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Vehicle Interior and Restraints Modeling Development of Full Vehicle Finite Element Model Including Vehicle Interior and Occupant Restraints Systems For Occupant Safety Analysis Using THOR Dummies

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16. Abstract

NHTSA awarded a contract to EDAG, Inc., to develop a full vehicle finite element model including a vehicle interior and occupant restraint systems for the driver and front-seat passenger. The resulting finite element model represents a model year (MY) 2014 Honda Accord mid-size sedan. This report documents the work done to fulfill the requirements of this Task Order. Specifically, the predicted results demonstrate that the baseline vehicle FEM model correlates well with the safety performance exhibited in full vehicle test results for vehicle acceleration and intrusion responses in NCAP frontal, IIHS moderate overlap, IIHS small overlap test procedures, and left and right NHTSA oblique frontal tests.

The vehicle FEM also includes test device for human occupant restraint (THOR) 50th percentile male frontal dummy models in the driver and front passenger seats. Simulation results using these dummies demonstrate the performance in left and right NHTSA oblique frontal crash tests. Occupant kinematics, belt loads, and injury criteria results are compared against the existing test results. Overall the FEM simulation results compare well with test results for THOR dummy accelerations and injury criteria.

The FEM simulation results using comparison GHBMC model dummies compare well with test results and FEM of THOR dummies. The computer run time, however, is much higher with GHBMC dummies compared with the THOR model.

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1 Executive Summary

The National Highway Traffic Safety Administration awarded a contract to EDAG, Inc., an automotive design and engineering company, to develop a full vehicle finite element model (FEM) including a vehicle interior and occupant restraint systems for the driver and front seat passenger. The resulting finite element model represents a model year (MY) 2014 Honda Accord mid-size sedan. This vehicle meets the structural intrusion requirements for a "Good" or "Acceptable" structural rating in the Insurance Institute for Highway Safety (IIHS) small overlap test, a "Good" rating in IIHS moderate overlap and 5-star rating in the NHTSA New Car Assessment Program (NCAP). Test results for the NHTSA oblique test are also available for this vehicle. This report documents the work done to fulfill the requirements of this task order. Specifically:

1. The predicted results from the FEM demonstrate that the baseline vehicle FEM model correlates well with the safety performance exhibited in full vehicle test results for vehicle acceleration and intrusion responses in NCAP frontal, IIHS moderate overlap, IIHS small overlap test procedures, and left and right NHTSA oblique frontal tests.
2. The vehicle interior and occupant restraint systems FEM for the driver and front seat passenger incorporate detailed vehicle interior elements, such as:
    - Steering wheel and column;
    - Instrument panel with knee bolsters;
    - Seating for driver and passenger;
    - Interior trim panels (door, b-pillar), carpets;
    - All the occupant restraints for crash protection such as front, side and curtain air bags, seat belt pretensioners and load limiters;
    - Component design and operational characteristics, such as air bag folding patterns, inflator mass flow characteristics, pretensioner activation and load limiter performance based on comprehensive component testing and detailed bill of material for these components; and
    - Representation of material properties of all safety components, such as belt webbing, using actual components in the vehicle.
3. The vehicle FEM also includes test device for human occupant restraint (THOR) 50th percentile male frontal dummy models (publicly available from the University of Virginia) in the driver and front passenger seats. Simulation results using this dummy model demonstrate the performance in left and right NHTSA oblique frontal crash tests. Occupant kinematics, belt loads, and injury criteria results are compared against the existing test results. Overall the FEM simulation results compare well with test results for THOR dummy accelerations and injury criteria.
4. Human body models of a 50th percentile male, developed by the Global Human Body Model Consortium (GHBMC), in the driver and front passenger seating positions are also used to evaluate performance in left and right NHTSA oblique frontal crash tests. The FEM simulation results using the GHBMC model compare well with test results and FEM of THOR dummy. The computer run time, however, is much higher with the GHBMC model compared with the THOR model -- 43 hours versus 17 hours, respectively. The simulations were run using LS-DYNA R7.1.1, using 96 CPU cores.

2 Introduction and Scope of Work

2.1 Introduction

The report titled "Fatalities in Frontal Crashes Despite Seat Belts and Air Bags – Review of All CDS Cases – Model and Calendar Years 2000-2007 122 Fatalities" [1] concluded that aside from "exceedingly severe" crashes, one of the common configurations for crashes with belted occupant fatalities in vehicles with air bags was oblique offset crashes. Prior to this report, NHTSA developed a controlled crash test procedure[2] to reproduce vehicle damage and occupant kinematics through crash dummy injury measures that reflect these field-investigated crashes. The resulting test procedure involves a high-speed oblique moving deformable barrier (OMDB) hitting a stationary vehicle with a 35-percent overlap and an angle of 15 degrees from collinear, in both left- and right-side impacts. Results from this test procedure are consistent with the struck vehicle damage, occupant contact points with the vehicle interior, and dummy injury measure predictions are consistent with the types of injuries observed in real-world crashes.

In 2013 NHTSA released a report that detailed the development of an integrated occupant-vehicle model for the analysis of safety in crashes.[3] The resulting occupant-vehicle finite element model was used to conduct a range of sensitivity and occupant studies using a variety of anthropomorphic test devices (ATDs) and human body finite element models. This effort has been the basis of several follow-on studies to evaluate test procedures, performance metrics, and injury countermeasures. Additionally, NHTSA has subsequently developed several full vehicle finite element models that are suitable for simulating vehicle-to-vehicle crash conditions. However, since these vehicle models do not generally include vehicle interior geometry, seats, or occupant restraints, these models are unsuitable for evaluating occupant injury potential.

The occupant safety performance in some of the newer frontal crash test conditions, particularly oblique frontal crash tests, is significantly dependent on the occupant interaction with the intruding vehicle components and the vehicle restraint system. It is desirable to develop full vehicle finite element models that can be used to study how changes in frontal crash test conditions can affect the occupant interaction with the restraint systems and the occupant injury outcomes.

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[1] Bean, J. D., Kahane, C. J., Mynatt, M., Rudd, R. W., Rush, C. J., & Wiacek, C. (2009, September). Fatalities in frontal crashes despite seat belts and air bags – Review of all CDS cases – Model and calendar years 2000-2007 – 122 fatalities (Report No. DOT HS 811 102). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Crashworthiness/Small%20Overlap%20and%20Oblique%20Research/811102.PDF

[2] National Highway Traffic Safety Administration. (2015, December 5). Laboratory test procedure for oblique offset moving deformable barrier impact test (in NHTSA Docket No. NHTSA-2015-0119-0017). Washington, DC: SAuthor. Available at https://www.regulations.gov/contentStreamer?documentId=NHTSA-2015-0119-0017&attachmentNumber=1&contentType=pdf

[3] Reichert, R., Park, C-K., & Morgan, R. M. (2014, December). Development of integrated vehichle-occupant model for crashworthiness safety analysis (Report No. DOT HS 812 087). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/812087_ivomforcrashworthiness.pdf

The oblique frontal crash test currently uses the THOR dummy for evaluating occupant responses in the test vehicles. Currently there are two finite element models of the THOR available. One version is publicly available from the University of Virginia. A second commercial THOR model is available for lease from Humanetics, Inc. For this study, the University of Virginia THOR model V2.1 was used.

Additionally, there is considerable interest in using finite element models of the human body to compare their response and kinematics against the test dummies. Human body models that are commonly used for automotive research include the Global Human Body Model Consortium (GHBMC) model and the Total Human Model for Safety (THUMS) model from Livermore Software Technology Corporation.[4] For this study the GHBMC[5] M50 Occupant Version 4.5 for LS-DYNA was licensed from Elemance, LLC.

2.2 Program Tasks Summary

The objective of this task order was to develop full vehicle finite element model, including the vehicle interior and occupant restraint systems for the driver and front seat passenger simulations using THOR and Human body models.

This report summarizes the work performed under contract DTNH22-15-D-00006/0002 that includes the following tasks.

- Baseline Vehicle Simulations
- Vehicle Interior Model Development
- THOR 50th Simulations
- Human Body Model Simulations

[4] Livermore Software Technology Corporation, Livermore, CA. See www.lstc.com/thums
[5] The Global Human Body Model Consortium is comprised of subsidiary units from Fiat Chrysler, General Motors, Honda, Hyundai, Nissan, Renault, French manufacturer PSA Group (Peugeot, Citroën, DS, Opel and Vauxhall brands), and air bag manufacturer Takata, with Ford Motor Co., the Partnership for Dummy Technology and Biomechanics Corp. (PDB), and NHTSA as sponsors and participants. It is headquartered in Troy, MI. Its marketing and licensing agent is Elemance LLD, Winston-Salem, NC.

3 Baseline Vehicle Simulation

3.1 Baseline Vehicle Choice

The selected vehicle was the MY 2014 Honda Accord mid-size sedan. This vehicle was also used for the NHTSA Contract DTNH22-15-D-00006 Structural Countermeasure/Research Program called "Mass and Cost Increase due to Oblique Offset Moving Deformable Barrier Impact Test." The chosen vehicle met the structural intrusion requirements for a "Good" or "Acceptable" structural rating in the IIHS small overlap test, "Good" rating in IIHS moderate overlap, and 5-star rating in the New Car Assessment Program.

For this Task Order the correlated baseline CAE model developed for the oblique frontal impact test NHTSA Contract DTNH22-15-D-00006 (Structural Countermeasures) was used.

3.2 Baseline Vehicle CAE Model Correlation

3.2.1 NCAP Frontal

This test is used to determine the crashworthiness of the vehicle to protect occupants in full frontal impact crash cases. NHTSA's NCAP frontal impact test is a full-frontal barrier test at a vehicle speed of 56 km/h (35 mph). The LS-DYNA models for the baseline 2014 Honda Accord were created to represent the test setup, such as vehicle velocity of 56 km/h against a flat rigid wall barrier. The test vehicles were equipped with hybrid III 50th percentile male dummies on the driver seat and hybrid III 5th percentile female dummies on the front outboard passenger seats, with combined occupant's mass of 141 kg and cargo mass of 44.8 kg. These masses were also accounted for in the CAE models. A comparison of the test vehicle and the CAE model is shown in Table 1.

Description	Test Vehicle	Baseline CAE
Model Year	2014	2014 (updated 2011)
Engine Disp. (L)	2.4	2.4
Tested Weight (kg)	1,722	1,720

Table 1: Test Vehicle Versus Baseline CAE Model – Vehicle Specifications

The test vehicle and LS-DYNA set up for the frontal crash test of the baseline model into a rigid barrier is shown in Figure 1.

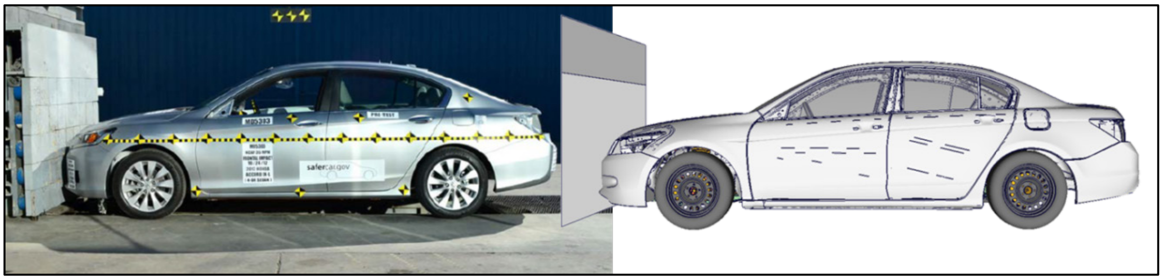


Figure 1: Test Versus CAE Model – NCAP Frontal Test Setup

Images of the post-crash vehicles for the actual laboratory crash test and the simulation are shown in Figure 2 and Figure 3. The overall predicted vehicle kinematics and the crushed shapes from the front side and from underneath the vehicle correlate very well with the test vehicles.

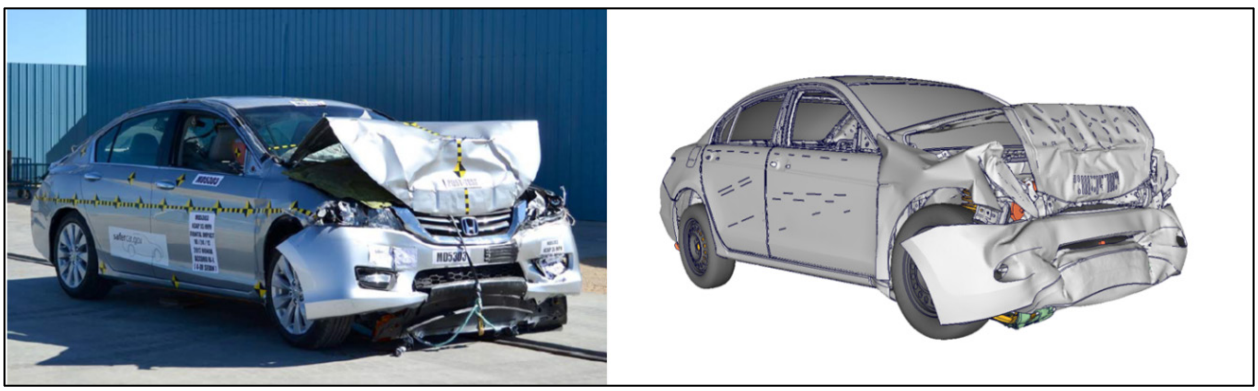


Figure 2: Test Versus CAE Model – Post-Crash Comparison

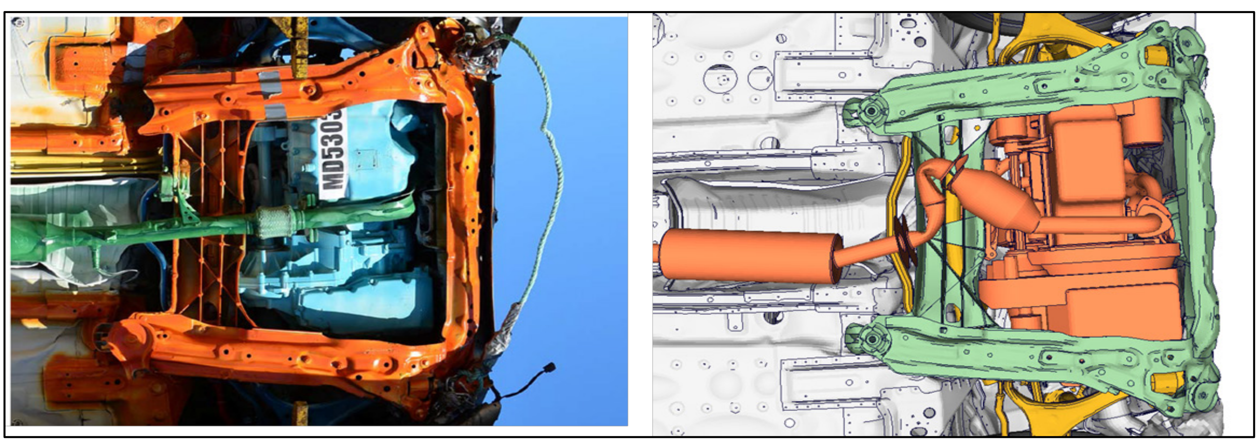
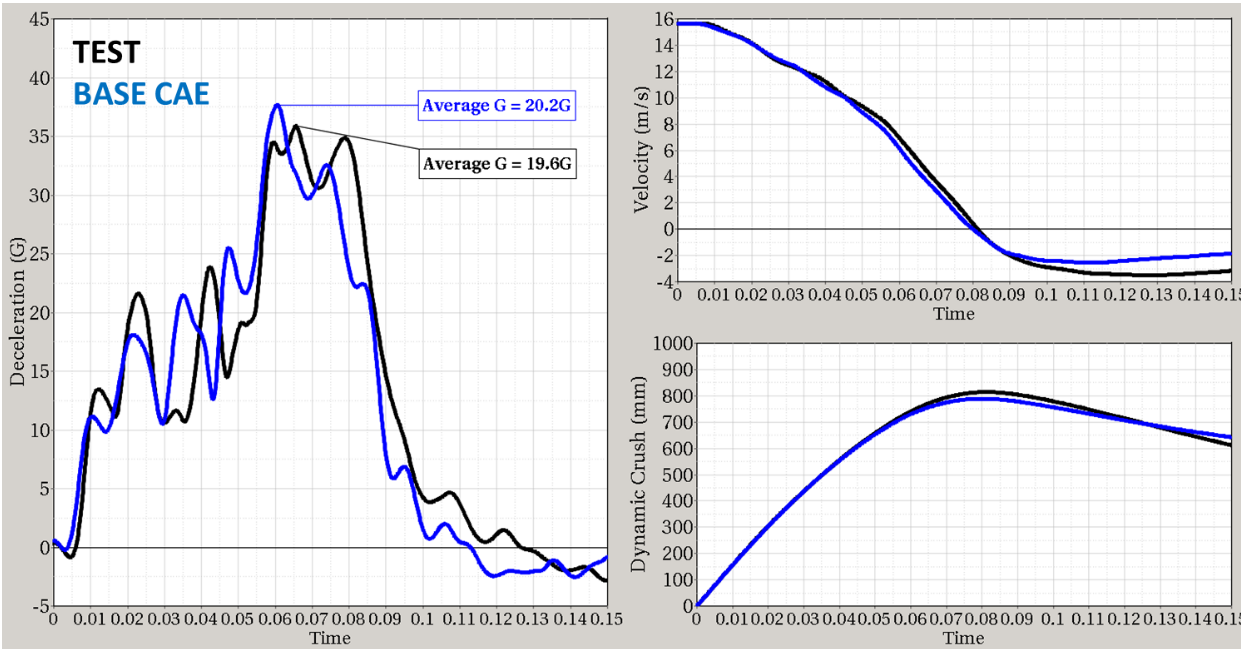


Figure 3: Test Versus CAE Model – Post-Crash Comparison

Comparison of the vehicle acceleration pulse, time-to-zero velocity, and the dynamic crush of the vehicle is shown in Figure 4. The test vehicle and baseline CAE model correlate well on all three parameters with a CORA score of 83 percent for the acceleration pulse and the difference between average G-pulse of only 3 percent.



	Test	Base CAE
Avg G (G)	19.6	20.2
Time to Zero (ms)	81	79
Dynamic Crush (mm)	814	785

Figure 4: Test Versus Baseline – Vehicle Motion Comparison

In terms of vehicle velocity-to-zero, the baseline model correlates well with the test as it reaches zero velocity only 2 ms earlier than the test. The dynamic crush of the baseline model also correlates well with the test having 29 mm less dynamic crush than the baseline.

In summary, the CAE model correlates well with the test results in terms of kinematics, deformation, and intrusion.

3.2.2 IIHS Moderate Overlap Frontal Crash Test

The IIHS moderate overlap frontal crash test runs the test vehicle into a partial frontal impact with a stationary deformable barrier. The test vehicle is aligned such that the right edge of the barrier face is offset to the left of the vehicle centerline by 10 ± 1 percent of the vehicle width (defined in SAE J1100 – Motor Vehicle Dimensions) [6] to make sure 40 percent of the test vehicle's front face is struck in the crash.

The LS-DYNA models for the baseline Accord was created to represent the test setup, such as vehicle velocity of 64 km/h against the deformable barrier. The test vehicle is equipped with a hybrid III 50th percentile male dummy on the driver seat. The mass of the test dummy was accounted for in the CAE models. Comparisons of vehicle parameters are shown in Table 2.

Description	Test Vehicle	Baseline CAE
Model Year	2013	2014 (updated 2011)
Engine Disp. (L)	2.4	2.4
Tested Weight (kg)	1,478	1,548

Table 2: IIHS Frontal Moderate - Test Vehicles and CAE Models Parameters

The LS-DYNA model set up for the IIHS frontal moderate crash test of the baseline model is shown in Figure 5.

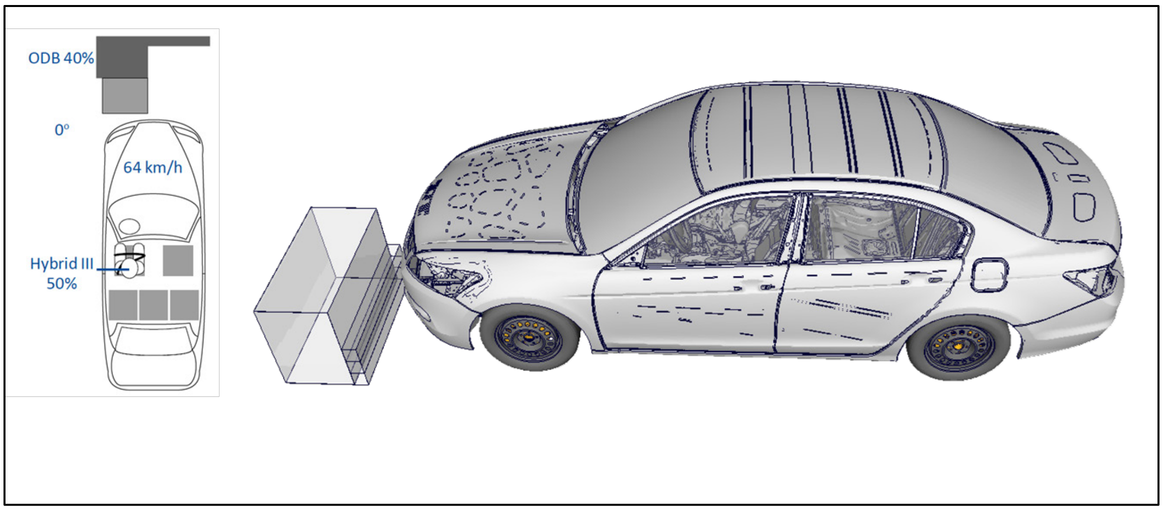


Figure 5: IIHS Frontal Moderate - Test and LS-DYNA Model Setup

The only available data from IIHS regarding this test are the intrusion numbers; therefore there is no comparison with the test in terms structural deformation and kinematics.

[6] Insurance Institute for Highway Safety. (2017 July). Moderate overlap frontal crashworthiness evaluation crash test protocol (Version XVIII). Arlington, VA: Author. Available at www.iihs.org/media/f70ff6eb-d7a1-4b60-a82f-e4e8e0be7323/5VJbtw/Ratings/Protocols/current/test_protocol_high.pdf

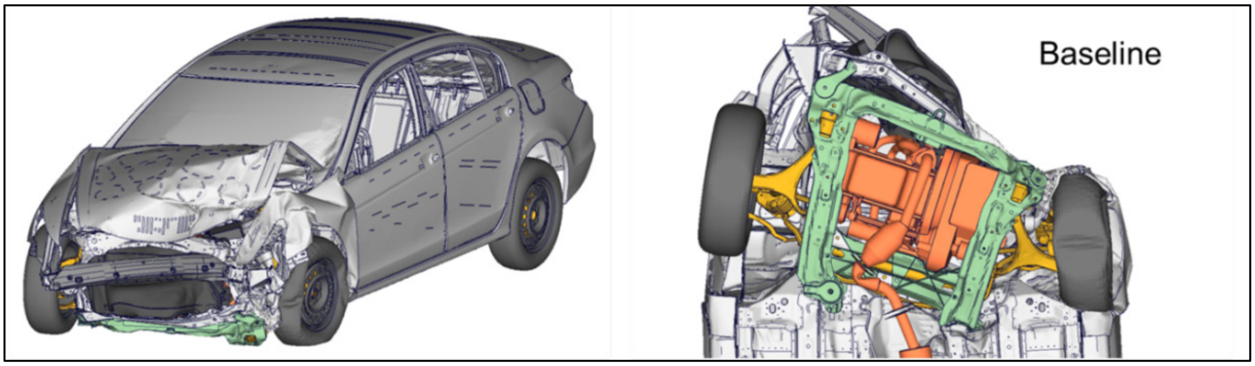


Figure 6: IIHS Frontal Offset - Post-Crash CAE Results for Baseline

Post-crash images of the simulation results shown in Figure 6 are the overall predicted vehicle crushed shapes from the front and from underneath the vehicle. The baseline CAE model shows similar crash performance to that of the test.

