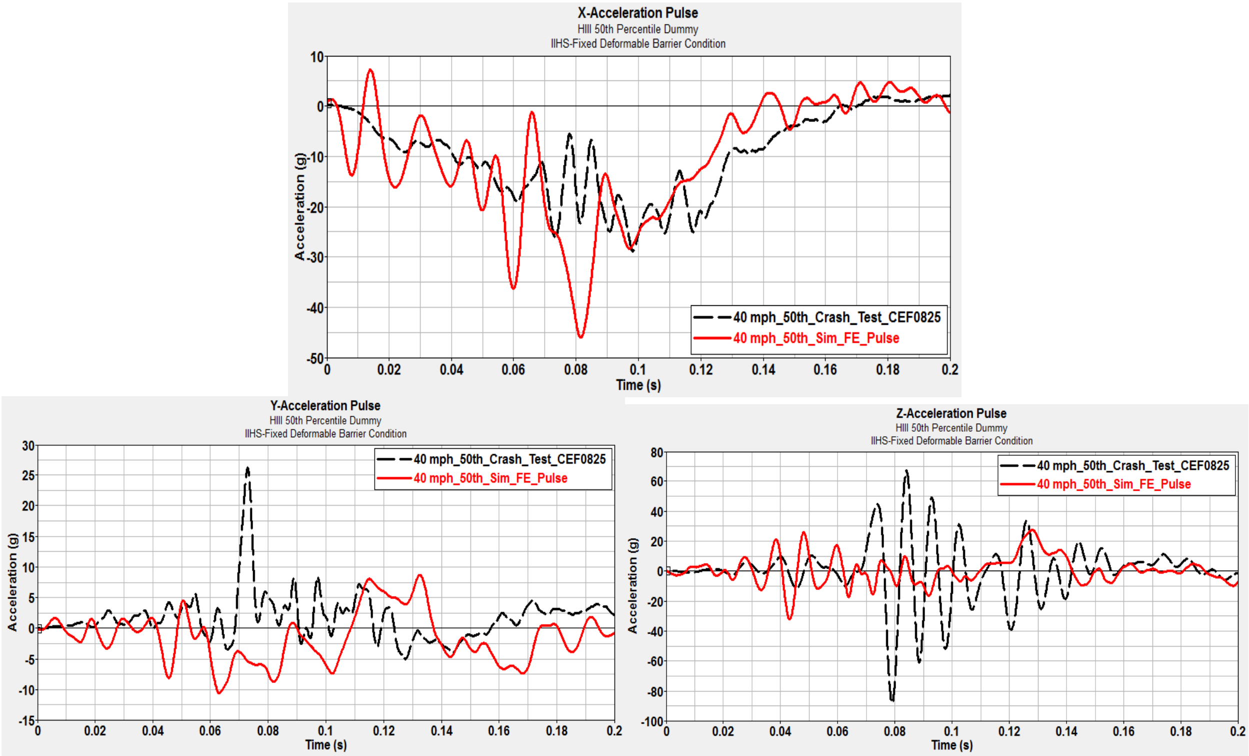

Figure 11-10 – Comparison of X, Y, and Z vehicle acceleration from test and simulations for offset frontal impact

A comparison of the lap and shoulder belt forces between the test and both simulations is shown in Figure 11-11.

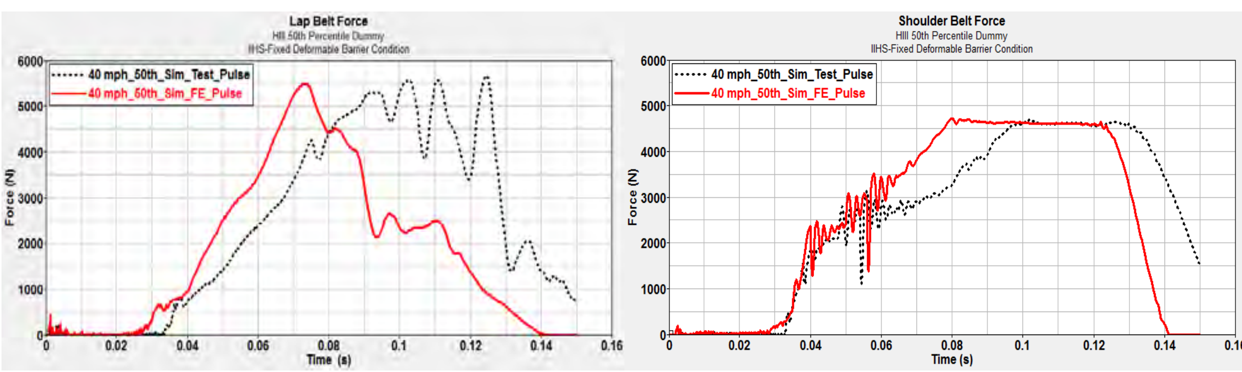

Figure 11-11 – Comparison of lap (left) and shoulder (right) belt forces between test and simulations

The chest deflection (Figure 11-12), head acceleration (Figure 11-13), neck tension (Figure 11-14), and femur forces (Figure 11-15) were compared between the test and simulations, showing reasonable correlation.

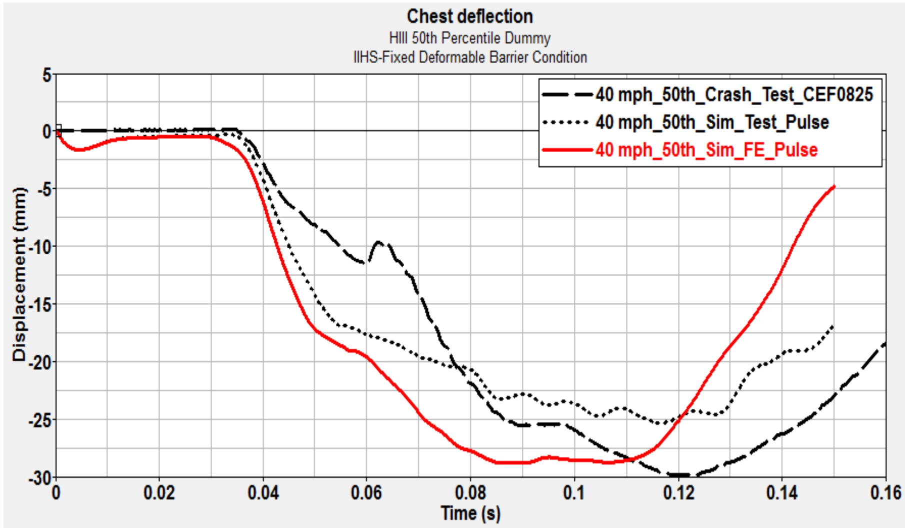

Figure 11-12 – Comparison of chest deflection from test and simulations for offset frontal impact

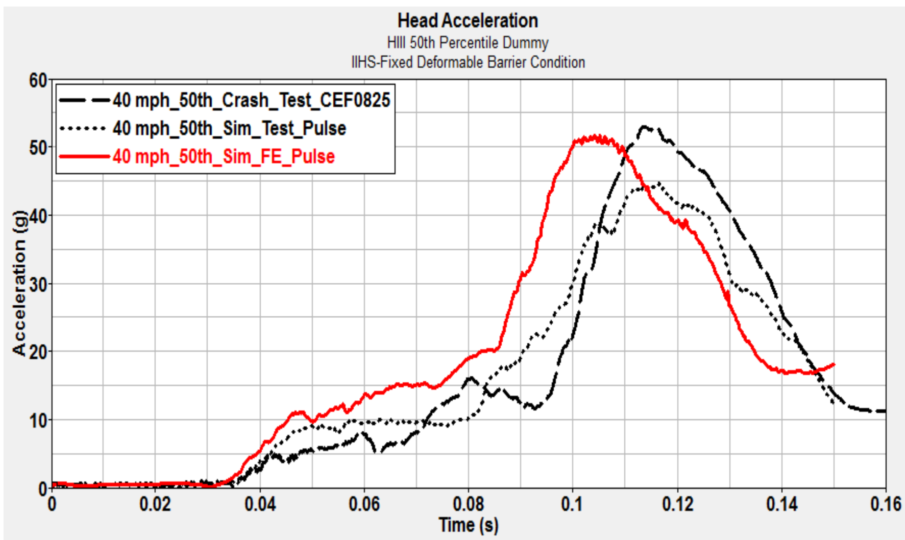

Figure 11-13 – Comparison of head acceleration from test and simulations for offset frontal impact

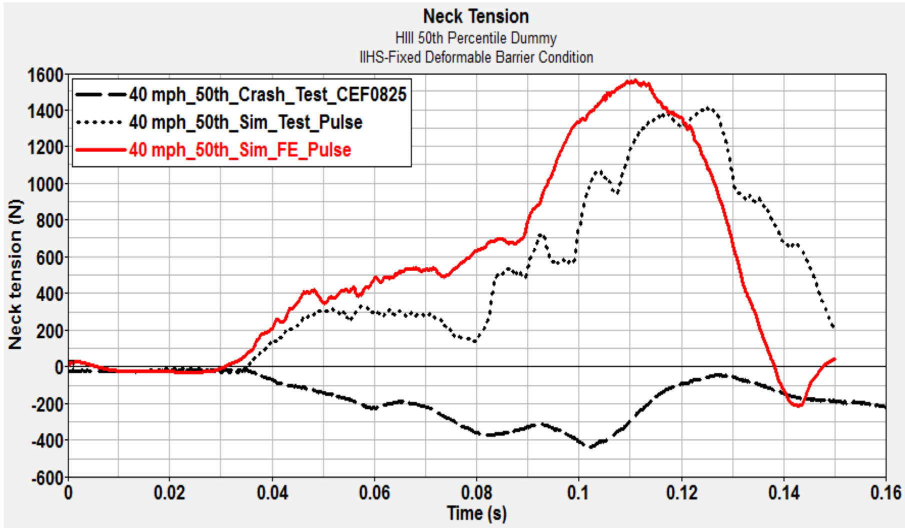

Figure 11-14 – Comparison of neck tension from test and simulations for offset frontal impact

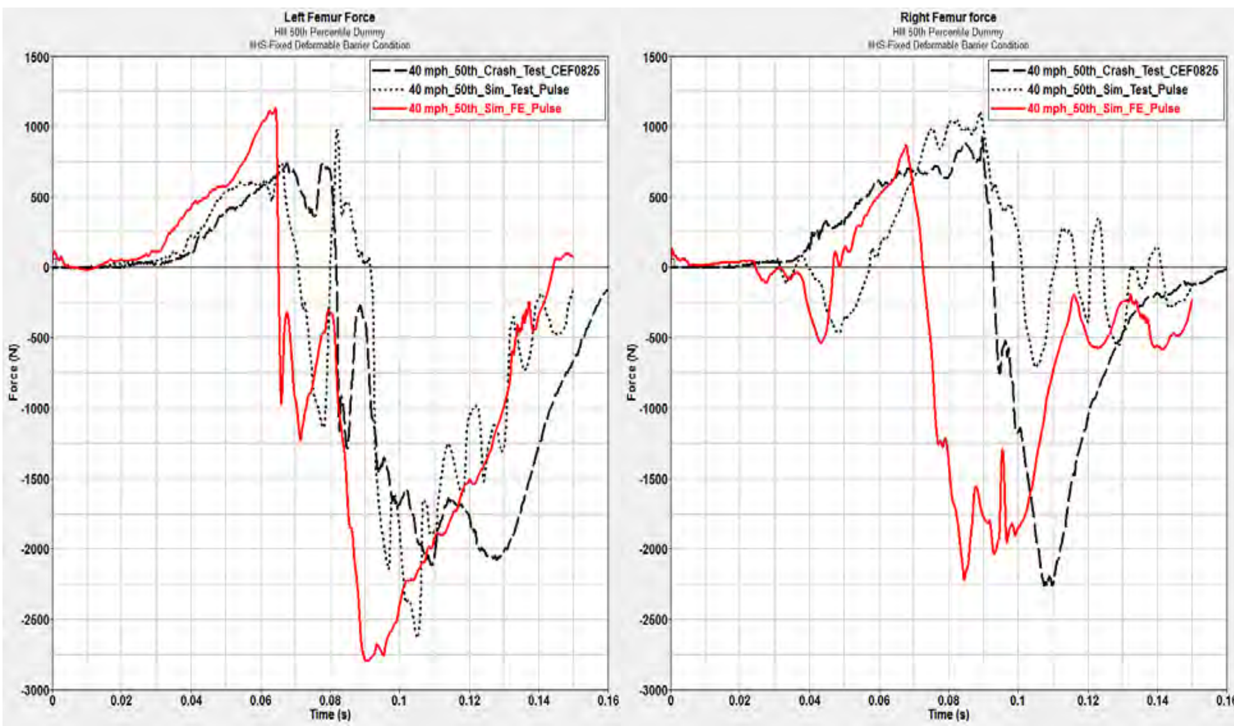

Figure 11-15 – Comparison of left and right femur forces from test and simulations for offset frontal impact

11.4 Model Verification and Robustness

Both the 50th percentile and 5th percentile simulations were run in a centerline pole impact at 25 mph and 35 mph. These simulations were performed to show that the model was stable and that the model would trend as expected. For the centerline pole impact, the X, Y, and Z vehicle linear accelerations from the LS-DYNA full vehicle simulations were used to drive the model (Figure 11-16).

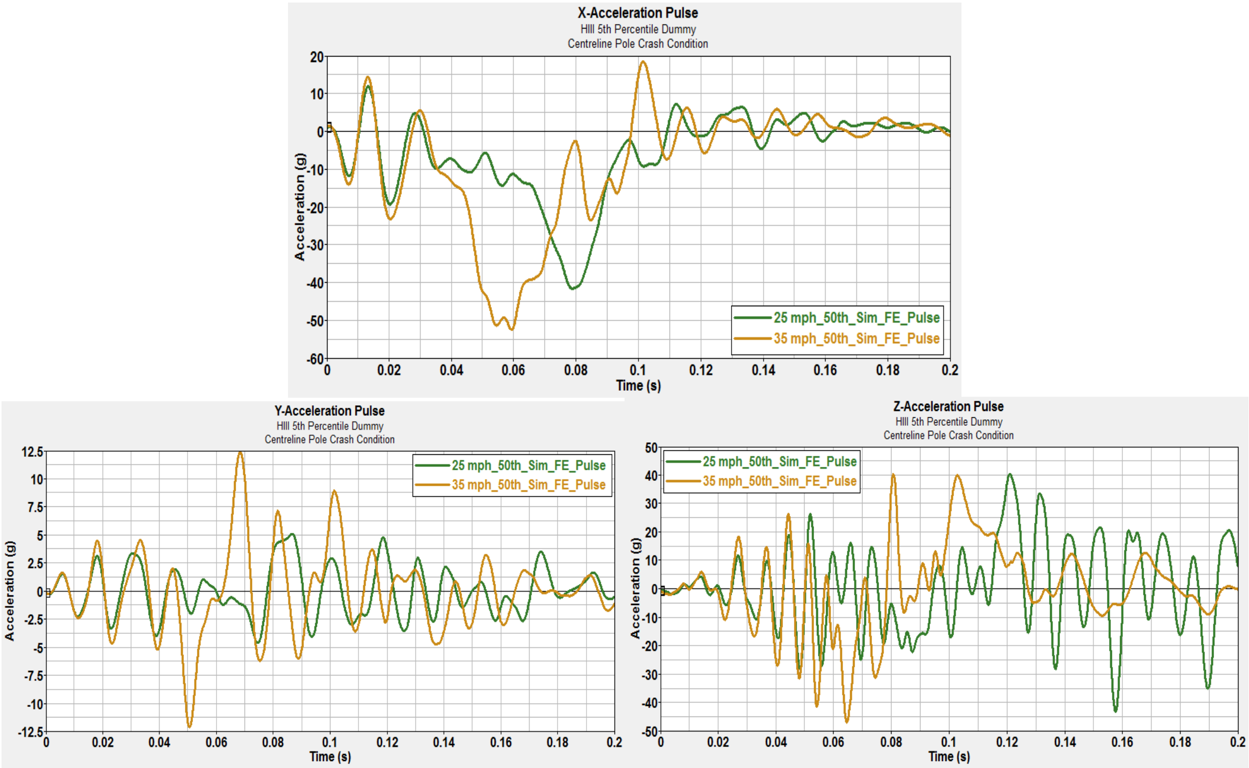

Figure 11-16 – Comparison of X, Y, and Z vehicle accelerations from 25 mph and 35 mph centerline pole impacts

The simulations were also run in offset frontal impacts into a deformable barrier at 25 mph and 40 mph. For this crash configuration, the X, Y, and Z linear accelerations from the LS-DYNA full vehicle simulations were used to drive the model (Figure 11-17).

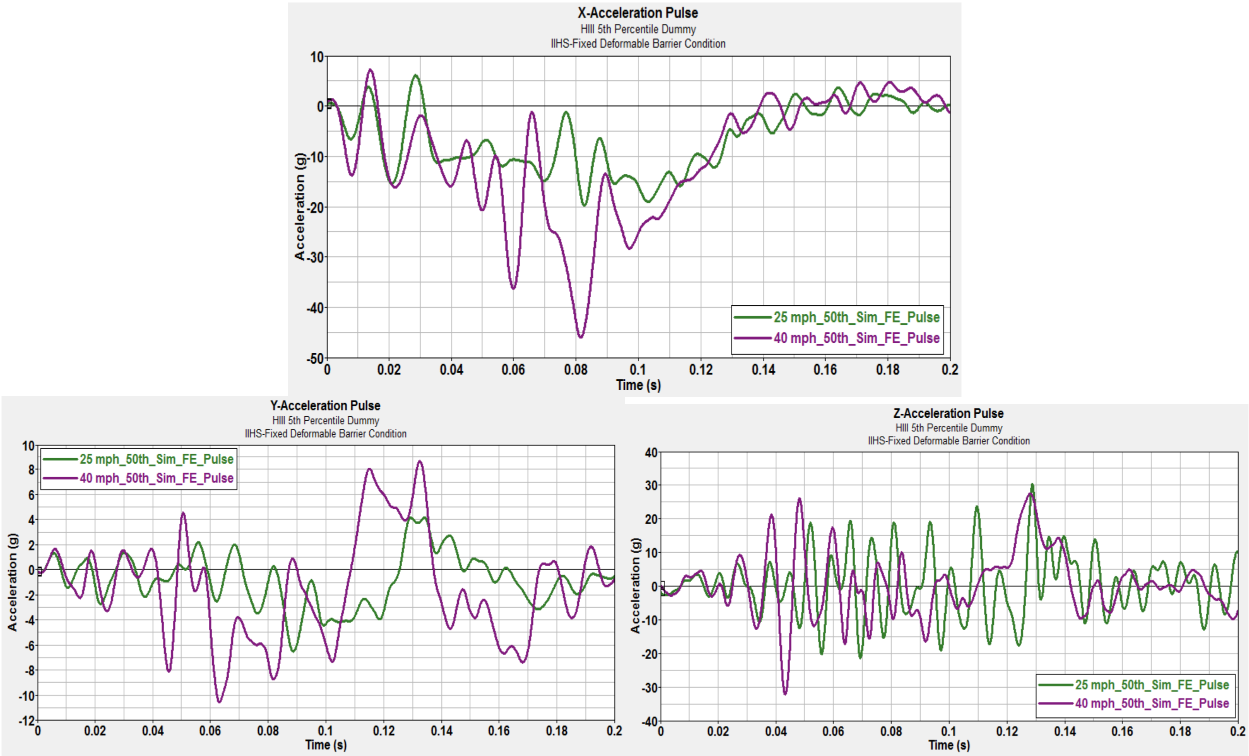

Figure 11-17 – Comparison of X, Y, and Z vehicle accelerations from 25 mph and 40 mph offset frontal impacts

The results for the 50th percentile dummy and 5th percentile dummy for these verification and robustness runs are shown in Table 11-1 and Table 11-2. These results show the expected trends, with higher injury risk corresponding to the higher speed impact and lower injury risk corresponding to the lower speed impact.

Table 11-1 – Comparison of injury results for 50th percentile dummy for verification and robustness simulations

	H350/50th	Centerline pole 25 mph 50th	Centerline pole 35 mph 50th	IIHS 25 mph 50th	IIHS 40 mph 50th
Response	**Formula**	**Simulation Results**	**Simulation Results**	**Simulation Results**	**Simulation Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	153.9	363.7	85	261
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	211.2	570	141	450
Neck Tension (T)	**Upper Neck Fz Max**	1186.2	2249.8	779	1160
Chest deflection (mm)	**Max deflection**	34.9	39	28	29
Chest acceleration (g)	**Max acceleration**	37.3	59	21	38
Femur Load - Left (N)	**Max Compression force Fz**	2977.8	10905	1002	2792
Femur Load - Right (N)	**Max Compression force Fz**	4862	10206	204	2220
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.05%	1.77%	0.00%	0.54%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def)^0.4612)))**	7.76%	11.40%	3.51%	4.07%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.326* max Femur /1000)) - 1/(1+EXP(4.9795))**	2.56%	18.71%	0.26%	1.00%
Neck Tension (AIS3%)	**1/(1+EXP(10.9745-2.375* NeckTension//1000))**	0.03%	0.36%	0.01%	0.03%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.10	0.30	0.04	0.06

Table 11-2 – Comparison of injury results for 5th percentile dummy for verification and robustness simulations

	H305/5th	Centerline pole 25 mph 5th	Centerline pole 35 mph 5th	IIHS 25 mph 5th	IIHS 40 mph 5th
Response	**Formula**	**Simulation Results**	**Simulation Results**	**Simulation Results**	**Simulation Results**
HIC15	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	96.89	399.3	47.87	77.5
HIC36	$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$	124.03	501.66	83.25	171.5
Neck Tension (T)	**Upper Neck Fz Max**	1005.8	1768.11	833.35	956.9
Chest deflection (mm)	**Max deflection**	28.7	34.22	25.25	26.83
Chest acceleration (g)	**Max acceleration**	34.9	55.1	28.4	32.4
Femur Load - Left (N)	**Max Compression force Fz**	590.9	1542.8	960.4	1242.7
Femur Load - Right (N)	**Max Compression force Fz**	1051.15	2867	624.5	1567.5
HIC15 Risk (AIS3 %)	**NORMDIST(LN(HIC15),7.45231,0.73998,1)**	0.01%	2.40%	0.00%	0.00%
Chest Deflection (AIS 3%)	**1/(1+EXP(12.597-0.05861*35-1.568*((chest def/0.817)^0.4612)))**	7.94%	14.59%	5.14%	6.31%
Femur Load Max (AIS 3+%)	**1/(1+EXP(4.9795-0.47941* max Femur /1000)) - 1/(1+EXP(4.9795))**	0.44%	1.96%	0.40%	0.75%
Neck Tension (AIS3%)	**1/(1+EXP(10.958-3.77*NeckTension/1000))**	0.08%	1.35%	0.04%	0.06%
Combined Injury Risk	**(1-(1-HR%)*(1-CD%)*(1-FL%)*(1-NT%))**	0.08	0.19	0.06	0.07

11.5 Summary and Conclusions

The models of the 50th percentile dummy and 5th percentile dummy seated in the Silverado were validated against available crash data from regulatory and consumer information tests. Further verification and robustness simulations run under varying crash conditions confirmed that the model was stable. Low and high speeds were also run for the full frontal impact configuration. The analysis and documentation for the low and high speed full frontal impact simulations will be provided in a future update of the documentation.

11.6 Acknowledgements

The authors wish to acknowledge the Federal Highway Administration and National Highway Traffic Safety Administration of the U.S. Department of Transportation for supporting these modeling and simulation efforts.

11.7 References

1. Patel, R.B. and F. Richardson, KARCO Engineering, "Final Report of New Car Assessment Program Testing of a 2007 Chevrolet Silverado LT1 4-Door Truck," NHTSA Test No. 5877, November 2006.
2. Insurance Institute for Highway Safety, "Crash Test Report: 2009 Chevrolet Silverado," IIHS Test CEF0825, February 2009.
3. Transportation Research Center Inc., "2007 Chevrolet Silverado into Fixed 40% Left Offset Deformable Load Cell Barrier at 64.4 km/h," NHTSA Test No. 6277, December 2007.
4. Fischer, B., MGA Research Corporation, "Final Report of New Car Assessment Program Testing of a 2007 Chevrolet Silverado Ext Cab 1500," NHTSA Test No. 5907, January 2007.

