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Update to Future Midsize Lightweight Vehicle Findings in Response to Manufacturer Review and IIHS Small-Overlap Testing

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16. Abstract

In 2011, NHTSA funded a study to design a future midsize lightweight vehicle (LWV) that would use technology available in model years 2017 to 2025 and could be produced in high volume (200,000 or more units per year). The goal was to determine the maximum feasible weight reduction while maintaining the same vehicle functionalities such as performance, safety, and crash rating, as the baseline vehicle and control the price of the LWV within +10 percent of the baseline vehicle. A model year 2011 Honda Accord was selected as the baseline vehicle. After the LWV design was complete (LWV 1.0), Honda provided comments to NHTSA on the findings. In 2013, NHTSA awarded a subsequent contract to modify the initial LWV design to update the design to address Honda's comments (LWV1.1) and update the design to correlate to the IIHS Small Overlap (SOL) crash test results (LWV1.2).

In addressing Honda's comments, the weight of the body structure of the LWV 1.1 was increased by 11.5 kg and the cost was reduced by $13.08 from the original LWV 1.0 design. In addition, some of Honda's recommendations for NVH and durability were accepted. The total weight and cost of the LWV 1.1 increased by 21.75 kg and $18.13, respectively. To address the IIHS SOL test (LWV 1.2) the weight of the vehicle was increased by 6.90 kg and the cost by $26.88. The new LWV 1.2 design was modeled and assessed for the performance of crashworthiness in seven crash safety tests. The new design achieved a "good," rating in all tests that are comparable to the safety rating of the model year 2013 Accord.

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1 Executive Summary

The National Highway Traffic Safety Administration contracted a team consisting of Electricore, Inc. (prime contractor), EDAG, Inc., and the George Mason University to perform four major tasks under Contract DTNH22-13-C-00320.

First, the team created a detailed finite element model of the model year (MY) 2011 baseline Honda Accord. The model consists of over 1,000 parts and close to 2 million elements. It was created such that it can best represent a MY 2011 Accord for its design and performances in NHTSA NCAP and IIHS safety tests and can be used in multiple impact scenarios. Several full-scale crash tests were used to validate the model. These included NHTSA NCAP tests (frontal, side, and side pole) and IIHS tests (moderate frontal offset, side impact, and roof crush). Additionally, an experimental small-overlap (SOL) test that was conducted at the Insurance Institute for Highway Safety (IIHS) was used for model validations. The researchers used LS-DYNA software to simulate and correlate the crash acceleration and occupant compartment intrusion against the real-world crash test results. They evaluated the occupant compartment acceleration in terms of peak acceleration and relevant intrusion measurements for the different crash modes.

The Electricore team then re-designed the original LWV version 1.0 to version 1.1 to address the comments from Honda, including improving the vehicle's torsional stiffness and the performance on the tests listed below.

- IIHS Offset Barrier – Reduced passenger compartment intrusions
- Side Crash – Eliminated material failure by using lower strength higher ductility steel grades
- Rear Impact – Re-routed fuel filler pipe to create required clearance

These changes increased the weight of the body structure of the LWV 1.1 by 11.5 kg and reduced the cost by $13.08 from the original LWV 1.0 design. In addition, some of Honda's recommendations for NVH and drivability were accepted. The total weight and cost of the LWV 1.1 increased by 21.75 kg and $18.13, respectively.

The next main task discussed in this report is to upgrade the LWV 1.1 design to address the IIHS SOL test (LWV 1.2). To do this, the following design changes were made to LWV 1.1 which increased the weight of the vehicle by 6.90 kg and the cost by $26.88.

1. Triangular shaped blocks were added to the front ends of the rails. At the initial contact with barrier this block acts as a deflector and also directs loads into the front rail.
2. The design of the suspension and drive components including the wheel were not changed but these components were represented in the CAE model with non-linear material properties with appropriate material failure criteria.
3. The A-pillar section and the A-pillar to front body hinge pillar joints were reinforced. The rocker section was also reinforced with an additional reinforcement panel. These changes stabilize passenger compartment, reducing the intrusions significantly.

The new LWV 1.2 design was modeled and assessed for the performance of crashworthiness in seven crash safety tests. The new design achieved a "Good" rating in all tests which are comparable to the safety rating of the MY2013 Accord.

Finally, the team used the updated LWV 1.2 design created in the previous task to estimate the added weight for other vehicle sub-classes due to the addition of IIHS SOL test. The average light duty vehicle mass reduction decreased from -18.2 percent in the LWV 1.0 design to -16.3 percent.

2 Introduction

In 2011 NHTSA awarded contract DTNH22-11-C-00193 to Electricore, Inc. to design a future midsize lightweight vehicle (LWV).[1] This vehicle was supposed to use manufacturing processes available in MYs 2017 to 2025 and capable of high-volume production (200,000 units or more per year). The goal was to determine the maximum feasible weight reduction while maintaining the same vehicle functionalities, such as performance, safety, and crash rating, as the baseline vehicle. Furthermore, the retail price of the LWV must be within ±10 percent of the original vehicle. Based upon its production volume, market share, and 5-Star crash rating, the model year 2011 Honda Accord was selected as the baseline vehicle. After the LWV design was complete, Honda provided comments.[2]

In 2013 NHTSA awarded a subsequent contract, DTNH22-13-C-00320, to Electricore, Inc. (prime contractor), EDAG, and George Mason University to modify the original LWV design to address two major issues:

1. Update the original LWV design created under contract DTNH22-11-C-00193 to address Honda's comments; and
2. Update the LWV model created in the first task to correlate to the IIHS SOL test results.

This report summarizes the work performed under contract DTNH22-13-C-00320 which includes the following Tasks listed below.

2.1 Lightweight Vehicle Version Number

The Electricore project team uses the following numbering system for each version of the LWV design.

- **MY 2011 Accord -** Baseline **MY** 2011 Honda Accord
- **LWV 1.0 -** Original LWV design created under NHTSA contract DTNH22-11-C-00193
- **LWV 1.1 -** Modified LWV design to address comments from Honda
- **LWV 1.2 -** Modified LWV design to address SOL test

2.2 C.5.1 Create and Update a MY 2011 Baseline Honda Accord Model

The main objectives of Task C.5.1 were to focus on updating the MY 2011 baseline Honda Accord, including the following tasks:

2.2.1 C.5.1.1 Create a MY 2011 Baseline Honda Accord Model

Under the previous DOT contract, an FE analysis model for a baseline MY 2009 Honda Accord was obtained and updated to compare vehicle crash performance and to build cost model. This

[1] National Highway Traffic Safety Administration. (n.d.). Research Supporting 2017-2025 CAFE Final Rule [Web page]. Washington, DC: Author. Available at www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/Research+Supporting+2017-2025+CAFE+Final+Rule

[2] NHTSA. (2012, July 26). Peer review for "Mass reduction for light-duty vehicles for model year 2017-2025. Washington, DC: Author. Available at www.regulations.gov/contentStreamer?documentId=NHTSA-2010-0131-0329&attachmentNumber=1&disposition=attachment&contentType=pdf

baseline Accord model has proprietary information and can only be accessed by one of the subcontractors.

In this current program (DTNH22-13-C-00320), the team from Electricore (prime), George Mason University and EDAG created a publically releasable FE model for NHTSA to use in future research and to make the research transparent to the public. The model created under this task was based on the tear-down under the original lightweight vehicle (LWV) program. The team paid attention to the material properties and structure/joint modeling to ensure that the new model would achieve comparable teardown, crashworthiness modeling, and cost analysis results to previous one.

2.2.2 C.5.1.2 Update the Baseline Honda Accord Model

IIHS recently updated the SOL test and evaluation protocol. Because this is a relatively new test protocol, the team first worked to understand the baseline vehicle structural performance, failure mode and load case for this test. The team also investigated the recently tested MY 2009 Honda Accord and understand the vehicle structural performance, failure mode and load case for this vehicle.

In this task, the team updated the baseline Honda Accord model to correlate to the SOL test results. By carrying out this step, the team gained a good understanding of the load case under this test condition and be able to use the knowledge gained in this step to design and update the original LWV model. The updated baseline Honda Accord crash model is compatible with other available FE analysis models from George Washington University.

2.3 C.5.6 Update Lightweighted Vehicle Model in Response to Honda’s Comments

In response to Honda’s comments on the original LWV 1.0 design created under the previous contract, the Electricore team updated the design to LWV 1.1 to address these concerns. The team examined the effects of the changes proposed by Honda including, the amount of mass and cost change, as well as, how the new model performs in the various crash tests.

2.4 C.5.2 Weight and Cost Change for Lightweighted Vehicle

For this task, the results from the previous tasks to re-optimize the design of the LWV 1.2 for the IIHS SOL test. The primary goal of this task was to ensure the LWV 1.2 will achieve a “Good” rating in the IIHS SOL test for structural performance. The LWV 1.2 shall also achieve an equivalent or better performance in other safety tests compared to LWV 1.0. These other tests include:

- Frontal NCAP Test,
- Lateral NCAP Moving Deformable Barrier Test,
- Lateral NCAP Pole Test,
- IIHS Roof Crush Test,
- IIHS Lateral Moving Deformable Barrier Test,
- IIHS Moderate Frontal Offset Test, and
- IIHS Small-overlap Front Test.

Once LWV 1.2 design is finalized and achieves satisfactory ratings in the safety simulations, Electricore estimated the mass and cost changes for the updated design for the countermeasures for the SOL test. The results of this task includes a description of the LWV 1.2 design, results of the crashworthiness simulations, amount of additional weight added to address the IIHS SOL and the additional cost associated with the changes.

2.5 C.5.3 Vehicle Weight Change for Other Vehicle Sub-Classes

For the current LWV program, the Electricore team used the knowledge gained in the original LWV program along with the information gained in developing LWV 1.1 and 1.2 to address Honda’s comments and the IIHS SOL test, respectively, to estimate the added weight for other vehicle sub-classes due to the addition of SOL test.

3 2011 Baseline Honda Accord

3.1 Baseline Honda Accord Crash Testing

3.1.1 Baseline Vehicle

The chosen baseline vehicle for this project is the 2011 Honda Accord, a 4-door midsize sedan. The midsize sedans are the single largest sales volume segment in the United States in MY 2010, with nearly 20 percent of the market. In this segment the Honda Accord was second overall in vehicle sales for 2010 and is regarded as a benchmark vehicle with good performance in all areas, roominess, comfort, fuel economy, safety, luxury features, with a competitive price. Figure 1 below lists the top five vehicle models in terms of U.S. vehicle sales in the midsize car category for MY 2010.

Ranking	Vehicle	Vehicles
1	Toyota Camry	327,804
2	**Honda Accord**	**311,381**
3	Toyota Corolla	266,082
4	Honda Civic	260,218
5	Nissan Altima	229,263

Figure 1: U.S. Vehicle Sales in the midsized car category for MY2010[3]

3.1.1.1 New Car Assessment Program Ratings

The 2011 Accord achieved 5-Star ratings in NHTSA's New Car Assessment Program (NCAP) for overall rating, frontal crash (driver and passenger), side crash (rear seat), and rollover resistance.

Year/Make/Model	Overall	Frontal Crash	Side Crash	Rollover
2011 Honda Accord Sedan FWD	★★★★★	★★★★★	★★★★★	★★★★★

Figure 2: Honda Accord NHTSA 5-Star5-Star Rating[4]

The newly introduced "Overall Vehicle Score" is part of the Federal Government's more stringent NCAP test that is first being applied to 2011 models. As a convenience to new car shoppers, the Overall Vehicle Score represents the combined results of the overall ratings from the frontal crash tests, the side crash tests and the rollover-resistance into a single summary score between one and five stars.[5] The 2011 Honda Accord currently is one of only six vehicles to achieve the NHTSA 5-Star Overall Vehicle Score and is the first to achieve 5 stars in each of the three ratings categories 5-Star frontal and side crash rating combined results of side barrier and side pole and 5-Star rollover rating. See Figure 3 for detailed rating information.

[3] Crain, T. Top 10 Best-Selling Cars In America - 2010 Year End. Available at www.goodcarbadcar.net/2011/01/top-10-best-selling-cars-in-america_04.html
[4] NHTSA. (continuously updated). Shop Smart for a Safer Car, SUV, Mini-Van or Light Truck. (NHTSA 5-Star Safety Ratings website). Washington, DC: Author. Available at www.safercar.gov/Safety+Ratings
[5] NHTSA, www.safercar.gov/Safety+Ratings

2011 Honda Accord Sedan NCAP Ratings	
Category	Star Rating
Overall Vehicle Rating	**5**
Overall Frontal Crash Safety Rating	**5**
Driver (Male)	5
Passenger (Female)	5
Overall Side Crash Safety Rating	**5**
Overall Side-Barrier Crash Safety Rating	5
Front Seat Position (Male)	4
Front Seat Position (Female)	5
Side-Pole Crash Safety Rating	5
Front Seat Side Impact Rating	4
Rear Seat Side Impact Rating	5
Rollover Rating	**5**

Figure 3: Honda Accord NCAP 5-Star5-Star Rating[6]

3.1.1.2 Insurance Institute for Highway Safety Ratings

IIHS tests evaluate two aspects of safety: **crashworthiness** — how well a vehicle protects its occupants in a crash — and **crash avoidance and mitigation** — technology that can prevent a crash or lessen its severity.

To determine crashworthiness, IIHS rates vehicles good, acceptable, marginal or poor, based on performance in five tests: moderate overlap front, small-overlap front, side, roof strength and head restraints. In the area of crash avoidance and mitigation, IIHS assigns vehicles with available front crash prevention systems ratings of basic, advanced or superior, based on the type of system and performance in track tests.[7]

The small-overlap frontal test was not rated in 2011. However, in 2010 the IIHS performed a small-overlap frontal test on a 2009 Honda Accord.

Test	Rating
Moderate Overlap Front	Good
Side	Good
Roof Strength	Average
Head Restraints and Seats	Good

Figure 4: IIHS Rating for 2011 Honda Accord 4-door

3.1.2 Frontal NCAP Test

The NCAP frontal test is a full-width impact to the front of the vehicle. Crash test dummies are seated in the location of the driver and the right-front passenger. The vehicle crashes head-on

[6] www.safercar.gov/Safety+Ratings
[7] Insurance Institute for Highway Safety (continuously updated). IIHS safety awards(website safety ratings home page). Arlington, VA: Author. Available at http://www.iihs.org/iihs/ratings

into a rigid concrete barrier at a nominal 56 km/h (35 mph). During the collision, instruments in the dummies measure the severity of the impact to the body of the occupant. As compared to the IIHS frontal test, the NCAP frontal test has shorter pulse time width and lower occupant compartment intrusion. Figure 5 shows the test set-up and the post-crash vehicle for the NCAP frontal test.

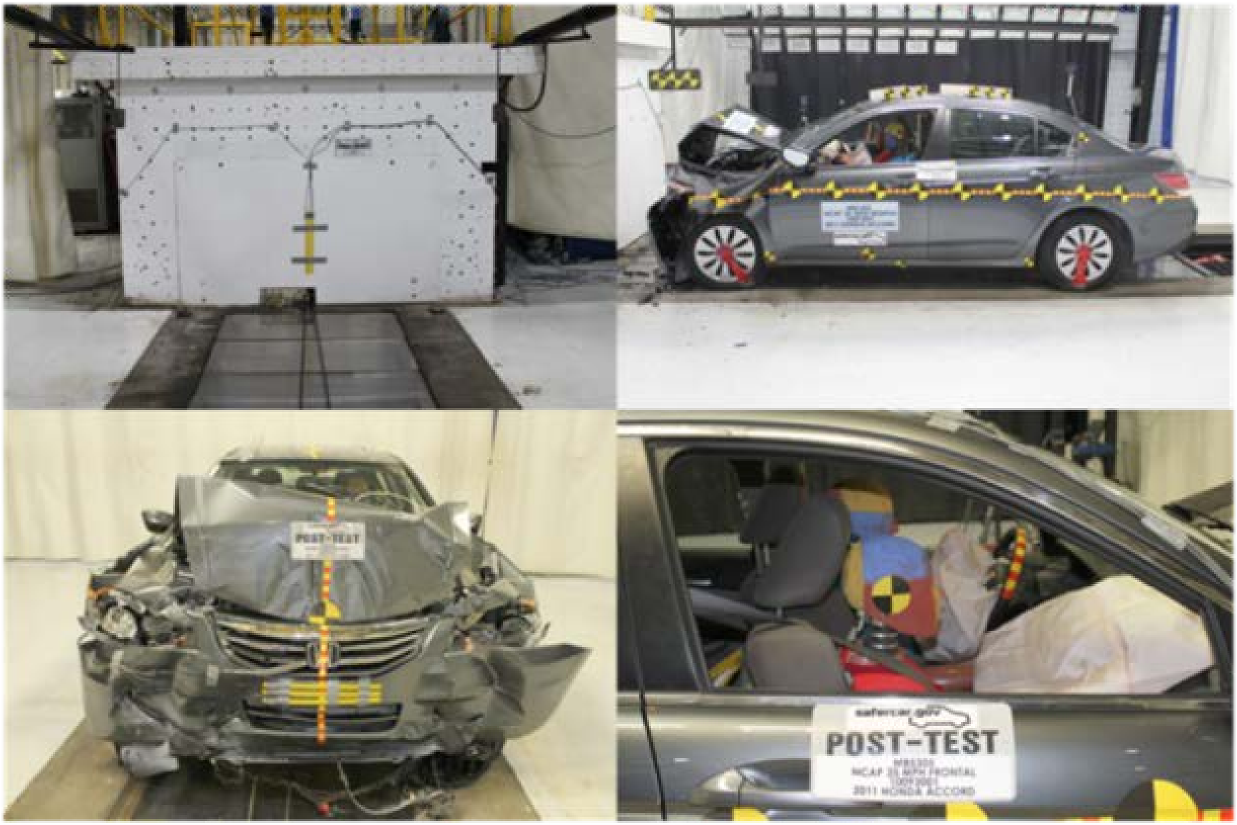

Figure 5: Test set-up and the post-crash vehicle of the NCAP frontal crash[8]

The 2011 Honda Accord sedan underwent a frontal barrier impact test on September 30, 2010.[9] The crash was conducted by MGA Research at an initial speed of 56.5 km/h (35.1 mph). A 50th percentile male ATD was positioned in the left front seat and a 5th percentile female ATD was positioned in the right front seat. In subsequent analysis, the Honda Accord was awarded a 5-Star Safety Rating (*i.e.*, the highest safety rating) for the frontal NCAP test.[10]

An in-depth investigation of the restraint systems and injury criterion readings of the ATD is beyond the scope and funds of this project. Instead, the project concentrates on the dynamic and static response of the structure of the basic Honda Accord. Based on the measured acceleration from the accelerometer mounted at the left rear cross member in the longitudinal direction, the crash pulse of the 2011 Honda Accord is shown in Figure 6. The sudden drop in acceleration

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[8] MGA Research. (2010, October 28). *New Car Assessment Program (NCAP) Frontal Barrier Impact Test 2011 Honda Accord LX Sedan* (Report No. NCAP-MGA-2011-027). Burlington, WI: Author.

[9] MGA Research, NCAP-MGA-2011-027.

[10] NHTSA 5-Star Safety Ratings website

(around 50 ms) appears to be associated with the engine dropping down during the crash, which could actually be observed during the test in an undercarriage camera.[11]

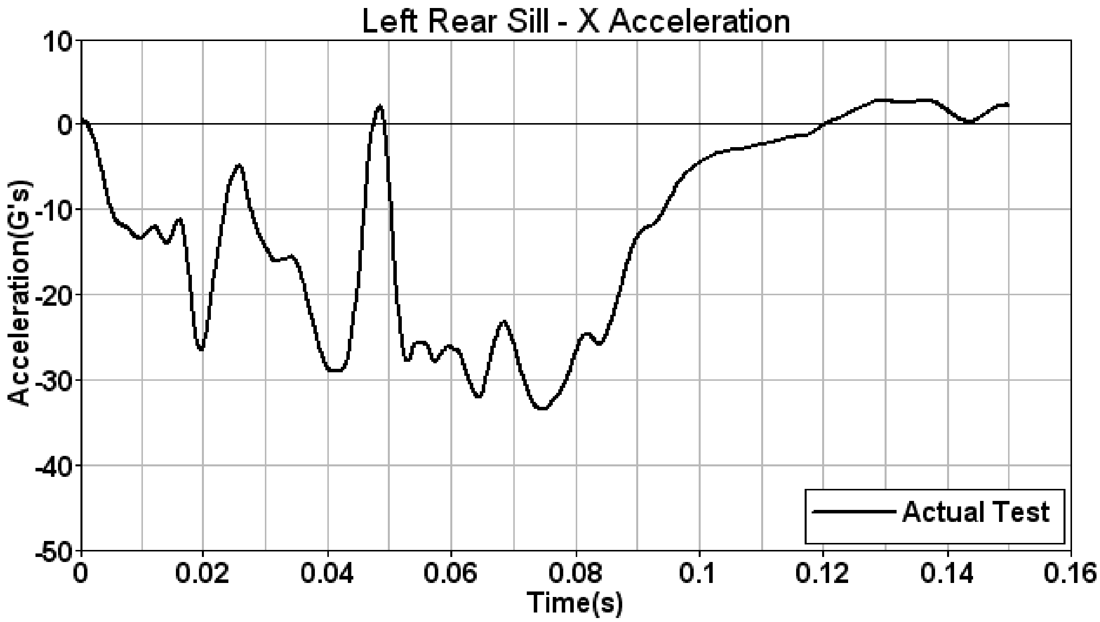

Figure 6: Crash pulse from frontal NCAP test of Honda Accord 2011

Intrusion measurements taken post-crash showed low values. Eight measurement points on the floor pan is illustrated in Figure 7. For all eight sites, the differences in pre-crash location and post-crash location were zero, i.e., there was no deformation of the floor pan. Vehicle intrusion measurements are depicted in Figure 8. The post-crash driver-compartment intrusion measurements are listed in Figure 9. For purposes of safety, these intrusions are minuscule.

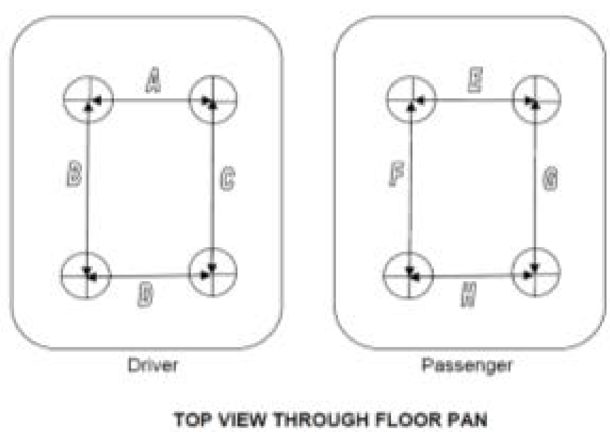

Figure 7: Scheme used to measure under-body floorboard deformation[12]

[11] MGA Research, NCAP-MGA-2011-027.
[12] MGA Research, NCAP-MGA-2011-027.

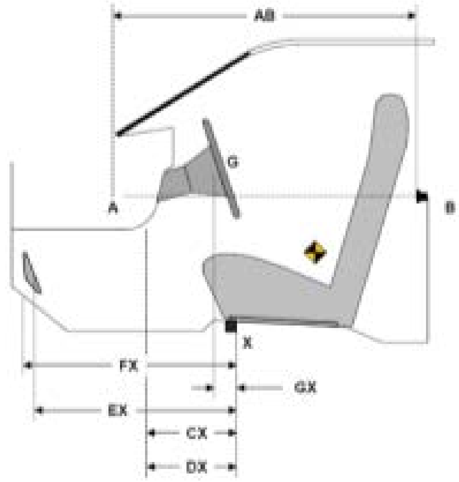

Figure 8: Scheme for driver compartment intrusion measurement[13]

Symbol	Description	Units	Difference in pre-test and post-test measurement
CX	Left knee bolster	mm	-1
DX	Right knee bolster	mm	-1
EX	Brake pedal	mm	-3
FX	Foot rest	mm	8
GX	Center of steering column wheel hub	mm	5

Figure 9: Driver compartment intrusion in x direction[14]

3.1.3 Lateral NCAP Moving Deformable Barrier Test

For the NCAP side impact test with a moving deformable barrier, a 1,368 kg (3,015 pounds) trolley impacts the side of the struck vehicle. This trolley (with wheels crabbed at 27 degrees to its forward line of motion) strikes a stationary vehicle (positioned at an angle of 63 degrees to the line of forward motion). See Figure 10 for trolley to vehicle orientation.[15] The trolley, with a deformable barrier on the front, moves at 62 km/h (38.6 mph). Crash test dummies are positioned on the struck side at the location of the front seat and the rear seat occupant. During the collision, instruments in the dummies measure the severity of the impact to the body of the occupant. Figure 11 shows the test set-up and the post-crash vehicle.

[13] MGA Research, NCAP-MGA-2011-027.
[14] MGA Research, NCAP-MGA-2011-027.
[15] MGA Research (2010, October 28). *Moving Deformable Barrier Side Impact Test 2011 Honda Accord LX Sedan* (Report No. SINCAP-MGA-2011-028).

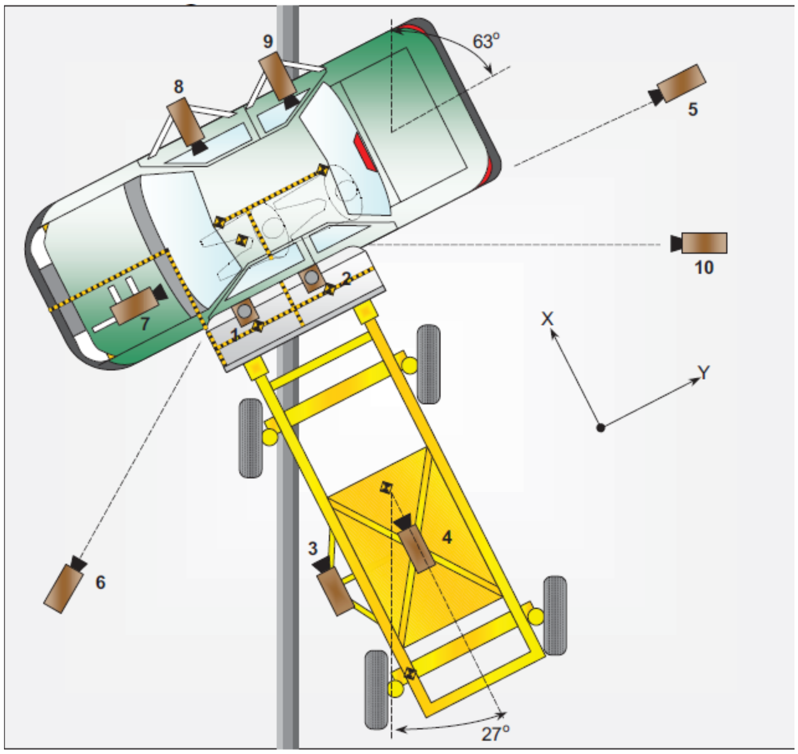

Figure 10: Orientation of trolley to struck vehicle in NCAP side test with moving deformable barrier[16]

Figure 11: Test set-up and the post-crash vehicle of the NCAP side impact test with moving deformable barrier[17]

[16] MGA Research, SINCAP-MGA-2011-028.
[17] MGA Research, .SINCAP-MGA-2011-028.

The 2011 Honda Accord sedan was struck by a moving deformable barrier on October 1, 2010.[18] (This analysis is for the Accord sedan and should not be extended to the crash performance of the Accord coupe.) The crash was conducted by MGA Research for Honda with the barrier moving at an initial speed of 61.8 km/h (38.4 mph). A 50th percentile male ATD was positioned in the left front seat and a 5th percentile female ATD was positioned in the left rear seat. In subsequent analysis, the Honda Accord was awarded a 5-Star-Star safety rating for the side NCAP test.[19]

Vehicle crush measurements were recorded following the diagram in Figure 12. Following the diagram, the crush sustained by the baseline Honda Accord is given in Figure 13. The levels are (1) sill top, (2) occupant H-point, (3) mid-door, (4) window sill, and (5) window top.

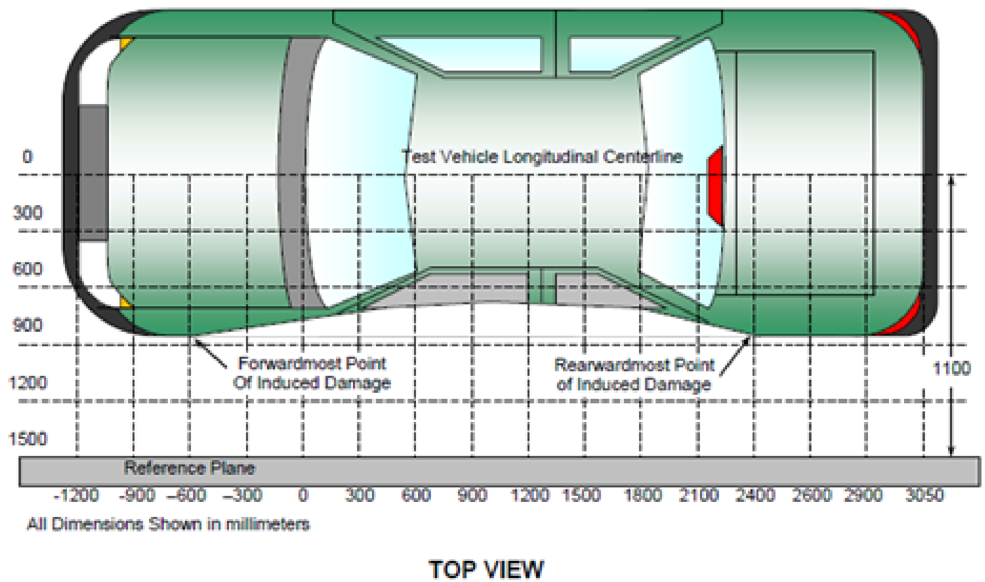

Figure 12: Diagram used for recording crush in side impact with moving barrier[20]

[18] MGA Research, .SINCAP-MGA-2011-028.
[19] NHTSA 5-Star Safety Rating. website.
[20] MGA Research, .SINCAP-MGA-2011-028.

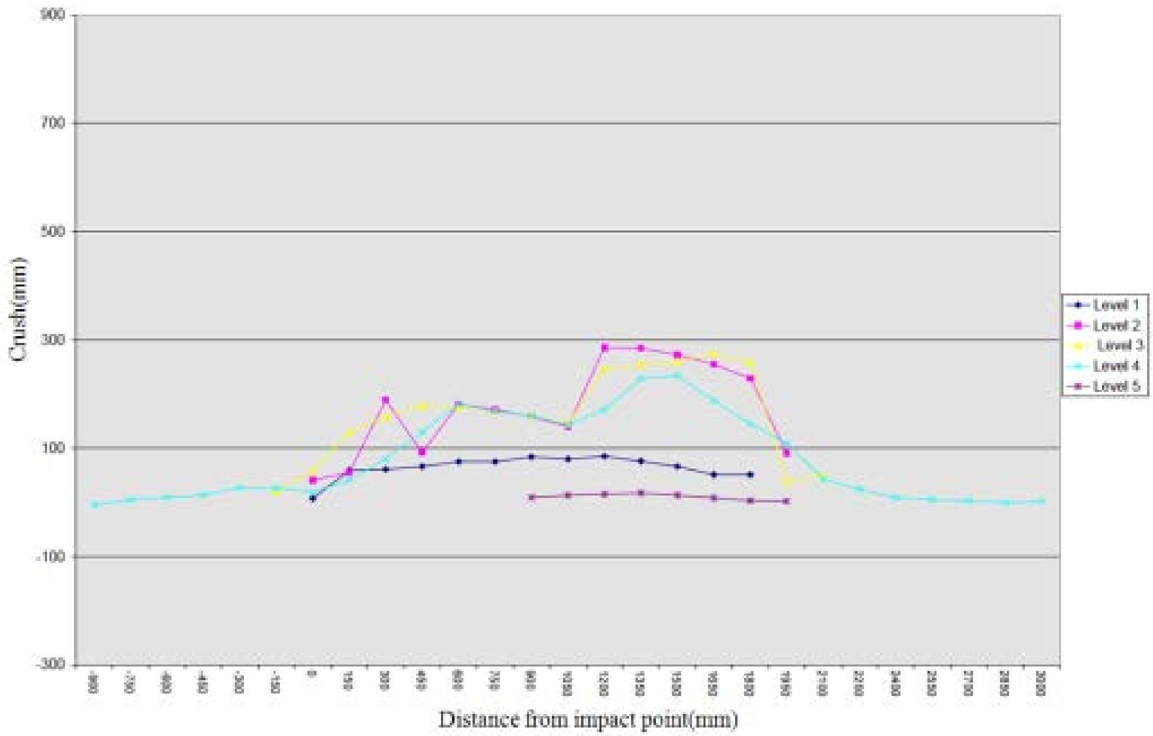

Figure 13: Measurements of crush of Honda Accord 2011 in NCAP moving barrier side test[21]

3.1.4 Lateral NCAP Pole Test

A vehicle in the NCAP side pole test is sent into a fixed, rigid pole 254 mm (10 inches) in diameter, at a speed of 32 km/h (20 mph). Figure 14 shows the pole. A 5th percentile female dummy is positioned in the front seating position. The complete test set-up is illustrated in Figure 15.[22]

[21] MGA Research, .SINCAP-MGA-2011-028

[22] MGA Research, *Side Impact Pole Test 2011 Honda Accord LX Sedan*, Report No. SPNCAP-MGA-2011-026.

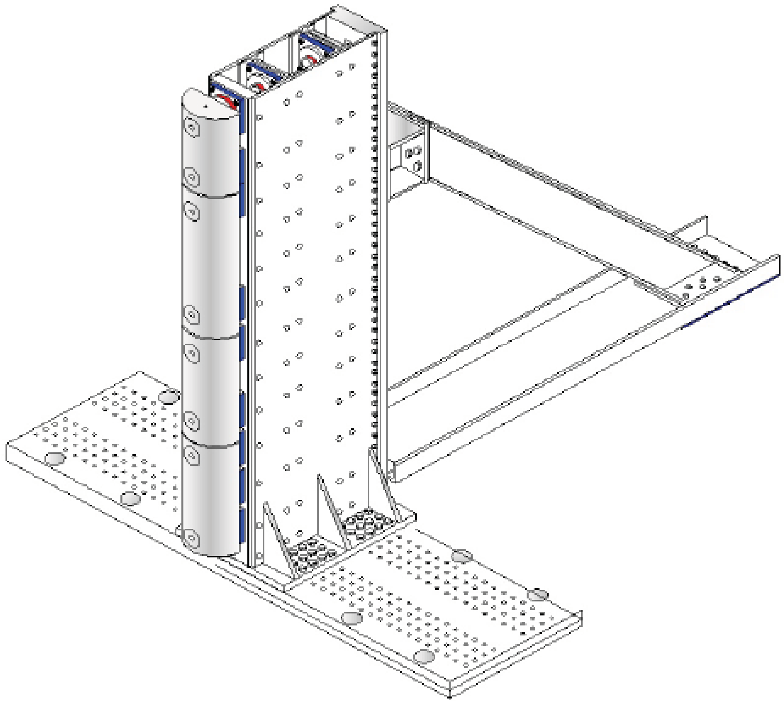

Figure 14: Fixed, rigid pole 254 mm (10 inches) in diameter, used for NCAP side pole test[23]

The 2011 Honda Accord sedan was struck in the side by a rigid pole on September 29, 2010.[24] The crash was conducted by MGA Research for Honda with the Honda Accord moving at an initial speed of 32.2 km/h (20.0 mph) into the pole. A 5th percentile female ATD was positioned in the left front seat. In subsequent analysis, the Honda Accord was awarded a 5-Star Safety Rating for this side NCAP test into a rigid pole.[25]

[23] National Highway Traffic Safety Administration. (2007, August). Laboratory test procedure for FMVSS 214 rigid pole side impact test. (Report No. TP-214P-00). Washington, DC: Author. Available at www.carsandracingstuff.com/library/nhtsa/TP-214P-00Draft4FR.pdf

[24] MGA Research, SPNCAP-MGA-2011-026.

[25] NHTSA, 5-Star Safety Rating.

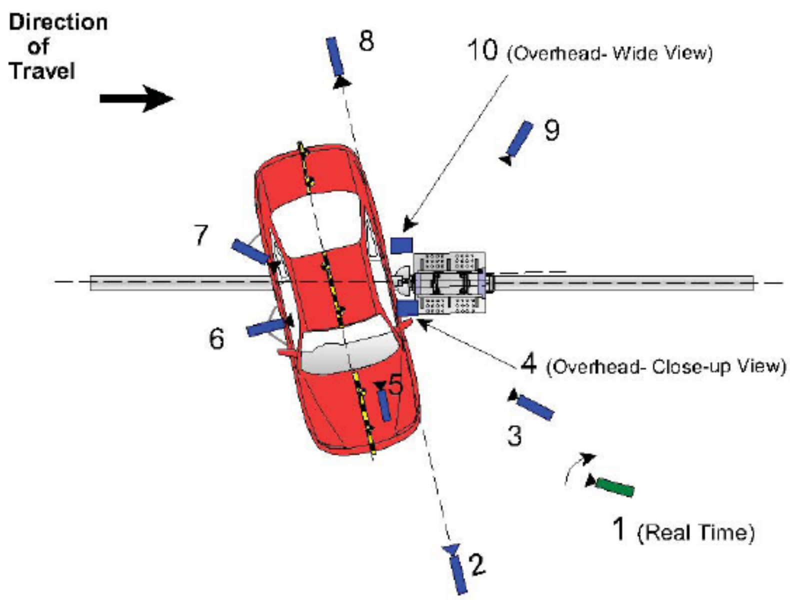

Figure 15: Complete test set-up for NCAP side pole test[26]

For the pole test, Figure 16 shows the velocity versus time of the middle B-pillar on the struck side. Vehicle crush measurements were recorded following the diagram in Figure 17. Following the diagram, the crush sustained by the baseline Honda Accord is given in Figure 18. Just as in the moving barrier NCAP test, the levels are (1) sill top, (2) occupant H-point, (3) mid-door, (4) window sill, and (5) window top.

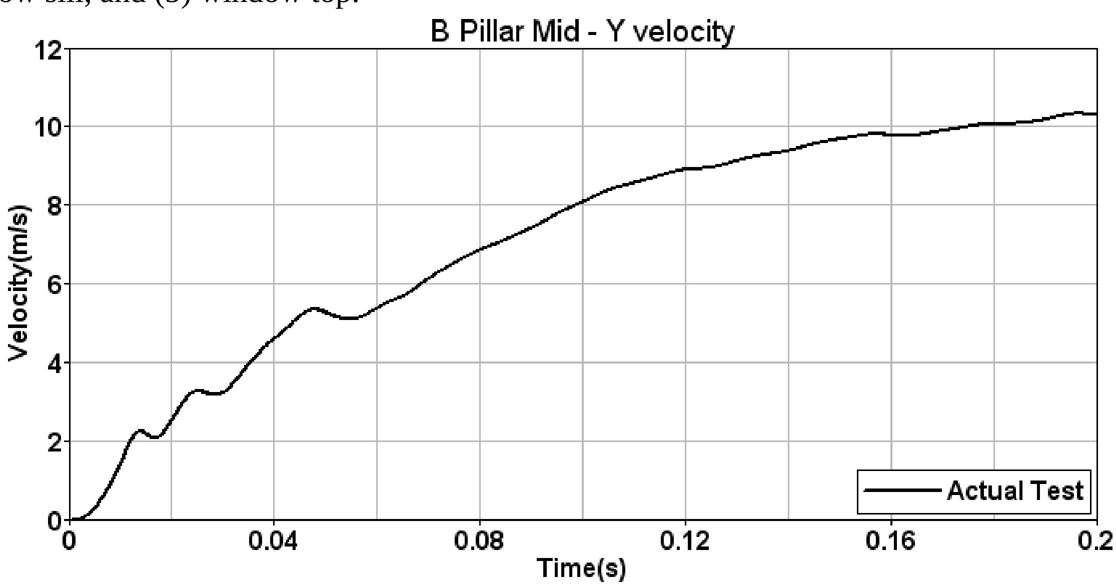

Figure 16: Velocity versus time for the left middle B-pillar for the side NCAP test with the rigid pole[27]

[26] MGA Research, SPNCAP-MGA-2011-026.
[27] MGA Research, SPNCAP-MGA-2011-026.

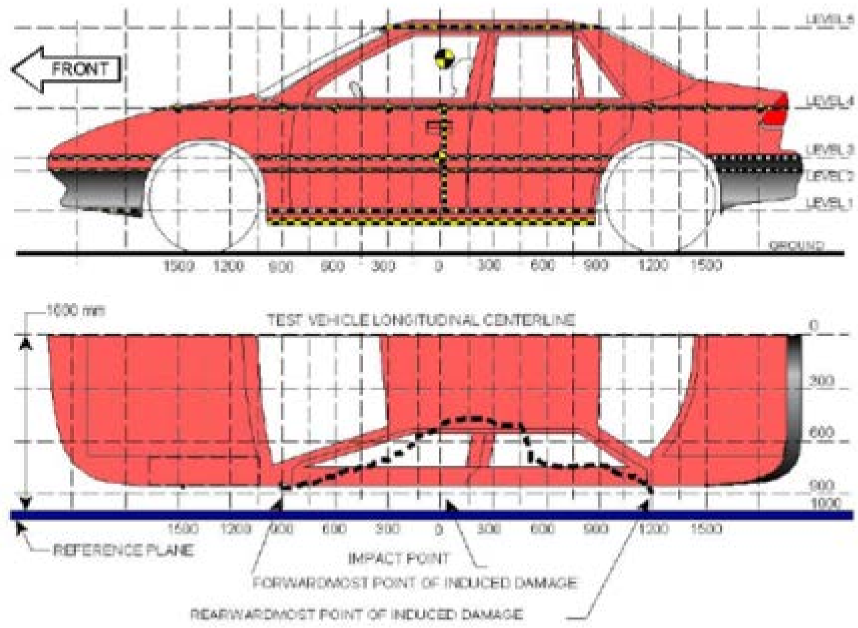

Figure 17: Diagram used for recording crush in side impact with rigid pole[28]

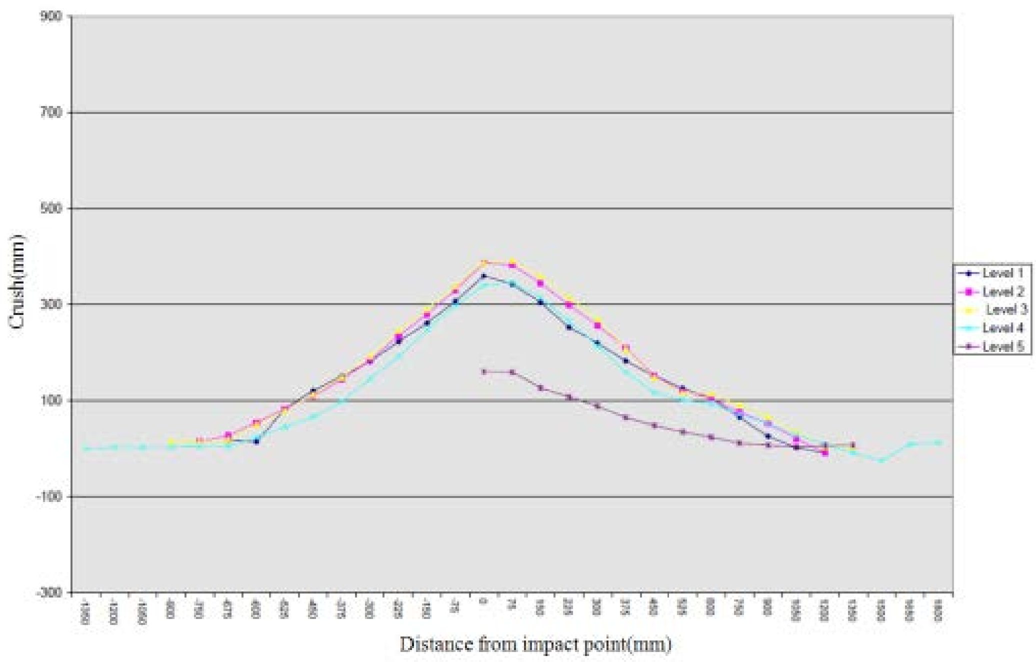

Figure 18: Measurements of crush of Honda Accord 2011 in NCAP rigid pole side test[29]

[28] MGA Research, SPNCAP-MGA-2011-026.
[29] MGA Research, SPNCAP-MGA-2011-026.