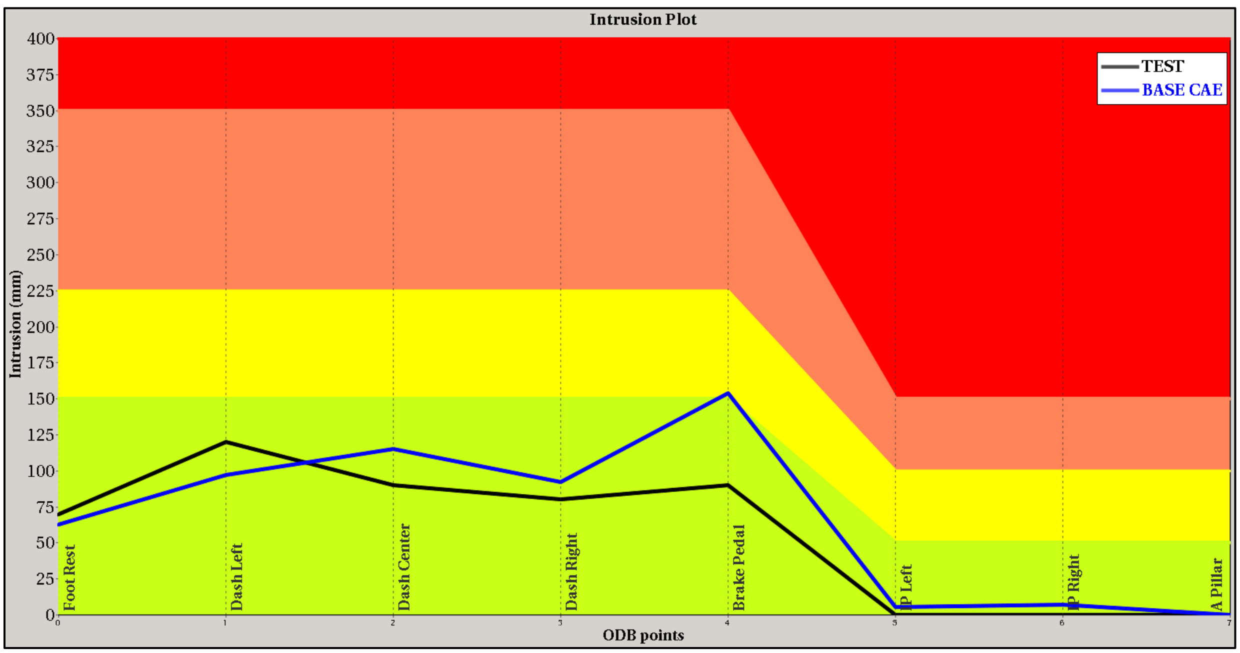


Figure 7: IIHS Frontal Moderate – Intrusion Values Comparison Test Versus CAE Results for Baseline

The IIHS intrusion results for CAE baseline correlates well with the test in every point except for the brake pedal as shown in Figure 7.

3.2.3 IIHS Small Overlap Frontal Barrier Test

The IIHS small overlap frontal barrier 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 air bag designs.

In this test, a vehicle travels at 40 mph toward a 5-foot-tall rigid steel barrier. A hybrid III 50th percentile male 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 as shown in Figure 8. On most vehicles, the barrier is outboard of the main longitudinal members of the vehicle structure.

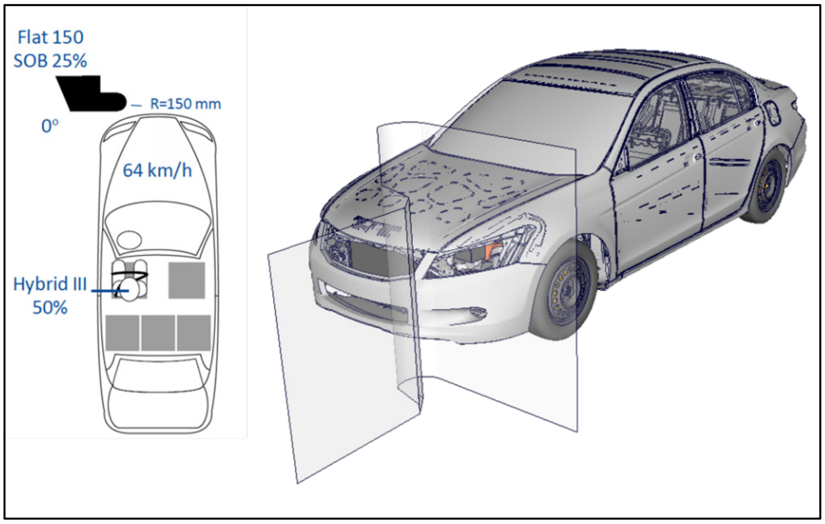


Figure 8: IIHS Small Overlap Test – Test Setup

Post-crash images of the simulation results shown in Figure 9 and Figure 10 compares well the overall predicted vehicle crushed shapes from the side and from underneath the vehicle.

Figure 9: IIHS Small Overlap Test Versus Base CAE

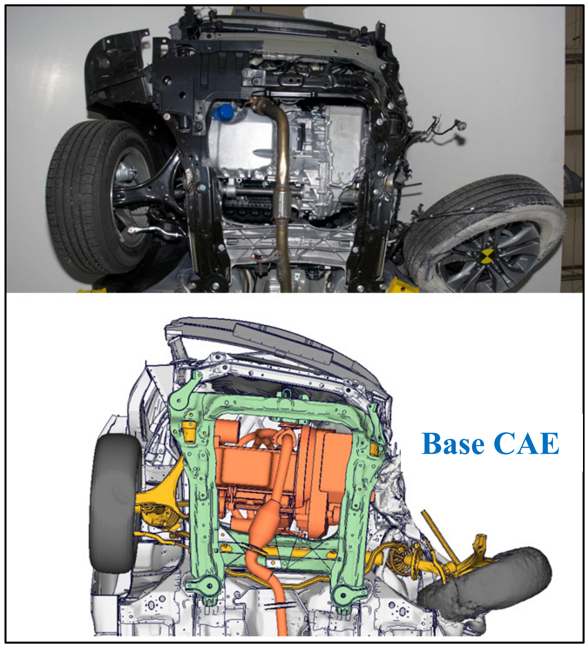


Figure 10: IIHS Small Overlap Test Versus Base CAE

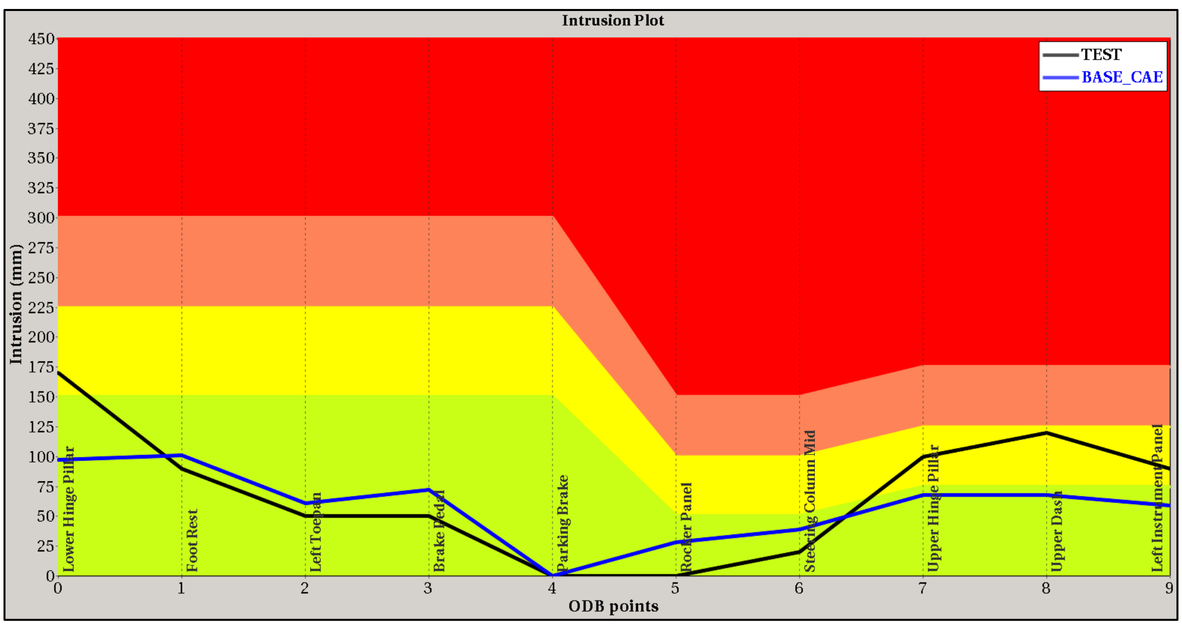


Figure 11: IIHS Small Overlap Intrusion - Test Versus Base CAE

The results of the baseline CAE model shown in Figure 11 show good overall correlation with the test results.

3.2.4 NHTSA Oblique Test Driver Side

This test is used to determine the crashworthiness of the vehicle to protect occupants in oblique frontal impact crash cases. The test consists of an OMDB that weighs 2,490.2 kg traveling at a target speed of 90.12 km/h into a stationary vehicle. The struck vehicle's longitudinal centerline is positioned 15 degrees clockwise from the moving barrier's centerline for right impacts. The test vehicle is struck 35 percent of the vehicle width left or right side of the vehicle as shown in Figure 12.

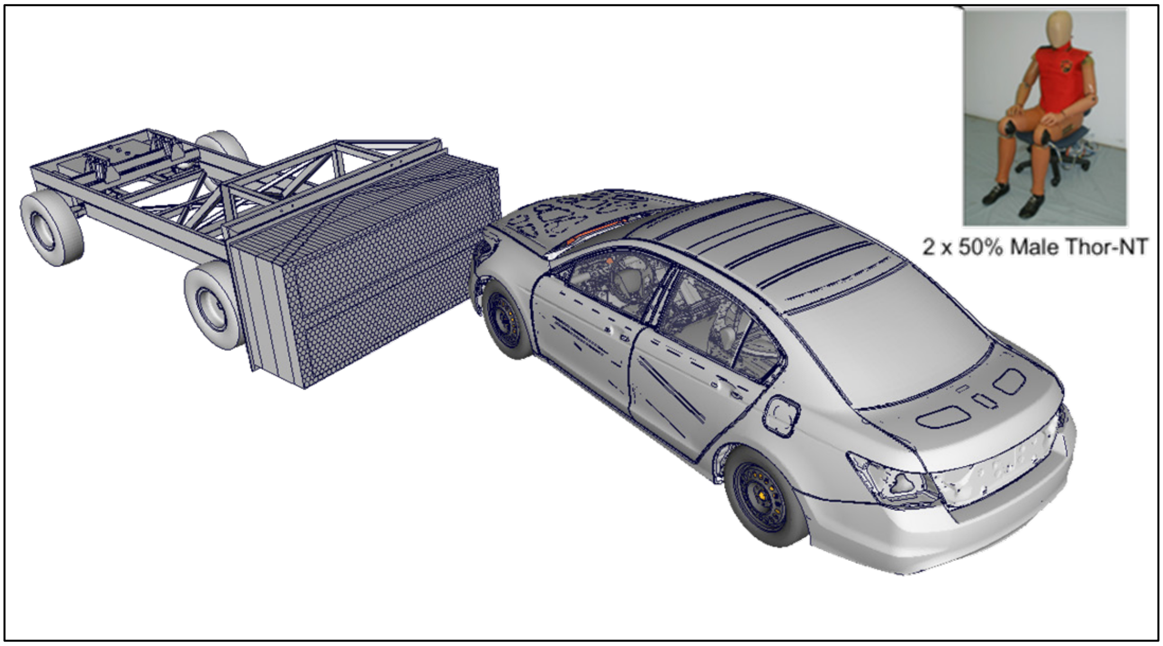


Figure 12: NHTSA Oblique Test Left

The test vehicle is equipped with two 50th percentile male THOR-NT dummies with combined mass of 197.8kg and a cargo mass of 44.8kg. These masses were accounted for in the CAE model. The test vehicle and CAE set up for the oblique crash test is shown in Table 3.

Description	Test Vehicle	EDAG CAE Baseline
Model Year	2014 Honda Accord	2012 CAE model updated to represent 2014 Honda Accord
Engine Disp. (L)	2.4	2.4
Tested Weight (kg)	1,708	1,720

Table 3: Test Versus CAE Vehicle Specification

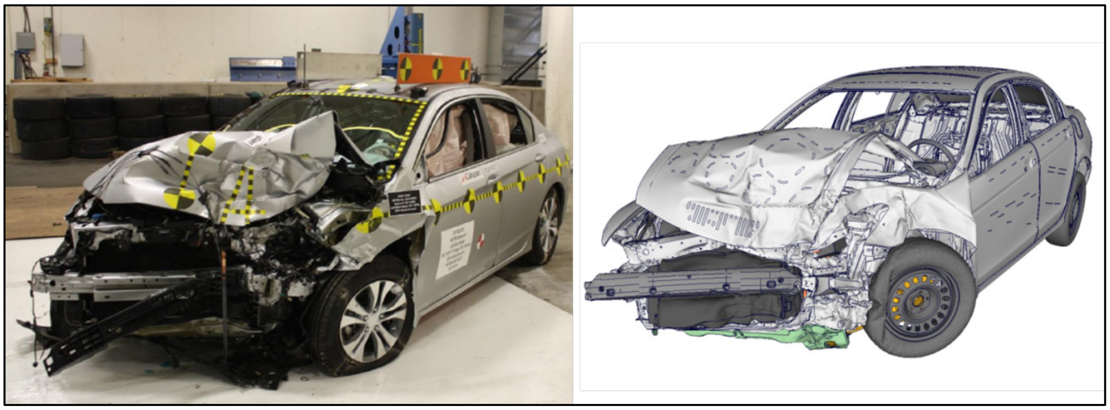


Figure 13: NHTSA Oblique Test Left – Post-Crash Comparison Test Versus CAE Baseline

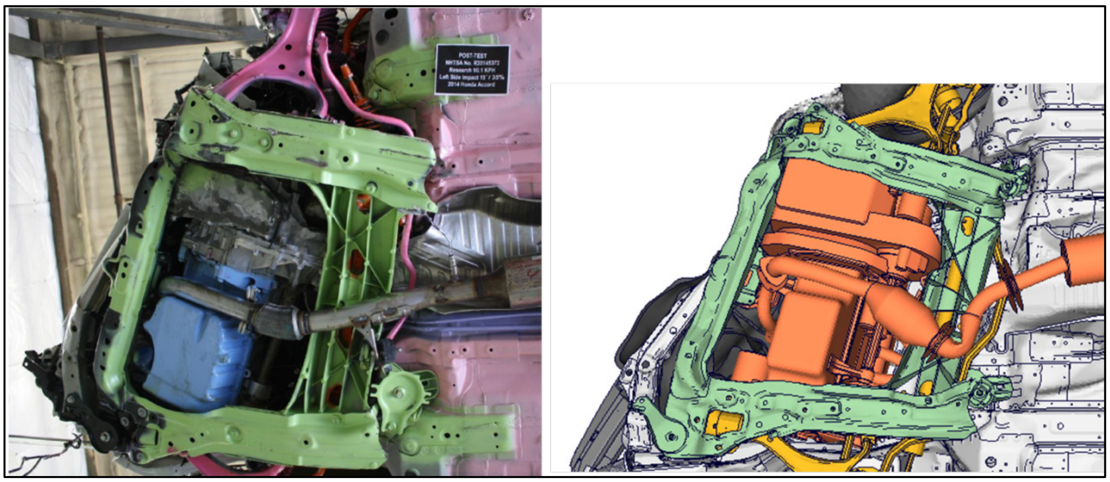


Figure 14: NHTSA Oblique Test Left – Post-Crash Comparison Test Versus CAE Baseline

Figure 13 and Figure 14 shows the post-crash comparison of both Test and CAE simulation. The overall kinematics, deformation shape, and the material failures especially in the sub-frame on the simulation structure correlates well with test. Some of the test figures were taken when the EDAG team visited CALSPAN proving ground to inspect and take additional measurements of the crash tested vehicle. This visit helped the EDAG team to observe of the tested vehicle in several aspects such as spot-weld failure, sub-frame failure, and overall deformation modes that were not available from the full test report.

The acceleration in X and Y of the vehicle is shown in Figure 15. The data is taken from accelerometers attached under the B-pillar sill section. The CAE model shows good overall agreement in terms of pulse shape, width, and magnitude compared with the test pulse. The average pulse difference between test and CAE model for both components are less than 5 percent. The average pulse is measured between 0 ms to the time acceleration reaches 10 Gs after peak. The velocity of both vehicles also showed very good correlation with a CORA score higher than 90 percent for both velocity components as shown in Figure 16.

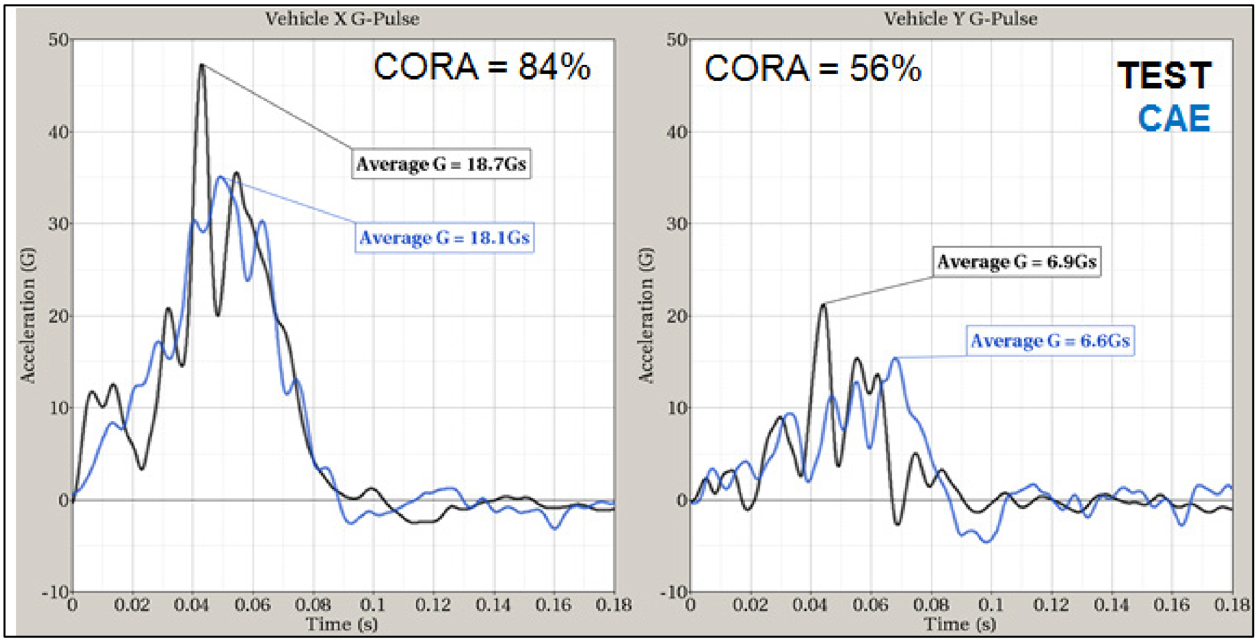


Figure 15: Test Versus CAE X and Y Acceleration Pulse

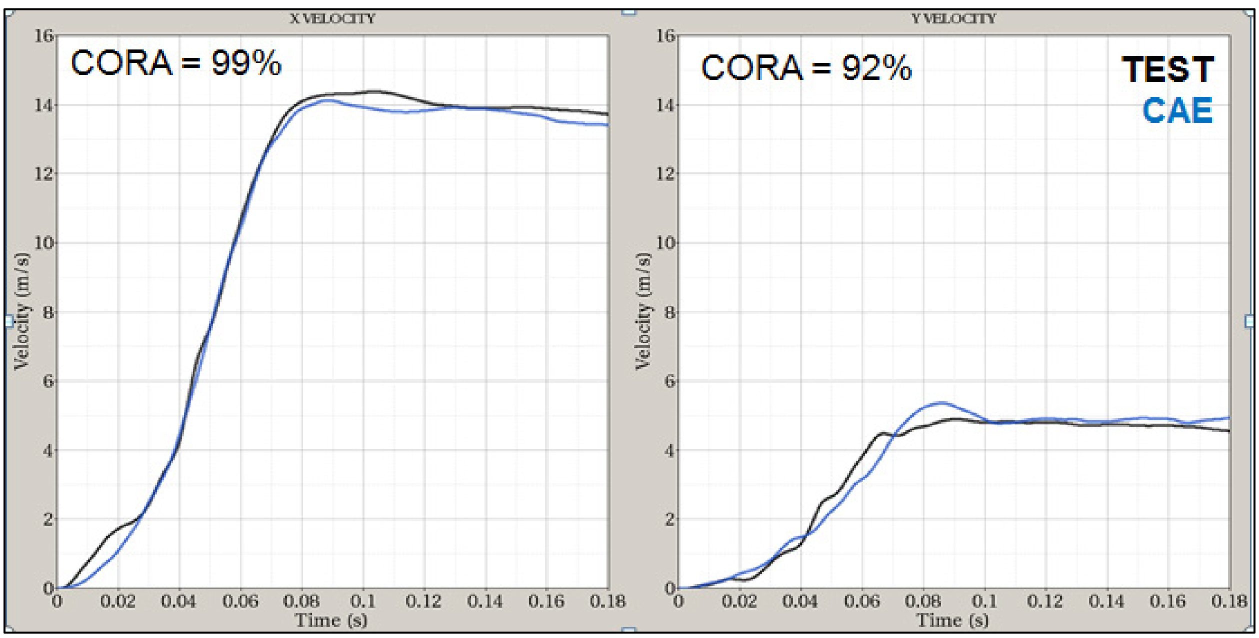


Figure 16: Test Versus CAE X and Y Velocity

For intrusion comparison, the standard NCAP driver compartment intrusion is measured along with the deformation of the floor for the driver as per the oblique test protocol. The passenger side intrusion is not included in the report as the intrusions are very small. The driver compartment and floor pan intrusion are shown in Figure 17 and Figure 18 respectively. For evaluation purpose, we used IIHS intrusion rating methodology to evaluate the floor pan intrusion. The rating is divided into 4 categories classed as Good (< 150 mm), Acceptable (< 225 mm), Moderate (< 300 mm) and Poor (> 300 mm). The CAE simulations correlates very well with the test intrusion numbers, and are all within 15 mm as shown in Figure 18.

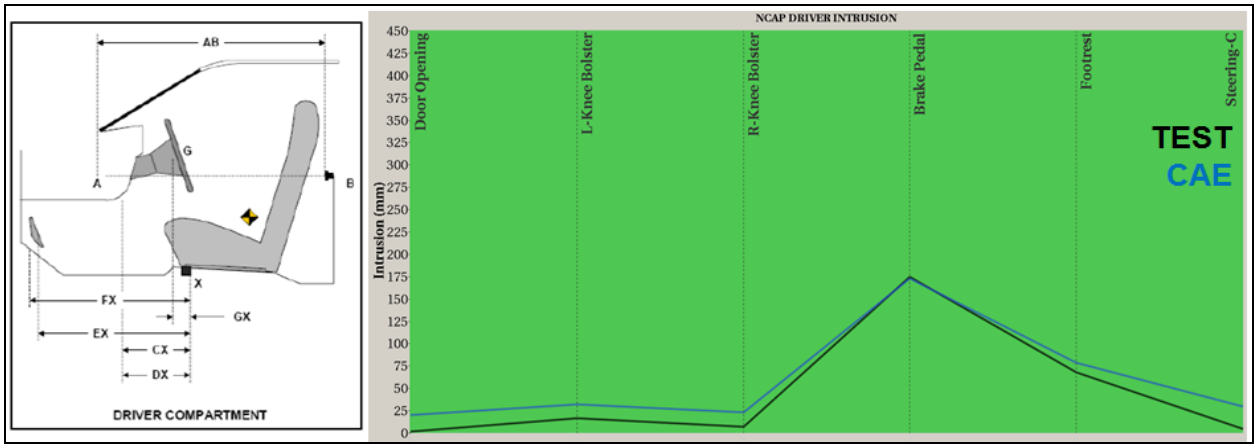


Figure 17: Test Versus CAE NCAP Driver Compartment Intrusion

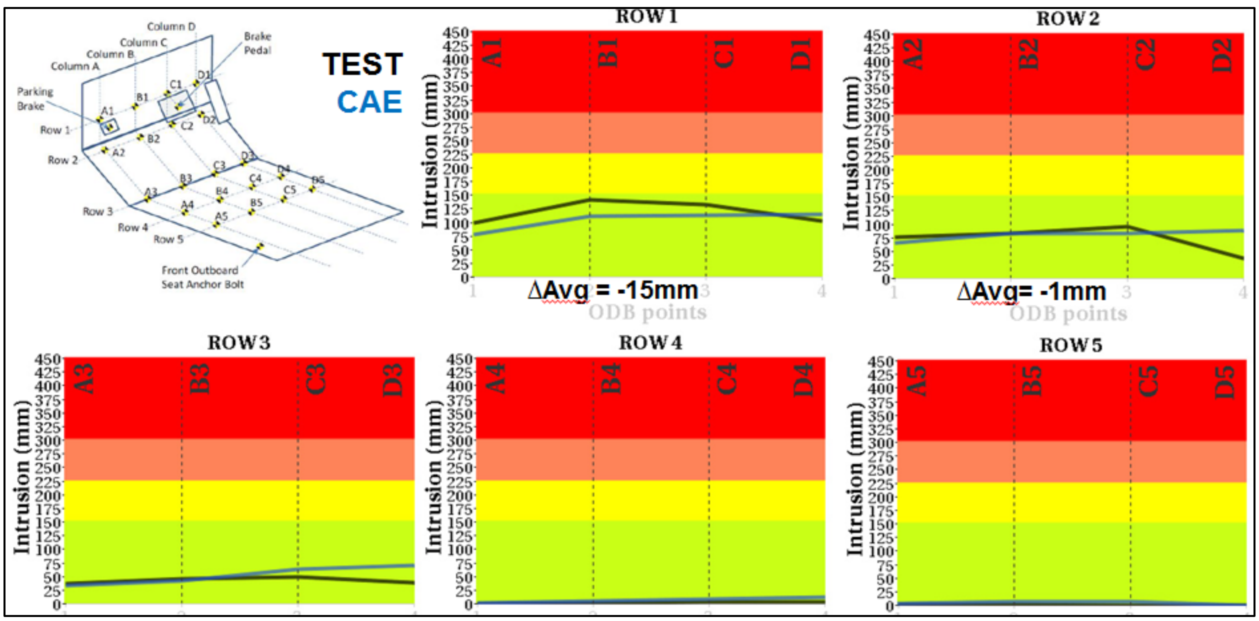


Figure 18: Test Versus CAE NCAP Driver Floor Pan Intrusion

Overall, the CAE simulation for the oblique impact correlates well with the test vehicle in both kinematics and intrusion.