12 APPENDIX 12: BASELINE TAURUS RESULTS

Table 12-1 – Baseline Taurus 50th percentile occupant results in single-vehicle crashes

TAURUS BASELINE TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	50	22	1696	849	0.0%	1.8%	0.5%	0.0%	2.3%	1.8%
	20	83	24	2379	1008	0.0%	2.3%	0.8%	0.0%	3.1%	2.3%
	25	124	25	3112	1264	0.0%	2.6%	1.2%	0.0%	3.8%	2.6%
	30	146	26	4098	1303	0.0%	2.9%	1.9%	0.0%	4.8%	3.0%
	35	169	26	5273	1348	0.1%	2.9%	3.0%	0.0%	6.0%	3.1%
Offset Frontal	20	20	18	221	508	0.0%	1.0%	0.1%	0.0%	1.1%	1.0%
	25	31	20	349	631	0.0%	1.3%	0.1%	0.0%	1.4%	1.3%
	30	39	21	660	729	0.0%	1.5%	0.2%	0.0%	1.7%	1.5%
	35	85	23	1300	1070	0.0%	2.0%	0.4%	0.0%	2.4%	2.0%
	40	108	24	1522	1152	0.0%	2.3%	0.4%	0.0%	2.7%	2.3%
Center Pole	15	13	16	308	401	0.0%	0.7%	0.1%	0.0%	0.8%	0.7%
	20	32	19	667	608	0.0%	1.2%	0.2%	0.0%	1.3%	1.2%
	25	82	23	1274	911	0.0%	2.0%	0.3%	0.0%	2.4%	2.0%
	30	109	27	1980	1037	0.0%	3.3%	0.6%	0.0%	3.9%	3.3%
	35	219	28	3437	1262	0.3%	3.7%	1.4%	0.0%	5.3%	4.0%

Table 12-2 – Baseline Taurus 5th percentile occupant results in single-vehicle crashes

TAURUS BASELINE TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	171	23	1834	1399	0.1%	3.8%	0.9%	0.3%	5.1%	4.2%
	20	176	24	2035	1395	0.1%	4.3%	1.1%	0.3%	5.8%	4.8%
	25	184	24	2215	1415	0.1%	4.3%	1.3%	0.4%	6.0%	4.8%
	30	191	25	2389	1438	0.1%	5.0%	1.4%	0.4%	6.8%	5.5%
	35	190	26	2556	1412	0.1%	5.7%	1.6%	0.4%	7.6%	6.1%
Offset Frontal	20	144	20	1995	1382	0.0%	2.4%	1.1%	0.3%	3.8%	2.8%
	25	149	21	2130	1460	0.0%	2.8%	1.2%	0.4%	4.4%	3.3%
	30	157	23	2174	1504	0.1%	3.8%	1.2%	0.5%	5.5%	4.3%
	35	168	23	2113	1487	0.1%	3.8%	1.2%	0.5%	5.4%	4.3%
	40	155	23	2093	1400	0.1%	3.8%	1.2%	0.3%	5.3%	4.2%
Center Pole	15	142	18	1373	1374	0.0%	1.8%	0.6%	0.3%	2.7%	2.1%
	20	152	20	1504	1424	0.1%	2.4%	0.7%	0.4%	3.5%	2.8%
	25	175	22	1593	1589	0.1%	3.3%	0.8%	0.7%	4.8%	4.0%
	30	194	25	2169	1621	0.2%	5.0%	1.2%	0.8%	7.0%	5.9%
	35	193	26	2442	1523	0.2%	5.7%	1.5%	0.5%	7.7%	6.3%

Table 12-3 – Baseline Taurus 50th percentile occupant results in vehicle-to-vehicle crashes

TAURUS BASELINE TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	53	22	1567	810	0.0%	1.8%	0.5%	0.0%	2.2%	1.8%
	20	107	25	2463	1158	0.0%	2.6%	0.8%	0.0%	3.4%	2.6%
	25	138	26	4758	1266	0.0%	2.9%	2.5%	0.0%	5.4%	3.0%
	30	194	27	6027	1479	0.2%	3.3%	4.0%	0.1%	7.4%	3.5%
	35	281	27	5375	1606	0.7%	3.3%	3.1%	0.1%	7.1%	4.1%
Explorer Offset	15	21	20	268	597	0.0%	1.3%	0.1%	0.0%	1.4%	1.3%
	20	45	22	695	885	0.0%	1.8%	0.2%	0.0%	1.9%	1.8%
	25	102	24	2235	1205	0.0%	2.3%	0.7%	0.0%	3.0%	2.3%
	30	132	27	3017	1448	0.0%	3.3%	1.1%	0.1%	4.5%	3.4%
	35	265	28	3985	1833	0.6%	3.7%	1.8%	0.1%	6.1%	4.4%
Silverado Full	15	35	21	1396	691	0.0%	1.5%	0.4%	0.0%	1.9%	1.5%
	20	104	25	3070	1130	0.0%	2.6%	1.2%	0.0%	3.7%	2.6%
	25	124	26	5256	1205	0.0%	2.9%	3.0%	0.0%	5.9%	3.0%
	30	164	27	7590	1401	0.1%	3.3%	6.9%	0.0%	10.1%	3.4%
	35	220	27	8914	1532	0.3%	3.3%	10.5%	0.1%	13.7%	3.6%
Silverado Offset	15	36	21	373	827	0.0%	1.5%	0.1%	0.0%	1.6%	1.5%
	20	67	24	983	1057	0.0%	2.3%	0.3%	0.0%	2.6%	2.3%
	25	113	24	1628	1133	0.0%	2.3%	0.5%	0.0%	2.8%	2.3%
	30	144	26	2485	1365	0.0%	2.9%	0.8%	0.0%	3.8%	3.0%
	35	169	27	3373	1488	0.1%	3.3%	1.3%	0.1%	4.7%	3.4%
Yaris Full	15	30	20	1110	658	0.0%	1.3%	0.3%	0.0%	1.6%	1.3%
	20	59	23	1998	925	0.0%	2.0%	0.6%	0.0%	2.6%	2.0%
	25	110	25	3577	1180	0.0%	2.6%	1.5%	0.0%	4.1%	2.6%
	30	132	25	4258	1291	0.0%	2.6%	2.0%	0.0%	4.6%	2.7%
	35	162	27	5655	1276	0.1%	3.3%	3.5%	0.0%	6.8%	3.4%
Yaris Offset	15	5	11	219	315	0.0%	0.3%	0.1%	0.0%	0.4%	0.3%
	20	9	15	259	356	0.0%	0.6%	0.1%	0.0%	0.7%	0.6%
	25	30	21	441	703	0.0%	1.5%	0.1%	0.0%	1.6%	1.5%
	30	82	22	1148	976	0.0%	1.8%	0.3%	0.0%	2.1%	1.8%
	35	152	24	1853	1277	0.1%	2.3%	0.6%	0.0%	2.9%	2.4%
Taurus Full	15	27	20	1078	605	0.0%	1.3%	0.3%	0.0%	1.6%	1.3%
	20	66	23	1918	920	0.0%	2.0%	0.6%	0.0%	2.6%	2.0%
	25	111	24	2827	1202	0.0%	2.3%	1.0%	0.0%	3.3%	2.3%
	30	132	26	4334	1254	0.0%	2.9%	2.1%	0.0%	5.0%	3.0%
	35	163	26	5124	1349	0.1%	2.9%	2.8%	0.0%	5.8%	3.0%
Taurus Offset	15	12	17	254	429	0.0%	0.9%	0.1%	0.0%	0.9%	0.9%
	20	21	19	224	624	0.0%	1.2%	0.1%	0.0%	1.2%	1.2%
	25	47	22	559	781	0.0%	1.8%	0.1%	0.0%	1.9%	1.8%
	30	90	24	1634	1043	0.0%	2.3%	0.5%	0.0%	2.8%	2.3%
	35	194	26	2471	1513	0.2%	2.9%	0.8%	0.1%	4.0%	3.1%

Table 12-4 – Baseline Taurus 5th percentile occupant results in vehicle-to-vehicle crashes

TAURUS BASELINE TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	171	23	1887	1437	0.1%	3.8%	1.0%	0.4%	5.2%	4.2%
	20	186	24	1998	1475	0.1%	4.3%	1.1%	0.5%	5.9%	4.9%
	25	210	26	2048	1605	0.2%	5.7%	1.1%	0.7%	7.6%	6.6%
	30	204	27	2663	1398	0.2%	6.4%	1.7%	0.3%	8.5%	6.9%
	35	209	28	3040	1476	0.2%	7.3%	2.2%	0.5%	9.9%	7.9%
Explorer Offset	15	152	21	2181	1445	0.1%	2.8%	1.2%	0.4%	4.5%	3.3%
	20	170	24	2185	1615	0.1%	4.3%	1.2%	0.8%	6.3%	5.2%
	25	203	26	2323	1833	0.2%	5.7%	1.4%	1.7%	8.7%	7.5%
	30	199	27	1985	1687	0.2%	6.4%	1.1%	1.0%	8.5%	7.5%
	35	220	28	1813	1707	0.3%	7.3%	0.9%	1.1%	9.4%	8.5%
Silverado Full	15	174	22	2009	1442	0.1%	3.3%	1.1%	0.4%	4.8%	3.8%
	20	179	24	1936	1423	0.1%	4.3%	1.0%	0.4%	5.8%	4.8%
	25	188	26	2236	1441	0.1%	5.7%	1.3%	0.4%	7.4%	6.2%
	30	203	27	2634	1445	0.2%	6.4%	1.7%	0.4%	8.6%	7.0%
	35	201	27	3301	1366	0.2%	6.4%	2.6%	0.3%	9.3%	6.9%
Silverado Offset	15	168	22	2134	1605	0.1%	3.3%	1.2%	0.7%	5.2%	4.1%
	20	187	25	2168	1675	0.1%	5.0%	1.2%	1.0%	7.2%	6.0%
	25	187	26	2307	1721	0.1%	5.7%	1.4%	1.1%	8.1%	6.9%
	30	215	27	2036	1744	0.2%	6.4%	1.1%	1.2%	8.8%	7.8%
	35	221	28	2003	1776	0.3%	7.3%	1.1%	1.4%	9.8%	8.8%
Yaris Full	15	170	22	2045	1419	0.1%	3.3%	1.1%	0.4%	4.8%	3.7%
	20	166	23	1848	1371	0.1%	3.8%	1.0%	0.3%	5.1%	4.1%
	25	184	25	2046	1418	0.1%	5.0%	1.1%	0.4%	6.5%	5.4%
	30	167	25	2390	1340	0.1%	5.0%	1.4%	0.3%	6.7%	5.3%
	35	196	26	2469	1477	0.2%	5.7%	1.5%	0.5%	7.7%	6.3%
Yaris Offset	15	125	14	1585	1276	0.0%	0.9%	0.8%	0.2%	1.9%	1.1%
	20	136	18	1732	1401	0.0%	1.8%	0.9%	0.3%	3.0%	2.1%
	25	162	22	2067	1552	0.1%	3.3%	1.1%	0.6%	5.0%	3.9%
	30	159	23	2199	1507	0.1%	3.8%	1.3%	0.5%	5.5%	4.3%
	35	191	25	2222	1671	0.1%	5.0%	1.3%	0.9%	7.2%	6.0%
Taurus Full	15	160	21	1971	1335	0.1%	2.8%	1.1%	0.3%	4.2%	3.2%
	20	184	23	1898	1468	0.1%	3.8%	1.0%	0.4%	5.3%	4.3%
	25	179	24	2087	1394	0.1%	4.3%	1.2%	0.3%	5.9%	4.8%
	30	188	25	2312	1436	0.1%	5.0%	1.4%	0.4%	6.8%	5.5%
	35	178	25	2563	1366	0.1%	5.0%	1.6%	0.3%	6.9%	5.4%
Taurus Offset	15	139	19	2180	1426	0.0%	2.1%	1.2%	0.4%	3.7%	2.5%
	20	148	21	2194	1526	0.0%	2.8%	1.2%	0.5%	4.6%	3.4%
	25	163	22	2179	1507	0.1%	3.3%	1.2%	0.5%	5.0%	3.8%
	30	158	23	2203	1398	0.1%	3.8%	1.3%	0.3%	5.4%	4.2%
	35	178	25	2185	1532	0.1%	5.0%	1.2%	0.6%	6.8%	5.6%

Table 12-5 – Partner vehicle 50th percentile occupant results in vehicle-to-vehicle crashes with baseline Taurus

TAURUS BASELINE PARTNER VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	14	23	2449	475	0.0%	2.0%	0.8%	0.0%	2.8%	2.0%
	20	38	28	3322	622	0.0%	3.7%	1.3%	0.0%	5.0%	3.7%
	25	87	29	3642	954	0.0%	4.2%	1.5%	0.0%	5.6%	4.2%
	30	173	29	4236	1274	0.1%	4.2%	2.0%	0.0%	6.2%	4.3%
	35	244	30	5023	1431	0.4%	4.7%	2.7%	0.1%	7.7%	5.1%
Explorer Offset	15	9	16	2001	465	0.0%	0.7%	0.6%	0.0%	1.4%	0.7%
	20	14	18	2188	515	0.0%	1.0%	0.7%	0.0%	1.7%	1.0%
	25	42	21	2620	570	0.0%	1.5%	0.9%	0.0%	2.4%	1.5%
	30	54	27	3227	864	0.0%	3.3%	1.2%	0.0%	4.5%	3.3%
	35	115	29	3796	1061	0.0%	4.2%	1.6%	0.0%	5.8%	4.2%
Silverado Full	15	10	22	343	393	0.0%	1.8%	0.1%	0.0%	1.8%	1.8%
	20	38	27	643	496	0.0%	3.3%	0.2%	0.0%	3.5%	3.3%
	25	99	29	1681	667	0.0%	4.2%	0.5%	0.0%	4.7%	4.2%
	30	171	30	2612	794	0.1%	4.7%	0.9%	0.0%	5.6%	4.8%
	35	221	30	2717	939	0.3%	4.7%	1.0%	0.0%	5.8%	4.9%
Silverado Offset	15	19	21	63	304	0.0%	1.5%	0.0%	0.0%	1.6%	1.5%
	20	32	23	181	439	0.0%	2.0%	0.0%	0.0%	2.1%	2.0%
	25	83	24	254	708	0.0%	2.3%	0.1%	0.0%	2.4%	2.3%
	30	126	26	390	869	0.0%	2.9%	0.1%	0.0%	3.1%	3.0%
	35	166	28	756	1074	0.1%	3.7%	0.2%	0.0%	4.0%	3.8%
Yaris Full	15	62	22	3032	703	0.0%	1.8%	1.1%	0.0%	2.9%	1.8%
	20	89	24	3655	766	0.0%	2.3%	1.5%	0.0%	3.8%	2.3%
	25	97	24	3717	894	0.0%	2.3%	1.6%	0.0%	3.8%	2.3%
	30	139	25	4325	1097	0.0%	2.6%	2.1%	0.0%	4.7%	2.6%
	35	286	27	7696	1444	0.8%	3.3%	7.1%	0.1%	10.9%	4.1%
Yaris Offset	15	23	19	463	381	0.0%	1.2%	0.1%	0.0%	1.3%	1.2%
	20	57	23	551	654	0.0%	2.0%	0.1%	0.0%	2.1%	2.0%
	25	100	27	1705	1133	0.0%	3.3%	0.5%	0.0%	3.8%	3.3%
	30	295	29	2978	1160	0.9%	4.2%	1.1%	0.0%	6.1%	5.0%
	35	469	29	4353	1188	3.9%	4.2%	2.1%	0.0%	9.9%	8.0%
Taurus Full	15	27	20	1078	605	0.0%	1.3%	0.3%	0.0%	1.6%	1.3%
	20	66	23	1918	920	0.0%	2.0%	0.6%	0.0%	2.6%	2.0%
	25	111	24	2827	1202	0.0%	2.3%	1.0%	0.0%	3.3%	2.3%
	30	132	26	4334	1254	0.0%	2.9%	2.1%	0.0%	5.0%	3.0%
	35	163	26	5124	1349	0.1%	2.9%	2.8%	0.0%	5.8%	3.0%
Taurus Offset	15	12	17	254	429	0.0%	0.9%	0.1%	0.0%	0.9%	0.9%
	20	21	19	224	624	0.0%	1.2%	0.1%	0.0%	1.2%	1.2%
	25	47	22	559	781	0.0%	1.8%	0.1%	0.0%	1.9%	1.8%
	30	90	24	1634	1043	0.0%	2.3%	0.5%	0.0%	2.8%	2.3%
	35	194	26	2471	1513	0.2%	2.9%	0.8%	0.1%	4.0%	3.1%

Table 12-6 – Partner vehicle 5th percentile occupant results in vehicle-to-vehicle crashes with baseline Taurus

TAURUS BASELINE PARTNER VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	60	22	1379	980	0.0%	3.3%	0.6%	0.1%	4.0%	3.3%
	20	68	23	1532	1155	0.0%	3.8%	0.7%	0.1%	4.6%	3.9%
	25	86	24	1754	1211	0.0%	4.3%	0.9%	0.2%	5.4%	4.5%
	30	106	27	1812	1333	0.0%	6.4%	0.9%	0.3%	7.6%	6.7%
	35	106	28	1857	1462	0.0%	7.3%	1.0%	0.4%	8.6%	7.7%
Explorer Offset	15	103	21	1821	1060	0.0%	2.8%	0.9%	0.1%	3.8%	2.9%
	20	102	21	1925	1094	0.0%	2.8%	1.0%	0.1%	3.9%	2.9%
	25	81	21	2090	1103	0.0%	2.8%	1.2%	0.1%	4.1%	2.9%
	30	72	21	2172	1050	0.0%	2.8%	1.2%	0.1%	4.1%	2.9%
	35	98	24	2316	1132	0.0%	4.3%	1.4%	0.1%	5.8%	4.5%
Silverado Full	15	62	24	283	895	0.0%	4.3%	0.1%	0.1%	4.5%	4.4%
	20	54	27	706	996	0.0%	6.4%	0.3%	0.1%	6.8%	6.5%
	25	94	28	983	981	0.0%	7.3%	0.4%	0.1%	7.7%	7.4%
	30	169	29	1104	963	0.1%	8.2%	0.5%	0.1%	8.8%	8.4%
	35	126	29	887	973	0.0%	8.2%	0.4%	0.1%	8.6%	8.3%
Silverado Offset	15	66	23	196	821	0.0%	3.8%	0.1%	0.0%	3.9%	3.8%
	20	64	24	363	791	0.0%	4.3%	0.1%	0.0%	4.5%	4.4%
	25	59	25	523	880	0.0%	5.0%	0.2%	0.0%	5.2%	5.0%
	30	58	26	657	911	0.0%	5.7%	0.3%	0.1%	6.0%	5.7%
	35	78	28	746	967	0.0%	7.3%	0.3%	0.1%	7.6%	7.4%
Yaris Full	15	212	25	1331	961	0.2%	5.0%	0.6%	0.1%	5.8%	5.3%
	20	279	28	1814	1003	0.7%	7.3%	0.9%	0.1%	8.9%	8.0%
	25	329	30	2124	1003	1.3%	9.2%	1.2%	0.1%	11.5%	10.5%
	30	344	30	2183	1056	1.5%	9.2%	1.2%	0.1%	11.8%	10.7%
	35	349	31	2729	1055	1.5%	10.4%	1.8%	0.1%	13.4%	11.8%
Yaris Offset	15	135	18	575	711	0.0%	1.8%	0.2%	0.0%	2.0%	1.8%
	20	170	21	894	863	0.1%	2.8%	0.4%	0.0%	3.3%	3.0%
	25	280	27	1226	1183	0.7%	6.4%	0.5%	0.2%	7.7%	7.2%
	30	326	28	1586	1259	1.2%	7.3%	0.8%	0.2%	9.3%	8.6%
	35	321	28	1785	1130	1.2%	7.3%	0.9%	0.1%	9.3%	8.5%
Taurus Full	15	160	21	1971	1335	0.1%	2.8%	1.1%	0.3%	4.2%	3.2%
	20	184	23	1898	1468	0.1%	3.8%	1.0%	0.4%	5.3%	4.3%
	25	179	24	2087	1394	0.1%	4.3%	1.2%	0.3%	5.9%	4.8%
	30	188	25	2312	1436	0.1%	5.0%	1.4%	0.4%	6.8%	5.5%
	35	178	25	2563	1366	0.1%	5.0%	1.6%	0.3%	6.9%	5.4%
Taurus Offset	15	139	19	2180	1426	0.0%	2.1%	1.2%	0.4%	3.7%	2.5%
	20	148	21	2194	1526	0.0%	2.8%	1.2%	0.5%	4.6%	3.4%
	25	163	22	2179	1507	0.1%	3.3%	1.2%	0.5%	5.0%	3.8%
	30	158	23	2203	1398	0.1%	3.8%	1.3%	0.3%	5.4%	4.2%
	35	178	25	2185	1532	0.1%	5.0%	1.2%	0.6%	6.8%	5.6%

13 APPENDIX 13: LW3 TAURUS RESULTS

Table 13-1 – LW3 Taurus 50th percentile occupant results in single-vehicle crashes

LW3 TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	66	24	2684	1025	0.0%	2.3%	0.9%	0.0%	3.2%	2.3%
	20	124	25	4324	1215	0.0%	2.6%	2.1%	0.0%	4.6%	2.6%
	25	146	26	4870	1323	0.0%	2.9%	2.6%	0.0%	5.5%	3.0%
	30	168	26	5476	1336	0.1%	2.9%	3.3%	0.0%	6.2%	3.1%
	35	230	27	6539	1570	0.3%	3.3%	4.8%	0.1%	8.3%	3.7%
Offset Frontal	20	26	20	432	580	0.0%	1.3%	0.1%	0.0%	1.4%	1.3%
	25	40	21	471	713	0.0%	1.5%	0.1%	0.0%	1.7%	1.5%
	30	56	23	1059	892	0.0%	2.0%	0.3%	0.0%	2.3%	2.0%
	35	97	24	1279	1127	0.0%	2.3%	0.3%	0.0%	2.7%	2.3%
	40	138	25	1731	1322	0.0%	2.6%	0.5%	0.0%	3.2%	2.7%
Center Pole	15	16	17	394	450	0.0%	0.9%	0.1%	0.0%	1.0%	0.9%
	20	39	21	892	685	0.0%	1.5%	0.2%	0.0%	1.8%	1.5%
	25	91	25	1599	1016	0.0%	2.6%	0.5%	0.0%	3.1%	2.6%
	30	115	27	2659	1118	0.0%	3.3%	0.9%	0.0%	4.2%	3.3%
	35	232	28	3526	1248	0.3%	3.7%	1.4%	0.0%	5.5%	4.1%

Table 13-2 – LW3 Taurus 5th percentile occupant results in single-vehicle crashes

LW3 TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	174	24	1981	1389	0.1%	4.3%	1.1%	0.3%	5.8%	4.7%
	20	181	25	2482	1375	0.1%	5.0%	1.5%	0.3%	6.8%	5.4%
	25	184	25	2674	1379	0.1%	5.0%	1.7%	0.3%	7.0%	5.4%
	30	192	26	2797	1424	0.2%	5.7%	1.9%	0.4%	7.9%	6.2%
	35	212	27	2865	1479	0.2%	6.4%	2.0%	0.5%	8.9%	7.1%
Offset Frontal	20	158	21	2121	1415	0.1%	2.8%	1.2%	0.4%	4.4%	3.2%
	25	159	21	2281	1404	0.1%	2.8%	1.3%	0.3%	4.5%	3.2%
	30	182	25	2371	1649	0.1%	5.0%	1.4%	0.9%	7.2%	5.9%
	35	177	25	2328	1564	0.1%	5.0%	1.4%	0.6%	7.0%	5.7%
	40	174	25	2102	1498	0.1%	5.0%	1.2%	0.5%	6.6%	5.5%
Center Pole	15	149	18	1536	1375	0.0%	1.8%	0.7%	0.3%	2.8%	2.1%
	20	164	22	1674	1497	0.1%	3.3%	0.8%	0.5%	4.6%	3.8%
	25	187	24	1808	1584	0.1%	4.3%	0.9%	0.7%	6.0%	5.1%
	30	207	26	1920	1665	0.2%	5.7%	1.0%	0.9%	7.7%	6.7%
	35	206	27	2641	1536	0.2%	6.4%	1.7%	0.6%	8.7%	7.2%

Table 13-3 – LW3 Taurus 50th percentile occupant results in vehicle-to-vehicle crashes

LW3 TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	83	24	2060	1030	0.0%	2.3%	0.6%	0.0%	2.9%	2.3%
	20	135	25	3774	1245	0.0%	2.6%	1.6%	0.0%	4.2%	2.7%
	25	179	27	6739	1428	0.1%	3.3%	5.1%	0.1%	8.4%	3.5%
	30	316	28	6949	1909	1.1%	3.7%	5.5%	0.2%	10.2%	4.9%
	35	389	28	6733	1941	2.2%	3.7%	5.1%	0.2%	10.8%	6.0%
Explorer Offset	15	21	18	306	563	0.0%	1.0%	0.1%	0.0%	1.1%	1.0%
	20	59	24	979	1007	0.0%	2.3%	0.3%	0.0%	2.6%	2.3%
	25	110	25	2818	1330	0.0%	2.6%	1.0%	0.0%	3.6%	2.6%
	30	195	27	3852	1539	0.2%	3.3%	1.7%	0.1%	5.1%	3.5%
	35	492	28	4596	1859	4.5%	3.7%	2.3%	0.1%	10.3%	8.2%
Silverado Full	15	58	23	2065	918	0.0%	2.0%	0.6%	0.0%	2.7%	2.0%
	20	134	26	4556	1256	0.0%	2.9%	2.3%	0.0%	5.2%	3.0%
	25	170	27	7808	1425	0.1%	3.3%	7.4%	0.1%	10.6%	3.4%
	30	300	28	13056	1818	0.9%	3.7%	32.0%	0.1%	35.2%	4.7%
	35	382	28	12747	1964	2.1%	3.7%	29.8%	0.2%	33.9%	5.9%
Silverado Offset	15	44	22	486	934	0.0%	1.8%	0.1%	0.0%	1.9%	1.8%
	20	96	25	1697	1190	0.0%	2.6%	0.5%	0.0%	3.1%	2.6%
	25	137	26	2609	1269	0.0%	2.9%	0.9%	0.0%	3.9%	3.0%
	30	158	27	3533	1386	0.1%	3.3%	1.4%	0.0%	4.8%	3.4%
	35	346	28	5184	1666	1.5%	3.7%	2.9%	0.1%	8.0%	5.2%
Yaris Full	15	47	23	1891	838	0.0%	2.0%	0.6%	0.0%	2.6%	2.0%
	20	101	25	3522	1097	0.0%	2.6%	1.4%	0.0%	4.0%	2.6%
	25	137	26	5145	1268	0.0%	2.9%	2.9%	0.0%	5.8%	3.0%
	30	162	26	5800	1322	0.1%	2.9%	3.7%	0.0%	6.6%	3.0%
	35	203	27	6063	1412	0.2%	3.3%	4.0%	0.0%	7.4%	3.5%
Yaris Offset	15	6	13	219	310	0.0%	0.4%	0.1%	0.0%	0.5%	0.4%
	20	16	16	324	413	0.0%	0.7%	0.1%	0.0%	0.8%	0.7%
	25	50	22	641	916	0.0%	1.8%	0.2%	0.0%	1.9%	1.8%
	30	122	24	1569	1188	0.0%	2.3%	0.5%	0.0%	2.8%	2.3%
	35	205	25	2411	1555	0.2%	2.6%	0.8%	0.1%	3.6%	2.9%
Taurus Full	15	42	22	1720	755	0.0%	1.8%	0.5%	0.0%	2.3%	1.8%
	20	111	25	2906	1207	0.0%	2.6%	1.1%	0.0%	3.7%	2.6%
	25	132	25	4045	1291	0.0%	2.6%	1.8%	0.0%	4.4%	2.7%
	30	159	26	5515	1329	0.1%	2.9%	3.3%	0.0%	6.2%	3.0%
	35	239	27	6387	1513	0.4%	3.3%	4.5%	0.1%	8.1%	3.7%
Taurus Offset	15	26	20	338	680	0.0%	1.3%	0.1%	0.0%	1.4%	1.3%
	20	34	21	763	710	0.0%	1.5%	0.2%	0.0%	1.7%	1.5%
	25	82	24	618	981	0.0%	2.3%	0.2%	0.0%	2.5%	2.3%
	30	116	25	1848	1201	0.0%	2.6%	0.6%	0.0%	3.2%	2.6%
	35	172	26	2714	1561	0.1%	2.9%	1.0%	0.1%	4.0%	3.1%

Table 13-4 – LW3 Taurus 5th percentile occupant results in vehicle-to-vehicle crashes