3.1.5 IIHS Roof Crush Test

The IIHS roof crush test (shown in Figure 19) is used to evaluate the crashworthiness of the vehicle structure in rollover crashes. This test is conducted by crushing the roof structure of the vehicle against a rigid plate (platen) until 5 inches of crush is achieved. Then, the maximum force sustained by the roof before 5 inches of crush is compared to the vehicle's curb weight to find the strength-to-weight ratio. The vehicle is held rigidly with clamps about the rocker section. Both NHTSA and IIHS do a roof crush test. FMVSS No. 216 specifies that roof structure should sustain a load three times the vehicle curb weight. The IIHS roof crush rating stipulates that the roof structure must sustain loading of four times the curb weight for a *good* ratings. The NHTSA roof crush test is FMVSS No. 216, and is a regulation that does not rate the tested vehicle for safety. The IIHS roof crush test is a consumer information test, and rates the tested vehicle for safety. NHTSA tests both sides of the roof of the vehicle. IIHS tests just one side of the roof but requires a higher resistance to crush, which is a ratio of resistance force/curb weight must be 4 or greater for a "Good" rating as illustrated in Figure 20. As shown in the IIHS data comparison in Figure 22 the test strength-to-weight ratio for the Honda Accord vehicle averages to a value of 3.25.[30] NHTSA tested a 2008 Honda Accord. The IIHS tested a 2009 Honda Accord. For this study, the researchers analyzed the IIHS roof crush test because (1) the vehicle used in IIHS test was a more recent MY sedan and (2) the IIHS test requires a higher SWR than the NHTSA test, with which the vehicle can be compared.

Figure 19: Test set-up for IIHS roof crush test[31]

[30] IIHS. (2011). *Procedures for rating roof crush*. Arlington, VA: Author.
[31] IIHS, 2011.

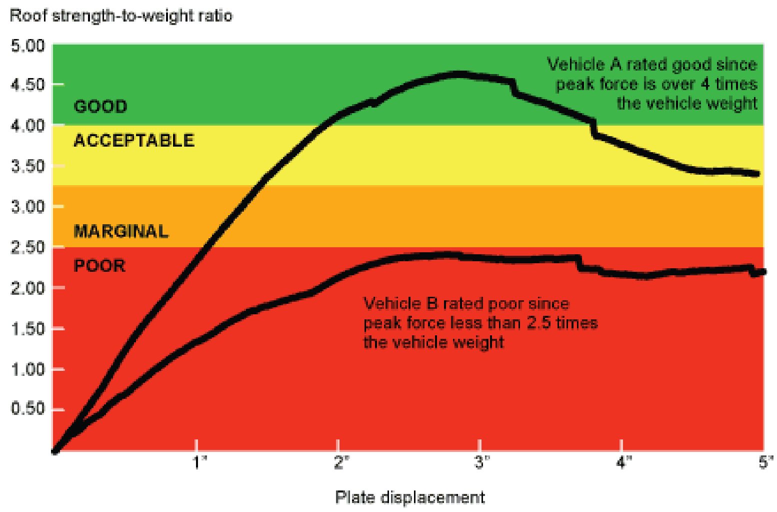

Figure 20: IIHS Sample data comparing test results for vehicles rated "Good" and "Poor"[32]

For the IIHS roof crush test on October 21, 2009, IIHS researchers struck a 2009 Honda Accord with a curb weight of 3,273 lbs. quasi-statically with a platen. The peak force measured within 5 in. of crush was 12,656-lb (IIHS, 2009). The strength-to-weight ratio was 3.87. The plot of force versus crush of the platen is presented in Figure 21. The Honda Accord was rated "acceptable" in the roof crush test. The IIHS rating diagram is shown in Figure 22.[33]

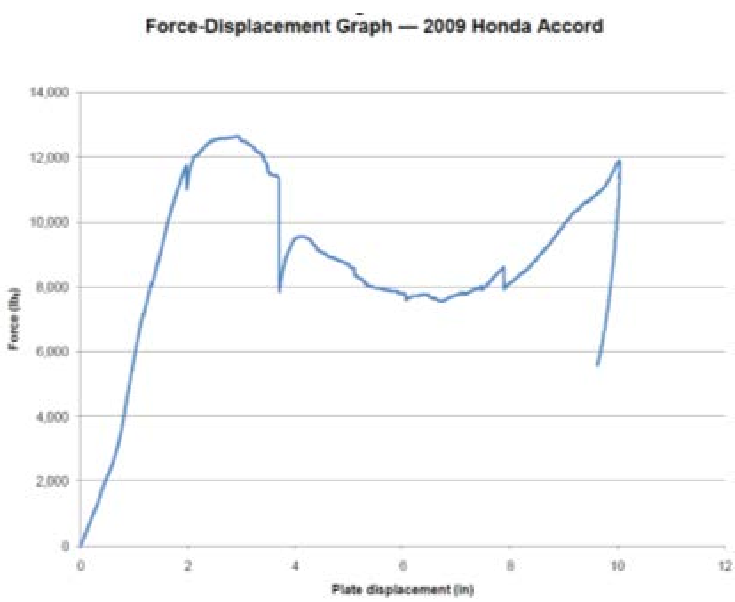

Figure 21: Force versus crush of the platen for Honda Accord 2009[34]

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[32] IIHS, 011.
[33] IIHS (n.d.). *Roof Strength Report 2009 Honda Accord* (Report No. SWR0936). Arlington, VA: Author. [Date of crash test October 21, 2009.]
[34] IIHS, SWR0936.

Figure 22: Honda Accord was rated "acceptable" in the IIHS roof crush test[35]

3.1.6 IIHS Lateral Moving Deformable Barrier Test

The IIHS side impact crash tests consist of a stationary test vehicle struck on the driver's side by a trolley fitted with an IIHS deformable barrier element. (IIHS, 2008) The 1,500 kg moving deformable barrier has an impact velocity of 50 km/h (31.1 mi/h) and strikes the vehicle on the driver's side at a 90-degree angle. The longitudinal impact point of the barrier on the side of the test vehicle is dependent on the vehicle's wheelbase. The impact reference distance is defined as the distance rearward from the test vehicle's front axle to the closest edge of the deformable barrier when it first contacts the vehicle (Figure 23). The MDB is found in Figure 24.[36]

[35] IIHS, SWR0936.
[36] IIHS. (2008a, May). *Side impact crashworthiness evaluation: Crash test protocol (Version V)* Arlington, VA: Author.

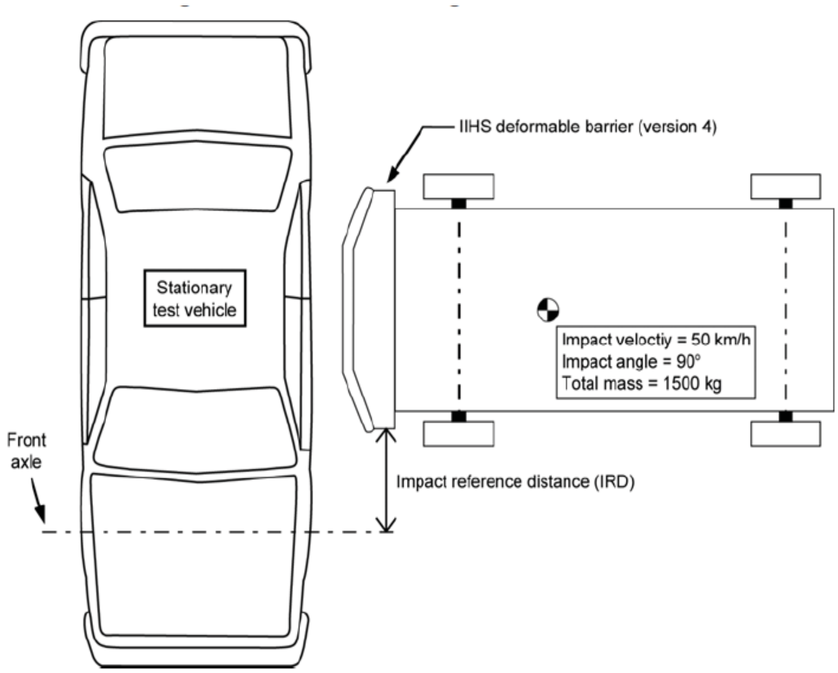

Figure 23: IIHS moving deformable barrier aligned with vehicle to be tested[37]

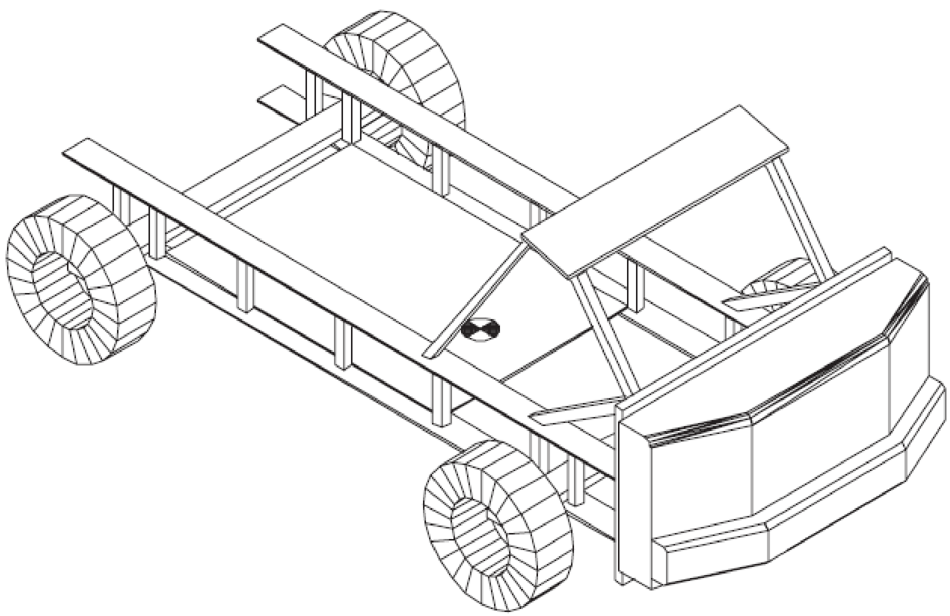

Figure 24: IIHS deformable barrier used in side impact test[38]

A lateral IIHS moving deformable barrier test was performed into the side of a 2008 Honda Accord by IIHS on September 27, 2007.[39] The B-pillar intrusion profile is documented in Figure

[37] IIHS, 2008a.
[38] IIHS, 2008a.

25. A crush profile at the mid-door level is documented in Figure 26**.** The Honda Accord was rated "Good" in the IIHS side impact test safety rating. The IIHS side impact rating diagram is shown in Figure 27 for the Honda Accord 2008.

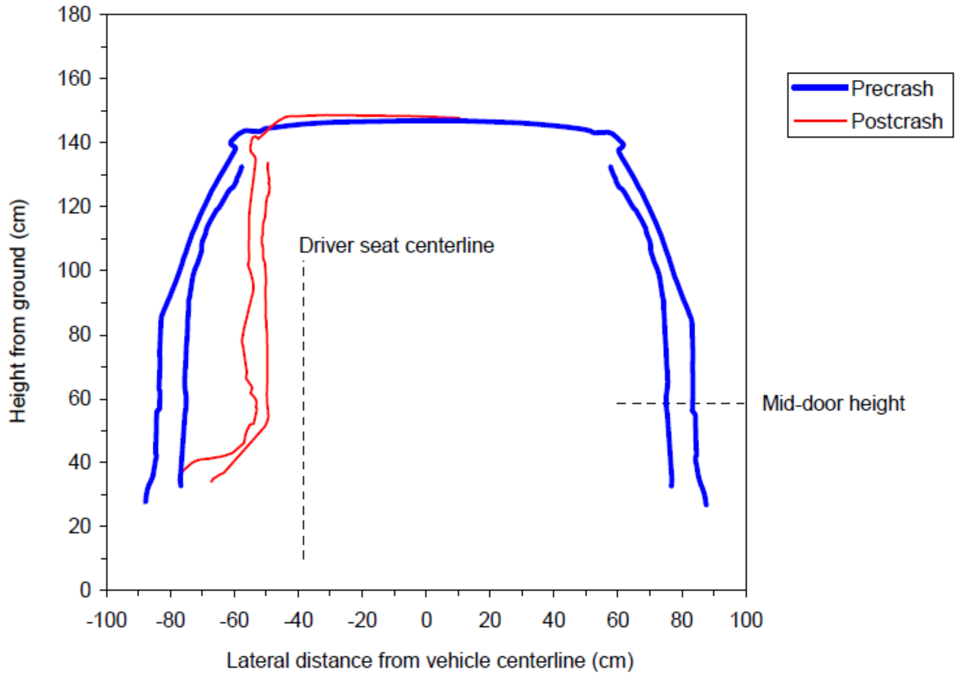

Figure 25: B-pillar exterior and interior profile for 2008 Honda Accord[40]

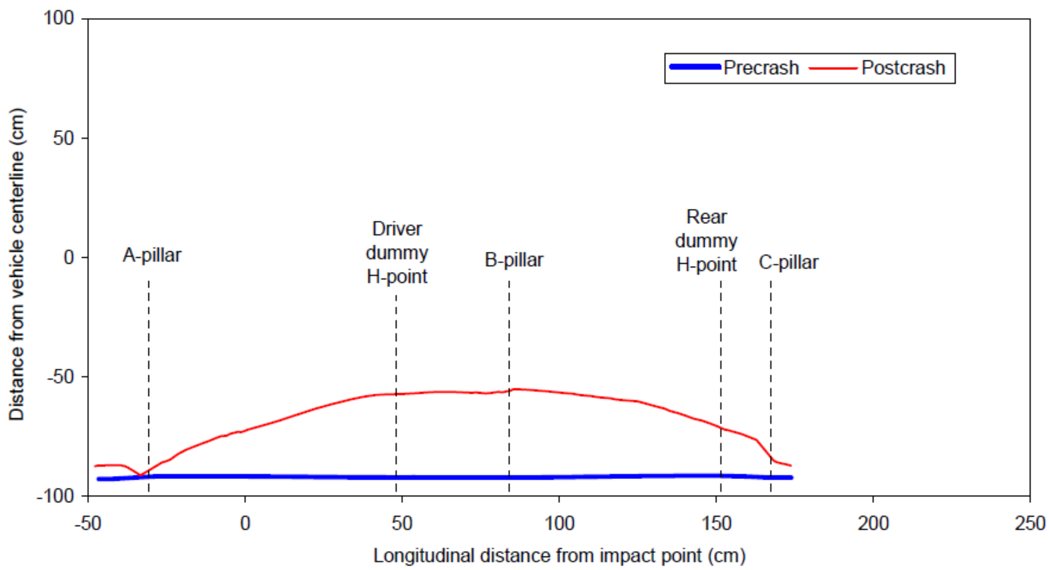

Figure 26: Crush profile at mid-door level for 2008 Honda Accord[41]

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[39] IIHS. (n.d.) *Side impact crashworthiness evaluation crash test report 2008 Honda Accord*.(Report No. CES0735). Arlington, VA: Author. [Crash test date September 27, 2007.]
[40] IIHS, CES0735.

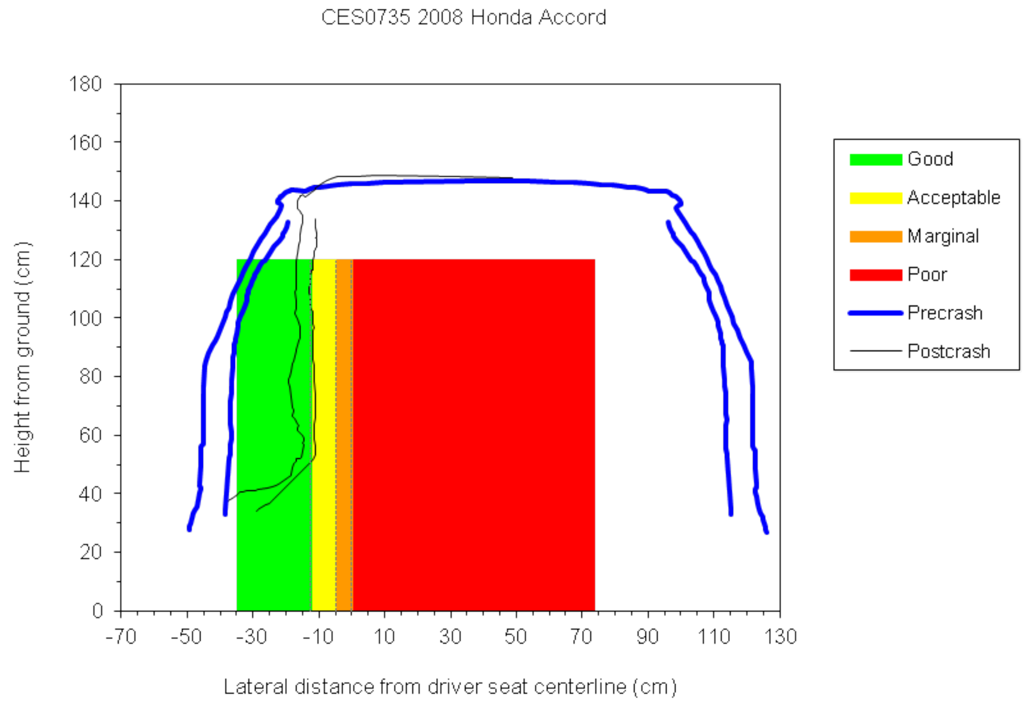

Figure 27: Honda Accord was rated "Good" in the IIHS side impact test[42]

3.1.7 IIHS Moderate Frontal Offset Test

The IIHS moderate frontal 40 percent offset test is conducted at 64.4 ± 1 km/h (40 ± 0.6 mi/h) and 40 ± 1 percent overlap. (IIHS, 2008) A 50th percentile male dummy with instrumented lower legs is positioned in the driver seat. IIHS measures a total of 14 locations on the driver side interior and exterior of the vehicle, and their longitudinal, lateral, and vertical coordinates are recorded. These same marks are measured after the crash using the same reference coordinate system.[43] The test set-up is shown in Figure 28. The barrier into which the vehicle is crashed is shown in Figure 29.

[41] IIHS, CES0735.
[42] IIHS, CES0735.
[43] IIHS (2008b, May). *Frontal offset crashworthiness evaluation: Offset barrier crash test protocol (Version XIII).* Arlington, VA: Author..

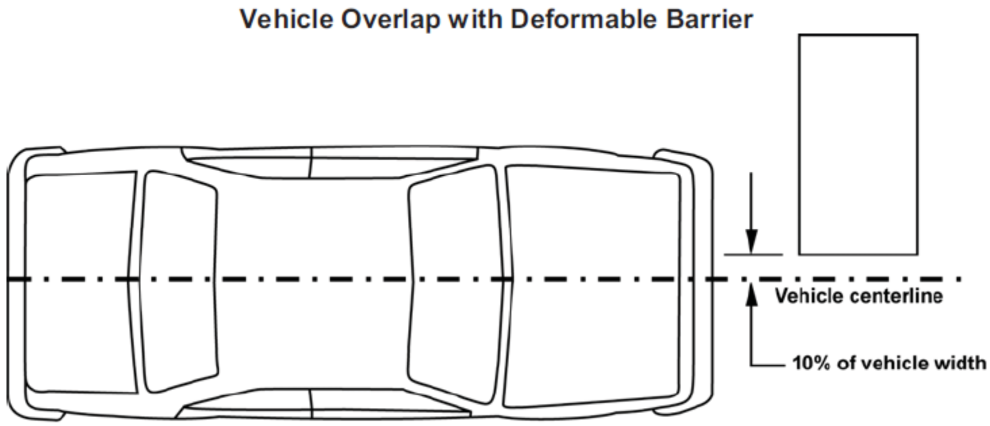

Figure 28: Set-Up of the IIHS frontal 40 percent offset barrier test[44]

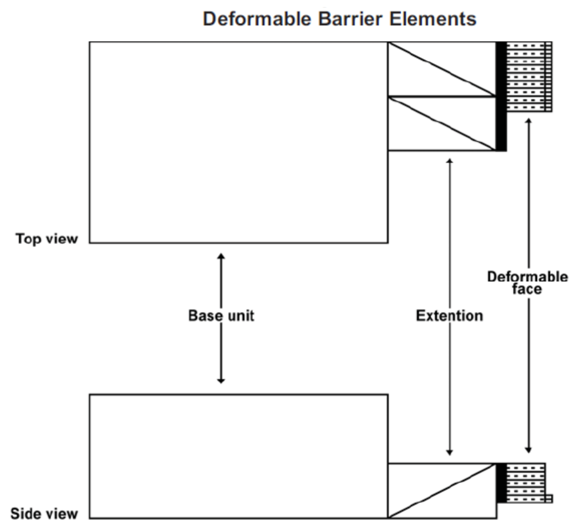

Figure 29: Deformable barrier used in IIHS frontal 40 percent offset barrier test[45]

The most recent Honda Accord tested by IIHS was the year 2003 model. Since then, Accord has undergone major structure redesign. Therefore for crash comparison, the 2003 Honda Accord cannot be matched up to the 2011 Honda Accord because the safety design is different.

For purposes of this project, given that the prior version of the Honda Accord tested by IIHS had characteristics that made it not particularly comparable, the Electricore Team searched the IIHS database and identified that IIHS tested the 2010 Honda Crosstour. The front structure of the 2010 Honda Crosstour and the 2011 Honda Accord are the same design and build. Therefore, the crash behavior of the 2010 Honda Crosstour and the 2011 Honda Accord should be similar in a frontal crash. The Honda Crosstour was tested on April 14, 2010.[46] The crash pulse of the 2010 Honda Crosstour is shown in Figure 30. As shown in Figure 31 for occupant compartment

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[44] IIHS, 2008b.
[45] IIHS, 2008b.
[46] IIHS (n.d.). *Frontal Crashworthiness Evaluation Crash Test Report 2010 Honda Crosstour*(Report No. CEF1003). Arlington, VA: Author. [Crash test date April 14, 2010.]

intrusion, the Honda Crosstour was rated “Good” in the IIHS moderate frontal offset test safety rating.

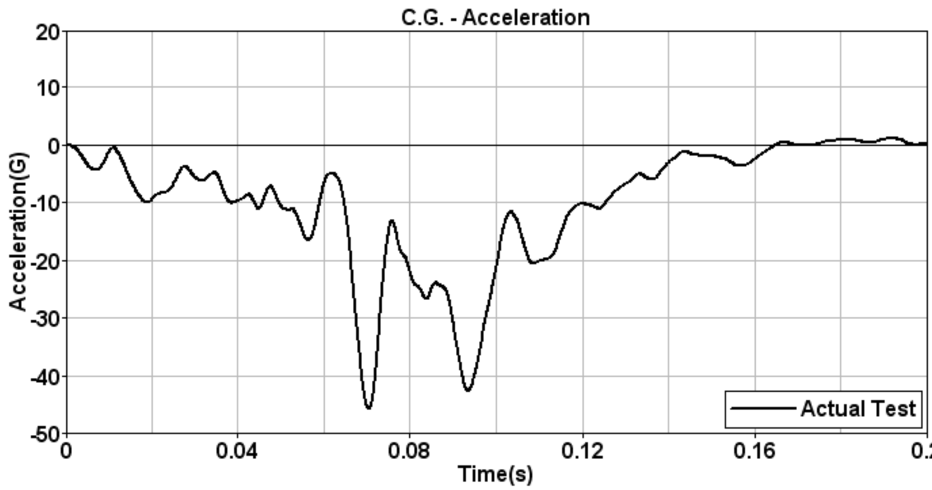


Figure 30: 2010 Honda Crosstour crash pulse in IIHS frontal offset test[47]

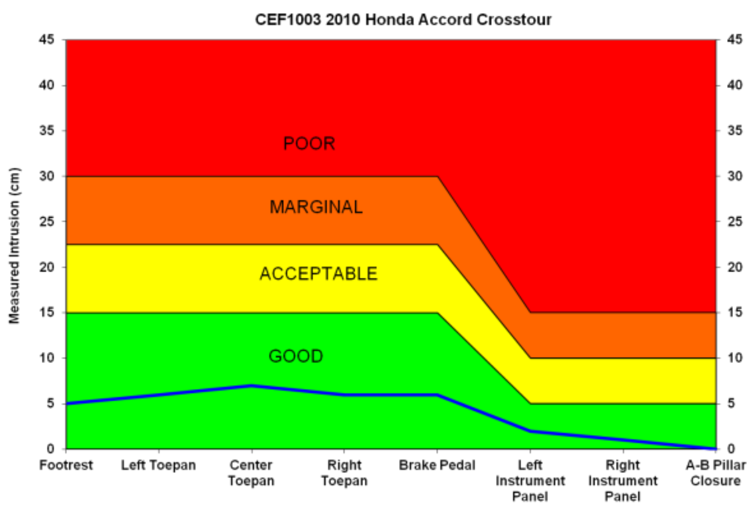


Figure 31: Honda Crosstour was rated “Good” in the IIHS frontal offset test[48]

3.1.8 IIHS Small-overlap Frontal Barrier Test

The IIHS SOL test is designed to reproduce what happens when the front corner of a vehicle hits another vehicle or an object like a tree or utility pole. Because occupants move both forward and toward the side of the vehicle, the small-overlap test is also a trial for some safety belt and airbag designs.

[47] IIHS, CEF1003.
[48] IIHS, CEF1003.

In this test, a vehicle travels at 40 mph toward a 5-foot-tall rigid barrier. A Hybrid III dummy representing an average-size man is positioned in the driver seat. Twenty-five percent of the total width of the vehicle strikes the barrier on the driver side. Figure 32 illustrates the test set-up from a top view and the barrier. The orientation of the tested vehicle to the barrier is provided in Figure 33.

Figure 32: Configuration of the IIHS SOL test

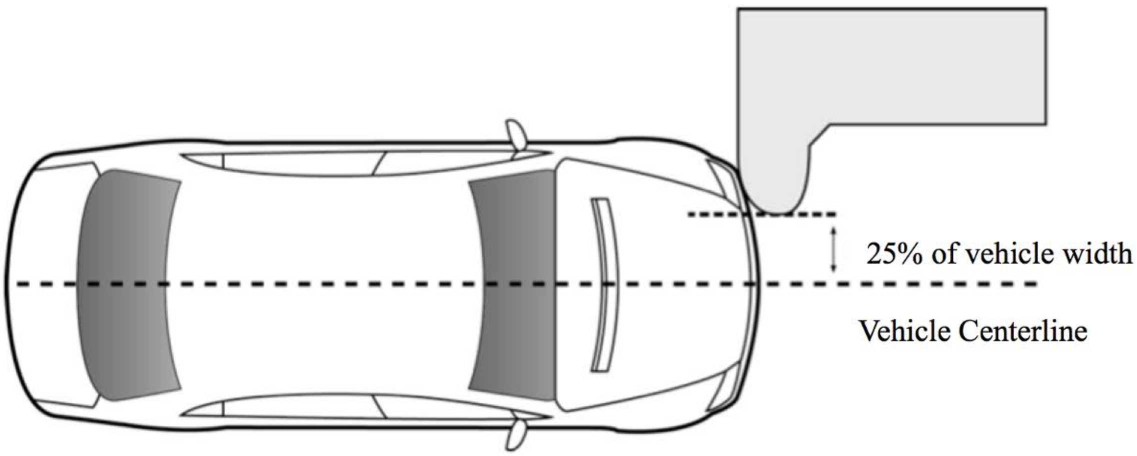


Figure 33: Vehicle overlay on flat 150 small-overlap barrier

To measure intrusion after the IIHS SOL test, the locations shown in Figure 34 are examined for the amount of residual movement about the occupant compartment of the driver.

Vehicle performance in the IIHS SOL test is determined by three categories: restraint and dummy kinematics, dummy injury measures, and vehicle structural performance. The structural rating is based on (1) the movement of seven points on the vehicle interior plus (2) the movement of three points along the door frame as shown in Figure 34.

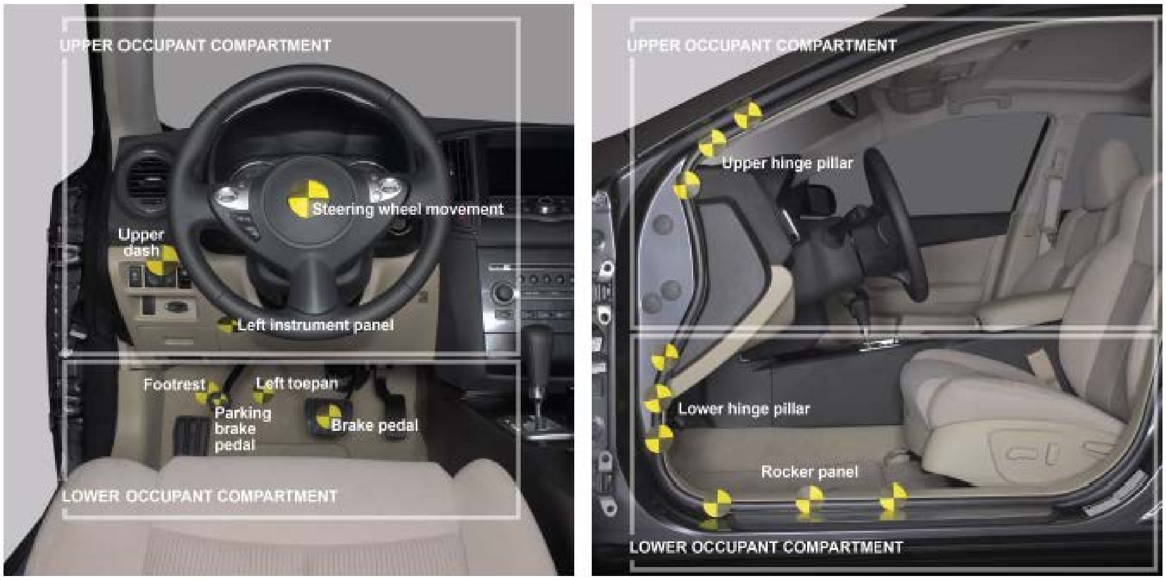


Figure 34: Locations used for measuring vehicle intrusion

A 2009 Honda Accord was crash tested on September 2, 2010, into a fixed rigid barrier at 64.3 km/h (40.0 mph), with a 21 percent overlap on the driver side.[49] A Hybrid III 50th percentile male dummy was positioned in the driver seat with the lap/shoulder belt fastened. The fixed rigid barrier was designed and built by IIHS and was a flat steel face plate 152 cm high, 157 cm wide, and curved at inboard edge with a 5 cm radius. The barrier is shown in Figure 35.

Figure 36, Figure 37, and Figure 38 show the occupant compartment intrusion, deformation near driver door region, and longitudinal accelerations at vehicle center of gravity.

Figure 35: Two views of the fixed rigid barrier used in IIHS test CF 10021

[49] IIHS. (2010, October). Crash Test Report: 2009 Honda Accord (CF10021). Arlington, VA: Author.

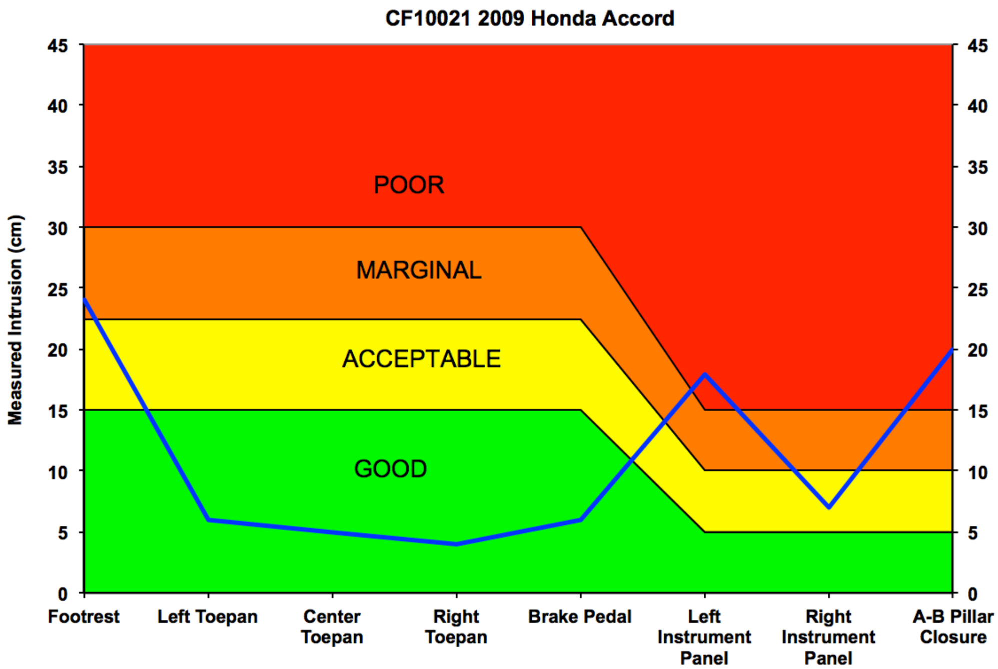


Figure 36: Occupant compartment intrusion for 2009 Honda Accord SOL test

Figure 37: Dummy and vehicle interior, post-crash, 2009 Honda Accord SOL test

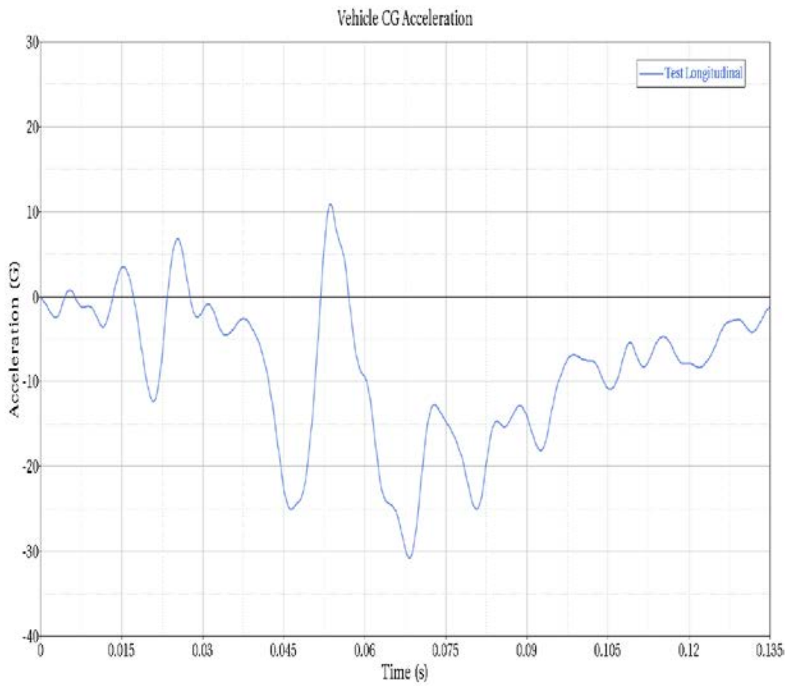


Figure 38: Acceleration at the vehicle center of gravity, 2009 Honda Accord SOL test

3.1.9 Summary of Baseline 2011 Honda Accord Crash Tests

Figure 39 summarizes the dynamic and static (crush and intrusion) crash test results of the baseline 2011 Honda Accord.

Test	Dynamic	Static
NCAP frontal	Acceleration and the pulse time width in Figure 6	Driver compartment intrusion in Figure 8
NCAP side with moving deformable barrier	Meaningful comparison not possible as instruments on B-pillar were damaged or rotated excessively in actual laboratory test	Vehicle crush in Figure 13
NCAP pole	Velocity versus time for B-pillar in Figure 16	Vehicle crush in Figure 18
IIHS roof crush	Strictly a static test and not a dynamic examination	Roof crush in Figure 22
IIHS side with moving deformable barrier	No dynamic instrumentation on A- or B-pillar	Occupant compartment intrusion in Figure 27
IIHS 40% offset frontal	Acceleration and the pulse time width in Figure 30	Occupant compartment intrusion in Figure 31
IIHS SOL test	Acceleration and the pulse time width in Figure 38	Occupant compartment intrusion in Figure 36

Figure 39: Structural Response of the Honda Accord 2011

3.2 Validation of Baseline Honda Accord CAE Model

3.2.1 Crash Modeling Software

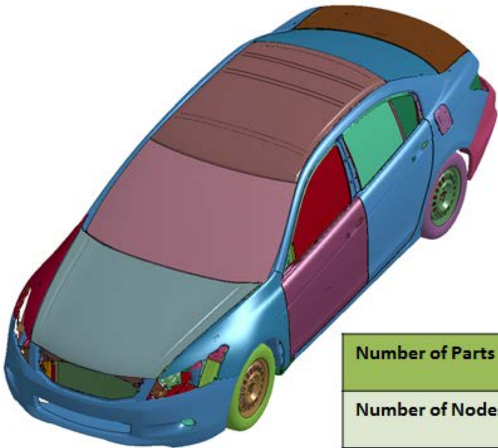
An FE model of the 2011 Honda Accord was developed for crashworthiness analysis by Electricore, Inc. (prime contractor), EDAG, and GMU. The work was done under contract with NHTSA. This vehicle was selected for modeling because it established the safety level used as a criterion in DOT Contract DTNH22-11-C-00193, titled *Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025*.[50] This vehicle model was developed to be used in frontal, side, and roof crush tests, as well as in occupant risk analyses.

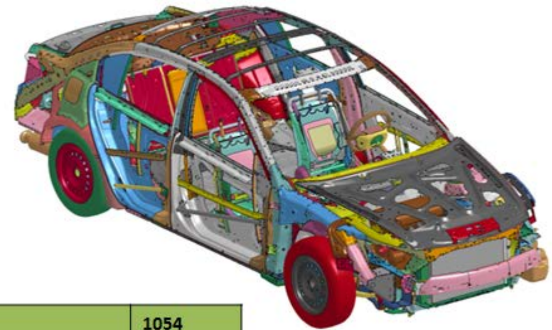
FEA methods and models have been used extensively by automotive industry researchers and engineers to both simulate and analyze automotive crashes and also design and develop safety systems for passenger vehicles in high-speed impacts. LS-DYNA finite element software was used and is the industry standard software for crash simulation and modeling. LS-DYNA software is based on computer programs originally developed by Lawrence Livermore National Laboratory for impact and defense applications. This software is based on non-linear explicit FE formulations, suited for large deformation applications, which is typical of the crashed structures seen in the automobile industry (single vehicles, vehicle-to-vehicle, vehicle-to-barrier, etc.). Other desirable features of LS-DYNA include an extensive library of material models, handling of large material deformation and material fracture, computational efficiency in explicit formulation, and domain decomposition by parallel processing for large simulations.

This model was based on an actual, physical 2011 Honda Accord. The vehicle 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 was 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 40.

Simulations of different impacts were performed using the developed model and the results were compared to full-scale crash test data. These impacts included: a Frontal NCAP Test, a Lateral NCAP Moving Deformable Barrier Test, a Lateral NCAP Pole Test, a Roof Crush Test, an IIHS Lateral Moving Deformable Barrier Test, an IIHS Moderate Frontal Offset Test, and an IIHS Small-Overlap Front Test. Summary of these comparisons are presented in the next sections.

[50] Singh, H., Kabeer, B., Jansohn, W., Davies, J., Kan, C-D., Kramer, D. Marzougui, D., Morgan, R. M., & Quong, S. (2012, August). *Mass reduction for light-duty vehicles for model years 2017-2025*. (Report No. DOT HS 811 666). Washington, DC: National Highway Traffic Safety Administration.





Number of Parts	1054
Number of Nodes	1,969,784
Number of Shell Elements	1,815,276
Number of Beam Elements	659
Number of Solid Elements	98,716
Total Number of Elements	1,914,659

Figure 40: Model characteristics of 2011 Honda Accord finite element model

3.2.2 Frontal NCAP Test

The frontal impact test of the NCAP, undertaken by the NHTSA, is a full frontal barrier test at a vehicle speed of 56 km/h (35 mph). This test is used to determine the crashworthiness of the vehicle to protect occupants in frontal impact crash cases.

Using LS-DYNA software, the Honda Accord FE model was simulated in an NCAP frontal crash, which is a full frontal impact into a rigid barrier at 56 km/h (35 mph). A full frontal NCAP laboratory test (Test #7078) was available for validation of the Honda Accord FE model. A comparison of the vehicle parameters used for the simulation and the NCAP laboratory test are shown in Figure 41. The pre-test physical vehicle and model are shown in Figure 42. Figure 43 shows pictures of the laboratory-tested vehicle and the model during the crash.

	FE Model	**Test 7078**
Weight (kg)	1668.2	1661.0
Engine Type	2.4L I4	2.4L I4
Tire Size	P215/60R16	P215/60R16
Attitude (mm)	F – 693	F – 684
	R – 687	R – 681
Wheelbase (mm)	2799	2794
CG (mm) Rear of front wheel C/L	1164	1175
Body type	4-Door Sedan	4-Door Sedan

Figure 41: Comparison of vehicle characteristics for FE model and the NCAP laboratory test vehicle

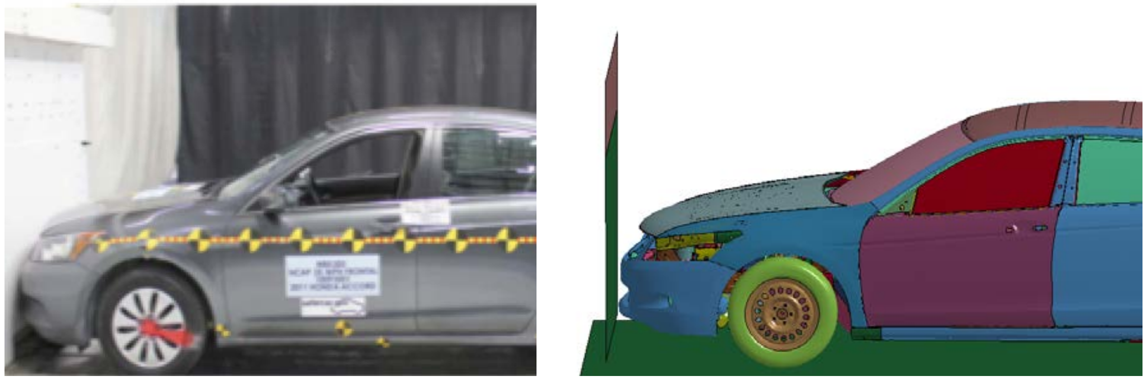


Figure 42: Pre-test laboratory vehicle and model of the 2011 Honda Accord for NCAP frontal barrier test

Figure 44 compares the left and right rear seat accelerations of the laboratory test and simulation. The comparisons show good corrections between the simulation and test pulses at both accelerometer locations with correlation (CORA) numbers of 0.715 and 0.723 respectively. The figure clearly shows that the test and simulation acceleration pulses had very similar magnitude and duration. Figure 45 compares the left and right rear seat velocity of the laboratory test and the LS-DYNA simulation computed from the acceleration pulses. The test and simulation velocities are very similar with CORA numbers greater that 0.9 at both locations.