4 Vehicle Interior Model Development and THOR Simulations

4.1 Vehicle Interior FEM Development

The correlated vehicle FEM from Section 3 was updated to include vehicle interior and occupant restraint systems for the driver and front seat passenger. Scanned computer aided design (CAD) data for the interior of 2012 MY Honda Accord was used to represent the interior geometry of all relevant parts: instrument/dash panel assembly, center console, driver, and passenger seat, etc.

4.1.1 Steering Wheel and Column

In the vehicle model, the steering column has two joints that are modeled with universal joints, as shown in Figure 19, and a translational joint with a break-away force of 8 kN.[7] These joints are necessary in the model to provide actual motion of the links in the column during a crash simulation. If these joints are not represented in the model, the column will be too rigid and will cause additional damage to where it is connected to the instrument panel structure, causing increased steering wheel intrusions into the passenger compartment.

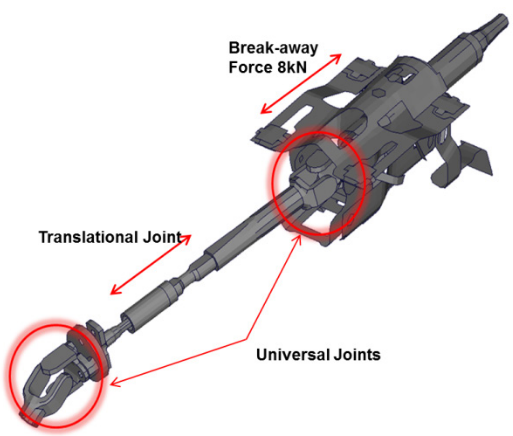


Figure 19: Steering Column Joints

Figure 20 shows the steering wheel model used in the vehicle. The wheel consists of magnesium frame covered with polyurethane foam and interior plastics trim panels.

[7] Tyan, T., Vinton, J., Beckhold, E., Zhang, X., & Rupp, J., Kochhar, N., & Barbat, S., (2014 Modeling of an Advanced Steering Wheel and Column Assembly for Frontal and Side Impact Simulations, *SAE International Journal of Materials and Manufacturing,* 7(2):2014, doi:10.4271/2014-01-0803

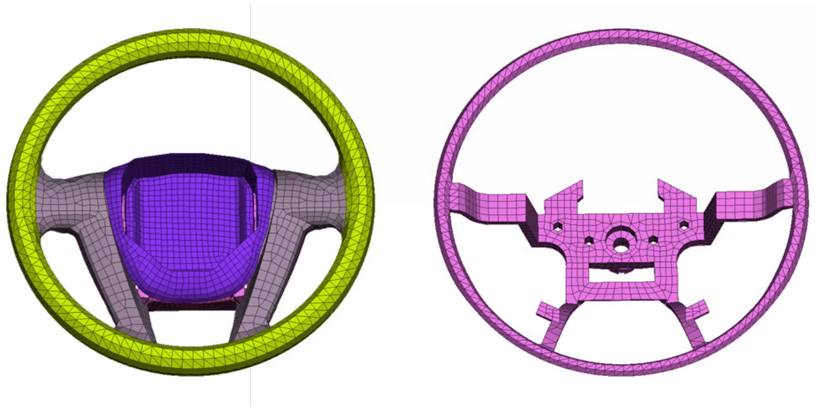


Figure 20: Steering Wheel

4.1.2 Instrument Panel with Knee Bolsters

For this program, the instrument panel steel structure and the knee bolster brackets were added in the vehicle as they are crucial to limit the forces reacted by the dummy's femur. The structure is designed in a way that it behaves like an energy absorbing/dissipating spring/damper system when force is applied to it, compressing to a certain displacement based on given stiffness/strength. The knee bolster structure is attached to the instrument panel beam as shown in Figure **21**.

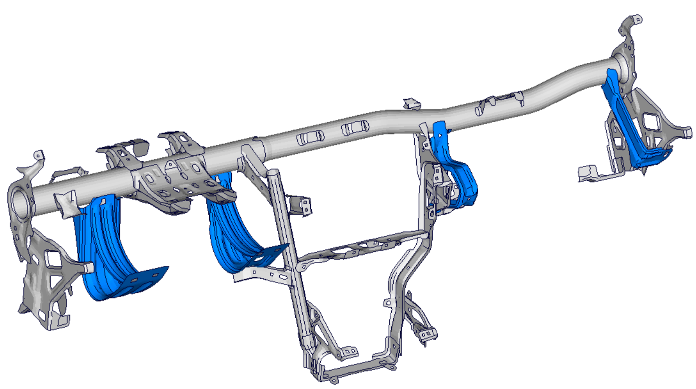


Figure 21: **Instrument Panel** Structure With Knee Bolsters (Blue)

4.1.3 Dash and Center Console

During most crash events the front seat occupants have significant interaction with the dash panel surfaces, in particular the forward motion of the knees, arms, and often the head. Behind the stylized surfaces several components are packaged.: The steering column mounting brackets, HVAC unit, air ducts and vents, instrument cluster, glove box, passenger side air bag module are mounted onto a support structure assembly. For this vehicle, the support is the steel welded instrument panel beam shown in Figure 21. All structurally significant components in the dash and center console as shown in Figure 22 are included in the interior CAE model. The material properties specified in the FEM for these components are from EDAG's in-house materials database.

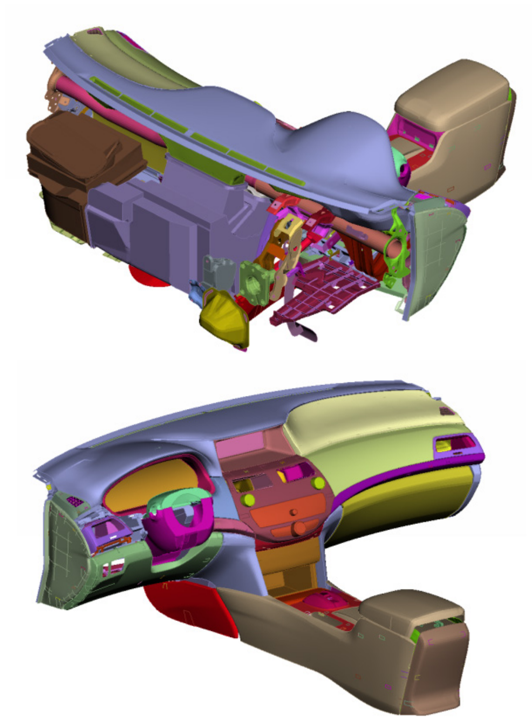


Figure 22: Dash and Center Console

4.1.4 Interior Trim Panels

Other interior trim panels that are likely to contact the occupant during a crash event, such as the door inner (Figure 23) and B-pillar trim are also represented in the interior FEM. The B-pillar trim, shown in Figure 24 is not important for the contact with the dummy, but the trim provides a more accurate path for the curtain air bag to unfold and open. Without this trim, the curtain air bag rolls along the b-pillar structure that is slightly more outwards from the dummy position, causing the dummy to miss the curtain air bag during the crash simulation.

Figure 23: Door Trim (Blue)

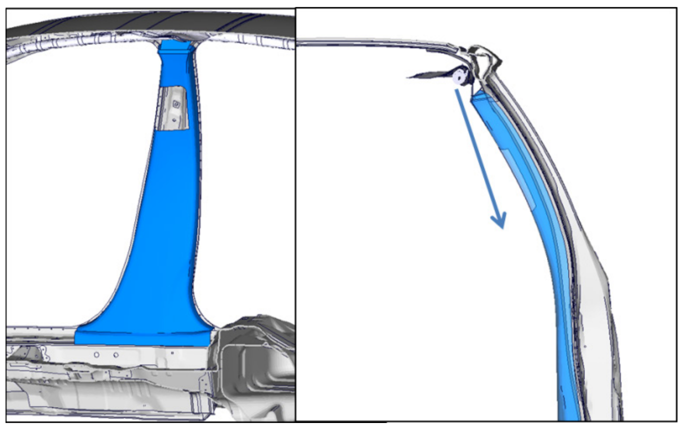


Figure 24: B-Pillar Trim (Blue)

4.1.5 Seating for Driver and Passenger

The full vehicle finite element analysis (FEA) model includes front driver and passenger seat sub-systems. For occupant safety simulation, the important aspects of having seat models are to have realistic interaction between occupant and seat cushion that affect the occupant kinematics significantly. For ease of height adjustability, the seat models include kinematic model of the seat mechanism.

Figure 25: Seat FEM – Height Adjustment Mechanism

The seat cushions were modeled as solid elements and were assigned foam material properties. Another important requirement to have more realistic occupant kinematics is to have the seat cushions pre-deformed due to weight of the dummy to match the lower torso profile impression on the seat bottom cushion and upper torso impression over the seat back cushion. The model was gravity settled prior to simulation. The seat cushions were deformed to the THOR dummy shapes by using LS-DYNA pre-simulations. Figure 26 shows the pre-deformed seat cushions attached to the seat structure.

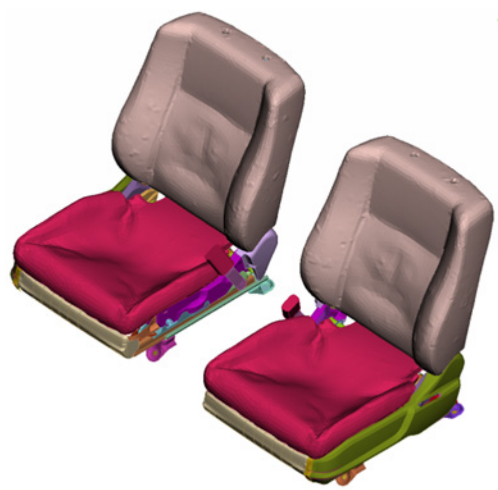


Figure 26: Seat Models With Deformed Cushions

4.1.6 Driver and Passenger Frontal Air Bags

Finite element (FE) air bags for driver and passenger occupant frontal crash protection were integrated into the full vehicle model. Driver front air bags, passenger front air bag for frontal crash were modeled, validated and integrated with the occupant compartment. The driver air bag was mounted on the steering wheel and the passenger air bag was mounted on the passenger side instrument panel brackets by following the vehicle specifications. In order to develop reasonably accurate air bag models for realistic occupant frontal crash simulation, the air bag model validations were carried out in the following steps.

1. Tear down air bag
2. Scan air bag fabrics (or cushion) for FE modeling
3. Conduct inflator tank test
4. Conduct drop tower test
5. Build FE models of air bags including air bag folding
6. Simulate the drop tower test and correlate the air bag characteristics

EDAG teamed with Key Safety Systems (KSS)[8] to perform steps 1 to 4 and obtained the necessary data for steps 5 and 6.

The tear-down and scanning process included disassembling the air bags from air bag containers and scanning the parts, air bag cushions and recording the tether attachment details and tether size. While scanning the air bag cushions, the folding patterns were recorded for FE folding of the air bags. The purpose of inflator tank test was to record the inflator characteristics of deployment pressure, volume, and triggering time as well as gas compositions. The drop tower test was conducted with steering wheel to obtain air bag force-deflection characteristics. Details of tests performed by KSS are included in Appendix A.

4.1.6.1 Drive Air Bag Modeling

The driver air bag FE model was created using scanned CAD data with elements size of 5 mm for accurate deployment and smooth contact purposes. The first driver air bag was modeled as a flat air bag on a bench as shown in Figure 27, and then folded by using DynaFold simulations. The folding simulations included thin folding and flattening for each fold. Once all thin folds were completed, the folded bag was fit into the air bag container (or housing) by using housing simulation technique. The final folded driver air bag is shown in Figure 28.

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[8] Key Safety Systems (KSS), headquartered in Sterling Heights, Michigan, has a global network of 32 sales, engineering and manufacturing facilities with has 5 main technical centers in China, Germany, Japan, South Korea, and the United States.It develops and manufactures automotive as well as non-automotive safety systems. See www.keysafetyinc.com/

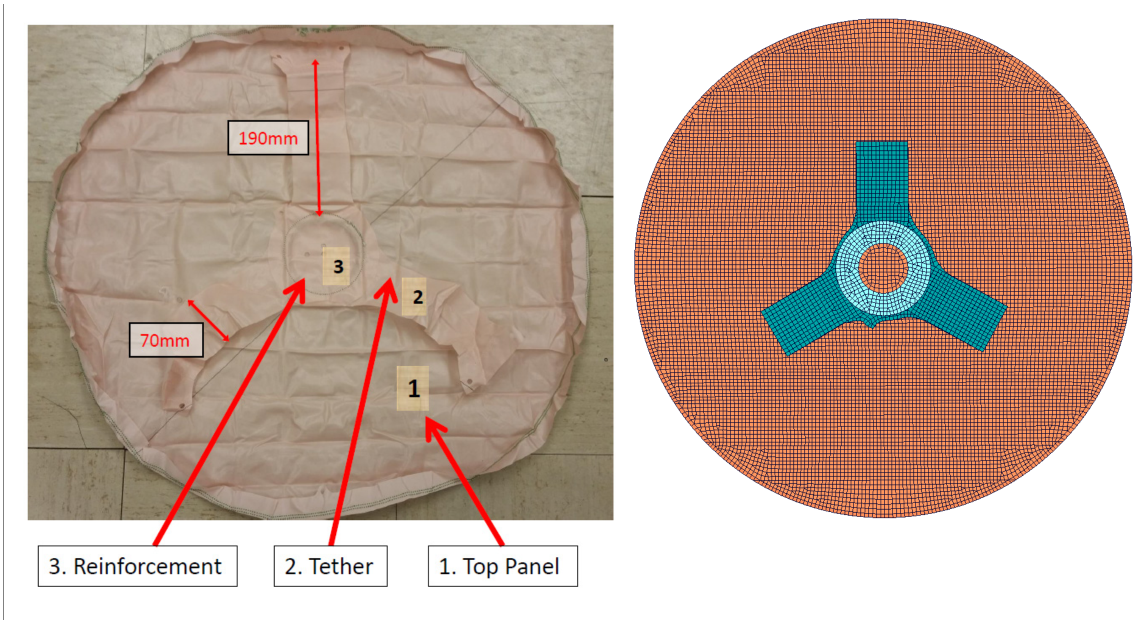


Figure 27: Drive Air Bag FE Model Before Folding

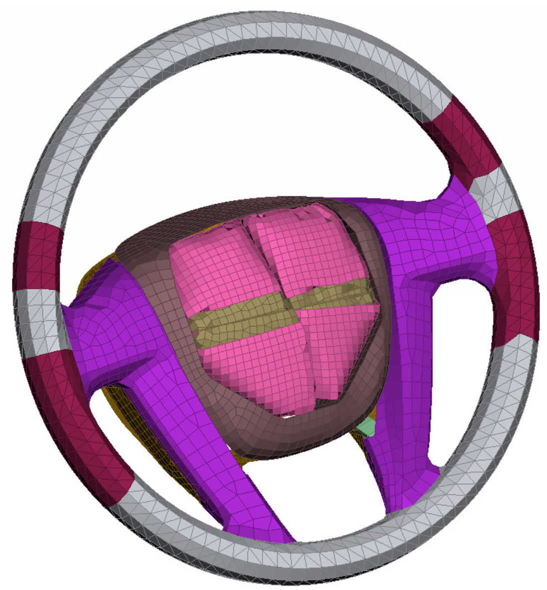


Figure 28: Folded Drive Air Bag

4.1.6.2 Drive Air Bag Validation

In the validation process, the drop tower test was simulated with the folded bag supported on the steering wheel sub-system and the inflator data obtained from the tank test. The air bag force characteristics were compared to that of the drop tower test result. The drop tower test setup and FEA model setup are shown in Figure 29.

Figure 29: Drive Air Bag Drop Tower Test Setup and FEA Model Setup

The simulation was carried out for 120 ms and the air bag triggering time of 16 ms as per the test that was used to simulate the driver air bag deployment. The kinematics of the simulation and test were compared accordingly. Very reasonable correlation was obtained with a few modeling iterations such as folding accuracy improvements, gas compositions, and engineering judgements. The comparisons of air bag force, impactor acceleration, velocity, and displacement with that of the test are shown in Figure 30.

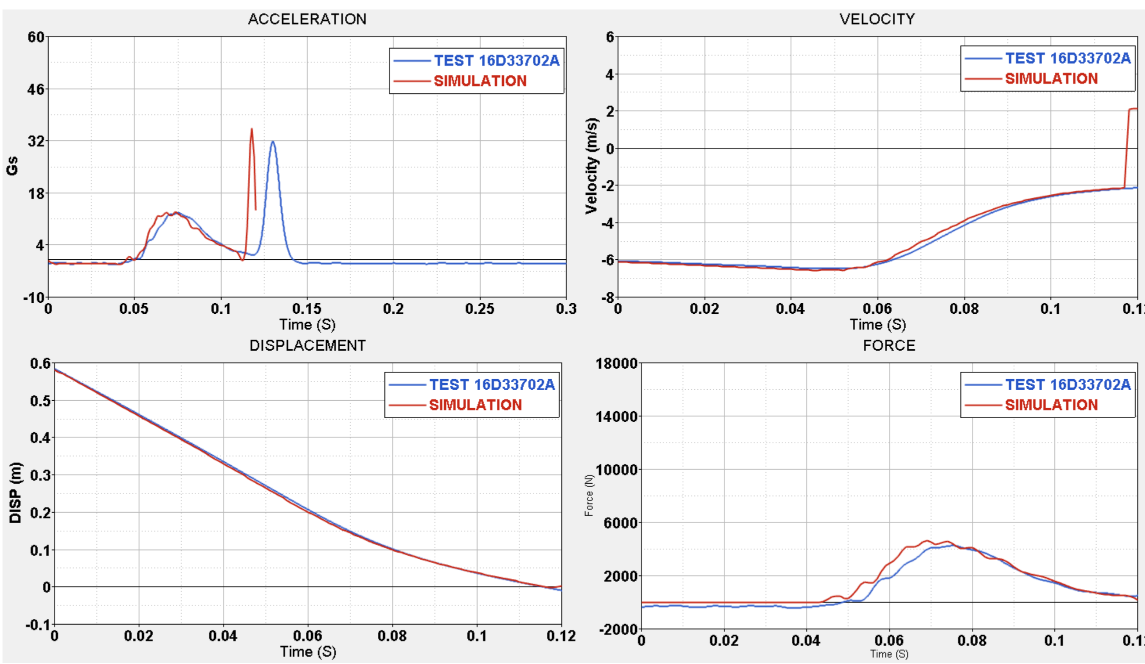


Figure 30: Drive Air Bag Validation – Drop Tower Test and Simulation

4.1.6.3 Passenger Air Bag Modeling

The passenger air bag FE model was created using scanned CAD data with elements size of 5 mm for accurate deployment and smooth contact purposes. The passenger air bag is a three dimensional (3D) geometry with volume. Two-dimensional CAD data was obtained from the scanning process. The first passenger air bag was modeled as a flat air bag on a bench with geometry flattening as shown in Figure 31, and then folded by using DynaFold simulations. The folding simulations included cumulative thin folding and flattening for each stage. Once all thin folds were completed, the folded bag was fitted into the air bag housing by using housing simulation technique. The final folded passenger air bag inside the housing is shown in Figure 32.

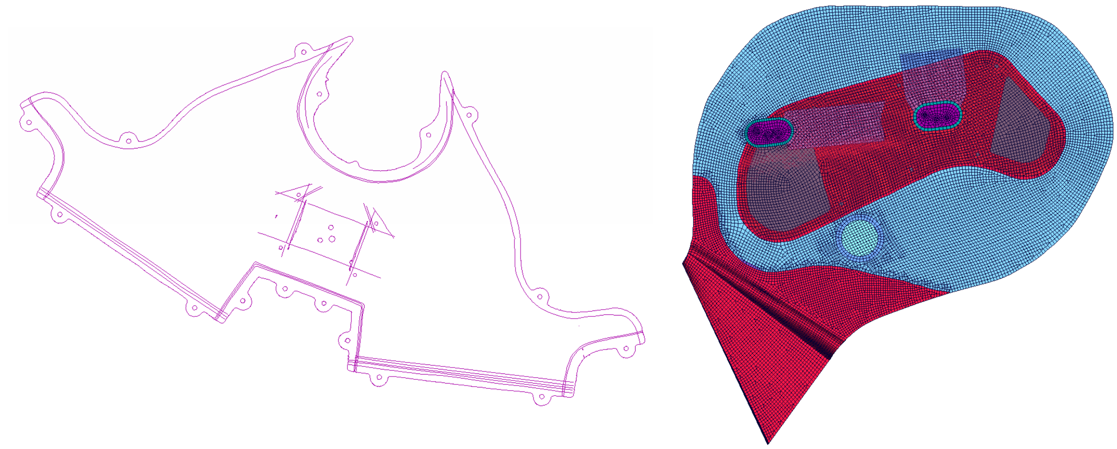


Figure 31: Passenger Air Bag – 2D Geometry and Flattened FE Bag

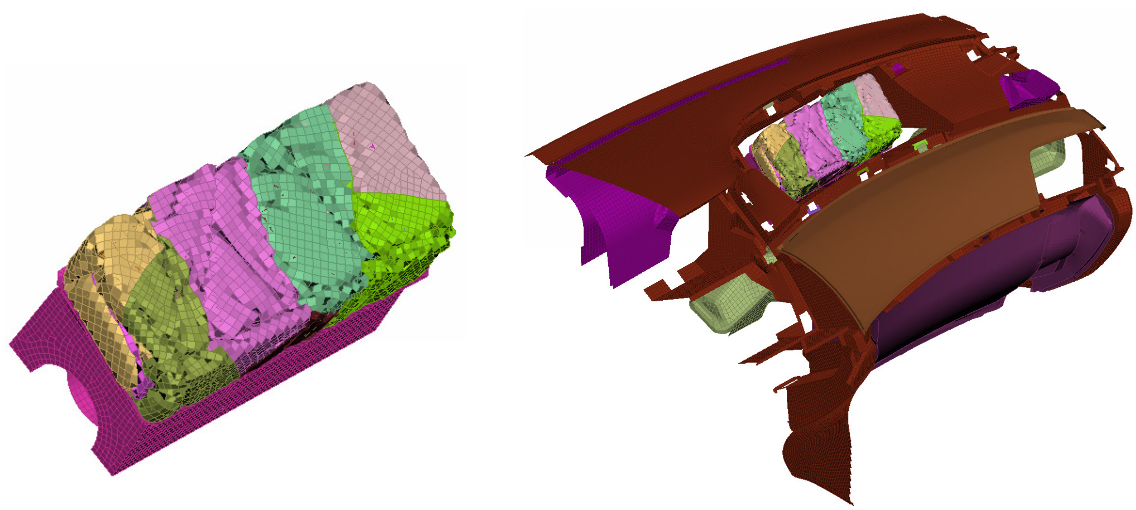


Figure 32: Folded Passenger Air Bag

4.1.6.4 Passenger Air Bag Validation

In the validation process, the drop tower test was simulated with the folded passenger air bag fit in the bag housing sub-system and the inflator data obtained from the tank test. The air bag force characteristics were compared to those of the drop tower test result. The drop tower test setup and FEA model setup are shown in Figure 33.

