Development of a 2015 Mid-Size Sedan Vehicle Model

Rudolf Reichert, Steve Kan

George Mason University
Center for Collision Safety and Analysis

1 Abstract

A detailed finite element model of a 2015 mid-size sedan vehicle was developed using a reverse engineering process. The model consists of about 1000 parts and 2.25 million elements representing geometry, connections, and material characteristics of relevant structural and interior components. This paper describes the level of detail of the simulation model, the validation process, and how it performs in various impact configurations when compared to full-scale crash test data. Members of the Center for Collision Safety and Analysis (CCSA) at George Mason University, formerly known as the National Crash Analysis Center (NCAC), have been developing a fleet of finite element vehicle models over the last 20 years. The updated mid-size sedan presented in this paper is the latest model with a high level of detail using state-of-the-art modeling techniques. A thorough validation process, using test results from frontal, side, and roof crush impact configurations, ensures a high level of correlation for a variety of load cases. Special focus has been placed on occupant compartment intrusion and vehicle pulse evaluation for frontal impact scenarios. Realistic wheel kinematics in the Insurance Institute for Highway Safety (IIHS) small overlap load case was achieved through adequate failure modeling. An objective correlation analysis tool was used to evaluate how well simulation results match respective test results. The model is currently being used for several research studies, including the development of structural countermeasures to significantly reduce occupant compartment intrusion for the National Highway Traffic Safety Administration's (NHTSA) left and right frontal oblique offset configurations.

2 Introduction

Over the past 10 years, the number of vehicle accident related fatalities in the United States of America decreased by approximately 25% [1]. Advances in vehicle safety with respect to structural, interior, and restraint system components have contributed to the reduction of fatalities and injuries over the years. Despite major improvements in vehicle safety, there is a need for further research to evaluate real world accident configurations, impacts with roadside hardware, light weight vehicle designs, and new challenges that will be posed by autonomously driven vehicles in the future. Finite element (FE) simulation plays an important role in vehicle development and vehicle safety research. Car manufacturers and suppliers have been successfully using simulation as a complementary tool to full-scale testing. Detailed models that include relevant components, such as vehicle structure, suspension, steering, interior, and restraints, are being used to evaluate the crashworthiness of a vehicle in a variety of regulation and consumer information test configurations. The models used in industry are based on available CAD data. Validated component models of seats, interior trims, steering, and restraints, which are often obtained from suppliers, add to the validity of the full vehicle models. These models are proprietary to the respective companies and generally cannot be used by other research institutions.

Several publicly available vehicle models have been developed by the CCSA team and by other institutions. An example is the "Development & Validation of a Finite Element Model for the 2010 Toyota Yaris Passenger Sedan" [2]. The model presented here is based on a previous publication called "Development & Validation of a Finite Element Model for a Mid-Sized Passenger Sedan" [3]. In the previous publication the Model Year (MY) 2012 model did not include most interior components, such as trims and detailed seats. Focus was put on model development and validation against the New Car Assessment Program (NCAP) full frontal impact test. The updated model presented here includes detailed interior components and updated vehicle structure from the MY 2015 vehicle. In addition, several other components and modeling techniques not included in the initial model were

added. The updated model underwent a thorough validation process using test data from the NCAP full overlap impact, the IIHS small and moderate overlap, NHTSA's left and right oblique frontal offset, various side impact configurations, and a roof crush analysis.
After giving a brief overview of the reverse engineering process, methods used during the validation process are described. This includes the use of the software tool "CORrelation and Analysis" (CORA) [4], which allows users to objectively rate how well test and simulation output data compare. The results for various frontal, side, and roof crush configurations are outlined and their correlation with available full-scale crash test data is provided. The results are discussed and limitations are outlined to give the reader a good understanding of the detail of the model and the depth of validation. Three application examples are presented. The first example, conducted in cooperation with NHTSA, outlines the development of structural countermeasures to significantly reduce occupant compartment intrusion in the oblique impact configuration. The second example describes the use of the model in combination with human occupant models and relevant restraints to evaluate kinematics and interactions in side impact and run-off-road impact configurations. The third example outlines how the model can be used to conduct a fleet study comparing the crash performance of barrier-to-vehicle and vehicle-to-vehicle impacts in the IIHS side impact configuration.

3 Methods

3.1 Reverse Engineering

A MY 2012 mid-size sedan vehicle was purchased and its mass, center of gravity (C.G.) location, and inertial properties were determined. A digitizing device was used to scan all relevant components including their internal structure. GEOmagic software was used to create accurate CAD surfaces and HyperMesh and ANSA were used for FE mesh generation. All components were positioned relative to a defined reference coordinate system and checked for correct position and penetrations. Spot-welds, bead welds, bolts, and joints were used for respective part connections. Material thicknesses and mass distribution were assigned to the individual parts and components. Measured C.G. location and inertial properties of the entire vehicle were verified. Material property data for most structural parts was obtained by cutting specimens from the actual vehicle components and conducting material coupon tests.
Analysis of a physical MY 2015 mid-size sedan and information from the manufacturer was used to determine differences between the MY 2012 and MY 2015 vehicles. To improve performance in the IIHS small overlap test from POOR to ACCEPTABLE, a spacer was added beyond the bumper reinforcement to the front side member. This spacer directs crash energy through the side member into the reinforced A-pillar, which diffuses it through the roof rail, rocker panel, and floor pan. The available FE model was updated accordingly. In addition, advanced modeling techniques for wheel connections were implemented to better represent failure mechanisms and wheel kinematics seen in the IIHS small overlap impact.