LW3 TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	169	24	1885	1377	0.1%	4.3%	1.0%	0.3%	5.7%	4.7%
	20	190	25	2180	1443	0.1%	5.0%	1.2%	0.4%	6.7%	5.5%
	25	229	27	2437	1659	0.3%	6.4%	1.5%	0.9%	8.9%	7.6%
	30	251	30	2993	1559	0.5%	9.2%	2.1%	0.6%	12.1%	10.2%
	35	318	31	3349	1824	1.1%	10.4%	2.6%	1.7%	15.1%	12.8%
Explorer Offset	15	148	20	2334	1534	0.0%	2.4%	1.4%	0.6%	4.4%	3.0%
	20	168	25	2157	1527	0.1%	5.0%	1.2%	0.5%	6.7%	5.6%
	25	207	27	2068	1803	0.2%	6.4%	1.1%	1.5%	9.1%	8.1%
	30	241	28	1965	1936	0.4%	7.3%	1.1%	2.5%	10.9%	10.0%
	35	243	29	2343	1811	0.4%	8.2%	1.4%	1.6%	11.3%	10.0%
Silverado Full	15	184	24	1809	1468	0.1%	4.3%	0.9%	0.4%	5.8%	4.9%
	20	191	25	2236	1462	0.1%	5.0%	1.3%	0.4%	6.7%	5.5%
	25	215	27	2685	1527	0.2%	6.4%	1.7%	0.5%	8.8%	7.2%
	30	226	28	3250	1509	0.3%	7.3%	2.5%	0.5%	10.3%	8.0%
	35	311	31	3999	1722	1.0%	10.4%	3.8%	1.1%	15.6%	12.3%
Silverado Offset	15	168	24	2243	1604	0.1%	4.3%	1.3%	0.7%	6.3%	5.1%
	20	185	26	2039	1610	0.1%	5.7%	1.1%	0.7%	7.5%	6.5%
	25	193	27	1950	1645	0.2%	6.4%	1.0%	0.9%	8.3%	7.4%
	30	228	28	1995	1788	0.3%	7.3%	1.1%	1.5%	9.9%	8.9%
	35	258	30	1967	1860	0.5%	9.2%	1.1%	1.9%	12.4%	11.4%
Yaris Full	15	182	23	1834	1459	0.1%	3.8%	0.9%	0.4%	5.2%	4.3%
	20	178	24	2191	1383	0.1%	4.3%	1.2%	0.3%	5.9%	4.8%
	25	190	26	2461	1440	0.1%	5.7%	1.5%	0.4%	7.6%	6.2%
	30	193	26	2714	1398	0.2%	5.7%	1.8%	0.3%	7.8%	6.1%
	35	199	27	2834	1413	0.2%	6.4%	1.9%	0.4%	8.7%	6.9%
Yaris Offset	15	133	16	1717	1227	0.0%	1.3%	0.9%	0.2%	2.3%	1.5%
	20	144	17	1878	1350	0.0%	1.5%	1.0%	0.3%	2.8%	1.8%
	25	178	23	2154	1679	0.1%	3.8%	1.2%	1.0%	6.0%	4.8%
	30	173	25	2096	1550	0.1%	5.0%	1.2%	0.6%	6.7%	5.6%
	35	182	25	2128	1564	0.1%	5.0%	1.2%	0.6%	6.8%	5.7%
Taurus Full	15	169	23	1927	1399	0.1%	3.8%	1.0%	0.3%	5.2%	4.2%
	20	172	24	2222	1369	0.1%	4.3%	1.3%	0.3%	5.9%	4.7%
	25	173	25	2487	1355	0.1%	5.0%	1.5%	0.3%	6.8%	5.3%
	30	187	26	2686	1402	0.1%	5.7%	1.7%	0.3%	7.8%	6.1%
	35	204	26	2866	1447	0.2%	5.7%	2.0%	0.4%	8.1%	6.2%
Taurus Offset	15	152	22	2313	1499	0.1%	3.3%	1.4%	0.5%	5.1%	3.8%
	20	166	21	2230	1431	0.1%	2.8%	1.3%	0.4%	4.5%	3.3%
	25	162	23	2393	1509	0.1%	3.8%	1.4%	0.5%	5.7%	4.3%
	30	182	26	2121	1563	0.1%	5.7%	1.2%	0.6%	7.5%	6.4%
	35	182	26	1890	1481	0.1%	5.7%	1.0%	0.5%	7.1%	6.2%

Table 13-5 – Partner vehicle 50th percentile occupant results in vehicle-to-vehicle crashes with LW3 Taurus

LW3 PARTNER VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	9	22	2264	452	0.0%	1.8%	0.7%	0.0%	2.5%	1.8%
	20	36	26	2983	517	0.0%	2.9%	1.1%	0.0%	4.0%	2.9%
	25	61	29	3614	804	0.0%	4.2%	1.5%	0.0%	5.6%	4.2%
	30	119	29	4198	1183	0.0%	4.2%	1.9%	0.0%	6.1%	4.2%
	35	191	29	4416	1337	0.1%	4.2%	2.1%	0.0%	6.4%	4.3%
Explorer Offset	15	8	15	1119	364	0.0%	0.6%	0.3%	0.0%	0.9%	0.6%
	20	10	17	2214	489	0.0%	0.9%	0.7%	0.0%	1.6%	0.9%
	25	26	19	2516	503	0.0%	1.2%	0.9%	0.0%	2.0%	1.2%
	30	59	24	2788	612	0.0%	2.3%	1.0%	0.0%	3.3%	2.3%
	35	91	29	3455	1031	0.0%	4.2%	1.4%	0.0%	5.5%	4.2%
Silverado Full	15	8	21	307	381	0.0%	1.5%	0.1%	0.0%	1.6%	1.5%
	20	20	25	444	478	0.0%	2.6%	0.1%	0.0%	2.7%	2.6%
	25	72	28	1188	635	0.0%	3.7%	0.3%	0.0%	4.0%	3.7%
	30	127	29	2032	697	0.0%	4.2%	0.6%	0.0%	4.8%	4.2%
	35	189	29	2180	865	0.1%	4.2%	0.7%	0.0%	5.0%	4.3%
Silverado Offset	15	15	21	30	334	0.0%	1.5%	0.0%	0.0%	1.5%	1.5%
	20	19	22	133	375	0.0%	1.8%	0.0%	0.0%	1.8%	1.8%
	25	78	24	251	612	0.0%	2.3%	0.1%	0.0%	2.4%	2.3%
	30	119	25	436	564	0.0%	2.6%	0.1%	0.0%	2.7%	2.6%
	35	132	26	672	875	0.0%	2.9%	0.2%	0.0%	3.1%	3.0%
Yaris Full	15	50	22	2985	701	0.0%	1.8%	1.1%	0.0%	2.9%	1.8%
	20	83	23	3466	731	0.0%	2.0%	1.4%	0.0%	3.4%	2.0%
	25	96	24	3878	752	0.0%	2.3%	1.7%	0.0%	4.0%	2.3%
	30	106	25	3878	958	0.0%	2.6%	1.7%	0.0%	4.3%	2.6%
	35	205	26	6218	1364	0.2%	2.9%	4.3%	0.0%	7.3%	3.2%
Yaris Offset	15	18	20	451	440	0.0%	1.3%	0.1%	0.0%	1.4%	1.3%
	20	49	22	539	654	0.0%	1.8%	0.1%	0.0%	1.9%	1.8%
	25	95	27	1535	1008	0.0%	3.3%	0.4%	0.0%	3.8%	3.3%
	30	122	28	1998	1264	0.0%	3.7%	0.6%	0.0%	4.4%	3.8%
	35	478	29	3726	1133	4.2%	4.2%	1.6%	0.0%	9.6%	8.2%
Taurus Full	15	25	20	1040	599	0.0%	1.3%	0.3%	0.0%	1.6%	1.3%
	20	51	23	1766	818	0.0%	2.0%	0.5%	0.0%	2.5%	2.0%
	25	106	25	3161	1155	0.0%	2.6%	1.2%	0.0%	3.8%	2.6%
	30	126	25	4031	1260	0.0%	2.6%	1.8%	0.0%	4.4%	2.6%
	35	146	26	5283	1318	0.0%	2.9%	3.0%	0.0%	5.9%	3.0%
Taurus Offset	15	13	18	262	477	0.0%	1.0%	0.1%	0.0%	1.1%	1.0%
	20	22	19	296	636	0.0%	1.2%	0.1%	0.0%	1.2%	1.2%
	25	35	21	687	756	0.0%	1.5%	0.2%	0.0%	1.7%	1.5%
	30	72	23	1210	938	0.0%	2.0%	0.3%	0.0%	2.3%	2.0%
	35	140	25	1892	1313	0.0%	2.6%	0.6%	0.0%	3.2%	2.7%

Table 13-6 – Partner vehicle 5th percentile occupant results in vehicle-to-vehicle crashes with LW3 Taurus

LW3 PARTNER VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	66	23	1373	953	0.0%	3.8%	0.6%	0.1%	4.4%	3.8%
	20	63	23	1493	1124	0.0%	3.8%	0.7%	0.1%	4.6%	3.9%
	25	85	24	1721	1141	0.0%	4.3%	0.9%	0.1%	5.3%	4.5%
	30	111	27	1803	1470	0.0%	6.4%	0.9%	0.4%	7.7%	6.9%
	35	101	27	1686	1338	0.0%	6.4%	0.8%	0.3%	7.5%	6.7%
Explorer Offset	15	70	18	1611	976	0.0%	1.8%	0.8%	0.1%	2.6%	1.8%
	20	105	21	1933	1111	0.0%	2.8%	1.0%	0.1%	3.9%	2.9%
	25	90	20	2033	1161	0.0%	2.4%	1.1%	0.1%	3.6%	2.6%
	30	79	21	2130	1074	0.0%	2.8%	1.2%	0.1%	4.1%	2.9%
	35	75	22	2199	1220	0.0%	3.3%	1.3%	0.2%	4.7%	3.4%
Silverado Full	15	65	24	215	952	0.0%	4.3%	0.1%	0.1%	4.5%	4.4%
	20	58	25	588	948	0.0%	5.0%	0.2%	0.1%	5.2%	5.0%
	25	82	28	854	939	0.0%	7.3%	0.3%	0.1%	7.7%	7.4%
	30	118	28	955	1015	0.0%	7.3%	0.4%	0.1%	7.7%	7.4%
	35	114	28	936	1012	0.0%	7.3%	0.4%	0.1%	7.7%	7.4%
Silverado Offset	15	65	22	264	769	0.0%	3.3%	0.1%	0.0%	3.4%	3.3%
	20	63	24	285	785	0.0%	4.3%	0.1%	0.0%	4.5%	4.4%
	25	58	24	515	867	0.0%	4.3%	0.2%	0.0%	4.6%	4.4%
	30	53	26	625	916	0.0%	5.7%	0.2%	0.1%	5.9%	5.7%
	35	69	27	674	901	0.0%	6.4%	0.3%	0.1%	6.7%	6.5%
Yaris Full	15	206	25	1219	931	0.2%	5.0%	0.5%	0.1%	5.7%	5.2%
	20	263	27	1791	949	0.6%	6.4%	0.9%	0.1%	7.9%	7.0%
	25	321	30	1666	1002	1.2%	9.2%	0.8%	0.1%	11.1%	10.4%
	30	328	30	2189	1015	1.2%	9.2%	1.2%	0.1%	11.6%	10.5%
	35	358	31	2521	1037	1.7%	10.4%	1.6%	0.1%	13.3%	11.9%
Yaris Offset	15	137	17	419	728	0.0%	1.5%	0.2%	0.0%	1.7%	1.6%
	20	161	20	832	811	0.1%	2.4%	0.3%	0.0%	2.9%	2.5%
	25	266	26	1207	1188	0.6%	5.7%	0.5%	0.2%	6.9%	6.4%
	30	318	28	1547	1197	1.1%	7.3%	0.7%	0.2%	9.2%	8.5%
	35	327	28	1724	1222	1.2%	7.3%	0.9%	0.2%	9.4%	8.6%
Taurus Full	15	156	21	1951	1333	0.1%	2.8%	1.0%	0.3%	4.1%	3.1%
	20	177	23	1887	1424	0.1%	3.8%	1.0%	0.4%	5.2%	4.2%
	25	181	25	2011	1410	0.1%	5.0%	1.1%	0.4%	6.4%	5.42%
	30	184	25	2362	1417	0.1%	5.0%	1.4%	0.4%	6.8%	5.44%
	35	179	25	2564	1375	0.1%	5.0%	1.6%	0.3%	6.9%	5.37%
Taurus Offset	15	141	20	2153	1452	0.0%	2.4%	1.2%	0.4%	4.0%	2.9%
	20	153	21	2231	1551	0.1%	2.8%	1.3%	0.6%	4.7%	3.5%
	25	165	22	2202	1554	0.1%	3.3%	1.3%	0.6%	5.1%	3.9%
	30	160	23	2224	1469	0.1%	3.8%	1.3%	0.4%	5.5%	4.3%
	35	165	25	2188	1427	0.1%	5.0%	1.2%	0.4%	6.6%	5.4%

14 APPENDIX 14: LW4 TAURUS RESULTS

Table 14-1 – LW4 Taurus 50th percentile occupant results in single-vehicle crashes

LW4 TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	78	25	3890	1079	0.0%	2.6%	1.7%	0.0%	4.3%	2.6%
	20	141	26	5980	1267	0.0%	2.9%	3.9%	0.0%	6.8%	3.0%
	25	176	27	6334	1421	0.1%	3.3%	4.5%	0.1%	7.8%	3.5%
	30	223	27	7173	1512	0.3%	3.3%	6.0%	0.1%	9.4%	3.6%
	35	370	28	9442	1937	1.9%	3.7%	12.3%	0.2%	17.3%	5.7%
Offset Frontal	20	19	19	327	477	0.0%	1.2%	0.1%	0.0%	1.2%	1.2%
	25	56	21	446	664	0.0%	1.5%	0.1%	0.0%	1.6%	1.5%
	30	81	23	1182	1082	0.0%	2.0%	0.3%	0.0%	2.3%	2.0%
	35	206	25	2761	1439	0.2%	2.6%	1.0%	0.1%	3.8%	2.8%
	40	928	27	3430	1407	20.1%	3.3%	1.4%	0.0%	23.9%	22.8%
Center Pole	15	20	18	504	485	0.0%	1.0%	0.1%	0.0%	1.1%	1.0%
	20	83	24	1430	932	0.0%	2.3%	0.4%	0.0%	2.7%	2.3%
	25	112	26	3013	1113	0.0%	2.9%	1.1%	0.0%	4.1%	3.0%
	30	172	28	4843	1331	0.1%	3.7%	2.5%	0.0%	6.3%	3.8%
	35	361	30	6086	1718	1.7%	4.7%	4.1%	0.1%	10.2%	6.4%

Table 14-2 – LW4 Taurus 5th percentile occupant results in single-vehicle crashes

LW4 TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	176	24	2153	1384	0.1%	4.3%	1.2%	0.3%	5.9%	4.7%
	20	193	26	2858	1391	0.2%	5.7%	2.0%	0.3%	8.0%	6.1%
	25	196	26	3112	1397	0.2%	5.7%	2.3%	0.3%	8.3%	6.1%
	30	216	28	3413	1475	0.3%	7.3%	2.7%	0.5%	10.5%	7.9%
	35	228	29	3461	1510	0.3%	8.2%	2.8%	0.5%	11.5%	9.0%
Offset Frontal	20	143	19	2004	1320	0.0%	2.1%	1.1%	0.3%	3.4%	2.4%
	25	147	20	2206	1359	0.0%	2.4%	1.3%	0.3%	4.0%	2.8%
	30	166	24	2318	1565	0.1%	4.3%	1.4%	0.6%	6.3%	5.0%
	35	185	27	2225	1695	0.1%	6.4%	1.3%	1.0%	8.7%	7.5%
	40	195	27	2001	1744	0.2%	6.4%	1.1%	1.2%	8.7%	7.7%
Center Pole	15	145	18	1324	1415	0.0%	1.8%	0.6%	0.4%	2.7%	2.2%
	20	170	23	1502	1483	0.1%	3.8%	0.7%	0.5%	5.0%	4.3%
	25	182	25	2017	1453	0.1%	5.0%	1.1%	0.4%	6.5%	5.5%
	30	203	27	2146	1536	0.2%	6.4%	1.2%	0.6%	8.3%	7.2%
	35	231	31	2563	1640	0.3%	10.4%	1.6%	0.8%	12.8%	11.4%

Table 14-3 – LW4 Taurus 50th percentile occupant results in vehicle-to-vehicle crashes

LW4 TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	66	23	1873	920	0.0%	2.0%	0.6%	0.0%	2.6%	2.0%
	20	135	26	3747	1246	0.0%	2.9%	1.6%	0.0%	4.5%	3.0%
	25	161	27	6507	1332	0.1%	3.3%	4.7%	0.0%	8.0%	3.4%
	30	255	28	11474	1703	0.5%	3.7%	21.8%	0.1%	25.1%	4.3%
	35	320	29	12944	1741	1.1%	4.2%	31.2%	0.1%	34.9%	5.4%
Explorer Offset	15	14	18	464	526	0.0%	1.0%	0.1%	0.0%	1.1%	1.0%
	20	66	25	2259	1175	0.0%	2.6%	0.7%	0.0%	3.3%	2.6%
	25	108	27	3606	1391	0.0%	3.3%	1.5%	0.0%	4.8%	3.4%
	30	135	28	4484	1598	0.0%	3.7%	2.2%	0.1%	5.9%	3.8%
	35	845	28	6197	1678	16.8%	3.7%	4.2%	0.1%	23.3%	19.9%
Silverado Full	15	62	24	2324	979	0.0%	2.3%	0.8%	0.0%	3.0%	2.3%
	20	133	26	4916	1255	0.0%	2.9%	2.6%	0.0%	5.5%	3.0%
	25	174	27	9167	1392	0.1%	3.3%	11.3%	0.0%	14.4%	3.4%
	30	203	28	9687	1514	0.2%	3.7%	13.2%	0.1%	16.7%	4.0%
	35	375	28	10882	1854	2.0%	3.7%	18.6%	0.1%	23.3%	5.7%
Silverado Offset	15	70	24	2151	1093	0.0%	2.3%	0.7%	0.0%	3.0%	2.3%
	20	100	26	4494	1368	0.0%	2.9%	2.2%	0.0%	5.1%	3.0%
	25	97	26	3973	1360	0.0%	2.9%	1.8%	0.0%	4.7%	3.0%
	30	112	26	4501	1400	0.0%	2.9%	2.2%	0.0%	5.1%	3.0%
	35	227	27	4141	1365	0.3%	3.3%	1.9%	0.0%	5.5%	3.6%
Yaris Full	15	37	22	1647	762	0.0%	1.8%	0.5%	0.0%	2.2%	1.8%
	20	65	24	3157	987	0.0%	2.3%	1.2%	0.0%	3.5%	2.3%
	25	128	25	4692	1237	0.0%	2.6%	2.4%	0.0%	5.0%	2.6%
	30	152	26	5733	1253	0.1%	2.9%	3.6%	0.0%	6.5%	3.0%
	35	183	27	9195	1469	0.1%	3.3%	11.4%	0.1%	14.5%	3.5%
Yaris Offset	15	5	13	321	304	0.0%	0.4%	0.1%	0.0%	0.5%	0.4%
	20	21	19	351	604	0.0%	1.2%	0.1%	0.0%	1.2%	1.2%
	25	48	23	968	970	0.0%	2.0%	0.3%	0.0%	2.3%	2.0%
	30	87	26	2931	1196	0.0%	2.9%	1.1%	0.0%	4.0%	3.0%
	35	129	26	3757	1187	0.0%	2.9%	1.6%	0.0%	4.5%	3.0%
Taurus Full	15	31	20	997	642	0.0%	1.3%	0.3%	0.0%	1.6%	1.3%
	20	49	23	1814	835	0.0%	2.0%	0.5%	0.0%	2.6%	2.0%
	25	122	25	4347	1247	0.0%	2.6%	2.1%	0.0%	4.7%	2.6%
	30	171	27	6562	1404	0.1%	3.3%	4.8%	0.0%	8.1%	3.4%
	35	214	28	8598	1550	0.2%	3.7%	9.5%	0.1%	13.1%	4.0%
Taurus Offset	15	13	18	296	515	0.0%	1.0%	0.1%	0.0%	1.1%	1.0%
	20	41	21	700	854	0.0%	1.5%	0.2%	0.0%	1.7%	1.5%
	25	74	24	1330	1090	0.0%	2.3%	0.4%	0.0%	2.7%	2.3%
	30	111	27	3331	1277	0.0%	3.3%	1.3%	0.0%	4.6%	3.3%
	35	135	27	4436	1348	0.0%	3.3%	2.2%	0.0%	5.5%	3.4%

Table 14-4 – LW4 Taurus 5th percentile occupant results in vehicle-to-vehicle crashes

LW4 TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	177	23	2012	1423	0.1%	3.8%	1.1%	0.4%	5.3%	4.2%
	20	198	25	2163	1472	0.2%	5.0%	1.2%	0.4%	6.7%	5.6%
	25	220	27	2551	1563	0.3%	6.4%	1.6%	0.6%	8.8%	7.3%
	30	222	29	2964	1543	0.3%	8.2%	2.1%	0.6%	10.9%	9.0%
	35	311	31	3340	1789	1.0%	10.4%	2.6%	1.5%	14.9%	12.6%
Explorer Offset	15	144	20	2601	1492	0.0%	2.4%	1.7%	0.5%	4.5%	2.9%
	20	186	26	2335	1703	0.1%	5.7%	1.4%	1.1%	8.1%	6.8%
	25	218	27	2039	1772	0.3%	6.4%	1.1%	1.4%	9.0%	8.0%
	30	239	29	2304	1878	0.4%	8.2%	1.4%	2.0%	11.6%	10.4%
	35	258	29	2435	1953	0.5%	8.2%	1.5%	2.7%	12.5%	11.1%
Silverado Full	15	175	24	1880	1398	0.1%	4.3%	1.0%	0.3%	5.7%	4.8%
	20	188	25	2405	1428	0.1%	5.0%	1.4%	0.4%	6.8%	5.5%
	25	227	27	2849	1538	0.3%	6.4%	1.9%	0.6%	9.1%	7.3%
	30	218	28	3442	1472	0.3%	7.3%	2.8%	0.4%	10.5%	7.9%
	35	306	31	4151	1780	1.0%	10.4%	4.1%	1.4%	16.1%	12.5%
Silverado Offset	15	190	25	1959	1738	0.1%	5.0%	1.0%	1.2%	7.2%	6.3%
	20	224	27	2075	1878	0.3%	6.4%	1.1%	2.0%	9.7%	8.6%
	25	213	27	2030	1808	0.2%	6.4%	1.1%	1.6%	9.1%	8.1%
	30	211	26	2301	1699	0.2%	5.7%	1.3%	1.0%	8.1%	6.9%
	35	200	27	2341	1667	0.2%	6.4%	1.4%	0.9%	8.8%	7.5%
Yaris Full	15	180	23	1904	1426	0.1%	3.8%	1.0%	0.4%	5.2%	4.3%
	20	174	24	2275	1354	0.1%	4.3%	1.3%	0.3%	6.0%	4.7%
	25	181	25	2674	1356	0.1%	5.0%	1.7%	0.3%	7.0%	5.4%
	30	192	26	2960	1374	0.2%	5.7%	2.1%	0.3%	8.1%	6.1%
	35	207	27	3101	1463	0.2%	6.4%	2.3%	0.4%	9.1%	7.0%
Yaris Offset	15	129	15	1519	1204	0.0%	1.1%	0.7%	0.2%	1.9%	1.2%
	20	160	20	1752	1396	0.1%	2.4%	0.9%	0.3%	3.7%	2.8%
	25	172	24	1908	1535	0.1%	4.3%	1.0%	0.6%	5.9%	5.0%
	30	205	26	1943	1781	0.2%	5.7%	1.0%	1.4%	8.2%	7.2%
	35	200	27	2054	1652	0.2%	6.4%	1.1%	0.9%	8.5%	7.4%
Taurus Full	15	160	21	1902	1318	0.1%	2.8%	1.0%	0.2%	4.1%	3.1%
	20	160	23	2173	1278	0.1%	3.8%	1.2%	0.2%	5.2%	4.1%
	25	172	25	2575	1348	0.1%	5.0%	1.6%	0.3%	6.9%	5.3%
	30	199	27	2898	1428	0.2%	6.4%	2.0%	0.4%	8.8%	7.0%
	35	231	28	3303	1530	0.3%	7.3%	2.6%	0.6%	10.5%	8.1%
Taurus Offset	15	147	21	2206	1501	0.0%	2.8%	1.3%	0.5%	4.6%	3.4%
	20	167	23	2296	1531	0.1%	3.8%	1.3%	0.6%	5.7%	4.4%
	25	175	25	2183	1606	0.1%	5.0%	1.2%	0.7%	6.9%	5.8%
	30	196	27	2306	1681	0.2%	6.4%	1.4%	1.0%	8.8%	7.5%
	35	210	28	2159	1768	0.2%	7.3%	1.2%	1.3%	9.9%	8.7%

Table 14-5 – Partner vehicle 50th percentile occupant results in vehicle-to-vehicle crashes with LW4 Taurus

LW4 PARTNER VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	21	25	2654	488	0.0%	2.6%	0.9%	0.0%	3.5%	2.6%
	20	48	29	3466	759	0.0%	4.2%	1.4%	0.0%	5.5%	4.2%
	25	110	29	3986	1177	0.0%	4.2%	1.8%	0.0%	5.9%	4.2%
	30	241	29	4916	1413	0.4%	4.2%	2.6%	0.0%	7.1%	4.6%
	35	279	30	5165	1512	0.7%	4.7%	2.9%	0.1%	8.1%	5.4%
Explorer Offset	15	11	16	1543	404	0.0%	0.7%	0.4%	0.0%	1.2%	0.7%
	20	29	20	2671	514	0.0%	1.3%	0.9%	0.0%	2.3%	1.3%
	25	60	24	2952	621	0.0%	2.3%	1.1%	0.0%	3.4%	2.3%
	30	101	30	3486	1134	0.0%	4.7%	1.4%	0.0%	6.0%	4.7%
	35	170	31	4030	1201	0.1%	5.2%	1.8%	0.0%	7.0%	5.3%
Silverado Full	15	13	24	409	446	0.0%	2.3%	0.1%	0.0%	2.4%	2.3%
	20	43	27	941	537	0.0%	3.3%	0.2%	0.0%	3.5%	3.3%
	25	127	29	2127	701	0.0%	4.2%	0.7%	0.0%	4.8%	4.2%
	30	193	29	1927	875	0.2%	4.2%	0.6%	0.0%	4.9%	4.3%
	35	234	30	3150	1094	0.3%	4.7%	1.2%	0.0%	6.2%	5.0%
Silverado Offset	15	19	22	114	331	0.0%	1.8%	0.0%	0.0%	1.8%	1.8%
	20	58	25	220	452	0.0%	2.6%	0.1%	0.0%	2.6%	2.6%
	25	70	24	149	596	0.0%	2.3%	0.0%	0.0%	2.3%	2.3%
	30	144	26	532	838	0.0%	2.9%	0.1%	0.0%	3.1%	3.0%
	35	185	27	356	1202	0.1%	3.3%	0.1%	0.0%	3.5%	3.5%
Yaris Full	15	74	23	4020	742	0.0%	2.0%	1.8%	0.0%	3.8%	2.0%
	20	92	24	3768	768	0.0%	2.3%	1.6%	0.0%	3.9%	2.3%
	25	112	25	5458	957	0.0%	2.6%	3.2%	0.0%	5.8%	2.6%
	30	187	27	6932	1271	0.1%	3.3%	5.5%	0.0%	8.8%	3.5%
	35	383	31	7832	1600	2.1%	5.2%	7.4%	0.1%	14.2%	7.3%
Yaris Offset	15	27	23	460	639	0.0%	2.0%	0.1%	0.0%	2.1%	2.0%
	20	75	27	1011	859	0.0%	3.3%	0.3%	0.0%	3.6%	3.3%
	25	109	28	2404	1227	0.0%	3.7%	0.8%	0.0%	4.5%	3.8%
	30	314	29	4804	1231	1.1%	4.2%	2.5%	0.0%	7.6%	5.2%
	35	393	28	5956	1332	2.3%	3.7%	3.9%	0.0%	9.6%	6.0%
Taurus Full	15	34	21	1306	682	0.0%	1.5%	0.4%	0.0%	1.9%	1.5%
	20	55	23	2021	867	0.0%	2.0%	0.6%	0.0%	2.6%	2.0%
	25	121	25	3713	1247	0.0%	2.6%	1.6%	0.0%	4.2%	2.6%
	30	147	26	4447	1294	0.0%	2.9%	2.2%	0.0%	5.1%	3.0%
	35	171	26	4893	1333	0.1%	2.9%	2.6%	0.0%	5.6%	3.1%
Taurus Offset	15	13	17	265	463	0.0%	0.9%	0.1%	0.0%	0.9%	0.9%
	20	32	21	515	778	0.0%	1.5%	0.1%	0.0%	1.7%	1.5%
	25	64	23	836	902	0.0%	2.0%	0.2%	0.0%	2.2%	2.0%
	30	116	26	2170	1205	0.0%	2.9%	0.7%	0.0%	3.6%	3.0%
	35	203	27	3204	1594	0.2%	3.3%	1.2%	0.1%	4.8%	3.6%