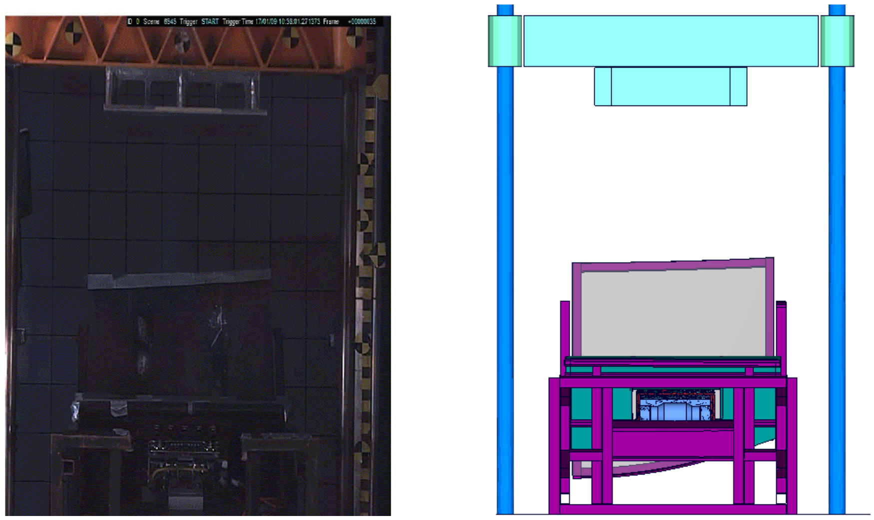


Figure 33: Passenger Air Bag Drop Tower Test Setup and FEA Model Setup

The simulation was carried out for 120 ms and the air bag triggering time of 33 ms as per the test was used to simulate the passenger air bag deployment. The kinematics of the simulation and test video were compared accordingly. A very reasonable correlation was obtained with a bag folding accuracy improvements, gas compositions and engineering judgements. The comparison of air bag force, impactor acceleration, velocity, and displacement with that of the test is shown in Figure 34.

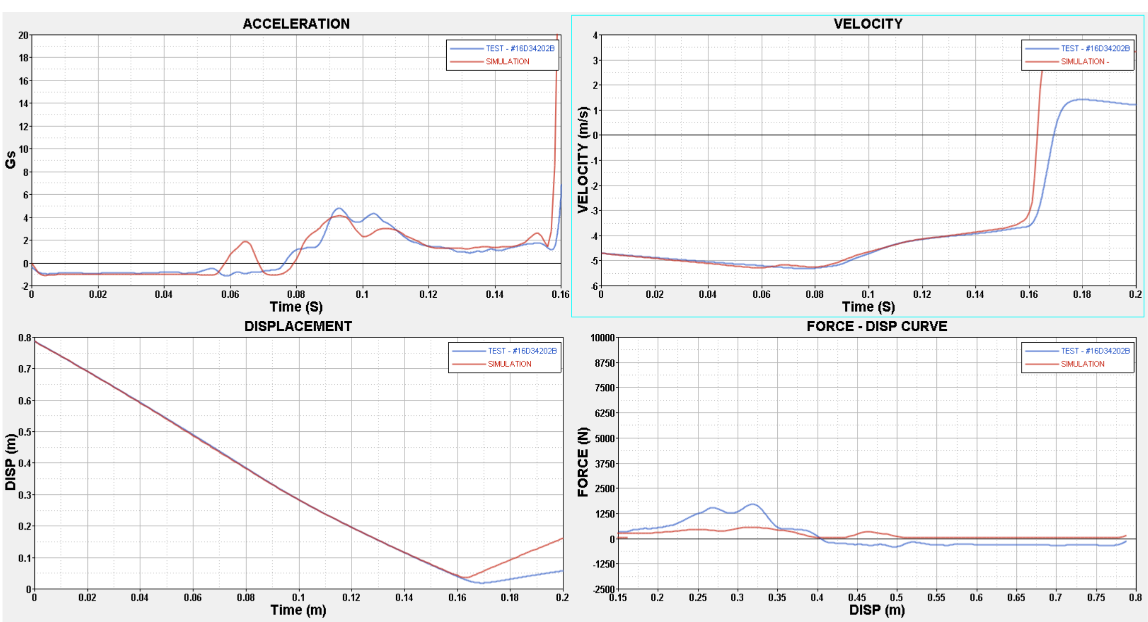


Figure 34: Passenger Air Bag Validation – Drop Tower Test and Simulation

4.1.7 Side Air Bags

Side air bags are also considered in this occupant simulation. The side air bag is mounted on the front passenger seat for side impact protection. Even though the scope of the project is oblique frontal impact, EDAG intended to include the folded side air bag to the seats structure. By following the approach explained in Section 4.1.6, an FE model of side air bag was created using the scanned CAD data and validated by simulating the drop test.

4.1.7.1 Side Air Bag Modeling

The side air bag FE model was created using scanned CAD data with elements size of 5 mm for accurate deployment and smooth contact purposes. First side air bag was modeled as flat air bag on bench as shown in Figure 35 and then folded by using DynaFold simulations. The folding simulations included thin folding and flattening sequences for each fold. Once all thin folds were completed, the folded bag was fit into the side air bag housing by using housing simulation technique. The final folded side air bag is also shown in Figure 35.

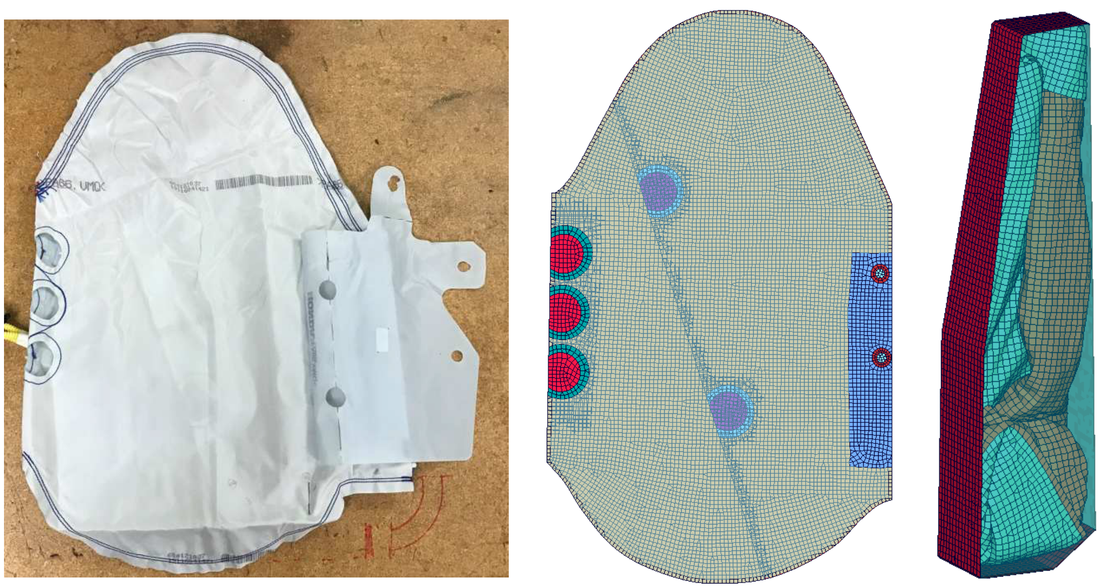


Figure 35: Side Air Bag FE Model Before and After Folding

4.1.7.2 Side Air Bag Validation

In the validation process the drop tower test was simulated with the folded bag supported on the side air bag box housing sub-system and the inflator data obtained from the tank test. The air bag force characteristics were compared to that of the drop tower test result. The drop tower test setup and FEA model setup are shown in Figure 36.

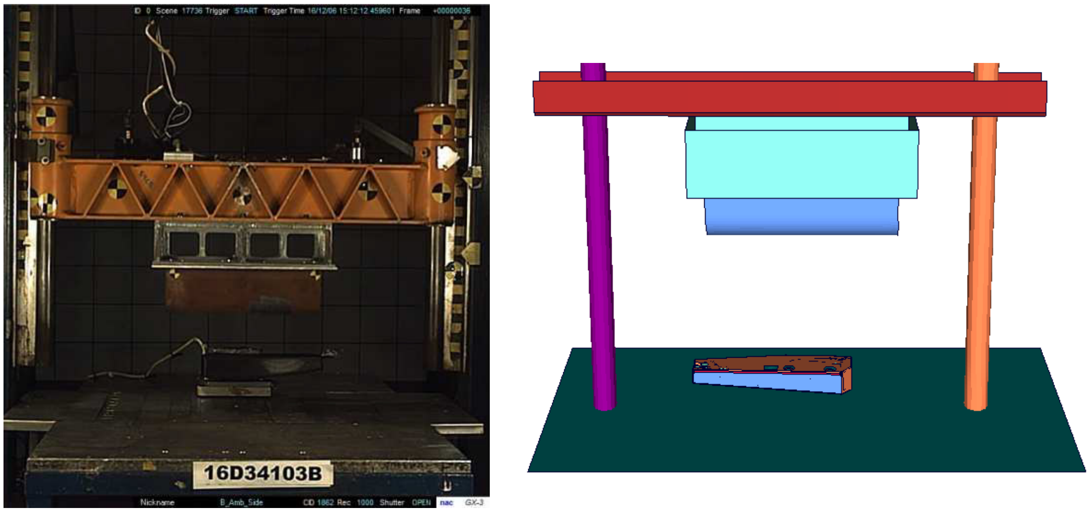


Figure 36: Side Air Bag Drop Tower Test Setup and FEA Model Setup

The simulation was carried out for 120 ms and the air bag triggering time of 36 ms as per the test was used to simulate the side air bag deployment. The kinematics of the simulation and test were compared accordingly. Very reasonable correlation was obtained with a few modeling iterations such as folding accuracy improvements and gas compositions and engineering judgements. The comparison of air bag force, impactor acceleration, velocity and displacement with that of the test is shown in Figure 37.

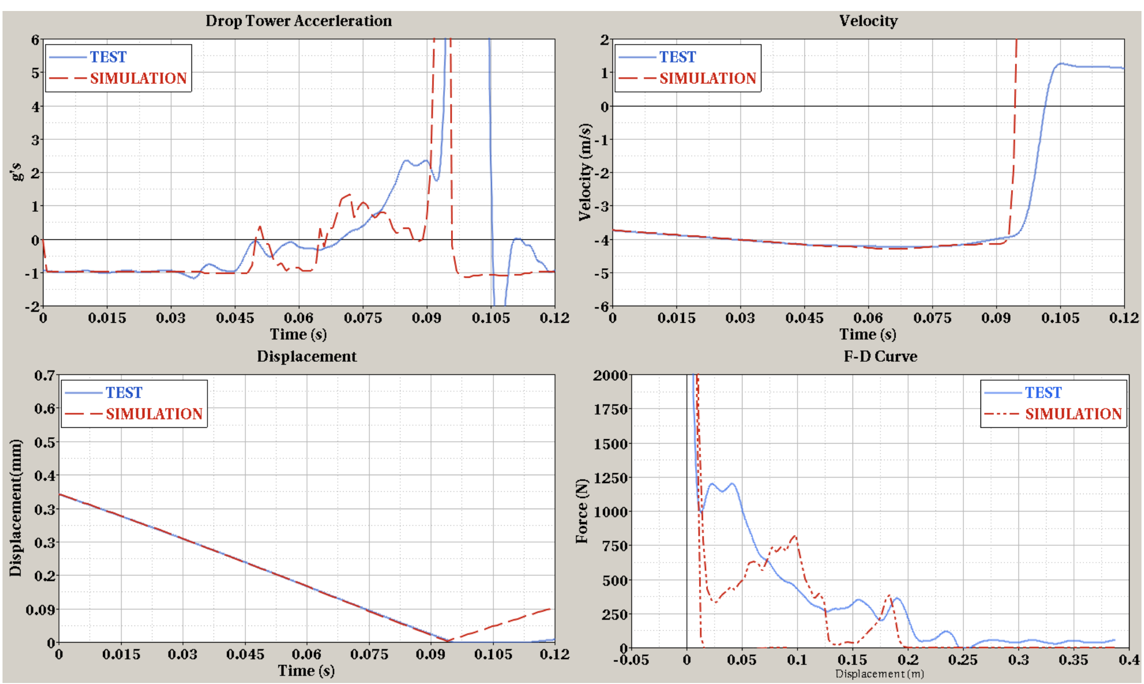


Figure 37: Side Air Bag Validation – Drop Tower Test and Simulation

4.1.8 Curtain Air Bags

The oblique frontal impact test shows occupant kinematics with a side curtain air bag deployed. Therefore, a side curtain air bag is also considered as an important component of full vehicle interior modeling for this study. The side curtain air bag is mounted mainly on the A-pillar and roof rail structure for side impact protection. The FE model of the side curtain air bag was created using the scanned CAD data and validated by simulating the drop test.

4.1.8.1 Side Curtain Air Bag Modeling

The side curtain air bag FE model was created using scanned CAD data with elements size of 5 mm for accurate deployment and smooth contact purposes. The first side curtain air bag was modeled as a flat air bag on a bench as shown in Figure 38 and then folded by using DynaFold simulations. The folding simulations included roll folding sequences. Once roll folding was completed, the rolled bag was fit into the side air bag tube along A-pillar and roof rail structure by using morphing techniques. The final folded side curtain air bag is shown in Figure 39.

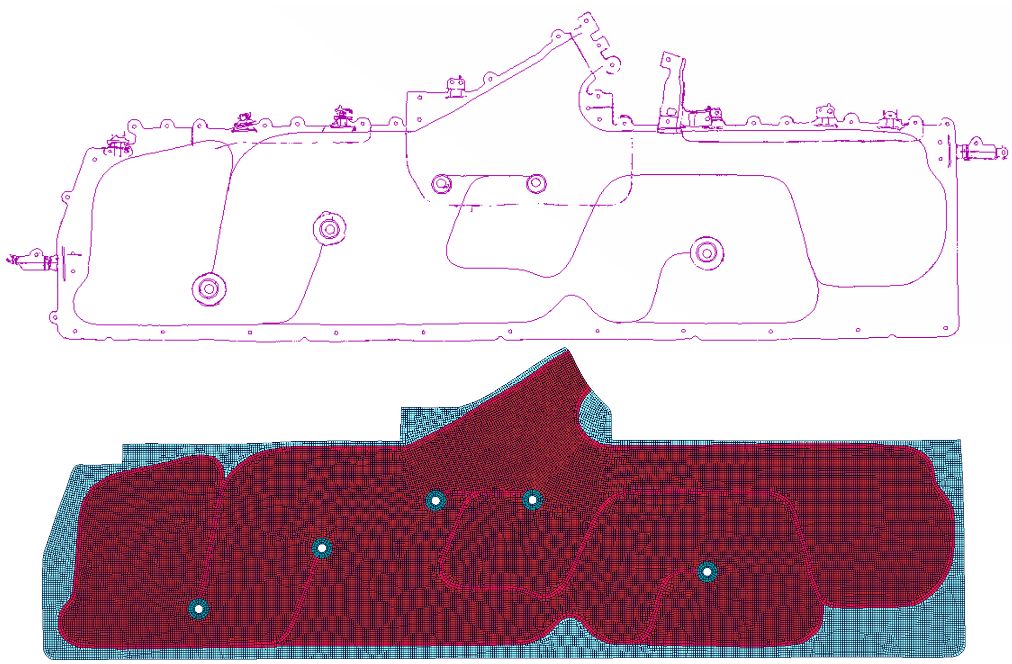


Figure 38: Side Curtain Air Bag FE Model before Folding

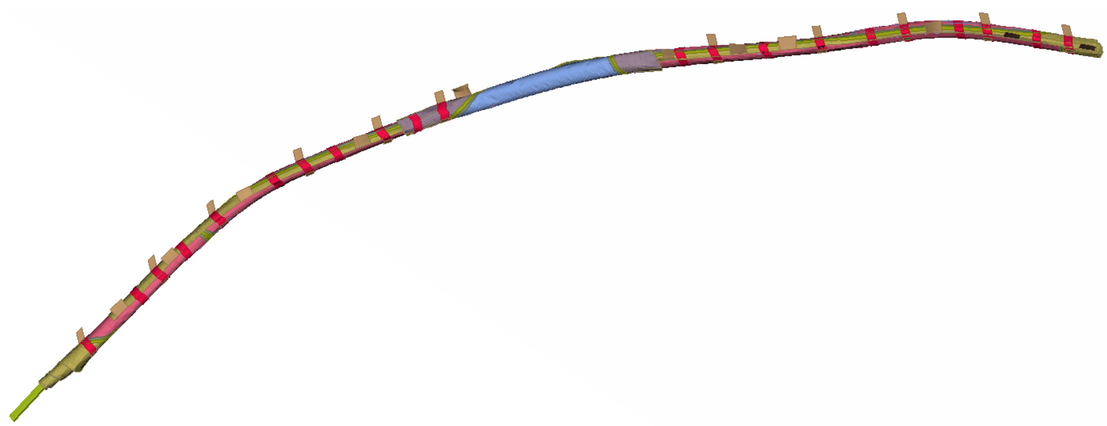


Figure 39: Folded Side Curtain Air Bag

4.1.8.2 Side Curtain Air Bag Validation

In the validation process, the drop tower test was simulated as per the test setup using the unfolded bag supported on the side curtain air bag tube housing sub-system and the inflator data obtained from the tank test. The air bag force characteristics were compared to that of the drop tower test result. The drop tower test setup and FEA model setup are shown in Figure 40. The test setup includes the representation of side pole supported on the ground and a free motion head form impactor dropped on the unfolded bag.

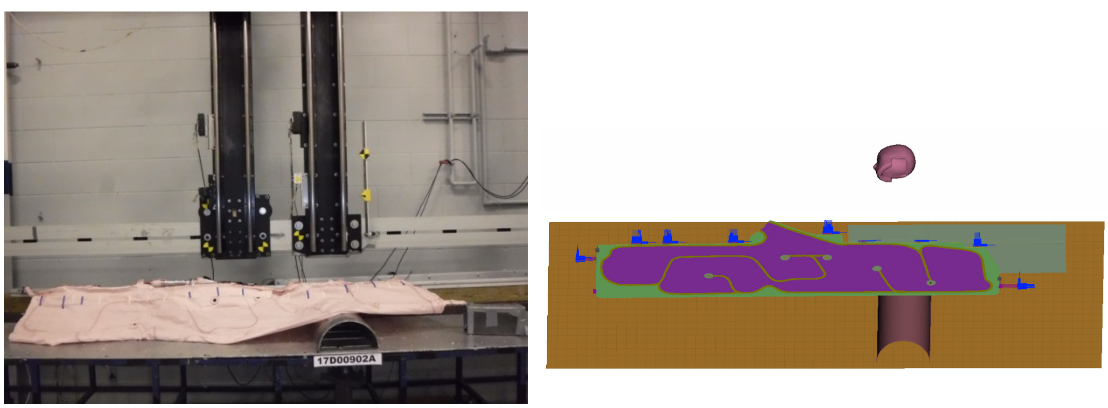


Figure 40: Side Curtain Air Bag Drop Tower Test Setup and FEA Model Setup

The simulation was carried out for 120 ms and the air bag triggering time of 30 ms as per the test was used to simulate the side air bag deployment. The kinematics of the simulation and test were compared accordingly. A very reasonable correlation was obtained with a necessary modeling iterations such as folding accuracy improvements and gas compositions and engineering judgements. The comparison of air bag force, impactor acceleration, velocity, and displacement with that of the test is shown in Figure 41.

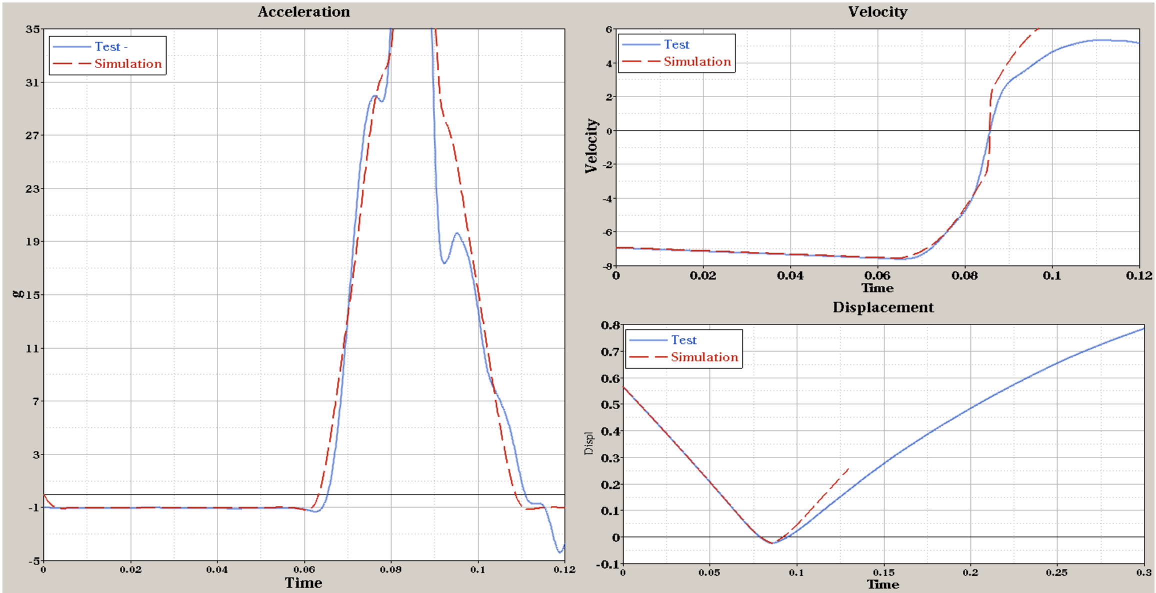


Figure 41: Side Curtain Air Bag Validation – Drop Tower Test and Simulation

4.1.9 Seat belt web strength test, belt pretensioners and load limiters

The full vehicle interior modeling for occupant simulation included driver and passenger seat belt models. Seat belt models require the following critical characteristics and parameters for accuracy.

1. Seat belt webbing elongation
2. Retractor pay-out and load-limiter characteristics
3. Retractor pretensionerer characteristics

These seat belt characteristics and parameters were obtained by carrying out the appropriate seat belt tests. EDAG teamed with KSS to conduct the seat belt webbing elongation test, retractor pay-out test and retractor pretensionerer test. EDAG purchased MY2014 Honda Accord seat belt modules for testing purposes. The retractor pay-out test was carried out with the necessary test fixtures whereas pretensionerer test was carried out in a sled test with 50th percentile dummy seated with seat belt buckled. The seat belt test setups are shown in Figure 42, 43, and 44.