3.2 Validation

In order to validate the developed MY 2015 vehicle model, a variety of load cases, including frontal oblique impact configurations, side barrier, and side pole impacts were configured and compared to respective full-scale crash test results. First, visual analysis of test pictures, test movies, and simulation animations was used to compare overall vehicle kinematics and crash characteristics. For the IIHS small and moderate overlap impacts, the lower and upper occupant compartment intrusion data was evaluated according to the respective test protocols. For NHTSA's full overlap and oblique impact configurations, available intrusion data from the simulation model and respective full-scale tests was compared.
Time history data plots, in combination with test videos and simulation animations, were used to evaluate crash modes and structural energy absorption mechanisms. CORA was used to rate how well test and simulation results compare. CORA was developed by the Partnership for Dummy technology and Biomechanics (PDB) and takes phase shift, size, and shape, as well as the comparison of values at each time increment, into account. Using these methods, an objective rating is given that indicates how well a curve (e.g., simulation) compares to a reference curve (e.g., test). Rating results range between 0 and 1, where 0 means no correlation and 1 means (close to) perfect correlation.

4 Results

4.1 MY 2015 Mid-Size Sedan FE Model

A MY 2012 mid-size sedan was purchased and a detailed FE model was built using the described reverse engineering process [3]. Relevant design changes for the MY 2015 vehicle were implemented. Fig. 1(a) illustrates significant structural differences between MY 2012 and MY 2015 vehicles [5]. To improve performance in the IIHS small overlap test from POOR to ACCEPTABLE, a spacer (2) was added beyond the bumper reinforcement (1) to the front side member (3). This spacer directs crash energy into the reinforced A-pillar (4), which diffuses it through the roof rail, rocker panel, and floor pan. Fig. 1(b) shows a bottom view of the finite element model with an enlarged view of the added bumper reinforcement extension and spacer for the physical vehicle and the simulation model. Fig. 1(c) depicts the effect of the bumper reinforcement and spacer in the IIHS small overlap impact. Due to the minor overlap of 25% with the vehicle, the longitudinal rail is not activated when no spacer exists. The frontal rail remains undeformed and no crash energy is absorbed. The effect of the added bumper reinforcement extension and spacer can be seen in Fig. 1(c) on the right. The added components interact with the IIHS small overlap barrier and activate the frontal rail on the driver side. The deformation of the longitudinal rail contributes to the structural crash energy absorption. Available full-scale test results show that the design changes mainly affected performance in the IIHS small overlap impact, while other crash configurations, such as NCAP full overlap and NHTSA left oblique impact, showed similar results for the 2012 and 2015 models. Advanced modeling techniques for the wheel connection were implemented in the FE model to better represent the failure mechanisms and wheel kinematics seen in the IIHS small overlap impact.

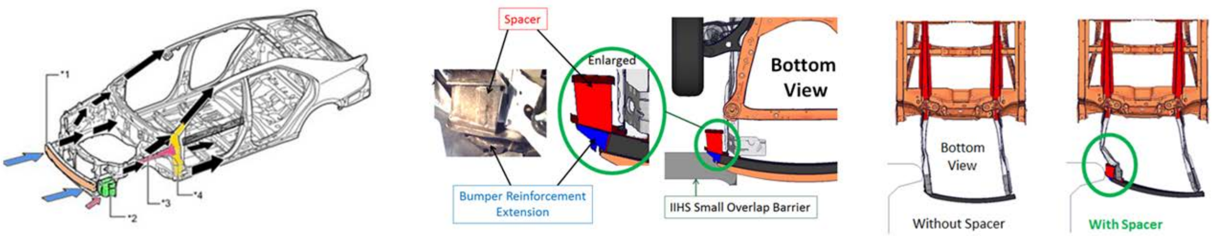


Fig.1: 2015 Vehicle Design Changes (a) Overall Schematic, (b) “Spacer”, (c)Effect of “Spacer”

The resulting MY 2015 FE model contains relevant structural and interior components, such as body in white, engine, drivetrain, steering, suspension, seats, trims, etc., which are represented by more than 1000 parts and approximately 2.25 million nodes and elements. Most components were modeled using shell elements with an average element size of 6 millimeters (mm). The model was evaluated and validated using the nonlinear, explicit FE code LS-DYNA [6] with a minimum time-step of 0.7 microseconds using 16 cpu on a Hewlett-Packard high-performance computer system. The results of the conducted simulations using the MY 2015 sedan FE model are outlined in this chapter. Simulation results were compared to available full-scale crash test results for NHTSA’s left and right oblique impacts, NCAP full overlap, and IIHS small and moderate overlap configurations. In addition, test and simulation results for side impact and roof crush configurations were compared.