Figure 43: Post-test laboratory vehicle and model of the 2011 Honda Accord for NCAP frontal barrier test

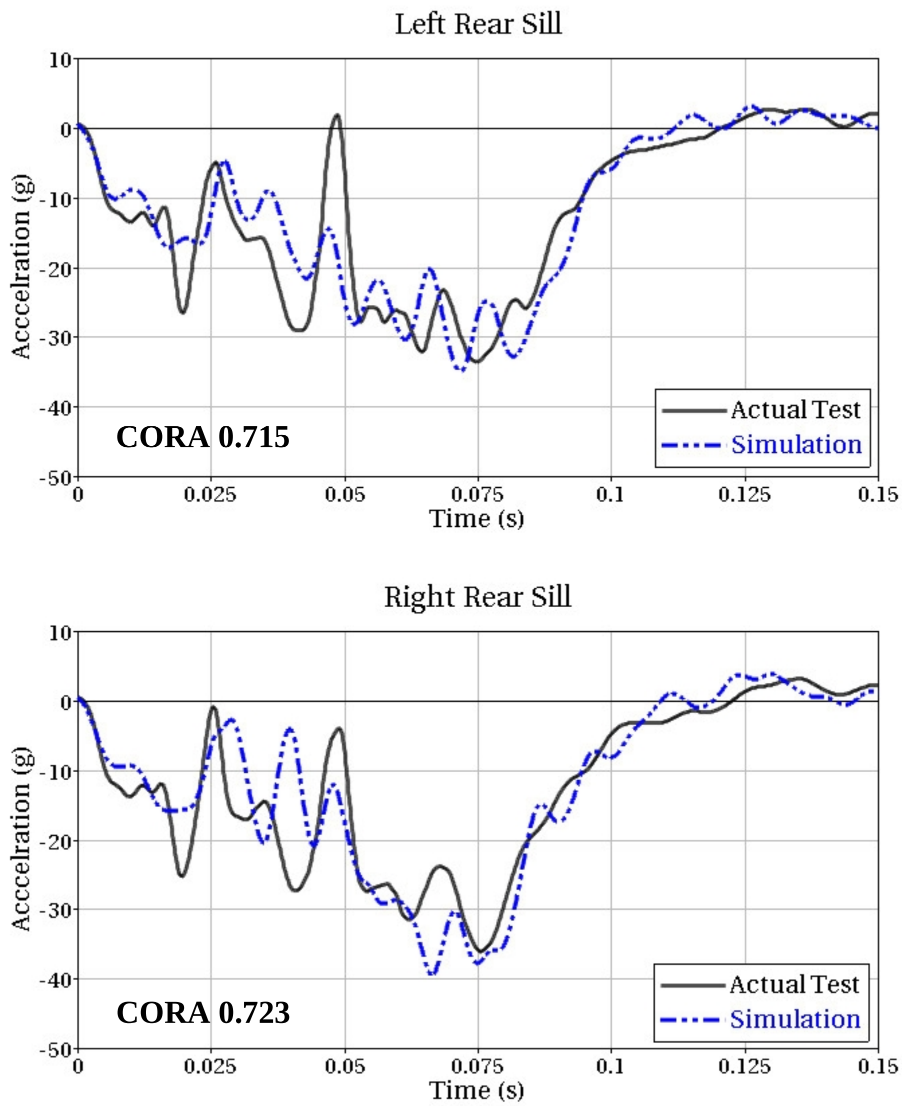
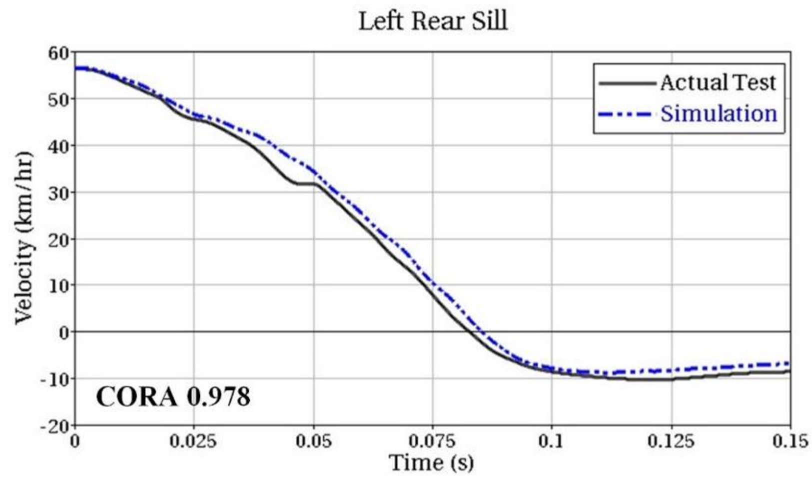


Figure 44: Comparison of left and right rear seat X accelerations for laboratory test and simulation for NCAP frontal crash test



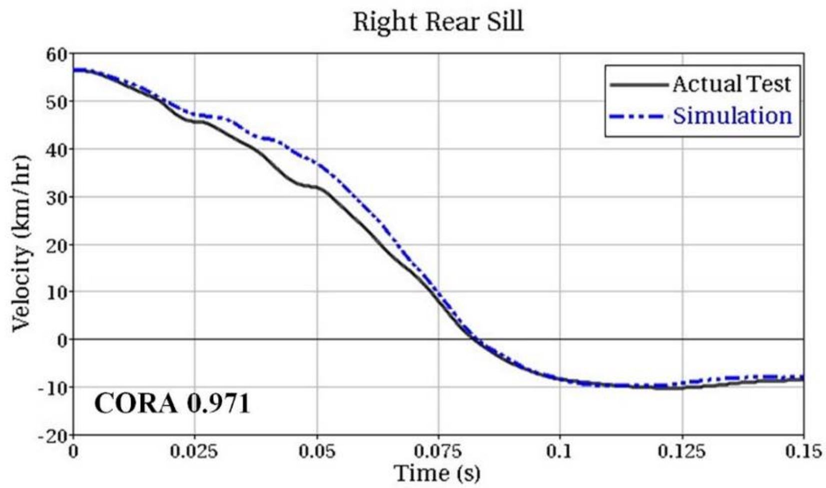


Figure 45: Comparison of left and right rear seat X velocity for laboratory test and simulation for NCAP frontal crash test

The comparison of occupant compartment intrusion is shown in Figure 46 for the NCAP frontal test. The simulation intrusions are slightly higher than the test with a 20 mm different for the brake pedal and a 10 mm different for the foot rest.

Final Intrusions

	Brake Pedal	Foot Rest
Test	-3	8
Simulation	-23	18

Figure 46: Comparison of brake pedal and foot rest intrusion for laboratory test and simulation for NCAP frontal crash test

The visual as well as the pulse comparisons of the simulation results to the test data indicate that the finite element model of the baseline Honda Accord correlates reasonably well with the baseline Honda Accord for the NCAP frontal rigid wall test.

3.2.3 Lateral NCAP Moving Deformable Barrier Test

The lateral NCAP MDB simulation was run using LS-DYNA software. Model validation results are compared to NHTSA Test #7098. The test vehicle used was a 2011 Honda Accord LX 4-door sedan. General specifications for the model and test vehicle are shown in Figure 47.

	FE Model	Test 7098
Weight (kg)	1668.2	1661.0
Engine Type	2.4L I4	2.4L I4
Tire Size	P215/60R16	P215/60R16
Wheelbase (mm)	2799	2794
CG (mm) Rear of front wheel C/L	1164	1175
Body type	4-Door Sedan	4-Door Sedan

Figure 47: Comparison of vehicle characteristics for FE model and the Lateral NCAP laboratory test vehicle

Figure 48 shows the pre-test set-up for the model and test vehicle. Post-test intrusion pictures for the model and test are shown in Figure 49. The NHTSA test measures struck-side profile deformation amount at 6 levels. Refer to Section 3.1.3 for further details including vertical height locations. Levels 2 and 3, which are near the mid-door level, were measured in the model and compared with the NHTSA test. An overlay of the Level 2 and 3 intrusion profile amounts for the model and test is shown in Figure 50. Figure 51 shows the B-pillar inner intrusions from both and the simulations. Comparison of lateral velocity at center of gravity is shown in Figure 52. Comparisons of the vehicle deformation profiles, the inner and outer intrusions, and the vehicle pulse at the CG indicate the model response is similar to the actual vehicle tested.

Figure 48: Model and Test #7098 Lateral NCAP MDB Test Setup

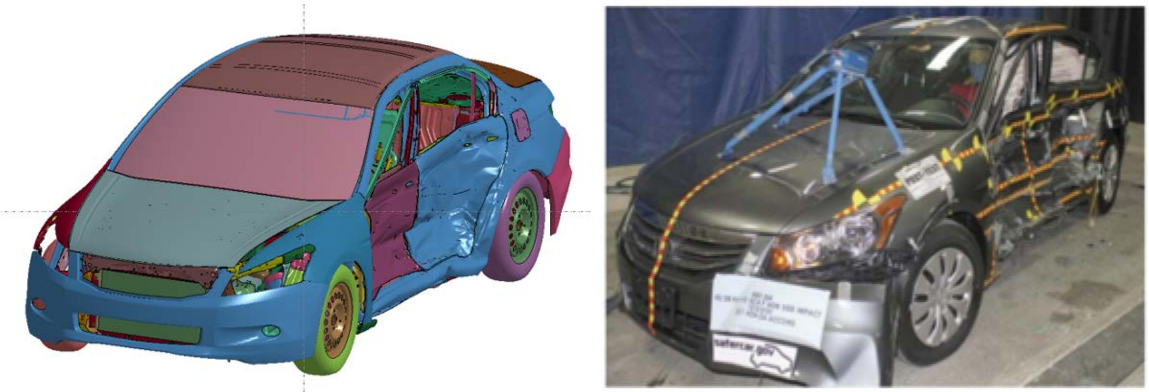


Figure 49: Model and Test #7098 Lateral NCAP MDB Post Test

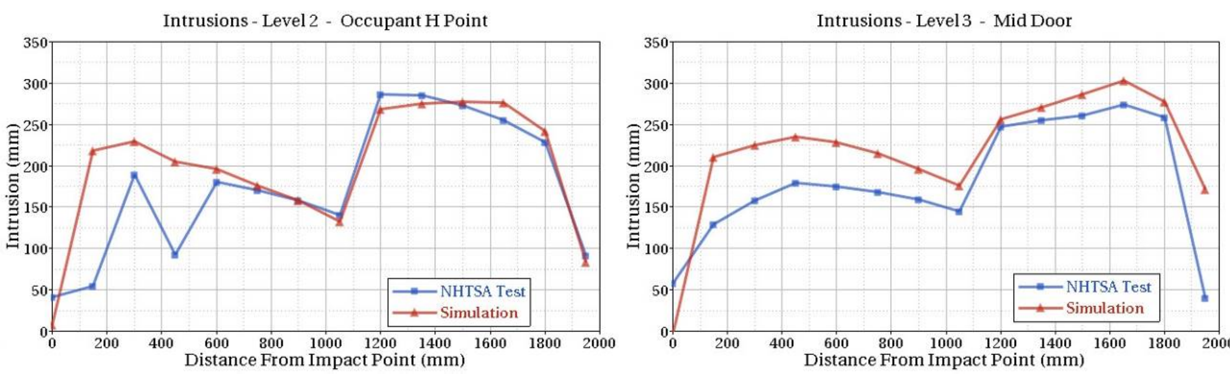


Figure 50: Model and Test #7098 Level 2 and 3 Struck-Side Intrusion Profile

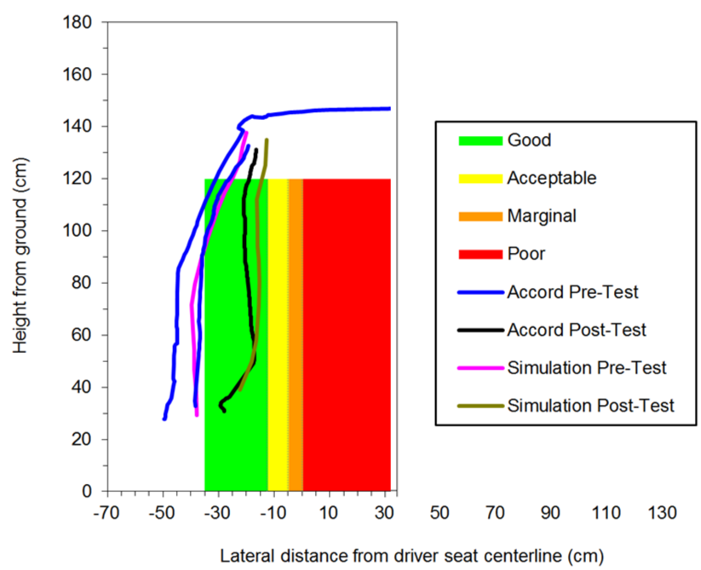


Figure 51: Model and Test #7098 B-Pillar Inner Intrusion Profile

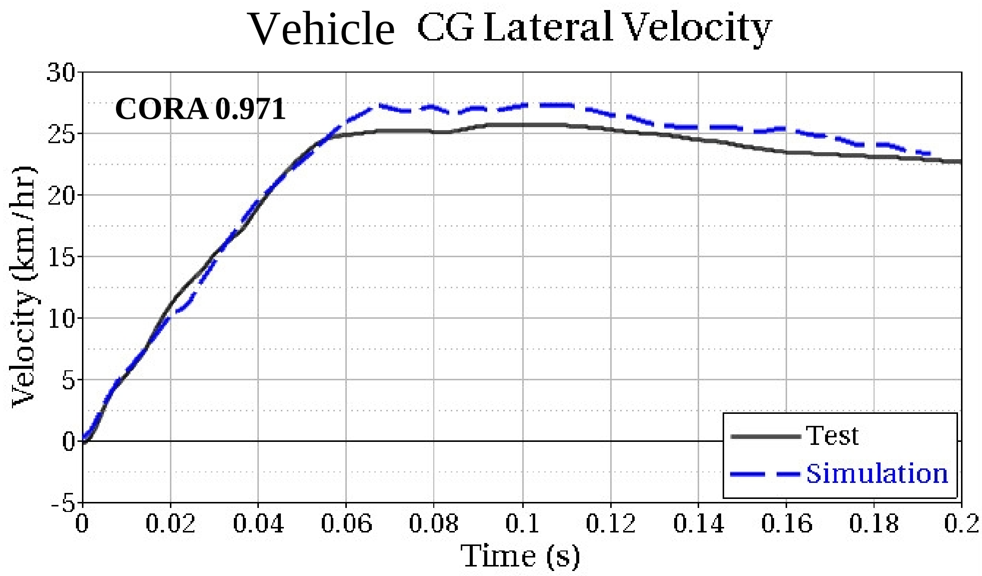


Figure 52: Model and Test #7098 Center-of-Gravity Lateral Velocity

It is important to note that the exterior surface crush profile in Figure 50 shows a sudden drop in the exterior intrusion values. This is due to the front door outer panel separating from the door inner structure and being pulled by the barrier in the test, as shown in Figure 53. A different phenomenon was seen in the FEA simulation. The pulling between the barrier and the vehicle in the simulation caused the front door to separate from the vehicle as shown in Figure 53. The outer panel spring back deflections are not very important since the occupants are by the interior surfaces of the door and the B-pillar.

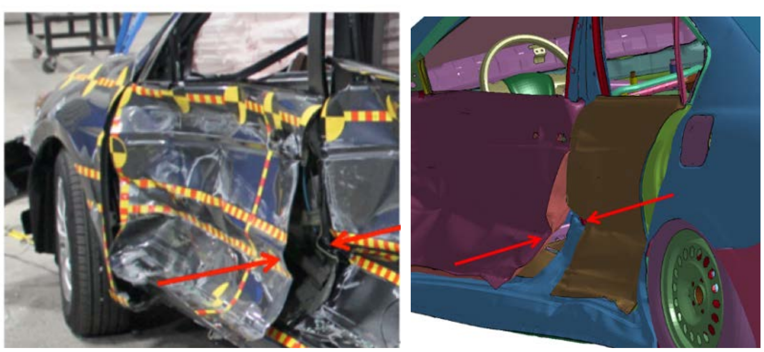


Figure 53: Model and Test #7098 Level 2 Struck-Side Intrusion Profile

3.2.4 Lateral NCAP Pole Test

The NHTSA pole test was analyzed using LS-DYNA software. The model was validated with NHTSA test #7077, which used a 2011 Honda Accord LX 4-door sedan. General specifications for the model and test vehicle are listed in Figure 54. Pre-test vehicle to pole positioning can be seen in Figure 55. Vehicle deformation after the impact for the model and test is shown in Figure 56. Intrusion is recorded at 5 levels during the NCAP pole test. Refer to Section 2.4 for details including vertical locations of the 5 monitored intrusion levels. B-pillar velocity and side profile intrusion at levels 2, 3 and 4 were extracted from the model for comparison with the test results.

Figure 57 compares the vehicle CG change in velocity in the lateral (Y) direction and Figure 58 shows the struck-side B-pillar mid-point velocity for the test and model run. The intrusion profiles for the model and test can be seen in Figure 59. All comparisons indicate that the finite element model of the baseline Honda Accord correlates reasonably well with the baseline Honda Accord for the Lateral NCAP Pole Test.

	FE Model	Test 7078
Weight (kg)	1668.2	1584.0
Engine Type	2.4L I4	2.4L I4
Tire Size	P215/60R16	P215/60R16
Wheelbase (mm)	2799	2794
CG (mm) Rear of front wheel C/L	1164	1175
Body type	4-Door Sedan	4-Door Sedan

Figure 54: Comparison of vehicle characteristics for FE model and the NHTSA Pole Laboratory Test Vehicle

Figure 55: Model and Test #7077 NCAP Pole Test Setup

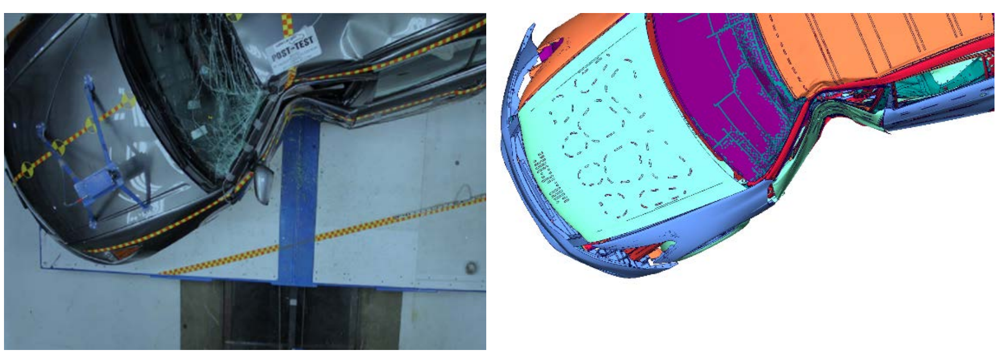


Figure 56: Model and Test #7077 Lateral NCAP Pole Post Test

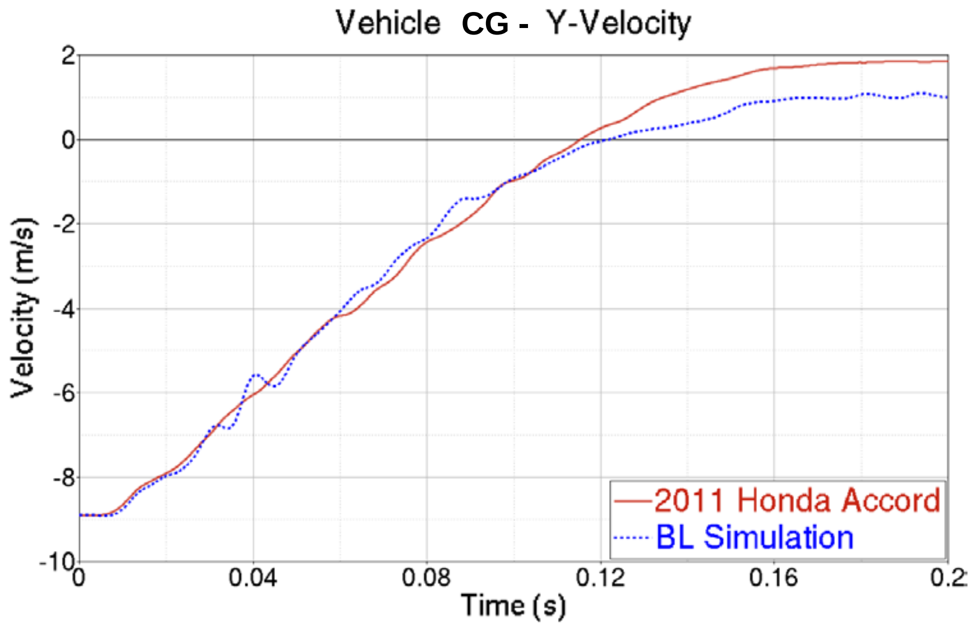


Figure 57: Model and Test #7077 Vehicle CG Velocity

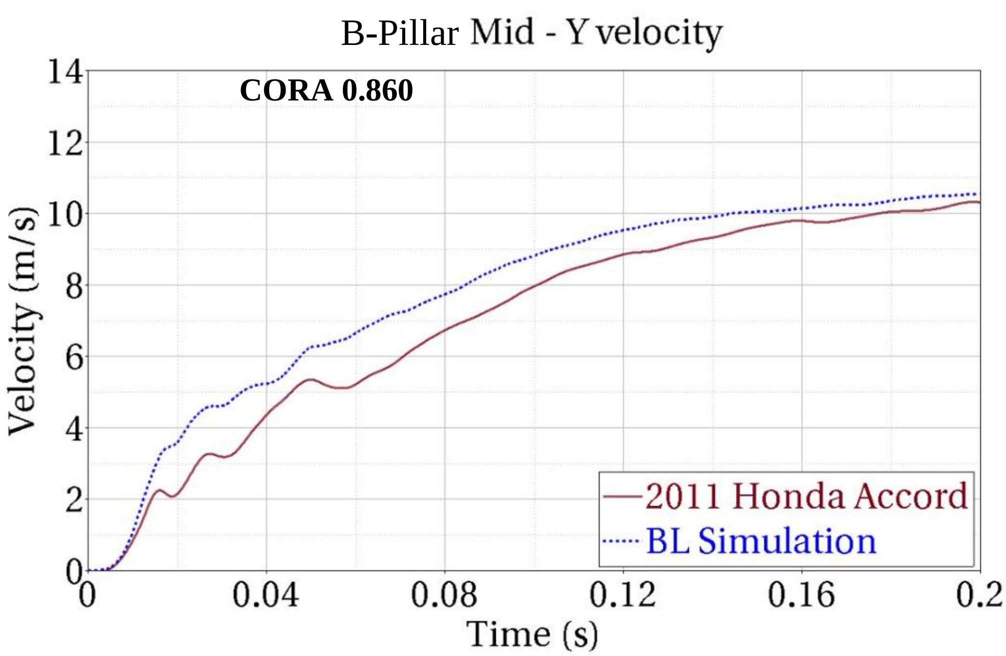
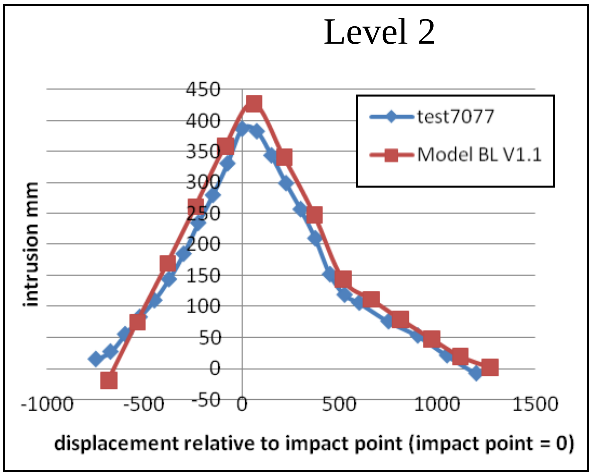


Figure 58: Model and Test #7077 Struck-Side Mid-B-Pillar Velocity



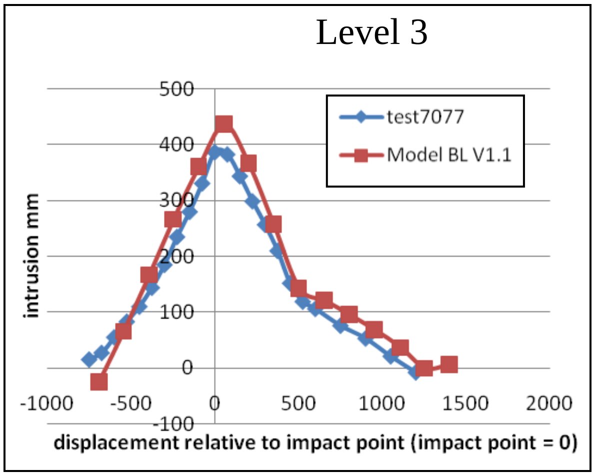


Figure 59: Model and Test #7077 Level 2 and 3 Struck-Side Intrusion Profile

3.2.5 IIHS Roof Crush Test

The analysis of the roof crush test was conducted using LS-DYNA software. Boundary conditions were applied to the full vehicle model. And, the platen was simulated as a rigid wall with prescribed motion. The analysis was validated with IIHS test number SWR 0936. The test vehicle curb weight, which was the same value as that used for the model, was 1484 kg (3273 lb). Figure 60 shows the set-up of the IIHS and the Honda Accord model. Post event body deformation comparison is shown in Figure 61. Overlays of the model and test for 1) the strength to weight ratio (SWR) versus platen displacement and 2) the force versus platen displacement are shown in Figure 62 and Figure 63 respectively. The comparisons indicate that the finite element model of the baseline Honda Accord correlates reasonably well with the baseline Honda Accord for the IIHS Roof Crush Test.

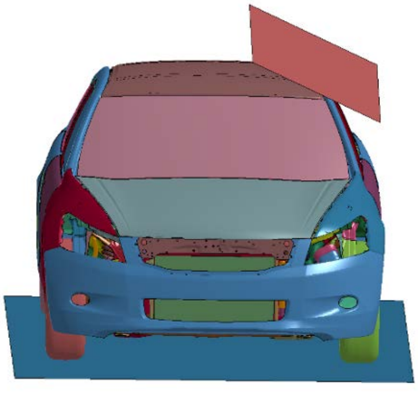


Figure 60: Model and Test #SWR 0936 IIHS Roof Crush Test Setup

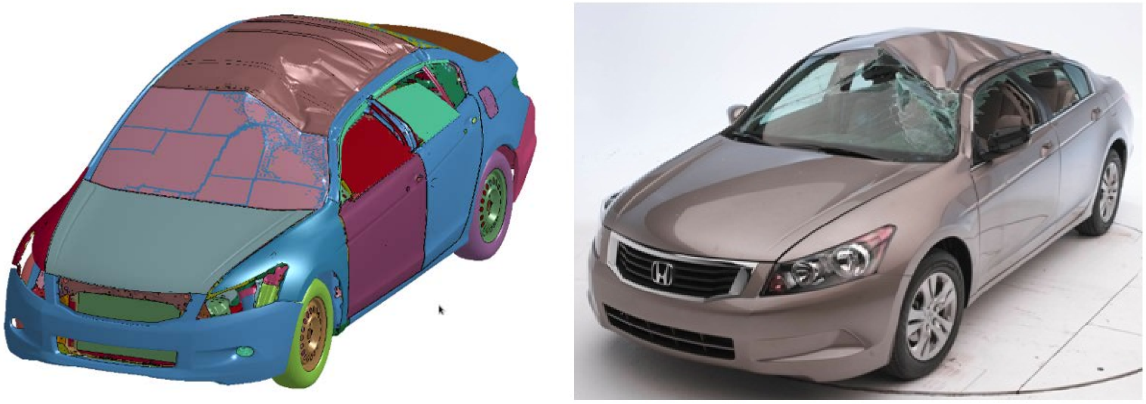


Figure 61: Model and Test #SWR 0936 IIHS Side Post Test

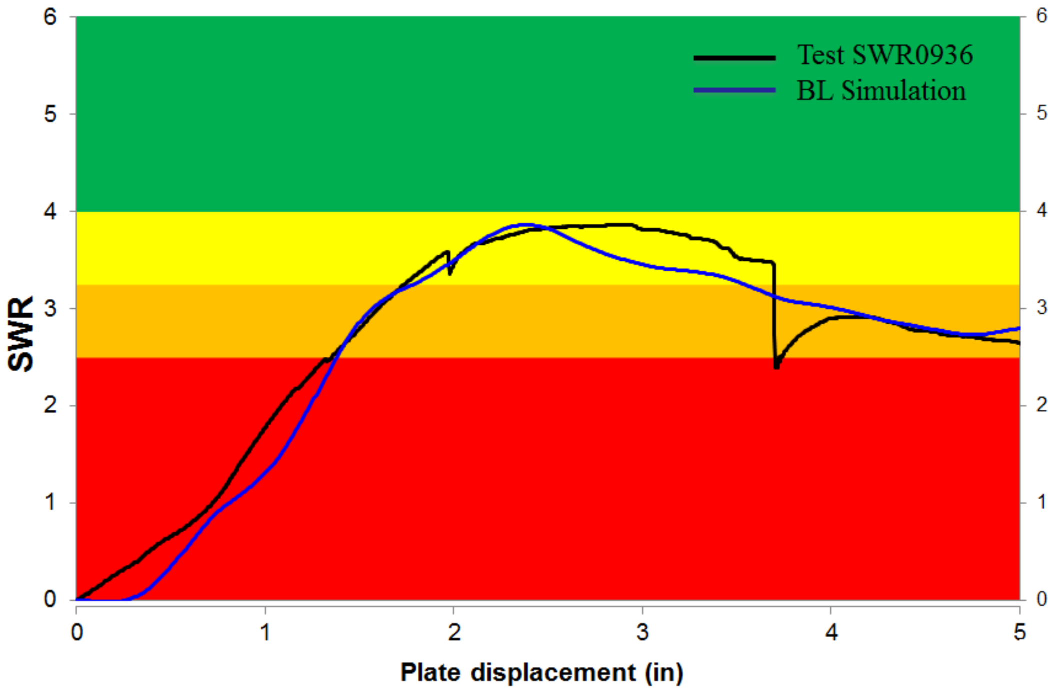


Figure 62: Model and Test #SWR 0936 IIHS Side SWR Versus Platen Displacement Overlay

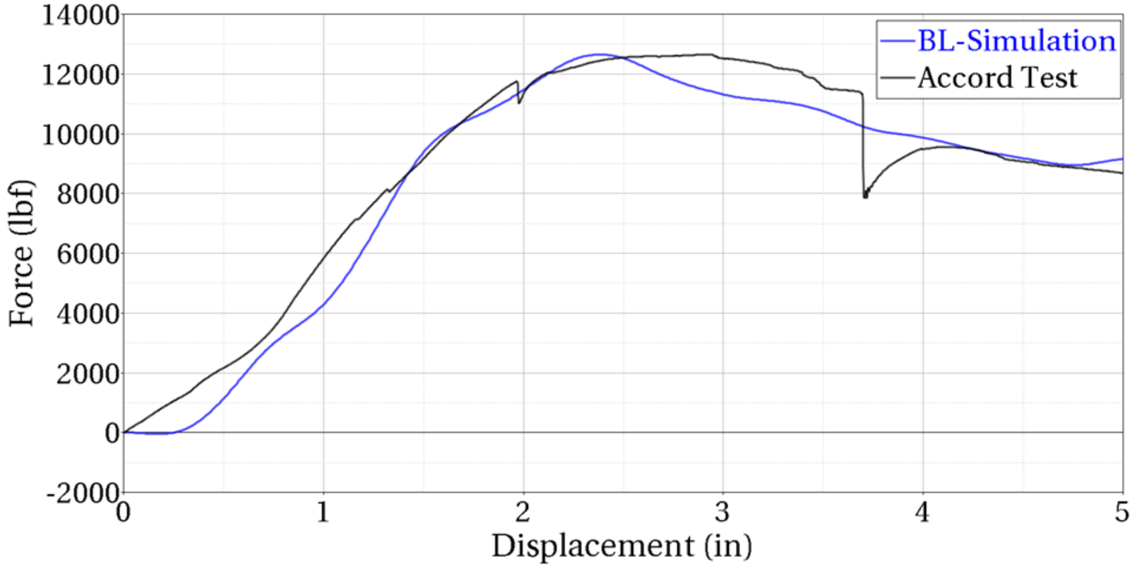


Figure 63: Model and Test #SWR 0936 IIHS Side Force Versus Platen Displacement Overlay

3.2.6 IIHS Lateral Moving Deformable Barrier Test

The IIHS lateral MDB test was run using LS-DYNA software. The model was set-up and the structural performance validated using IIHS test # CES 0735. The test was conducted with a 2008 Honda Accord 2.4L 4-door sedan. General specifications for the model and test are shown in Figure 64. Figure 65 shows the initial test set-up for the model. Post-test body side deformation for the test and vehicle are shown in Figure 66. The IIHS test also monitors dummy performance. However, for the NHTSA analysis, only structural performance, including body side intrusion profile and IIHS B-pillar intrusion rating, was monitored and validated. An overlay of the mid-door level side profile intrusion is shown in Figure 67. The IIHS rating for B-pillar intrusion relative to the driver seat centerline can be seen in Figure 68 for the model and test respectively. Figure 69 shows comparisons of the test and simulation vehicle right-rear-sill velocity. All figures and comparisons indicate that the finite element model of the baseline Honda Accord correlates reasonably well with the baseline Honda Accord for the IIHS lateral MDB Test.

	FE Model	**Test 7078**
Weight (kg)	1668.2	1664.0
Engine Type	2.4L I4	3.5L I4
Tire Size	P215/60R16	P215/60R16
Wheelbase (mm)	2799	2794
CG (mm)Rear of front wheel center	1168	1175
Body type	4-Door Sedan	4-Door Sedan

Figure 64: Comparison of vehicle characteristics for FE model and the IIHS Lateral MDB Lab Test Vehicle

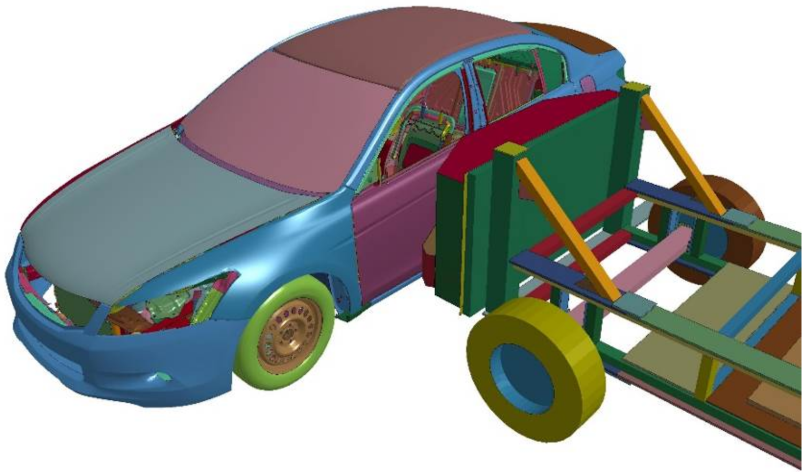


Figure 65: Model and Test #CES 0735 IIHS Lateral MDB Test Setup

Figure 66: Model and Test #CES 0735 IIHS Lateral MDB Post Test

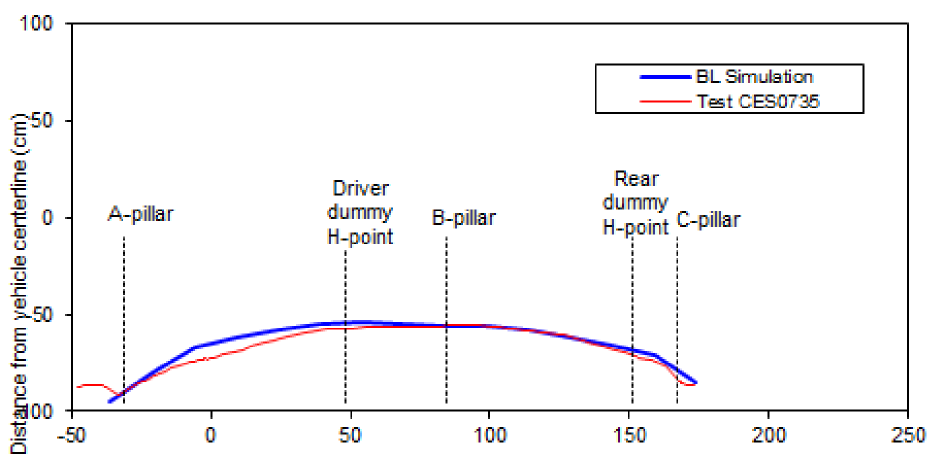


Figure 67: Model and Test #CES 0735 IIHS Side Intrusion Test and Model Overlay

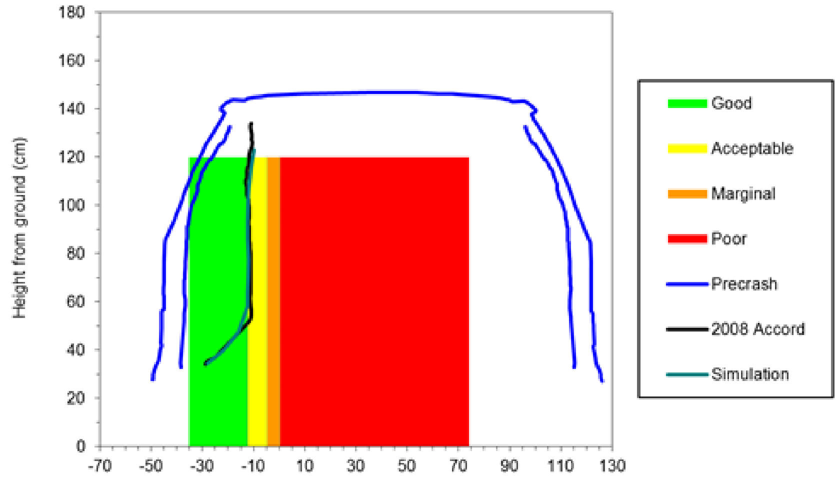


Figure 68: Model B-Pillar Intrusion Relative to Seat Centerline Test Versus FEA Model

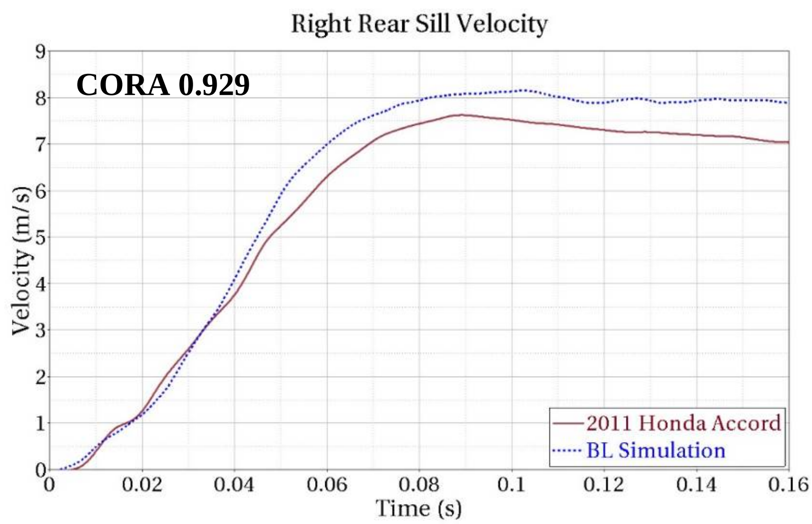


Figure 69: Model and Test #CES 0735 Vehicle Right Rear Sill Velocity

3.2.7 IIHS Moderate Frontal Offset Test

A full frontal laboratory test (IIHS Test #CEF1003) was available for validation of the Honda Accord FE model. A comparison of the vehicles used for the simulation and the IIHS 40 percent offset laboratory test are shown in Figure 70. The weight and engine size of the tested 2010 Honda Crosstour were greater than those of the baseline Honda Accord model. The analysts did not adjust the weight and engine size to match the weight and engine size of the 2010 Honda Crosstour tested. Herein, the simulation response of the Honda Accord finite element model is compared to the actual data recorded in the IIHS frontal test of the 2010 Honda Crosstour. The pre-test physical vehicle and model are shown in Figure 71. Figure 72 gives pictures of the laboratory-tested vehicle and the model during the crash. The acceleration at the center of gravity is plotted in Figure 73 for the laboratory test and the model simulation. The actual test has a higher acceleration than the model at about 70 ms. This is attributed to the fact that the test vehicle had a larger engine size and significantly higher mass than the model. Other than the difference at 70 ms, the shape of the model generally follows the shape of the laboratory pulse. Figure 74 compares the velocity at the center of gravity for the laboratory test and the LS-DYNA software simulation, showing similar response for laboratory test and simulation. The maximum intrusion in the laboratory test and finite element simulation of baseline Honda Accord in the IIHS frontal deformable barrier test is given in Figure 75 using the IIHS intrusion rating scheme.

	FE Model	Test 7078
Weight (kg)	1668.2	1932.0
Engine Type	2.4L I4	3.5L I6
Tire Size	P215/60R16	P215/60R16
Wheelbase (mm)	2799	2800
Body S type	4-Door Sedan	4-Door Sedan

Figure 70: Comparison of vehicle characteristics for FE model and the test vehicle for the IIHS frontal deformable barrier test

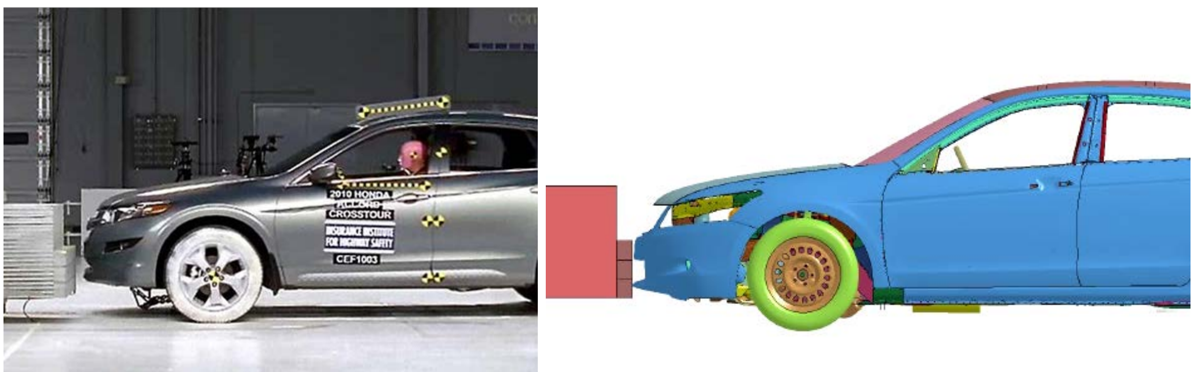


Figure 71: Pre-test laboratory vehicle and model of the 2011 Honda Accord for IIHS frontal deformable barrier test

Figure 72: Post-test laboratory vehicle and model of the 2011 Honda Accord for IIHS deformable barrier test

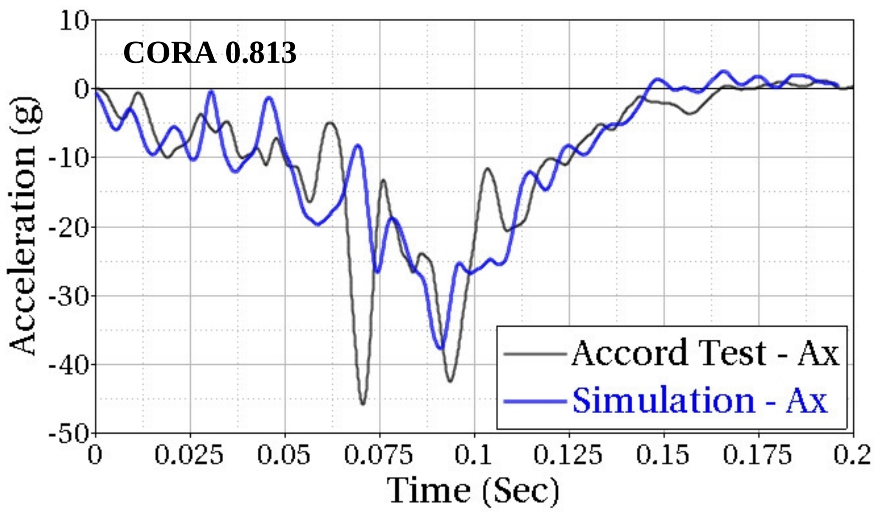


Figure 73: Comparison of center of gravity accelerations for laboratory test and simulation for IIHS frontal deformable barrier test

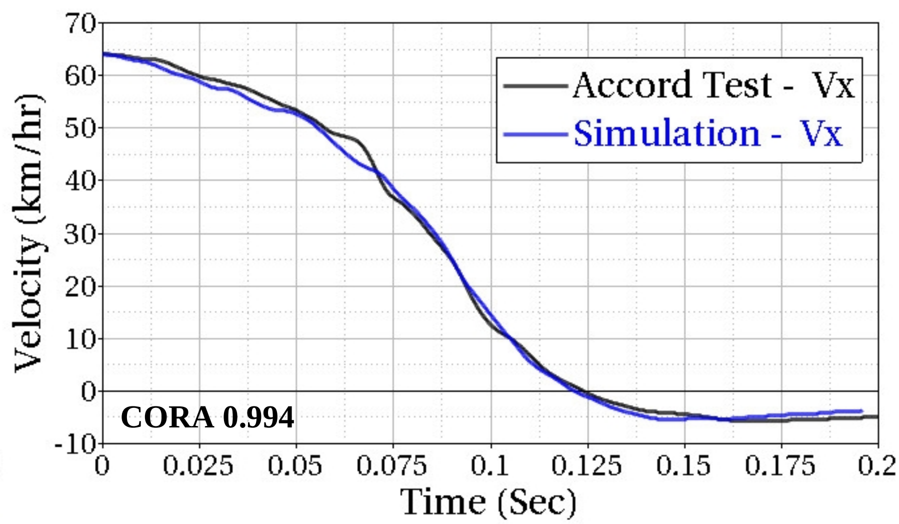


Figure 74: Comparison of velocity at the center of gravity for laboratory test and simulation for IIHS frontal deformable barrier test

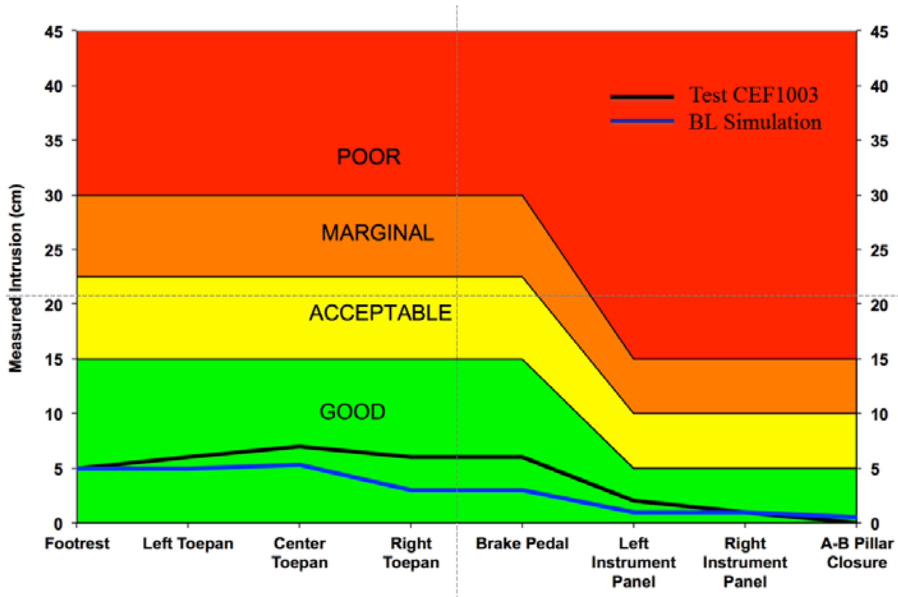


Figure 75: Maximum intrusion in laboratory test and finite element simulation of baseline Honda Accord in IIHS frontal deformable barrier test using IIHS intrusion rating scheme

All these data indicate that the finite element model of the baseline Honda Accord correlates reasonably well with the baseline Honda Accord for the IIHS frontal deformable barrier test. The acceleration at the center of gravity is higher for the laboratory test at 70 ms, but the shapes of both laboratory test and simulation are otherwise similar. The velocity at the center of gravity is similar comparing simulation to laboratory test. The maximum intrusions are similar and all in the "Good" region of the IIHS rating scheme.