Table 14-6 – Partner vehicle 5th percentile occupant results in vehicle-to-vehicle crashes with LW4 Taurus

LW4 PARTNER VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	69	22	1465	1080	0.0%	3.3%	0.7%	0.1%	4.0%	3.4%
	20	74	23	1605	1175	0.0%	3.8%	0.8%	0.1%	4.7%	3.9%
	25	106	26	1894	1394	0.0%	5.7%	1.0%	0.3%	6.9%	6.0%
	30	146	27	1875	1367	0.0%	6.4%	1.0%	0.3%	7.7%	6.8%
	35	176	28	1780	1296	0.1%	7.3%	0.9%	0.2%	8.4%	7.6%
Explorer Offset	15	93	19	1865	940	0.0%	2.1%	1.0%	0.1%	3.1%	2.1%
	20	83	20	2118	1056	0.0%	2.4%	1.2%	0.1%	3.7%	2.5%
	25	63	19	2545	1005	0.0%	2.1%	1.6%	0.1%	3.7%	2.2%
	30	72	22	2794	1062	0.0%	3.3%	1.9%	0.1%	5.2%	3.4%
	35	148	26	2885	1179	0.0%	5.7%	2.0%	0.1%	7.7%	5.9%
Silverado Full	15	62	25	511	869	0.0%	5.0%	0.2%	0.0%	5.2%	5.0%
	20	78	28	863	963	0.0%	7.3%	0.3%	0.1%	7.7%	7.4%
	25	107	28	1042	972	0.0%	7.3%	0.4%	0.1%	7.8%	7.4%
	30	97	27	781	922	0.0%	6.4%	0.3%	0.1%	6.8%	6.5%
	35	184	29	1038	1010	0.1%	8.2%	0.4%	0.1%	8.8%	8.4%
Silverado Offset	15	61	24	275	790	0.0%	4.3%	0.1%	0.0%	4.5%	4.4%
	20	53	25	506	906	0.0%	5.0%	0.2%	0.1%	5.2%	5.0%
	25	57	25	603	870	0.0%	5.0%	0.2%	0.0%	5.2%	5.0%
	30	60	25	636	932	0.0%	5.0%	0.2%	0.1%	5.3%	5.0%
	35	60	27	866	926	0.0%	6.4%	0.3%	0.1%	6.8%	6.5%
Yaris Full	15	260	27	1804	1074	0.5%	6.4%	0.9%	0.1%	7.9%	7.0%
	20	281	28	1786	972	0.7%	7.3%	0.9%	0.1%	8.9%	8.0%
	25	360	30	2299	1074	1.7%	9.2%	1.3%	0.1%	12.1%	10.9%
	30	340	31	2289	1029	1.4%	10.4%	1.3%	0.1%	12.9%	11.7%
	35	337	30	2671	1094	1.4%	9.2%	1.7%	0.1%	12.1%	10.6%
Yaris Offset	15	158	19	471	769	0.1%	2.1%	0.2%	0.0%	2.3%	2.2%
	20	239	25	1107	1048	0.4%	5.0%	0.5%	0.1%	5.9%	5.4%
	25	304	27	1465	1240	1.0%	6.4%	0.7%	0.2%	8.1%	7.5%
	30	328	28	2252	1240	1.2%	7.3%	1.3%	0.2%	9.8%	8.6%
	35	335	30	2287	1212	1.3%	9.2%	1.3%	0.2%	11.8%	10.6%
Taurus Full	15	166	22	1982	1364	0.1%	3.3%	1.1%	0.3%	4.7%	3.6%
	20	181	24	1861	1424	0.1%	4.3%	1.0%	0.4%	5.7%	4.8%
	25	180	25	2212	1402	0.1%	5.0%	1.3%	0.3%	6.6%	5.4%
	30	196	25	2332	1456	0.2%	5.0%	1.4%	0.4%	6.8%	5.5%
	35	183	25	2511	1405	0.1%	5.0%	1.6%	0.3%	6.9%	5.4%
Taurus Offset	15	137	20	2152	1426	0.0%	2.4%	1.2%	0.4%	4.0%	2.8%
	20	160	22	2121	1501	0.1%	3.3%	1.2%	0.5%	5.0%	3.8%
	25	160	23	2286	1477	0.1%	3.8%	1.3%	0.5%	5.6%	4.3%
	30	176	25	2134	1505	0.1%	5.0%	1.2%	0.5%	6.7%	5.5%
	35	191	28	2118	1511	0.1%	7.3%	1.2%	0.5%	9.0%	7.9%

15 APPENDIX 15: BASELINE ACCORD RESULTS

Table 15-1 – Baseline Accord 50th percentile occupant results in single-vehicle crashes

BASELINE ACCORD TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	55	28	517	879	0.000%	3.715%	0.124%	0.014%	3.8%	3.7%
	20	54	28	949	817	0.000%	3.715%	0.245%	0.012%	4.0%	3.7%
	25	68	29	1524	895	0.0%	4.2%	0.4%	0.0%	4.6%	4.2%
	30	72	30	2284	851	0.0%	4.7%	0.7%	0.0%	5.4%	4.7%
	35	106	30	3851	851	0.0%	4.7%	1.7%	0.0%	6.3%	4.7%
Offset Frontal	20	26	24	38	533	0.0%	2.3%	0.0%	0.0%	2.3%	2.3%
	25	38	25	163	679	0.0%	2.6%	0.0%	0.0%	2.6%	2.6%
	30	76	29.3	73	1023	0.0%	4.3%	0.0%	0.0%	4.3%	4.3%
	35	68	27.5	77	862	0.0%	3.5%	0.0%	0.0%	3.5%	3.5%
	40	331	30	212	1011	1.3%	4.7%	0.0%	0.0%	5.9%	5.9%
Center Pole	15	21	22.6	80	600	0.0%	1.9%	0.0%	0.0%	1.9%	1.9%
	20	53	26.7	34	804	0.0%	3.2%	0.0%	0.0%	3.2%	3.2%
	25	54	29	19	813	0.0%	4.2%	0.0%	0.0%	4.2%	4.2%
	30	117	28.7	427	900	0.0%	4.0%	0.1%	0.0%	4.2%	4.1%
	35	226	34	3246	1007	0.3%	7.1%	1.3%	0.0%	8.6%	7.4%

Table 15-2 – Baseline Accord 5th percentile occupant results in single-vehicle crashes

BASELINE ACCORD TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	172	25	474	1098	0.1%	5.0%	0.2%	0.1%	5.3%	5.2%
	20	180	24	809	1042	0.1%	4.3%	0.3%	0.1%	4.8%	4.5%
	25	200	25	1203	1126	0.2%	5.0%	0.5%	0.1%	5.8%	5.3%
	30	256	25.5	1388	1280	0.5%	5.3%	0.6%	0.2%	6.6%	6.0%
	35	263	26	1531	1306	0.6%	5.7%	0.7%	0.2%	7.1%	6.4%
Offset Frontal	20	117	20	638	734	0.0%	2.4%	0.2%	0.0%	2.7%	2.5%
	25	125	23	942	893	0.0%	3.8%	0.4%	0.1%	4.2%	3.8%
	30	137	24	1613	974	0.0%	4.3%	0.8%	0.1%	5.2%	4.4%
	35	160	24	1530	1065	0.1%	4.3%	0.7%	0.1%	5.2%	4.5%
	40	335	21	1800	1614	1.3%	2.8%	0.9%	0.8%	5.7%	4.9%
Center Pole	15	87	18	368	726	0.0%	1.8%	0.1%	0.0%	1.9%	1.8%
	20	127	21.3	699	867	0.0%	3.0%	0.3%	0.0%	3.3%	3.0%
	25	181	25	1025	1226	0.1%	5.0%	0.4%	0.2%	5.7%	5.3%
	30	231	27	2270	1252	0.3%	6.4%	1.3%	0.2%	8.2%	6.9%
	35	324	28	3467	1470	1.2%	7.3%	2.8%	0.4%	11.4%	8.8%

Table 15-3 – Baseline Accord 50th percentile occupant results in vehicle-to-vehicle crashes

BASELINE ACCORD TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	57	28	923	866	0.0%	3.7%	0.2%	0.0%	3.9%	3.7%
	20	69	29	1398	858	0.0%	4.0%	0.4%	0.0%	4.4%	4.0%
	25	77	30	2350	864	0.0%	4.5%	0.8%	0.0%	5.3%	4.5%
	30	137	31	4208	937	0.0%	5.4%	2.0%	0.0%	7.3%	5.5%
	35	316	33	5245	1454	1.1%	6.2%	3.0%	0.1%	10.0%	7.3%
Explorer Offset	15	37	23	268	688	0.0%	1.9%	0.1%	0.0%	2.0%	2.0%
	20	59	28	157	814	0.0%	3.7%	0.0%	0.0%	3.8%	3.7%
	25	222	32	1785	1128	0.3%	5.6%	0.5%	0.0%	6.4%	5.9%
	30	539	33	5166	1480	5.8%	6.2%	2.9%	0.1%	14.3%	11.7%
	35	1340	38	7186	1979	36.7%	10.3%	6.0%	0.2%	46.7%	43.3%
Silverado Full	15	54	28	804	847	0.0%	3.7%	0.2%	0.0%	3.9%	3.7%
	20	72	29	1579	864	0.0%	4.0%	0.5%	0.0%	4.5%	4.0%
	25	80	30	2945	836	0.0%	4.8%	1.1%	0.0%	5.8%	4.8%
	30	206	31	4105	1007	0.2%	5.4%	1.9%	0.0%	7.4%	5.6%
	35	313	31	4228	1246	1.1%	5.3%	2.0%	0.0%	8.1%	6.3%
Silverado Offset	15	47	25	274	829	0.0%	2.8%	0.1%	0.0%	2.8%	2.8%
	20	75	28	74	906	0.0%	3.6%	0.0%	0.0%	3.6%	3.6%
	25	264	31	2610	1275	0.6%	5.3%	0.9%	0.0%	6.7%	5.8%
	30	609	34	6245	1538	8.0%	7.3%	4.3%	0.1%	18.5%	14.8%
	35	1104	36	7045	2046	27.4%	9.0%	5.7%	0.2%	37.8%	34.1%
Yaris Full	15	51	27	334	864	0.0%	3.2%	0.1%	0.0%	3.3%	3.2%
	20	61	28	828	918	0.0%	3.8%	0.2%	0.0%	4.0%	3.8%
	25	72	29	1671	858	0.0%	4.1%	0.5%	0.0%	4.6%	4.1%
	30	72	29	2111	840	0.0%	4.3%	0.7%	0.0%	5.0%	4.3%
	35	89	30	3285	875	0.0%	4.8%	1.3%	0.0%	6.1%	4.9%
Yaris Offset	15	26	22	325	720	0.0%	1.7%	0.1%	0.0%	1.7%	1.7%
	20	43	25	170	758	0.0%	2.5%	0.0%	0.0%	2.6%	2.5%
	25	59	28	72	731	0.0%	3.6%	0.0%	0.0%	3.6%	3.6%
	30	168	32	962	1206	0.1%	5.8%	0.2%	0.0%	6.1%	5.9%
	35	327	35	3428	1176	1.2%	7.9%	1.4%	0.0%	10.3%	9.0%
Taurus Full	15	57	27	580	895	0.0%	3.3%	0.1%	0.0%	3.4%	3.3%
	20	65	28	1047	902	0.0%	3.8%	0.3%	0.0%	4.0%	3.8%
	25	72	29	1795	906	0.0%	4.1%	0.5%	0.0%	4.6%	4.1%
	30	78	30	2554	843	0.0%	4.7%	0.9%	0.0%	5.5%	4.7%
	35	173	31	4206	983	0.1%	5.5%	2.0%	0.0%	7.4%	5.6%
Taurus Offset	15	45	24	267	859	0.0%	2.4%	0.1%	0.0%	2.5%	2.4%
	20	51	25	105	792	0.0%	2.7%	0.0%	0.0%	2.8%	2.8%
	25	68	27	161	853	0.0%	3.2%	0.0%	0.0%	3.3%	3.3%
	30	169	32	68	980	0.1%	6.1%	0.0%	0.0%	6.2%	6.2%
	35	385	34	3138	1294	2.1%	7.2%	1.2%	0.0%	10.3%	9.2%

Table 15-4 – Baseline Accord 5th percentile occupant results in vehicle-to-vehicle crashes

BASELINE ACCORD TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	181	24	611	1090	0.1%	4.6%	0.2%	0.1%	5.1%	4.8%
	20	205	25	1025	1121	0.2%	4.8%	0.4%	0.1%	5.6%	5.2%
	25	254	26	1473	1270	0.5%	5.3%	0.7%	0.2%	6.6%	6.0%
	30	312	27	1782	1403	1.0%	6.1%	0.9%	0.3%	8.3%	7.4%
	35	336	27	1694	1431	1.4%	6.4%	0.8%	0.4%	8.8%	8.0%
Explorer Offset	15	103	19	831	815	0.0%	2.1%	0.3%	0.0%	2.4%	2.1%
	20	161	23	783	1051	0.1%	3.8%	0.3%	0.1%	4.2%	3.9%
	25	285	27	1089	1639	0.8%	6.1%	0.5%	0.8%	8.0%	7.6%
	30	324	27	1275	1683	1.2%	6.6%	0.6%	1.0%	9.1%	8.6%
	35	396	29	1917	1940	2.4%	7.9%	1.0%	2.6%	13.2%	12.4%
Silverado Full	15	174	25	698	1080	0.1%	4.7%	0.3%	0.1%	5.1%	4.9%
	20	203	25	1347	1116	0.2%	4.9%	0.6%	0.1%	5.7%	5.2%
	25	266	26	1545	1285	0.6%	5.6%	0.7%	0.2%	7.1%	6.4%
	30	303	27	1752	1394	0.9%	6.1%	0.9%	0.3%	8.1%	7.3%
	35	298	27	1668	1357	0.9%	6.1%	0.8%	0.3%	8.0%	7.2%
Silverado Offset	15	110	20	993	720	0.0%	2.3%	0.4%	0.0%	2.7%	2.3%
	20	167	23	1039	1002	0.1%	4.0%	0.4%	0.1%	4.6%	4.2%
	25	245	27	1044	1447	0.4%	6.2%	0.4%	0.4%	7.4%	6.9%
	30	317	27	1820	1672	1.1%	6.7%	0.9%	0.9%	9.4%	8.6%
	35	368	29	1869	1834	1.9%	8.3%	1.0%	1.7%	12.4%	11.5%
Yaris Full	15	181	24	611	1090	0.1%	4.6%	0.2%	0.1%	5.1%	4.8%
	20	192	25	693	1121	0.2%	4.7%	0.3%	0.1%	5.2%	4.9%
	25	208	25	1035	1126	0.2%	4.9%	0.4%	0.1%	5.6%	5.2%
	30	234	25	1245	1179	0.3%	5.2%	0.6%	0.1%	6.1%	5.6%
	35	271	26	1641	1313	0.6%	5.9%	0.8%	0.2%	7.4%	6.7%
Yaris Offset	15	101	18	338	672	0.0%	1.7%	0.1%	0.0%	1.8%	1.7%
	20	111	19	702	717	0.0%	2.2%	0.3%	0.0%	2.5%	2.2%
	25	165	25	1051	1132	0.1%	4.7%	0.4%	0.1%	5.3%	4.9%
	30	250	25	1389	1298	0.5%	5.3%	0.6%	0.2%	6.5%	5.9%
	35	364	27	1517	1509	1.8%	6.7%	0.7%	0.5%	9.5%	8.8%
Taurus Full	15	168	25	619	1087	0.1%	4.7%	0.2%	0.1%	5.1%	4.9%
	20	187	25	879	1094	0.1%	4.7%	0.4%	0.1%	5.2%	4.9%
	25	215	25	1066	1173	0.2%	4.9%	0.5%	0.1%	5.7%	5.3%
	30	254	26	1368	1277	0.5%	5.3%	0.6%	0.2%	6.6%	6.0%
	35	303	27	1715	1383	0.9%	6.2%	0.9%	0.3%	8.1%	7.3%
Taurus Offset	15	111	18	364	702	0.0%	1.9%	0.1%	0.0%	2.1%	1.9%
	20	135	21	623	848	0.0%	2.8%	0.2%	0.0%	3.1%	2.9%
	25	172	24	1171	1100	0.1%	4.4%	0.5%	0.1%	5.1%	4.6%
	30	258	25	1440	1300	0.5%	5.3%	0.7%	0.2%	6.6%	6.0%
	35	354	27	1434	1481	1.6%	6.4%	0.7%	0.5%	8.9%	8.3%

Table 15-5 – Partner vehicle 50th percentile occupant results in vehicle-to-vehicle crashes with baseline Accord

BASELINE ACCORD PARTNER VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	9	19.7	2121	440	0.0%	1.3%	0.7%	0.0%	1.9%	1.3%
	20	39	26	2865	496	0.0%	2.9%	1.0%	0.0%	3.9%	2.9%
	25	88	29	3851	849	0.0%	4.2%	1.7%	0.0%	5.8%	4.2%
	30	209	29	4444	1269	0.2%	4.2%	2.2%	0.0%	6.5%	4.4%
	35	366	29	4852	1488	1.8%	4.2%	2.6%	0.1%	8.4%	6.0%
Explorer Offset	15	9.4	13.66	1533	413.7	0.0%	0.5%	0.4%	0.0%	0.9%	0.5%
	20	33	20.1	2716	524	0.0%	1.4%	1.0%	0.0%	2.3%	1.4%
	25	64	28	3375	799	0.0%	3.7%	1.3%	0.0%	5.0%	3.7%
	30	105	30.1	4259.39	1010	0.0%	4.7%	2.0%	0.0%	6.6%	4.7%
	35	149	31	4825	1097	0.0%	5.2%	2.5%	0.0%	7.7%	5.3%
Silverado Full	15	9.3	21.2	291	403	0.0%	1.6%	0.1%	0.0%	1.6%	1.6%
	20	22.3	24.9	460	492.5	0.0%	2.6%	0.1%	0.0%	2.7%	2.6%
	25	93.3	27.8	1328	612.3	0.0%	3.6%	0.4%	0.0%	4.0%	3.6%
	30	180	29	2258	845	0.1%	4.3%	0.7%	0.0%	5.1%	4.4%
	35	200	28	2179	860	0.2%	3.8%	0.7%	0.0%	4.7%	4.0%
Silverado Offset	15	13	21	352	351	0.0%	1.5%	0.1%	0.0%	1.6%	1.5%
	20	20	23	865	401	0.0%	2.0%	0.2%	0.0%	2.2%	2.0%
	25	93	26	1002	637	0.0%	2.9%	0.3%	0.0%	3.1%	2.9%
	30	167	27	1416	945	0.1%	3.2%	0.4%	0.0%	3.6%	3.2%
	35	207	27	3171	1110	0.2%	3.4%	1.2%	0.0%	4.8%	3.6%
Yaris Full	15	52	23	2301	696	0.0%	1.9%	0.8%	0.0%	2.7%	1.9%
	20	77	24	3152	713	0.0%	2.1%	1.2%	0.0%	3.3%	2.2%
	25	95	24	3544	771	0.0%	2.4%	1.5%	0.0%	3.8%	2.4%
	30	101	25	3882	1019	0.0%	2.6%	1.7%	0.0%	4.3%	2.7%
	35	279	27	5741	1474	0.7%	3.2%	3.6%	0.1%	7.4%	3.9%
Yaris Offset	15	36	23	492	707	0.0%	2.0%	0.1%	0.0%	2.2%	2.0%
	20	72	26	550	771	0.0%	2.9%	0.1%	0.0%	3.0%	2.9%
	25	109	27	1493	1037	0.0%	3.3%	0.4%	0.0%	3.8%	3.4%
	30	455	28	4247	896	3.6%	3.8%	2.0%	0.0%	9.1%	7.2%
	35	871	30	6730	1485	17.8%	4.6%	5.1%	0.1%	25.7%	21.6%
Taurus Full	15	27	18	986	601	0.0%	1.0%	0.3%	0.0%	1.3%	1.0%
	20	53	23	1894	842	0.0%	2.0%	0.6%	0.0%	2.6%	2.0%
	25	106	25	2833	1170	0.0%	2.6%	1.0%	0.0%	3.6%	2.6%
	30	139	25.6	4354	1296	0.0%	2.8%	2.1%	0.0%	4.9%	2.9%
	35	162	26.3	5220	1307	0.1%	3.0%	3.0%	0.0%	6.0%	3.1%
Taurus Offset	15	13	18	210	503	0.0%	1.0%	0.0%	0.0%	1.0%	1.0%
	20	20	19	355	508	0.0%	1.1%	0.1%	0.0%	1.2%	1.1%
	25	54	22	606	829	0.0%	1.7%	0.1%	0.0%	1.8%	1.7%
	30	104	25	1309	1092	0.0%	2.5%	0.4%	0.0%	2.9%	2.5%
	35	160	25	1791	1271	0.1%	2.7%	0.5%	0.0%	3.4%	2.8%

Table 15-6 – Partner vehicle 5th percentile occupant results in vehicle-to-vehicle crashes with baseline Accord

BASELINE ACCORD PARTNER VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	73	22	1412	994	0.0%	3.3%	0.7%	0.1%	4.0%	3.3%
	20	64	22.5	1458	1041	0.0%	3.5%	0.7%	0.1%	4.3%	3.6%
	25	94	24.6	1832	1275	0.0%	4.7%	0.9%	0.2%	5.8%	4.9%
	30	111	27	2267	1380	0.0%	6.4%	1.3%	0.3%	8.0%	6.7%
	35	150	28.5	2009	1354	0.0%	7.7%	1.1%	0.3%	9.1%	8.1%
Explorer Offset	15	83	20	1653	1013	0.0%	2.4%	0.8%	0.1%	3.3%	2.5%
	20	85	21.2	1879	1042	0.0%	2.9%	1.0%	0.1%	4.0%	3.0%
	25	65	19.4	2170	1055	0.0%	2.2%	1.2%	0.1%	3.5%	2.3%
	30	77	22.5	2475	1120	0.0%	3.5%	1.5%	0.1%	5.1%	3.6%
	35	118	23.9	2852	1274	0.0%	4.3%	1.9%	0.2%	6.4%	4.5%
Silverado Full	15	59	24.6	206.3	1029	0.0%	4.7%	0.1%	0.1%	4.9%	4.8%
	20	62.6	25.3	511.3	903.8	0.0%	5.2%	0.2%	0.1%	5.4%	5.2%
	25	90.29	27.8	928.7	993.8	0.0%	7.1%	0.4%	0.1%	7.5%	7.2%
	30	139.8	28.8	1057	1022.2	0.0%	8.0%	0.4%	0.1%	8.5%	8.1%
	35	147.7	28.8	938.6	978	0.0%	8.0%	0.4%	0.1%	8.5%	8.1%
Silverado Offset	15	61.9	22.9	125.6	944.7	0.0%	3.7%	0.0%	0.1%	3.8%	3.8%
	20	60.3	23.5	207	770.8	0.0%	4.1%	0.1%	0.0%	4.2%	4.1%
	25	54.9	24.48	678.1	789.3	0.0%	4.6%	0.3%	0.0%	4.9%	4.7%
	30	64.8	26.7	1078	898.8	0.0%	6.2%	0.5%	0.1%	6.7%	6.3%
	35	104.9	28	1353	947.3	0.0%	7.3%	0.6%	0.1%	7.9%	7.4%
Yaris Full	15	243	25.6	951	1144	0.4%	5.4%	0.4%	0.1%	6.3%	5.9%
	20	277	27.8	930	1088	0.7%	7.1%	0.4%	0.1%	8.2%	7.8%
	25	331	29.5	1306	1095	1.3%	8.7%	0.6%	0.1%	10.5%	10.0%
	30	353	30.7	2399	1016	1.6%	10.0%	1.4%	0.1%	12.8%	11.5%
	35	346	30.8	2756	1034	1.5%	10.1%	1.8%	0.1%	13.2%	11.6%
Yaris Offset	15	164	21.3	485	941	0.1%	3.0%	0.2%	0.1%	3.3%	3.1%
	20	228	24.5	569	1103	0.3%	4.7%	0.2%	0.1%	5.3%	5.1%
	25	289	27	1408	1176	0.8%	6.3%	0.6%	0.1%	7.8%	7.2%
	30	323	28	1853	1109	1.2%	7.2%	1.0%	0.1%	9.3%	8.4%
	35	338	29	2627	1520	1.4%	8.1%	1.7%	0.5%	11.4%	9.8%
Taurus Full	15	176	22	2101	1502	0.1%	3.1%	1.2%	0.5%	4.8%	3.7%
	20	179	23	1950	1447	0.1%	4.0%	1.0%	0.4%	5.5%	4.5%
	25	179	24	1969	1407	0.1%	4.5%	1.1%	0.3%	6.0%	5.0%
	30	191	25	2213	1442	0.1%	5.1%	1.3%	0.4%	6.8%	5.6%
	35	192	26	2404	1437	0.2%	5.6%	1.4%	0.4%	7.4%	6.1%
Taurus Offset	15	152	20	1478	1393	0.1%	2.5%	0.7%	0.3%	3.6%	2.9%
	20	152	20	1680	1362	0.1%	2.5%	0.8%	0.3%	3.7%	2.9%
	25	167	23	1768	1511	0.1%	3.8%	0.9%	0.5%	5.3%	4.4%
	30	175	26	1688	1544	0.1%	5.4%	0.8%	0.6%	6.9%	6.1%
	35	172	26	1739	1514	0.1%	5.6%	0.9%	0.5%	7.0%	6.2%

16 APPENDIX 16: LW ACCORD RESULTS

Table 16-1 – LW Accord 50th percentile occupant results in single-vehicle crashes