4.2 NHTSA’s Left Oblique Impact

NHTSA’s left oblique full-scale impact test #8790, consisting of a Research Moving Deformable Barrier (RMDB) traveling at a speed of 90 kilometers per hour (km/h) into the front driver side of the stationary MY 2015 mid-size sedan, was used to evaluate the developed FE model. The vehicle was positioned with a 15 degree angle relative to the RMDB and impacted with a 35% overlap.
Fig. 2 depicts the overall vehicle deformation and specific occupant compartment intrusion values in test and simulation. Fig. 2(a) shows the overall vehicle deformation in the baseline simulation on the top and in the full-scale crash test on the bottom. Similar deformation of the frontal structure, door frame, and roof were observed. There was no significant door sill deformation in either test or simulation. Intrusion along the rocker pillar and minor buckling of the A-pillar area were well captured in the simulation. Toe-pan intrusion was recorded for measurement points in 5 rows, consisting of 4 points each, in test and simulation, as shown in Fig. 2(b). The maximum intrusion values for each row are visualized in the adapted structural rating chart, derived from the IIHS moderate overlap evaluation protocol. Fig. 2(c) visualizes the maximum intrusion for row 1 to row 4, brake-pedal, left and right

instrument panel, and A- to B-pillar closure. MY 2015 test results are shown in black and simulation results in blue. The highest values occured in row 1, which is the most forward and upward location at the toe-pan. Values decreased for more rearward locations in both test and simulation. A maximum intrusion of 94 mm was observed in the simulation, versus 99 mm in the test. Lower and upper occupant compartment intrusion, including toe-pan deformation from the full-scale crash test, was well captured in the simulation. The developed FE model represents well the structural intrusion characteristics of the MY 2015 sedan in the left oblique impact configuration.

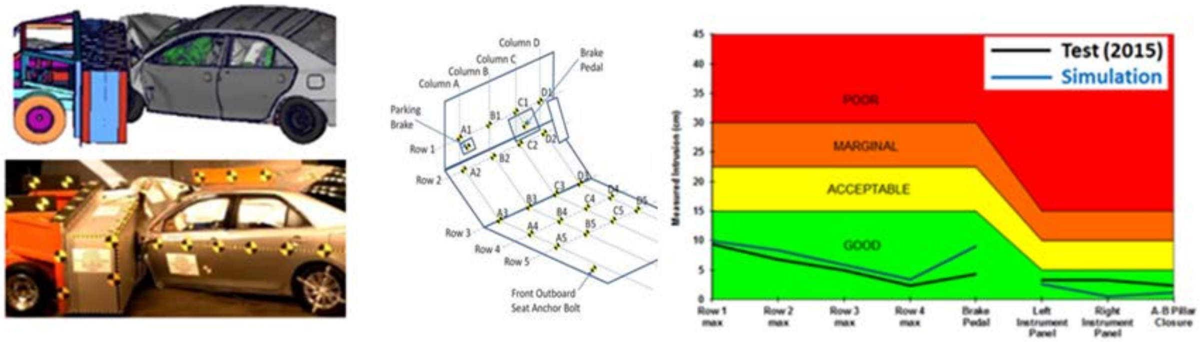


Fig.2: 2015 Left Oblique Test versus Simulation (a) Overall, (b) Measurement Points, (c) Intrusion

Fig. 3(a) shows the vehicle acceleration pulse for the MY 2015 sedan in test and simulation in the left oblique impact configuration. Test results are depicted using a black solid line and simulation results using a blue dashed line. Good overall correlation, with a CORA rating value of 0.94, was observed. Fig. 3(b) depicts the RMDB acceleration pulse for the left oblique impact configuration. Test data is depicted using a black solid line and simulation data using a blue dashed line. Good correlation between test and simulation, with a CORA rating value of 0.95, was observed. The FE model represents well the vehicle and barrier pulse characteristics of the MY 2015 sedan in the left oblique impact configuration.

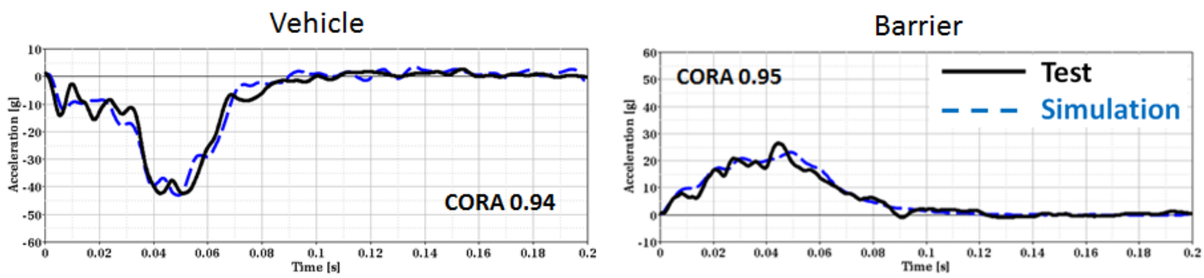


Fig.2: 2015 Left Oblique Test versus Simulation (a) Vehicle Pulse, (b) Barrier Pulse

4.3 NHTSA’s Right Oblique Impact

NHTSA’s right oblique impact test #9121, consisting of an RMBD traveling at a speed of 90 km/h into the front passenger side of a stationary MY 2012 sedan, was used to evaluate the developed simulation model. The target vehicle was positioned with a 15 degrees angle relative to the RMDB and impacted with a 35% overlap. No full-scale crash test data of a MY 2015 sedan was available. Test results for the left oblique impact configuration showed similar vehicle deformation, intrusion, and vehicle pulse characteristics for MY 2012 and MY 2015 vehicles. Therefore, it was assumed that MY 2015 test results for the right oblique configuration are similar to the available data from a MY 2012 sedan.