Figure 42: Webbing Elongation Test Setup

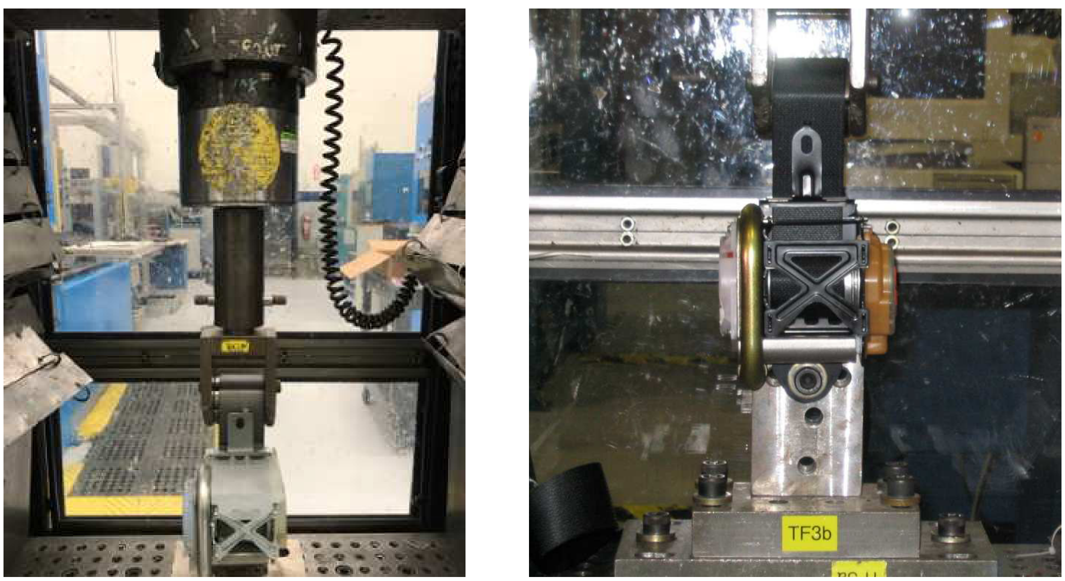


Figure 43: Retractor Pay-out (load limiter) Test Setup

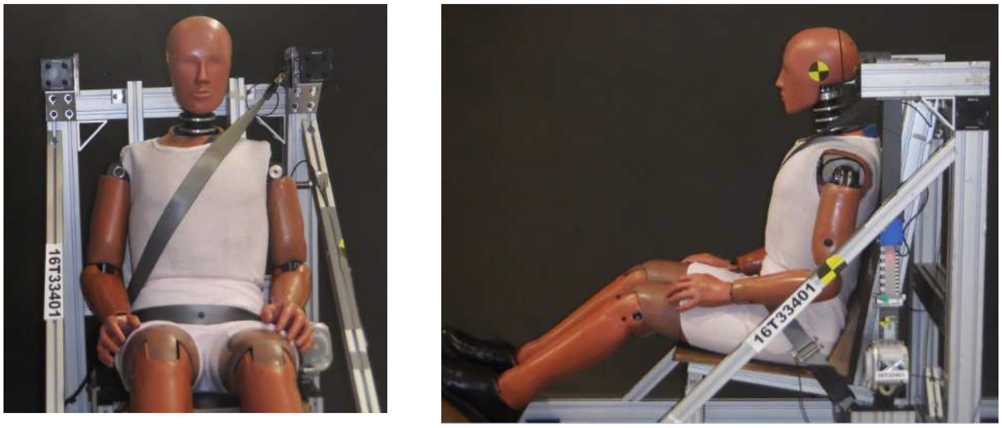


Figure 44: Retractor Pretensionerer Deployment Test

The output of webbing elongation tests are force versus displacement (F-D) loading and unloading curves and percentage elongation of the webbing. The output of retractor pay-out (load limiter) test is F-D loading curve and amount belt pay-out. The outputs of the pretensionerer test are webbing pull-in length and belt force. The seat belt FE models were created by defining the above F-D curves and values in LS-DYNA seat belt definition. More technical details and F-D plots are provided in Appendix.

4.1.10 Sled simplified model

At the initial stage of the program, a simplified sled model was developed based on the full vehicle model shown in Figure 45. The sled model consists of the front occupant space with all interior trims included. Trims were given its original material properties but the steel structure was given rigid material properties as we did not expect any deformation to take place in this sled model. Acceleration pulse from the oblique impact test was applied to the sled model to resemble the actual vehicle motion as in test, and at the same time to make sure all air bags, seat, seat belt and dummy performs as desired before including in the full vehicle model.

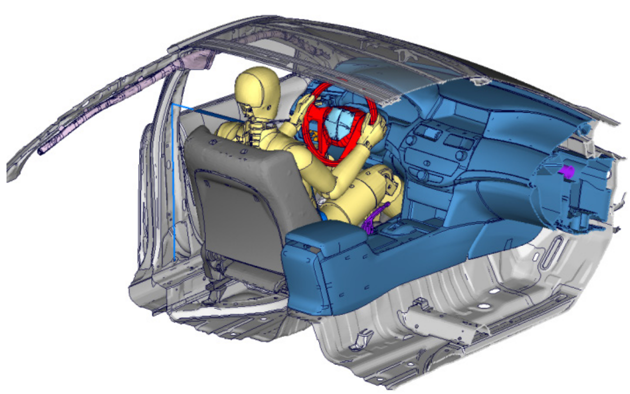


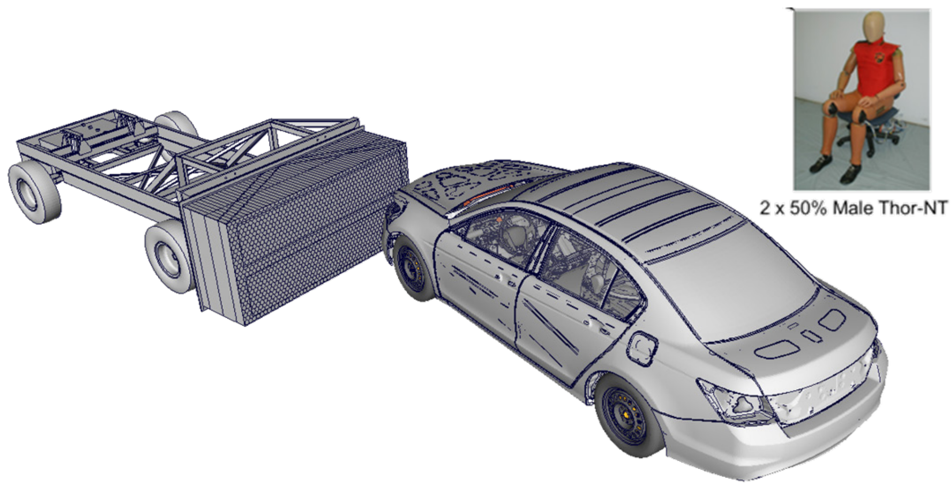
Figure 45: Sled Model Setup

4.2 Vehicle Interior THOR Simulation

4.2.1 Oblique Impact Left and Right – correlation results

This test is used to determine the crashworthiness of the vehicle to protect occupants in offset frontal impact crash cases. The test consists of an oblique moving deformable barrier (OMDB) that weighs 2,490.2 kg traveling at a target speed of 90.12 km/h into a stationary vehicle. The struck vehicle is positioned 15 degrees relative to the moving barrier and impacted 35 percent of the left or right side of the vehicle as shown in Figure 46.

With the addition of two THOR CAE models the size of the total FEM (with the barrier) increased to 5,214,631 elements as shown in Figure 46.



ELEMENT TYPE	NUMBERS OF ELEMENTS (without the Barrier Model)
SHELL	3,679,226
SOLID	1,533,452
MASS	39
DISCRETE	26
BEAM	1,762
SEAT BELT	126
Total	5,214,631

Figure 46: Oblique Left Impact Test Setup

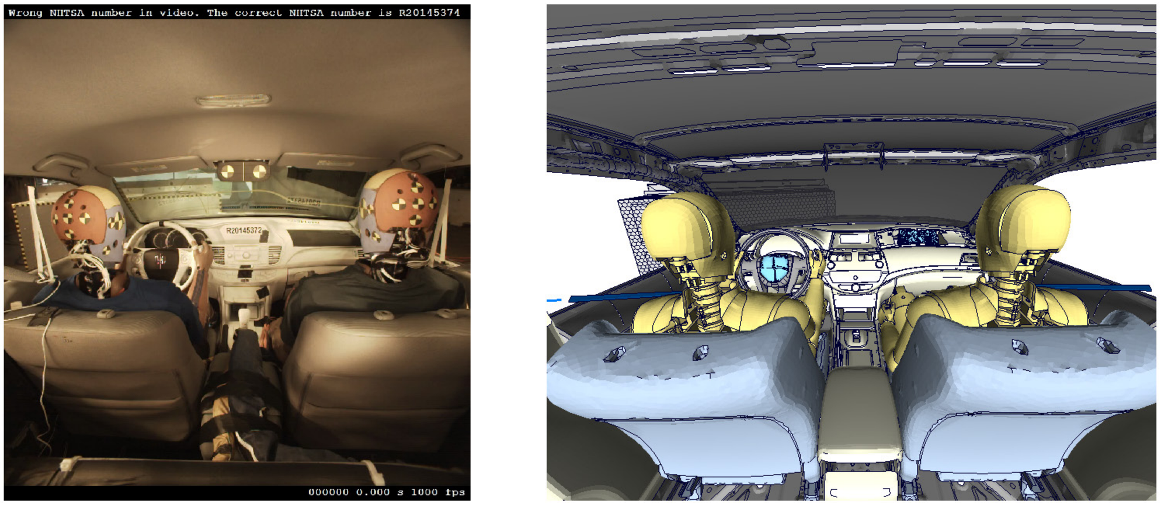


Figure 47: Test Versus CAE at 0 ms

Figure 47 to Figure 51 show the timeline of the crash while comparing the test and CAE model with the occupants, air bags, seat belts, surrounding trims and seat with foams. The driver air bag and passenger air bag deploy at 14 ms. At 14 ms both seat belt pretensioners fire and tighten up any slack defined as length of 25 mm.

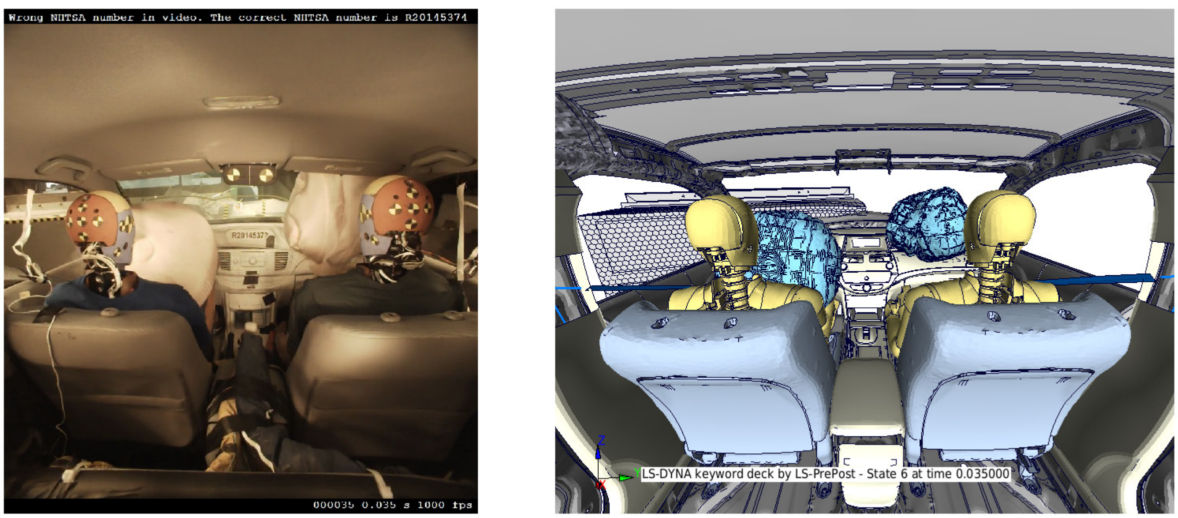


Figure 48: Test Versus CAE at 35 ms

At 35 ms the driver air bag is fully deployed and the passenger air bag is not completely deployed. Both dummies have not made contact with the air bags. The curtain air bag on the driver side is triggered at 42 ms per the test trigger time.

Figure 49: Test Versus CAE at 70 ms

At 70 ms the passenger and curtain air bags are fully deployed, and both dummies make contact with their respective air bags. The seat belt on the passenger dummy already slips off from its shoulder causing the passenger dummy to have higher rotational motion toward the inside of the vehicle.

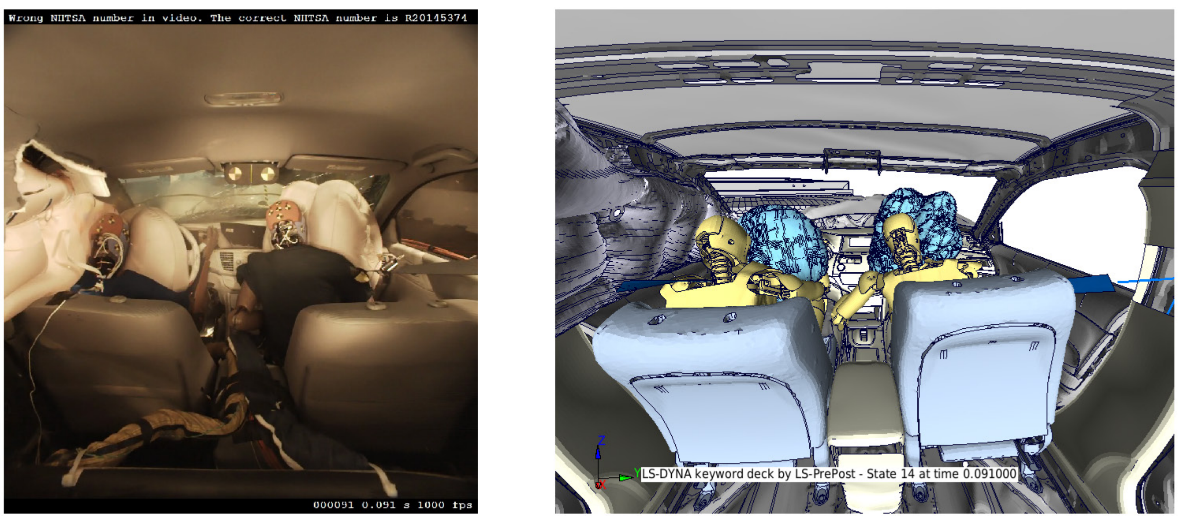


Figure 50: Test Versus CAE at 90 ms

At 90 ms the driver dummy’s head is sandwiched between both curtain and driver air bag. The passenger dummy continues to move forward in the direction of impact.

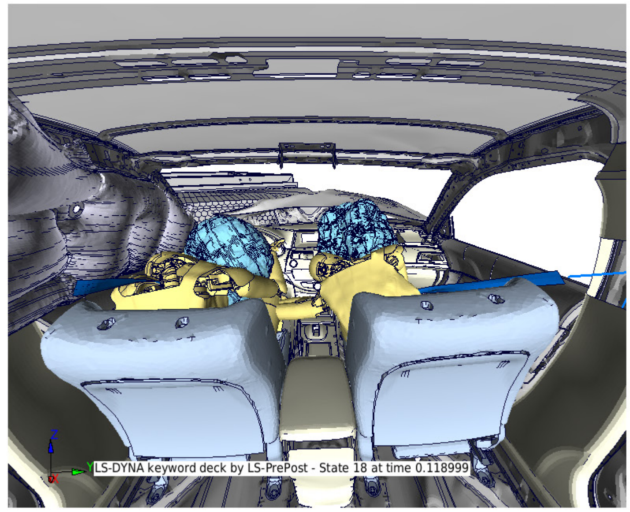


Figure 51: Test Versus CAE at 120 ms

At 120 ms the driver dummy's head remains sandwiched in between the air bags, meanwhile the passenger dummy's head impacts the dashboard. Overall the kinematics of the CAE THOR dummy show good correlation with the test results.

The dummy's head acceleration, pelvic acceleration, seat belt forces and femur force were also compared as part of the correlation study. The CAE THOR dummy already has all the required time history nodes to make this comparison.

Figure 52 and Figure 53 shows the driver and passenger head acceleration comparison between simulation and test results. The overall shape of driver head x y and z-acceleration shows good correlation with CORA score 76 percent, 66 percent and 63 percent respectively. The HIC obtained from CAE result is at 181 compared to test at 226, both occurring under very similar 15 ms window.

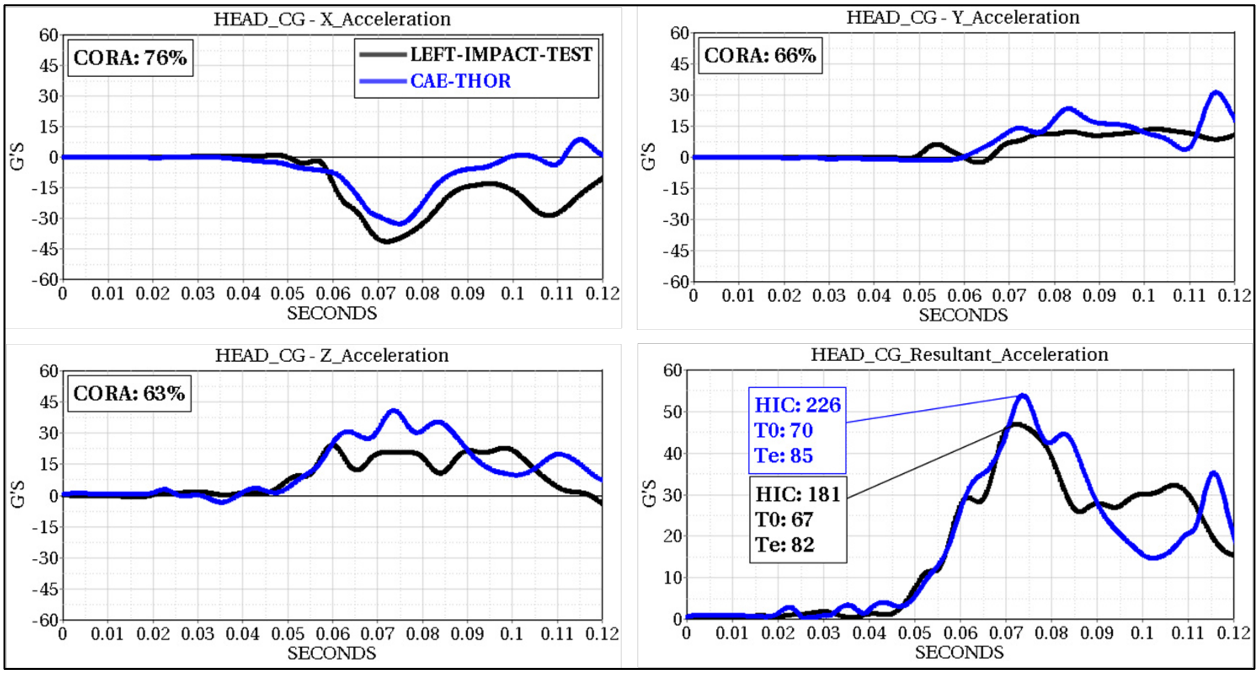


Figure 52: Driver Head CG Acceleration

For the passenger side x, y and z-acceleration, the CORA score obtained is 62 percent,78 percent and 77 percent respectively. The x-acceleration for passenger's head CG also correlates well with test with the maximum magnitude 5 percent less than the test and occurring 5 ms later. The first peak at -10G is when the passenger dummy hits the air bag and the second peak is when the dummy's head hits the dashboard. As for the y-acceleration, although the overall CORA score is 78 percent, the test experienced sharp peak at 100Gs compared to the CAE model at around 37Gs. This difference is due to the passenger's test dummy head hitting the dashboard at a higher speed compared to the CAE THOR dummy. The difference could be due to the setting of the restraint system such as the seatbelt retractor timing, seatbelt friction and dummy's friction with the seat but the similar setting are used on the driver side restraint and the correlation observed are good. Due to this y-acceleration difference, the HIC value for the passenger did not correlate well, test experiencing HIC of 869 compared to CAE at 335.

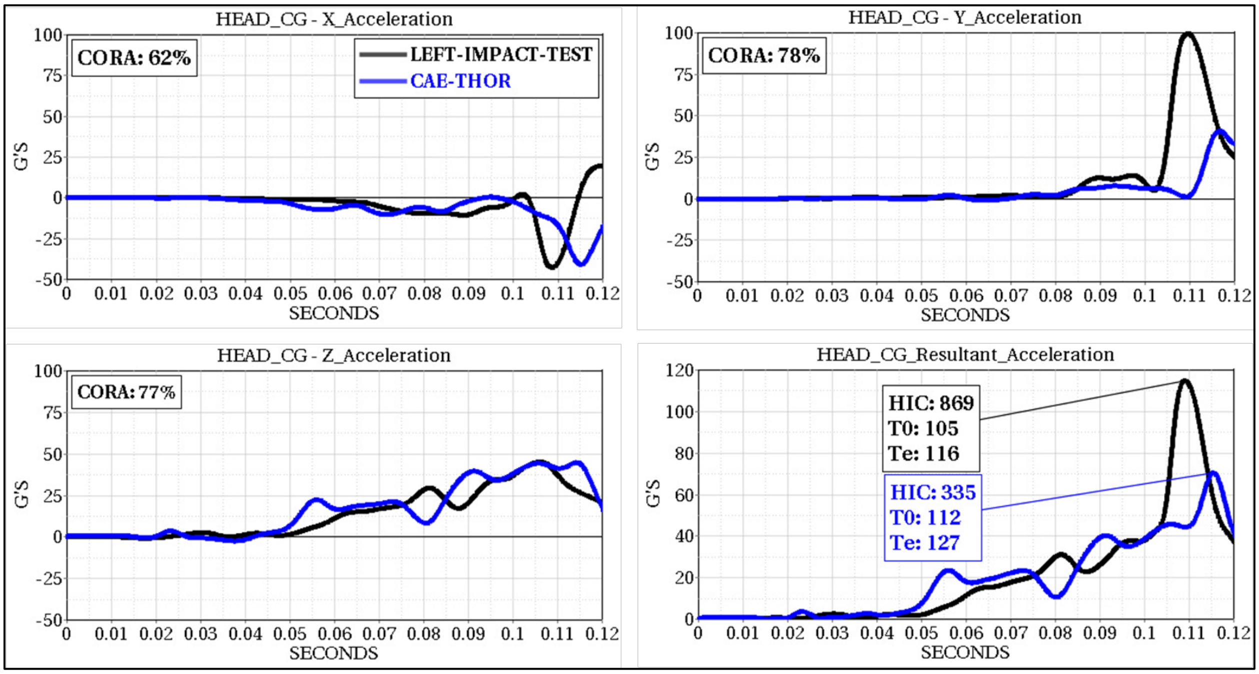


Figure 53: Passenger Head CG Acceleration

The driver's pelvic x-acceleration curve shape correlates well with the test, peak magnitude in CAE is 11 percent higher than in test and it occurs 10 ms earlier than in test, as shown in Figure 54.

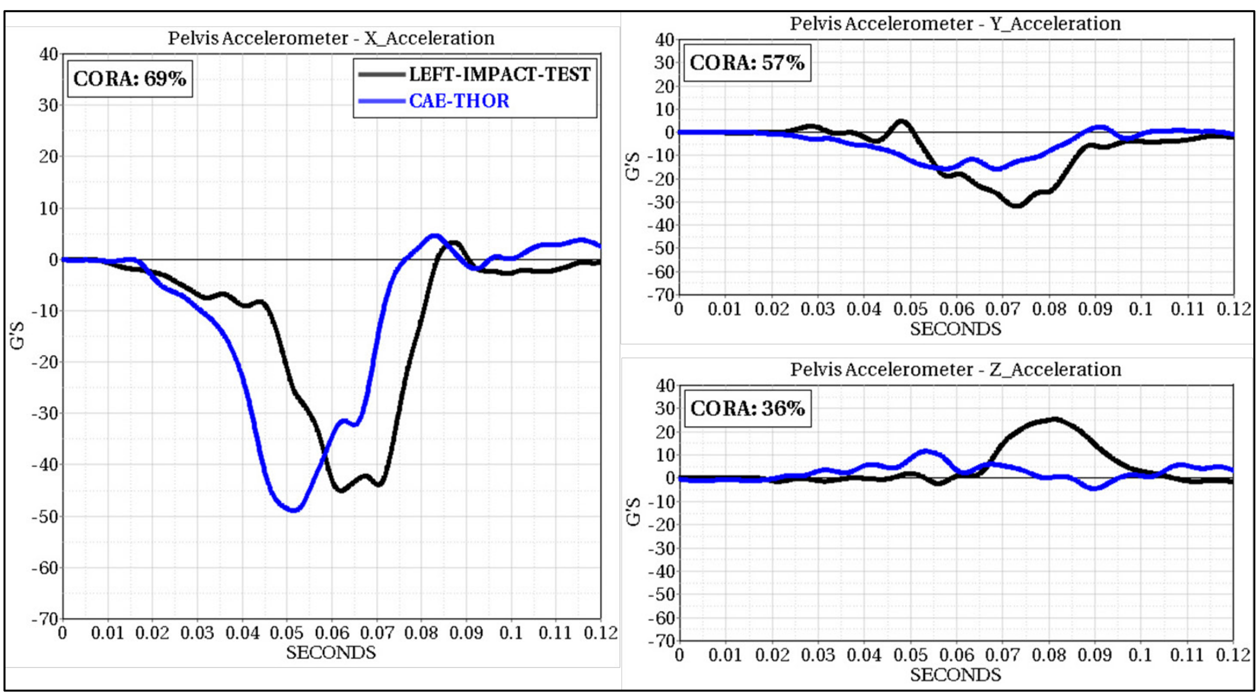


Figure 54: Driver Pelvic CG Acceleration

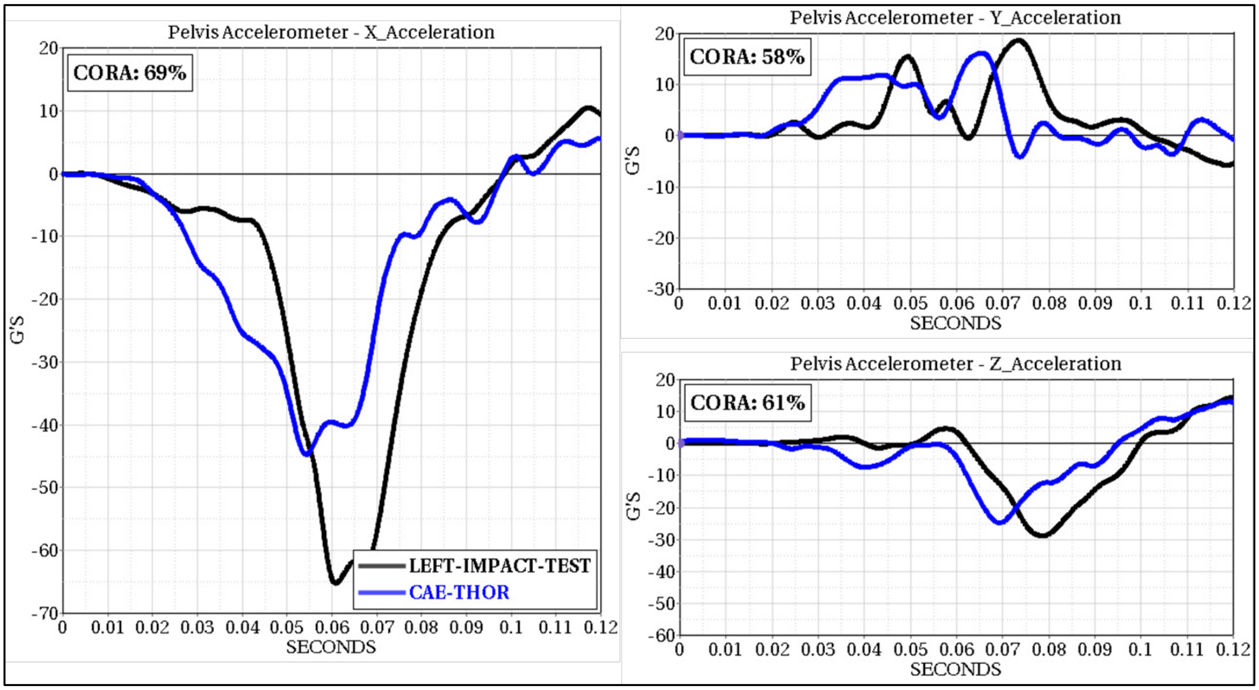


Figure 55: Passenger Pelvic CG Acceleration

The passenger pelvic x-acceleration also showed similar behavior to driver, slowing down earlier compared to test, as shown Figure 55. One issue faced with the passenger side dummy was the seat belt slips in between the shoulder and arm joint shown in Figure 56. This restrains the dummies from forward motion. In the test the belt slips off the shoulder and the dummy moves forward and makes contact with the dash. The contact between the arm and the seat belt had to be removed so that the seat belt slips off to allow the dummy freedom to move forward and eventually makes contact with the dash, replicating what happened in test.