3.2.8 IIHS Small-Overlap Front Test

Computer simulations were performed to validate the 2009 Honda Accord model against an IIHS Small-overlap Front impact. Test #CEF10021 was used for the validation. A comparison of the vehicles used for the simulation and the IIHS laboratory test are shown in Figure 76. The weight and engine size of the tested 2009 Honda Accord 4-door sedan was similar to the baseline computer model. A 76 kg mass was added at driver seat to represent the H3 50th percentile dummy used in the test. Herein, results from the simulation response are compared to the actual data recorded in the IIHS SOL test. The pre-test physical vehicle and model are shown in Figure 77. Figure 78 gives pictures of the laboratory-test vehicle and the model during the crash. The post-crash occupant compartment profile comparison is shown in Figure 79. The acceleration and change in velocity at the center of gravity for the laboratory test and the simulation are plotted in Figure 80 and Figure 81. Plot of the intrusions from the laboratory test and finite element simulation are shown in Figure 82. All comparisons and simulations indicate that the finite element results are close to the ones from the test.

	FE Model V1.1	Test CF10021
Weight (kg)	1667.7	1,662.5
Engine Type	2.4L I4	2.4L I4
Tire size	P215/ 60R16	P215/ 60R16
Wheelbase (mm)	2800	2800
Body Style	4-Door Sedan	4-Door Sedan

Figure 76: Comparison of vehicle characteristics for FE model and the test vehicle for the IIHS SOL test

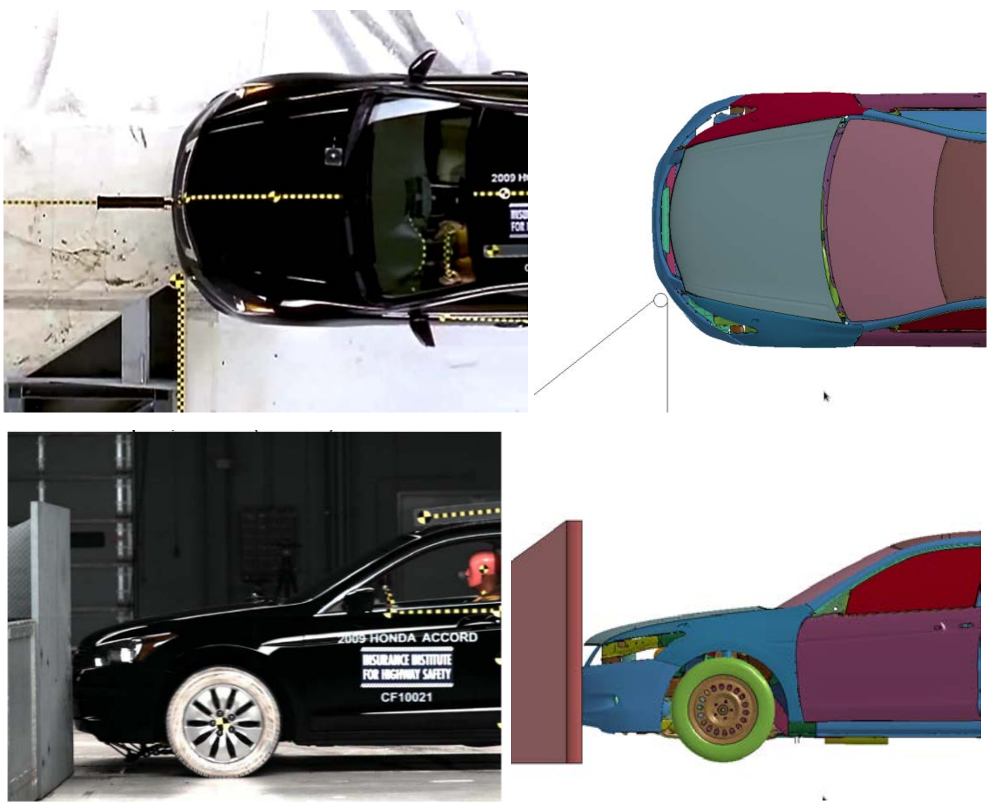


Figure 77: Pre-test laboratory vehicle and model of the 2009 Honda Accord for IIHS SOL test

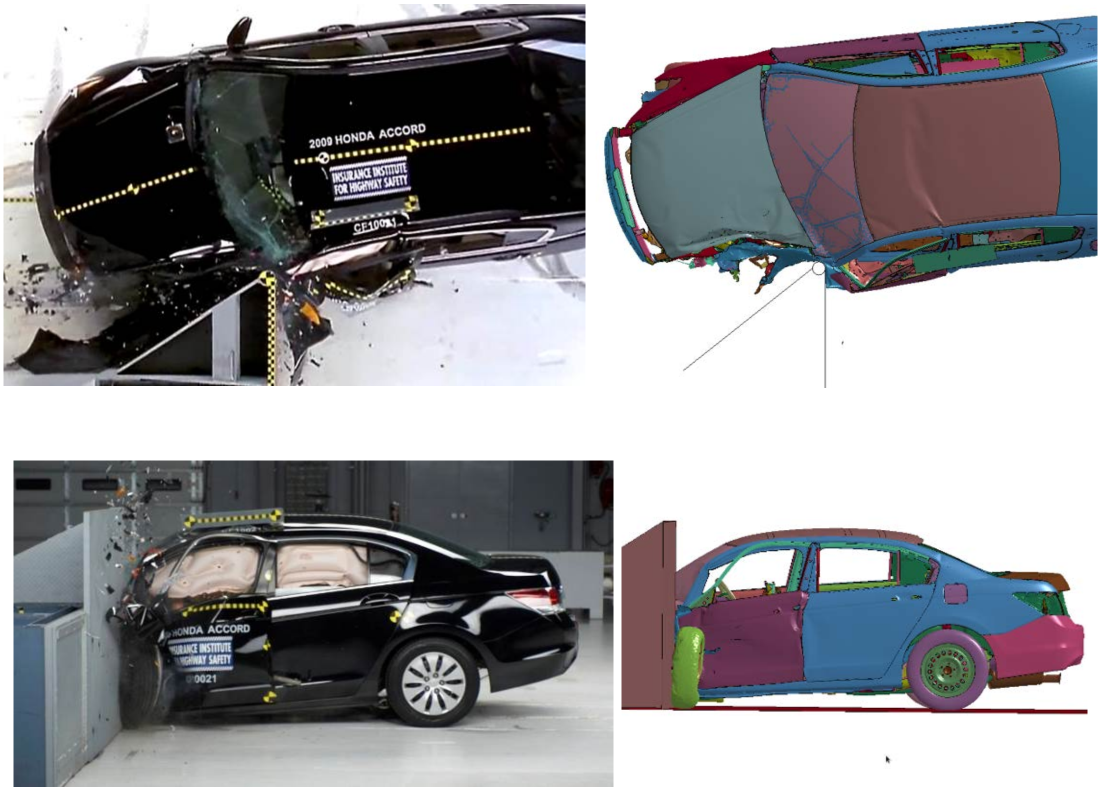


Figure 78: Post-test laboratory vehicle and model of the 2009 Honda Accord for IIHS SOL test

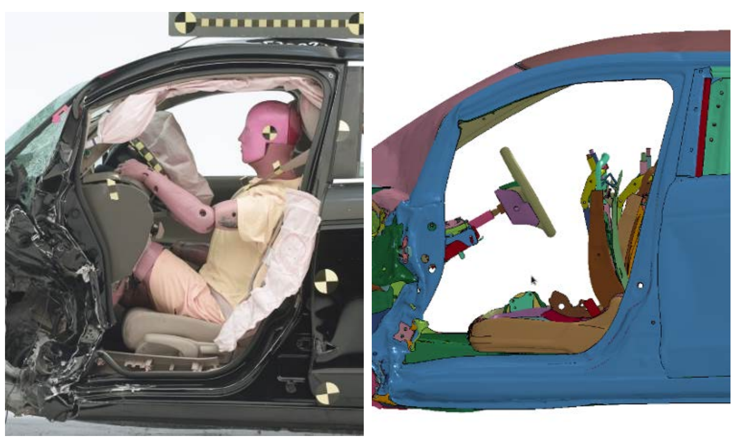
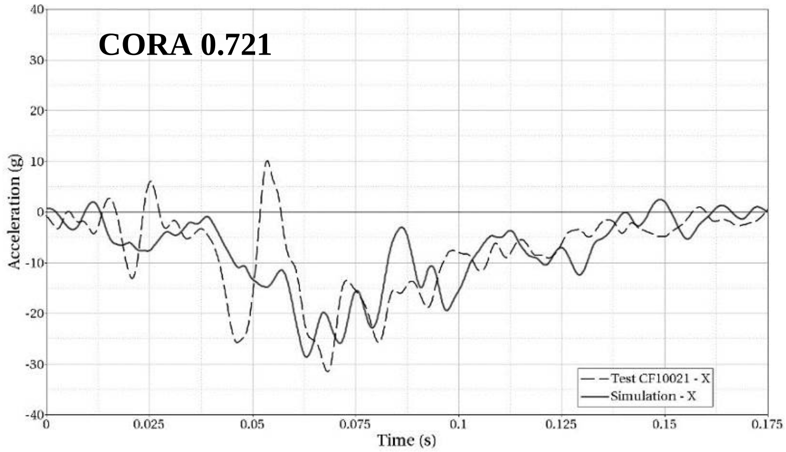
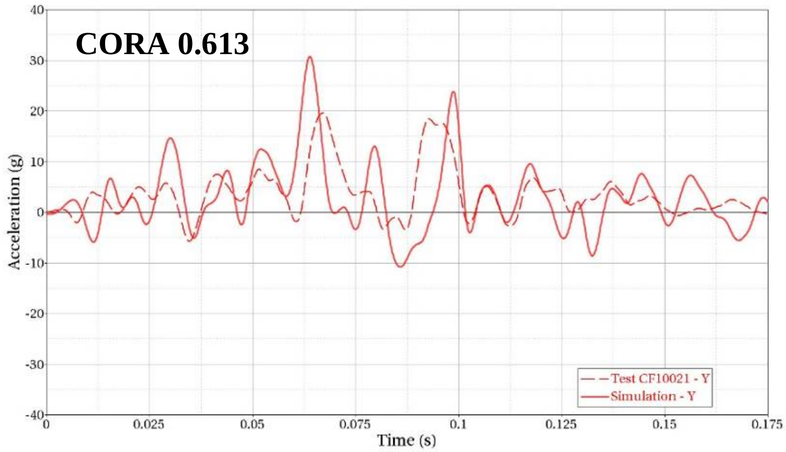


Figure 79: Occupant compartment deformation profile for laboratory test and simulation for IIHS SOL test



a- Longitudinal acceleration



b- Lateral acceleration

Figure 80: Comparison of center of gravity accelerations for laboratory test and simulation for IIHS SOL test

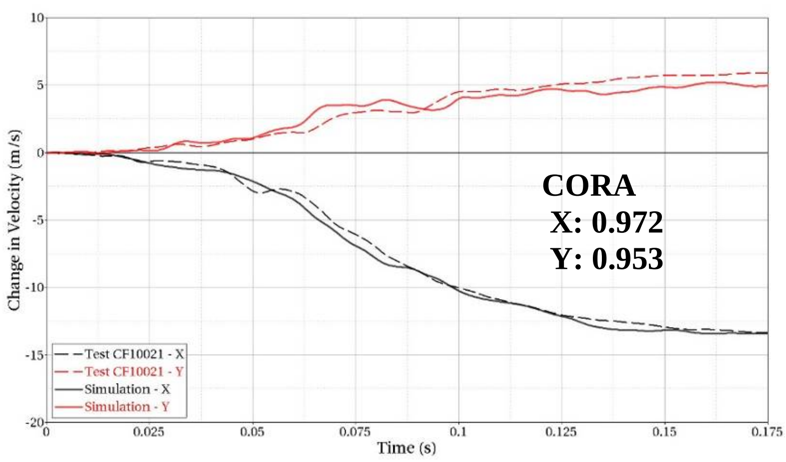


Figure 81: Comparison of velocity at the center of gravity for laboratory test and simulation for IIHS SOL test

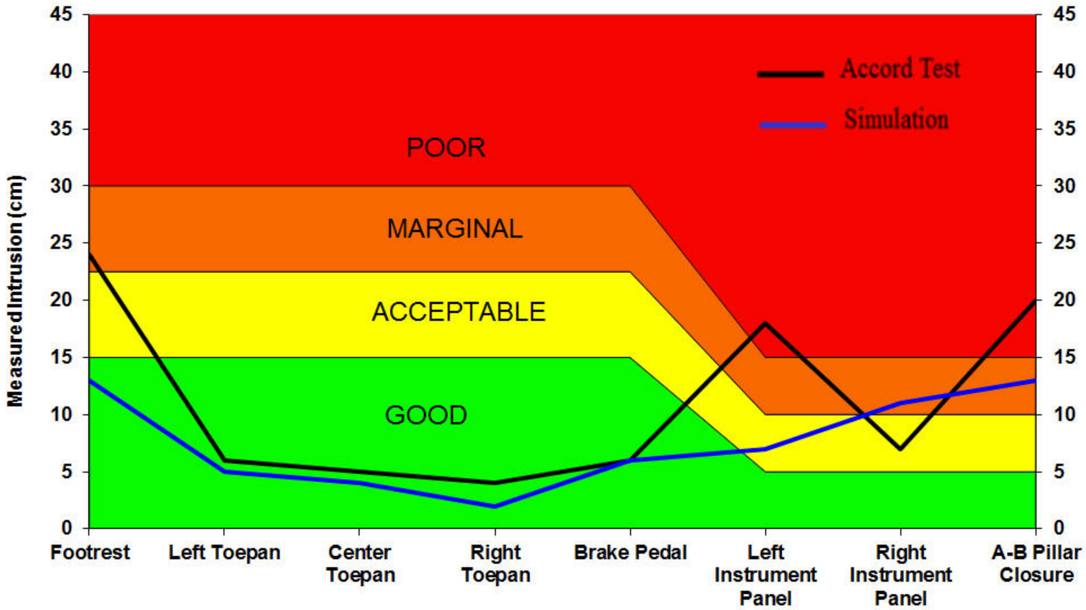


Figure 82: Maximum intrusion in laboratory test and finite element simulation in IIHS SOL frontal impact

4 LWV SOL Weight and Cost

4.1 Task C.5.6 Update Lightweighted Vehicle Model in Response to Honda's Comments

4.1.1 Honda's Comments

Honda provided feedback to the original LWV 1.0 design in meetings and summarized their comments in a presentation given by Chuck Thomas at the NHTSA Mass-Size-Safety Workshop on May 13 and 14, 2013.[51]

In general, Honda stated on the second slide of the presentation that "The EDAG/GWU report is a good study of lightweighting possibilities…" and "Many of the technologies and approaches to lightweighting in the report reflect Honda's own research and direction." However, Honda believed that the LWV 1.0 would not achieve the same performance levels as the 2011 Accord in the areas of crashworthiness, performance and drivability, and ground clearance. Honda also stated that the effects of "[p]latform [c]ommonality" were not considered in the project. All of these issues would create a mass rebounding effect that would further increase the weight and cost of the LWV 1.0 design.

Figure 83 summarizes Honda's comments and Honda proposed countermeasures to the LWV 1.0 Design. It also lists the effect on vehicle mass. The total effect of Honda's countermeasure would increase the mass of the LWV 1.0 from 1,148 kg to 1,305 kg.

Item	Honda Comment	Honda Proposed Solution	Weight Change (kg)
	Crashworthiness (Slide 15)		**50**
1	Dashboard, lower (firewall), pedal area intrusion and deformation – impacting lower extremities is larger on LWV than Accord, resulting in more injury risk to the driver (Slide 10).	Increase strength of toe board, front rail end, front wheel house upper member, front pillars, side sill, and seat foot	25
2	Hard to maintain integrity of the safety cage due to many predicted fractures (Slide 12)	1. Apply better elongation material (lower yield strength) to the large deformation portion on LWV 2. Adjust LWV thickness equal to the Accord thickness 3. Adjust the cross member thickness to transfer the bigger side impact load according to the CTR PLR countermeasures	10
3	Fuel filler pipe was not including in LWV 1.0. When Honda added the fuel filler pipe to the simulation, deformation occurred (Slide 14)	Adjust the REAR FRAME and SUB FRAME lateral member strength 1.4 times to the compared to LWV	15

[51] Thomas, C. (2013). Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025 (PowerPoint presentation delivered at NHTSA Mass-Size-Safety Workshop on May 13 and 14, 2013). Torrance, CA: American Honda Motor Co. Available at www.nhtsa.gov/staticfiles/rulemaking/pdf/MSS/4-Thomas-Honda_Report.pdf

	Performance and Drivability (Slide 22)		**18.35**
4	LWV body torsional stiffness is more than 25% lower than Accord	The crashworthiness countermeasures proposed by Honda address this issue.	
5	Honda estimates that the road noise for the LWV 1.0 would be higher compared to the 2011 Honda Accord (Slide 20)	Return wheel thickness of rim to 2011 Honda Accord levels	
6	Honda estimates that the cruising noise for the LWV 1.0 would be higher compared to the 2011 Honda Accord (Slide 20)	Add insulation to the door panel	
7	Inadequate ground clearance can result in hitting objects, suspension damage, etc. (Slide 21)	Increase sub frame thickness and change lower arm connecting structure	
8	**Incorrect Baseline Weight (Slide 22)**		**7.4**
	Wheel, temper tire/wheel, front brake disk and caliper had incorrect weights	Wheel (+1.4 kg), temper tire/wheel (+0.8 kg), front brake disk (+3.3 kg) and caliper (+1.9 kg)	
9	**Platform Commonality (Slide 25)**		**40**
	The LWV designers did not consider platform commonality with the Accord V6 engine model and Crosstour.	When using a common platform it is necessary to consider heaviest vehicle	
10	**Mass Rebound Effect (Slide 28)**		**42**
	Increased weight due to Honda's countermeasures will increase the size of the powertrain and other components		
	Honda's estimated -total weight change due to Countermeasures from 1148 kg to 1305 kg (Slide #29)		**157**

Figure 83: Summary of Honda's Comments to LWV 1.0 Design

4.1.2 Lightweight Vehicle v1.1 Crashworthiness Design Changes

The recommendations by Honda were reviewed and several design changes were made to the *vehicle body structure* of LWV 1.0 to address the shortfalls in performance. This updated design is designated as LWV 1.1 and the modified components are highlighted in Figure 84. These changes were assessed using LS-DYNA and NASTRAN analysis codes. The full vehicle model was subjected to a full suite of crash modeling analysis. The body structure was analyzed using NASTRAN to determine the torsional stiffness. The analysis shown in Figure 84 and Figure 87 only includes the changes to address Honda's crashworthiness comments. The design changes due to drivability, ride comfort, noise, and mass compounding are discussed in the previous Section.

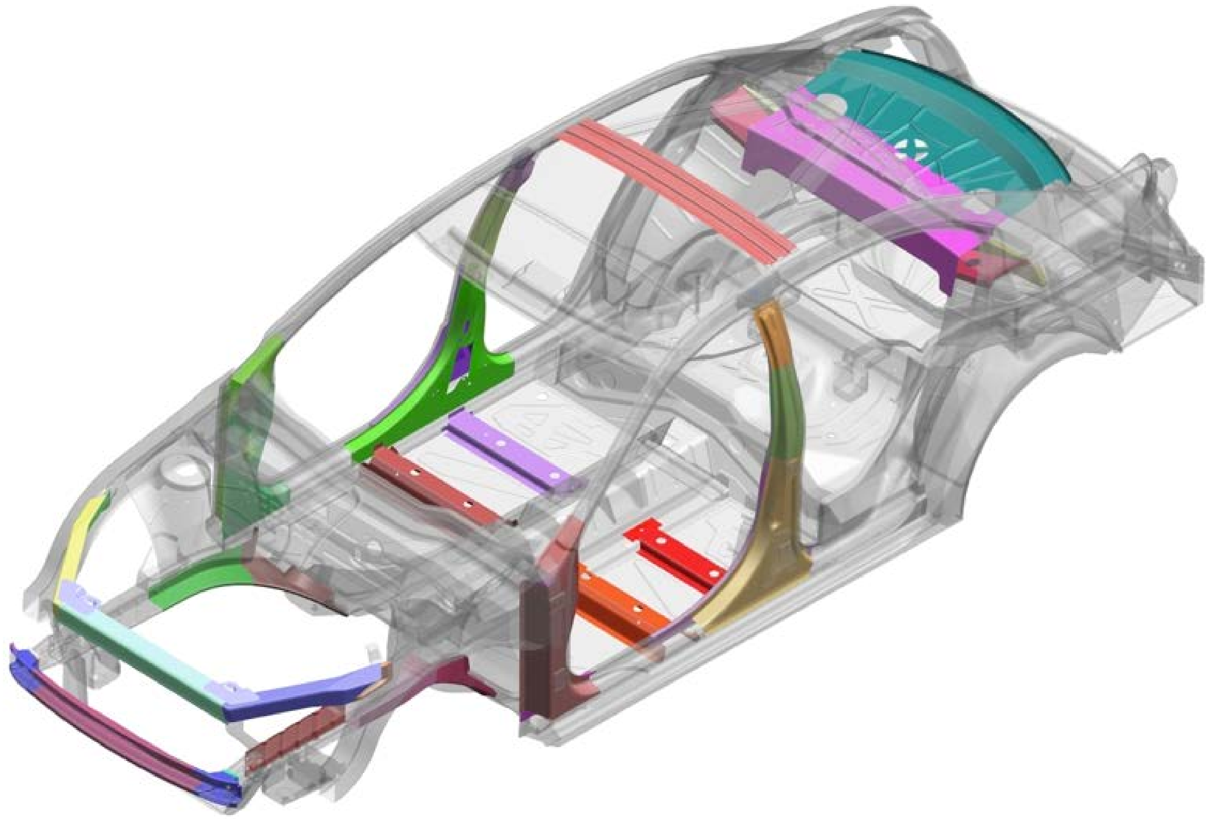


Figure 84: Changes to body structure – thickness and steel grades were changed for the highlighted panels

Figure 85 shows the test results of Honda's Accord's crash safety performance in IIHS frontal barrier test, along with the LWV 1.0 and 1.1 designs. A summary of all of the modified parts, along with their changes is shown in Appendix 7. Although the LWV 1.0 results were in the GOOD range, it did not perform as well as shown in Honda's test results for the MY 2011 (IIHS Test #CEF 1003) . On Slide 9 of Honda's presentation, Honda commented, "dashboard, lower (firewall), pedal area intrusion and deformation – impacting lower extremities is larger on LWV than Accord, resulting in more injury risk to the driver". The body structure front-end and front body hinge pillar area of the LWV was modified to reduce the passenger compartment intrusion levels. The mass increase due to these changes was approximately 3.9 kg, as shown in Appendix 7. As can be seen in Figure 85, the passenger compartment intrusions for the LWV 1.1 are comparable to or lower than the Honda test results.

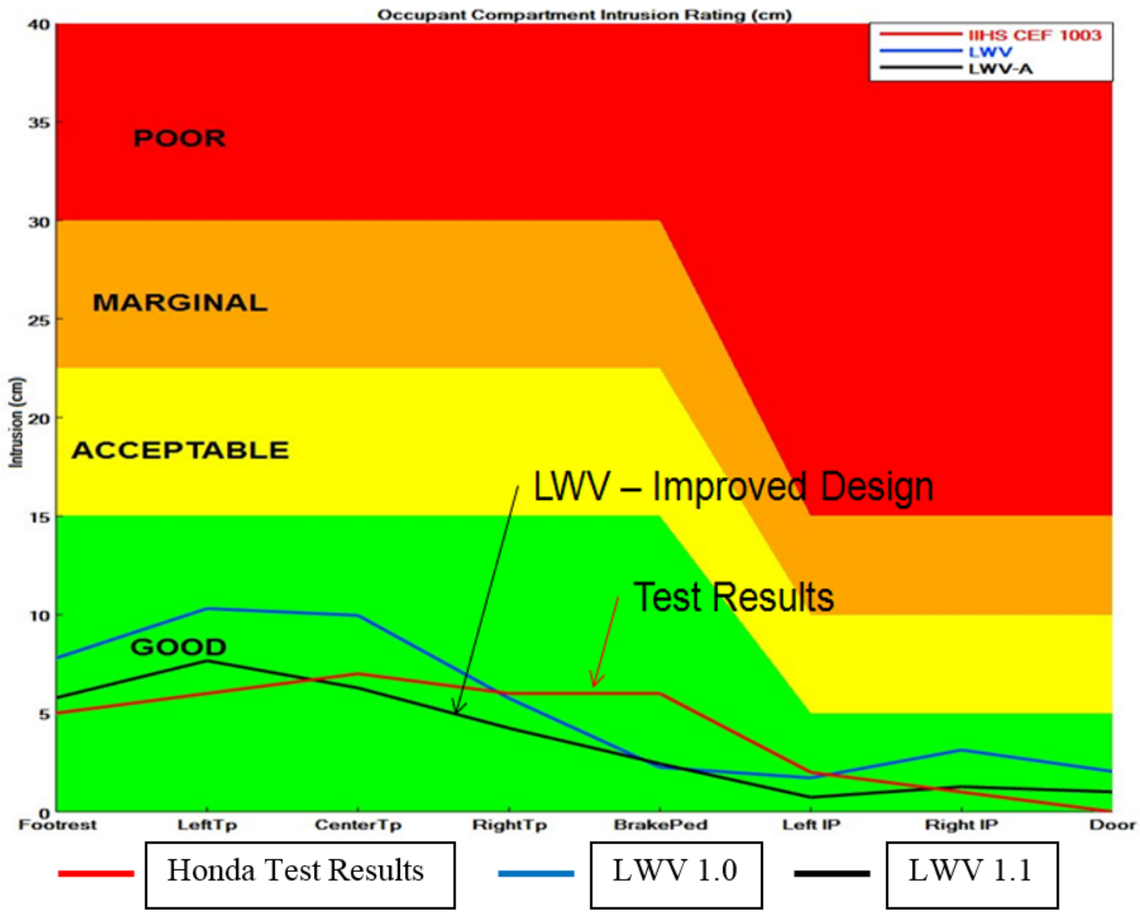


Figure 85: IIHS Offset Barrier – reduced passenger compartment intrusions LWV 1.1 improved design

The results for the IIHS side barrier impact test for the LWV 1.0 and for the LWV 1.1 are shown in Figure 86. On the LWV 1.0 the B-pillar inner panel is constructed from a grade of hot-stamped steel. Hot stamped grades are very high strength with limited material elongation. The LS-DYNA crash results predicted small regions of material fracture. Honda's commented on Slide 11 that it is "…hard to maintain integrity of the safety cage due to many predicted fractures…" and recommended the following three modifications on Slide 12, "1. Apply better elongation material (lower yield strength) to the large deformation portion on LWV, 2. Adjust LWV thickness equal to the Accord thickness, 3. Adjust the cross member thickness to transfer the bigger side impact load according to the [B-pillar] countermeasures." To respond to this comment, the steel grades at B-pillar were changed from the hot stamped boron steel to dual phase (DP) grades with higher elongation with no change in the thickness. These recommendations were implemented in the LWV 1.1 model and the results (Figure 86) show no material failure is predicted. The mass increase due to these changes was 3.8 kg.

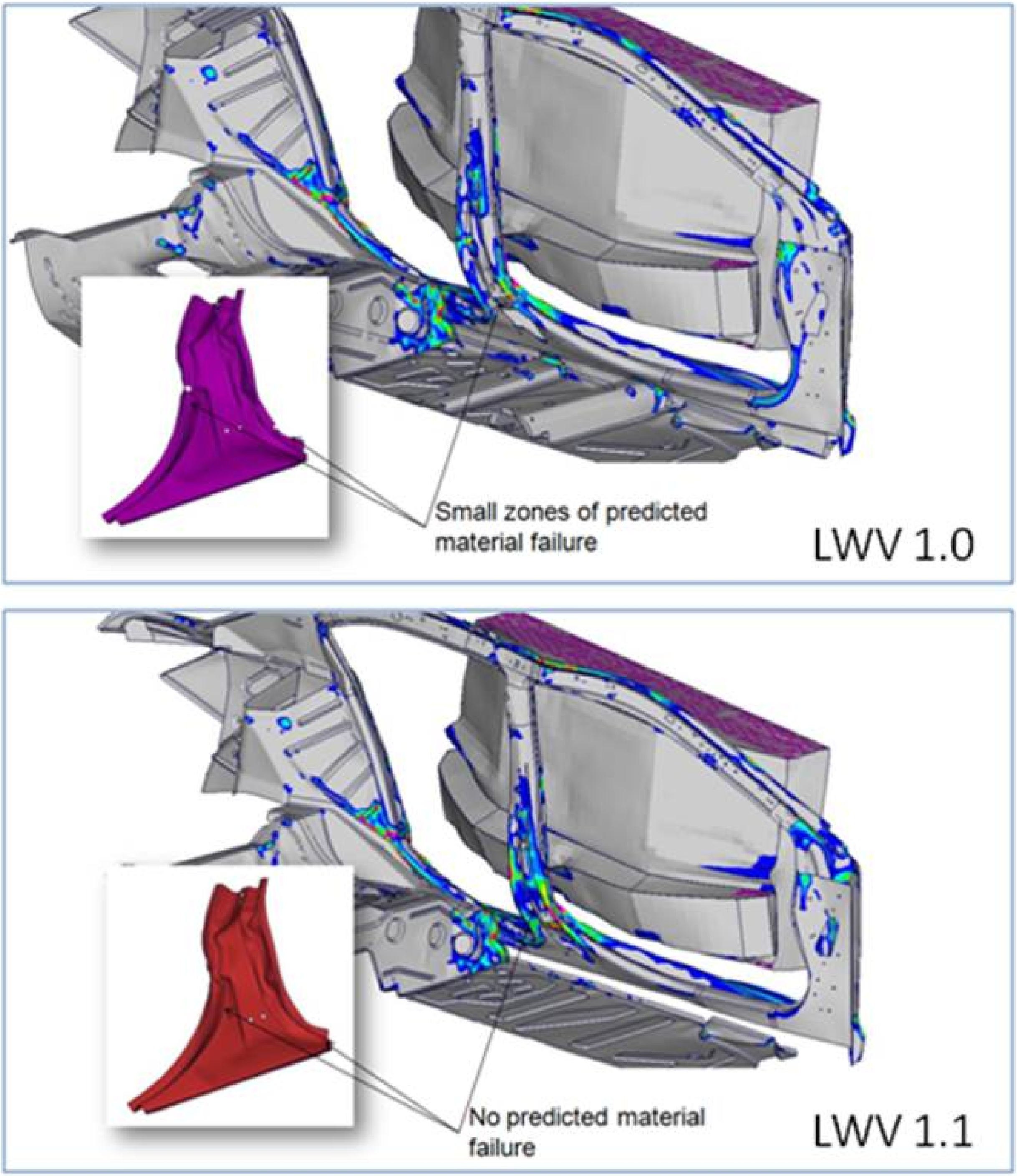


Figure 86: Side Crash – eliminated material failure by using lower strength higher ductility steel grades

Honda identified that the body torsional stiffness of the LWV 1.0 structure is more than 25 percent lower than the BL Accord. Also, the torsional stiffness test conducted on BL Honda Accord used slightly different test holding fixture compared with the way the CAE model simulated the boundary constraints. The CAE models for LWV 1.0 and LWV 1.1 were analyzed using NASTRAN with two different methods of boundary conditions. The torsional stiffness results are shown in Figure 87. The predicted torsional stiffness for the LWV 1.0 and LWV 1.1 are higher than the baseline Honda Accord test results. Using the Honda method of boundary constraints the LWV 1.1 torsional stiffness of 21.16 KN m/deg is 30 percent higher than the LWV 1.0 value of 16.25 KN m/deg. The increase in stiffness was achieved by making several changes to the rear top of the shock tower cross member as shown in Figure 84 and Appendix 7. The mass increase due to these changes was 3.8 kg.

Description	Torsional Stiffness (KN m/deg)		
	Baseline Vehicle Test	LWV 1.0	LWV 1.1 Improved
Constrained at Rear Rail	**12.33**	**14.40**	**16.99**
Constrained at Rear Top of Shock Tower		**16.25**	**21.16**

Figure 87: Torsional stiffness LWV 1.1

Due to these changes and other changes to the vehicle to improve the performance in line with Honda's comments the mass of the LWV 1.1 increased by 11.5 kg. The body structure increased from 252 to 264 kg. These changes are summarized in Figure 88.

Crashworthiness Issue	**Design Change and recommendations**	**Weight Increase (kg)**
Crash Safety— IIHS Offset Barrier	Reduced passenger compartment intrusions as shown in Figure 85	3.9
Crash Safety— Side Crash	Eliminated material failure by using lower strength higher ductility steel grades as shown Figure 86	3.8
Crash Safety— Rear Impact	Re-route fuel filler pipe to create required clearance	0.0
Torsional Stiffness	Increased torsional stiffness (Figure 87)	3.8
Mass increase of LWV 1.1 Body Structure		**11.5**

Figure 88: LWV 1.1 Design and weight changes to address Honda's crashworthiness comments

4.1.3 Other Design Changes Based Upon in Response to Honda's Comments

Honda identified that the ground clearance on the LWV 1.0 was inadequate and this can result in hitting objects on the grounds leading to suspension damage, etc. The ground clearance of the Honda Accord 148 mm compared to the LWV 1.0 ground clearance of 124 mm, as shown in Figure 89. The design of the engine cradle was investigated and modified to 148 mm ground clearance condition. The flange facing downward towards the ground was revised to the horizontal direction similar to the baseline Honda Accord design. The engine cradle cross members and exhaust pipe were also revised to increase the ground clearance. The impact of the three changes discussed above and as shown in Figure 89 was 0.95 kg increase in the mass of the engine cradle. This mass change is not made to the LS-DYNA model, but the geometry changes have been made in LWV 1.1; it is believed that mass change of 0.95 kg will not have any detrimental effect on frontal crash results.

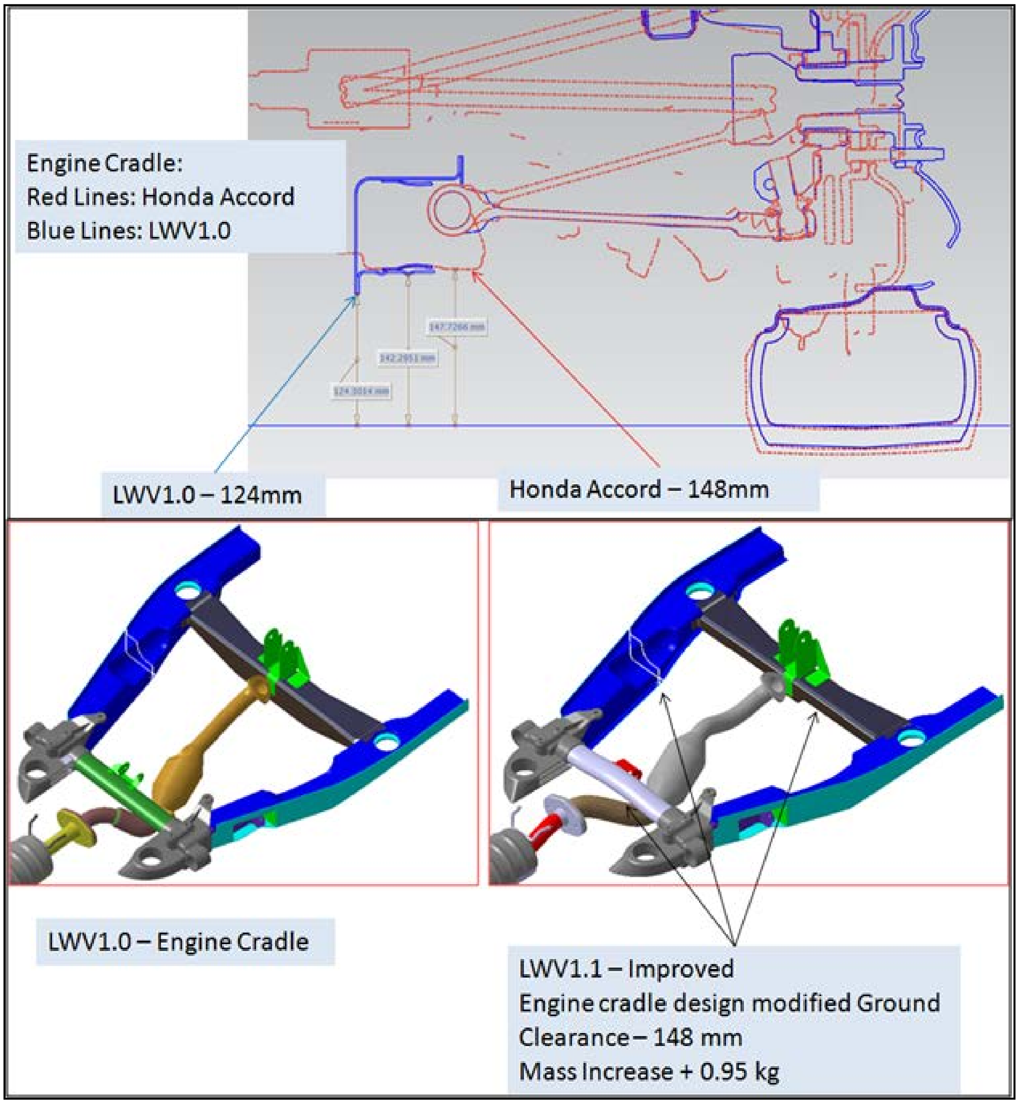


Figure 89: Ground clearance increased by modification to engine cradle

There were other comments from Honda on the drivability, ride comfort, noise, and mass compounding effect of the vehicle. These were not included in the LWV 1.1 design changes, but this section addresses Honda's concerns.

As shown in Figure 90, to address Honda's recommendations, hydraulic suspension mounts are used to improve ride comfort on flat and smooth road surfaces (3.5 kg weight increase). To dampen wheel body frequencies, rubber bushings with hydraulic damping are used. The hydraulic mounts/mounting bushes are installed at the shock tower and rear lower control mounts. Similarly hydraulic bushings are used on the rear suspension at key locations. The wheel rim thickness was also increased and insulation in aluminum doors and hood were added (5.8 kg) as recommended by Honda.

Honda identified 7.4 kg as incorrect mass, including wheel (+1.4 kg), temper tire/wheel (+0.8 kg), front brake disk (+3.3 kg) and caliper (+1.9 kg). These missing weights were accounted for in the latches/fasteners/mirrors-misc group in Figure 233 of the LWV report.[52] The total weight of the baseline vehicle was measured at 1,480 kg. Any vehicle system incorrect mass were captured in the latches/fasteners/mirrors-misc line in Figure 233.

This analysis did not include Honda's recommended mass increase of 40 kg mass due to platform sharing with heavier vehicles within the same family. One solution to this mass increase is to design the parts for the highest selling variant of the vehicle (in this case the Honda Accord) and add additional structure for the heavier variants as promoted by GM.[53] However, this is a business decision and beyond the scope of work for this project. This is an important concept and future research may want to focus on this important aspect.

There are other lightweighting technologies that were not implemented in the LWV 1.0 which can be used to offset the increase in weight proposed by Honda. Some of these technologies are further discussed in a presentation given by Harry Singh at the NHTSA Mass-Size-Safety Workshop on May 13and 14, 2013.[54] If these changes were implemented, the mass of the vehicle would further decrease by 27.0 kg over LWV 1.0 design.

The mass rebound effects of 42 kg identified by Honda are only relevant for Honda's mass estimates which are significantly different from the project team's estimates, i.e., 115 kg added back by Honda's estimate and 21.75 kg added back by the project team's estimates. So the rebound effect is small and was not accounted for in the project.

Issue	Design Change and recommendations	Weight Increase (kg)
LWV Mass Increase for Crashworthiness	See Table 3	11.50
Drivability	Increased ground clearance by modifying engine cradle	0.95
Ride Comfort	Use hydraulic suspension mounts to improve ride comfort on flat and smooth road surfaces	3.50
Noise	Increase wheel rim thickness	4.60
Noise	Additional insulation in aluminum doors and hood	1.20
Total LWV 1.0 mass increase		**21.75**

Figure 90: LWV 1.1 Design and Weight Changes to address Honda's Comments

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[52] Singh, 2012.

[53] Colias, M. (2013, February 8), "Crash diet gets results at GM." Detroit: Automotive News. Available at www.autonews.com/article/20130218/OEM03/302189922/crash-diet-gets-results-at-gm

[54] Singh, H. (2013). Feasible Amount of Mass Reduction for Light Duty Vehicles for Model Years 2017-2025. (PowerPoint presentation. © Copyright 2011 Engineering + Design AG [EDAG]). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/staticfiles/rulemaking/pdf/MSS/3-Singh-EDAG-NHTSA_2013.pdf

4.1.4 Conclusion

The mass and cost changes made to the body structure shown in Figure 84 are summarized in Figure 92. With these changes the mass of the body structure increased by 11.5 kg with a cost reduction of $13.41. The cost reduction is due the fact that lower grade (low cost premium) steel grades combined with lower cost manufacturing processes were used on the upgraded structure. Also, hot-stamping process used on several parts was replaced with regular stamping as shown in Figure 91. The martensitic steel rolled formed sections shown in Figure 91 were replaced with DP grade steel. The thickness of the rolled formed parts was increased to achieve same level of strength as the martensitic steel, this leads to a mass and cost increase of 3.96 kg and $2.05 respectively. The advanced high strength steel grade used for the LWV wheels was changed to lower cost high strength steel grade leading to mass increase of 4.60 kg and cost reduction of $8.80.