Fig. 3 compares overall vehicle deformation and specific occupant compartment intrusion values in test and simulation. Fig. 3(a) shows the overall vehicle deformation in the simulation on the top and in the full-scale crash test on the bottom. Similar deformation of the frontal structure, door frame, and roof was observed. The A-pillar showed minor buckling and moderate door sill deformation in both test and simulation. Intrusion along the rocker pillar and minor bending of the A-pillar area were well captured in the simulation. Toe-pan intrusion was recorded for measurement points in 5 rows, consisting of 3 points each, as shown in Fig. 3(b). The maximum intrusion values for each row are visualized in the adapted chart, derived from the IIHS moderate overlap structural evaluation rating. Figure 3(c) visualizes the maximum intrusion for row 1 to row 4, brake-pedal, left and right instrument panel, and A- to B-pillar closure. Test results are shown using a black dashed line and simulation results using a blue solid line. The highest values occured in row 1, which is the most forward and upward location at the toe-pan. Values decreased for more rearward locations in test and simulation. A maximum intrusion of 163 mm in row 1 was observed in the simulation and 131 mm in the test.

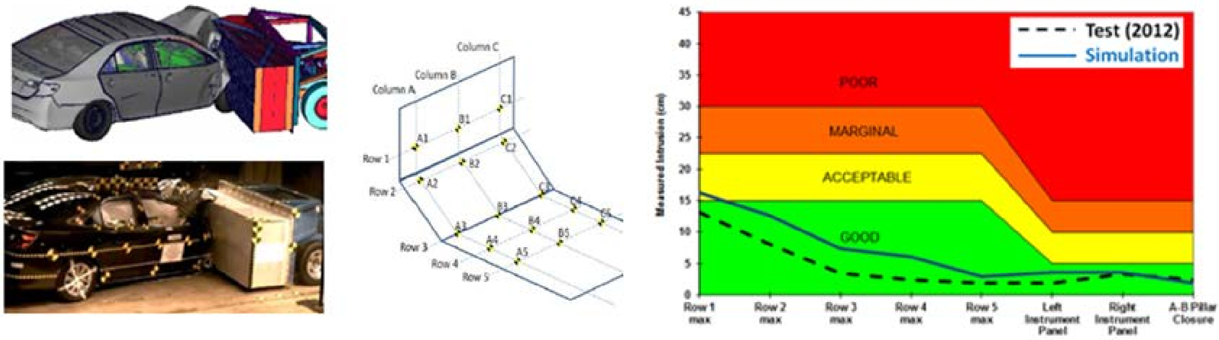


Fig.3: Right Oblique Test versus Simulation (a) Overall, (b) Measurement Points, (c) Intrusion

Fig. 4(a) shows the vehicle acceleration pulse in test and simulation in the right oblique impact configuration. Test results are depicted using a black solid line and simulation results using a blue dashed line. Good overall correlation, with a CORA rating value of 0.93, was achieved. Fig. 4(b) depicts the RMDB acceleration pulse for the left oblique impact configuration. Test data is depicted using a black solid line and simulation data using a blue dashed line. Good correlation between test and simulation with a CORA rating value of 0.95 was observed. The FE model represents well the vehicle and barrier pulse characteristics in the right oblique impact configuration.

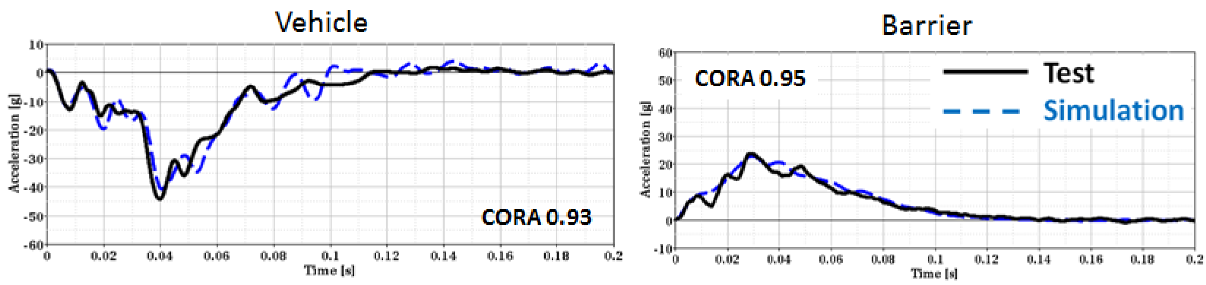


Fig.4: Right Oblique Test versus Simulation (a) Vehicle Pulse, (b) Barrier Pulse

4.4 IIHS Small and Moderate Overlap Impact

IIHS Small Overlap (SO) test CEN1349 of a MY 2015 sedan traveling at 64 km/h into a fixed rigid barrier with a 25% overlap was used to evaluate the developed simulation model. Fig. 5(a) shows the overall vehicle deformation in the simulation and in the full-scale crash test. Similar deformation of the frontal structure, door frame, and roof was observed. The A-pillar showed noticeable buckling in test and simulation. Failure mechanism of the wheel-to-control-arm connection and overall wheel kinematics were well captured. In the later stages of the impact, after maximum intrusion and occupant injury values have occurred, additional material failure of various components in the rocker pillar, door, and sill area were observed in the test which are not completely captured in the simulation. Consequently, some differences in the rebound phase exist.
Fig. 5(b) depicts the intrusion for the lower and upper occupant compartment according to the IIHS SO rating protocol. MY 2015 test results are shown using a black solid line and simulation results using a blue solid line. Respective results correlate well, resulting in an ACCEPTABLE structural rating for test and simulation. Occupant compartment intrusion characteristics were well captured in the simulation.
Fig. 5(c) compares the vehicle acceleration pulse. Test results are depicted using a black solid line and simulation results using a blue dashed line. Reasonable overall correlation for the vehicle time

history data was observed. An objective CORA rating value of 0.69 documents the reasonable correlation between test and simulation.