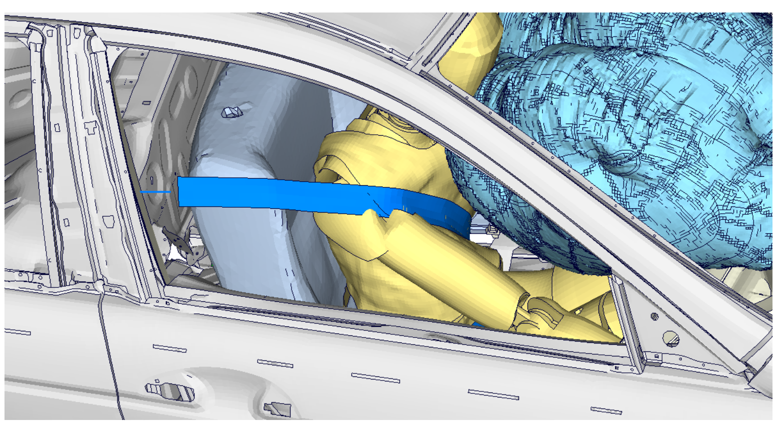


Figure 56: Seat belt slip in between shoulder and arm joint

The seat belt force shown in Figure 57 is measured as the tension experienced by the belt to restraint the occupant during the crash simulation. Both driver and passenger belt force correlates well with the test. The initial peaks in both curves is due to pretensioner firing to remove any slack remaining from the belt, pulling the occupant closer to the seat before the inertia of the dummy from the impact forces itself to move forward, exerting more force on the belt.

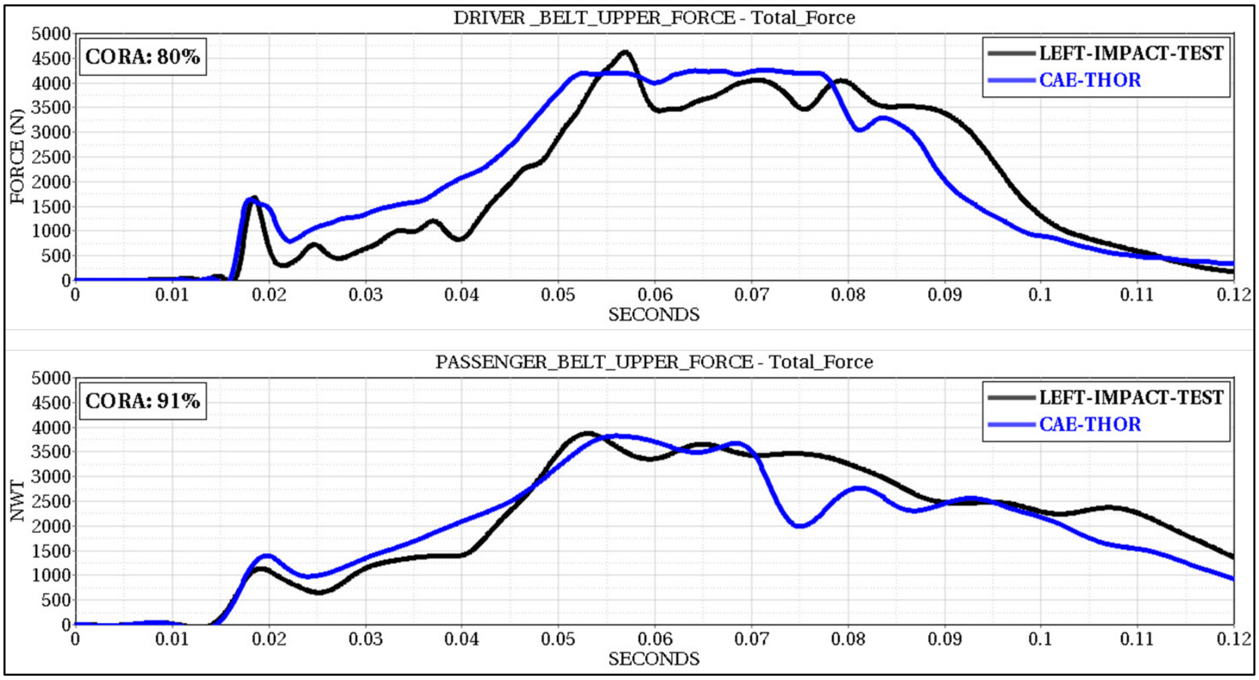


Figure 57: Driver and Passenger Seat belt Force

The femur force as shown in Figure 58 was also measured as the axial force experienced by the dummy's femur making contact with the dash structure. Both test and CAE driver dummy maximum left femur force is approximately 750 N. For the driver right femur, the test experienced slightly higher force at 750 N as compared to 500 N in CAE.

For the passenger side, the left femur for test has maximum force of 1,000 N and in CAE model it is higher at 1,500 N. For the right femur force, the test sees a maximum force of 1,500 N compared to CAE model at 2,000 N.

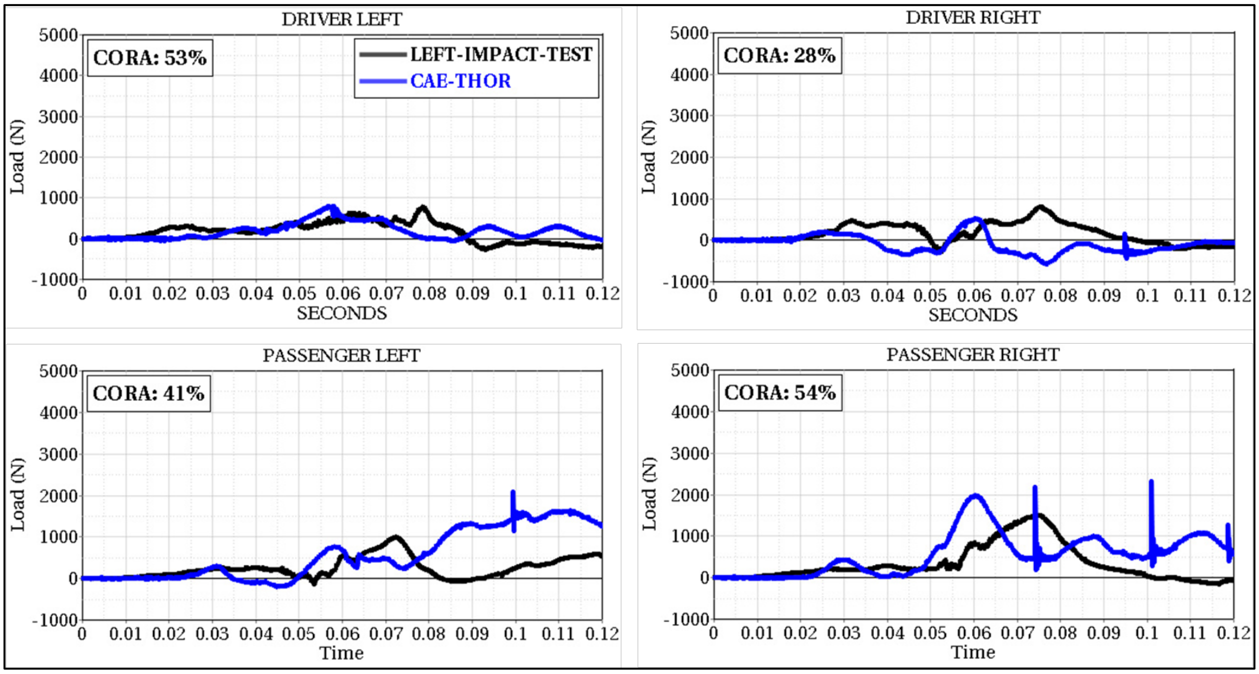


Figure 58: Driver and Passenger Femur Force

Similar to the driver side, the base model was also compared to the oblique test that impacts the vehicle on the passenger side. The setup of the test/model is the same but the barrier is positioned on the right side. The setup of the model and CAE model is shown in Figure 59.

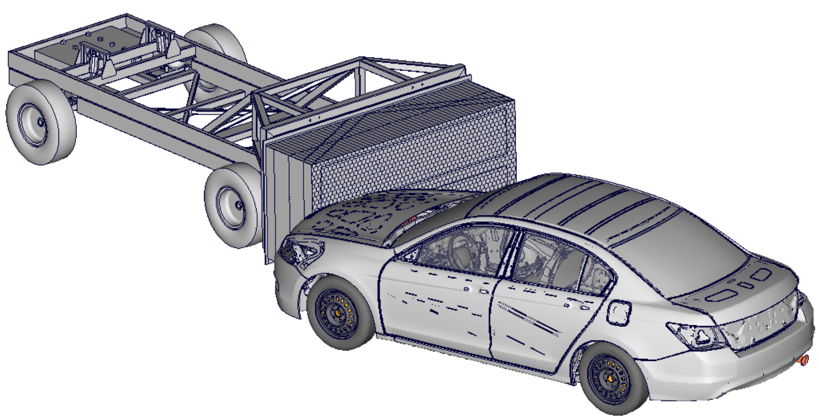


Figure 59: Right Oblique Impact Setup

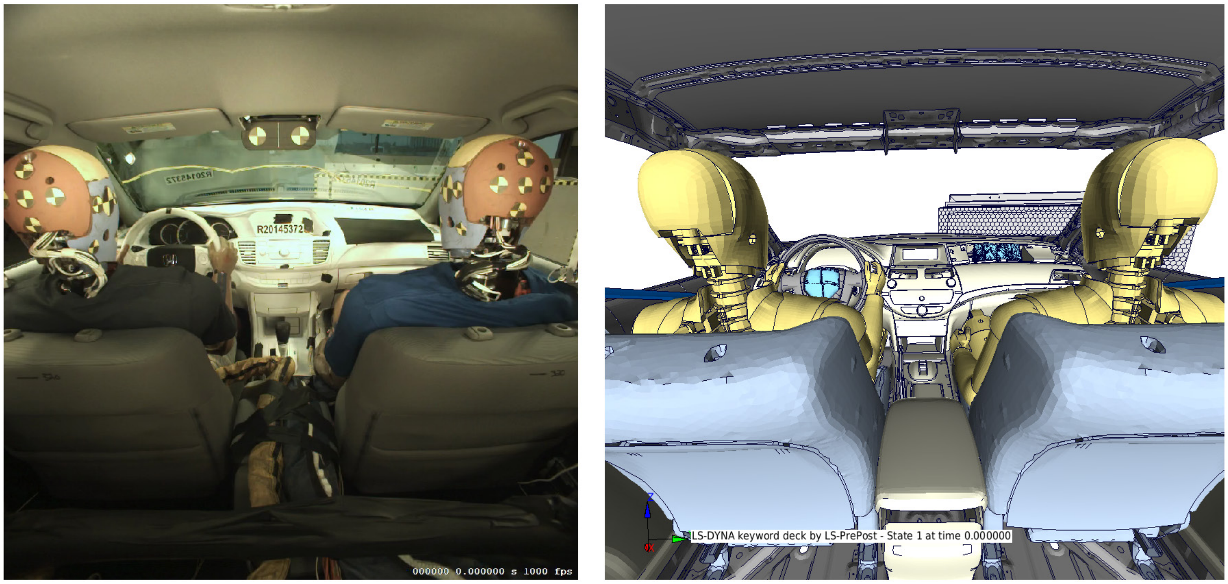


Figure 60: Test Versus CAE at 0 ms

Figure 60 to Figure 64 show the timeline of the crash while comparing the test and CAE model with the occupants, air bags, seat belts, surrounding trims and seat. The driver air bag and passenger air bag are triggered at 14 ms. Also at 14 ms the seat belt pretensioner is initiated.

Figure 61: Test Versus CAE at 35 ms

At 35 ms the driver air bag is fully deployed and the passenger air bag is partly deployed. Both dummies are yet to make contact with the air bags. The curtain air bag on the passenger side will trigger at 38 ms as per test.

Figure 62: Test Versus CAE at 70 ms

At 70 ms the passenger and curtain air bag is fully deployed, both dummies make contact with their respective air bag. The seat belt on the driver dummy starts to slip off from its shoulder causing the driver dummy to have higher rotational and forward motion toward the center of the vehicle.

Figure 63: Test Versus CAE at 90 ms

At 90 ms the passenger dummy head is in contact with both curtain and driver air bag. The driver dummy continues to move forward towards the center of the dash.

Figure 64: Test Versus CAE at 120 ms

At 120 ms the passenger's head is sandwiched in between the air bags. Meanwhile the passenger dummy's head hits the dashboard. Overall the kinematics of the CAE THOR dummy compares well with the test results.

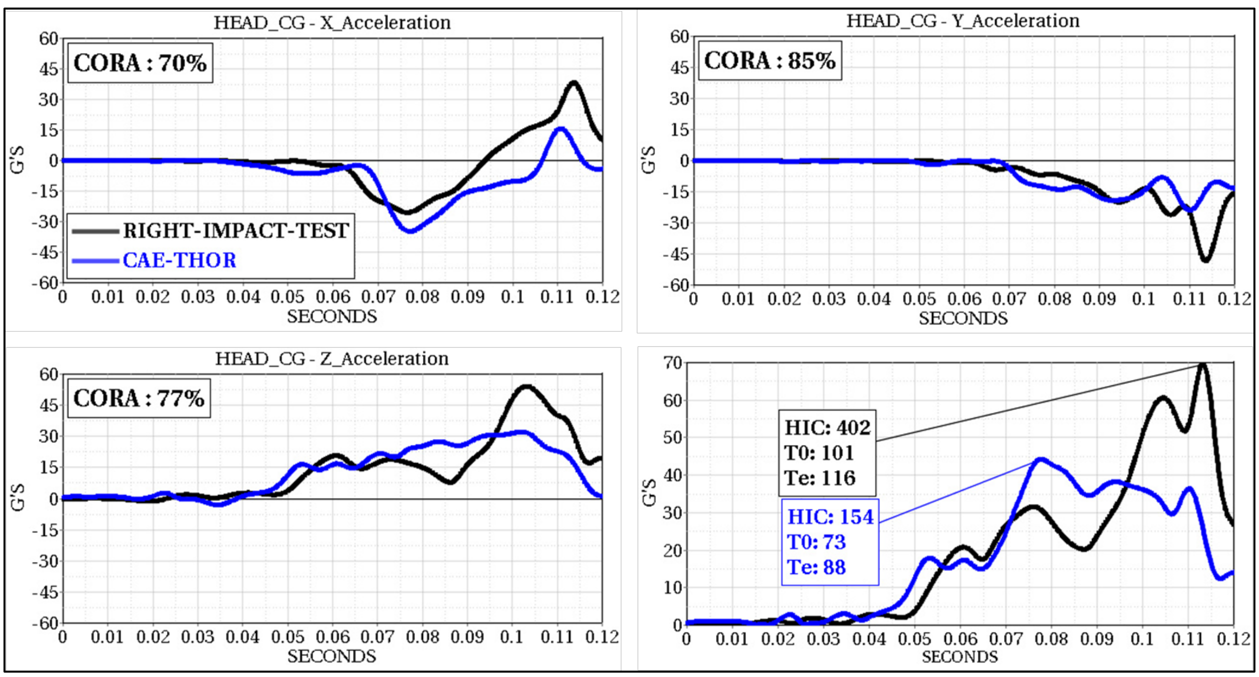


Figure 65: Driver Head CG Acceleration

The overall shape of the driver head x-acceleration shows good correlation as shown in Figure 65, peaking at a similar time (77 ms) when the driver's head forward motion is completely stopped by the air bag and the head begins to rotate. The passenger head impact with the passenger air bag and side curtain air bag is a very complex interaction. In the passenger head acceleration shown in Figure 66, the x-acceleration correlates well up to 80 ms, and departs significantly from 80 to 110 ms.

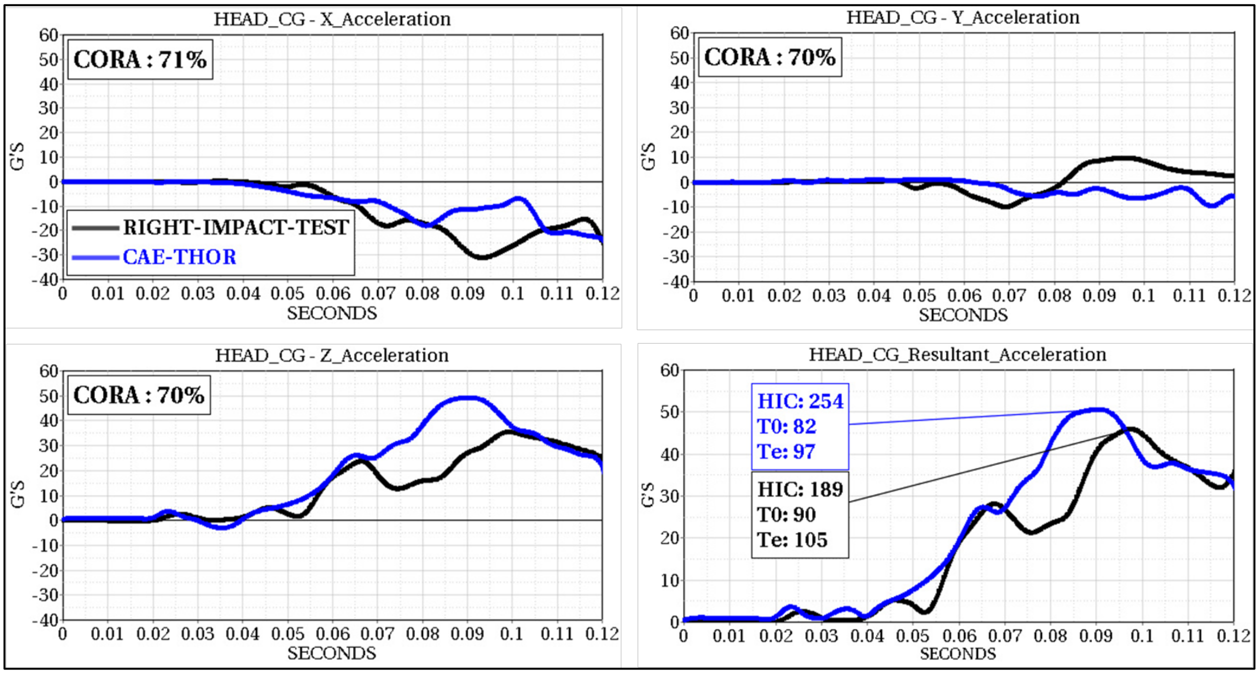


Figure 66: Passenger Head CG Acceleration

The driver's and passenger's pelvic acceleration are shown in Figure 67 and Figure **68** respectively and correlates well with the test. The peak magnitude in CAE matches the initial peak in the test at 40G, but the test shows a rise and drop further to 47G.