LW ACCORD TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	61	28	1413	912	0.0%	3.7%	0.4%	0.0%	4.1%	3.7%
	20	60	30	2556	874	0.0%	4.7%	0.9%	0.0%	5.5%	4.7%
	25	67	30	2856	835	0.0%	4.7%	1.0%	0.0%	5.7%	4.7%
	30	80	30	3647	840	0.0%	4.7%	1.5%	0.0%	6.1%	4.7%
	35	139	30.4	4210	1040	0.0%	4.9%	2.0%	0.0%	6.8%	4.9%
Offset Frontal	20	40	26	79	673	0.0%	3.0%	0.0%	0.0%	3.1%	3.0%
	25	65	29	104	873	0.0%	3.9%	0.0%	0.0%	4.0%	4.0%
	30	64	27	204	847	0.0%	3.5%	0.0%	0.0%	3.5%	3.5%
	35	175	29	232	947	0.1%	4.1%	0.1%	0.0%	4.3%	4.2%
	40	387	30	238	999	2.2%	4.6%	0.1%	0.0%	6.8%	6.7%
Center Pole	15	54	25	129	1042	0.0%	2.7%	0.0%	0.0%	2.7%	2.7%
	20	59	29	45	788	0.0%	4.0%	0.0%	0.0%	4.0%	4.0%
	25	126	31	280	930	0.0%	5.2%	0.1%	0.0%	5.3%	5.2%
	30	158	33	384	931	0.1%	6.2%	0.1%	0.0%	6.3%	6.2%
	35	196	35	1901	1176	0.2%	7.5%	0.6%	0.0%	8.3%	7.7%

Table 16-2 – LW Accord 5th percentile occupant results in single-vehicle crashes

LW ACCORD TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	185	25	407	1194	0.1%	5.0%	0.1%	0.2%	5.4%	5.2%
	20	265	26	1046	1295	0.6%	5.7%	0.4%	0.2%	6.8%	6.4%
	25	264	26	1420	1253	0.6%	5.7%	0.7%	0.2%	7.0%	6.4%
	30	275	26	1511	1300	0.7%	5.7%	0.7%	0.2%	7.2%	6.5%
	35	278	26	2390	1230	0.7%	5.7%	1.4%	0.2%	7.8%	6.5%
Offset Frontal	20	135	23	815	876	0.0%	3.6%	0.3%	0.0%	3.9%	3.6%
	25	161	25	1234	1058	0.1%	5.0%	0.5%	0.1%	5.6%	5.1%
	30	176	25	1510	1142	0.1%	4.9%	0.7%	0.1%	5.8%	5.1%
	35	199	25	1583	1134	0.2%	5.0%	0.8%	0.1%	6.0%	5.3%
	40	228	26	2598	1355	0.3%	5.3%	1.7%	0.3%	7.4%	5.9%
Center Pole	15	118	21	352	882	0.0%	2.7%	0.1%	0.0%	2.9%	2.8%
	20	168	23	1046	1025	0.1%	3.9%	0.4%	0.1%	4.5%	4.1%
	25	204	25	1428	1197	0.2%	5.2%	0.7%	0.2%	6.2%	5.6%
	30	266	27	1928	1360	0.6%	6.6%	1.0%	0.3%	8.4%	7.5%
	35	329	28	2406	1467	1.3%	7.5%	1.4%	0.4%	10.4%	9.1%

Table 16-3 – LW Accord 50th percentile occupant results in vehicle-to-vehicle crashes

LW ACCORD TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	66	29	1860	935	0.0%	4.2%	0.6%	0.0%	4.7%	4.2%
	20	72	31	3479	929	0.0%	5.2%	1.4%	0.0%	6.5%	5.2%
	25	88	31	4762	940	0.0%	5.2%	2.5%	0.0%	7.5%	5.2%
	30	139	32	4651	1123	0.0%	5.8%	2.4%	0.0%	8.0%	5.8%
	35	301	31	6018	1582	0.9%	5.2%	4.0%	0.1%	9.9%	6.1%
Explorer Offset	15	47	24	151	772	0.0%	2.3%	0.0%	0.0%	2.3%	2.3%
	20	77	27.8	61	835	0.0%	3.6%	0.0%	0.0%	3.7%	3.6%
	25	267	29.8	87	1132	0.6%	4.6%	0.0%	0.0%	5.2%	5.1%
	30	406	32.7	3447	1531	2.5%	6.2%	1.4%	0.1%	9.9%	8.7%
	35	560	35.6	5771	2306	6.4%	8.3%	3.6%	0.4%	17.7%	14.6%
Silverado Full	15	61	29.4	2242	1014	0.0%	4.4%	0.7%	0.0%	5.1%	4.4%
	20	67	30.5	3202	923	0.0%	4.9%	1.2%	0.0%	6.1%	4.9%
	25	83	31.2	4466	919	0.0%	5.3%	2.2%	0.0%	7.4%	5.3%
	30	153	31.5	5326	1071	0.1%	5.5%	3.1%	0.0%	8.5%	5.6%
	35	306	31.13	6384	1462	1.0%	5.3%	4.5%	0.1%	10.5%	6.2%
Silverado Offset	15	50	27.2	100	858	0.0%	3.4%	0.0%	0.0%	3.4%	3.4%
	20	51	27.2	106	833	0.0%	3.4%	0.0%	0.0%	3.4%	3.4%
	25	243	31.6	1464	1343	0.4%	5.5%	0.4%	0.0%	6.3%	6.0%
	30	395	34.1	4078	1503	2.3%	7.2%	1.9%	0.1%	11.1%	9.4%
	35	627	35.6	5002	1983	8.6%	8.3%	2.7%	0.2%	18.6%	16.3%
Yaris Full	15	58	28	937	900	0.0%	3.8%	0.2%	0.0%	4.0%	3.8%
	20	65	30	3017	851	0.0%	4.6%	1.1%	0.0%	5.6%	4.6%
	25	70	30	2835	817	0.0%	4.6%	1.0%	0.0%	5.6%	4.6%
	30	80	30	3354	815	0.0%	4.5%	1.3%	0.0%	5.8%	4.5%
	35	109	30	3902	926	0.0%	4.9%	1.7%	0.0%	6.5%	4.9%
Yaris Offset	15	25	23	153	647	0.0%	2.0%	0.0%	0.0%	2.0%	2.0%
	20	63	26	46	978	0.0%	2.9%	0.0%	0.0%	2.9%	2.9%
	25	67	30	170	879	0.0%	4.5%	0.0%	0.0%	4.5%	4.5%
	30	138	32	396	1042	0.0%	5.7%	0.1%	0.0%	5.9%	5.8%
	35	290	32	5177	1194	0.8%	5.7%	2.9%	0.0%	9.2%	6.5%
Taurus Full	15	60	28.1	1180	942	0.0%	3.8%	0.3%	0.0%	4.1%	3.8%
	20	63	30.1	2690	838	0.0%	4.7%	0.9%	0.0%	5.6%	4.7%
	25	72	29.8	3049	824	0.0%	4.6%	1.1%	0.0%	5.7%	4.6%
	30	96	30.1	3875	891	0.0%	4.7%	1.7%	0.0%	6.3%	4.7%
	35	279	31	4747	1242	0.7%	5.2%	2.4%	0.0%	8.2%	5.9%
Taurus Offset	15	45	26.5	218	792	0.0%	3.1%	0.0%	0.0%	3.2%	3.1%
	20	58	26.9	115	817	0.0%	3.3%	0.0%	0.0%	3.3%	3.3%
	25	81	28.5	196	1003	0.0%	3.9%	0.0%	0.0%	4.0%	4.0%
	30	290	29.8	319	1376	0.8%	4.6%	0.1%	0.0%	5.4%	5.4%
	35	443	31	3860	1131	3.3%	5.2%	1.7%	0.0%	9.9%	8.4%

Table 16-4 – LW Accord 5th percentile occupant results in vehicle-to-vehicle crashes

LW ACCORD TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	198	25	886	1161	0.2%	5.0%	0.4%	0.1%	5.6%	5.3%
	20	293	26	1437	1375	0.8%	5.7%	0.7%	0.3%	7.4%	6.7%
	25	316	27	1595	1413	1.1%	6.4%	0.8%	0.4%	8.5%	7.8%
	30	313	27	1921	1440	1.1%	6.4%	1.0%	0.4%	8.7%	7.8%
	35	326	27	1892	1293	1.2%	6.4%	1.0%	0.2%	8.7%	7.8%
Explorer Offset	15	125	21	774	900	0.0%	2.8%	0.3%	0.1%	3.2%	2.9%
	20	190	24	1320	1220	0.1%	4.3%	0.6%	0.2%	5.2%	4.6%
	25	248	26	1394	1552	0.4%	5.7%	0.6%	0.6%	7.2%	6.7%
	30	331	27	1556	1670	1.3%	6.4%	0.7%	0.9%	9.2%	8.5%
	35	372	28	2036	1749	1.9%	7.3%	1.1%	1.3%	11.2%	10.2%
Silverado Full	15	202	25.8	823	1189	0.2%	5.5%	0.3%	0.2%	6.2%	5.8%
	20	272	26.6	1326	1267	0.6%	6.1%	0.6%	0.2%	7.5%	6.9%
	25	323	26.8	1652	1416	1.2%	6.3%	0.8%	0.4%	8.5%	7.7%
	30	325	27	1681	1404	1.2%	6.4%	0.8%	0.3%	8.7%	7.9%
	35	337	27.1	1897	1364	1.4%	6.5%	1.0%	0.3%	9.0%	8.1%
Silverado Offset	15	150	22.6	877	1028	0.0%	3.6%	0.4%	0.1%	4.0%	3.7%
	20	168	24	1061	1102	0.1%	4.3%	0.4%	0.1%	5.0%	4.5%
	25	283	26.6	1484	1629	0.7%	6.1%	0.7%	0.8%	8.2%	7.6%
	30	338	27.6	1968	1634	1.4%	6.9%	1.1%	0.8%	9.9%	9.0%
	35	377	29	2175	1754	2.0%	8.2%	1.2%	1.3%	12.3%	11.2%
Yaris Full	15	185	25	404	1151	0.1%	4.9%	0.1%	0.1%	5.2%	5.1%
	20	251	26	1101	1241	0.5%	5.5%	0.5%	0.2%	6.6%	6.1%
	25	260	26	1330	1307	0.5%	5.7%	0.6%	0.2%	7.0%	6.5%
	30	260	26	3098	1218	0.5%	5.7%	2.3%	0.2%	8.4%	6.3%
	35	271	26	4322	1247	0.6%	5.7%	4.5%	0.2%	10.7%	6.5%
Yaris Offset	15	100	18	282	688	0.0%	1.9%	0.1%	0.0%	2.0%	1.9%
	20	145	23	971	907	0.0%	3.8%	0.4%	0.1%	4.3%	3.9%
	25	193	25	1333	1198	0.2%	5.3%	0.6%	0.2%	6.2%	5.6%
	30	273	26	1413	1443	0.6%	5.9%	0.7%	0.4%	7.5%	6.9%
	35	324	26	1127	1592	1.2%	6.0%	0.5%	0.7%	8.2%	7.8%
Taurus Full	15	176	24.8	698	1157	0.1%	4.8%	0.3%	0.1%	5.3%	5.1%
	20	266	26.1	1160	1294	0.6%	5.7%	0.5%	0.2%	7.0%	6.5%
	25	263	26	1367	1271	0.6%	5.7%	0.6%	0.2%	7.0%	6.4%
	30	282	26.4	2882	1320	0.7%	6.0%	2.0%	0.3%	8.7%	6.9%
	35	298	26.3	3667	1287	0.9%	5.9%	3.2%	0.2%	9.9%	6.9%
Taurus Offset	15	143	21	683	876	0.0%	2.8%	0.3%	0.0%	3.2%	2.9%
	20	149	22	1064	902	0.0%	3.3%	0.4%	0.1%	3.8%	3.4%
	25	224	25.3	1332	1330	0.3%	5.2%	0.6%	0.3%	6.3%	5.7%
	30	274	25.2	1613	1449	0.6%	5.1%	0.8%	0.4%	6.8%	6.1%
	35	330	25.8	1982	1459	1.3%	5.5%	1.1%	0.4%	8.1%	7.1%

Table 16-5 – Partner vehicle 50th percentile occupant results in vehicle-to-vehicle crashes with LW Accord

LW ACCORD PARTNER VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	8.96	19.8	2137	458	0.0%	1.3%	0.7%	0.0%	2.0%	1.3%
	20	28	25.2	3002	527	0.0%	2.7%	1.1%	0.0%	3.7%	2.7%
	25	57	26.9	3500	847	0.0%	3.3%	1.4%	0.0%	4.7%	3.3%
	30	63	26.9	3332	779	0.0%	3.3%	1.3%	0.0%	4.5%	3.3%
	35	206	29.4	4416	1319	0.2%	4.4%	2.1%	0.0%	6.6%	4.6%
Explorer Offset	15	6	13	1475	379	0.0%	0.4%	0.4%	0.0%	0.9%	0.4%
	20	30	17	2537	513.6	0.0%	0.9%	0.9%	0.0%	1.7%	0.9%
	25	60	21.6	3246	600	0.0%	1.7%	1.3%	0.0%	2.9%	1.7%
	30	85	27.5	3736	723	0.0%	3.5%	1.6%	0.0%	5.0%	3.5%
	35	164	30.7	4501	967	0.1%	5.0%	2.2%	0.0%	7.2%	5.1%
Silverado Full	15	8.6	20.8	133	344.3	0.0%	1.5%	0.0%	0.0%	1.5%	1.5%
	20	18	23.3	444	454.5	0.0%	2.1%	0.1%	0.0%	2.2%	2.1%
	25	33.2	25	671.4	504.6	0.0%	2.6%	0.2%	0.0%	2.8%	2.6%
	30	85.3	26.8	1072	361	0.0%	3.2%	0.3%	0.0%	3.5%	3.2%
	35	134	27.4	1693	715.7	0.0%	3.5%	0.5%	0.0%	4.0%	3.5%
Silverado Offset	15	12.3	19.5	99	253	0.0%	1.2%	0.0%	0.0%	1.3%	1.2%
	20	27.4	20.6	147	341.5	0.0%	1.5%	0.0%	0.0%	1.5%	1.5%
	25	56	23	642	428	0.0%	2.0%	0.2%	0.0%	2.2%	2.0%
	30	121	24.5	993	513	0.0%	2.4%	0.3%	0.0%	2.7%	2.5%
	35	173	25.6	2281	647	0.1%	2.8%	0.7%	0.0%	3.6%	2.9%
Yaris Full	15	50	23	2468	703	0.0%	2.0%	0.8%	0.0%	2.8%	2.0%
	20	82	24	3376	745	0.0%	2.2%	1.3%	0.0%	3.5%	2.2%
	25	96	24	3834	794	0.0%	2.4%	1.7%	0.0%	4.0%	2.4%
	30	111	25	4763	980	0.0%	2.6%	2.5%	0.0%	5.1%	2.7%
	35	233	26	5985	1422	0.3%	3.0%	3.9%	0.1%	7.2%	3.4%
Yaris Offset	15	24	20	473	521	0.0%	1.4%	0.1%	0.0%	1.5%	1.4%
	20	68	26	517	765	0.0%	2.8%	0.1%	0.0%	2.9%	2.8%
	25	107	27	1379	1074	0.0%	3.5%	0.4%	0.0%	3.9%	3.5%
	30	348	29	3900	916	1.5%	4.1%	1.7%	0.0%	7.2%	5.6%
	35	739	30	6115	1245	12.6%	4.5%	4.1%	0.0%	20.1%	16.6%
Taurus Full	15	35	21	1067	697	0.0%	1.5%	0.3%	0.0%	1.8%	1.5%
	20	54	23	1837	861	0.0%	2.0%	0.6%	0.0%	2.5%	2.0%
	25	110	25	2943	1200	0.0%	2.5%	1.1%	0.0%	3.6%	2.6%
	30	131	25	3804	1256	0.0%	2.8%	1.6%	0.0%	4.4%	2.8%
	35	153	26	4448	1302	0.1%	2.9%	2.2%	0.0%	5.1%	2.9%
Taurus Offset	15	10	16	207	420	0.0%	0.7%	0.0%	0.0%	0.8%	0.7%
	20	19	19	232	517	0.0%	1.1%	0.1%	0.0%	1.1%	1.1%
	25	38	20	388	670	0.0%	1.4%	0.1%	0.0%	1.5%	1.4%
	30	96	23	692	1103	0.0%	1.9%	0.2%	0.0%	2.1%	1.9%
	35	175	25	2017	1406	0.1%	2.5%	0.6%	0.0%	3.2%	2.6%

Table 16-6 – Partner vehicle 5th percentile occupant results in vehicle-to-vehicle crashes with LW Accord

LW ACCORD PARTNER VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	67	22	1311	993	0.0%	3.3%	0.6%	0.1%	3.9%	3.3%
	20	65	22.7	1542	1017	0.0%	3.6%	0.7%	0.1%	4.4%	3.7%
	25	72	24.1	1683	1216	0.0%	4.4%	0.8%	0.2%	5.4%	4.6%
	30	97	22.7	1547	1196	0.0%	3.6%	0.7%	0.2%	4.5%	3.8%
	35	97	26.4	1783	1346	0.0%	6.0%	0.9%	0.3%	7.1%	6.2%
Explorer Offset	15	80	20.3	1467	970	0.0%	2.5%	0.7%	0.1%	3.3%	2.6%
	20	85	20.8	1810	1058	0.0%	2.7%	0.9%	0.1%	3.7%	2.8%
	25	71	20.8	2110	1079	0.0%	2.7%	1.2%	0.1%	4.0%	2.8%
	30	79	22.2	2362	1106	0.0%	3.4%	1.4%	0.1%	4.8%	3.5%
	35	121	24	2676	1303	0.0%	4.3%	1.7%	0.2%	6.2%	4.6%
Silverado Full	15	61.5	23.35	130	964.4	0.0%	4.0%	0.0%	0.1%	4.1%	4.0%
	20	68.4	24.8	463.6	881.8	0.0%	4.8%	0.2%	0.0%	5.0%	4.9%
	25	59.7	27.14	690	859.5	0.0%	6.6%	0.3%	0.0%	6.8%	6.6%
	30	93	28	789.2	933	0.0%	7.3%	0.3%	0.1%	7.6%	7.4%
	35	133	28.7	816	987	0.0%	7.9%	0.3%	0.1%	8.3%	8.0%
Silverado Offset	15	58	22	78	826	0.0%	3.3%	0.0%	0.0%	3.3%	3.3%
	20	61	22.6	301	897	0.0%	3.6%	0.1%	0.1%	3.7%	3.6%
	25	53.7	23.9	531.8	793	0.0%	4.3%	0.2%	0.0%	4.5%	4.3%
	30	65.2	26.7	760.6	859	0.0%	6.2%	0.3%	0.0%	6.5%	6.2%
	35	105	28	1353	947	0.0%	7.3%	0.6%	0.1%	7.9%	7.4%
Yaris Full	15	227	26	998	1057	0.3%	5.4%	0.4%	0.1%	6.2%	5.8%
	20	286	28	1284	1118	0.8%	7.6%	0.6%	0.1%	8.9%	8.4%
	25	307	29	2119	1063	1.0%	8.6%	1.2%	0.1%	10.6%	9.6%
	30	356	30	1912	1040	1.6%	9.4%	1.0%	0.1%	11.9%	11.0%
	35	325	30	2155	997	1.2%	9.7%	1.2%	0.1%	11.9%	10.9%
Yaris Offset	15	141	20	448	866	0.0%	2.4%	0.2%	0.0%	2.7%	2.5%
	20	243	25	673	1099	0.4%	5.0%	0.3%	0.1%	5.7%	5.5%
	25	281	27	1109	1183	0.7%	6.5%	0.5%	0.2%	7.8%	7.3%
	30	325	28	1504	1143	1.2%	7.6%	0.7%	0.1%	9.5%	8.9%
	35	327	28	1973	1108	1.2%	7.5%	1.1%	0.1%	9.7%	8.7%
Taurus Full	15	173	21	2010	1503	0.1%	2.6%	1.1%	0.5%	4.3%	3.2%
	20	181	23	1972	1446	0.1%	4.0%	1.1%	0.4%	5.6%	4.5%
	25	184	25	1888	1452	0.1%	4.7%	1.0%	0.4%	6.1%	5.2%
	30	185	25	2048	1411	0.1%	4.8%	1.1%	0.4%	6.4%	5.3%
	35	179	25	2287	1377	0.1%	5.0%	1.3%	0.3%	6.6%	5.4%
Taurus Offset	15	141	18	1466	1270	0.0%	1.7%	0.7%	0.2%	2.7%	2.0%
	20	144	21	1743	1370	0.0%	2.6%	0.9%	0.3%	3.8%	3.0%
	25	158	22	1719	1415	0.1%	3.2%	0.9%	0.4%	4.5%	3.6%
	30	149	23	1759	1346	0.0%	3.9%	0.9%	0.3%	5.1%	4.2%
	35	167	26	1744	1521	0.1%	5.6%	0.9%	0.5%	7.0%	6.2%

17 APPENDIX 17: BASELINE VENZA RESULTS

Table 17-1 – Baseline Venza 50th percentile occupant results in single-vehicle crashes

BASELINE VENZA TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	78	22	869	890	0.0%	1.8%	0.2%	0.0%	2.0%	1.8%
	20	121	23	2560	1016	0.0%	2.0%	0.9%	0.0%	2.9%	2.0%
	25	143	24	3537	1220	0.0%	2.3%	1.4%	0.0%	3.8%	2.4%
	30	178	25	4285	1566	0.1%	2.6%	2.0%	0.1%	4.7%	2.8%
	35	242	25.3	4970	1768	0.4%	2.7%	2.7%	0.1%	5.8%	3.2%
Offset Frontal	20	25	19	723	659	0.0%	1.2%	0.2%	0.0%	1.3%	1.2%
	25	46	21	907	864	0.0%	1.5%	0.2%	0.0%	1.8%	1.5%
	30	72	22	1013	1003	0.0%	1.8%	0.3%	0.0%	2.0%	1.8%
	35	156	22	1731	1339	0.1%	1.8%	0.5%	0.0%	2.4%	1.9%
	40	447	24	3209	1518	3.4%	2.3%	1.2%	0.1%	6.8%	5.7%
Center Pole	15	29	19.4	779	647	0.0%	1.2%	0.2%	0.0%	1.4%	1.2%
	20	67	25	1917	850	0.0%	2.6%	0.6%	0.0%	3.2%	2.6%
	25	105	25.14	4380	1074	0.0%	2.6%	2.1%	0.0%	4.7%	2.7%
	30	194	25.1	3803	1422	0.2%	2.6%	1.6%	0.1%	4.4%	2.8%
	35	286	26	5800	1322	0.8%	2.9%	3.7%	0.0%	7.2%	3.7%

Table 17-2 – Baseline Venza 5th percentile occupant results in single-vehicle crashes

BASELINE VENZA TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	216	27	2423	1673	0.3%	6.4%	1.5%	0.9%	8.9%	7.6%
	20	271	27	2561	1840	0.6%	6.4%	1.6%	1.8%	10.1%	8.7%
	25	316	27	2670	1871	1.1%	6.4%	1.7%	2.0%	10.9%	9.3%
	30	320	30	3048	1967	1.1%	9.2%	2.2%	2.8%	14.7%	12.8%
	35	324	30	3738	2001	1.2%	9.2%	3.3%	3.2%	16.0%	13.2%
Offset Frontal	20	23	21	951	509	0.0%	2.8%	0.4%	0.0%	3.2%	2.8%
	25	30	23	1318	597	0.0%	3.8%	0.6%	0.0%	4.4%	3.8%
	30	38	24	1490	853	0.0%	4.3%	0.7%	0.0%	5.1%	4.4%
	35	120	25	1733	1154	0.0%	5.0%	0.9%	0.1%	5.9%	5.1%
	40	473	26	1957	1278	4.0%	5.7%	1.0%	0.2%	10.6%	9.7%
Center Pole	15	48	23	1060	742	0.0%	3.8%	0.4%	0.0%	4.2%	3.8%
	20	235	27	2416	1614	0.4%	6.4%	1.5%	0.8%	8.8%	7.5%
	25	133	30	3078	1294	0.0%	9.2%	2.2%	0.2%	11.5%	9.5%
	30	200	28	3857	1307	0.2%	7.3%	3.5%	0.2%	10.9%	7.7%
	35	202	32	4043	1482	0.2%	11.6%	3.9%	0.5%	15.5%	12.1%

Table 17-3 – Baseline Venza 50th percentile occupant results in vehicle-to-vehicle crashes

BASELINE VENZA TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	20	17	1242.5	447	0.0%	0.9%	0.3%	0.0%	1.2%	0.9%
	20	56	22	1512	748	0.0%	1.8%	0.4%	0.0%	2.2%	1.8%
	25	110	24	1055	924	0.0%	2.3%	0.3%	0.0%	2.6%	2.3%
	30	106	24	1729	931	0.0%	2.3%	0.5%	0.0%	2.8%	2.3%
	35	181	26	3241	1381	0.1%	2.9%	1.3%	0.0%	4.3%	3.1%
Explorer Offset	15	11	16	1154	389	0.0%	0.7%	0.3%	0.0%	1.0%	0.7%
	20	18	19	1336	551	0.0%	1.2%	0.4%	0.0%	1.5%	1.2%
	25	21	19	1407	531	0.0%	1.2%	0.4%	0.0%	1.6%	1.2%
	30	40	22	1541	772	0.0%	1.8%	0.4%	0.0%	2.2%	1.8%
	35	577	23	3234	1335	7.0%	2.0%	1.3%	0.0%	10.0%	8.9%
Silverado Full	15	69	23	1422	826.5	0.0%	2.0%	0.4%	0.0%	2.4%	2.0%
	20	120	24	1517	973	0.0%	2.3%	0.4%	0.0%	2.7%	2.3%
	25	140	25.3	2100	1141	0.0%	2.7%	0.7%	0.0%	3.4%	2.7%
	30	196	25	3581	1469	0.2%	2.6%	1.5%	0.1%	4.2%	2.8%
	35	199	25	3980	1493	0.2%	2.6%	1.8%	0.1%	4.5%	2.8%
Silverado Offset	15	22	19	1250	557	0.0%	1.2%	0.3%	0.0%	1.5%	1.2%
	20	50	20	1480	790	0.0%	1.3%	0.4%	0.0%	1.8%	1.3%
	25	68	22	2106	894	0.0%	1.8%	0.7%	0.0%	2.4%	1.8%
	30	240	23	2472	1570	0.4%	2.0%	0.8%	0.1%	3.3%	2.5%
	35	543	23	3194	1530	5.9%	2.0%	1.2%	0.1%	9.0%	7.9%
Yaris Full	15	34	18	1247	536	0.0%	1.0%	0.3%	0.0%	1.3%	1.0%
	20	108	21	1482	951	0.0%	1.5%	0.4%	0.0%	2.0%	1.6%
	25	140	22	2114	1006	0.0%	1.8%	0.7%	0.0%	2.5%	1.8%
	30	159	23	3050	1218	0.1%	2.0%	1.1%	0.0%	3.2%	2.1%
	35	167	24	3915	1263	0.1%	2.3%	1.7%	0.0%	4.1%	2.4%
Yaris Offset	15	23	17	1122	478	0.0%	0.9%	0.3%	0.0%	1.2%	0.9%
	20	45	20	1038	568	0.0%	1.3%	0.3%	0.0%	1.6%	1.3%
	25	93	23	1125	799	0.0%	2.0%	0.3%	0.0%	2.3%	2.0%
	30	117	26	1202	1159	0.0%	2.9%	0.3%	0.0%	3.3%	3.0%
	35	175	26	1292	1224	0.1%	2.9%	0.4%	0.0%	3.4%	3.1%
Taurus Full	15	42	20	1342	645	0.0%	1.3%	0.4%	0.0%	1.7%	1.3%
	20	95	22	1527	923	0.0%	1.8%	0.4%	0.0%	2.2%	1.8%
	25	157	22.3	2115	1077	0.1%	1.8%	0.7%	0.0%	2.6%	1.9%
	30	132	23	2890	1106	0.0%	2.0%	1.1%	0.0%	3.1%	2.1%
	35	186	24	3741	1424	0.1%	2.3%	1.6%	0.1%	4.0%	2.5%
Taurus Offset	15	27	17	1277	442	0.0%	0.9%	0.3%	0.0%	1.2%	0.9%
	20	48	23	1479	628	0.0%	2.0%	0.4%	0.0%	2.4%	2.0%
	25	94	24	1715	850	0.0%	2.3%	0.5%	0.0%	2.8%	2.3%
	30	87	23	2292	934	0.0%	2.0%	0.7%	0.0%	2.8%	2.0%
	35	140	22	2660	1046	0.0%	1.8%	0.9%	0.0%	2.7%	1.8%