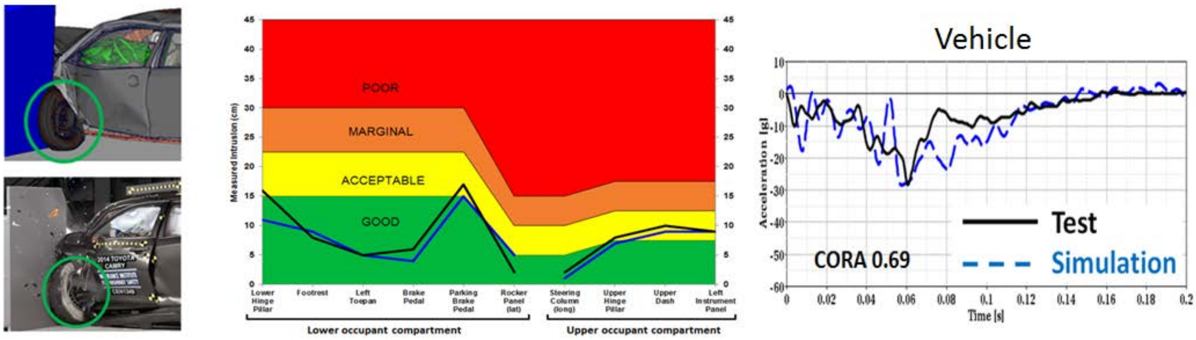


Fig.5: IIHS SO Test versus Simulation (a) Overall, (b) Intrusion, (c) Vehicle Pulse

Available data from the IIHS Moderate Overlap (MO) test #1109 was used to evaluate the developed FE model. The test, where the vehicle travels at 64 km/h into a barrier with a deformable aluminum honeycomb face with a 40% overlap, was conducted by Toyota as part of the frontal crash test verification. Some occupant injury criteria and vehicle intrusion measurements were available from the conducted test, but no video or technical time history data was accessible. An IIHS GOOD structural rating is documented for the lower and upper occupant compartment. The developed FE model was run in the same configuration. Roof, A-pillar, and door sill remained practically un-deformed. A GOOD structural rating for the lower and upper occupant comparment according to the IIHS structural rating protocol was observed for the simulation, matching the available full-scale test results.

4.5 NCAP Full Overlap

NHTSA test #8545 was used to evaluate the developed FE model in the 56 km/h NCAP full overlap impact into a rigid barrier. Fig. 6 compares overall vehicle deformation, occupant compartment intrusion values, and vehicle pulse in test and simulation. Fig. 6(a) shows the overall vehicle deformation in the simulation on the top and in the full-scale crash test on the bottom. Similar deformation of the frontal structure, door frame, and roof was observed. No significant deformation of the roof, A-pillar, or door sill occured in either test or simulation. The same measurement points used for the IIHS moderate overlap configuration were evaluated for the simulation and illustrated using the respective structural intrusion rating chart.
Figure 6(b) visualizes the maximum intrusion for the lower and upper occupant compartment in the simulation using blue solid line. Available test results are depicted using a black solid line. Respective points that were not recorded in the test were interpolated from existing measurements and are illustrated using a black dashed line. Intrusion values were small when compared to previously analyzed frontal impact configurations.
Fig. 6(c) compares the vehicle acceleration pulse. Test results are depicted using a black solid line and simulation results using a blue dashed line. The objective CORA rating value of 0.86 documents the good correlation between test and simulation.

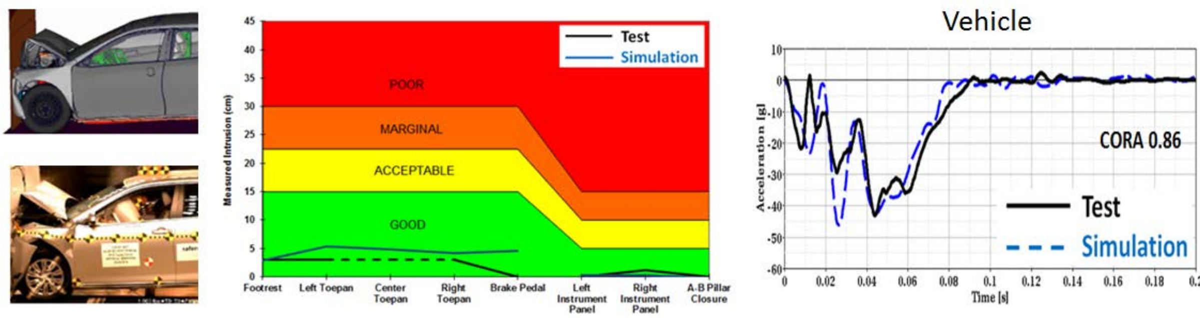


Fig.6: NCAP Test versus Simulation, (a) Overall, (b) Intrusion, (c) Vehicle Pulse