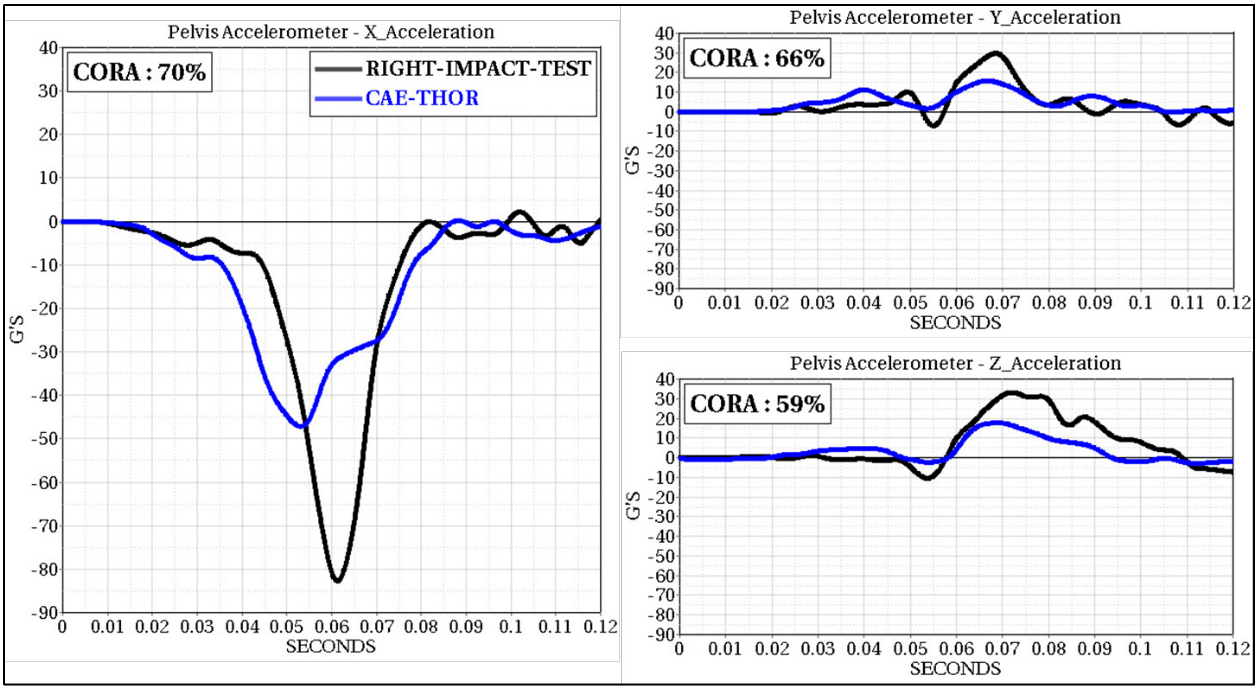


Figure 67: Driver Pelvic CG Acceleration

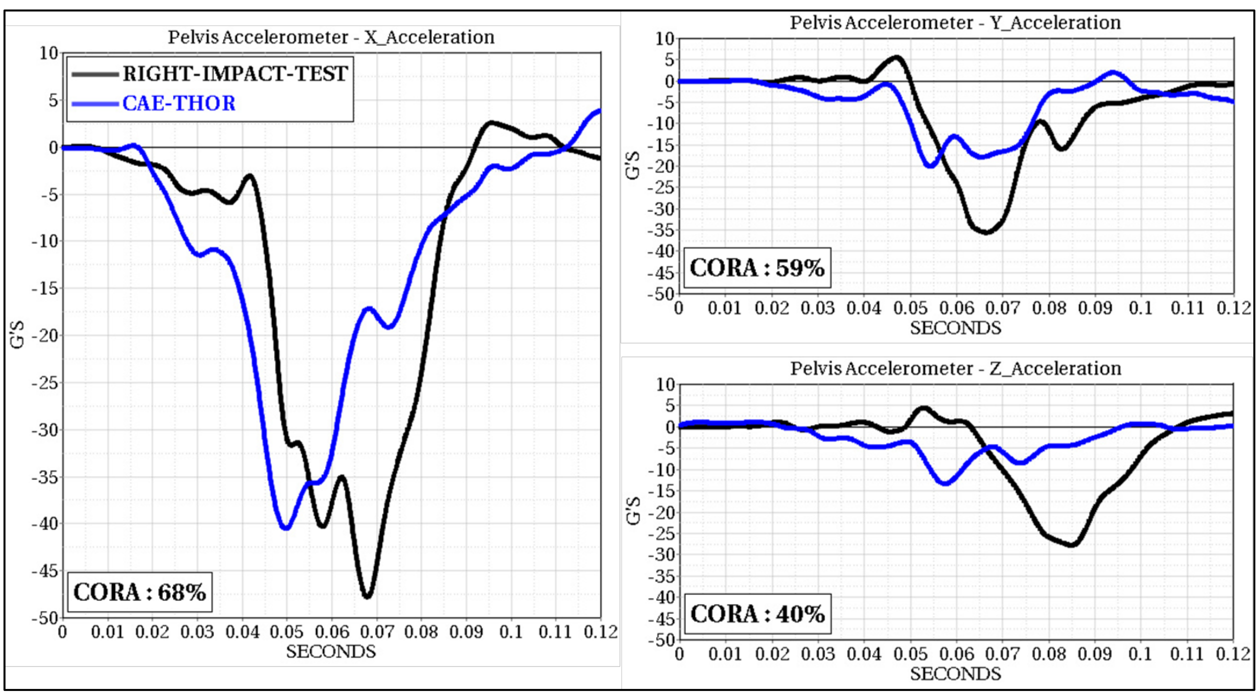


Figure 68: Passenger Pelvic CG Acceleration

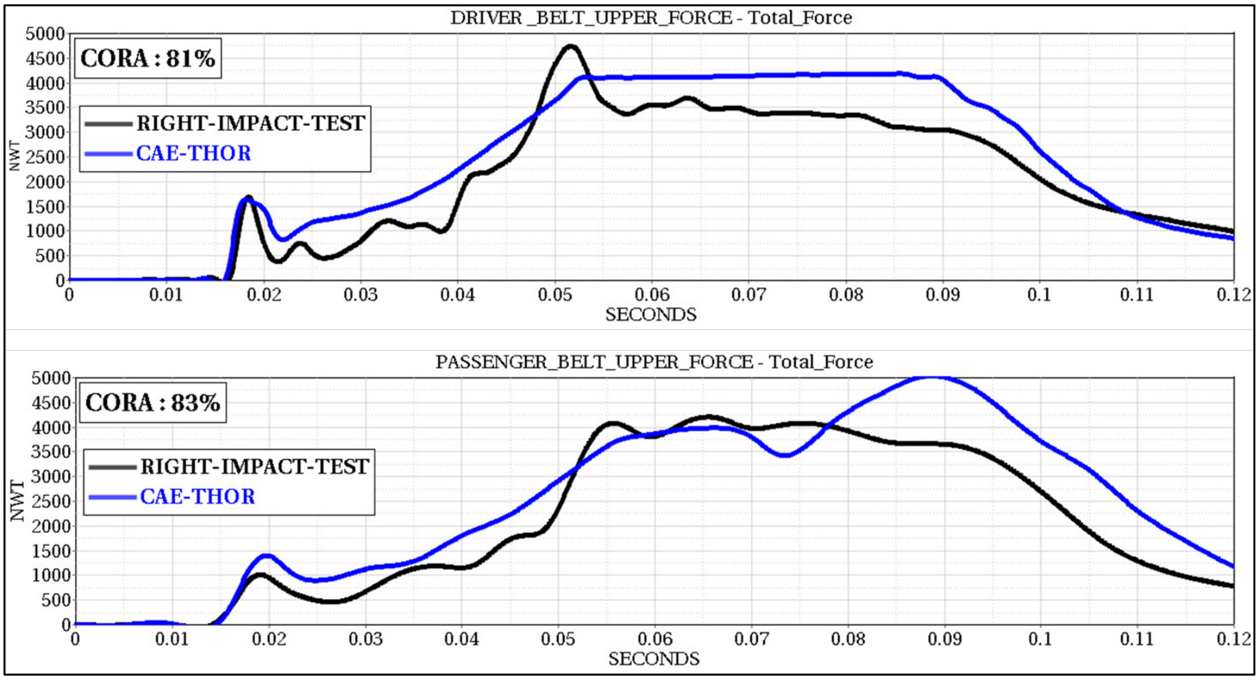


Figure 69: Driver and Passenger Seat belt Force

Seat belt force shown in Figure 69 is measured as the tension experienced by the belt to re-straintthe occupant during the crash simulation. Both driver and passenger belt force correlates well with the test. The initial peaks in both curves are due to pretensioner firing to remove any slack remaining from the belt, pulling the occupant closer to the seat before the inertia of the dummy from the impact forces itself to move forward, exerting more force on the belt.

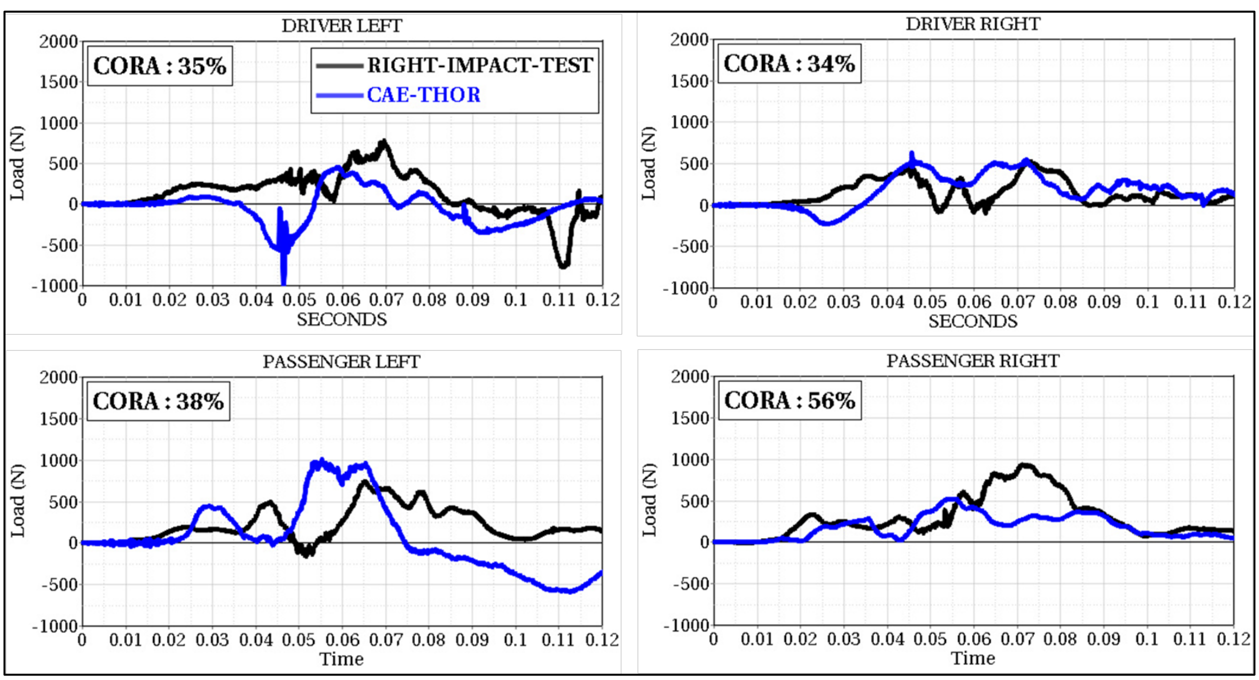


Figure 70: Driver and Passenger Femur Force

The femur forces as shown in Figure 70 were also measured as the axial force experienced by the dummy's femur making contact with the dash interior trim. For the driver side, the left femur for the test has a maximum force of 750 N and in CAE model is slightly lower at 500 N. Both test and CAE driver dummy maximum right femur forces are 500 N. For the passenger side, the left femur test has a maximum force of 750 N and in CAE model is slightly higher at 1,000N. For the right femur force, the test sees a maximum force of 1,000 N compared to CAE model at only 500 N. These numbers are well below the threshold set at 10 kN.

4.2.2 Common Difficulties in Simulation Setup Observed and Overcome

As per the scope of the project, the full vehicle FEA model was integrated with interiors, trims, functional seat systems, and occupant safety restraint systems such as seat belt and air bags. The occupant model selected for simulation is 50th percentile THOR dummy model. The same THOR dummy model was duplicated for the passenger side; thus both driver and passenger occupants were seated as per ATD position data explained in the previous sections. The following challenges were encountered during the modeling and simulation of the THOR dummy for driver and passenger side simultaneously, and the steps taken to overcome these problems.

1. FEA model size significantly increased that caused issues in accommodating the node and element numbering of two THOR dummy models in already detailed full vehicle model. The vehicle had to be split into smaller subsystems and renumbered accordingly to accommodate the dummy and the occupant safety systems.
2. The THOR dummy when included in the vehicle with components with greater density/stiffness causes contact instability during LS-DYNA simulations. Contact parameter SOFT=2 is used to eliminate this problem with some computational time penalty.
3. Inconsistent material properties assigned to body parts such as forearms, femur, tibia, and lower torso caused out-of-range deformation during impact simulation. Hourglass for several parts had to be changed to stabilize the model.

5 Human Body Model Simulations

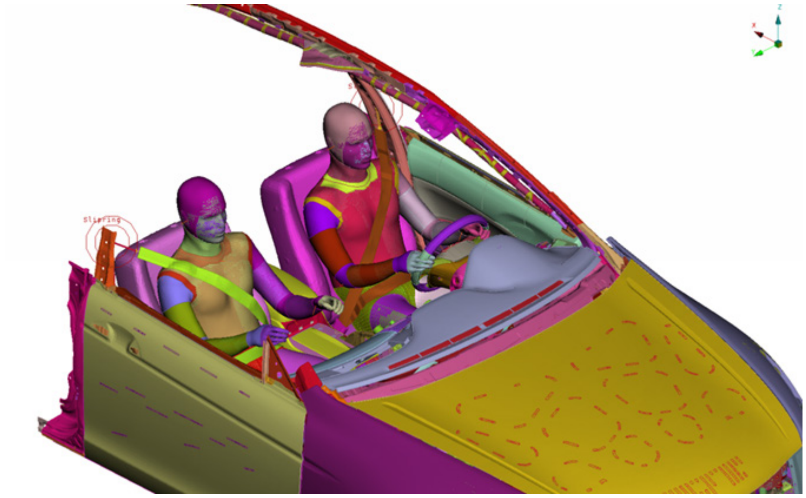
5.1 Brief History Global Human Body Model Consortium

Founded in April 2006, the Global Human Body Models Consortium is an international consortium of automakers and suppliers working with research institutes and government agencies to advance human body modeling technologies for crash simulations. The objective of the GHBMC is to consolidate worldwide research and development activities in human body modeling into a single global effort to advance crash safety technology. During Phase I of development activities, the GHBMC established six centers of expertise (COEs) to develop a detailed model representing the average male in a driving posture. Body region model (BRM) COEs led the development and validation of regional finite element models using CAD geometries developed from a multi-modality medical image dataset by the full body model (FBM) COE. These regional models were then integrated by the FBM COE for full body validation. More than 70 unique load cases were simulated for validation of the detailed average male occupant model. Currently concluding the second phase of development, the GHBMC has grown its family to include models of different size, sex, posture, and complexity. To date, the GHBMC family has 13 models representing both detailed and simplified versions of the small female, average male, and large male in occupant and pedestrian postures. A simplified pedestrian model of a 6-year-old has also been developed as a tool for enhancing child pedestrian protection. In the future, the focus for the GHBMC is to further enhance the bio-fidelity and injury prediction capabilities of their human body models.

For this study the GHBMC M50 Occupant Version 4.5 for LS-DYNA was licensed from Elemance, LLC.

5.2 Oblique Impact Left and Right Using GHBMC

The THOR dummy CAE model was replaced by the GHBMC model to compare how the human body model performs with the THOR dummy model. All parameters of the crash load case remain the same. With the addition of two GHBMC M50 models the size of the total FEM (with the barrier) increased to 8,674,315 elements as shown in Figure 71. The combined model takes over 43 hours to run 120 ms using 96 CPU cores.



ELEMENT TYPE	NUMBERS OF ELEMENTS
SHELL	4,601,604
SOLID	4,059,888
MASS	73
DISCRETE	130
BEAM	12,496
SEAT BELT	124
Total	8,674,315

Figure 71: Vehicle FEM With GHBMC

Figure 72 to Figure 76 show the the timeline of the crash while comparing the CAE THOR and GHBMC with air bags, seat belts, surrounding trims and seat. The driver air bag and passenger air bag are triggered at 14 ms. Also at 14 ms the seat belt pretensioner is initiated.

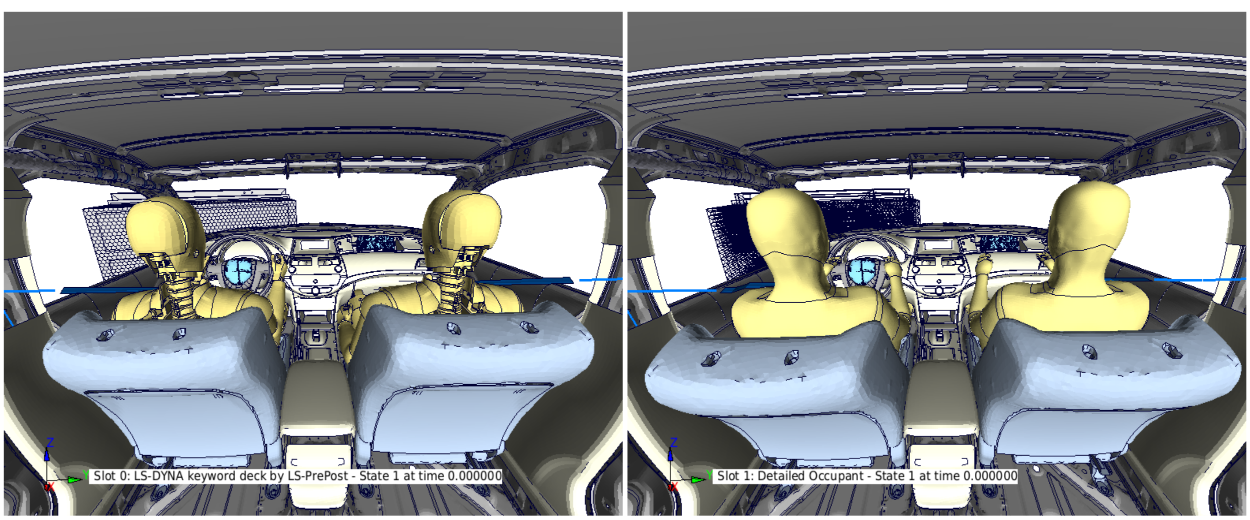


Figure 72: CAE-THOR Versus GHBMC at 0 ms

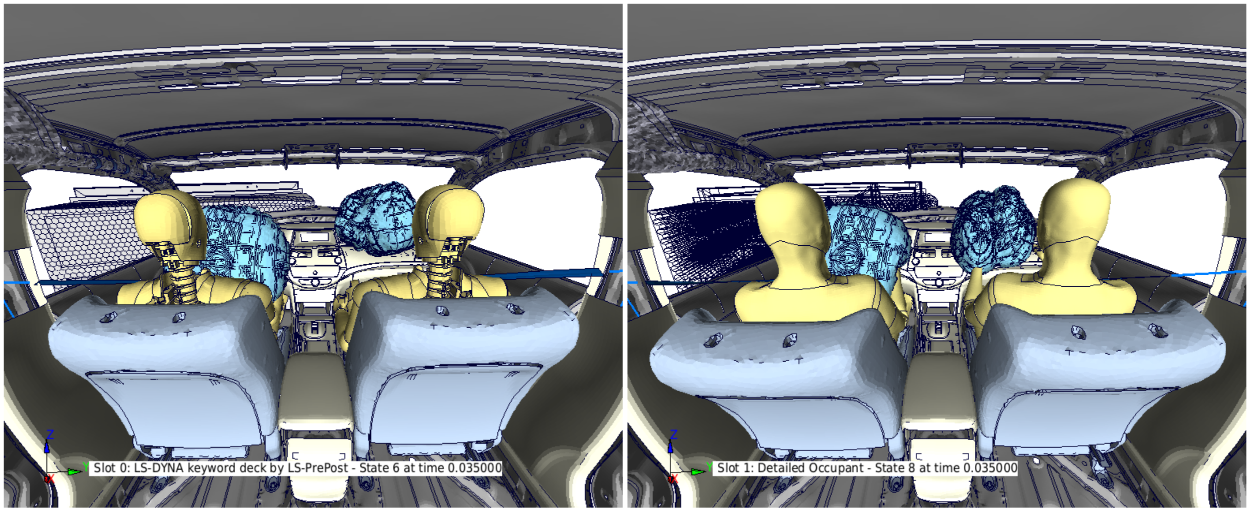


Figure 73: CAE-THOR Versus GHBMC at 35 ms

At 35 ms the driver air bag is fully deployed and the passenger air bag is partly deployed. Both dummies are yet to make contact with the air bags. The curtain air bag on the driver side will trigger at 38 ms as per test.

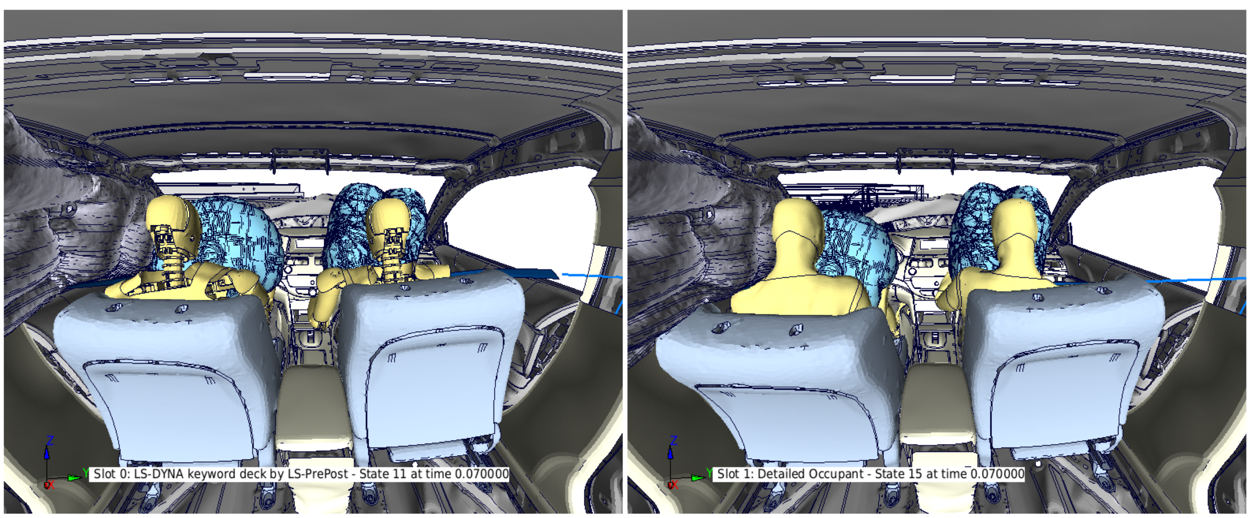


Figure 74: CAE-THOR Versus GHBMC at 70 ms

At 70 ms the passenger air bag and driver curtain air bag are fully deployed; both dummies make contact with their respective air bags. The seat belt on the passenger dummy starts to slips off from its shoulder causing the passenger dummy to have higher rotational and forward motion toward the center of the vehicle.

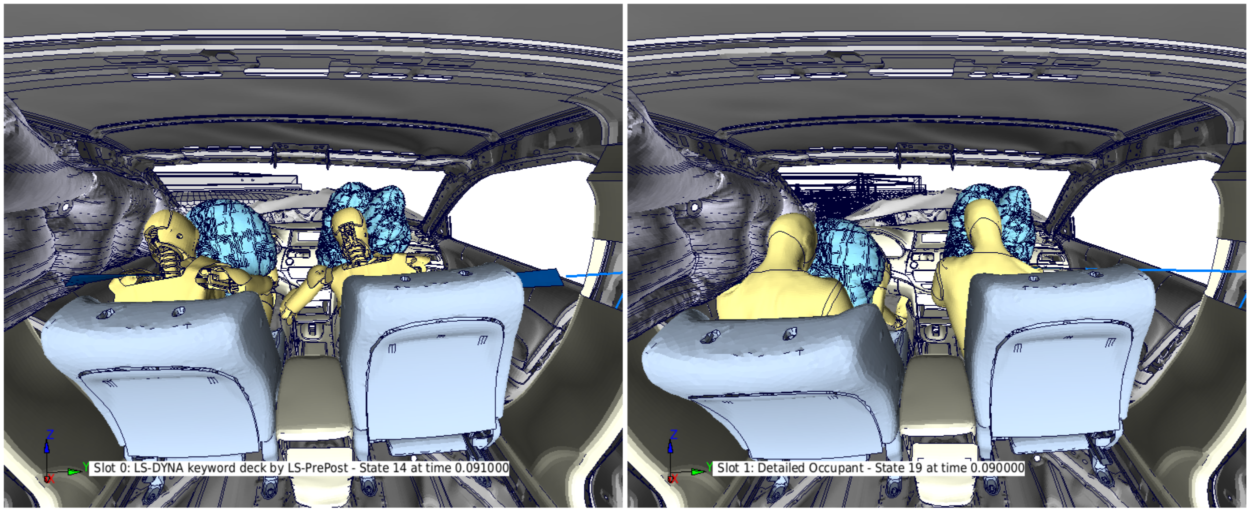


Figure 75: CAE-THOR Versus GHBMC at 90 ms

At 90 ms the driver dummy head is in contact with both curtain and driver air bags. The passenger dummy continues to move forward towards the center of the dash.

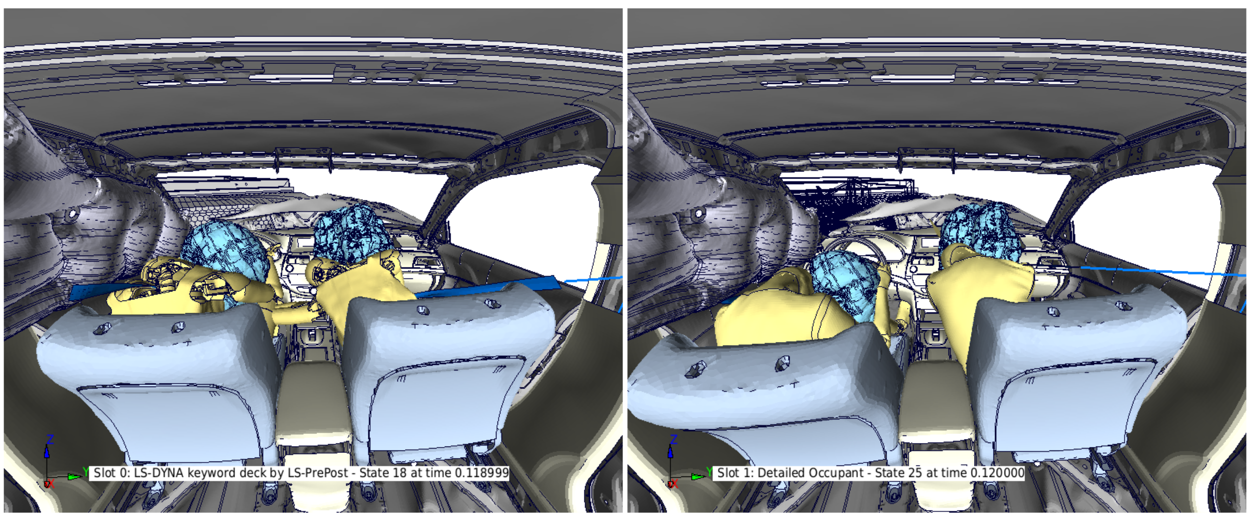


Figure 76: CAE-THOR Versus GHBMC at 120 ms

In terms of kinematic, the behavior of the GHBMC model seems very similar to the THOR dummy model, except for the seat belt on the passenger side. In the GHBMC passenger model, the seat belt does not completely slip off the shoulder, resisting it to strike the dash as per the THOR model.