Table 17-4 – Baseline Venza 5th percentile occupant results in vehicle-to-vehicle crashes

BASELINE VENZA TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	151	19	1111	1411	0.0%	2.1%	0.5%	0.4%	2.9%	2.5%
	20	140	23	2291	1417	0.0%	3.8%	1.3%	0.4%	5.4%	4.2%
	25	267	29	2326	1912	0.6%	8.2%	1.4%	2.3%	12.1%	10.9%
	30	241	28	3083	1840	0.4%	7.3%	2.2%	1.8%	11.3%	9.3%
	35	415	31	3245	2093	2.7%	10.4%	2.5%	4.4%	18.7%	16.7%
Explorer Offset	15	141	19	1608	1407	0.0%	2.1%	0.8%	0.3%	3.2%	2.5%
	20	164	20	1991	1505	0.1%	2.4%	1.1%	0.5%	4.0%	3.0%
	25	144	20	1945	1324	0.0%	2.4%	1.0%	0.3%	3.7%	2.7%
	30	158	22	2485	1431	0.1%	3.3%	1.5%	0.4%	5.2%	3.7%
	35	278	29	2478	2145	0.7%	8.2%	1.5%	5.4%	15.1%	13.7%
Silverado Full	15	176	25	2303	1548	0.1%	5.0%	1.3%	0.6%	6.9%	5.6%
	20	303	30	2541	1952	0.9%	9.2%	1.6%	2.7%	13.9%	12.5%
	25	368	31	2713	2051	1.8%	10.4%	1.8%	3.8%	16.9%	15.4%
	30	421	30	3512	2108	2.8%	9.2%	2.9%	4.7%	18.4%	16.0%
	35	418	31	3960	2118	2.8%	10.4%	3.7%	4.9%	20.2%	17.1%
Silverado Offset	15	154	20	1934	1605	0.1%	2.4%	1.0%	0.7%	4.2%	3.2%
	20	166	21	2323	1598	0.1%	2.8%	1.4%	0.7%	4.9%	3.6%
	25	179	24	2602	1740	0.1%	4.3%	1.7%	1.2%	7.2%	5.6%
	30	187	25	2424	1667	0.1%	5.0%	1.5%	0.9%	7.4%	6.0%
	35	250	28	2153	1815	0.5%	7.3%	1.2%	1.6%	10.3%	9.2%
Yaris Full	15	179	23	1626	1504	0.1%	3.8%	0.8%	0.5%	5.1%	4.4%
	20	278	28	2133	1836	0.7%	7.3%	1.2%	1.7%	10.6%	9.5%
	25	327	29	2457	1937	1.2%	8.2%	1.5%	2.5%	13.0%	11.6%
	30	373	30	3000	1997	1.9%	9.2%	2.1%	3.1%	15.6%	13.8%
	35	380	31	3524	2032	2.1%	10.4%	2.9%	3.6%	17.8%	15.3%
Yaris Offset	15	177	21	1396	1421	0.1%	2.8%	0.6%	0.4%	3.9%	3.3%
	20	212	23	2184	1560	0.2%	3.8%	1.2%	0.6%	5.8%	4.6%
	25	247	26	2485	1734	0.4%	5.7%	1.5%	1.2%	8.6%	7.2%
	30	294	27	2828	1825	0.8%	6.4%	1.9%	1.7%	10.5%	8.8%
	35	386	30	2935	2181	2.2%	9.2%	2.0%	6.1%	18.3%	16.6%
Taurus Full	15	142	23	1867	1382	0.0%	3.8%	1.0%	0.3%	5.1%	4.1%
	20	231	27	2241	1710	0.3%	6.4%	1.3%	1.1%	9.0%	7.8%
	25	363	30	2585	2030	1.8%	9.2%	1.6%	3.5%	15.4%	14.0%
	30	330	31	3119	1998	1.3%	10.4%	2.3%	3.2%	16.3%	14.3%
	35	417	31	3569	2195	2.8%	10.4%	3.0%	6.4%	20.8%	18.4%
Taurus Offset	15	200	21	1709	1466	0.2%	2.8%	0.9%	0.4%	4.2%	3.4%
	20	206	25	2160	1654	0.2%	5.0%	1.2%	0.9%	7.1%	6.0%
	25	274	26	2558	1871	0.6%	5.7%	1.6%	2.0%	9.6%	8.1%
	30	212	28	2987	1784	0.2%	7.3%	2.1%	1.4%	10.8%	8.8%
	35	373	31	3289	2014	1.9%	10.4%	2.5%	3.3%	17.2%	15.0%

Table 17-5 – Partner vehicle 50th percentile occupant results in vehicle-to-vehicle crashes with baseline Venza

BASELINE VENZA PARTNER VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	13	25	3059	547	0.0%	2.6%	1.1%	0.0%	3.7%	2.6%
	20	27	30	3753	634	0.0%	4.7%	1.6%	0.0%	6.2%	4.7%
	25	69	29	4148	1099	0.0%	4.2%	1.9%	0.0%	6.0%	4.2%
	30	181	30	4981	1367	0.1%	4.7%	2.7%	0.0%	7.4%	4.8%
	35	328	30	5391	1513	1.2%	4.7%	3.2%	0.1%	8.9%	5.9%
Explorer Offset	15	6	16	1050	377	0.0%	0.7%	0.3%	0.0%	1.0%	0.7%
	20	12	18	1519	501	0.0%	1.0%	0.4%	0.0%	1.4%	1.0%
	25	34	20	2137	684	0.0%	1.3%	0.7%	0.0%	2.0%	1.3%
	30	86	24	2923	893	0.0%	2.3%	1.1%	0.0%	3.3%	2.3%
	35	250	24	3322	1716	0.5%	2.3%	1.3%	0.1%	4.1%	2.8%
Silverado Full	15	15	24	466	505	0.0%	2.3%	0.1%	0.0%	2.4%	2.3%
	20	58	28	2378	653	0.0%	3.7%	0.8%	0.0%	4.5%	3.7%
	25	153	30	4130	832	0.1%	4.7%	1.9%	0.0%	6.5%	4.7%
	30	181	30	4130	806	0.1%	4.7%	1.9%	0.0%	6.6%	4.8%
	35	202	30	4130	955	0.2%	4.7%	1.9%	0.0%	6.7%	4.9%
Silverado Offset	15	20	21	494	334	0.0%	1.5%	0.1%	0.0%	1.7%	1.5%
	20	40	23	731	461	0.0%	2.0%	0.2%	0.0%	2.2%	2.0%
	25	128	26	966	623	0.0%	2.9%	0.3%	0.0%	3.2%	3.0%
	30	244	29	2020	1029	0.4%	4.2%	0.6%	0.0%	5.2%	4.6%
	35	265	29	2390	1270	0.6%	4.2%	0.8%	0.0%	5.5%	4.7%
Yaris Full	15	23	22	1550	804	0.0%	1.8%	0.4%	0.0%	2.2%	1.8%
	20	55	25	3759	616	0.0%	2.6%	1.6%	0.0%	4.2%	2.6%
	25	74	26	4400	687	0.0%	2.9%	2.1%	0.0%	5.0%	2.9%
	30	105	27	5207	916	0.0%	3.3%	2.9%	0.0%	6.2%	3.3%
	35	236	29	6664	1267	0.4%	4.2%	5.0%	0.0%	9.3%	4.5%
Yaris Offset	15	19	17	950	253	0.0%	0.9%	0.2%	0.0%	1.1%	0.9%
	20	61	19	1874	790	0.0%	1.2%	0.6%	0.0%	1.7%	1.2%
	25	102	22	3408	1156	0.0%	1.8%	1.4%	0.0%	3.1%	1.8%
	30	450	23	5910	980	3.5%	2.0%	3.8%	0.0%	9.1%	5.4%
	35	489	33	7116	1579	4.4%	6.4%	5.9%	0.1%	15.9%	10.6%
Taurus Full	15	36	20	1247	698	0.0%	1.3%	0.3%	0.0%	1.7%	1.3%
	20	76	23	1910	983	0.0%	2.0%	0.6%	0.0%	2.6%	2.0%
	25	121	24	2509	1236	0.0%	2.3%	0.9%	0.0%	3.2%	2.3%
	30	151	26	3469	1337	0.0%	2.9%	1.4%	0.0%	4.4%	3.0%
	35	175	26	4534	1387	0.1%	2.9%	2.2%	0.0%	5.2%	3.1%
Taurus Offset	15	19	18	843	533	0.0%	1.0%	0.2%	0.0%	1.2%	1.0%
	20	46	20	1076	756	0.0%	1.3%	0.3%	0.0%	1.6%	1.3%
	25	123	22	1413	1275	0.0%	1.8%	0.4%	0.0%	2.2%	1.8%
	30	175	24	2528	1496	0.1%	2.3%	0.9%	0.1%	3.3%	2.4%
	35	155	24	2961	1427	0.1%	2.3%	1.1%	0.1%	3.5%	2.4%

Table 17-6 – Partner vehicle 5th percentile occupant results in vehicle-to-vehicle crashes with baseline Venza

BASELINE VENZA PARTNER VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	95	25	1406	1241	0.0%	5.0%	0.6%	0.2%	5.8%	5.2%
	20	96	27	1562	1333	0.0%	6.4%	0.8%	0.3%	7.4%	6.7%
	25	89	29	1301	1432	0.0%	8.2%	0.6%	0.4%	9.1%	8.6%
	30	139	30	1291	1447	0.0%	9.2%	0.6%	0.4%	10.2%	9.6%
	35	163	30	1681	1382	0.1%	9.2%	0.8%	0.3%	10.4%	9.6%
Explorer Offset	15	93	16	1280	753	0.0%	1.3%	0.6%	0.0%	1.9%	1.3%
	20	153	22	1296	865	0.1%	3.3%	0.6%	0.0%	3.9%	3.4%
	25	146	22	1213	999	0.0%	3.3%	0.5%	0.1%	3.9%	3.4%
	30	243	26	1387	1143	0.4%	5.7%	0.6%	0.1%	6.8%	6.2%
	35	90	28	2009	1151	0.0%	7.3%	1.1%	0.1%	8.4%	7.4%
Silverado Full	15	88	26	496	954	0.0%	5.7%	0.2%	0.1%	5.9%	5.7%
	20	114	28	724	923	0.0%	7.3%	0.3%	0.1%	7.6%	7.4%
	25	155	29	1132	977	0.1%	8.2%	0.5%	0.1%	8.8%	8.3%
	30	155	29	1132	1007	0.1%	8.2%	0.5%	0.1%	8.8%	8.3%
	35	155	29	1132	1007	0.1%	8.2%	0.5%	0.1%	8.8%	8.3%
Silverado Offset	15	68	23	414	819	0.0%	3.8%	0.1%	0.0%	4.0%	3.8%
	20	47	23	542	808	0.0%	3.8%	0.2%	0.0%	4.0%	3.8%
	25	73	25	842	904	0.0%	5.0%	0.3%	0.1%	5.3%	5.0%
	30	114	27	1250	916	0.0%	6.4%	0.6%	0.1%	7.0%	6.5%
	35	154	28	1091	966	0.1%	7.3%	0.5%	0.1%	7.8%	7.4%
Yaris Full	15	191	26	954	815	0.1%	5.7%	0.4%	0.0%	6.2%	5.8%
	20	302	30	1113	1074	0.9%	9.2%	0.5%	0.1%	10.6%	10.2%
	25	248	30	908	1021	0.4%	9.2%	0.4%	0.1%	10.1%	9.7%
	30	312	31	2348	1038	1.0%	10.4%	1.4%	0.1%	12.6%	11.4%
	35	320	31	3475	1016	1.1%	10.4%	2.8%	0.1%	14.0%	11.5%
Yaris Offset	15	180	24	976	902	0.1%	4.3%	0.4%	0.1%	4.9%	4.5%
	20	219	26	1526	919	0.3%	5.7%	0.7%	0.1%	6.7%	6.0%
	25	259	29	1012	1128	0.5%	8.2%	0.4%	0.1%	9.2%	8.8%
	30	285	28	2378	959	0.8%	7.3%	1.4%	0.1%	9.4%	8.0%
	35	328	29	3098	1178	1.2%	8.2%	2.3%	0.1%	11.6%	9.5%
Taurus Full	15	163	22	1601	1358	0.1%	3.3%	0.8%	0.3%	4.4%	3.6%
	20	171	24	1433	1403	0.1%	4.3%	0.7%	0.3%	5.4%	4.8%
	25	172	25	1932	1367	0.1%	5.0%	1.0%	0.3%	6.3%	5.3%
	30	182	25	2363	1418	0.1%	5.0%	1.4%	0.4%	6.8%	5.4%
	35	187	26	2491	1415	0.1%	5.7%	1.5%	0.4%	7.6%	6.1%
Taurus Offset	15	151	20	1745	1390	0.0%	2.4%	0.9%	0.3%	3.7%	2.8%
	20	161	22	1697	1446	0.1%	3.3%	0.8%	0.4%	4.5%	3.7%
	25	172	24	1662	1502	0.1%	4.3%	0.8%	0.5%	5.7%	4.9%
	30	189	25	1601	1590	0.1%	5.0%	0.8%	0.7%	6.5%	5.8%
	35	196	26	1562	1563	0.2%	5.7%	0.8%	0.6%	7.1%	6.4%

18 APPENDIX 18: LWLO VENZA RESULTS

Table 18-1 – LWLO Venza 50th percentile occupant results in single-vehicle crashes

LWLO VENZA TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	67	22	909	800	0.0%	1.8%	0.2%	0.0%	2.0%	1.8%
	20	112	23	1587	999	0.0%	2.0%	0.5%	0.0%	2.5%	2.0%
	25	127	24	3464	1049	0.0%	2.3%	1.4%	0.0%	3.7%	2.3%
	30	197	26	4403	1576	0.2%	2.9%	2.1%	0.1%	5.2%	3.2%
	35	375	25	4751	2041	2.0%	2.6%	2.5%	0.2%	7.0%	4.7%
Offset Frontal	20	34	21	710	635	0.0%	1.5%	0.2%	0.0%	1.7%	1.5%
	25	68	23	1029	820	0.0%	2.0%	0.3%	0.0%	2.3%	2.0%
	30	95	23	964	1007	0.0%	2.0%	0.2%	0.0%	2.3%	2.0%
	35	141	25	957	1101	0.0%	2.6%	0.2%	0.0%	2.9%	2.7%
	40	455	24	2902	1398	3.6%	2.3%	1.1%	0.0%	6.8%	5.8%
Center Pole	15	45	21	851	704	0.0%	1.5%	0.2%	0.0%	1.8%	1.5%
	20	71	24	1810	917	0.0%	2.3%	0.5%	0.0%	2.8%	2.3%
	25	104	24	5345	1121	0.0%	2.3%	3.1%	0.0%	5.3%	2.3%
	30	171	25	4647	1334	0.1%	2.6%	2.4%	0.0%	5.0%	2.7%
	35	332	26	6026	1331	1.3%	2.9%	4.0%	0.0%	8.1%	4.2%

Table 18-2 – LWLO Venza 5th percentile occupant results in single-vehicle crashes

LWLO VENZA TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	190	25	3262	1520	0.1%	5.0%	2.5%	0.5%	8.0%	5.6%
	20	290	30	3221	1883	0.8%	9.2%	2.4%	2.1%	14.0%	11.8%
	25	335	31	3159	1945	1.3%	10.4%	2.3%	2.6%	15.9%	13.9%
	30	402	32	3509	2171	2.5%	11.6%	2.9%	5.9%	21.2%	18.8%
	35	451	31	3348	2193	3.5%	10.4%	2.6%	6.4%	21.1%	19.0%
Offset Frontal	20	136	23	1881	1395	0.0%	3.8%	1.0%	0.3%	5.1%	4.1%
	25	181	25	2091	1562	0.1%	5.0%	1.2%	0.6%	6.8%	5.7%
	30	212	27	2322	1721	0.2%	6.4%	1.4%	1.1%	9.0%	7.7%
	35	286	28	2416	1918	0.8%	7.3%	1.5%	2.3%	11.5%	10.2%
	40	260	27	2114	1781	0.5%	6.4%	1.2%	1.4%	9.3%	8.3%
Center Pole	15	200	22	1171	1432	0.2%	3.3%	0.5%	0.4%	4.3%	3.8%
	20	165	25	2402	1265	0.1%	5.0%	1.4%	0.2%	6.6%	5.2%
	25	319	29	3423	1337	1.1%	8.2%	2.7%	0.3%	12.0%	9.5%
	30	207	29	4775	1342	0.2%	8.2%	5.7%	0.3%	13.8%	8.7%
	35	187	31	5145	1299	0.1%	10.4%	6.8%	0.2%	16.8%	10.7%

Table 18-3 – LWLO Venza 50th percentile occupant results in vehicle-to-vehicle crashes

LWLO VENZA TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	88	22	1368	883	0.0%	1.8%	0.4%	0.0%	2.1%	1.8%
	20	118	23	2299	1010	0.0%	2.0%	0.8%	0.0%	2.8%	2.0%
	25	129	24	4134	1201	0.0%	2.3%	1.9%	0.0%	4.2%	2.3%
	30	211	24	5518	1616	0.2%	2.3%	3.3%	0.1%	5.8%	2.6%
	35	373	25	5861	1829	1.9%	2.6%	3.8%	0.1%	8.2%	4.6%
Explorer Offset	15	43	23	1278	811	0.0%	2.0%	0.3%	0.0%	2.4%	2.0%
	20	74	24	1926	1020	0.0%	2.3%	0.6%	0.0%	2.9%	2.3%
	25	112	23	2305	1088	0.0%	2.0%	0.8%	0.0%	2.8%	2.0%
	30	446	23	3086	1384	3.4%	2.0%	1.2%	0.0%	6.5%	5.4%
	35	562	24	3876	2324	6.5%	2.3%	1.7%	0.4%	10.6%	9.0%
Silverado Full	15	38	20	831	746	0.0%	1.3%	0.2%	0.0%	1.6%	1.3%
	20	132	25	1431	986	0.0%	2.6%	0.4%	0.0%	3.0%	2.6%
	25	169	26	2352	1273	0.1%	2.9%	0.8%	0.0%	3.8%	3.0%
	30	196	26	3211	1510	0.2%	2.9%	1.2%	0.1%	4.4%	3.2%
	35	237	26	4072	1713	0.4%	2.9%	1.8%	0.1%	5.2%	3.4%
Silverado Offset	15	60	23	1262	697	0.0%	2.0%	0.3%	0.0%	2.4%	2.0%
	20	178	24	1490	955	0.1%	2.3%	0.4%	0.0%	2.8%	2.4%
	25	128	24	1483	1006	0.0%	2.3%	0.4%	0.0%	2.7%	2.3%
	30	191	25	1326	1348	0.1%	2.6%	0.4%	0.0%	3.1%	2.8%
	35	230	24	2173	1626	0.3%	2.3%	0.7%	0.1%	3.4%	2.7%
Yaris Full	15	61	21	1279	723	0.0%	1.5%	0.3%	0.0%	1.9%	1.5%
	20	136	22	1471	940	0.0%	1.8%	0.4%	0.0%	2.2%	1.8%
	25	174	23	2713	1189	0.1%	2.0%	1.0%	0.0%	3.1%	2.1%
	30	202	24	3929	1435	0.2%	2.3%	1.7%	0.1%	4.2%	2.5%
	35	229	24	5283	1752	0.3%	2.3%	3.0%	0.1%	5.6%	2.7%
Yaris Offset	15	24	18	1126	422	0.0%	1.0%	0.3%	0.0%	1.3%	1.0%
	20	85	23	1105	895	0.0%	2.0%	0.3%	0.0%	2.3%	2.0%
	25	116	25	1127	945	0.0%	2.6%	0.3%	0.0%	2.9%	2.6%
	30	227	26	1262	1234	0.3%	2.9%	0.3%	0.0%	3.6%	3.3%
	35	227	26	2073	1431	0.3%	2.9%	0.7%	0.1%	3.9%	3.3%
Taurus Full	15	63	21	1322	783	0.0%	1.5%	0.4%	0.0%	1.9%	1.5%
	20	133	22	1872	1010	0.0%	1.8%	0.6%	0.0%	2.4%	1.8%
	25	140	22	3317	1209	0.0%	1.8%	1.3%	0.0%	3.1%	1.8%
	30	168	23	4276	1406	0.1%	2.0%	2.0%	0.0%	4.1%	2.1%
	35	239	25	5848	1847	0.4%	2.6%	3.7%	0.1%	6.7%	3.1%
Taurus Offset	15	23	19	1206	490	0.0%	1.2%	0.3%	0.0%	1.5%	1.2%
	20	53	23	1436	828	0.0%	2.0%	0.4%	0.0%	2.4%	2.0%
	25	86	25	1490	934	0.0%	2.6%	0.4%	0.0%	3.0%	2.6%
	30	147	25	1382	1063	0.0%	2.6%	0.4%	0.0%	3.0%	2.7%
	35	166	24	2836	1516	0.1%	2.3%	1.0%	0.1%	3.4%	2.4%

Table 18-4 – LWLO Venza 5th percentile occupant results in vehicle-to-vehicle crashes

LWLO VENZA TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	215	26	2180	1669	0.2%	5.7%	1.2%	0.9%	7.9%	6.8%
	20	279	29	2786	1860	0.7%	8.2%	1.9%	1.9%	12.3%	10.6%
	25	319	31	3188	1938	1.1%	10.4%	2.4%	2.5%	15.7%	13.6%
	30	326	31	3308	1911	1.2%	10.4%	2.6%	2.3%	15.7%	13.5%
	35	362	31	3439	2023	1.7%	10.4%	2.8%	3.5%	17.3%	15.0%
Explorer Offset	15	213	23	2216	1647	0.2%	3.8%	1.3%	0.9%	6.0%	4.8%
	20	237	26	2408	1792	0.4%	5.7%	1.5%	1.5%	8.7%	7.4%
	25	259	28	2929	2057	0.5%	7.3%	2.0%	3.9%	13.2%	11.4%
	30	274	30	3044	2050	0.6%	9.2%	2.2%	3.8%	15.2%	13.3%
	35	360	31	3111	2377	1.7%	10.4%	2.3%	12.0%	24.2%	22.4%
Silverado Full	15	115	21	2428	1316	0.0%	2.8%	1.5%	0.2%	4.5%	3.1%
	20	347	30	2761	2110	1.5%	9.2%	1.8%	4.7%	16.4%	14.8%
	25	402	32	3082	2259	2.5%	11.6%	2.2%	8.0%	22.4%	20.6%
	30	456	32	3556	2215	3.6%	11.6%	3.0%	6.9%	23.0%	20.6%
	35	462	32	3930	2315	3.8%	11.6%	3.6%	9.7%	26.0%	23.1%
Silverado Offset	15	206	23	1782	1712	0.2%	3.8%	0.9%	1.1%	5.9%	5.0%
	20	377	27	2238	1955	2.0%	6.4%	1.3%	2.7%	11.9%	10.8%
	25	310	27	2507	1916	1.0%	6.4%	1.6%	2.3%	11.0%	9.6%
	30	433	30	3019	2315	3.1%	9.2%	2.2%	9.7%	22.3%	20.6%
	35	410	30	3244	2249	2.6%	9.2%	2.5%	7.7%	20.5%	18.5%
Yaris Full	15	241	25	1764	1678	0.4%	5.0%	0.9%	1.0%	7.1%	6.3%
	20	308	28	2231	1920	1.0%	7.3%	1.3%	2.4%	11.5%	10.4%
	25	404	30	2517	2042	2.5%	9.2%	1.6%	3.7%	16.1%	14.8%
	30	418	30	3073	2091	2.8%	9.2%	2.2%	4.4%	17.5%	15.7%
	35	460	31	3614	2322	3.7%	10.4%	3.1%	9.9%	24.6%	22.3%
Yaris Offset	15	175	21	1644	1430	0.1%	2.8%	0.8%	0.4%	4.1%	3.3%
	20	229	25	2338	1731	0.3%	5.0%	1.4%	1.2%	7.7%	6.4%
	25	297	28	2423	2016	0.9%	7.3%	1.5%	3.4%	12.5%	11.2%
	30	419	29	2751	2185	2.8%	8.2%	1.8%	6.2%	17.8%	16.3%
	35	441	30	3426	2287	3.3%	9.2%	2.7%	8.8%	22.2%	20.0%
Taurus Full	15	161	25	1929	1431	0.1%	5.0%	1.0%	0.4%	6.4%	5.4%
	20	299	29	2292	1895	0.9%	8.2%	1.3%	2.2%	12.2%	11.0%
	25	341	30	2584	1940	1.4%	9.2%	1.6%	2.5%	14.2%	12.8%
	30	381	31	3161	2062	2.1%	10.4%	2.4%	4.0%	17.7%	15.7%
	35	396	31	3653	2189	2.3%	10.4%	3.1%	6.3%	20.5%	17.9%
Taurus Offset	15	174	21	1439	1503	0.1%	2.8%	0.7%	0.5%	4.1%	3.4%
	20	144	24	1964	1433	0.0%	4.3%	1.0%	0.4%	5.8%	4.8%
	25	206	26	2343	1618	0.2%	5.7%	1.4%	0.8%	7.9%	6.6%
	30	298	29	2677	1996	0.9%	8.2%	1.7%	3.1%	13.4%	11.9%
	35	331	32	3538	2167	1.3%	11.6%	2.9%	5.8%	20.2%	17.8%

Table 18-5 – Partner vehicle 50th percentile occupant results in vehicle-to-vehicle crashes with LWLO Venza