4.6 Side Impact Configurations

Test results from NHTSA's 62 km/h crabbed barrier and oblique pole side impact configurations, as well as the IIHS 50 km/h 90 degree barrier side impact, were used to evaluate and validate the developed FE model. Intrusions and velocity profiles play an important role in side impacts since occupant injury patterns are mainly influenced by direct interaction with the intruding vehicle structure, interior, and restraints. Besides engineering judgement of vehicle kinematics, intrusion behavior, and accelerometer output data, CORA was used to objectively rate the correlation of test and simulation.
No structural changes relevant for side impact performance occured between the MY 2012 and MY 2015 vehicles. NHTSA test #7517, a 62 km/h crabbed barrier side impact test into the stationary sedan vehicle, was used to validate the FE model. Weight and vehicle C.G. location were closely matched between test and simulation. Test vehicle exterior crush measurements were evaluated after the crash at the height of the sill top, the occupant hip point, mid-door, window sill, and window top. The different measurement heights are depicted with yellow markers on the tested vehicle in Fig. 7(a) on the bottom. The measured intrusion profiles from the test were extracted and overlaid with the simulation. The lines, shown in blue, represent intrusions measured in the full-scale crash test and correlate well with the intrusions seen in the simulation. Similar deformation patterns and intrusion depth in the roof, door, and sill areas were observed in test and simulation. The comparison of vehicle and barrier kinematics in test and simulation showed good correlation, with a CORA rating of 0.92 for the vehicle velocity time history data and 0.87 for the barrier pulse, as shown in Fig 7(b).
NHTSA test #8558, a 32 km/h 75 degree oblique pole side impact NCAP test with the sedan vehicle, was used to evaluate and validate the FE model. Pole location in the test was matched in the simulation. Figure 7(c) shows the post-crash deformation pattern of the tested vehicle on the bottom and the simulation after 200 milliseconds on the top. Test vehicle exterior crush measurements were taken after the crash at the height of the sill top, the occupant hip point, mid-door, window sill, and window top. Similar deformation patterns and intrusion depth were observed in test and simulation.
The developed sedan vehicle model was tested in the IIHS side crash configuration by Toyota. In this test a moving deformable barrier with a mass of 1500 kg hits the stationary vehicle at an angle of 90 degree and a velocity of 50 km/h. No technical time history data was accessible from the conducted test. The maximum B-pillar intrusion measurement was available and was closely matched, resulting in a GOOD structural rating in test and simulation. In the test, the maximum B-pillar intrusion point was 12.5 centimeters (cm) away from the driver seat center line. In the simulation, the maximum intrusion point was 12.6 cm away from the seat center line, as shown in Fig. 7(d).

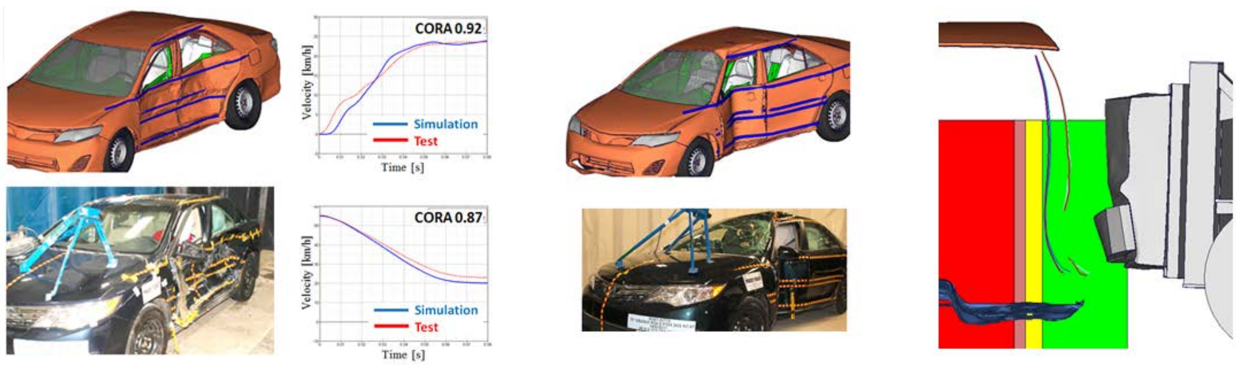
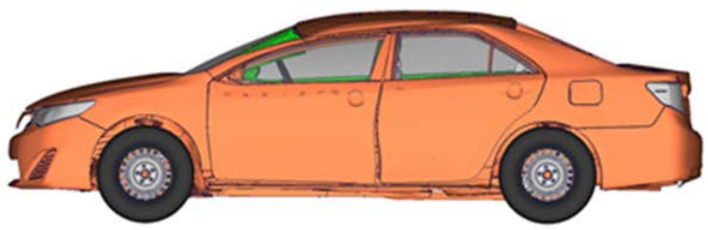


Fig.7: (a) SINCAP Deformation, (b) SINCAP Pulse, (c) Oblique Pole, (d)IIHS Side Impact

4.7 Roof Crush

IIHS test results of the sedan vehicle in a quasi-static roof crush test procedure, where a metal plate is moved at a constant speed into the vehicle roof, were evaluated. The crush distance and measured force were used to evaluate the developed FE model. Fig. 8(a) shows the deformed vehicle in the simulation and Fig. 8(b) depicts the strength-to-weight ratio versus plate displacement available from the test in red dotted line and for the simulation in blue solid line. Test and simulation results showed an IIHS GOOD rating with a strength-to-force ratio above 4.0. Test results showed a maximum value of 4.8 after 3.2 inches plate displacement, whereas the simulation showed a maximum value of 5.6 after 4.2 inches plate displacement. Windshield failure was more prominent in the test and contributed to the differences after 3.2 inches plate displacement.