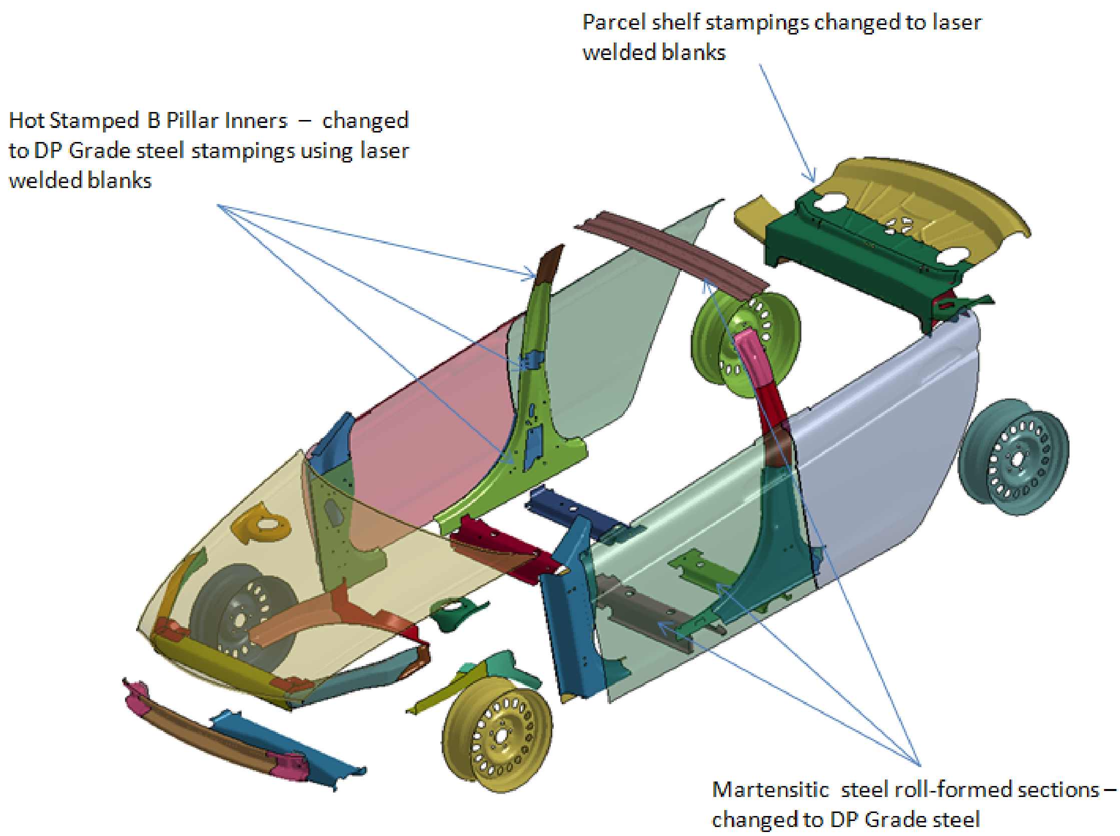


Figure 91: Modified parts from 1.0 to 1.1 design

Manufacturing Technology	Parts Weight (kg)	Manufacturing and Assembly Cost ($)
Stamping	3.73	3.35
Stamping Laser Welded Blanks	13.94	31.79
Hot Stamping	0.00	0.00
Hot Stamping Laser Welded Blanks	-10.18	-50.92
Roll-forming Open/Closed	3.96	2.05
Body Structure Part Manufacture	**11.5**	**-13.73**
Body Structure Assembly		**0.32**
Body Structure Delta Increase (- Decrease) From V1.0 to V1.1	**11.5**	**-13.41**
Increased ground clearance by modifying engine cradle	0.95	**4.59**
Use hydraulic suspension mounts to improve ride comfort on flat and smooth road surfaces ($4.75 x 4)	3.50	**19.00**
Increase wheel rim thickness (and lower cost of steel)	4.60	**-8.80**
Additional insulation in aluminum doors and hood ($3.35x5)	1.20	**16.75**
Total Delta Increase (- Decrease) From V1.0 to V1.1	**21.75**	**$18.13**

Figure 92: Summary of Mass and Cost for the updated design LWV 1.1

The total mass of the LWV 1.0 vehicle 1,148 kg is increased by 21.75 kg to 1,170 kg to represent the LWV 1.1 vehicle. This is equivalent to 20.9 percent (310 kg) mass saving from the 2011 Honda Accord baseline vehicle mass of 1,480 kg. The incremental direct manufacturing cost of $319[55] for LWV 1.0 is increased by $18.13 to $338 for the LWV 1.1. The direct manufacturing mass saving cost premium for the LWV 1.1 is calculated to be $1.09 per kg ($338/310 kg) and is shown in Figure 93.

[55] Singh, 2012.

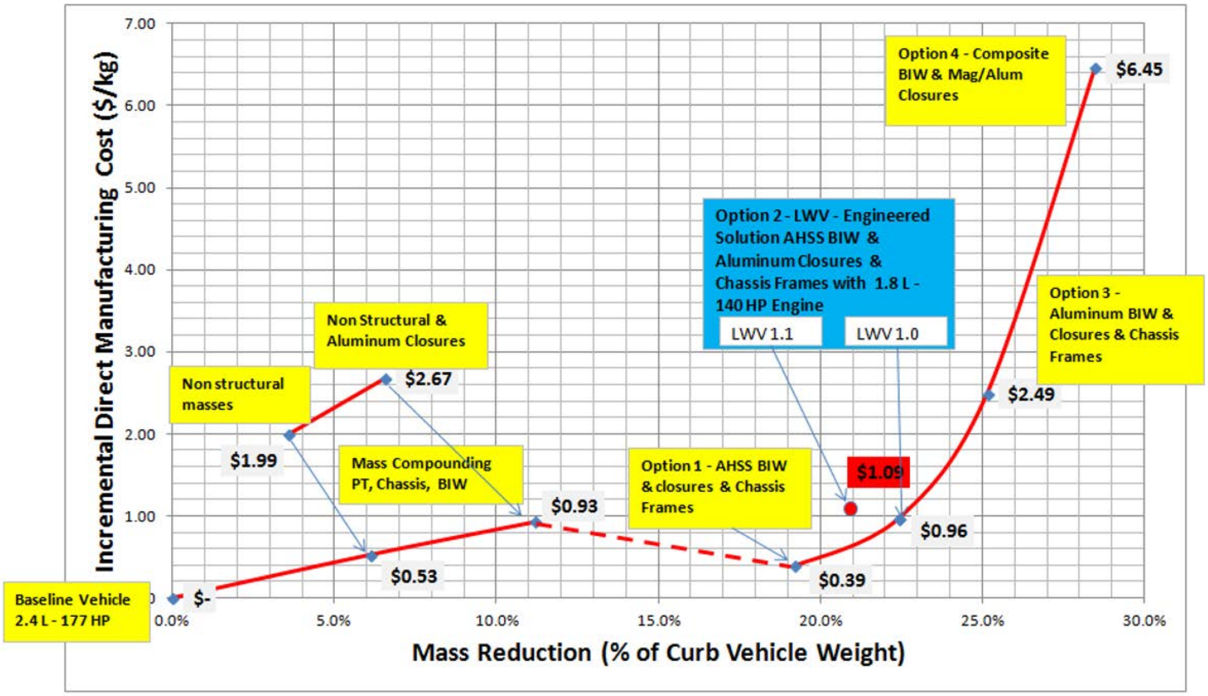


Figure 93: LWV 1.0 and LWV 1.1 mass savings versus costs premium (with Powertrain costs) curve

4.2 C.5.2 Weight and Cost Changes for LWV for Small Frontal Offset Test

4.2.1 IIHS Small-Overlap Frontal Barrier Test

The IIHS SOL test is designed to reproduce what happens when the front corner of a vehicle hits another vehicle or an object like a tree or utility pole. Because occupants move both forward and toward the side of the vehicle, the small-overlap test may also lead to improved safety belt and airbag designs.

In this test, a vehicle travels at 40 mph toward a 5-foot-tall rigid barrier. A Hybrid III dummy representing an average-size male is positioned in the driver seat. Twenty-five percent of the total width of the vehicle strikes the barrier on the driver side. More details on the SOL test are discussed in Section 3.1.8

Vehicle performance in the IIHS SOL test is determined by three categories: restraint and dummy kinematics, dummy injury measures, and vehicle structural performance. The structural rating is based on (1) the structural intrusions into the passenger compartment at seven locations on the vehicle interior plus (2) the movement of three points along the door frame.

On most vehicles the 25 percent offset barrier is outboard of the main front-rail structure of the vehicle as shown Figure 94. On review of several IIHS crash videos, it was noticed that vehicles that do not perform well in the test shows the following characteristics:

1. The front frame rail does not engage the barrier and hence does not play a significant role in slowing the vehicle down.

2. There is significant failure of the suspension and drive components, such as control arm, knuckle, drive-shaft, steering link, ball joints, wheel rim and tire.
3. The tire wheel assembly is pushed hard into the Front Body Hinge Pillar structure, causing the A Pillar' and Rocker Section to collapse
4. The failures of the A-Pillar' and the Rocker lead to excessive penetration of the Dash Panel, Instrument Panel and Steering Column/Wheel into the passenger compartment. This collection of structural failures also leads to lateral movement of the steering wheel thus displacing the driver airbag.

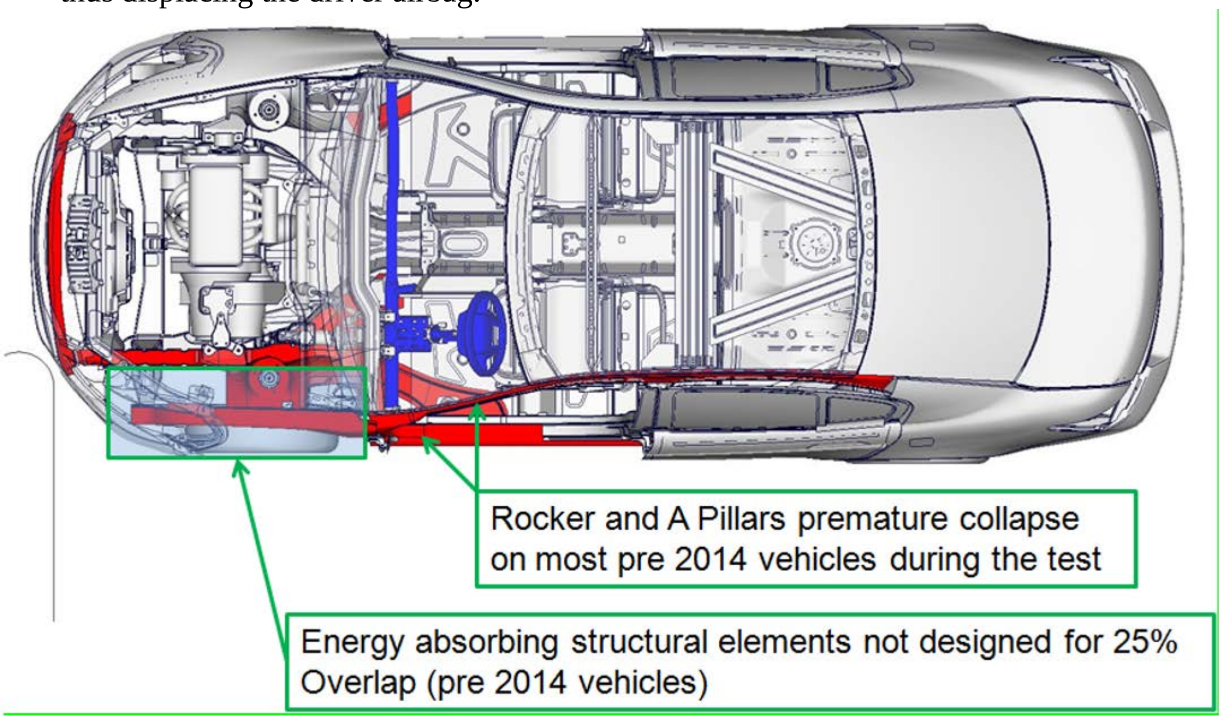


Figure 94: Typical pre-2014 vehicle design structure

4.2.2 LWV 1.2 Design Changes to Address SOL Test

In order to improve the structural performance during the SOL test, several options were considered and implemented using a detailed LS-DYNA crash model that was originally part of the NHTSA LWV 1.0 study. The CAE model LWV 1.0 was first updated to version 1.1 to address the shortfalls in performance as identified by Honda as discussed in Section 3.

The team reviewed seven design options to improve the structure performance for SOL test. These design options are shown in Appendix 7. The most effective design changes are chosen as shown in Figure 95.

These changes include reinforcement of three major areas in the body structure and were designed for easy manufacturability easily assembly into the body structure.

1. Triangular shaped blocks were added to the front ends of the rails to connect the front rail with the upper rail as shown in Figure 95. This structural change increased the weight by 1.72 kg. At the initial contact with barrier this block acts as a deflector and also directs loads into the front rail. The deformation of the rails also absorbs kinetic energy and help to slow the vehicle down as shown in Figure 96 and Figure 97.

2. The A-pillar section and the A-pillar to front body hinge pillar shown in Figure 95 joints were reinforced which increase the vehicle weight by 1.90 kg. The Rocker and Shotgun sections shown in Figure 95 were also reinforced with additional reinforcement panels that increase vehicle mass by 1.84 kg and 1.44 kg, respectively. These changes stabilize passenger compartment, reducing the intrusions significantly; the results with these changes are further discussed in in Section 5.1 of this report. The avoidance of failures of the A-pillar' and the rocker reduces the excessive penetration of the dash panel, instrument panel and steering column/wheel into the passenger compartment. Due to these changes the lateral movement of the steering wheel is also significantly reduced keeping the driver airbag in place as shown in Figure 96 and Figure 97.
3. The design of the suspension and drive components including the wheel were not changed, but these components were represented in the CAE model with non-linear material properties and appropriate material failure criteria.

All of these changes of upgrading LWV 1.1 to 1.2 resulted in a total mass increase of 6.9 kg.

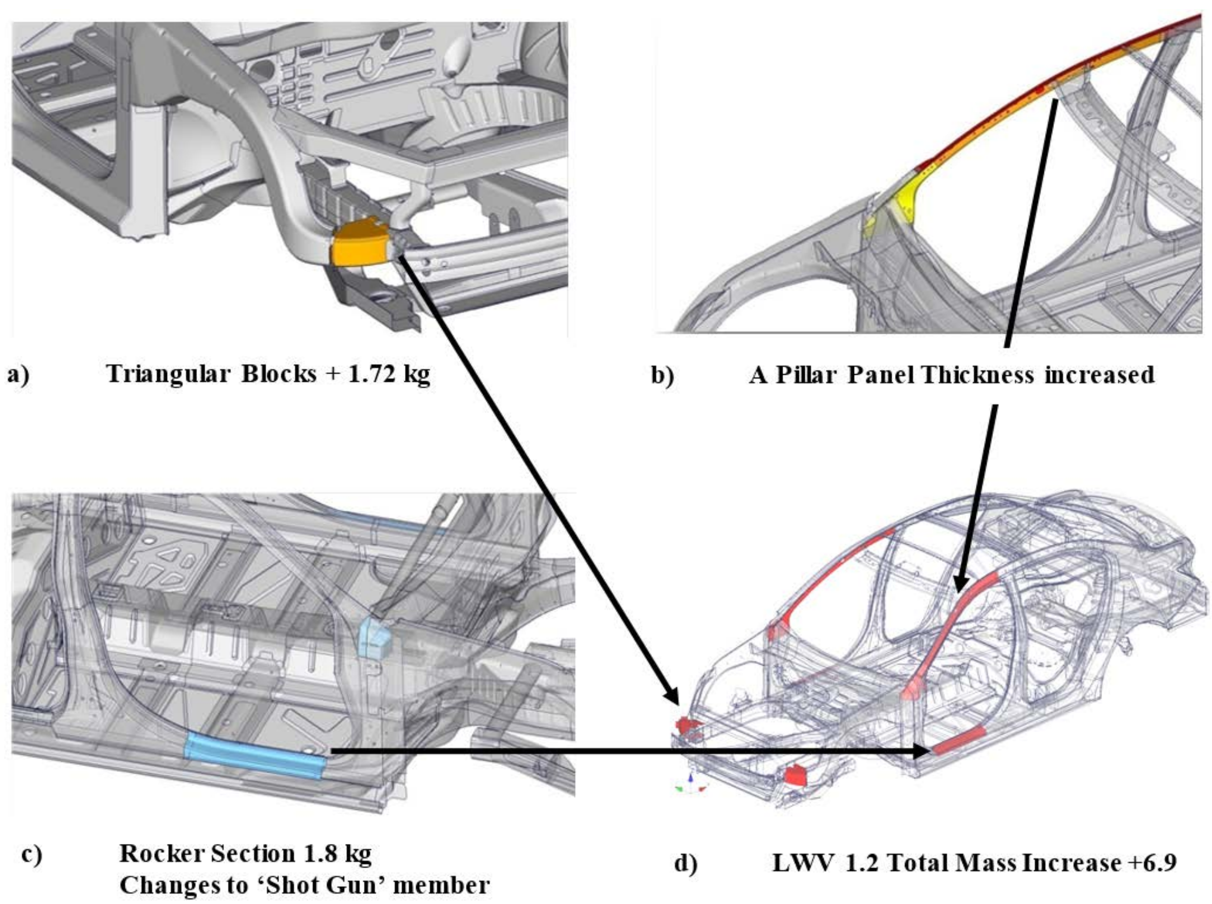


Figure 95: Recommended changes to meet SOL test requirements

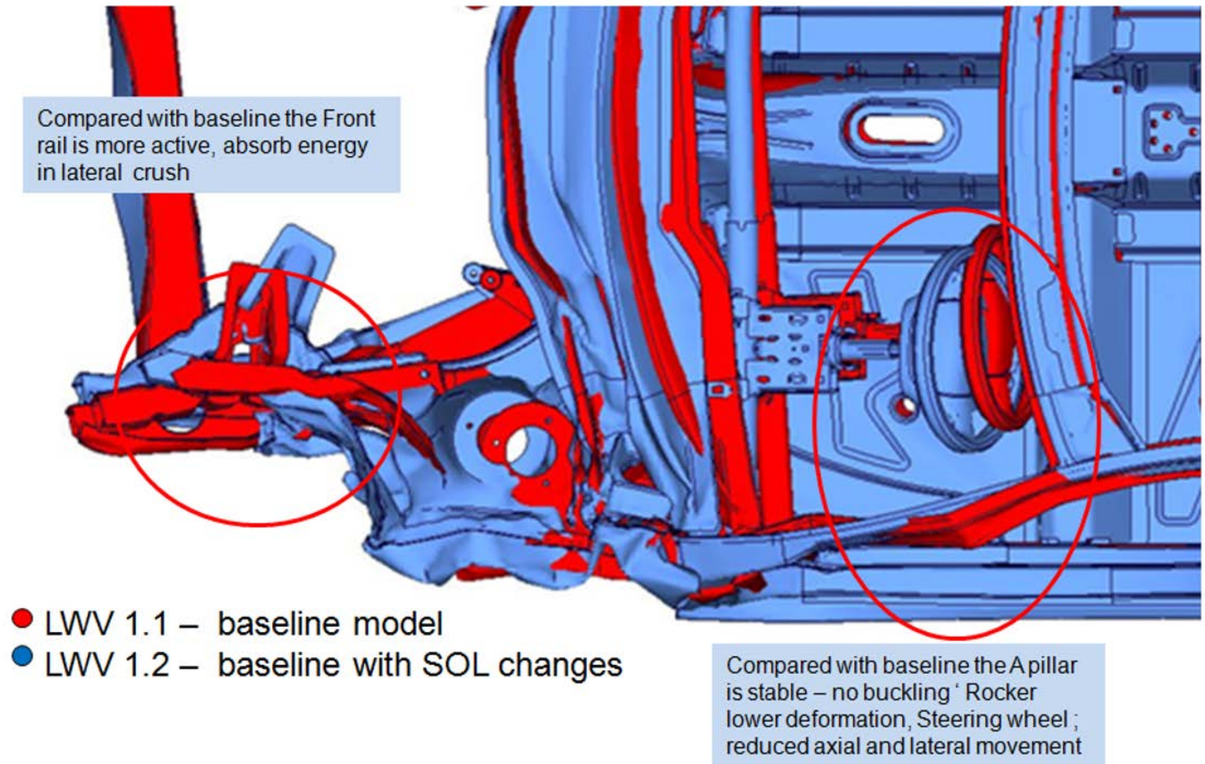


Figure 96: Comparison structural deformation Baseline LWV 1.1 versus LWV 1.2 with SOL design changes

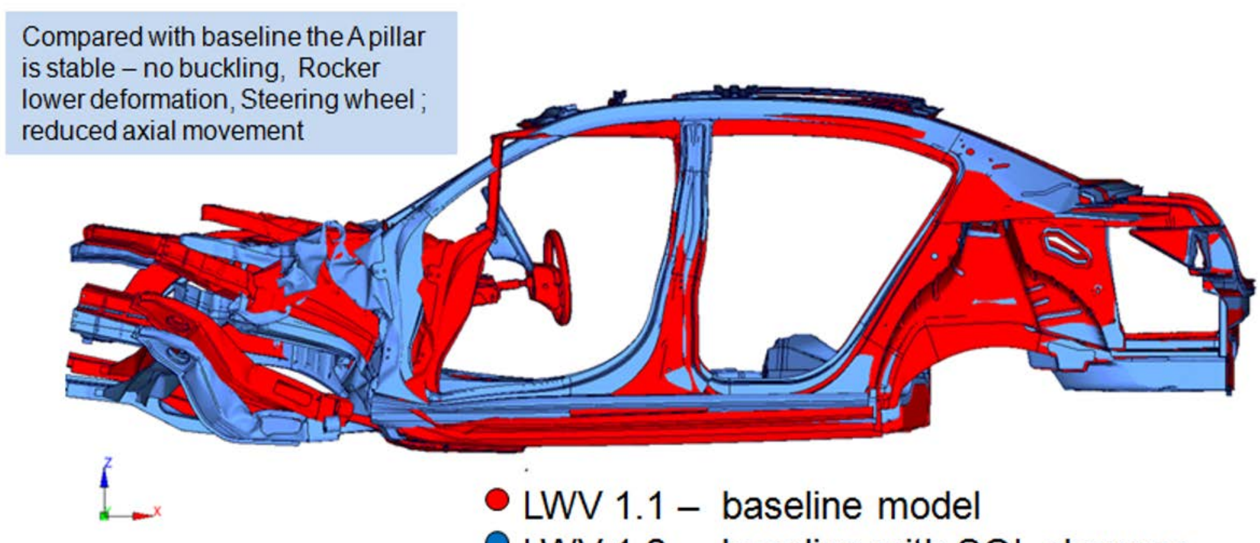


Figure 97: Comparison structural deformation Baseline LWV 1.1 versus LWV 1.2 with SOL design changes

4.2.3 Weight and Cost Increase to Meet SOL Requirements

Several design changes were made to the LWV 1.2 to achieve most cost and mass efficient solution. The changes made to the vehicle body structure and material thickness and grade are highlighted in Figure 94. The mass and cost impact of the changes made to the body structure to meet SOL test requirements are summarized in Figure 98 . With these changes from LWV 1.1 to 1.2, the mass of the body structure increased by 6.90 kg with a cost increase of $26.88.

Manufacturing Technology	Parts Weight (kg)	Manufacturing and Assembly Cost ($)
Stamping	2.89	7.70
Stamping Laser Welded Blanks	0.00	5.67
Hot Stamping	2.07	6.58
Hot Stamping Laser Welded Blanks	1.99	1.97
Roll-forming Open / Closed	-0.05	-1.40
Body Structure Manufacturing	6.90	20.52
Body Structure Assembly		6.36
Delta Increase (- Decrease) From V1.1 to V1.2	6.90	26.88

Figure 98: Summary of Mass and Cost for the updated design from LWV 1.1 to 1.2

The total mass of the LWV 1.1 vehicle 1,170 kg is increased by 6.9 kg to 1,177 kg to represent the LWV 1.2 vehicle. This is equivalent to 20.5 percent (303kg) mass saving from the 2011 Honda Accord baseline vehicle mass of 1,480 kg. The incremental direct manufacturing cost of $319[56] for LWV 1.0 is increased by $26.88 to $364 for the LWV 1.2. The direct manufacturing mass saving cost premium for the LWV 1.2 is calculated to be $1.20 per kg ($364/303kg) and is shown in Figure 99.

[56] Singh, 2012.

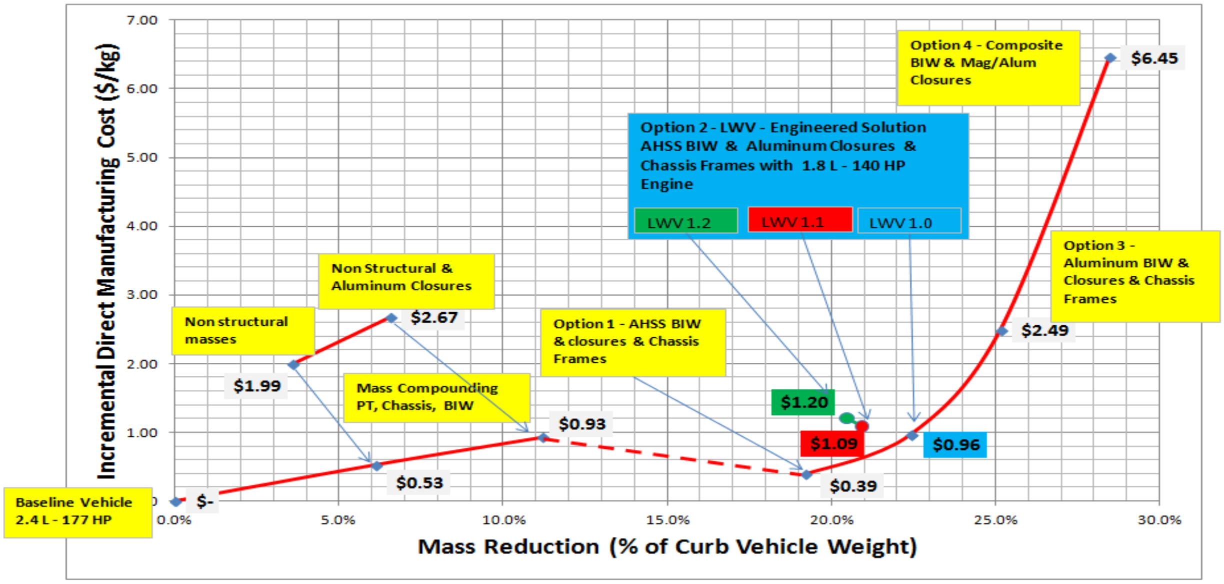


Figure 99: LWV 1.0, LWV 1.1 and LWV 1.2 mass savings versus costs premium (with Powertrain costs) curve

4.3 Lightweight Vehicle 1.2 Crashworthiness Modeling

The following section discusses the crashworthiness performance of the improved LWV 1.2 design. It is noteworthy to mention here that the improvements made in this phase of the study were focused only on the SOL impact and making the new LWV design performance equivalent or better than the new MY2013 Accord vehicle under this impact condition. The crashworthiness of the LWV 1.2 under the other impact cases was evaluated and presented here only to ensure that the vehicle performance is not negatively affected by the new updates. Consequently, the performances of the LWV 1.2 under the other impact conditions are expected to be similar to the original design (LWV 1.1) which was optimized in the previous study to be equivalent or better than MY2011 Accord vehicle and not the MY2013 (the previous study was completed prior to the release of the 2013 MY Accord).

For completeness, the LWV 1.2 simulation results are compared to both the MY2013 and MY2011 (or equivalent) Accord vehicle tests except for the following two cases:

- For the IIHS SOL impact, the simulation results were compared to only the MY2013 test. The MY2011 (or equivalent) tests were not included in the comparison because the vehicles were tested under different impact conditions (the barrier offset and curvature were different than the MY2013 test)
- For IIHS moderate offset impact, the simulation was compared to only a MY2009 (equivalent to MY2011) Accord test because no tests are available for the MY2013 vehicle.

4.3.1 <u>IIHS Small-Overlap Front Test</u>

The LWV 1.2 model was setup in an impact condition similar to the IIHS Test No. CEN1229. In this test, a MY2013 Accord vehicle traveling at 40 mph struck a 5-foot tall rigid barrier. The barrier edge has curvature radius of 150 mm. The offset relative to the barrier was Twenty-five percent of the total width of the vehicle. A Hybrid III dummy representing an average-size male was positioned in the driver seat. Figure 100 illustrates the LS-DYNA set-up from a top view of the LWV 1.2 and the barrier.

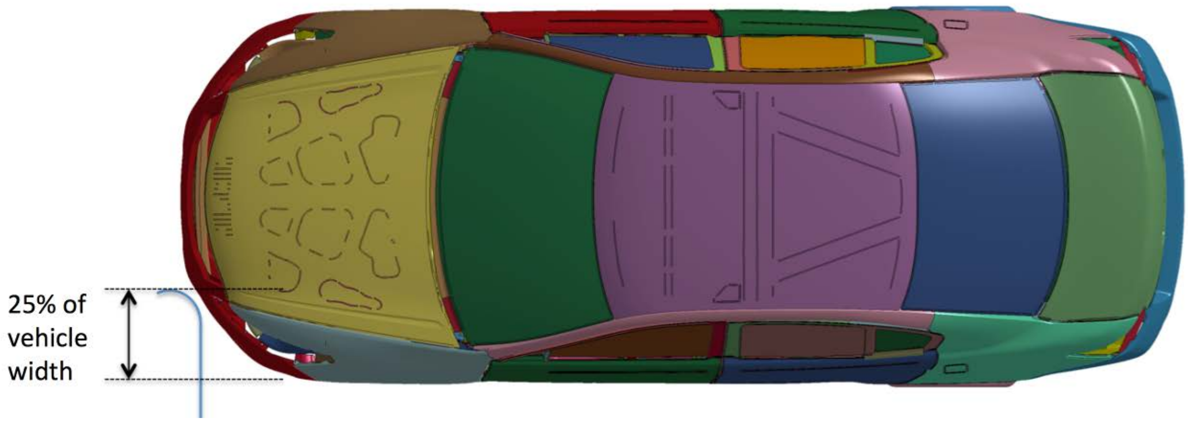


Figure 100: LS-DYNA set-up for IIHS 25 percent offset small-overlap of the LWV 1.2

The objective of this study is to improve the performance of the LWV design in SOL impact such that it is similar or better than the newly redesigned MY2013 Accord. The post-crash vehicles for the actual laboratory crash of MY2013 Honda Accord and the LWV 1.2 simulation are shown in Figure 101. The crash pulses in the longitudinal and lateral direction for the center of gravity (CG) are shown in Figure 102 and Figure 103 respectively. Also shown, the FEM predicted pulses has similar peaks compared to pulse from the one from the MY2013 Honda Accord crash test. Figure 104 shows the change in velocity in longitudinal and lateral direction of LWV 1.2 from simulation and the Honda Accord tests. The LWV 1.2 experiences a slightly higher change in velocity in longitudinal direction compared to Honda Accord tested. This could be attributed to difference in weight between the two vehicles. The vehicle comparison between the MY2013 Accord tested for IIHS SOL and the LWV 1.2 is shown in Figure 105. This difference should lead to negligible difference in occupant safety and overall crashworthiness since the acceleration pulses of the two vehicles in the same direction are similar in magnitude and duration. The post-crash intrusion measurement for LWV 1.2 and Honda Accord is shown in Figure 106 where it can be seen that occupant compartment intrusions from the LWV 1.2 simulation are smaller than MY 2013 Accord, especially at lower dash panel and the lower and upper hinge pillars. Figure 106 indicates that all intrusions from the LWV 1.2 are in the good region of the IIHS scale. All comparisons indicate that the LWV 1.2 performance is equivalent or better than the MY2013 Accord in the IIHS SOL impact.

Figure 101: Post-crash vehicles for the MY2013 Honda Accord actual laboratory crash and the simulation for LWV 1.2 in the IIHS small-overlap test

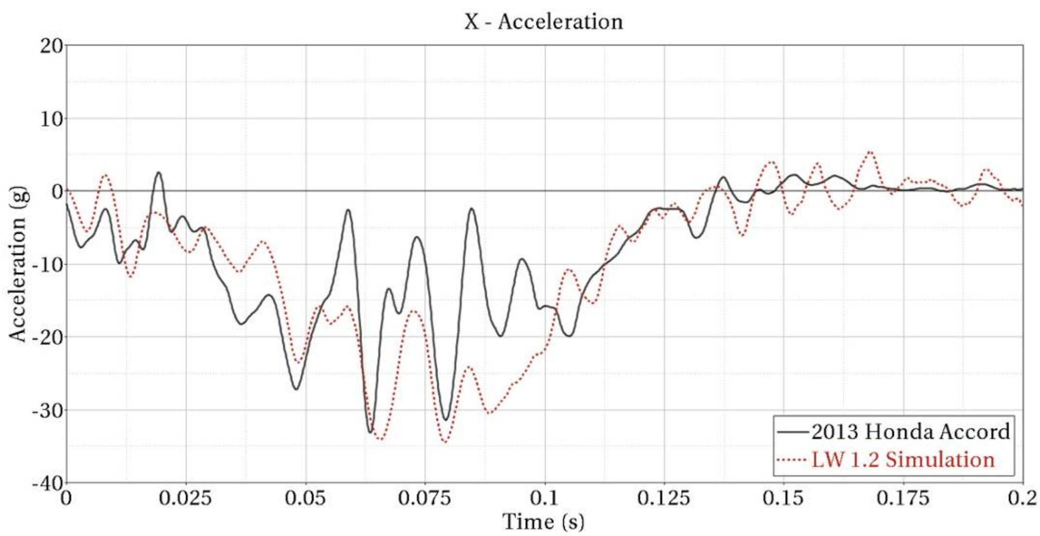


Figure 102: Crash pulse in the x-direction for the center of gravity of the MY2013 Honda Accord and the LWV 1.2 in IIHS small-overlap impact

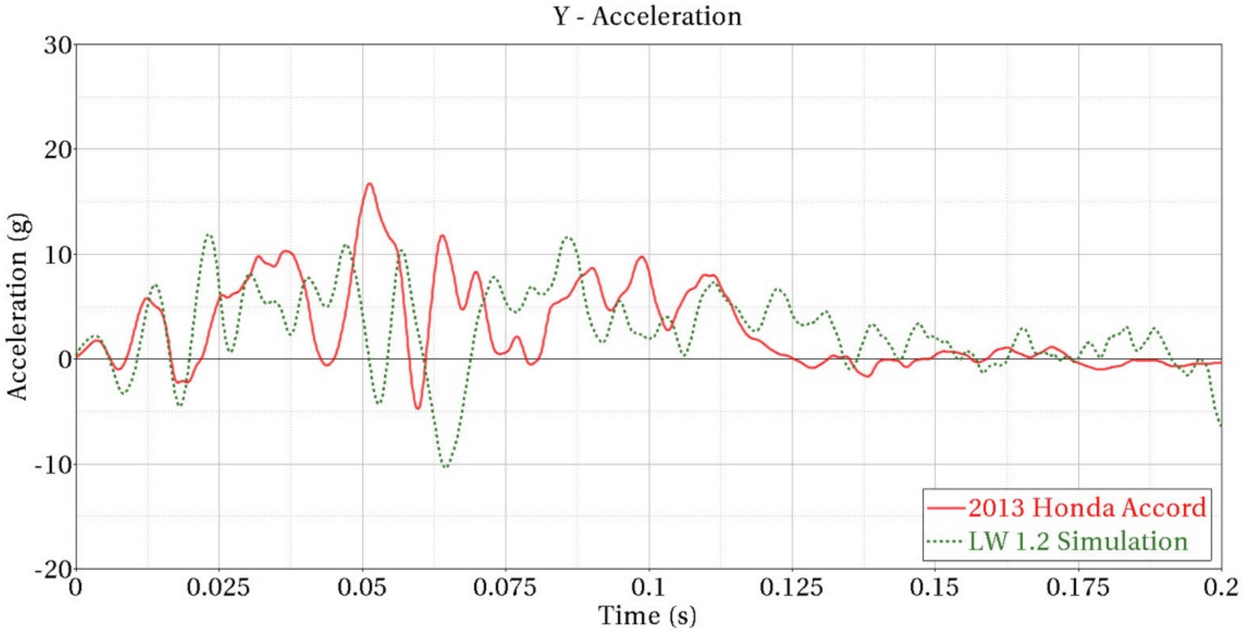


Figure 103: Crash pulse in the y-direction for the center of gravity of the MY2013 Honda Accord and the LWV 1.2 in IIHS small-overlap impact

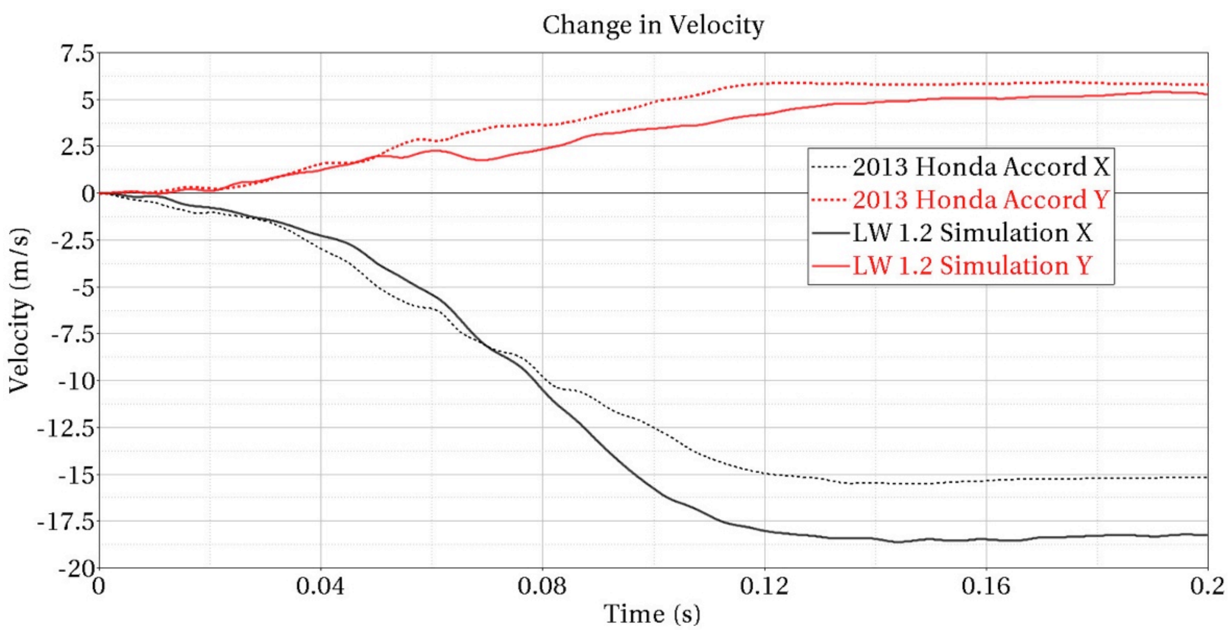


Figure 104: Change in velocity in x- and y-direction of MY2013 Accord and LWV 1.2

	LWV 1.2	Accord 2013
Weight (kg)	1,251	1,622
Engine Type	1.8L I4	2.4L I4
Tire size	P215/60R16	P215/60R16
Wheelbase (mm)	2800	2800
Body Style	4-Door Sedan	4-Door Sedan

Figure 105: Comparison of MY2013 Honda Accord and LWV 1.2

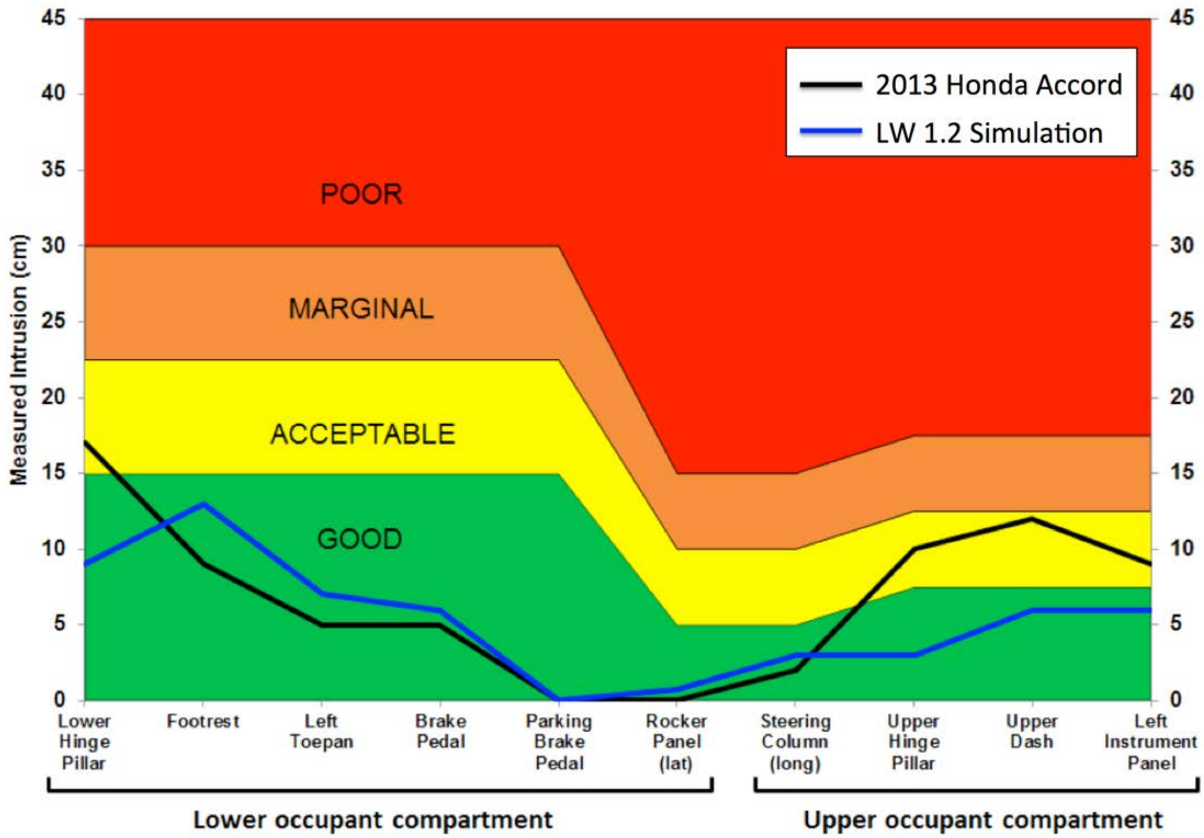


Figure 106: Intrusions of MY2013 Accord and the LWV 1.2 on the IIHS structural measuring scheme

4.3.2 Frontal NCAP Test

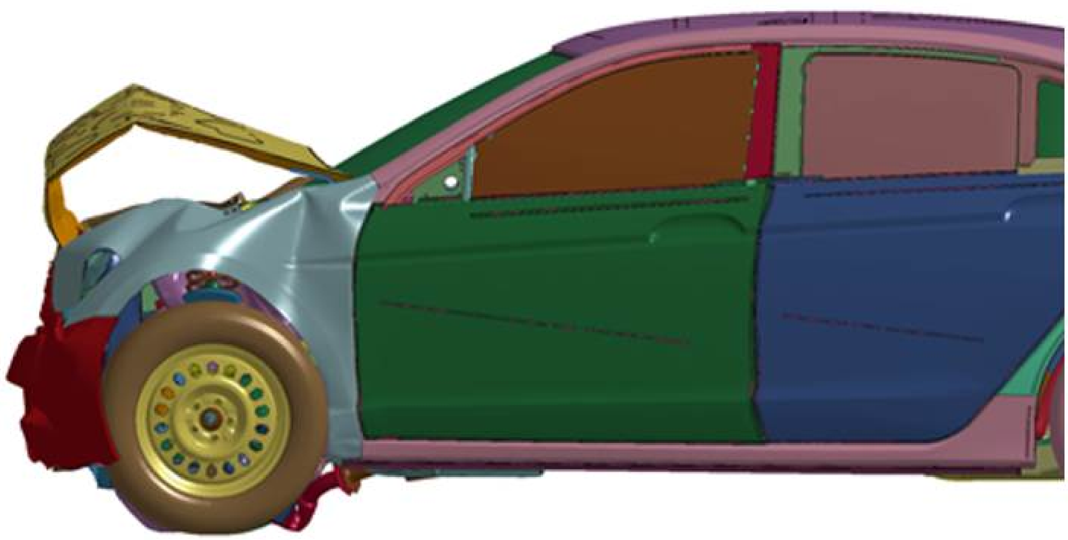
The frontal impact test of the NCAP, undertaken by the NHTSA, is a full frontal barrier test at a vehicle speed of 56 km/h (35 mph). This test is used to determine the crashworthiness of the vehicle to protect occupants in frontal impact crash cases.

The LWV 1.2 model used in the US NCAP analysis has a test weight of 1,339 kg, which includes curb weight of vehicle as 1,164 kg, 140 kg weight of two ADTs (a Hybrid III 50th percentile male driver and a Hybrid III 5th percentile female front passenger weight), and 45 kg cargo weight for the instrumentation.

The frontal NCAP test determines the crashworthiness of a vehicle based on the injury-based data (HIC, Nij, chest compression, and femur forces) obtained from the dummies. The scope of work of this study did not encompass simulation of dummy occupants in the finite element model of the crash. Therefore, the LWV 1.2 is evaluated based on structural-based safety parameters (crash pulse and occupant compartment intrusion) and compared with the safety rating of the MY2011 Honda Accord. It is assumed that if the structural performances of the LWV 1.2 and MY2011 Accord vehicles are similar, their occupant response and consequently the injury risk would be similar.