LWLO VENZA PARTNER VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	12	24	2588	550	0.0%	2.3%	0.9%	0.0%	3.2%	2.3%
	20	26	27	3493	575	0.0%	3.3%	1.4%	0.0%	4.7%	3.3%
	25	53	29	4068	974	0.0%	4.2%	1.8%	0.0%	5.9%	4.2%
	30	124	30	4342	1257	0.0%	4.7%	2.1%	0.0%	6.7%	4.7%
	35	308	30	4927	1409	1.0%	4.7%	2.6%	0.0%	8.1%	5.7%
Explorer Offset	15	11	20	1867	519	0.0%	1.3%	0.6%	0.0%	1.9%	1.3%
	20	26	25	2953	578	0.0%	2.6%	1.1%	0.0%	3.7%	2.6%
	25	73	27	2949	960	0.0%	3.3%	1.1%	0.0%	4.4%	3.3%
	30	134	27	3411	1305	0.0%	3.3%	1.4%	0.0%	4.7%	3.4%
	35	207	29	4037	1463	0.2%	4.2%	1.8%	0.1%	6.2%	4.4%
Silverado Full	15	12	21	487	439	0.0%	1.5%	0.1%	0.0%	1.7%	1.5%
	20	32	27	1613	626	0.0%	3.3%	0.5%	0.0%	3.8%	3.3%
	25	86	30	3771	778	0.0%	4.7%	1.6%	0.0%	6.2%	4.7%
	30	168	30	3775	801	0.1%	4.7%	1.6%	0.0%	6.3%	4.7%
	35	226	30	3407	914	0.3%	4.7%	1.4%	0.0%	6.3%	5.0%
Silverado Offset	15	18	22	568	347	0.0%	1.8%	0.1%	0.0%	1.9%	1.8%
	20	30	23	700	399	0.0%	2.0%	0.2%	0.0%	2.2%	2.0%
	25	85	26	992	583	0.0%	2.9%	0.3%	0.0%	3.2%	2.9%
	30	181	28	1573	814	0.1%	3.7%	0.5%	0.0%	4.3%	3.8%
	35	241	30	2514	1088	0.4%	4.7%	0.9%	0.0%	5.9%	5.1%
Yaris Full	15	19	21	1395	679	0.0%	1.5%	0.4%	0.0%	1.9%	1.5%
	20	41	24	2872	566	0.0%	2.3%	1.0%	0.0%	3.3%	2.3%
	25	70	25	4621	661	0.0%	2.6%	2.3%	0.0%	4.9%	2.6%
	30	94	27	6938	973	0.0%	3.3%	5.5%	0.0%	8.7%	3.3%
	35	127	27	5084	1072	0.0%	3.3%	2.8%	0.0%	6.1%	3.3%
Yaris Offset	15	16	13	576	442	0.0%	0.4%	0.1%	0.0%	0.6%	0.4%
	20	57	18	3082	733	0.0%	1.0%	1.2%	0.0%	2.2%	1.0%
	25	102	23	4629	1131	0.0%	2.0%	2.3%	0.0%	4.3%	2.0%
	30	408	25	6138	1301	2.6%	2.6%	4.2%	0.0%	9.1%	5.1%
	35	408	25	6566	1385	2.6%	2.6%	4.8%	0.0%	9.7%	5.1%
Taurus Full	15	33	20	1224	716	0.0%	1.3%	0.3%	0.0%	1.7%	1.3%
	20	67	23	1987	950	0.0%	2.0%	0.6%	0.0%	2.6%	2.0%
	25	121	25	3073	1234	0.0%	2.6%	1.2%	0.0%	3.8%	2.6%
	30	145	26	4190	1301	0.0%	2.9%	1.9%	0.0%	4.9%	3.0%
	35	163	27	4002	1304	0.1%	3.3%	1.8%	0.0%	5.1%	3.4%
Taurus Offset	15	19	18	864	527	0.0%	1.0%	0.2%	0.0%	1.2%	1.0%
	20	41	21	1058	752	0.0%	1.5%	0.3%	0.0%	1.8%	1.5%
	25	112	22	2054	1191	0.0%	1.8%	0.6%	0.0%	2.4%	1.8%
	30	148	23	2005	1370	0.0%	2.0%	0.6%	0.0%	2.7%	2.1%
	35	142	24	3312	1310	0.0%	2.3%	1.3%	0.0%	3.6%	2.4%

Table 18-6 – Partner vehicle 5th percentile occupant results in vehicle-to-vehicle crashes with LWLO Venza

LWLO VENZA PARTNER VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	69	24	1386	1218	0.0%	4.3%	0.6%	0.2%	5.1%	4.5%
	20	95	27	1550	1280	0.0%	6.4%	0.7%	0.2%	7.3%	6.6%
	25	92	29	1310	1405	0.0%	8.2%	0.6%	0.3%	9.1%	8.5%
	30	110	29	1631	1462	0.0%	8.2%	0.8%	0.4%	9.4%	8.6%
	35	133	30	1317	1472	0.0%	9.2%	0.6%	0.4%	10.2%	9.7%
Explorer Offset	15	68	22	1810	1083	0.0%	3.3%	0.9%	0.1%	4.3%	3.4%
	20	93	24	2016	1261	0.0%	4.3%	1.1%	0.2%	5.6%	4.5%
	25	104	25	2173	1366	0.0%	5.0%	1.2%	0.3%	6.4%	5.3%
	30	107	27	2185	1317	0.0%	6.4%	1.2%	0.2%	7.8%	6.7%
	35	126	27	2114	1397	0.0%	6.4%	1.2%	0.3%	7.9%	6.8%
Silverado Full	15	80	25	322	963	0.0%	5.0%	0.1%	0.1%	5.1%	5.0%
	20	104	27	604	955	0.0%	6.4%	0.2%	0.1%	6.7%	6.5%
	25	120	28	991	964	0.0%	7.3%	0.4%	0.1%	7.7%	7.4%
	30	137	28	1089	1067	0.0%	7.3%	0.5%	0.1%	7.8%	7.4%
	35	135	28	937	999	0.0%	7.3%	0.4%	0.1%	7.7%	7.4%
Silverado Offset	15	69	23	322	867	0.0%	3.8%	0.1%	0.0%	3.9%	3.8%
	20	81	24	401	868	0.0%	4.3%	0.1%	0.0%	4.5%	4.4%
	25	81	25	594	916	0.0%	5.0%	0.2%	0.1%	5.2%	5.0%
	30	79	25	935	889	0.0%	5.0%	0.4%	0.0%	5.4%	5.0%
	35	140	28	1294	1104	0.0%	7.3%	0.6%	0.1%	8.0%	7.4%
Yaris Full	15	136	24	836	708	0.0%	4.3%	0.3%	0.0%	4.7%	4.4%
	20	168	27	883	789	0.1%	6.4%	0.4%	0.0%	6.9%	6.6%
	25	192	28	2042	874	0.2%	7.3%	1.1%	0.0%	8.5%	7.5%
	30	224	31	3227	1021	0.3%	10.4%	2.4%	0.1%	12.9%	10.7%
	35	351	30	2451	1195	1.6%	9.2%	1.5%	0.2%	12.2%	10.8%
Yaris Offset	15	96	18	776	474	0.0%	1.8%	0.3%	0.0%	2.1%	1.8%
	20	130	24	731	701	0.0%	4.3%	0.3%	0.0%	4.7%	4.4%
	25	188	29	1573	940	0.1%	8.2%	0.8%	0.1%	9.1%	8.4%
	30	243	29	1900	1028	0.4%	8.2%	1.0%	0.1%	9.6%	8.7%
	35	252	29	2938	1158	0.5%	8.2%	2.1%	0.1%	10.7%	8.8%
Taurus Full	15	164	22	1617	1366	0.1%	3.3%	0.8%	0.3%	4.4%	3.6%
	20	166	24	1625	1353	0.1%	4.3%	0.8%	0.3%	5.4%	4.7%
	25	175	25	1971	1375	0.1%	5.0%	1.1%	0.3%	6.4%	5.4%
	30	183	25	2000	1389	0.1%	5.0%	1.1%	0.3%	6.4%	5.4%
	35	189	26	2355	1377	0.1%	5.7%	1.4%	0.3%	7.4%	6.1%
Taurus Offset	15	154	20	1688	1414	0.1%	2.4%	0.8%	0.4%	3.6%	2.8%
	20	151	22	1586	1404	0.0%	3.3%	0.8%	0.3%	4.4%	3.7%
	25	169	24	1567	1448	0.1%	4.3%	0.8%	0.4%	5.5%	4.8%
	30	181	26	1545	1503	0.1%	5.7%	0.7%	0.5%	6.9%	6.3%
	35	187	26	1530	1517	0.1%	5.7%	0.7%	0.5%	7.0%	6.3%

19 APPENDIX 19: LWHO VENZA RESULTS

Table 19-1 – LWHO Venza 50th percentile occupant results in single-vehicle crashes

LWHO VENZA TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	58	22	900	887	0.0%	1.8%	0.2%	0.0%	2.0%	1.8%
	20	86	23	2478	977	0.0%	2.0%	0.8%	0.0%	2.8%	2.0%
	25	115	24	3446	1228	0.0%	2.3%	1.4%	0.0%	3.7%	2.3%
	30	203	25	3954	1473	0.2%	2.6%	1.8%	0.1%	4.5%	2.8%
	35	320	26	4669	1660	1.1%	2.9%	2.4%	0.1%	6.4%	4.1%
Offset Frontal	20	83	21	2986	1018	0.0%	1.5%	1.1%	0.0%	2.6%	1.6%
	25	106	23	3221	1151	0.0%	2.0%	1.2%	0.0%	3.3%	2.0%
	30	160	23	3544	1391	0.1%	2.0%	1.5%	0.0%	3.5%	2.1%
	35	441	23	3754	1590	3.3%	2.0%	1.6%	0.1%	6.8%	5.3%
	40	596	24	3811	1712	7.6%	2.3%	1.6%	0.1%	11.2%	9.8%
Center Pole	15	40	22	796	723	0.0%	1.8%	0.2%	0.0%	2.0%	1.8%
	20	66	24	852	884	0.0%	2.3%	0.2%	0.0%	2.5%	2.3%
	25	96	23	1975	1089	0.0%	2.0%	0.6%	0.0%	2.6%	2.0%
	30	155	25	3493	1170	0.1%	2.6%	1.4%	0.0%	4.1%	2.7%
	35	313	26	4997	1509	1.1%	2.9%	2.7%	0.1%	6.6%	4.0%

Table 19-2 – LWHO Venza 5th percentile occupant results in single-vehicle crashes

LWHO VENZA TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Full Frontal	15	181	25	2244	1435	0.1%	5.0%	1.3%	0.4%	6.7%	5.5%
	20	198	27	2764	1488	0.2%	6.4%	1.8%	0.5%	8.8%	7.0%
	25	218	28	3341	1508	0.3%	7.3%	2.6%	0.5%	10.4%	8.0%
	30	240	29	3838	1634	0.4%	8.2%	3.5%	0.8%	12.5%	9.3%
	35	250	29	3756	1562	0.5%	8.2%	3.3%	0.6%	12.2%	9.2%
Offset Frontal	20	184	25	2294	1377	0.1%	5.0%	1.3%	0.3%	6.7%	5.4%
	25	187	25	2203	1386	0.1%	5.0%	1.3%	0.3%	6.6%	5.4%
	30	191	26	2406	1437	0.1%	5.7%	1.5%	0.4%	7.5%	6.2%
	35	198	26	2501	1457	0.2%	5.7%	1.5%	0.4%	7.7%	6.2%
	40	239	26	2802	1482	0.4%	5.7%	1.9%	0.5%	8.2%	6.5%
Center Pole	15	169	23	1422	1439	0.1%	3.8%	0.7%	0.4%	4.9%	4.2%
	20	181	25	2166	1405	0.1%	5.0%	1.2%	0.3%	6.6%	5.4%
	25	179	26	2442	382	0.1%	5.7%	1.5%	0.0%	7.2%	5.8%
	30	206	28	3125	1571	0.2%	7.3%	2.3%	0.6%	10.2%	8.1%
	35	251	30	3588	1779	0.5%	9.2%	3.0%	1.4%	13.6%	10.9%

Table 19-3 – LWHO Venza 50th percentile occupant results in vehicle-to-vehicle crashes

LWHO VENZA TARGET VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	106	22	2374	1011	0.0%	1.8%	0.8%	0.0%	2.6%	1.8%
	20	122	24	3916	1245	0.0%	2.3%	1.7%	0.0%	4.0%	2.3%
	25	194	25	4813	1468	0.2%	2.6%	2.5%	0.1%	5.2%	2.8%
	30	449	29	5368	2205	3.5%	4.2%	3.1%	0.3%	10.7%	7.8%
	35	1511	35	6608	2778	42.9%	7.8%	4.9%	1.2%	50.6%	48.1%
Explorer Offset	15	84	23	772	930	0.0%	2.0%	0.2%	0.0%	2.2%	2.0%
	20	148	23	2950	1267	0.0%	2.0%	1.1%	0.0%	3.1%	2.1%
	25	607	23	3812	1395	7.9%	2.0%	1.6%	0.0%	11.3%	9.8%
	30	914	30	4838	2817	19.6%	4.7%	2.5%	1.4%	26.3%	24.3%
	35	1434	31	4779	3060	40.2%	5.2%	2.5%	2.4%	46.0%	44.6%
Silverado Full	15	135	23	2603	1269	0.0%	2.0%	0.9%	0.0%	3.0%	2.1%
	20	145	25	3258	1428	0.0%	2.6%	1.3%	0.1%	3.9%	2.7%
	25	241	26	3835	1785	0.4%	2.9%	1.7%	0.1%	5.0%	3.4%
	30	598	33	5568	2482	7.6%	6.4%	3.4%	0.6%	17.0%	14.1%
	35	1150	39	6550	3246	29.2%	11.4%	4.8%	3.7%	42.5%	39.6%
Silverado Offset	15	51	22	694	673	0.0%	1.8%	0.2%	0.0%	1.9%	1.8%
	20	115	22	888	983	0.0%	1.8%	0.2%	0.0%	2.0%	1.8%
	25	190	22	3174	1511	0.1%	1.8%	1.2%	0.1%	3.2%	2.0%
	30	692	27	3032	2351	10.9%	3.3%	1.1%	0.5%	15.2%	14.2%
	35	1387	34	3770	2262	38.4%	7.1%	1.6%	0.4%	43.9%	43.0%
Yaris Full	15	54	20	1059	762	0.0%	1.3%	0.3%	0.0%	1.6%	1.3%
	20	104	21	1875	931	0.0%	1.5%	0.6%	0.0%	2.1%	1.6%
	25	151	23	3052	1257	0.0%	2.0%	1.1%	0.0%	3.2%	2.1%
	30	168	25	3971	1500	0.1%	2.6%	1.8%	0.1%	4.4%	2.7%
	35	253	25	4882	1748	0.5%	2.6%	2.6%	0.1%	5.7%	3.2%
Yaris Offset	15	30	20	815	530	0.0%	1.3%	0.2%	0.0%	1.5%	1.3%
	20	72	23	1548	842	0.0%	2.0%	0.4%	0.0%	2.5%	2.0%
	25	95	23	2382	940	0.0%	2.0%	0.8%	0.0%	2.8%	2.0%
	30	157	24	3650	1616	0.1%	2.3%	1.5%	0.1%	3.9%	2.4%
	35	201	26	4331	1796	0.2%	2.9%	2.1%	0.1%	5.2%	3.2%
Taurus Full	15	59	21	1380	832	0.0%	1.5%	0.4%	0.0%	1.9%	1.5%
	20	90	22	2864	1017	0.0%	1.8%	1.0%	0.0%	2.8%	1.8%
	25	149	23	3751	1237	0.0%	2.0%	1.6%	0.0%	3.7%	2.1%
	30	426	25	4379	1918	2.9%	2.6%	2.1%	0.2%	7.6%	5.6%
	35	512	26	5109	1532	5.0%	2.9%	2.8%	0.1%	10.5%	7.9%
Taurus Offset	15	63	21	999	856	0.0%	1.5%	0.3%	0.0%	1.8%	1.5%
	20	103	22	1111	1108	0.0%	1.8%	0.3%	0.0%	2.1%	1.8%
	25	303	22	2552	1335	0.9%	1.8%	0.9%	0.0%	3.6%	2.7%
	30	543	23	3383	1781	5.9%	2.0%	1.3%	0.1%	9.2%	7.9%
	35	785	28	4270	2644	14.4%	3.7%	2.0%	0.9%	20.0%	18.3%

Table 19-4 – LWHO Venza 5th percentile occupant results in vehicle-to-vehicle crashes

LWHO VENZA TARGET VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	290	28	2360	1843	0.8%	7.3%	1.4%	1.8%	10.9%	9.7%
	20	333	30	2557	1795	1.3%	9.2%	1.6%	1.5%	13.2%	11.8%
	25	344	30	3033	1800	1.5%	9.2%	2.2%	1.5%	13.9%	11.9%
	30	485	31	3244	2373	4.3%	10.4%	2.5%	11.8%	26.2%	24.4%
	35	621	32	3934	2675	8.4%	11.6%	3.7%	29.5%	44.9%	42.8%
Explorer Offset	15	253	25	2288	1654	0.5%	5.0%	1.3%	0.9%	7.5%	6.3%
	20	345	29	2179	2084	1.5%	8.2%	1.2%	4.3%	14.5%	13.5%
	25	343	29	2381	1955	1.5%	8.2%	1.4%	2.7%	13.3%	12.0%
	30	616	31	3372	2182	8.2%	10.4%	2.7%	6.1%	24.8%	22.8%
	35	905	32	4066	2665	19.2%	11.6%	3.9%	28.7%	51.0%	49.0%
Silverado Full	15	331	30	2764	1925	1.3%	9.2%	1.8%	2.4%	14.2%	12.6%
	20	329	30	2942	1896	1.3%	9.2%	2.1%	2.2%	14.1%	12.3%
	25	398	31	3200	2233	2.4%	10.4%	2.4%	7.3%	20.8%	18.9%
	30	546	31	3026	2404	6.0%	10.4%	2.2%	13.1%	28.3%	26.8%
	35	582	32	4080	2603	7.1%	11.6%	4.0%	24.1%	40.2%	37.7%
Silverado Offset	15	178	24	2373	1522	0.1%	4.3%	1.4%	0.5%	6.3%	5.0%
	20	245	28	2385	1788	0.4%	7.3%	1.4%	1.5%	10.3%	9.0%
	25	297	30	2438	1851	0.9%	9.2%	1.5%	1.8%	13.0%	11.7%
	30	292	28	2824	1897	0.8%	7.3%	1.9%	2.2%	11.8%	10.1%
	35	651	31	4093	2274	9.4%	10.4%	4.0%	8.4%	28.6%	25.6%
Yaris Full	15	167	24	2176	1444	0.1%	4.3%	1.2%	0.4%	6.0%	4.8%
	20	241	27	2516	1726	0.4%	6.4%	1.6%	1.2%	9.3%	7.9%
	25	349	30	2942	2013	1.5%	9.2%	2.1%	3.3%	15.4%	13.6%
	30	358	31	2867	1977	1.7%	10.4%	2.0%	2.9%	16.1%	14.4%
	35	358	31	3230	2186	1.7%	10.4%	2.5%	6.2%	19.4%	17.3%
Yaris Offset	15	166	22	1895	1472	0.1%	3.3%	1.0%	0.4%	4.7%	3.8%
	20	234	26	2061	1776	0.3%	5.7%	1.1%	1.4%	8.4%	7.3%
	25	310	27	2284	2038	1.0%	6.4%	1.3%	3.6%	12.0%	10.8%
	30	336	28	2439	2155	1.4%	7.3%	1.5%	5.6%	14.9%	13.6%
	35	352	30	3141	2258	1.6%	9.2%	2.3%	8.0%	19.7%	17.8%
Taurus Full	15	174	23	1809	1391	0.1%	3.8%	0.9%	0.3%	5.1%	4.2%
	20	167	26	2500	1310	0.1%	5.7%	1.5%	0.2%	7.4%	6.0%
	25	178	26	3110	1324	0.1%	5.7%	2.3%	0.3%	8.2%	6.0%
	30	200	31	3384	1498	0.2%	10.4%	2.7%	0.5%	13.3%	11.0%
	35	257	30	3782	1628	0.5%	9.2%	3.4%	0.8%	13.4%	10.4%
Taurus Offset	15	183	22	1870	1445	0.1%	3.3%	1.0%	0.4%	4.7%	3.8%
	20	169	25	1882	1296	0.1%	5.0%	1.0%	0.2%	6.2%	5.3%
	25	293	25	2419	1306	0.8%	5.0%	1.5%	0.2%	7.4%	6.0%
	30	348	32	2862	1762	1.5%	11.6%	2.0%	1.3%	15.7%	14.1%
	35	560	29	3949	1878	6.4%	8.2%	3.7%	2.0%	19.0%	15.9%

Table 19-5 – Partner vehicle 50th percentile occupant results in vehicle-to-vehicle crashes with LWHO Venza

LWHO VENZA PARTNER VEHICLE OCCUPANT											
HIII 50th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	11	22	2408	535	0.0%	1.8%	0.8%	0.0%	2.6%	1.8%
	20	12	26	2946	520	0.0%	2.9%	1.1%	0.0%	4.0%	2.9%
	25	29	28	2967	577	0.0%	3.7%	1.1%	0.0%	4.8%	3.7%
	30	109	30	4025	1222	0.0%	4.7%	1.8%	0.0%	6.4%	4.7%
	35	215	30	4107	1426	0.2%	4.7%	1.9%	0.1%	6.7%	4.9%
Explorer Offset	15	14	19	1704	411	0.0%	1.2%	0.5%	0.0%	1.7%	1.2%
	20	15	22	2954	594	0.0%	1.8%	1.1%	0.0%	2.8%	1.8%
	25	41	26	3909	719	0.0%	2.9%	1.7%	0.0%	4.6%	2.9%
	30	123	27	4112	1231	0.0%	3.3%	1.9%	0.0%	5.2%	3.4%
	35	191	29	5116	1480	0.1%	4.2%	2.8%	0.1%	7.1%	4.4%
Silverado Full	15	8	22	566	418	0.0%	1.8%	0.1%	0.0%	1.9%	1.8%
	20	21	27	819	589	0.0%	3.3%	0.2%	0.0%	3.5%	3.3%
	25	85	30	1246	673	0.0%	4.7%	0.3%	0.0%	5.0%	4.7%
	30	129	31	1709	749	0.0%	5.2%	0.5%	0.0%	5.7%	5.2%
	35	198	32	2487	881	0.2%	5.8%	0.8%	0.0%	6.7%	6.0%
Silverado Offset	15	16	8	665	397	0.0%	0.2%	0.2%	0.0%	0.3%	0.2%
	20	49	7	1140	739	0.0%	0.1%	0.3%	0.0%	0.4%	0.1%
	25	27	19	1258	624	0.0%	1.2%	0.3%	0.0%	1.5%	1.2%
	30	135	26	3266	808	0.0%	2.9%	1.3%	0.0%	4.2%	3.0%
	35	173	28	5284	821	0.1%	3.7%	3.0%	0.0%	6.7%	3.8%
Yaris Full	15	13	18	704	267	0.0%	1.0%	0.2%	0.0%	1.2%	1.0%
	20	26	24	1542	774	0.0%	2.3%	0.4%	0.0%	2.7%	2.3%
	25	57	26	3622	926	0.0%	2.9%	1.5%	0.0%	4.4%	2.9%
	30	81	27	4030	931	0.0%	3.3%	1.8%	0.0%	5.1%	3.3%
	35	221	28	5363	1251	0.3%	3.7%	3.1%	0.0%	7.0%	4.0%
Yaris Offset	15	9	14	616	287	0.0%	0.5%	0.2%	0.0%	0.7%	0.5%
	20	29	19	1242	976	0.0%	1.2%	0.3%	0.0%	1.5%	1.2%
	25	65	24	2049	754	0.0%	2.3%	0.6%	0.0%	2.9%	2.3%
	30	293	25	4292	1083	0.8%	2.6%	2.0%	0.0%	5.4%	3.4%
	35	609	27	4030	1396	8.0%	3.3%	1.8%	0.0%	12.7%	11.1%
Taurus Full	15	32	20	988	664	0.0%	1.3%	0.3%	0.0%	1.6%	1.3%
	20	48	22	1781	816	0.0%	1.8%	0.5%	0.0%	2.3%	1.8%
	25	108	24	2939	1160	0.0%	2.3%	1.1%	0.0%	3.4%	2.3%
	30	134	26	4539	1242	0.0%	2.9%	2.2%	0.0%	5.2%	3.0%
	35	142	26	5434	1354	0.0%	2.9%	3.2%	0.0%	6.1%	3.0%
Taurus Offset	15	27	20	912	670	0.0%	1.3%	0.2%	0.0%	1.6%	1.3%
	20	55	23	1815	911	0.0%	2.0%	0.5%	0.0%	2.6%	2.0%
	25	59	23	2209	969	0.0%	2.0%	0.7%	0.0%	2.7%	2.0%
	30	120	24	1947	1270	0.0%	2.3%	0.6%	0.0%	2.9%	2.3%
	35	136	25	3416	1324	0.0%	2.6%	1.4%	0.0%	4.0%	2.7%

Table 19-6 – Partner vehicle 5th percentile occupant results in vehicle-to-vehicle crashes with LWHO Venza