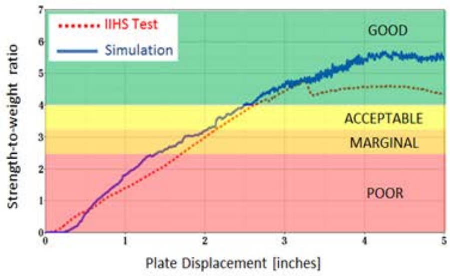
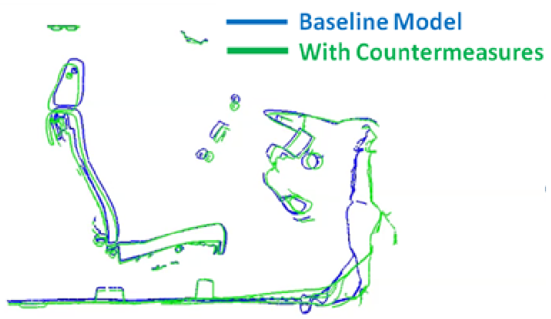


Fig.8: (a) Roof Crush Overall Deformation, (b) Strenght to Weight Ratio in Test and Simuation

5 Discussion

The developed FE model represents well the structural performance of a MY 2015 mid-size sedan in existing rating crash configurations, as well as in NHTSA's left and right oblique impacts. It enables research and vehicle safety studies in a broad range of areas. Three application examples are outlined in this chapter. In the first example, the developed FE model was used to evaluate structural countermeasures to significantly reduce occupant compartment intrusion in the oblique impact condition. The currently ongoing research is conducted in cooperation with NTHSA. In the second example, the developed FE model was used to evaluate human occupant kinematics and interactions in side impact and run-off-road impact conditions. The third example is conducted in cooperation with IIHS and evaluates the differences between barrier-to-vehicle and vehicle-to-vehicle crash performance in the IIHS side impact configuration.
The developed mid-size sedan model is currently being used to develop structural countermeasures for the oblique frontal offset impact configuration. Crash test results have shown that vehicles that receive good ratings in existing co-linear consumer information tests still may require structural modifications for good performance in NHTSA's frontal oblique offset test procedure. Incremental vehicle structural change requirements, and their associated mass and cost changes, in order to significantly reduce occupant compartment intrusion are being evaluated with this model. Fig. 9(a) shows a cross-section view of the driver side in the left oblique impact configuration. The developed baseline model is shown in blue and a model with structural countermeasures and significantly reduced occupant compartment intrusion is shown in green. Fig. 9(b) visualizes the maximum intrusion for row 1 to row 4, brake-pedal, left and right instrument panel, and A- to B-pillar closure. Baseline model results are shown in blue solid line and results of the model with improved vehicle structure are shown using green dashed line.



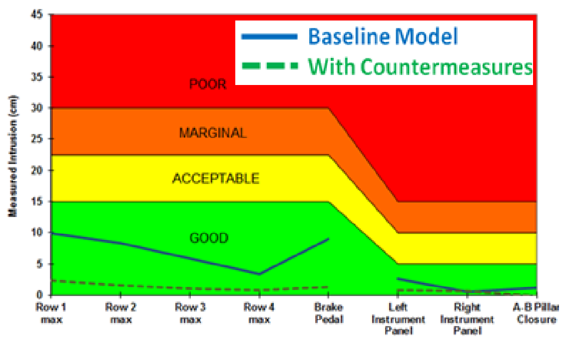


Fig.9: Application Example 1 - Reduction of Occupant Compartment Intrusion in the Oblique Impact

An integrated occupant-vehicle model, which consisted of the validated sedan, Total HUman Model for Safety (THUMS) human occupants on the driver and front passenger seat, and relevant restraints (seatbelts, side and curtain airbag), was used to evaluate occupant kinematics, interactions, and injury risks in three different impact conditions, as shown in Fig. 10. Potential injury risk due to occupant-to-occupant and occupant-to-vehicle interaction was identified for two laboratory side pole impact load cases, representing the impact with a tree for example, and an oblique frontal "New Jersey" barrier load case. The integrated occupant-vehicle simulation model enables realistic simulation of side impact and run-off-road impacts and analysis of occupant kinematics, interactions, and potential injury mechanisms. The research gives insight into occupant kinematics and interactions for near-side and far-side occupants [7].

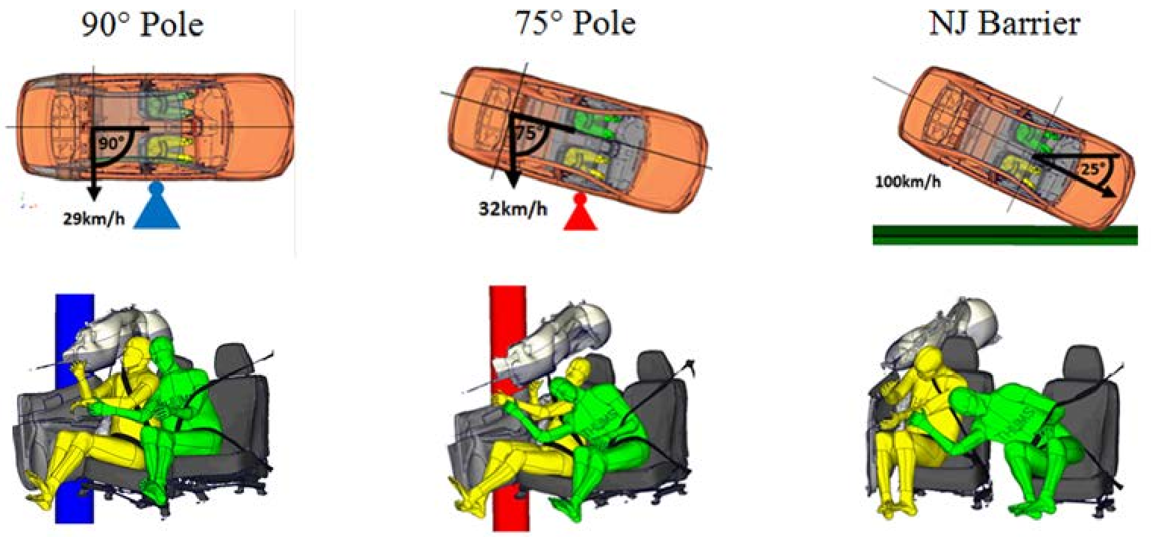


Fig.10: Application Example 2 - Injury Risk Analysis for (a) 90° Pole, (b) 75° Pole, (c) NJ Barrier

The developed model is currently being used to compare the IIHS side impact barrier-to-vehicle configuration with vehicle-to-vehicle impact conditions using a variety of bullet vehicles, as shown in Figure 11.