The LS-DYNA set-up for the frontal crash test of the lightweight vehicle model into a rigid barrier is shown in Figure 107. Images of the post-crash vehicles for the actual laboratory crash and the simulation are in Figure 108.

Figure 107: LS-DYNA set-up for frontal rigid wall test



Post-crash Picture of MY2011 BL Honda Accord (from Real Vehicle Test)

Post-crash Picture of LWV 1.2 (from Simulation)

Figure 108: Post-crash pictures of MY2011 Honda Accord and LWV 1.2

The crash pulse for the left rear sill is shown in Figure 109 indicating that the maximum acceleration of the FEM simulation is close to the actual laboratory pulse. The 111 ms time width of the FEM acceleration pulse is close to the ~120 ms time width of the tests. The sharp drop in acceleration of the MY2011 Honda Accord test between 40 ms to 50 ms is due to the engine cradle rear mount dropping from the body structure designed at predetermined loads to control the front end crash behavior. But this drop is not observed on in the MY2013 crash behavior. The engine cradle drop is a design feature used on some vehicles to control the magnitude of intrusion into the foot well area of the occupant compartment. The LWV 1.2 is designed to limit the foot well intrusion without this feature. The LWV 1.2 engine cradle is extended forward to become active early in crash event and as a result it becomes an energy absorbing member. This design feature alleviates the need for dropping the engine mount in the NCAP frontal test.

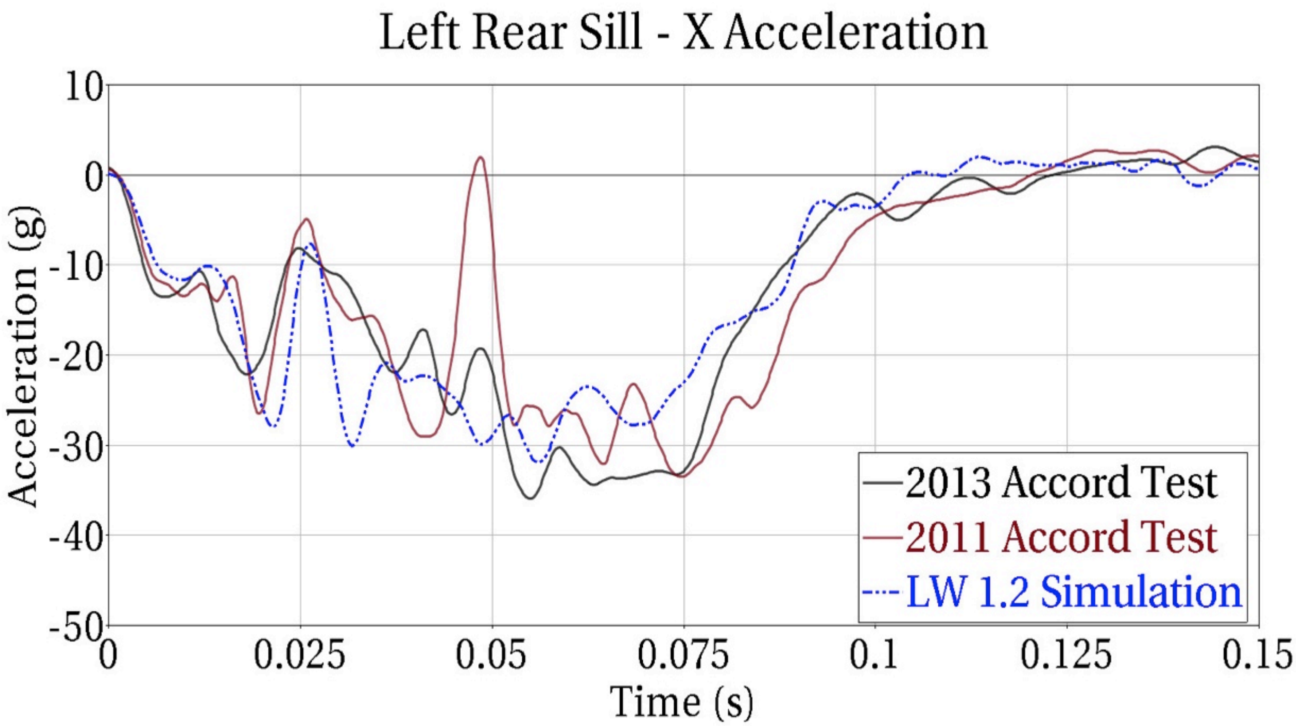


Figure 109: Acceleration pulse of MY2011 and MY2013 Honda Accord and LWV 1.2 for left-rear sill in rigid-wall crash

Timely airbag deployment is very critical in keeping the occupant injuries to the minimum and in meeting the 5-Star Safety Ratings. Figure 110 shows the acceleration plot from 0 to 0.02 seconds. The average value of acceleration generally is required to be of the order of 7G's or higher during 0.005 to 0.015 seconds for instruments to sense the crash event and deploy the airbags. As can be seen from Figure 110 the LWV 1.2 has average pulse value of -10g during this time frame, indicating that the instruments can be correlated to identify the event in a timely manner similar to the Honda Accord vehicle.

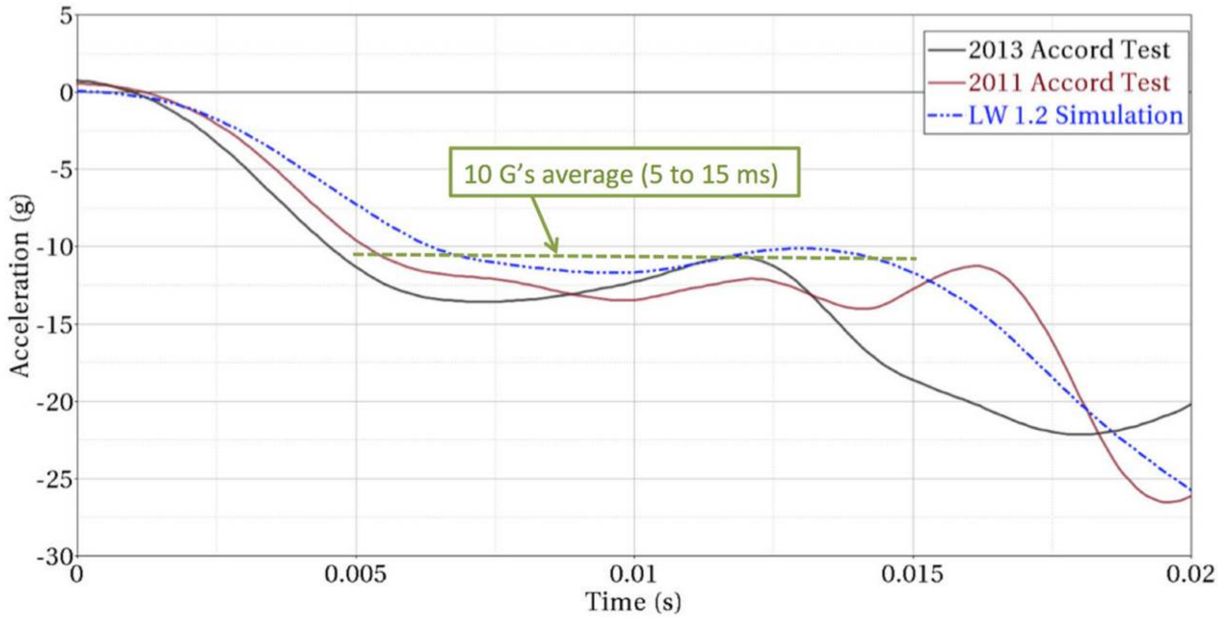


Figure 110: Acceleration pulse of MY2011 and MY2013 Honda Accord and LWV 1.2 for left-rear sill in rigid wall crash 0 to 20 ms

Figure 111 is the velocity plots for MY2011 and MY2013 Accord vehicle tests and LWV 1.2 at the left-rear sill. This figure shows that the structure of the LWV 1.2 stops (i.e., goes from the initial velocity to zero) about the same time as the structure of the MY2013 Accord. The occupant restraint systems that are designed for MY2013 Accord can be readily adopted on LWV 1.2.

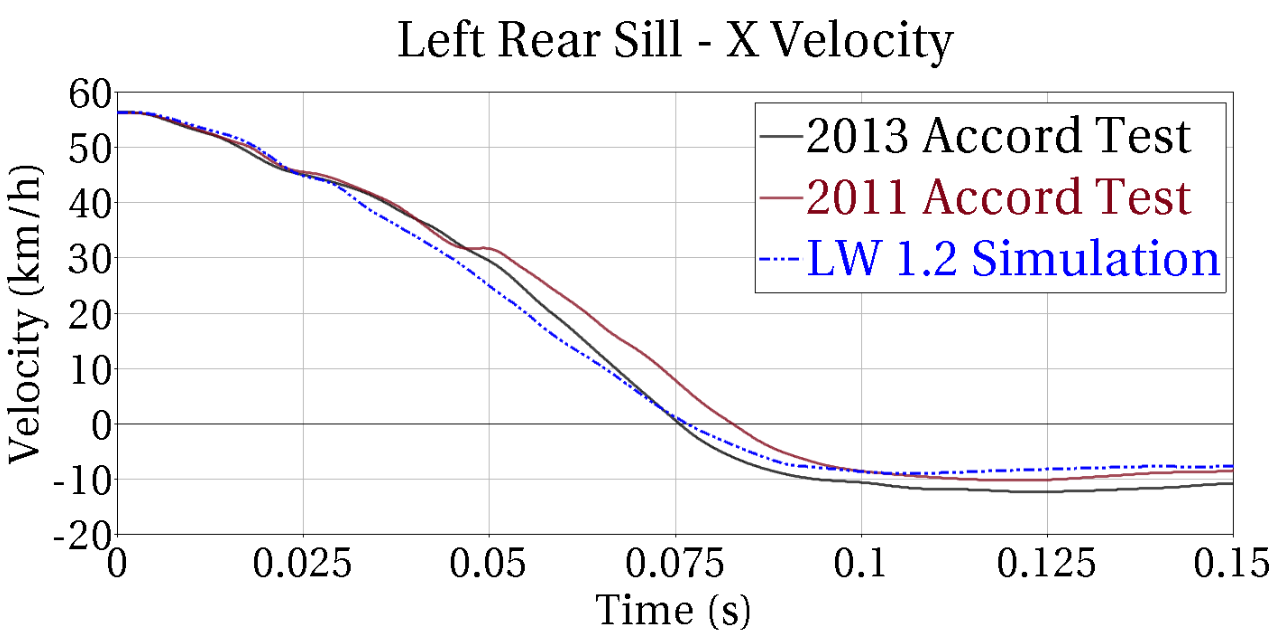


Figure 111: Velocity of MY2011 and MY2013 Accord and LWV 1.2 for left-rear sill in rigid wall crash

The acceleration and velocity for the right-rear sill are shown in Figure 112 and Figure 113. The curves of the left-rear sill acceleration and velocity are similar to the curves of the right-rear sill acceleration and velocity. The discussion of the left-rear sill accelerations and velocity can be equally applied to the right-rear sill acceleration and velocity.

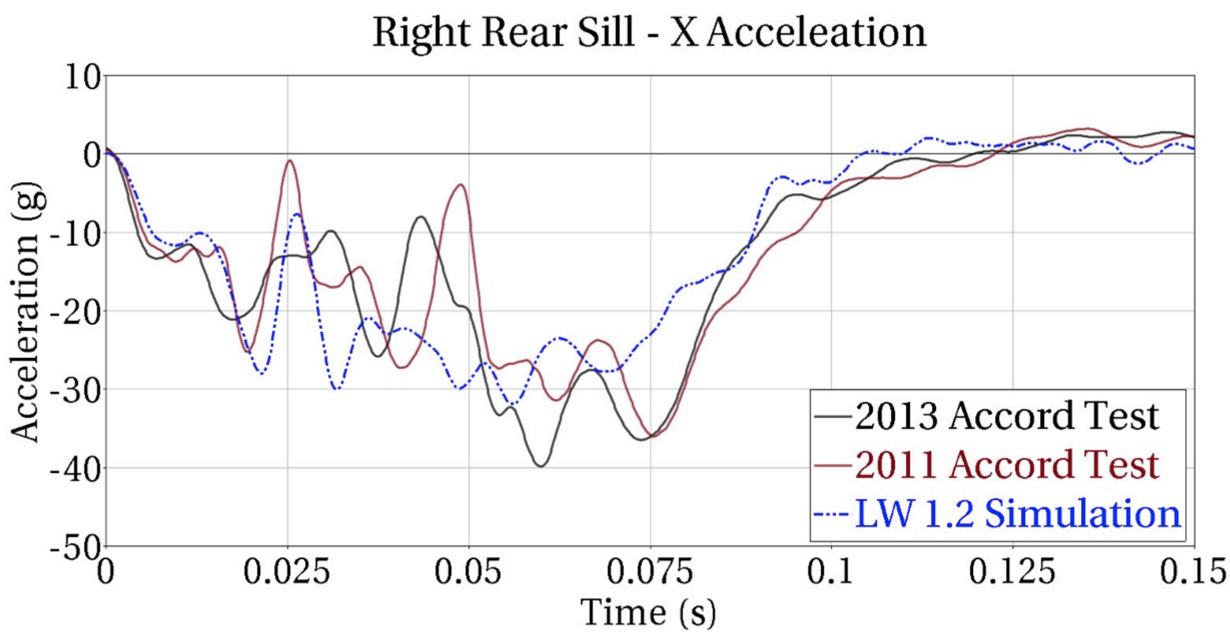


Figure 112: Acceleration pulse of MY2011 and MY2013 Accord and LWV 1.2 for right-rear sill in rigid wall crash

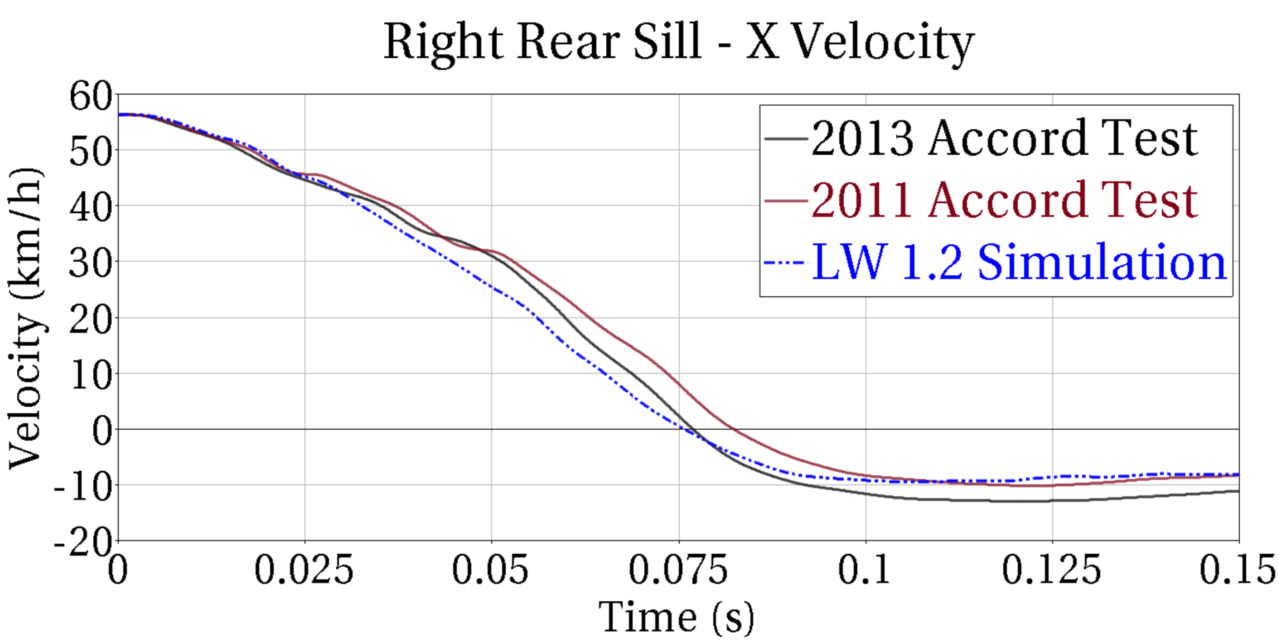


Figure 113: Velocity of MY2011 and MY2013 Honda Accord and LWV 1.2 for right-rear sill in rigid wall crash

Figure 114 lists the intrusion (post-crash deformation) into the occupant compartment for the MY2011 and MY2013 Honda Accord and the LWV 1.2. There was negative intrusion of 40 mm at the footrest (i.e., the distance between the foot rest and the measurement reference point is higher after impact), which is smaller and similar to the intrusion recorded in the MY2013 Honda Accord test. The brake pedal intrusion was 8 mm which is likely to achieve a “Good” safety rating in terms of brake pedal movement when compared with the criteria established by IIHS. Also, the LWV 1.2 had less brake pedal intrusion toward the driver compared to the MY2013 Honda Accord. The front design of the LWV 1.2 does not include dropping the engine cradle, but the LWV 1.2 has an equivalent safety rating compared to the MY2013 Honda Accord.

Vehicle	Brake pedal intrusion in NCAP frontal test (mm)	Foot rest intrusion in NCAP frontal test (mm)
MY2013 Honda Accord	35	-40
MY2011 Honda Accord	-3	8
Lightweight vehicle V1.2	8	-40

Figure 114: Occupant intrusion for MY2011 and MY2013 Honda Accord and LWV 1.2 vehicle in NCAP frontal test

4.3.3 Lateral NCAP Moving Deformable Barrier Test

In this crash test, a MDB with a mass of 1370 kg impacts the LWV 1.2 on the driver’s side with velocity of 60.9 ± 0.8 kph. The finite element model accounts for a 50th percentile male dummy, a 5th percentile female dummy, and cargo in the rear with a total mass of 185 kg.

The LS-DYNA software is set-up for the NCAP side impact crash test of the LWV 1.2 model with a moving deformable barrier is exemplified in Figure 115. Images of the post-crash vehicles for the actual laboratory crash of a MY2011 Honda Accord and the simulation are shown in Figure 116. Figure 117 shows exterior crush profile for level 2, which is located at approximately the H-point level of the driver dummy. The side intrusion of the MY2013 was less than the MY2011 vehicle. This is attributed to the fact that in MY2011 Accord test, the front door panel separates from the inner panel structure and is also reflected in a higher crush results between 1000 mm and 1250 mm from the impact point. The LWV 1.2 exterior crush results are between the MY2011 and MY2013 vehicle test results. These intrusions are smaller than the LWV 1.1 model developed in the first phase of the study. This reduction in intrusion is due to the increase in thickness of the hot stamped A-pillar body structure introduced to improve the SOL performance. Figure 118 shows exterior crush profile for level 3, which is located at approximately the mid-door level.

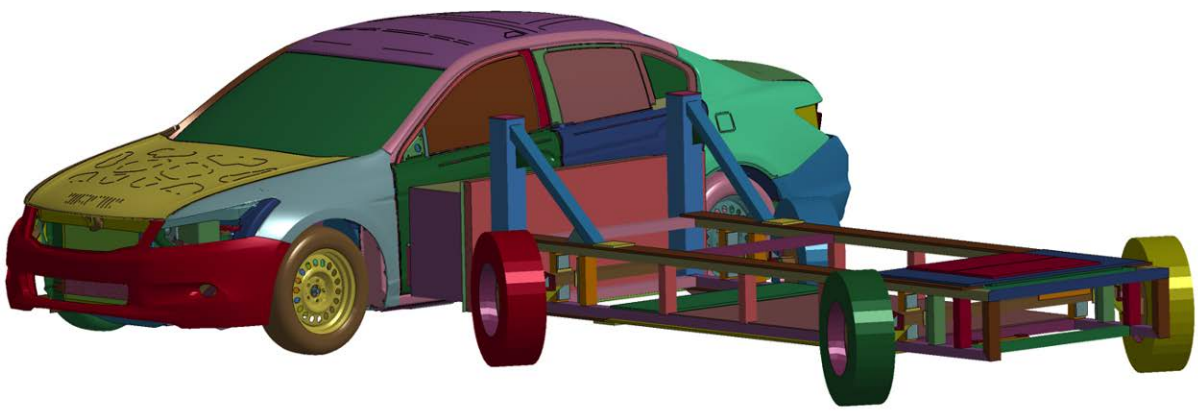


Figure 115: LS-DYNA set-up for the NCAP moving deformable barrier lateral test

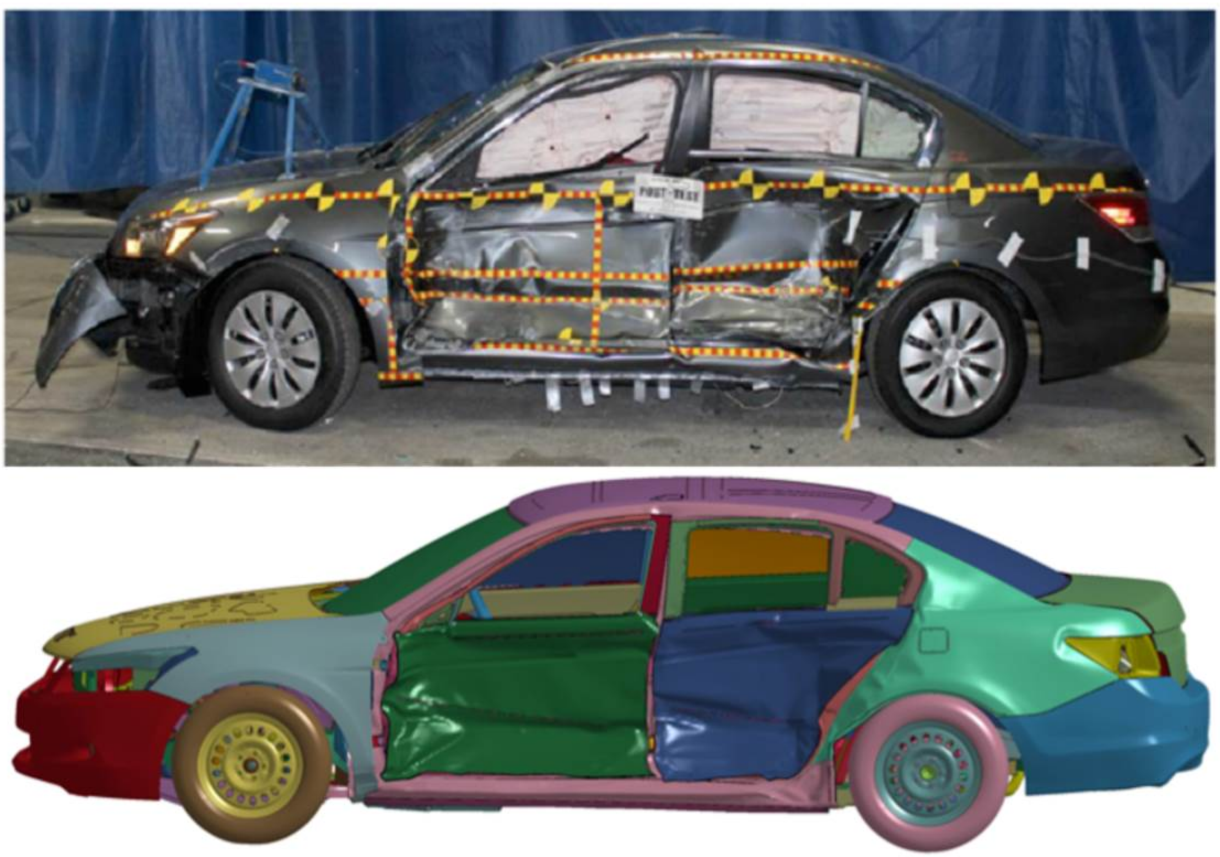


Figure 116: Post-crash picture of MY2011 Accord and LS-DYNA LWV 1.2

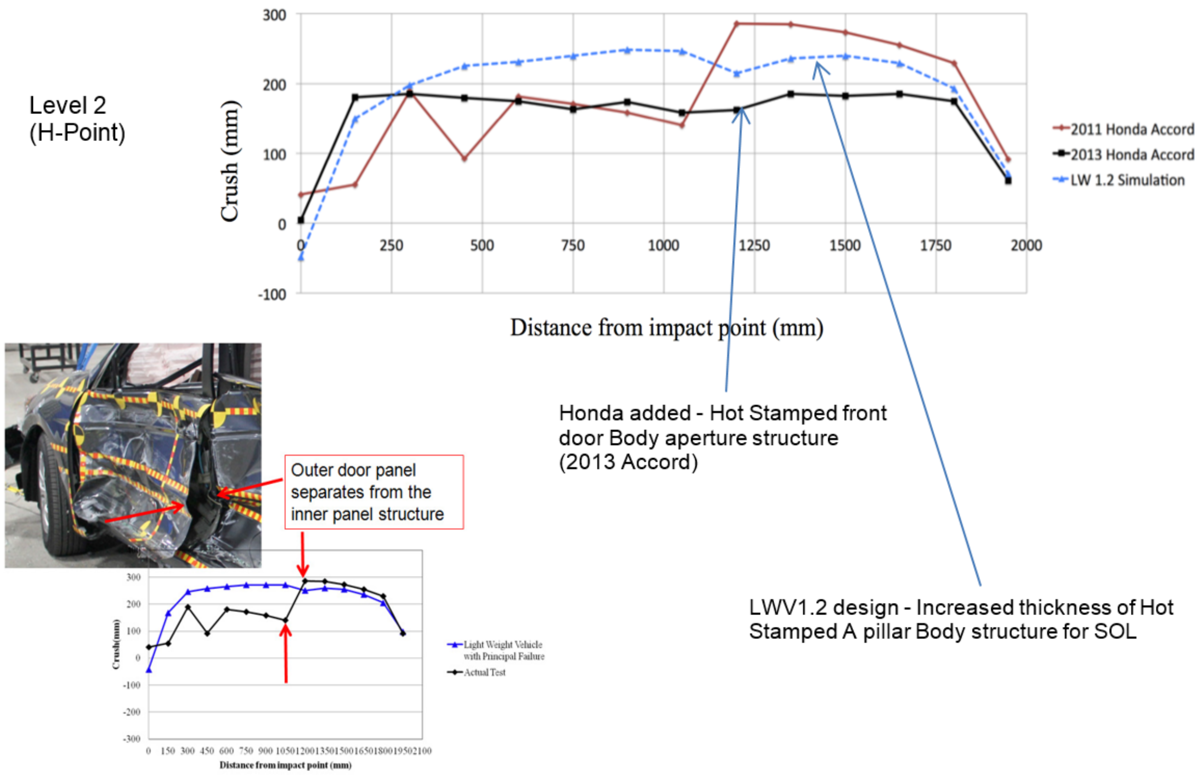


Figure 117: Exterior crush for level 2, approximately the mid-door level in NCAP MDB side test

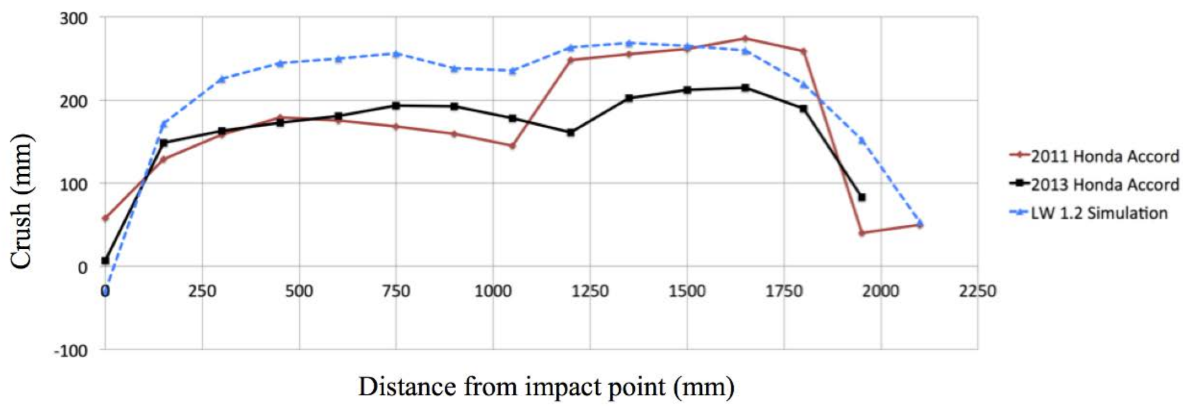


Figure 118: Exterior crush for level 3, approximately the mid-door level in NCAP MDB side test

The exterior crush of the LWV 1.2 model is more comparable to the MY2013 Accord. But the exterior crush profiles of the MY2011 Accord and the LWV 1.2 model are close toward the rear of the vehicles. The sudden drop in the exterior intrusion values for MY2011 Accord shown in Figure 117 and Figure 118 are due to front door outer panel separating from the door inner structure. The "open section" profile of the beam on the LWV 1.2 opens up during impact and this leads to slightly higher external intrusions of the outside surface of the door when compared with the Accord tests. However, the inner door intrusions, which are more critical to the occupant, are similar to the MY2011 Honda Accord as discussed below.

The MY2011 Honda Accord NCAP side MDB test vehicle was brought out of storage and further measurements were taken using the IIHS measurement method for the interior surfaces (door inner and b-pillar inner). IIHS measurement method was used because the NCAP side barrier test does not have an intrusion rating for safety. To determine the safety of a vehicle, the NCAP side barrier test uses the forces, deformation, and acceleration measurements in the occupants of the vehicle. The LWV 1.2 researchers used the IIHS safety rating scheme to assess the implications of the intrusions in the NCAP side barrier test. Following the IIHS rating scheme, Figure 119 illustrates the pre- and post-crush and intrusion for the LWV 1.2 in the NCAP side barrier test. Figure 120 illustrates that the LWV 1.2 is in the "Green" region for the NCAP side barrier test. The inner surface intrusions for LWV 1.2, which are more critical to the occupant injury, are similar to the MY2011 Honda Accord test results as shown in Figure 119.

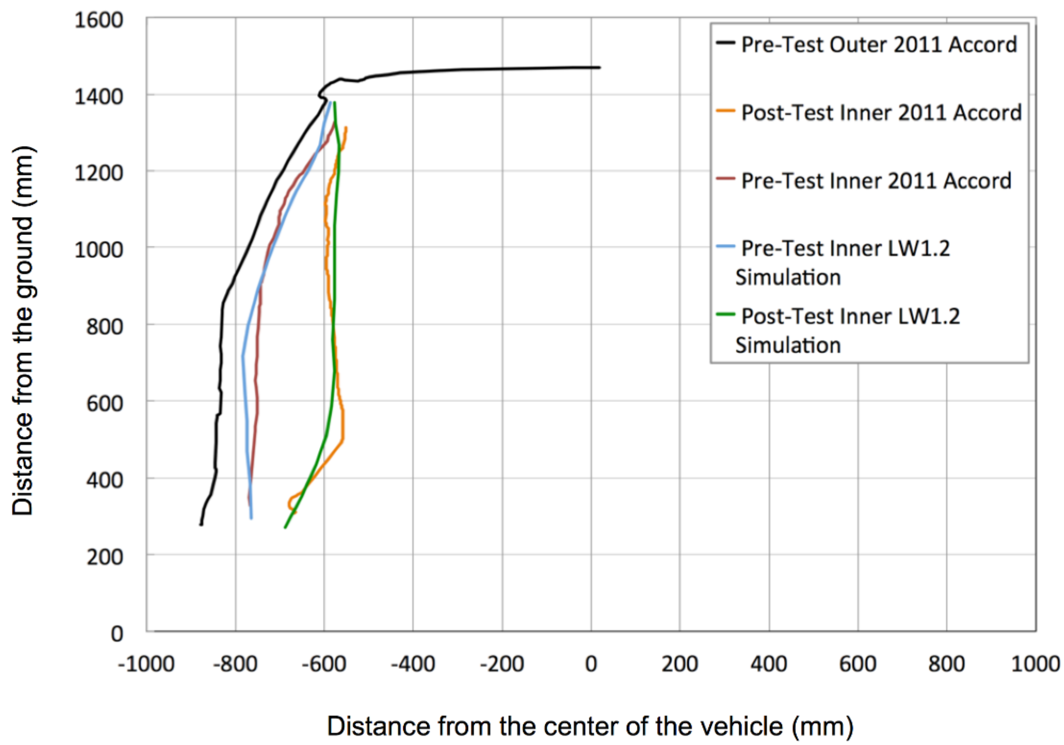


Figure 119: Pre- and post-crush and intrusion for the LWV 1.2 in the NCAP lateral test

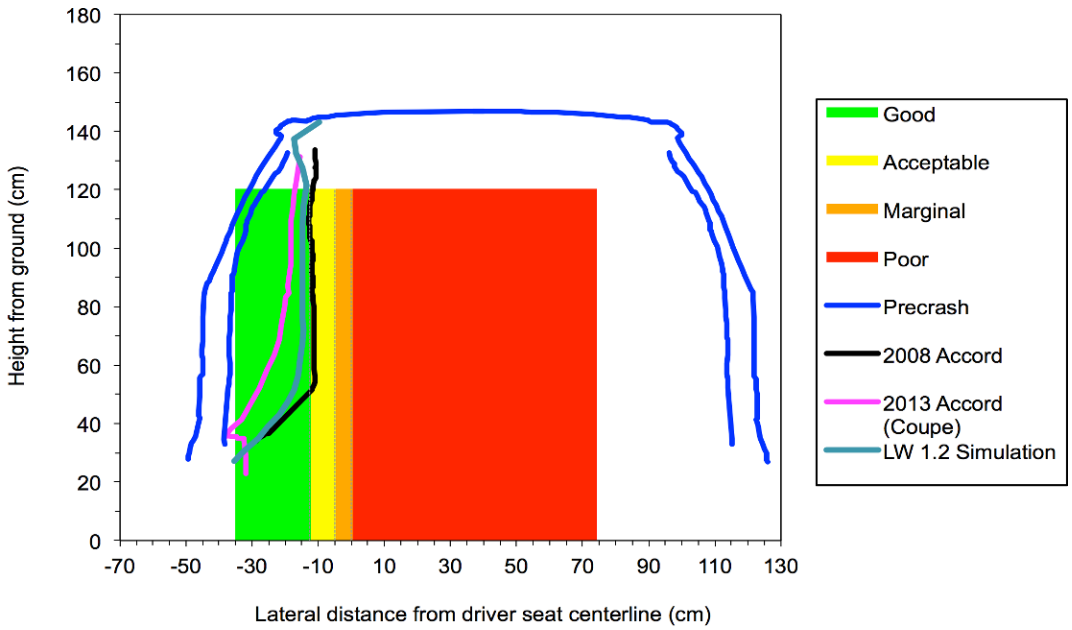


Figure 120: LWV 1.2 is in the "Green" region for the NCAP side barrier test

Figure 121 shows a graph of the lateral acceleration at the center of gravity for the LWV 1.2 and the MY2011 and MY2013 Honda Accord. Figure 122 shows a plot of the lateral velocity at the center of gravity for the LWV 1.2 and the MY2011 and MY2013 Honda Accord. Naturally, the LWV 1.2 has a lower mass than the 2011 Honda Accord. It can be concluded from all comparison, that the LWV 1.2 performance is equivalent to the MY2011 Accord in NCAP side barrier test.

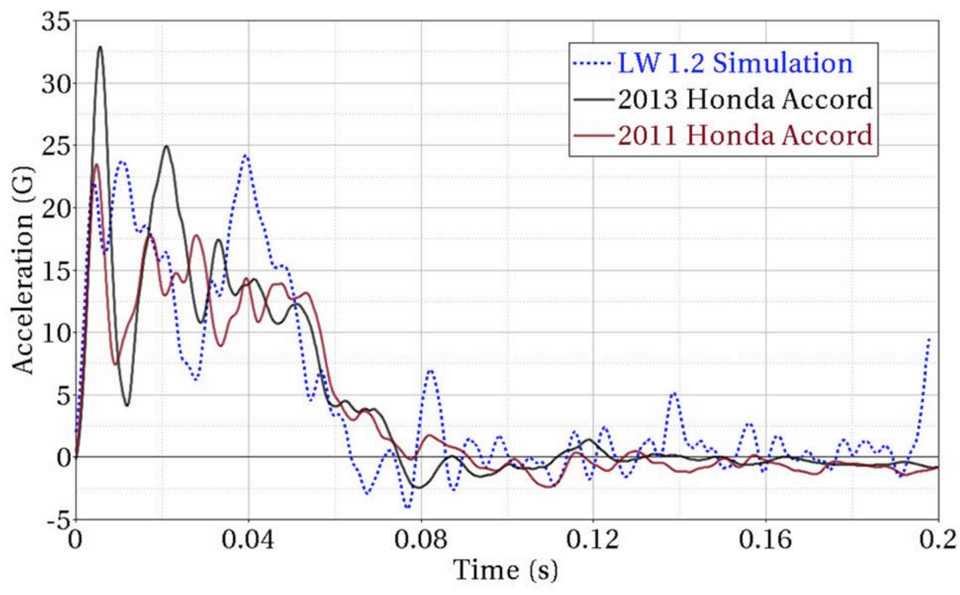


Figure 121: Lateral acceleration at the center of gravity of MY2011 and MY2013 Accord and LWV 1.2 in NCAP side barrier test

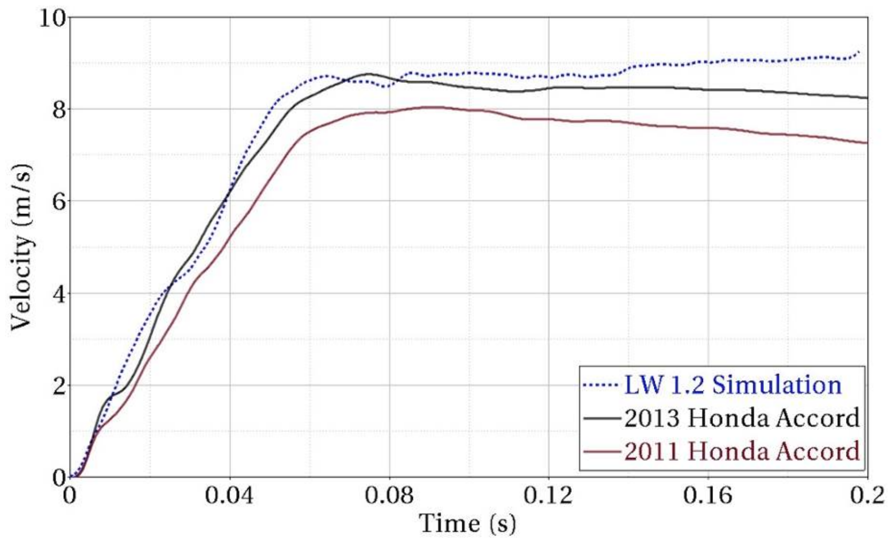


Figure 122: Lateral velocity at the center of gravity of MY2011 and MY2013 Accord and LWV 1.2 in NCAP side barrier test

4.3.4 Lateral NCAP Pole Test

In this test the LWV 1.2 impacts the rigid pole laterally at a speed of 32 km/h such that its line of forward motion forms an angle of 75 degrees with the vehicle's longitudinal axis, simulating a real-world crash in which the vehicle hits a tree while sliding on the road. The rigid pole is a vertically oriented metal structure with:

1. Diameter of 254 mm,
2. Beginning no more than 102 mm above the lowest point of the tires on the struck side of the fully loaded test vehicle, and
3. Extending at least 150 mm above the highest point of the roof of the test vehicle.

The direction of vehicle motion is such that the pole is always aligned with the CG of the head of the driver.

The LS-DYNA set-up for the side impact crash test of the LWV 1.2 model with a pole is shown in Figure 123. Images of the post-crash vehicles for the actual laboratory crash and the simulation are shown in Figure 124. The intruding side interior on the struck side presents a threat to the driver. To understand this treat, it is helpful to examine instrumentation near the intruding side interior near the driver. The B-pillar was close to the driver and had an accelerometer that functioned properly during the pole side impact. The velocity versus time plot at the mid-B-pillar (i.e., at a point half way between the floor sill and roof header) is in Figure 125, indicating that the FEM predicted response for LWV 1.2 is close to the actual test velocity of MY2013 Accord. Figure 126 shows the velocity versus time at the CG from the MY2011 and MY2013 Honda Accord tests and LWV 1.2 simulation. The velocity of the LWV 1.2 is similar to the velocity of the actual Honda Accords.

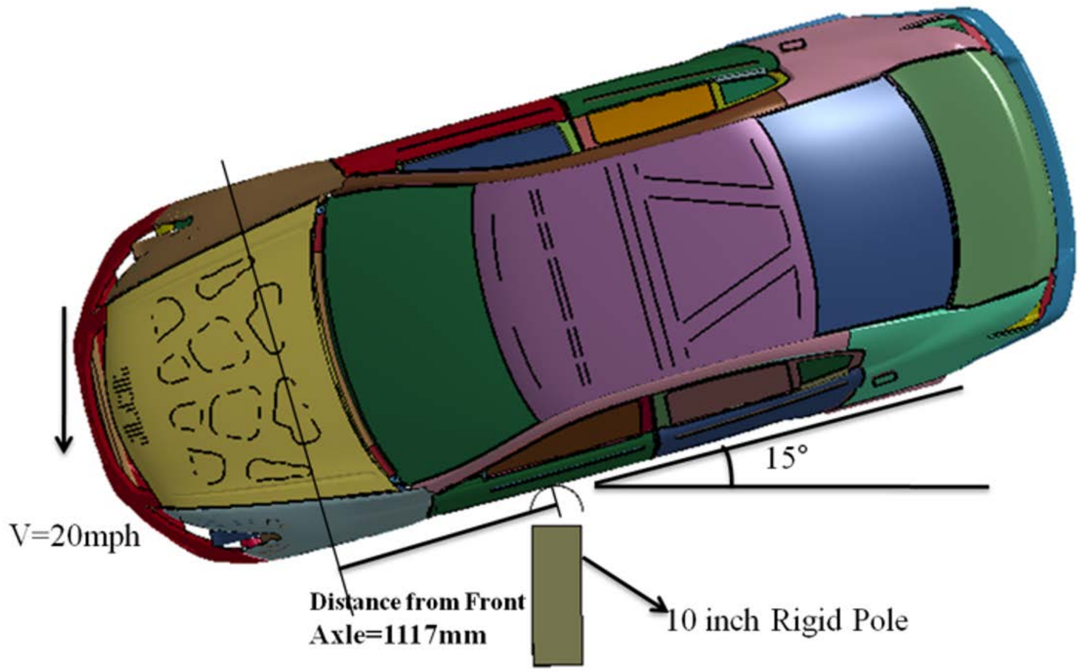


Figure 123: LS-DYNA set-up for the NCAP side pole test

Figure 124: Post-crash vehicles for the actual laboratory crash and the simulation in lateral pole test

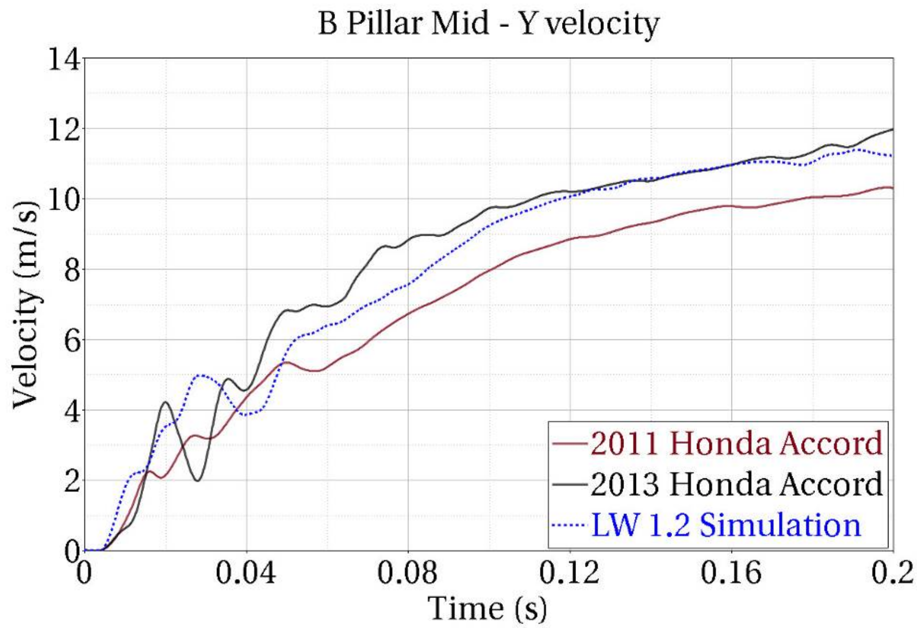


Figure 125: Velocity versus time for the mid-B-pillar in the lateral pole test

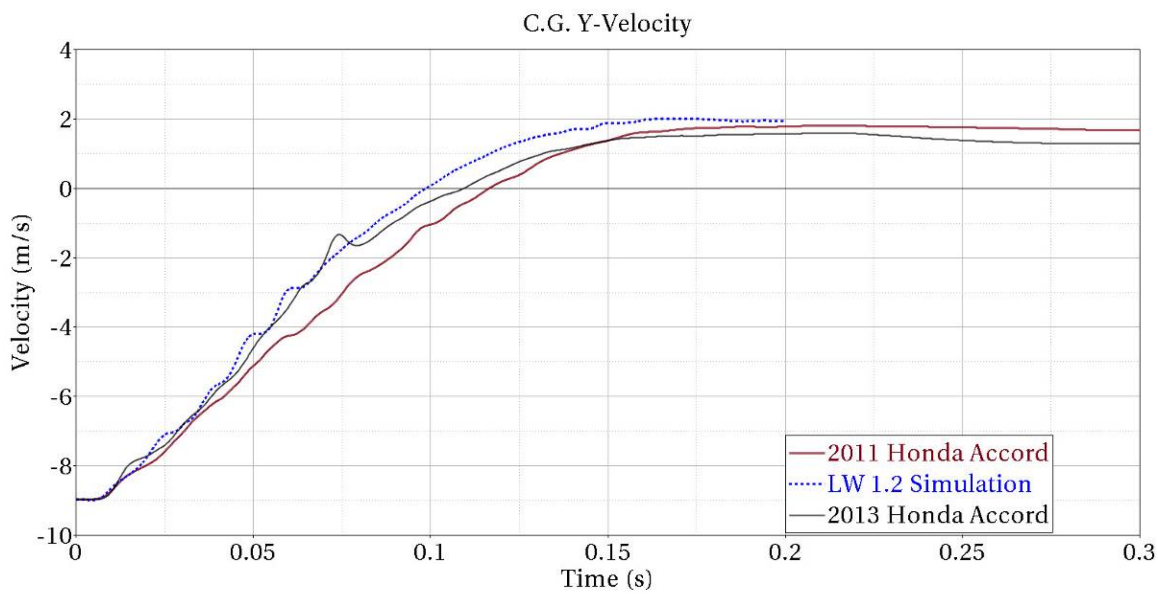


Figure 126: Lateral velocity at the center of gravity of LWV 1.2 and MY2011 and MY2013 Accords in the NCAP side pole test

Figure 127 shows the exterior crush profile for level 2, which is located at approximately the H-point level of the driver dummy. Figure 128 shows the exterior crush profile for level 3, which is located at approximately the mid-door level. Figure 129 shows exterior crush for level 4, approximately the window sill level. In setting up a crash test with the occupant seated in the vehicle, the location of the H-point is determined above the vehicle seat. The external crush is less for the LWV 1.2 when compared to MY2011 and MY2013 Accords. The safety of the LWV 1.2 with properly tuned restraints to protect the head and torso should have a similar safety rating to the Accord vehicle based upon the B-pillar velocity and residual crush results from the simulation.