LWHO VENZA PARTNER VEHICLE OCCUPANT											
HIII 5th %ile Dummy											
Crash Configuration	Speed (mph)	HIC15	Chest Deflection (mm)	Femur Max (N)	Neck Tension (N)	HIC15 Risk (%)	Chest Deflection (%)	Femur Max (%)	Neck Tension (T)(%)	Combined Injury Risk (%)	Combined Injury Risk II (No Femur) (%)
Explorer Full	15	92	26	1382	1223	0.0%	5.7%	0.6%	0.2%	6.4%	5.8%
	20	108	26	1519	1334	0.0%	5.7%	0.7%	0.3%	6.6%	5.9%
	25	78	24	1633	1157	0.0%	4.3%	0.8%	0.1%	5.2%	4.5%
	30	112	29	1671	1534	0.0%	8.2%	0.8%	0.6%	9.5%	8.8%
	35	103	29	1793	1471	0.0%	8.2%	0.9%	0.4%	9.5%	8.6%
Explorer Offset	15	88	21	1710	1123	0.0%	2.8%	0.9%	0.1%	3.8%	2.9%
	20	84	25	2044	1182	0.0%	5.0%	1.1%	0.1%	6.2%	5.1%
	25	88	28	2204	1255	0.0%	7.3%	1.3%	0.2%	8.6%	7.5%
	30	76	26	2068	1305	0.0%	5.7%	1.1%	0.2%	7.0%	5.9%
	35	118	28	2254	1320	0.0%	7.3%	1.3%	0.3%	8.7%	7.5%
Silverado Full	15	59	21	430	699	0.0%	2.8%	0.2%	0.0%	3.0%	2.9%
	20	111	28	449	894	0.0%	7.3%	0.2%	0.1%	7.5%	7.3%
	25	117	28	654	984	0.0%	7.3%	0.2%	0.1%	7.6%	7.4%
	30	155	28	657	970	0.1%	7.3%	0.3%	0.1%	7.6%	7.4%
	35	180	29	711	1041	0.1%	8.2%	0.3%	0.1%	8.7%	8.4%
Silverado Offset	15	59	21	430	700	0.0%	2.8%	0.2%	0.0%	3.0%	2.9%
	20	75	22	507	889	0.0%	3.3%	0.2%	0.0%	3.5%	3.3%
	25	45	21	758	804	0.0%	2.8%	0.3%	0.0%	3.2%	2.9%
	30	59	25	1077	996	0.0%	5.0%	0.5%	0.1%	5.5%	5.0%
	35	75	27	1120	961	0.0%	6.4%	0.5%	0.1%	7.0%	6.5%
Yaris Full	15	104	21	812	615	0.0%	2.8%	0.3%	0.0%	3.2%	2.9%
	20	176	26	825	831	0.1%	5.7%	0.3%	0.0%	6.1%	5.8%
	25	197	30	1083	953	0.2%	9.2%	0.5%	0.1%	9.9%	9.5%
	30	213	30	2503	977	0.2%	9.2%	1.5%	0.1%	10.9%	9.5%
	35	247	31	2866	1043	0.4%	10.4%	2.0%	0.1%	12.6%	10.8%
Yaris Offset	15	90	19	785	717	0.0%	2.1%	0.3%	0.0%	2.4%	2.1%
	20	122	22	979	832	0.0%	3.3%	0.4%	0.0%	3.7%	3.3%
	25	180	25	1637	976	0.1%	5.0%	0.8%	0.1%	5.9%	5.1%
	30	224	30	1473	1197	0.3%	9.2%	0.7%	0.2%	10.3%	9.7%
	35	226	30	1633	1248	0.3%	9.2%	0.8%	0.2%	10.4%	9.7%
Taurus Full	15	167	22	1591	1436	0.1%	3.3%	0.8%	0.4%	4.5%	3.7%
	20	168	23	1324	1451	0.1%	3.8%	0.6%	0.4%	4.8%	4.3%
	25	172	25	1695	1347	0.1%	5.0%	0.8%	0.3%	6.1%	5.3%
	30	185	26	1908	1409	0.1%	5.7%	1.0%	0.4%	7.1%	6.1%
	35	180	26	2125	1361	0.1%	5.7%	1.2%	0.3%	7.2%	6.1%
Taurus Offset	15	155	21	1304	1440	0.1%	2.8%	0.6%	0.4%	3.8%	3.3%
	20	173	24	1329	1516	0.1%	4.3%	0.6%	0.5%	5.5%	4.9%
	25	169	25	1550	1605	0.1%	5.0%	0.7%	0.7%	6.5%	5.8%
	30	166	24	1552	1341	0.1%	4.3%	0.7%	0.3%	5.4%	4.7%
	35	195	26	1894	1531	0.2%	5.7%	1.0%	0.6%	7.3%	6.3%

20 APPENDIX 20: SOCIETAL COMBINED INJURY RISK

		Societal Combined Injury Risk (CIR)- AIS3+ head, chest, neck, and femur - CIR I															
		Taurus Baseline		LW3		LW4		Accord Baseline		Accord LW		Venza		Low Option		High Option	
	HIII Driver Dummy	Taurus BL- 50th %ile Male	Taurus BL- 5th %ile Female	LW3- 50th %ile Male	LW3- 5th %ile Female	LW4- 50th %ile Male	LW4- 5th %ile Female	Accord BL- 50th %ile Male	Accord BL- 5th %ile Female	Accord LW- 50th %ile Male	Accord LW - 5th %ile Female	Venza- 50th %ile Male	Venza 5th %ile Female	Low Option - 50th %ile Male	Low Option 5th %ile Female	High Option 50th %ile Male	High Option - 5th %ile Female
Crash Configuration	Speed (mph)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)
Explorer Full	15	5.0%	9.1%	5.4%	10.1%	6.1%	8.3%	5.9%	9.0%	6.7%	9.5%	4.9%	8.7%	5.3%	13.0%	5.1%	17.4%
	20	8.4%	10.5%	8.2%	11.2%	10.1%	10.2%	8.3%	9.8%	10.3%	11.8%	8.4%	12.8%	7.5%	19.6%	8.0%	19.8%
	25	11.0%	13.0%	14.0%	14.2%	13.9%	14.2%	11.1%	12.5%	12.2%	13.9%	8.6%	21.2%	10.1%	24.8%	10.0%	19.1%
	30	13.6%	16.1%	16.3%	19.9%	32.2%	16.7%	13.8%	16.2%	12.6%	13.2%	10.2%	21.5%	12.5%	25.1%	17.1%	35.7%
	35	14.8%	18.5%	17.2%	22.6%	43.0%	21.0%	18.4%	17.8%	16.5%	15.8%	13.2%	29.1%	16.3%	27.5%	57.3%	54.4%
Explorer Offset	15	2.8%	8.3%	2.0%	7.0%	2.3%	6.0%	2.9%	5.7%	3.2%	6.5%	2.0%	5.1%	4.3%	10.3%	3.9%	11.3%
	20	3.6%	10.3%	4.1%	10.7%	5.6%	10.5%	6.1%	8.2%	5.4%	9.0%	3.0%	8.0%	6.5%	14.3%	6.0%	20.7%
	25	5.5%	12.8%	5.6%	12.8%	8.2%	11.7%	11.4%	11.5%	8.1%	11.2%	3.6%	7.6%	7.2%	19.6%	15.9%	21.9%
	30	9.0%	12.6%	8.4%	15.0%	12.0%	15.6%	20.9%	14.2%	15.0%	14.0%	5.6%	12.0%	11.2%	23.0%	31.4%	31.8%
	35	11.9%	15.2%	15.8%	15.9%	30.4%	18.9%	54.4%	19.6%	24.9%	17.4%	14.1%	23.5%	16.7%	32.1%	53.1%	59.8%
Silverado Full	15	3.8%	9.3%	4.3%	10.2%	5.4%	10.0%	5.6%	10.0%	6.6%	10.2%	4.8%	12.8%	3.2%	9.7%	4.9%	17.2%
	20	7.2%	12.5%	7.9%	12.0%	9.1%	13.1%	7.1%	11.1%	8.3%	12.5%	7.2%	21.5%	6.8%	23.1%	7.4%	21.6%
	25	10.5%	15.1%	14.6%	16.5%	19.2%	15.0%	9.8%	14.6%	10.1%	15.3%	9.9%	25.7%	10.0%	30.2%	10.0%	28.4%
	30	15.7%	17.4%	40.0%	18.1%	21.6%	14.7%	12.4%	16.7%	12.0%	16.3%	10.8%	27.2%	10.6%	30.8%	22.7%	36.0%
	35	19.6%	17.9%	38.9%	23.3%	29.4%	21.3%	12.8%	16.5%	14.5%	17.3%	11.2%	29.0%	11.4%	33.7%	49.2%	48.8%
Silverado Offset	15	3.2%	9.1%	3.4%	9.7%	4.8%	10.7%	4.4%	6.5%	4.7%	7.4%	3.2%	8.2%	4.3%	9.8%	2.3%	9.3%
	20	4.6%	11.7%	4.9%	12.0%	7.8%	13.8%	5.8%	8.7%	4.9%	8.7%	4.0%	8.9%	5.0%	16.5%	2.4%	13.8%
	25	5.1%	13.3%	6.2%	12.9%	7.0%	13.4%	9.8%	12.3%	8.5%	12.7%	5.6%	12.5%	5.9%	16.2%	4.7%	16.2%
	30	6.9%	14.8%	7.5%	15.9%	8.2%	12.1%	22.1%	16.1%	13.8%	16.5%	8.4%	14.4%	7.4%	27.7%	19.4%	17.2%
	35	8.7%	17.4%	11.1%	19.1%	9.0%	14.3%	42.6%	20.3%	22.2%	20.2%	14.5%	18.1%	9.2%	28.4%	50.7%	35.6%
Yaris Full	15	4.5%	10.6%	5.4%	10.9%	6.0%	12.1%	5.9%	11.3%	6.8%	11.4%	3.5%	11.3%	3.8%	11.8%	2.8%	9.1%
	20	6.4%	13.9%	7.4%	13.8%	7.4%	13.6%	7.3%	13.4%	9.2%	15.5%	6.1%	21.2%	5.5%	18.4%	4.8%	15.4%
	25	7.9%	18.0%	9.7%	18.7%	10.7%	17.4%	8.4%	16.1%	9.6%	17.7%	7.5%	23.0%	7.9%	24.6%	7.6%	25.3%
	30	9.2%	18.4%	10.9%	19.4%	15.3%	19.0%	9.3%	19.0%	10.9%	20.3%	9.4%	28.2%	12.9%	30.4%	9.5%	27.0%
	35	17.7%	21.1%	14.8%	22.1%	28.7%	19.2%	13.4%	20.6%	13.7%	22.6%	13.4%	31.8%	11.7%	36.8%	12.7%	31.9%
Yaris Offset	15	1.6%	3.9%	1.9%	4.0%	2.6%	3.6%	3.9%	5.1%	3.5%	4.7%	2.3%	8.8%	1.9%	6.2%	2.2%	7.1%
	20	2.8%	6.3%	2.7%	5.6%	4.8%	8.7%	5.6%	7.7%	5.8%	10.0%	3.3%	12.4%	4.5%	12.3%	4.0%	12.1%
	25	5.5%	12.8%	5.7%	12.8%	6.8%	13.1%	7.4%	13.1%	8.4%	13.9%	5.4%	17.8%	7.2%	21.6%	5.7%	17.9%
	30	8.1%	14.8%	7.1%	15.9%	11.6%	17.0%	15.2%	15.8%	13.1%	17.1%	12.3%	19.9%	12.7%	27.4%	9.3%	25.2%
	35	12.8%	16.5%	13.3%	16.2%	14.2%	19.2%	35.9%	20.8%	29.2%	17.9%	19.3%	29.9%	13.6%	32.8%	17.9%	30.1%
Taurus Full	15	3.2%	8.3%	3.9%	9.3%	3.5%	7.8%	4.7%	10.0%	5.8%	9.6%	3.4%	9.4%	3.6%	10.8%	3.5%	9.6%
	20	5.2%	10.6%	6.2%	11.1%	5.2%	9.8%	6.6%	10.7%	8.2%	12.5%	4.8%	14.3%	5.0%	17.7%	5.1%	12.3%
	25	6.6%	11.7%	8.2%	13.2%	8.8%	11.9%	8.3%	11.7%	9.3%	13.1%	5.7%	21.7%	6.9%	20.6%	7.0%	14.3%
	30	10.0%	13.5%	10.6%	14.5%	13.2%	13.8%	10.4%	13.4%	10.7%	15.1%	7.5%	23.0%	9.0%	24.1%	12.8%	20.4%
	35	11.6%	13.8%	14.1%	15.0%	18.7%	15.0%	13.4%	15.6%	13.2%	16.5%	9.3%	28.4%	11.9%	27.9%	16.6%	20.6%
Taurus Offset	15	1.8%	7.4%	2.5%	9.2%	2.0%	7.4%	3.5%	5.6%	3.9%	5.8%	2.4%	7.9%	2.7%	7.7%	3.4%	8.6%
	20	2.4%	9.2%	3.0%	9.2%	3.4%	9.4%	3.9%	6.8%	4.4%	7.6%	4.1%	11.7%	4.2%	10.1%	4.6%	11.7%
	25	3.8%	10.0%	4.2%	10.9%	4.9%	11.3%	5.1%	10.3%	5.5%	10.7%	5.0%	15.3%	5.5%	13.4%	6.3%	13.8%
	30	5.5%	10.7%	5.5%	13.0%	8.3%	14.2%	9.1%	13.5%	7.5%	11.9%	6.0%	17.3%	5.7%	20.4%	12.1%	21.1%
	35	7.9%	13.6%	7.2%	13.7%	10.2%	17.7%	13.7%	15.9%	13.1%	15.1%	6.2%	24.3%	7.1%	27.2%	23.9%	26.2%

NO FEMUR

Societal Combined Injury Risk (CIR)- AIS3+ head, chest, & neck- CIR II

		Taurus Baseline		LW3		LW4		Accord Baseline		Accord LW		Venza		Low Option		High Option	
	HIII Driver Dummy	Taurus BL- 50th %ile Male	Taurus BL- 5th %ile Female	LW3- 50th %ile Male	LW3- 5th %ile Female	LW4- 50th %ile Male	LW4- 5th %ile Female	Accord BL- 50th %ile Male	Accord BL- 5th %ile Female	Accord LW- 50th %ile Male	Accord LW - 5th %ile Female	Venza- 50th %ile Male	Venza 5th %ile Female	Low Option - 50th %ile Male	Venza 5th %ile Female	High Option - 50th %ile Male	Venza 5th %ile Female
Crash Configuration	Speed (mph)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)
Explorer Full	15	3.8%	7.6%	4.1%	8.6%	4.6%	7.6%	5.0%	8.2%	5.5%	8.6%	3.5%	7.6%	4.1%	11.3%	3.6%	15.5%
	20	6.3%	8.8%	5.6%	9.4%	7.2%	9.5%	6.9%	8.8%	7.9%	10.4%	6.4%	10.9%	5.4%	17.2%	5.3%	17.7%
	25	7.2%	11.1%	7.6%	12.0%	7.6%	13.3%	8.7%	10.9%	8.5%	12.4%	6.5%	19.4%	6.5%	22.2%	6.5%	16.4%
	30	7.8%	13.6%	9.1%	17.1%	8.9%	15.8%	9.9%	14.2%	9.1%	11.6%	7.1%	18.9%	7.3%	22.1%	12.5%	33.1%
	35	9.2%	15.6%	10.4%	19.5%	10.7%	20.2%	13.2%	16.0%	10.7%	14.0%	9.0%	26.3%	10.3%	24.6%	53.0%	51.5%
Explorer Offset	15	2.1%	6.2%	1.6%	4.9%	1.7%	5.1%	2.4%	4.6%	2.7%	5.5%	1.5%	3.7%	3.4%	8.2%	3.2%	9.2%
	20	2.8%	8.1%	3.2%	8.5%	4.0%	9.3%	5.1%	6.9%	4.5%	7.5%	2.2%	6.4%	4.9%	11.9%	3.9%	18.6%
	25	3.9%	10.4%	3.8%	10.6%	5.7%	10.1%	9.6%	9.9%	6.8%	9.5%	2.5%	6.1%	5.4%	16.6%	12.8%	19.5%
	30	6.7%	10.5%	5.8%	12.9%	8.5%	13.8%	16.5%	12.2%	12.2%	12.0%	4.1%	9.9%	8.7%	20.0%	27.7%	28.6%
	35	8.6%	13.0%	12.4%	13.5%	25.2%	17.0%	48.6%	16.9%	19.7%	14.8%	11.7%	21.2%	13.4%	29.2%	49.0%	56.6%
Silverado Full	15	3.3%	8.1%	3.6%	9.3%	4.6%	9.8%	5.3%	9.6%	5.9%	9.9%	4.3%	11.4%	2.9%	8.1%	3.8%	15.4%
	20	5.9%	11.3%	5.6%	10.6%	6.3%	12.8%	6.6%	10.4%	7.0%	11.8%	6.0%	19.9%	5.9%	21.4%	6.0%	19.7%
	25	7.2%	13.5%	7.2%	14.5%	7.6%	14.6%	8.4%	13.6%	7.9%	14.3%	7.5%	23.7%	7.7%	28.0%	8.1%	26.3%
	30	8.2%	15.4%	8.9%	15.4%	8.3%	14.4%	10.0%	15.4%	8.8%	15.2%	7.6%	24.3%	7.9%	28.0%	19.3%	34.2%
	35	8.6%	15.2%	10.2%	19.7%	10.7%	20.9%	10.3%	15.3%	9.7%	16.1%	7.7%	25.4%	8.3%	30.5%	45.5%	46.1%
Silverado Offset	15	3.1%	7.9%	3.3%	8.4%	4.1%	10.6%	4.3%	6.1%	4.6%	7.0%	2.7%	7.0%	3.8%	8.9%	1.9%	7.8%
	20	4.3%	10.4%	4.4%	10.9%	5.6%	13.6%	5.6%	8.3%	4.9%	8.2%	3.4%	7.4%	4.4%	15.2%	1.9%	12.3%
	25	4.6%	11.9%	5.3%	11.8%	5.3%	13.1%	8.7%	11.6%	8.0%	11.9%	4.7%	10.6%	5.3%	14.6%	3.1%	14.6%
	30	6.0%	13.5%	6.0%	14.6%	6.0%	11.9%	18.0%	14.8%	11.8%	15.2%	7.0%	12.5%	6.6%	25.6%	17.2%	15.1%
	35	7.3%	16.2%	8.2%	17.9%	7.1%	14.0%	37.7%	18.9%	19.2%	18.6%	12.6%	16.6%	7.7%	25.9%	46.8%	32.1%
Yaris Full	15	3.1%	9.0%	3.8%	9.5%	3.8%	11.3%	5.1%	10.7%	5.8%	10.9%	2.8%	10.2%	3.1%	10.7%	2.3%	7.7%
	20	4.3%	12.2%	4.6%	11.8%	4.6%	12.7%	5.9%	12.8%	6.8%	14.5%	4.2%	19.7%	4.1%	16.9%	3.9%	13.7%
	25	4.9%	15.9%	5.3%	16.5%	5.3%	16.2%	6.5%	15.2%	7.0%	16.0%	4.8%	21.4%	4.7%	22.3%	5.0%	23.1%
	30	5.3%	16.0%	5.7%	16.6%	6.5%	17.8%	7.0%	17.2%	7.2%	17.3%	5.4%	25.2%	5.8%	26.4%	6.1%	24.0%
	35	7.5%	18.1%	6.7%	18.9%	10.7%	17.6%	8.8%	18.2%	8.3%	17.4%	6.9%	26.8%	6.1%	33.1%	7.2%	28.2%
Yaris Offset	15	1.5%	2.9%	1.8%	3.0%	2.5%	3.4%	3.7%	4.8%	3.4%	4.4%	1.7%	7.8%	1.4%	5.1%	1.9%	5.9%
	20	2.6%	5.1%	2.5%	4.3%	4.5%	8.2%	5.4%	7.3%	5.7%	9.4%	2.5%	10.6%	3.0%	10.8%	3.2%	10.6%
	25	4.9%	11.2%	5.1%	11.2%	5.8%	12.5%	7.0%	12.1%	8.0%	12.9%	3.8%	16.0%	4.7%	19.6%	4.3%	15.9%
	30	6.8%	12.9%	6.1%	14.1%	8.2%	15.8%	13.2%	14.3%	11.4%	15.8%	8.4%	16.8%	8.4%	25.0%	5.8%	23.3%
	35	10.3%	14.5%	11.0%	14.3%	8.9%	18.0%	30.7%	18.6%	23.1%	16.5%	13.7%	26.1%	8.4%	28.7%	14.3%	27.5%
Taurus Full	15	2.7%	6.3%	3.1%	7.3%	2.9%	6.8%	4.3%	8.6%	5.3%	8.3%	2.7%	7.7%	2.9%	9.0%	2.9%	7.9%
	20	4.0%	8.6%	4.7%	9.0%	4.0%	8.9%	5.8%	9.4%	6.7%	11.0%	3.8%	12.5%	3.8%	15.7%	3.6%	10.2%
	25	4.7%	9.5%	5.3%	10.8%	5.3%	10.7%	6.8%	10.3%	7.1%	11.6%	4.2%	19.3%	4.5%	18.2%	4.4%	11.3%
	30	6.0%	10.9%	5.7%	11.6%	6.4%	12.5%	7.5%	11.6%	7.5%	12.2%	5.1%	19.7%	5.1%	21.1%	8.6%	17.1%
	35	6.1%	10.7%	6.7%	11.6%	7.1%	13.5%	8.7%	13.4%	8.8%	12.3%	5.5%	24.5%	6.5%	24.0%	10.9%	16.5%
Taurus Offset	15	1.7%	5.0%	2.3%	6.7%	1.9%	6.2%	3.4%	4.8%	3.8%	4.9%	1.9%	6.2%	2.2%	6.2%	2.9%	7.1%
	20	2.3%	6.8%	2.7%	6.7%	3.1%	8.2%	3.8%	5.8%	4.4%	6.3%	3.4%	9.7%	3.6%	8.4%	3.8%	10.2%
	25	3.5%	7.7%	3.9%	8.3%	4.3%	10.0%	4.9%	9.0%	5.3%	9.3%	4.1%	13.0%	4.4%	11.4%	4.7%	11.7%
	30	4.6%	8.3%	4.7%	10.6%	6.3%	13.1%	8.7%	12.1%	7.3%	10.3%	4.5%	14.6%	4.8%	18.1%	10.3%	18.7%
	35	6.3%	11.2%	5.8%	11.6%	6.9%	16.7%	12.1%	14.5%	11.0%	13.3%	4.2%	21.4%	4.8%	24.1%	21.0%	22.2%

Societal Combined Injury Risk (CIR)- AIS3+ head, chest, & neck- CIR II with A-Pillar Intrusion Penalty

NO FEMUR		Taurus Baseline		LW3		LW4		Accord Baseline		Accord LW	
	HIII Driver Dummy	Taurus BL- 50th %ile Male	Taurus BL- 5th %ile Female	LW3- 50th %ile Male	LW3- 5th %ile Female	LW4- 50th %ile Male	LW4- 5th %ile Female	Accord BL- 50th %ile Male	Accord BL- 5th %ile Female	Accord LW- 50th %ile Male	Accord LW - 5th %ile Female
Crash Configuration	Speed (mph)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)	Combined Injury Risk (%)
Explorer Full	15	3.8%	7.6%	4.1%	8.6%	4.6%	7.6%	5.0%	8.3%	5.5%	8.7%
	20	6.5%	9.0%	5.7%	9.6%	7.2%	9.6%	7.0%	8.9%	8.0%	10.6%
	25	7.4%	11.7%	8.4%	13.6%	7.8%	13.8%	9.1%	11.4%	9.3%	13.6%
	30	7.9%	13.9%	9.7%	18.3%	9.3%	16.7%	11.2%	16.0%	10.6%	13.6%
	35	9.5%	16.2%	11.3%	21.5%	11.1%	21.1%	16.9%	20.1%	16.0%	20.8%
Explorer Offset	15	2.1%	6.2%	1.6%	4.9%	1.8%	5.3%	2.5%	4.7%	2.9%	5.8%
	20	2.9%	8.4%	3.2%	8.6%	4.1%	9.7%	5.5%	7.3%	5.0%	8.2%
	25	4.1%	11.1%	4.2%	11.9%	6.0%	10.9%	11.4%	12.2%	8.9%	12.2%
	30	10.1%	18.0%	7.8%	18.4%	8.6%	14.1%	25.1%	18.6%	103.5%	103.5%
	35	104.2%	104.5%	104.2%	103.4%	28.4%	18.8%	91.9%	29.2%	105.1%	104.6%
Silverado Full	15	3.4%	8.3%	3.7%	9.5%	4.6%	9.8%	5.4%	9.8%	5.9%	9.9%
	20	6.3%	12.0%	5.8%	11.0%	6.6%	13.3%	6.7%	10.5%	7.3%	12.2%
	25	7.4%	14.1%	7.8%	16.0%	8.0%	15.4%	8.8%	14.0%	8.8%	15.6%
	30	8.5%	16.0%	9.8%	17.0%	8.3%	14.4%	11.7%	17.7%	11.3%	18.8%
	35	9.5%	17.0%	11.7%	22.7%	10.7%	20.9%	12.6%	18.0%	16.0%	24.2%
Silverado Offset	15	3.1%	7.9%	3.4%	8.6%	4.2%	11.1%	4.4%	6.2%	5.0%	7.4%
	20	4.7%	11.3%	4.7%	11.7%	5.8%	14.4%	6.0%	8.8%	5.5%	9.0%
	25	5.1%	13.4%	6.5%	14.6%	5.4%	13.5%	10.9%	14.2%	10.1%	14.5%
	30	9.0%	21.4%	8.2%	20.4%	6.0%	11.9%	31.7%	22.7%	21.2%	24.2%
	35	103.8%	107.4%	13.5%	29.3%	7.1%	14.0%	71.8%	30.4%	102.9%	107.4%
Yaris Full	15	3.1%	9.0%	3.8%	9.5%	3.8%	11.3%	5.2%	10.8%	5.8%	11.0%
	20	4.3%	12.2%	4.6%	11.8%	4.6%	12.7%	5.9%	12.8%	6.8%	14.5%
	25	4.9%	15.9%	5.3%	16.5%	5.3%	16.2%	6.5%	15.2%	7.1%	16.2%
	30	5.3%	16.0%	5.7%	16.6%	6.5%	17.8%	7.0%	17.2%	7.3%	17.4%
	35	7.5%	18.1%	6.7%	18.9%	10.7%	17.6%	8.8%	18.2%	8.4%	17.5%
Yaris Offset	15	1.5%	2.9%	1.8%	3.0%	2.5%	3.4%	3.7%	4.8%	3.4%	4.5%
	20	2.7%	5.2%	2.5%	4.4%	4.5%	8.2%	5.4%	7.3%	5.8%	9.5%
	25	4.9%	11.2%	5.2%	11.3%	5.8%	12.5%	7.0%	12.1%	8.3%	13.2%
	30	6.8%	12.9%	6.2%	14.5%	8.2%	15.8%	13.5%	14.6%	12.1%	16.6%
	35	10.9%	15.9%	11.4%	15.1%	8.9%	18.0%	30.9%	18.9%	25.0%	18.8%
Taurus Full	15	2.8%	6.5%	3.2%	7.6%	2.9%	6.9%	4.3%	8.7%	5.4%	8.4%
	20	4.2%	8.9%	4.9%	9.4%	4.1%	9.1%	5.8%	9.4%	6.7%	11.1%
	25	4.7%	9.5%	5.5%	11.3%	5.4%	11.0%	6.8%	10.3%	7.2%	11.6%
	30	6.0%	10.9%	5.7%	11.7%	6.4%	12.5%	7.5%	11.6%	7.6%	12.2%
	35	6.1%	10.8%	7.1%	12.1%	7.1%	13.5%	8.7%	13.5%	9.4%	13.0%
Taurus Offset	15	1.7%	5.0%	2.4%	6.9%	1.9%	6.2%	3.4%	4.8%	3.9%	4.9%
	20	2.4%	6.9%	2.8%	6.9%	3.1%	8.2%	3.8%	5.8%	4.4%	6.4%
	25	3.6%	7.9%	4.1%	8.7%	4.4%	10.3%	5.1%	9.2%	5.6%	9.7%
	30	4.8%	8.6%	5.1%	11.6%	6.3%	13.1%	9.2%	12.6%	8.0%	11.1%
	35	6.9%	12.2%	5.9%	12.0%	6.9%	16.7%	12.8%	15.1%	13.6%	15.6%

NOTE: CIR IIP was not computed for the Venza baseline or lightweight simulations because A-pillar intrusions were incorporated into the MADYMO occupant model using PSM.

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