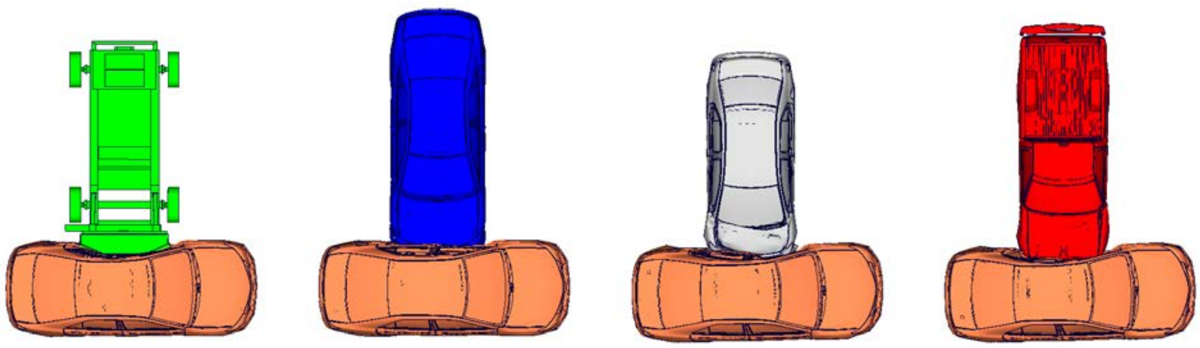


Fig.11: Application Example 3 - IIHS Side Impact in Comparison with Vehicle-to-Vehicle Impacts

Additional application examples in which the developed FE model was successfully used include occupant risk analysis in out-of-position configurations using uniform pressure and corpuscular particle (CPM) airbag modeling, child safety and child restraint system (CRS) analysis, Federal Motor Vehicle Safety Standards (FMVSS) 201 interior impact evaluations, comparison of dummy and human occupant models, light-weight vehicle studies using traditional and composite materials, and the development of an advanced passenger airbag to significantly reduce the brain injury criterion (BRIC) in NHTSA's oblique frontal impact.

6 Summary

A detailed finite element model of a MY 2015 mid-size sedan vehicle, consisting of 2.25 million nodes and elements, was created using a reverse engineering process with precise representation of vehicle geometry, material thicknesses and properties. Members of the Center for Collision Safety and Analysis at George Mason University, formerly known as the National Crash Analysis Center (NCAC), have been developing a fleet of FE vehicle models over the last 20 years. The updated mid-size sedan presented in this paper is the latest model with a high level of detail using state-of-the-art modeling techniques. Engineering judgement and the objective correlation software tool CORA were used to compare simulation and test results in various frontal, side, and roof crush impact configurations. The developed LS-DYNA vehicle model, which includes relevant structural and interior components, represents the physical vehicle well with respect to mass and inertia properties. Good correlation between test and simulation results was achieved with respect to observed load paths, deformation, and intrusion patterns. Vehicle kinematics and crash pulses, evaluated using velocity and acceleration time history data, showed a high level of correlation. Special focus was placed on occupant compartment intrusion for frontal impact scenarios. Realistic wheel kinematics in the IIHS small overlap load case was achieved through adequate failure modeling. The model is currently being used for a variety of vehicle and occupant analysis studies, including the development of structural countermeasures to significantly reduce occupant compartment intrusion for NHTSA's left and right frontal oblique offset configurations.

7 Acknowledgment

The authors would like to thank the Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation (DoT) for supporting modeling and simulation efforts presented in this paper.

8 Literature

[1] NHTSA's National Center for Statistics and Analysis, Traffic Safety Facts, "2013 Motor Vehicle Crashes: Overview", DOT HS 812 101, December 2014

[2] NCAC, "Development & Validation" of a Finite Element Model for the 2010 Toyota Yaris Passenger Sedan", Working Paper 2011-T-001, prepared by The George Washington University, Ashburn, VA, Jun 2011

[3] Marzougui, D., Brown, D., Park, H.K., Kan, C.D. et al., "Development & Validation of a Finite Element Model for a Mid-Sized Passenger Sedan", presented at the 13th International LS-DYNA Users Conference, USA, June 8-10, 2014

[4] Thunert, C., "CORA Release 3.6 User's Manual," Version 3.6, GNS mbH, Partnership for Dummy Technology and Biomechanics (PDB), 2012

[5] SAE International website, "Camry's Mid-Cycle 'Refresh' More Than Just Front and Rear Panels". http://www.articles.sae.org/13135, accessed September 7, 2016

[6] Hallquist, J.O., "LS-DYNA Keyword User Manual," Livermore Software Technology Corporation, February 2013

[7] Reichert, R., Kan, C.D., et al., "Comparison of Human Occupant Kinematics in Laboratory Impact and Run-off-road Crash Configurations", TRB, First International Roadside Safety Conference (IRSC), San Francisco, California - June, 2017