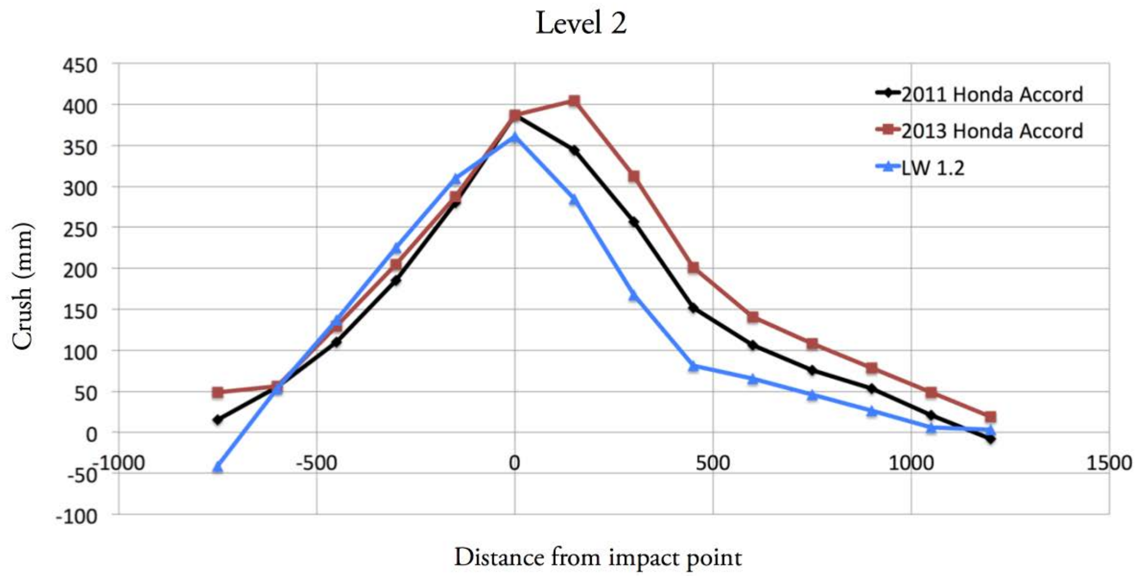


Figure 127: Exterior crush for level 2, approximately the H-point level in the lateral pole test

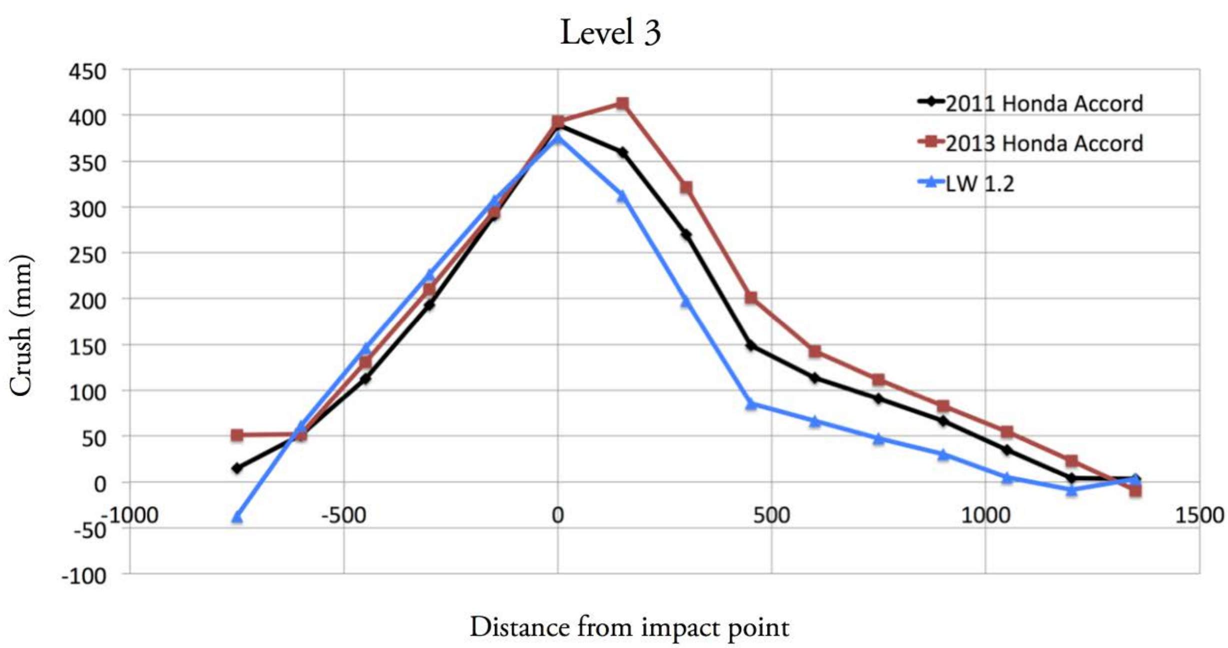


Figure 128: Exterior crush for level 3, approximately the mid-door level in the lateral pole test

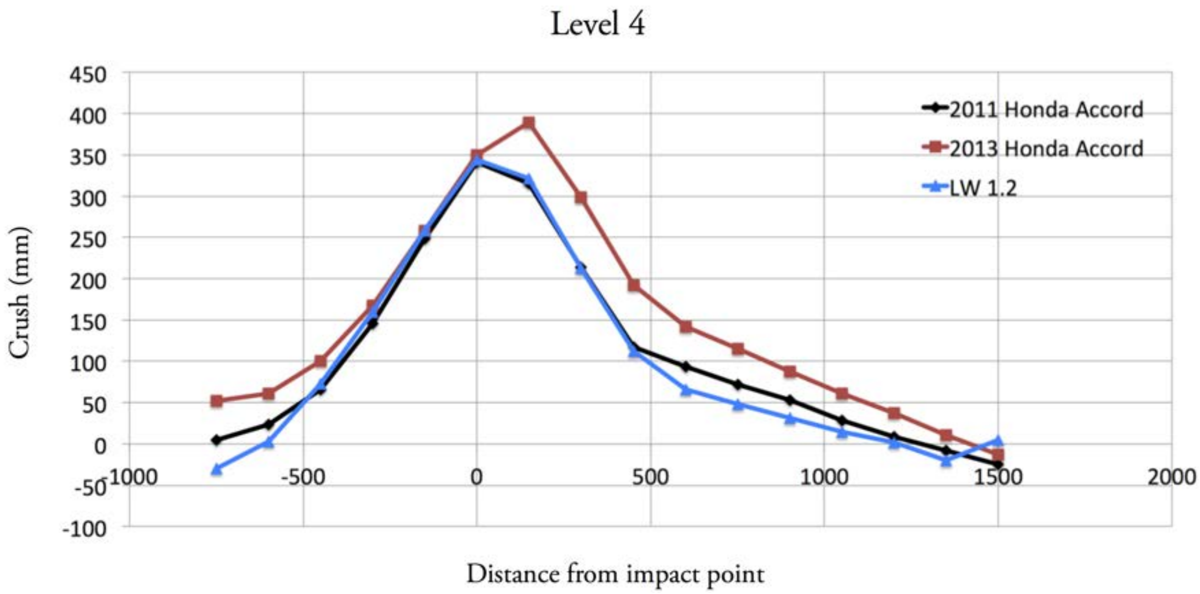


Figure 129: Exterior crush for level 4, approximately window sill level in the lateral pole test

4.3.5 IIHS Roof Crush Test

The IIHS roof crush test is used to evaluate the crashworthiness of the vehicle structure in rollover crashes. This test is conducted by crushing the roof structure of the vehicle against a rigid plate (platen) until 5 inches of crush is achieved. Then, the maximum force sustained by the roof before 5 in of crush is compared to the vehicle's curb weight to find the strength-to-weight ratio. The LWV 1.2 is held rigidly with clamps about the rocker section. Both NHTSA and IIHS have procedures for a roof crush test. FMVSS No. 216 specifies that roof structure should sustain a load three times the vehicle curb weight. The IIHS roof crush rating stipulates that the roof structure must sustain loading of four times the curb weight for a good ratings. The NHTSA roof crush test is FMVSS No. 216, and is a regulation, which does not rate the tested vehicle for safety. The IIHS roof crush test is a consumer-information test, and rates the tested vehicle for safety. The NHTSA tests both sides of the roof of the vehicle. The IIHS tests just one side of the roof but requires a higher resistance to crush, which is a ratio of resistance force/curb weight must be 4 or greater for a “Good” rating. The NHTSA tested the MY2008 Accord. The IIHS tested the MY2013 Accord. For this study, the researchers analyzed the IIHS roof crush test because (1) the IIHS vehicle was a more recent model year sedan and (2) the IIHS test gives a higher-level safety rating, with which the LWV 1.2 can be compared.

The LS-DYNA set-up for the IIHS roof crush test of the LWV 1.2 model is shown in Figure 130. The force versus platen displacements are given in Figure 131 for the actual tests and the LS-DYNA simulation. Figure 132 gives the strength to weight ratio, which is the force divided by curb weight, versus platen displacement. The SWR for the LWV 1.2 has a value above 4 and is in the “good” zone.

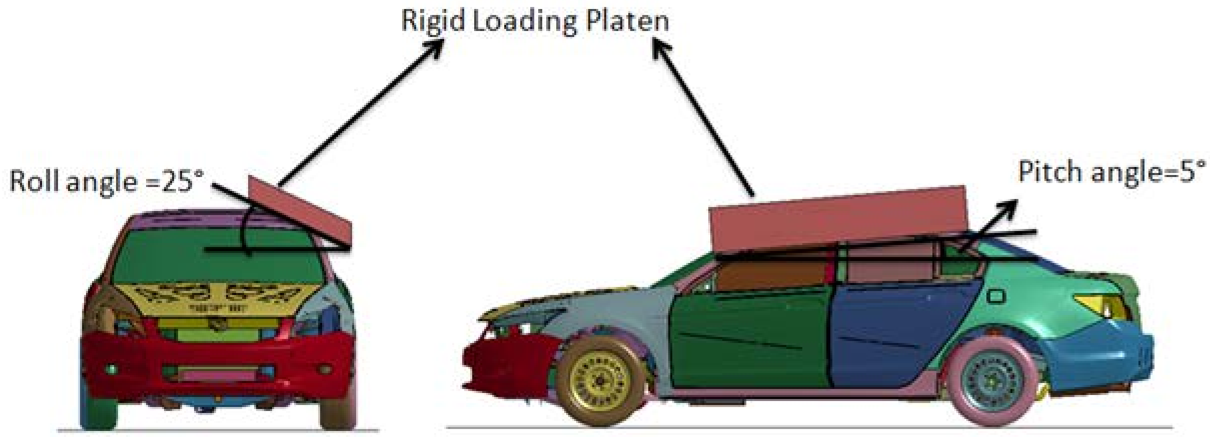


Figure 130: LS-DYNA set-up for the IIHS roof crush test

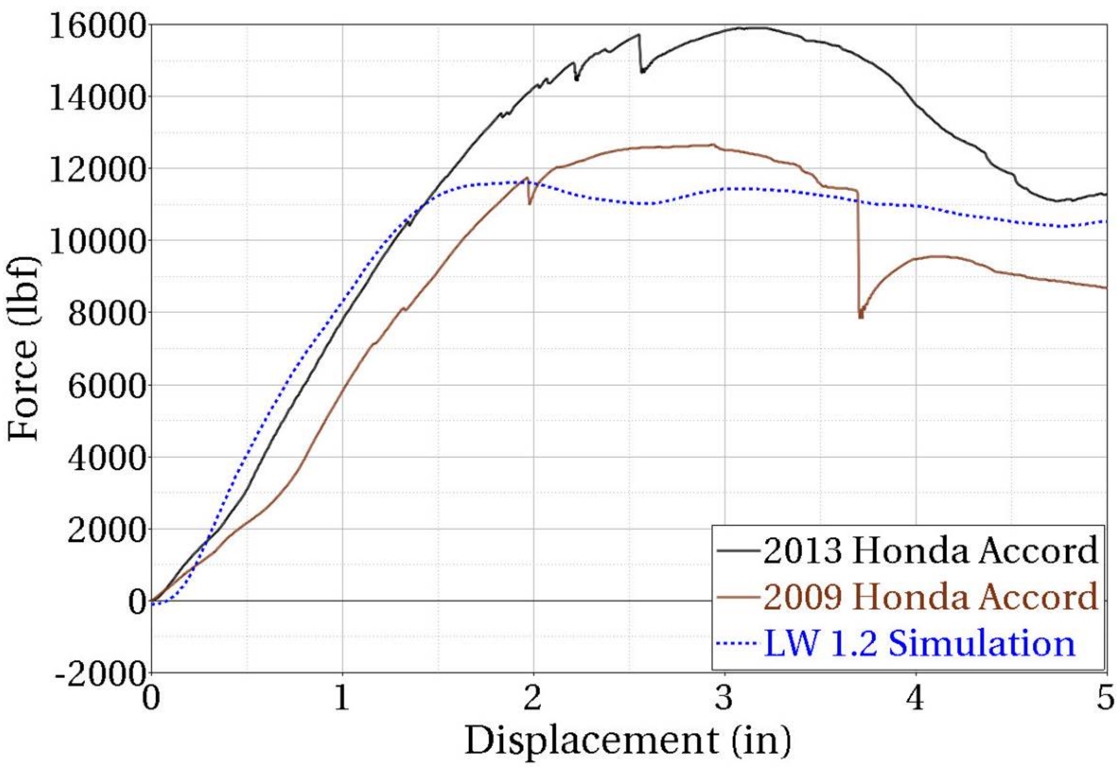


Figure 131: Force versus platen displacement for MY2009 and MY2013 Accord and LWV 1.2 in IIHS roof crush test

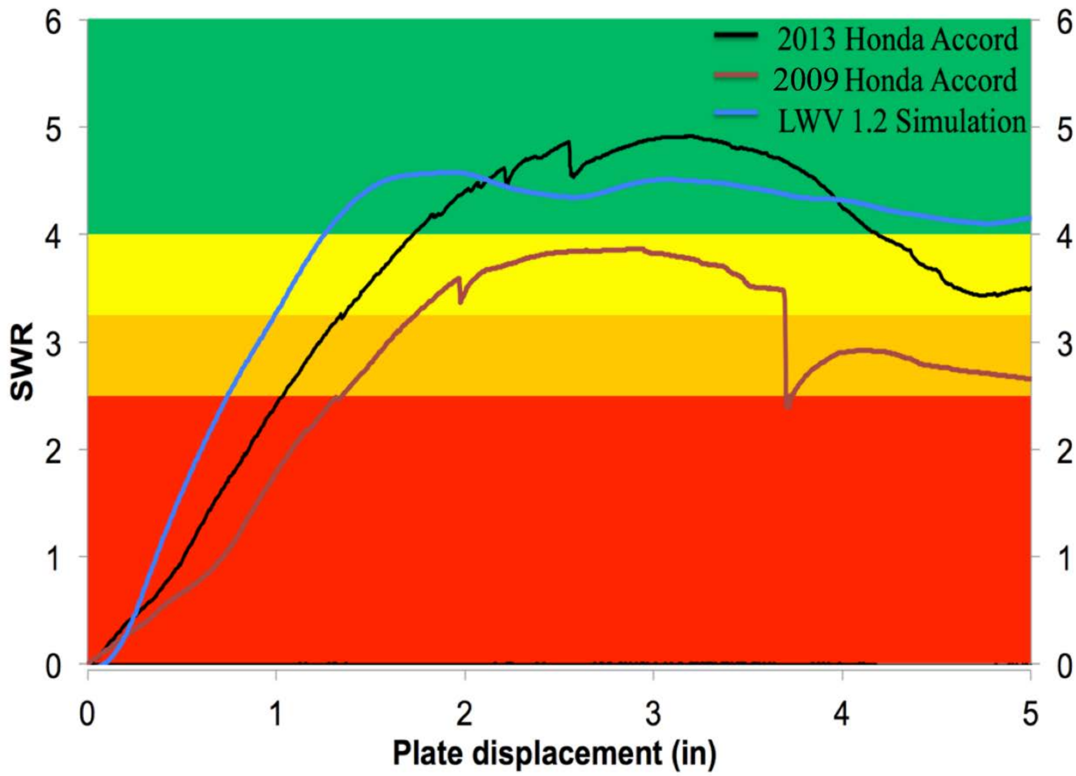


Figure 132: Force divided by curb weight versus platen displacement for MY2009 and MY2013 Honda Accord and LWV 1.2 in IIHS roof crush test

4.3.6 <u>IIHS Lateral Moving Deformable Barrier Test</u>

In the IIHS side barrier test, the front end of the MDB represents the front end of an SUV, with a test weight of 1,500 kg. The MDB impacts the LWV 1.2 on the driver's side with a velocity of 50 km/has shown in Figure 133. The LWV 1.2 carries the weight of two 5th percentile test dummies (45 kg each), one in the driver's seat and the other in the rear passenger seat directly behind the driver dummy. The vehicle also carries 32 kg of weight in the cargo area and 59 kg (instrumentation and camera) of weight on the non-struck front and rear side doors.

The LS-DYNA set-up for the IIHS side impact crash test of the LWV 1.2 model with a moving deformable barrier is presented in Figure 133. Images of the post-crash vehicles for the actual laboratory crash and the simulation are shown in Figure 134. The velocity versus time plot at the right rear sill on the non-struck side is shown in Figure 135. This figure indicates that the FEM predicted velocity is close to the actual measured laboratory velocity behavior of the MY2008 and MY2013 Accords. Figure 136 illustrates that the LWV 1.2 intrusions are located in the "Good" region for the IIHS rating format. The MY2008 Accord and the LWV 1.2 intrusions are observed to be equivalent in the IIHS lateral crash test. It is to be noted that MY2013 Accord was a two-door coupe.

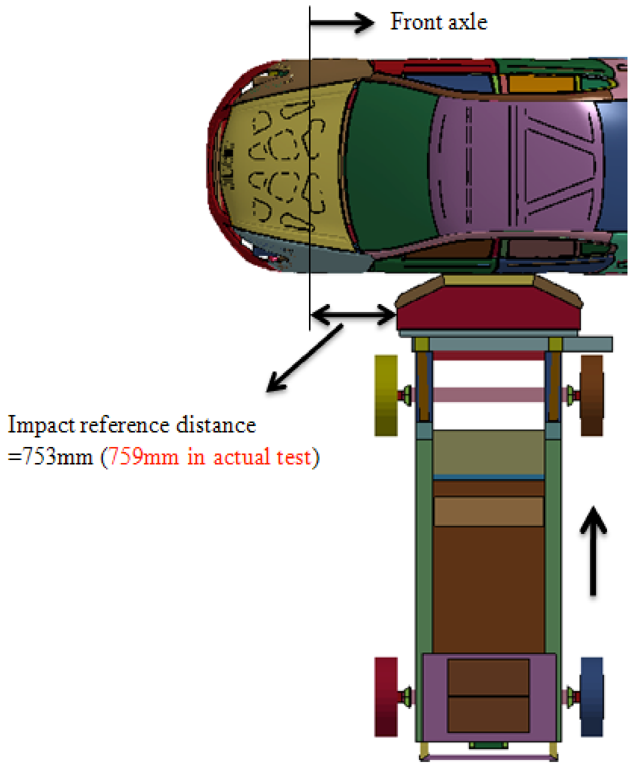


Figure 133: LS-DYNA set-up for the IIHS lateral impact test

Figure 134: Post-crash vehicles for the actual laboratory crash and the simulation in IIHS lateral impact test

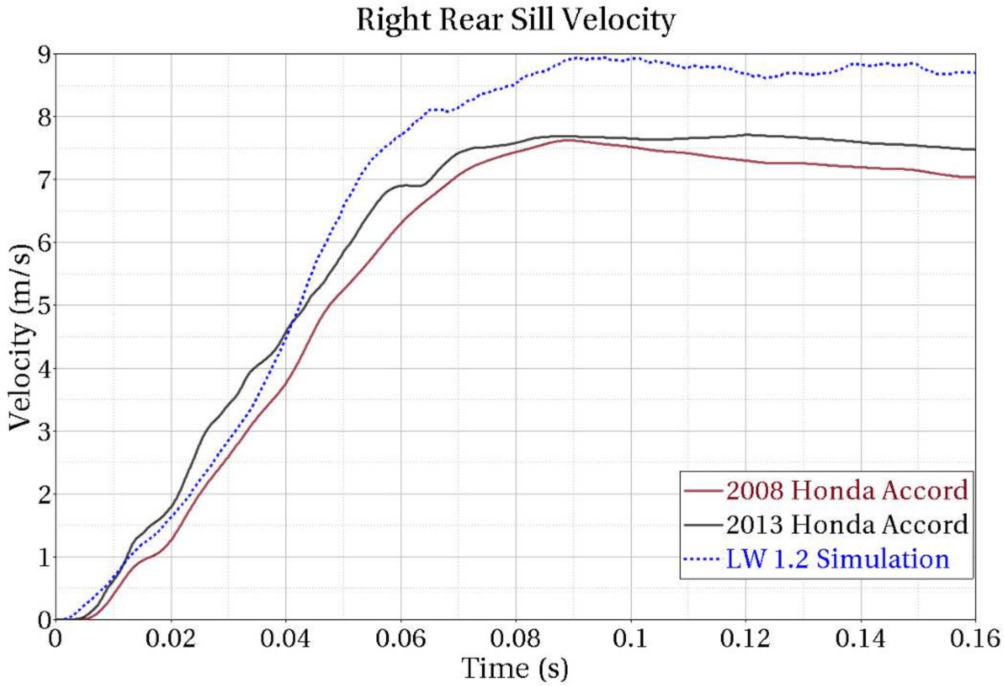


Figure 135: Velocity versus time plot at the right-rear sill on the non-struck side of MY2008 and MY2013 Accord and LWV 1.2

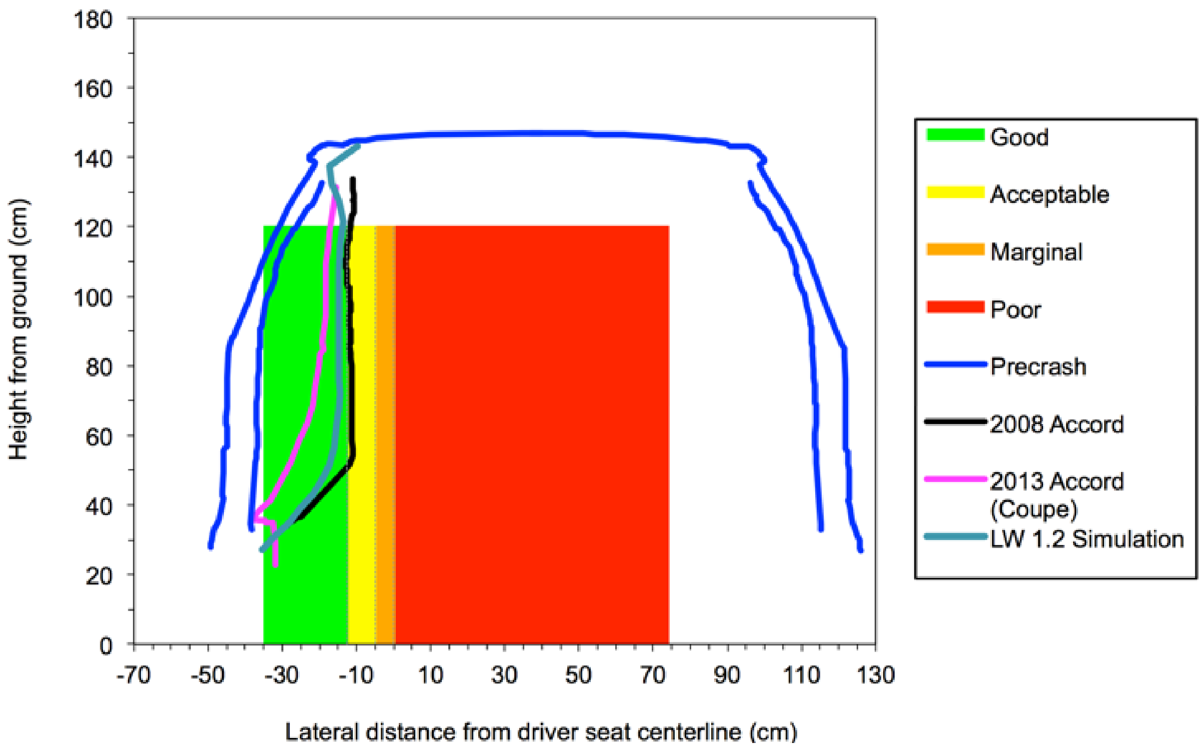


Figure 136: LWV 1.2 is in the "Good" region for the IIHS lateral test

4.3.7 IIHS Moderate Frontal Offset Test

For IIHS frontal offset test, the LWV 1.2 hits the deformable aluminum honeycomb barrier at a velocity of 64 km/h (40 mph). Forty percent of the total width of the vehicle strikes the barrier on the driver's side. A Hybrid III dummy representing an average-size (50th percentile) male is positioned in the driver seat. At the time of this report, IIHS did not perform a frontal offset barrier test on the MY2011 Accord. For comparison purposes, the MY2010 Crosstour safety rating results are used. The Accord Crosstour has a frontal body structure similar to the MY2011 Accord vehicle. The front structures of the MY2010 Crosstour and the MY2011 Accord have similar design and build. Therefore, their crash behavior should be similar in a frontal crash.

The LS-DYNA set-up for the 40 percent offset frontal crash test of the LWV 1.2 model into a deformable barrier is presented in Figure 137.

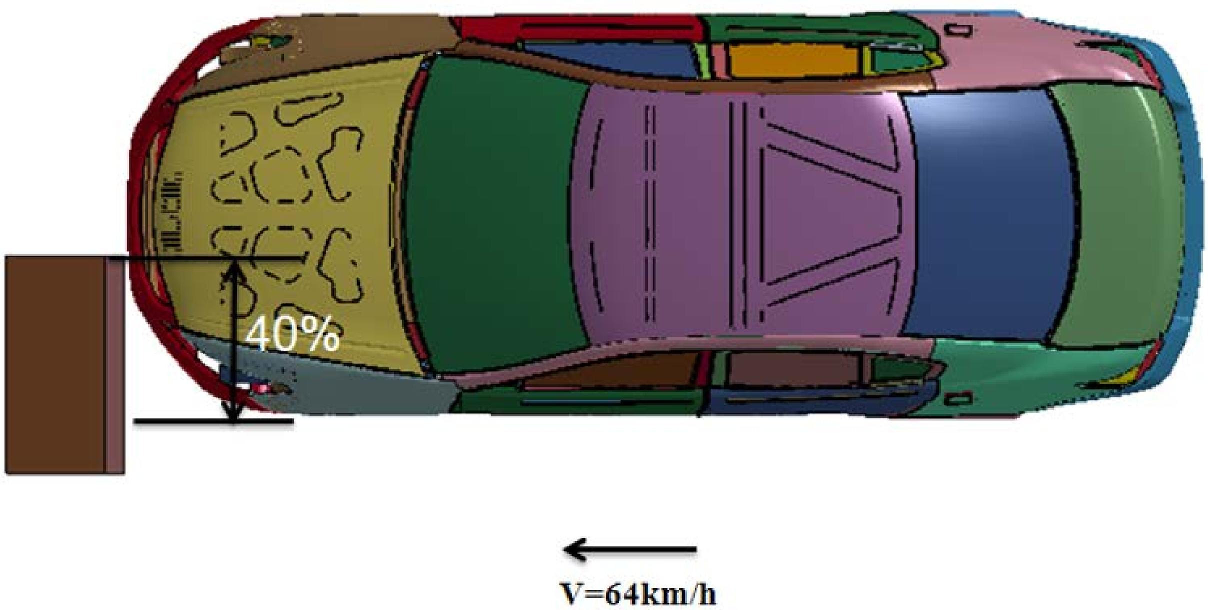


Figure 137: LS-DYNA set-up for the 40 percent offset frontal crash test into a deformable barrier of the LWV 1.2

The post-crash vehicles for the actual laboratory crash and the simulation are shown in Figure 138. The crash pulse in the x-direction for the CG is shown in Figure 139, where it is observed that the FEM predicted crash pulse has lower peaks compared to the MY2011 Crosstour laboratory pulse.

Figure 138: Post-crash vehicles for the MY2011 BL Honda Crosstour actual laboratory crash and the simulation for LWV 1.2 in the IIHS 40 percent offset frontal test

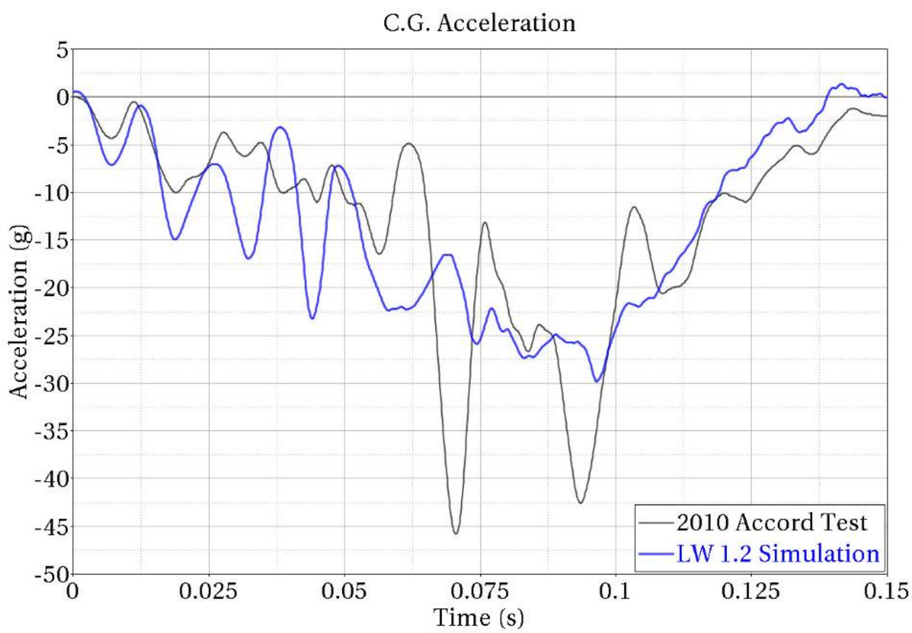


Figure 139: Crash pulse in the x-direction for the center of gravity of the MY2011 Crosstour and the LWV 1.2 in IIHS frontal test

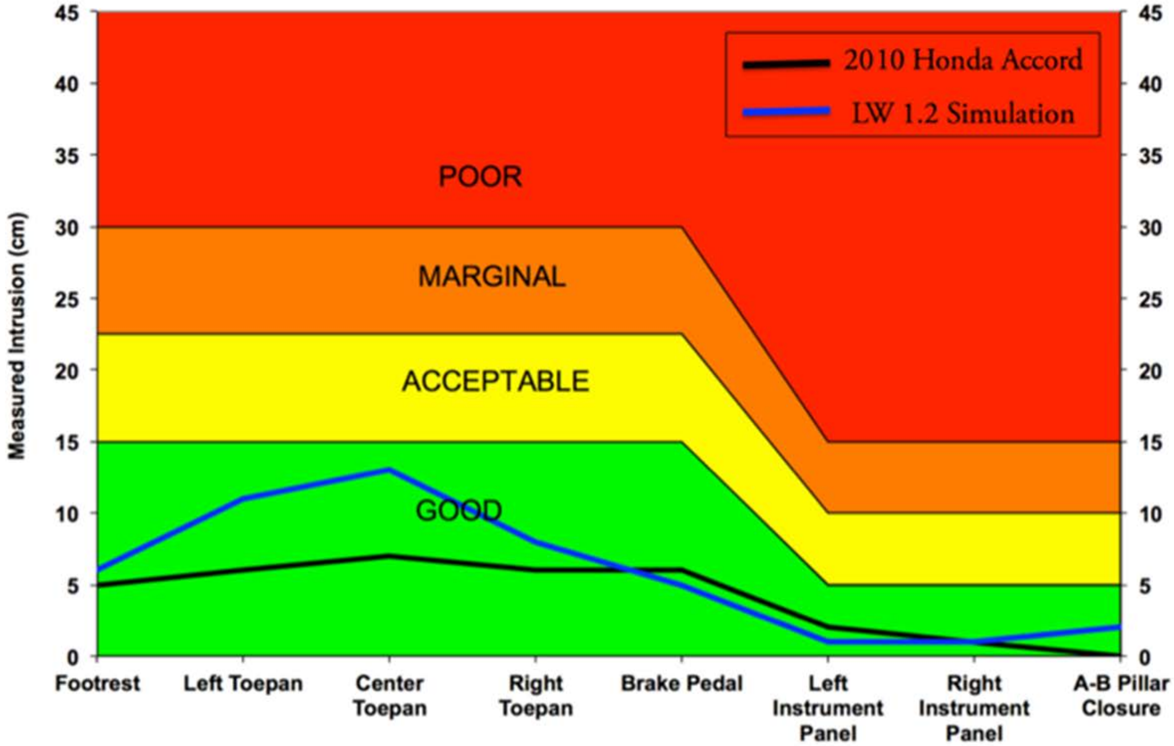


Figure 140: Intrusions of MY2010 Crosstour and the LWV 1.2 on the IIHS structural measuring scheme

The IIHS structural measuring scheme is illustrated in Figure 140. This scheme indicates that the LWV 1.2 has higher intrusion than the MY2010 Accord Crosstour, but is within the “Good” zone. The difference in the center toe pan is about 70 mm, which is about 3 inches. However, the center toe pan intrusion of the LWV 1.2 remains well within the corridor for the “Good” rating. Figure 141 shows the test results for the MY2014 Honda Accord[57] and MY2014 Chevrolet Malibu[58] intrusion values. The MY2014 Honda Accord with a “GOOD” rating for this test has comparable intrusion values to the LWV 1.2 predictions.

[57] IIHS. (n.d.) 2016 Honda Accord (Web page). Arlington, VA: Author. Available at www.iihs.org/iihs/ratings/vehicle/v/honda/accord-4-door-sedan

[58] IIHS. (n.d.) 2015 Chevrolet Malibu (Web page). Arlington, VA: Author. Available at www.iihs.org/iihs/ratings/vehicle/v/chevrolet/malibu

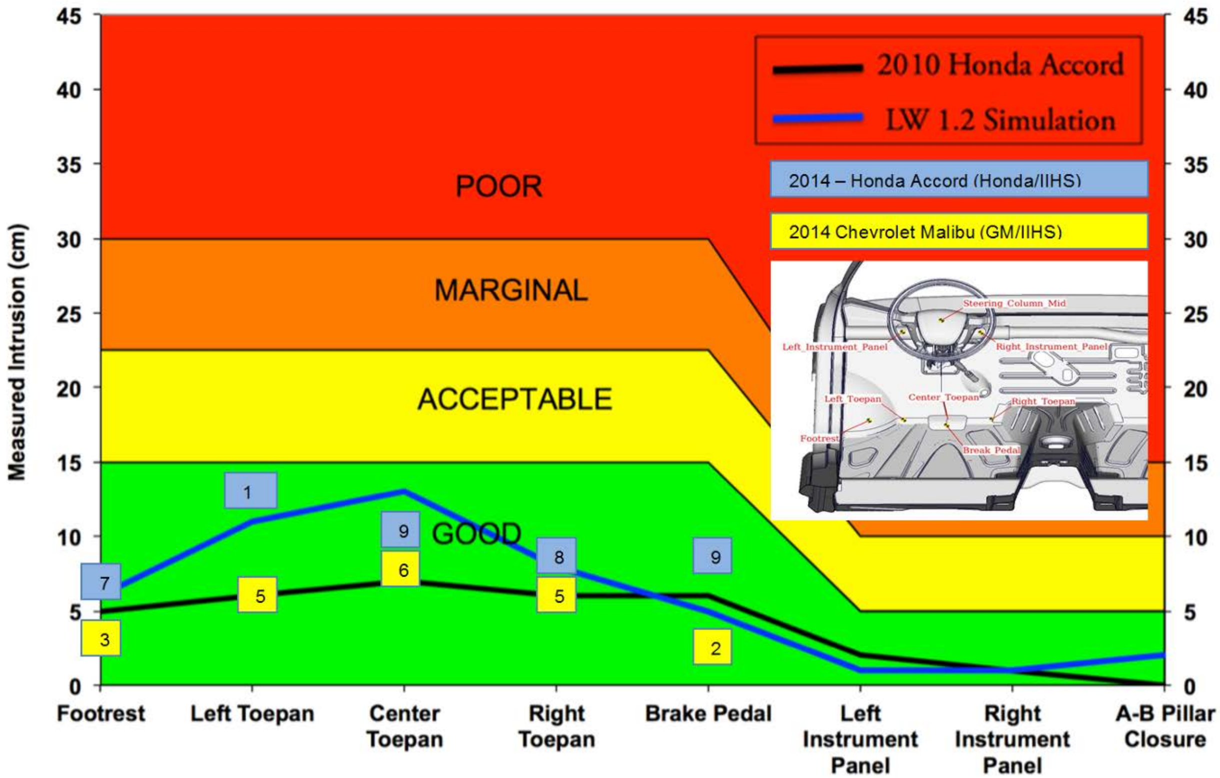


Figure 141: **LWV 1.2 IIHS Moderate Overlap Frontal Impact – Intrusion Comparisons with 2014 Accord and Malibu**

4.3.8 Summary of Crash Modeling

Figure 142 summarizes the crashworthiness comparison of the LWV 1.2 with the safety rating of Accord vehicle test results. Based on the seven crash tests, the overall safety performance of the LWV 1.2 model is “Good,” which is comparable to the safety rating of the MY2013 and MY2011 Accord vehicles.

For the NCAP frontal test, the acceleration versus time curves are similar and the intrusion into the occupant compartment of the LWV 1.2 is comparable to that from both the MY2013 and MY2011 Accord tests. In the NCAP side barrier test, the intrusion of the LWV 1.2 is slightly higher than the 2013 Accord near the driver space, but both vehicles satisfy the requirements for a “Good” safety rating. In the NCAP pole test, the LWV 1.2 is the same as the MY2013 Accord in terms of intrusion. For the IIHS roof crush test, the LWV 1.2 performs slightly poorer compared to MY2013 Accord. The SWR for LWV 1.2 is in “acceptable” region. In the IIHS side barrier test, the LWV 1.2 responded the same and satisfied the requirements for the same safety rating as the MY2013 Accord. In the IIHS moderate overlap frontal test, the LWV 1.2 had similar acceleration and velocity as the MY2010 Accord Crosstour. In the IIHS moderate overlap frontal test, the LWV 1.2 had minutely higher intrusion, but was well within the “Good” region. In the IIHS small-overlap frontal test, the LWV 1.2 has similar acceleration pulse compared to MY2013 Accord. In the IIHS small-overlap frontal test, the intrusions are comparable to MY2013 Accord.

Structural Response of the Lightweight Vehicle		
Test	**Dynamic**	**Static**
NCAP frontal	Acceleration magnitude and the pulse time width are similar to MY2013 and MY2011 Accord. For airbag deployment the average acceleration during 0.005 to 0.015 seconds is -10.65G's	Intrusion comparable to MY2013 Accord vehicle
NCAP side with MDB	The velocity at the CG and B-Pillar interior intrusion values of the LWV 1.2 are similar to the values of the MY2013 Accord vehicle.	Intrusion comparable to Accord and in the "Good" range for IIHS rating scheme
NCAP pole	Comparable to the MY2013 Accord vehicle	Intrusion Comparable to the BL Honda Accord
IIHS roof crush	NA	SWR for LWV 1.2 is slightly lower than MY2013 and is in "acceptable" range
IIHS side with MDB	Velocity comparable to MY2008 and MY2013 Accord vehicle	Crush is less than MY2008 and MY2013 Honda Accord
IIHS moderate overlap frontal	Acceleration about same magnitude as the MY 2010 Crosstour vehicle and the pulse time width is about the same as the pulse width of the Crosstour	Intrusion is slightly higher than MY2010 Accord Crosstour and comparable to MY2014 Accord and in the "Good" range for IIHS rating scheme
IIHS small-overlap frontal	Crash pulse has similar peaks as that of MY2013 Accord vehicle	Intrusion comparable to MY 2013 Accord vehicle

Figure 142: Comparison of safety performance of LWV 1.2 with safety of Accord vehicle

5 Vehicle Weight Change for Other Vehicle Sub-Classes

5.1 Original LWV 1.0 Mass Reduction for Other Light-Duty Vehicles (Optional Task 1)

In the original LWV 1.0 Optional Task 1 (Contract DTNH22-11-C-00193) NHTSA asked the project team to consider how the mass reduction evaluated for that vehicle can be applied to other light-duty passenger vehicles. Those "other" light-duty vehicles classes include:

- Subcompact passenger cars,
- Compact passenger cars,
- Midsize passenger cars,
- Large passenger cars,
- Minivans,
- Small crossovers, SUVs, and trucks,
- Midsize crossovers, SUVs, and trucks, and
- Large crossovers, SUVs, and trucks.

The chosen mass reduction technologies were to be feasible within the time frame of MY 2017 to 2025 and would be suitable for high volume production passenger cars and light-duty trucks. Consideration was also given to supplier capabilities to deliver these mass saving measures to the automotive industry in sufficient volumes to support this initiative.

5.1.1 Analytical Approach

The general approach in estimating the weight change for the other vehicle classes during the original LWV 1.0 Optional Task 1 can be summarized in the following steps:

1. Identify representative vehicles in each vehicle subclasses;
2. Pick representative vehicle for each vehicle subclass using A2Mac1 database;
3. Calculate average vehicle metrics for each vehicle subclasses;
4. Apply appropriate lightweighting technologies used in the midsize passenger car study as discussed in Chapter 5 of the original LWV 1.0 report[59] to each representative vehicle and calculate vehicle mass reduction amount.
5. The calculated mass reduction percentage is then applied to the "2010 Class Average"[60] to estimate the "2020 Class Average."

More details on the analytical approach for the mass reduction for other light duty vehicles are described in Section 8 of the original LWV 1.0 report[61].

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[59] NHTSA's market data file contains information about major vehicle characteristic, such as engine, transmission, weight, size, as well as vehicle production volume. For detailed information about this file, a brief description can be found in NHTSA and EPA's MY 2017-2025 TSD for NPRM at the following link: www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/2017-25_CAFE_Joint_TSD_Compiled_Signature_-Version_11162011b.pdf

[60] "2010 Class Average" is the average for vehicles listed in NHTSA's 2010 market data file for MY2017-2020 NPRM analysis.

[61] NHTSA's market data file contains information about major vehicle characteristic, such as engine, transmission, weight, size, as well as vehicle production volume. For detailed information about this file, a brief description can be found in NHTSA and EPA's MY 2017-2025 TSD for NPRM.

5.1.2 Results

In the original LWV 1.0 program, the team selected one baseline vehicle for each class as shown in Figure 143 below. The right three columns in the figure also show the estimated 2020 LWV 1.0 curb vehicle weight and their mass reduction. The mass saving potential for all the classes ranges from 16.3 percent to 19.3 percent.

This range of results is lower than the results obtained for the LWV mass reduction of 22.4 percent. This is mainly due to the baseline Honda Accord front suspension change from double wish-bone to the MacPherson strut design implemented on LWV, which is not applicable to other vehicles already with MacPherson strut design. Other material choices and manufacturing technologies implemented to achieve the mass reduction are similar to the detail design option of the LWV.

Vehicle Class	Selected Baseline Vehicle	Baseline Vehicle CVW (kg)	2020 - LWV CVW (kg)	Mass Reduction (kg)	Mass Reduction (%)
Sub-Compact Car	Ford Fiesta 1.6 TDCi (2008)	1,147	944	203	17.7%
Compact Car	Honda Civic 1.8 LX (2007)	1,252	1,024	228	18.2%
Mid-Sized Car	Honda Accord 2.2 i-DETC ES (2008)	1,550	1,263	287	18.5%
Large Car	Chrysler 300 C AWD (2006)	1,871	1,526	345	18.4%
MiniVans	Toyota Sienna LTD (2011)	2,154	1,758	396	18.4%
Small SUV/LT	Honda CR-V 2.0 (2006)	1,541	1,254	286	18.6%
Mid-Sized SUV/LT	Audi Q5 2.0 Tdi (2009)	1,779	1,490	289	16.3%
Large SUV/LT	Ford F150 (2003)	2,406	1,941	465	19.3%

Figure 143: Summary of Vehicle Sub-Class Weight Saving Results for LWV 1.0

Below, Figure 144 shows the estimated LWV 1.0 2020 class average mass compared with the 2010 Vehicle Class averages.

Vehicle Class	2010 - Class Average CVW (kg)	2020 - Class Average CVW (kg)	Mass Reduction (kg)	Mass Reduction (%)
Sub-Compact Car	1,261	1,038	223.3	17.7%
Compact Car	1,345	1,100	245.1	18.2%
Mid-Sized Car	1,561	1,272	288.8	18.5%
Small SUV/LT	1,592	1,296	295.7	18.6%
Large Car	1,752	1,429	323.0	18.4%
Mid-Sized SUV/LT	1,916	1,605	311.4	16.3%
MiniVans	2,035	1,661	374.4	18.4%
Large SUV/LT	2,391	1,929	462.0	19.3%
Light Duty Vehicle Average	1,732	1,416	315.5	18.2%

Figure 144: Comparison between 2010 and 2020 Class Average weights for LWV 1.0

In response to the recommendations made by Honda to improve LWV 1.0 performance, several design changes were made to LWV 1.0. The updated design is designated as version LWV 1.1 and leads to a mass increase of 21.75 kg. As this mass increase is designed for a MY2020 midsize passenger car, the mass increases for other vehicle classes are derived by proportioning 21.75 kg with the ratio of MY2020 average vehicle mass for each class and MY2020 midsize passenger car average vehicle mass. The formula is shown below in Figure 145 using a MY2020 sub-compact car as an example.

$$1{,}038\ kg + \left(\frac{21.75\ kg}{1{,}272\ kg}\right)\ x\ (1{,}038\ kg) =\ 1{,}055\ kg$$

Figure 145: MY2020 Sub-compact Car Example

For all the vehicle classes, the estimated masses for the 2020 are shown in Figure 146.

Vehicle Class	2010 - Class Average CVW (kg)	2020 - Class Average CVW with Honda Feedback (kg)	Mass Reduction (kg)	Mass Reduction (%)
Sub-Compact Car	1,261	1,055	205.6	16.3%
Compact Car	1,345	1,119	226.3	16.8%
Mid-Sized Car	1,561	1,294	267.0	17.1%
Small SUV/LT	1,592	1,318	273.5	17.2%
Large Car	1,752	1,453	298.6	17.0%
Mid-Sized SUV/LT	1,916	1,632	284.0	14.8%
MiniVans	2,035	1,689	346.0	17.0%
Large SUV/LT	2,391	1,962	429.0	17.9%
Light Duty Vehicle Average	1,732	1,440	291.2	16.8%

Figure 146: Comparison between 2010 and 2020 Class Average weights for LWV 1.1

In conclusion, all of the weight reduction technologies developed for the LWV 1.0 and updates for the LWV 1.1 program using the Honda Accord as the baseline vehicle can readily be introduced to all of the selected vehicles within each of the vehicle sub-classes, sub-compact to large SUV/light truck, to achieve weight savings from 16.3 percent to 17.9 percent.

5.2 C.5.3 Vehicle Weight Change for Other Vehicle Sub-Classes to Meet SOL

To calculate the vehicle weight change for other vehicle sub-classes to meet the IIHS SOL test, it is presumed that the total energy of the test vehicle at 40 mph (64.4 km/h) is proportional to the vehicle test weight (curb plus added test weight). The estimated mass to meet the SOL requirements for the LWV 1.2 was 6.90 kg., so, once the additional mass for meeting the SOL is identified, it is proportionally applied to other classes of vehicles.

The SOL test requires the vehicle to crash into a steel barrier with a 25 percent overlap condition. The test mass of the vehicle including the 50th percentile male anthropomorphic test device (ATD) adds 125 to 175 kg of additional mass as specified in the test protocol. Figure 147 shows sample vehicles which have completed the IIHS SOL Test and their curb and test weight. From the difference, the team calculated the added test weight for each vehicle. The added test mass varies from 131 kg for the Honda CR-V 2012 to 164 kg for the Toyota Corolla 2014. Using this information, the team decided to use a test mass of 150 kg for the LWV 1.2.

Vehicle	IIHS Test Number	Vehicle Curve Weight (kg)	Vehicle SOL Test Weight (kg)	Added Test Weight (kg)
2014 Ford Fiesta	CEN1343	1191	1338	147
2014 Toyota Corrola	CEN1332	1291	1455	164
2013 Honda Accord	CEN1229	1476	1622	146
2012 Honda CR-V	CEN1223	1535	1666	131
2014 Acurra MDX	CEN1339	1933	2071	138
2014 Chevrolet Equinex	CEN1401	1858	2000	142
		Average added test weight (kg)		145

Test Protocol - added test weight (kg)	125 to 175
Test Protocol Average weight (kg)	150

Figure 147: Test Masses Added to Vehicle Curb Weight

To estimate the LWV 1.2 weight change for other vehicle sub-classes, the project team took the 2010 and 2020 vehicle class average CVW shown in Figure 146 and Figure 144 and added 150 kg test weight. Then, the project team took the 2010 or 2020 weight and multiplied it by the ratio of the LWV 1.2 weight increase compared to LWV 1.1 curb weight plus 150 kg test weight. The formula shown below in Figure 148 is used to calculate vehicle mass increase for other vehicle classes.

$$Increase\ in\ mass\ to\ meet\ IIHS\ SOL = \left(\frac{LWV\ 1.2\ Mass\ Increase}{LWV\ 1.1\ Test\ Vehicle\ Weight}\right)\ x\ Vehicle\ Class\ Average\ Test\ Vehicle\ Weight$$

Figure 148: Vehicle Mass Increase for Other Vehicle Classes Formula

LWV 1.1 curb weight is 1,148 kg plus 21.75 kg, which is 1,169.75 kg after responding to Honda’s comments. Adding 150 kg to this curb weight arrives at 1320 kg test vehicle weight for

LWV 1.1. For example, the 2010 average vehicle curb weight for sub-compact car is 1261 kg. The mass increase for midsize car to meet IIHS SOL is 6.9 kg. The mass increase for the 2010 sub-compact car due to IIHS small-overlap test can be calculated as shown in Figure 149 below.

$$\left(\frac{6.90\ kg}{1{,}320\ kg}\right)\ x\ (1{,}261 + 150\ kg) = \ 7.4\ kg$$

Figure 149: Mass Increase for the 2010 Sub-compact car due to IIHS SOL Test Formula

Figure 150 and Figure 151 show the estimated mass increase to meet IIHS SOL for all vehicle sub-classes in 2010 and 2020, respectively. The estimated mass increase for the “body on frame vehicle” should be further reviewed and validated using a CAE model for such vehicles due to the different body structure design.

	2010 Vehicle Class Average			
Vehicle Class	**Curb Vehicle Weight (kg)**	**Test Vehicle Weight (kg)**	**Increase in mass to meet IIHS SOL (kg)**	**Curb Vehicle Weight w/ IIHS SOL Changes (kg)**
Sub-Compact Car	1,261	1,411	7.4	1,268
Compact Car	1,345	1,495	7.8	1,353
Mid-Sized Car	1,561	1,711	8.9	1,570
Small SUV/LT	1,592	1,742	9.1	1,601
Large Car	1,752	1,902	9.9	1,762
Mid-Sized SUV/LT	1,916	2,066	10.8	1,927
MiniVans	2,035	2,185	11.4	2,046
Large SUV/LT	2,391	2,541	13.3	2,404
Light Duty Vehicle Average	**1,732**	**1,882**	**9.8**	**1,741**

Figure 150: Estimated Mass Increase to meet IIHS SOL for 2010 vehicle classes

	2020 Vehicle Class Average			
Vehicle Class	**Curb Vehicle Weight (kg)**	**Test Vehicle Weight (kg)**	**Increase in mass to meet IIHS SOL (kg)**	**Curb Vehicle Weight w/ IIHS SOL Changes (kg)**
Sub-Compact Car	1,055	1,205	6.3	1,062
Compact Car	1,119	1,269	6.6	1,125
Mid-Sized Car	1,294	1,444	7.5	1,302
Small SUV/LT	1,318	1,468	7.7	1,326
Large Car	1,453	1,603	8.4	1,462
Mid-Sized SUV/LT	1,632	1,782	9.3	1,641
Mini Vans	1,689	1,839	9.6	1,699
Large SUV/LT	1,962	2,112	11.0	1,973
Light Duty Vehicle Average	**1,440**	**1,590**	**8.3**	**1,449**

Figure 151: Estimated Mass Increase to meet IIHS SOL for 2020 vehicle classes

Figure 152 show the amount of mass reduction of 2020-class average vehicles comparing to 2010-class average vehicles after responding to Honda’s comments and after counter measure masses are added for IIHS small-overlap tests.

Vehicle Class	2010-Class Average CVW (kg)	2020-Class Average CVW LWV1.0 (kg)	Mass Reduction (kg)	Mass Reduction (%)	2020-Class Average CVW LWV1.1 (kg)	Mass Reduction (kg)	Mass Reduction (%)	2020-Class Average CVW LWV1.2 (kg)	Mass Reduction (kg)	Mass Reduction (%)
Sub-Compact Car	1,261	1,038	-223.0	-17.7%	1,056	-205.3	-16.3%	1,062	-198.9	-15.8%
Compact Car	1,345	1,100	-245.0	-18.2%	1,119	-226.2	-16.8%	1,125	-219.6	-16.3%
Mid-Sized Car	1,561	1,272	-289.0	-18.5%	1,294	-267.3	-17.1%	1,301	-259.7	-16.6%
Small SUV/LT	1,592	1,296	-296.0	-18.6%	1,318	-273.8	-17.2%	1,326	-266.2	-16.7%
Large Car	1,752	1,429	-323.0	-18.4%	1,453	-298.6	-17.0%	1,462	-290.2	-16.6%
Mid-Sized SUV/LT	1,916	1,605	-311.0	-16.2%	1,632	-283.6	-14.8%	1,642	-274.2	-14.3%
MiniVans	2,035	1,661	-374.0	-18.4%	1,689	-345.6	-17.0%	1,699	-336.0	-16.5%
Large SUV/LT	2,391	1,929	-462.0	-19.3%	1,962	-429.0	-17.9%	1,973	-418.0	-17.5%
Light Duty Vehicle Average	1,732	1,416	-315.4	-18.2%	1,440	-291.2	-16.8%	1,449	-282.8	-16.3%

Figure 152: Comparison of 2010 and 2020 class average vehicle weight based on LWV 1.2

6 Conclusion

6.1 C.5.1 Create and Update a MY 2011 Baseline Honda Accord Model

The Electricore, EDAG, and GMU team developed an FE model of a baseline 2011 Honda Accord model and validated the results using NCAP and IIHS tests. The NCAP tests included frontal, side, and side pole impacts. For each of these rating tests, the team conducted appropriate crash simulations and correlated the crash acceleration and occupant compartment intrusion against test results of the baseline vehicle. The occupant compartment acceleration was evaluated in terms of the shape of the crash pulse, peak acceleration and relevant intrusion measurements for the crash mode. The team also conducted a crash simulation to correlate to the structural performance requirements of the IIHS roof crush, moderate offset, side, and small offset impacts. All simulation to test comparisons indicated that the model provided a good representation of the actual vehicle in these impacts.

6.2 C.5.6 Update Lightweighted Vehicle Model in Response to Honda's Comments

The mass and cost changes made to the body structure shown in Figure 84 are summarized in Figure 92. With these changes the mass of the body structure increased by 11.5 kg with a cost reduction of $13.41. The cost reduction is due the fact that lower grade (low cost premium) steel grades combined with lower cost manufacturing processes were used on the upgraded structure. Also, hot-stamping process used on several parts was replaced with regular stamping as shown in Figure 91.

The total mass of the LWV 1.0 vehicle 1,148 kg is increased by 21.75 kg to 1,170 kg to represent the LWV 1.1 vehicle. This is equivalent to 20.9 percent (310kg) mass saving from the 2011 Honda Accord baseline vehicle mass of 1,480 kg. The incremental direct manufacturing cost of $319[62] for LWV 1.0 is increased by $18.13 to $338 for the LWV 1.1. The direct manufacturing mass saving cost premium for the LWV 1.1 is calculated to be $1.09 per kg ($338/310kg) and is shown in Figure 93. Many components are used across multiple platforms. While this approach was outside the scope of the project, it is an important concept and future research may want to focus on this important aspect.

6.3 C.5.2 Weight and Cost Changes for LWV for Small Frontal Offset Test

Figure 142 summarizes the crashworthiness comparison of the LWV 1.2 with the safety rating of Accord vehicle test results. Based on the seven crash tests, the overall safety performance of the LWV 1.2 model is "Good," which is comparable to the safety rating of the MY2013 and MY2011 Accord vehicles.

For the NCAP frontal test, the acceleration versus time curves are similar and the intrusion into the occupant compartment of the LWV 1.2 is comparable to that from both the MY2013 and MY2011 Accord tests. In the NCAP side barrier test, the intrusion of the LWV 1.2 is slightly higher than the 2013 Accord near the driver space, but both vehicles satisfy the requirements for a "Good" safety rating. In the NCAP pole test, the LWV 1.2 is the same as the MY2013 Accord in terms of intrusion. For the IIHS roof crush test, the LWV 1.2 performs slightly poorer compared to MY2013 Accord. The SWR for LWV 1.2 is in "acceptable" region. In the IIHS side barrier test, the LWV 1.2 responded the same and satisfied the requirements for the same safety rating as the MY2013 Accord. In the IIHS moderate overlap frontal test, the LWV 1.2 had similar acceleration and velocity as the MY2010 Accord Crosstour. In the IIHS moderate overlap frontal test, the LWV 1.2 had minutely higher intrusion, but was well within the "Good" region. In the IIHS small-overlap frontal test, the LWV 1.2 has similar

[62] Singh, 2012.

acceleration pulse compared to MY2013 Accord. In the IIHS small-overlap frontal test, the intrusions are comparable to MY2013 Accord.

6.4 C.5.3 Vehicle Weight Change for Other Vehicle Sub-Classes to Meet SOL

In the original LWV 1.0 program, the team selected one baseline vehicle for each class as shown in Figure 143. The right three columns in the figure also show the estimated 2020 LWV 1.0 curb vehicle weight and their mass reduction. The mass saving potential for all the classes ranges from 16.3 percent to 19.3 percent.

This range of results is lower than the results obtained for the LWV mass reduction of 22.4 percent. This is mainly due to the baseline Honda Accord front suspension change from double wish-bone to the MacPherson strut design implemented on LWV, which is not applicable to other vehicles already with MacPherson strut design. Other material choices and manufacturing technologies implemented to achieve the mass reduction are similar to the detail design option of the LWV. Figure 144 shows the estimated LWV 1.0 2020 class average mass compared with the 2010 Vehicle Class averages.

In response to the recommendations made by Honda to improve LWV 1.0 performance, several design changes were made to LWV 1.0. The updated design is designated as version LWV 1.1 and leads to a mass increase of 21.75 kg. As this mass increase is designed for a MY2020 midsize passenger car, the mass increases for other vehicle classes are derived by proportioning 21.75 kg with the ratio of MY2020 average vehicle mass for each class and MY2020 midsize passenger car average vehicle mass. The formula is shown below in Figure 145 using a MY2020 sub-compact car as an example. For all the vehicle classes, the estimated masses for the 2020 are shown in Figure 146.

In conclusion, all of the weight reduction technologies developed for the LWV 1.0 and updates for the LWV 1.1 program using the Honda Accord as the baseline vehicle can readily be introduced to all of the selected vehicles within each of the vehicle sub-classes, sub-compact to large SUV/light truck, to achieve weight savings from 16.3 percent to 17.9 percent.

6.5 C.5.3 Overall Conclusions

The new LWV 1.2 design was modeled and assessed for the performance of crashworthiness in seven crash safety tests. The new design achieved a “good,” rating in all tests which are comparable to the safety rating of the MY2013 Accord. When the new design was applied to each of the light vehicle sub-classes, which span sub-compact cars to large SUV/light trucks, the project mass saving potential decreased from a range of 17.7 percent to 19.3 percent (18.2% on average) for LWV 1.0 to a range of 15.8 percent to 17.5 percent (16.3 % on average) for LWV 1.2.

7 Appendix

7.1 Comparison of part changes from LWV 1.0 to LWV 1.1

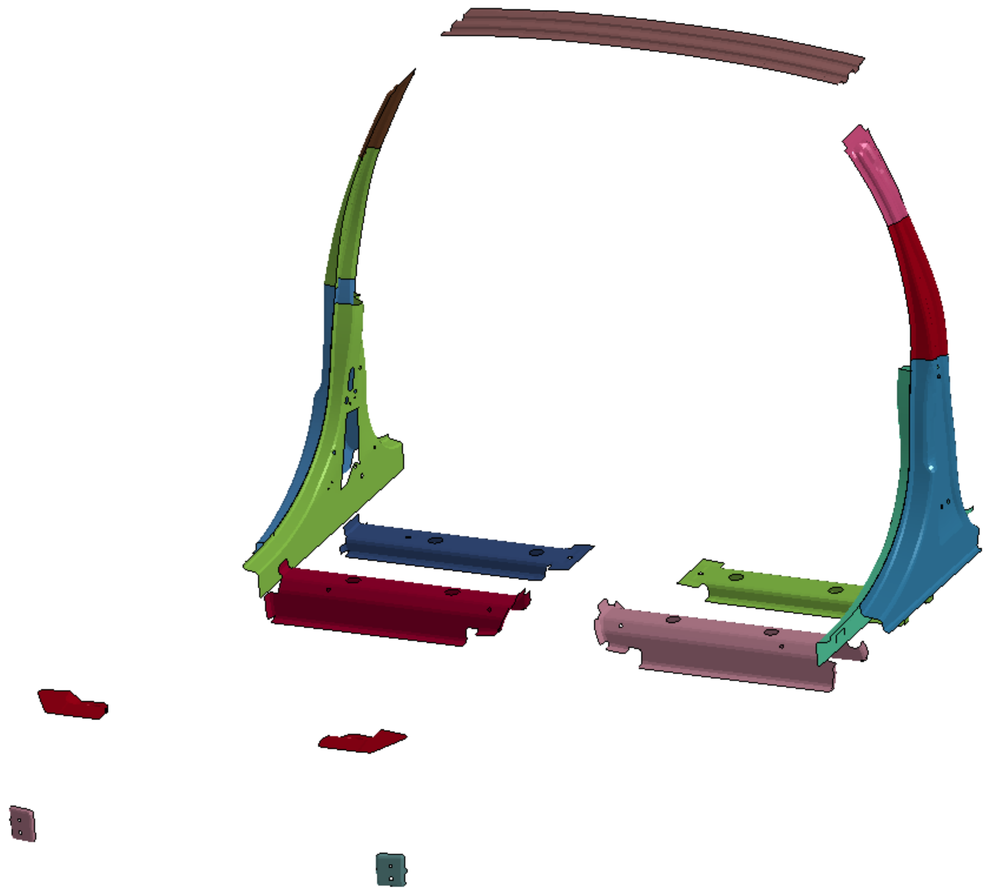


Figure 153: Parts with materials changed from high-strength to lower-strength steels

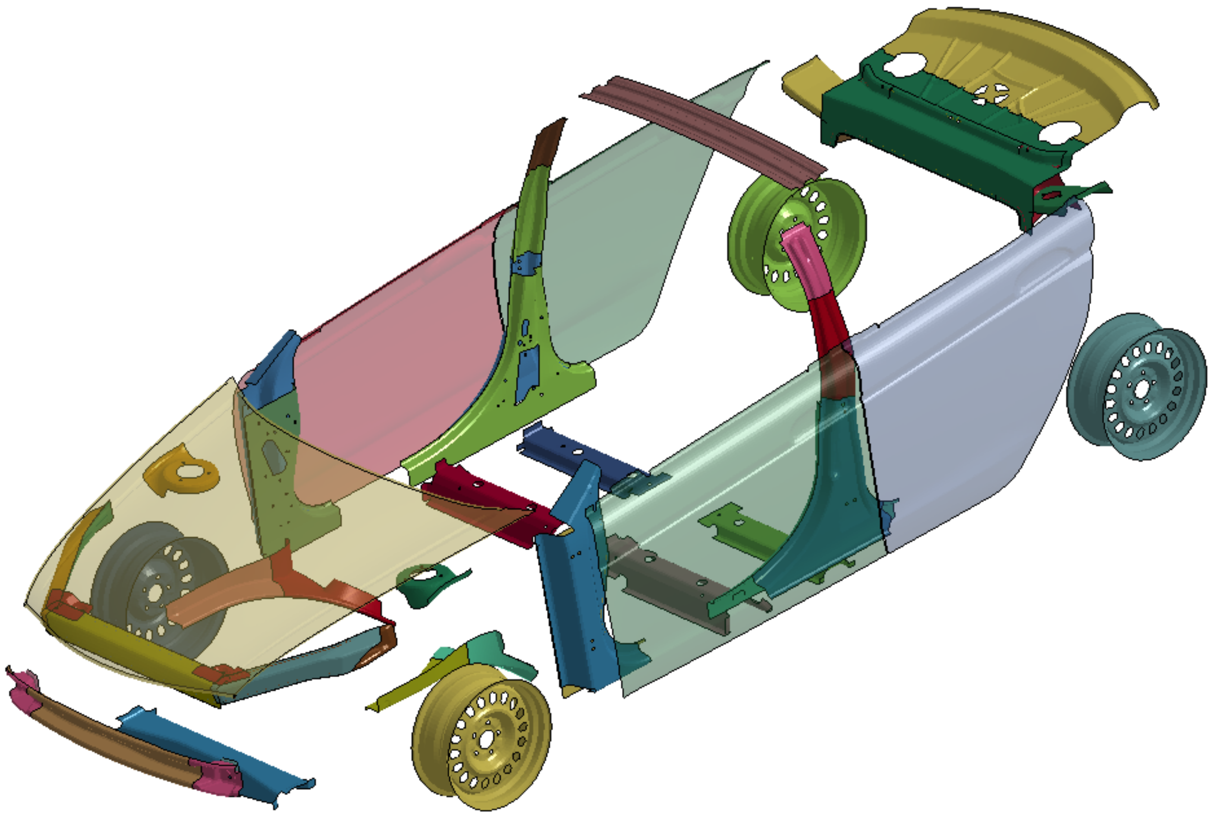


Figure 154: Parts with increased thickness or added mass

Part Number	Part Name	LW V1.0		LW 1.1	
		Material Number	Material Name	Material Number	Material Name
2000071	B-Pillar Inner Top Left	12	HF1050/1500	11	DP 500/800
2000073	B-Pillar Inner Mid Left	12	HF1050/1500	11	DP 500/800
2000074	B-Pillar Inner Bottom Left	12	HF1050/1500	11	DP 500/800
2000120	Roof Cross Member Center	22	MS950/1200	11	DP 500/800
2000155	Seat X-Member F-L	22	MS950/1200	11	DP 500/800
2000156	Seat X-Member R-L	22	MS950/1200	11	DP 500/800
2000185	B-Pillar Inner Mid Right	12	HF1050/1500	11	DP 500/800
2000186	B-Pillar Inner Bottom Right	12	HF1050/1500	11	DP 500/800
2000223	Seat X-Member F-R	22	MS950/1200	11	DP 500/800
2000224	Seat X-Member R-R	22	MS950/1200	11	DP 500/800
2000238	B-Pillar Inner Top Right	12	HF1050/1500	11	DP 500/800
2000450	Upper Radiator Tie-in	18	HSA 350	11	DP 500/800
2000473	Bumper Front Plate Left	16	DP700/100	11	DP 500/800
2000474	Bumper Front Plate Right	16	DP700/100	11	DP 500/800
2000620	B-Pillar Inner Lower Right	12	HF1050/1500	11	DP 500/800
2000623	B-Pillar Inner Lower Left	12	HF1050/1500	11	DP 500/800

Figure 155: List of parts with materials changed from high-strength to lower-strength steels

Part Number	Part Name	LW V 1.0		LW V 1.1		Mass Diff. (kg)
		Thickness (mm)	Mass (kg)	Thickness (mm)	Mass (kg)	
2000028*	Rear Panel Cross Member	0.60	1.556	1.00	2.786	1.230
2000038	Upper Load Path Tie1 Left	0.70	0.347	1.00	0.496	0.149
2000073	B-Pillar Inner Mid Left	1.00	0.462	1.40	0.646	0.184
2000074	B-Pillar Inner Bottom Left	0.70	1.031	1.00	1.473	0.442
2000120	Roof Cross Member Center	0.60	0.939	0.80	1.253	0.314
2000133**	Door Outer Front Left	1.10	2.570	1.10	2.810	0.240
2000134	Upper Load Path Front1	0.80	0.801	1.00	1.001	0.200
2000135	Upper Load Path Tie2 Left	0.70	0.372	1.00	0.532	0.160
2000142	Upper Load Path Front2	0.80	0.715	1.00	0.893	0.178
2000143**	Strut Housing Front Top Left	1.40	0.521	1.40	1.396	0.875
2000144*	Front Rail Lower Back Left	1.40	2.019	1.70	2.452	0.433
2000155	Seat X-Member F-L	0.80	1.252	1.10	1.722	0.470
2000156	Seat X-Member R-L	0.80	0.748	1.10	1.028	0.280
2000161	A-Pillar Outer Lower Left	0.80	1.514	1.20	2.270	0.756
2000167**	Strut Housing Rear Top Left	2.40	1.109	2.40	1.984	0.875
2000168	A-Pillar Inner Lower Left	1.20	1.350	1.80	2.025	0.675
2000179	A-Pillar Inner Lower Right	1.20	1.350	1.80	2.025	0.675
2000185	B-Pillar Inner Mid Right	1.00	0.462	1.40	0.646	0.184
2000186	B-Pillar Inner Bottom Right	0.70	1.027	1.00	1.468	0.441
2000201	Upper Load Path Tie2 Right	0.70	0.372	1.00	0.532	0.160
2000205**	Strut Housing Front Top Right	1.40	0.521	1.40	1.396	0.875
2000206*	Front Rail Lower Back Right	1.40	2.019	1.55	2.235	0.216
2000215	A-Pillar Outer Lower Right	0.80	1.514	1.20	2.270	0.756
2000223	Seat X-Member F-R	0.80	1.252	1.10	1.722	0.470
2000224	Seat X-Member R-R	0.80	0.748	1.10	1.028	0.280
2000226**	Strut Housing Rear Top Right	2.40	1.109	2.40	2.354	1.245
2000234	Upper Load Path Tie1 Right	0.70	0.347	1.00	0.496	0.149
2000369	Rim Front Right	2.50	13.479	2.71	14.629	1.150
2000371	Rim Front Left	2.50	13.477	2.70	14.627	1.150
2000450	Upper Radiator Tie-in	1.00	0.300	1.20	0.360	0.060
2000473	Bumper Front Plate Left	0.80	0.046	1.00	0.058	0.012
2000474	Bumper Front Plate Right	0.80	0.046	1.00	0.058	0.012
2000485**	Door Outer Rear Left	1.10	2.104	1.10	2.344	0.240
2000537**	Door Outer Front Right	1.10	2.570	1.10	2.810	0.240
2000539**	Door Outer Rear Right	1.10	2.104	1.10	2.344	0.240
2000574	Hood Outer	1.00	4.056	1.06	4.296	0.240
2000607*	Rear Shelf Panel	0.60	3.832	1.00	4.988	1.156
2000620	B-Pillar Inner Lower Right	0.90	1.357	1.20	1.809	0.452
2000623	B-Pillar Inner Lower Left	0.90	1.369	1.20	1.825	0.456
2000638	Bumper Front	1.30	2.622	1.40	2.802	0.180
2000647	Rim Rear Left	2.50	13.477	2.70	14.627	1.150
2000649	Rim Rear Right	2.50	13.479	2.71	14.629	1.150
2000654	Sub-frame Front	2.00	1.097	3.73	2.047	0.950
					Total	21.750

Figure 156: List of parts with modified thickness or added mass

* Thickness increase for only a portion of the part

** Mass increased by adjusting material density and not thickness

7.2 LWV 1.2 Design Options Considered

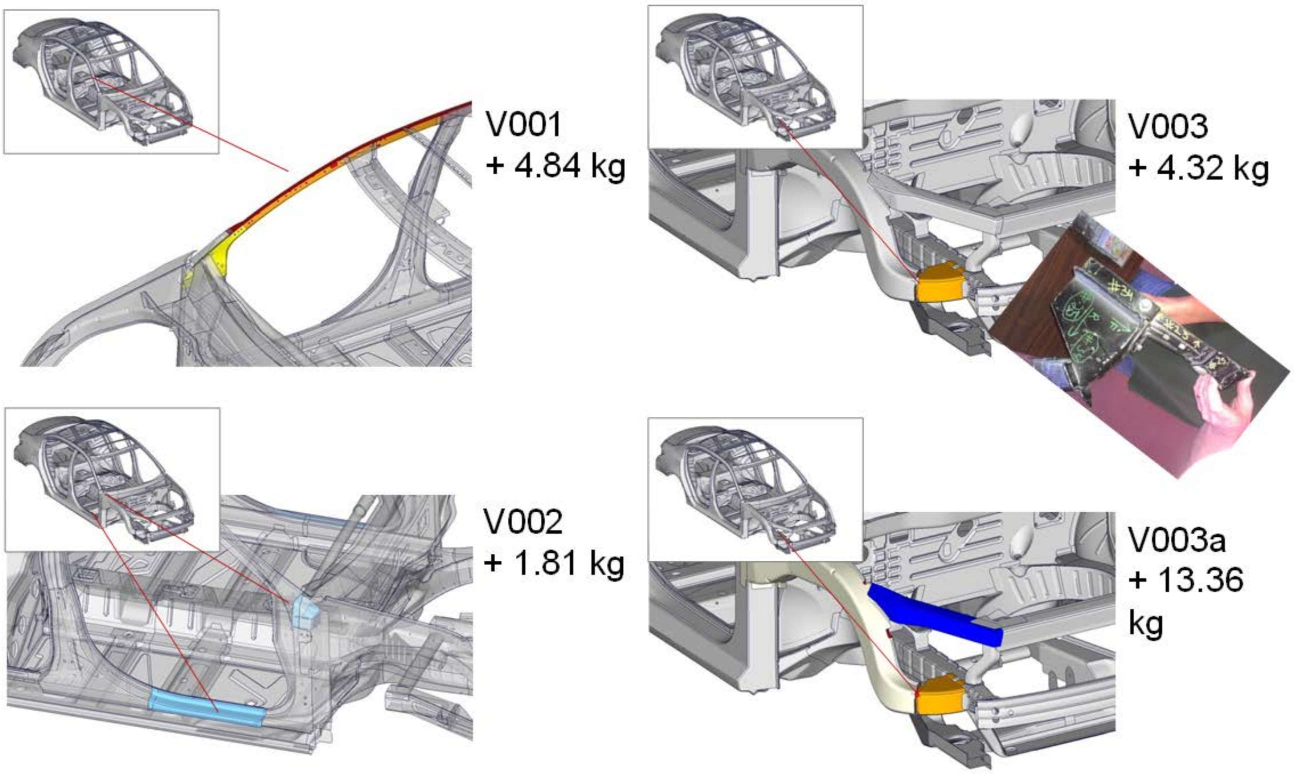


Figure 157: C.5.2 LWV Model Design Changes

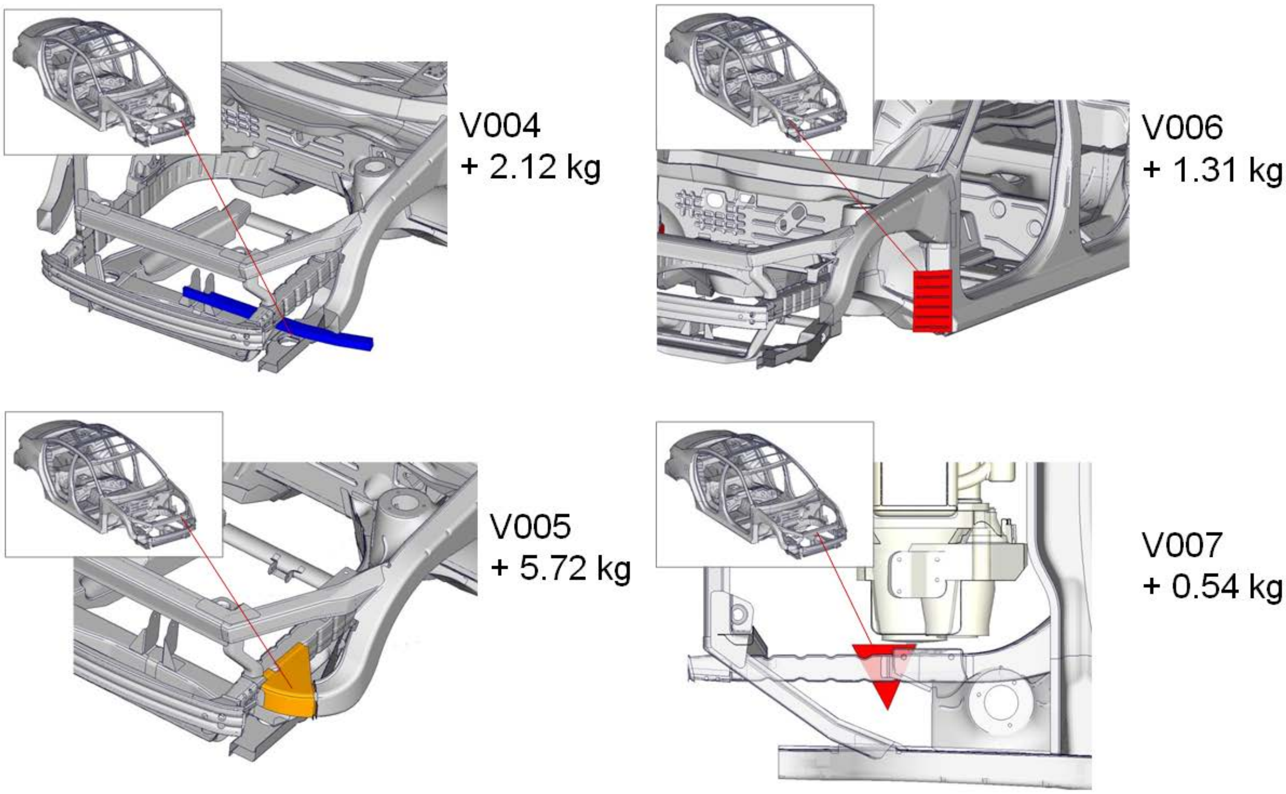


Figure 158: C.5.2 LWV Model Design Changes

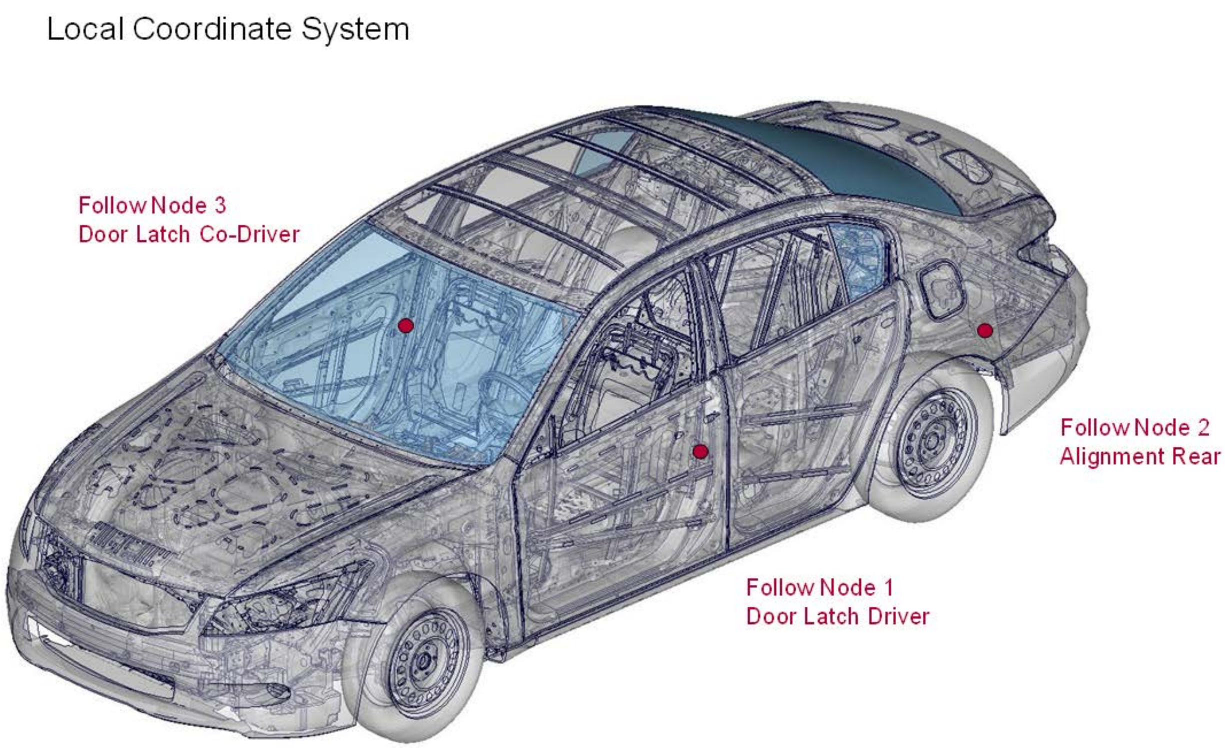


Figure 159: C.5.2 LWV Model – CAE Model Intrusion Comparison

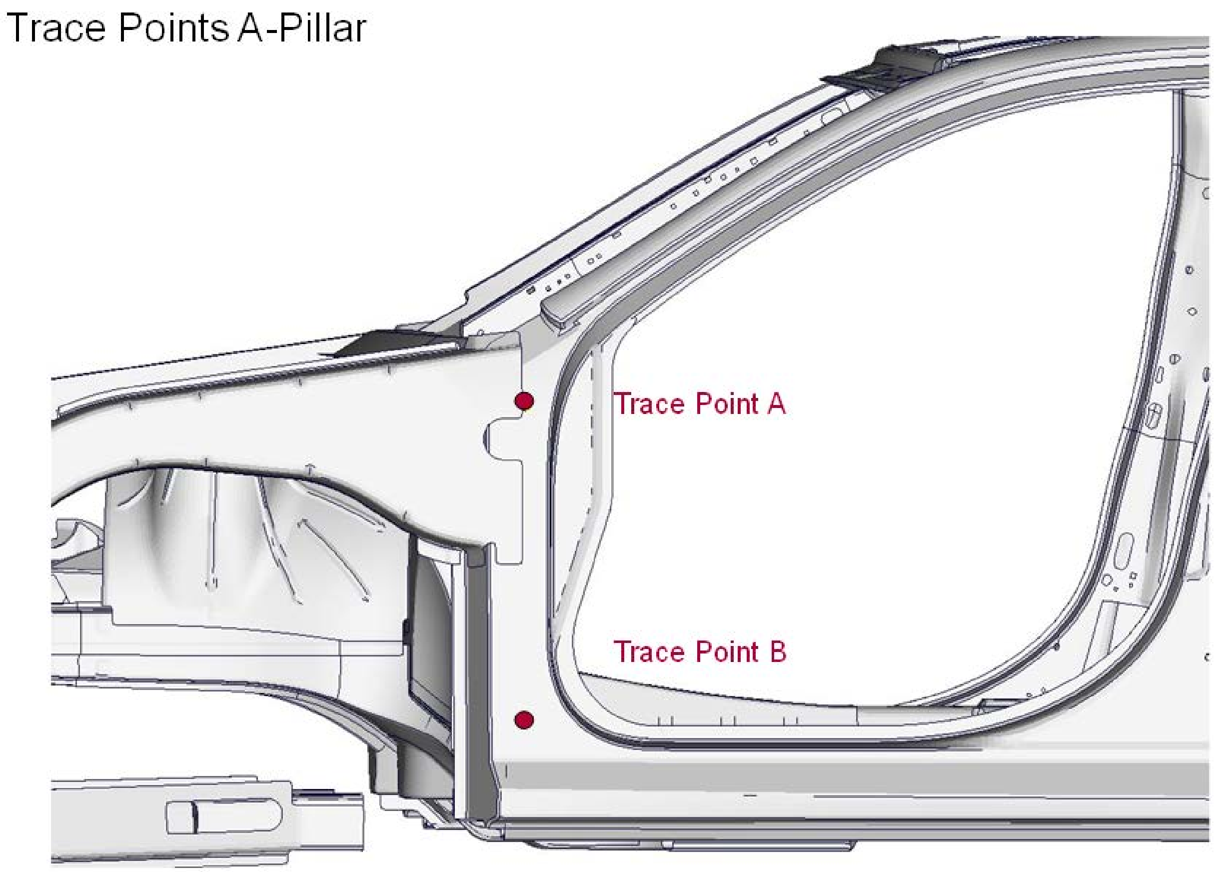


Figure 160: C.5.2 LWV Model – CAE Model Intrusion Comparison

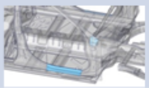
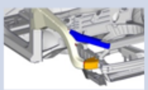
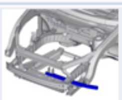
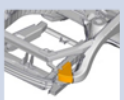
Variant	X-Displ A In mm	X- Displ B In mm	Add Weight In Kg
2009 Accord Test	200	300	
2013 Accord Test	106	35	
V000 Baseline Model	95.4	59.6	
V001 	39.2	34.0	4.84
V002 	68.0	41.5	1.81
V003 	67.8	51.8	4.32
V003a 	73.1	25.4	13.36
V004 	68.6	30.9	2.12
V005 	69.1	50.3	5.72

Figure 161: C.5.2 LWV Model – CAE Model Intrusion Comparison

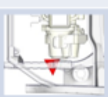
Variant	X-Displ A In mm	X- Displ B In mm	Add Weight In Kg
V000 Baseline	95.4	59.6	0
V006 	129.5	53.4	1.31
V007 	67.4	46.6	0.54

Figure 162: C.5.2 LWV Model – CAE Model Intrusion Comparison

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