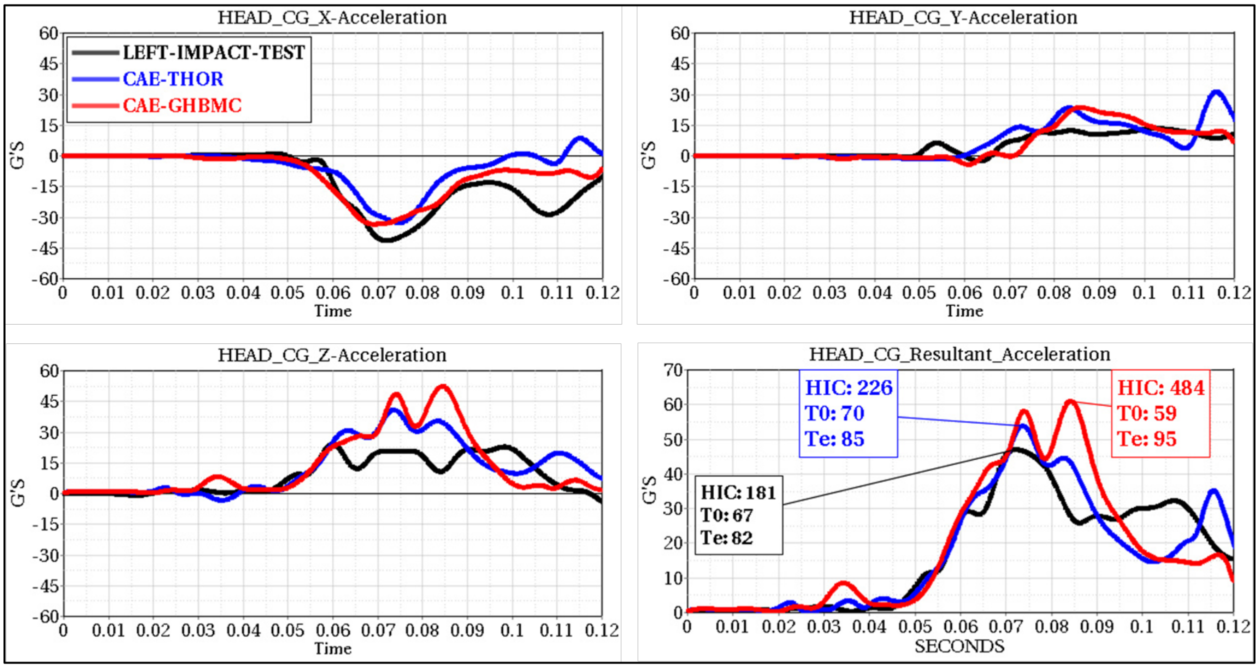


Figure 77: Driver Head CG Acceleration

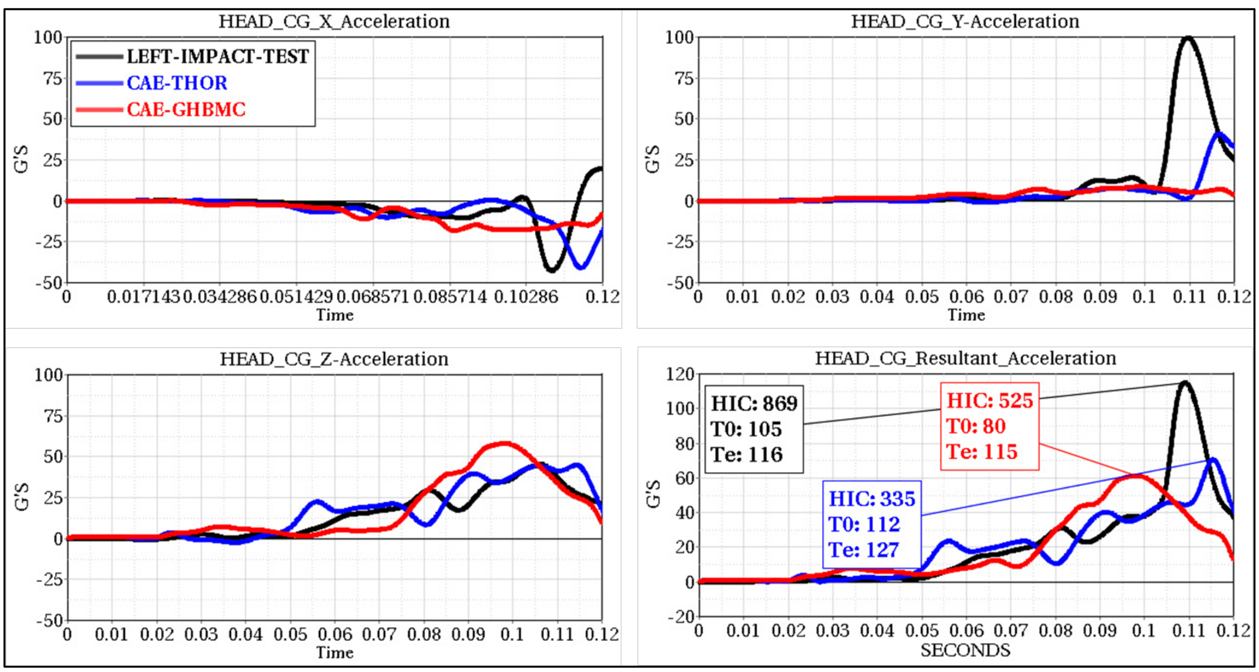


Figure 78: Passenger Head CG Acceleration

Figure 77 and Figure 78 compare the head CG acceleration of the driver and passenger CAE results with test results. For the driver side, the GHBMC model head CG x-acceleration shows similar performance to the THOR dummy, i.e., both lowest peaks at 33 Gs. The HIC value in the GHBMC model records 484, higher than the THOR CAE model due to the additional peak occurred in z-acceleration, but the overall resultant show good similarity between GHBMC model and the THOR CAE model. The passenger side curve did not correlate well due to seat belt not slipping off the shoulder of the GHBMC; it restricted the forward motion and avoided the contact with the dashboard. This event happened in the test and is similar to the THOR CAE model results.

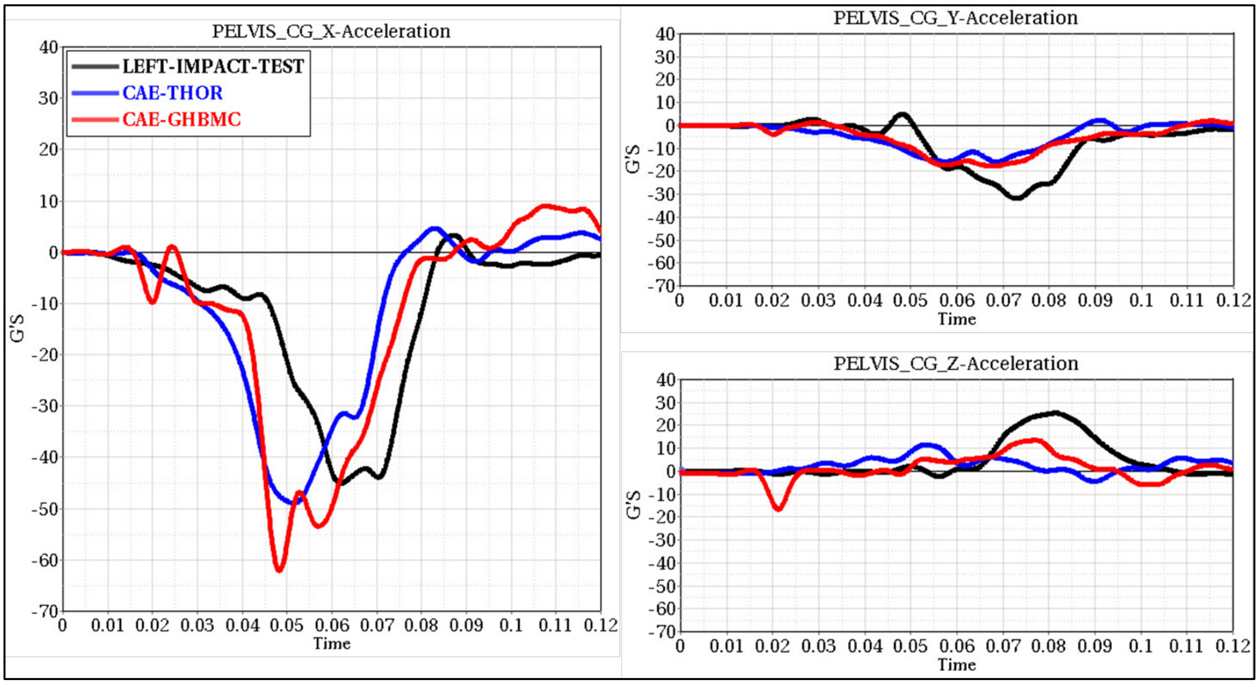


Figure 79: Driver Pelvic CG Acceleration

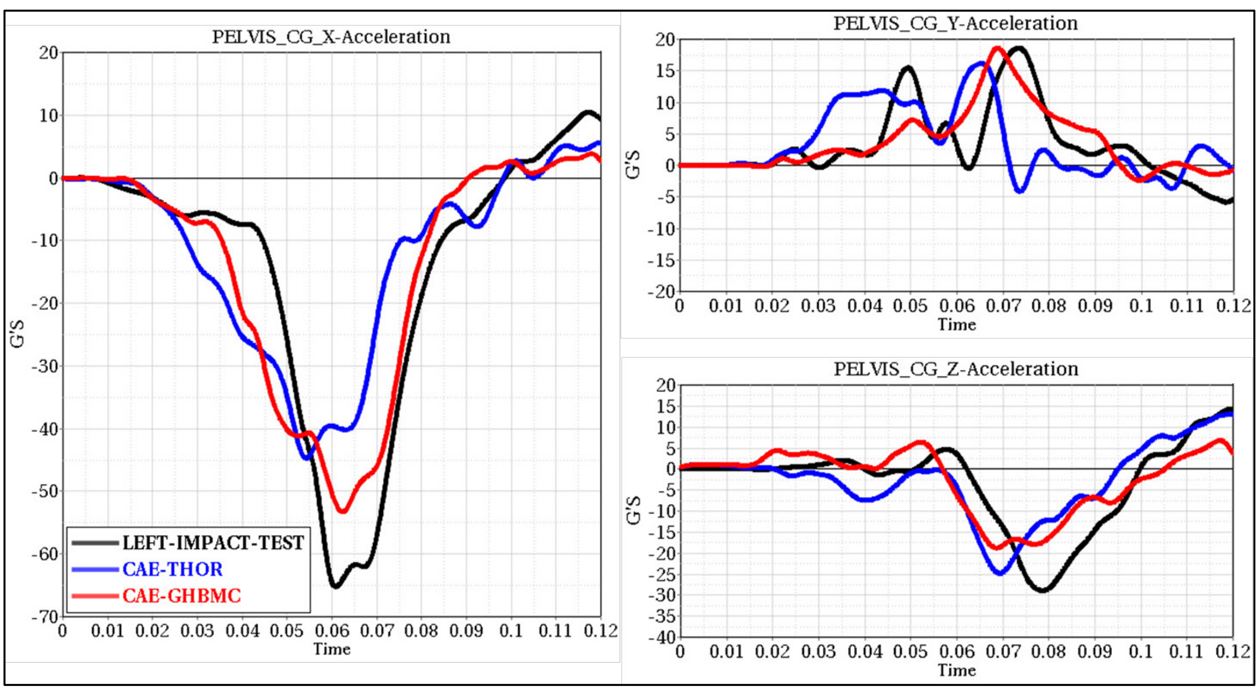


Figure 80: Passenger Pelvic CG Acceleration

Figure 79 and Figure 80 compares the pelvic CG accelerations of both CAE models versus the test. The GHBMC model curve shows similar performance to the THOR CAE model. For the passenger side, the GHBMC model pelvic CG acceleration is closer to the test performance compared to THOR CAE model.

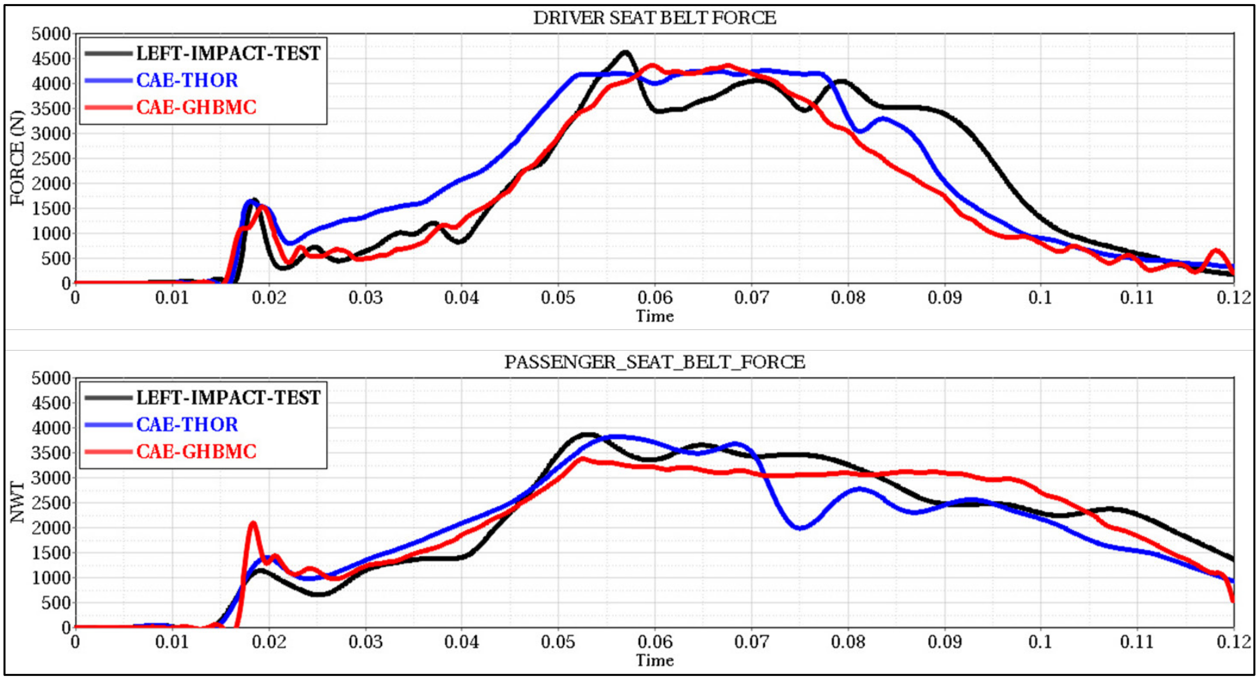


Figure 81: Driver and Passenger Belt Force

Figure 81 shows the seat belt forces for both driver and passenger. Overall, the GHBMC curves are very close to CAE-THOR and test for both driver and passenger.

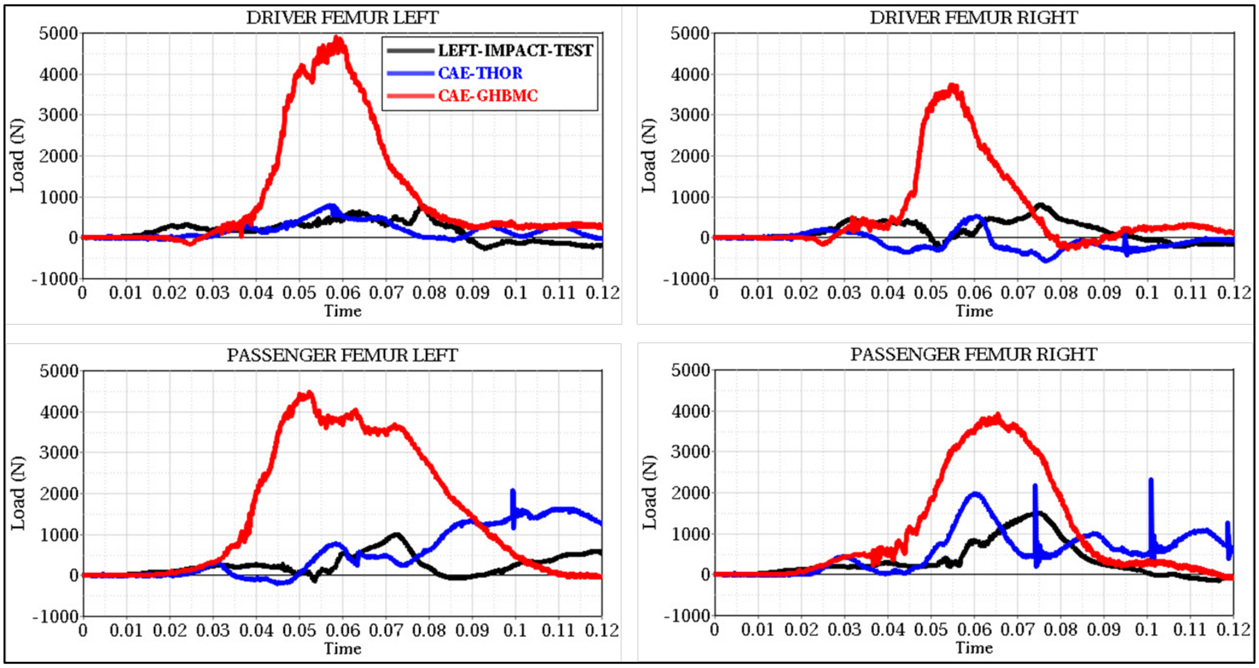


Figure 82: Driver and Passenger Femur Force

Figure 82 shows the driver and passenger femur forces. In the THOR CAE, the force is measured from a beam element that connects two metal sockets moving axially between each other along the femur. In the GHBMC model, the force is taken from a cross-section force of the actual femur bone made of solid elements. The human body model seems to experience more load through the femur compared to the THOR model.

A similar comparison study of human body model and THOR model has been done for the right oblique impact crash load case. Figure 83 to Figure 86 show the timeline of the event comparing both the CAE dummy models in the occupant compartment during the crash

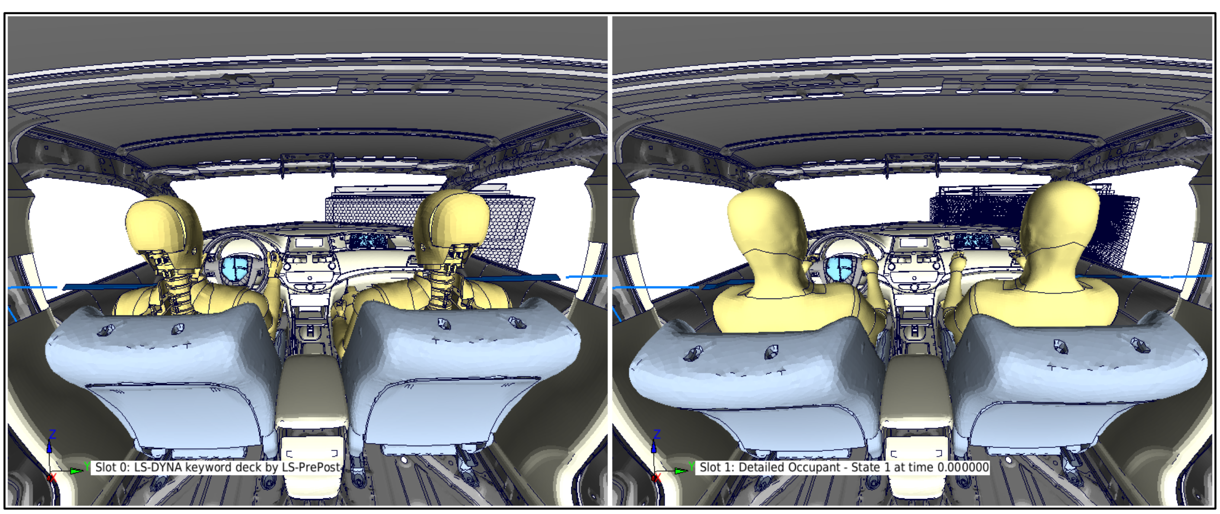


Figure 83: THOR CAE Versus GHBMC Model at 0 ms

At 35 ms the driver air bag is fully deployed and the passenger air bag is partly deployed. Both dummies are yet to make contact with the air bags. The curtain air bag on the passenger side will trigger at 38 ms as per test.

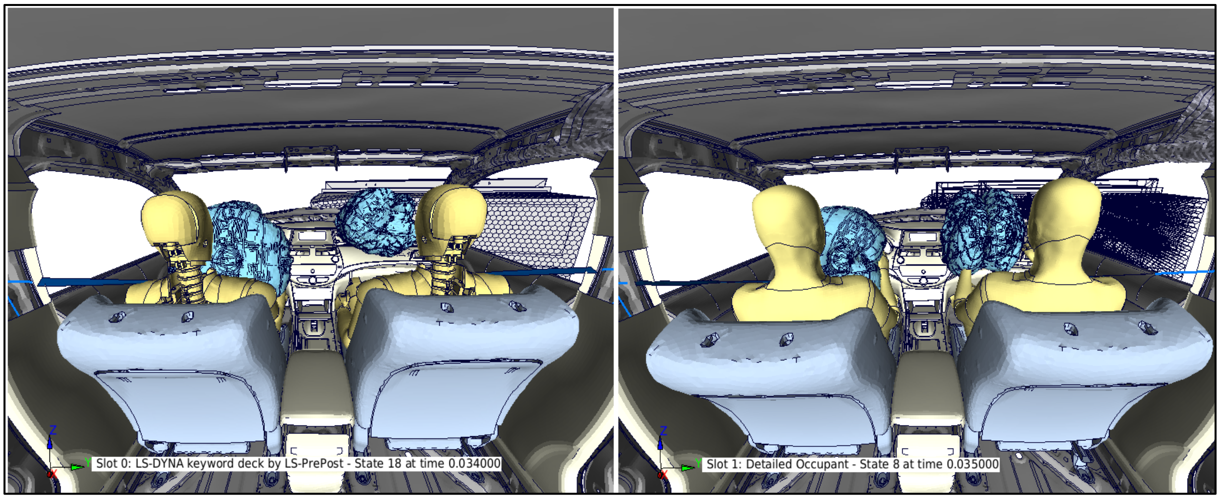


Figure 84: THOR CAE Versus GHBMC Model at 35 ms

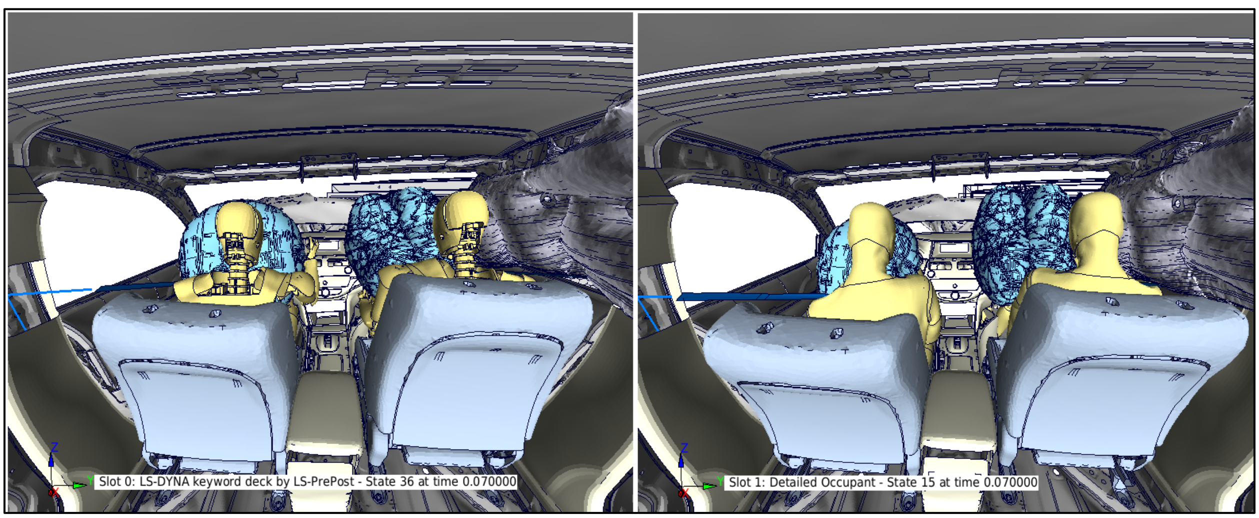


Figure 85: THOR CAE Versus GHBMC Model at 70 ms

At 70 ms the passenger and curtain air bags are fully deployed; both dummies make contact with their respective air bags. The seat belt on the driver dummy starts to slips off from its shoulder, causing the driver dummy to have higher rotational and forward motion toward the center of the vehicle.

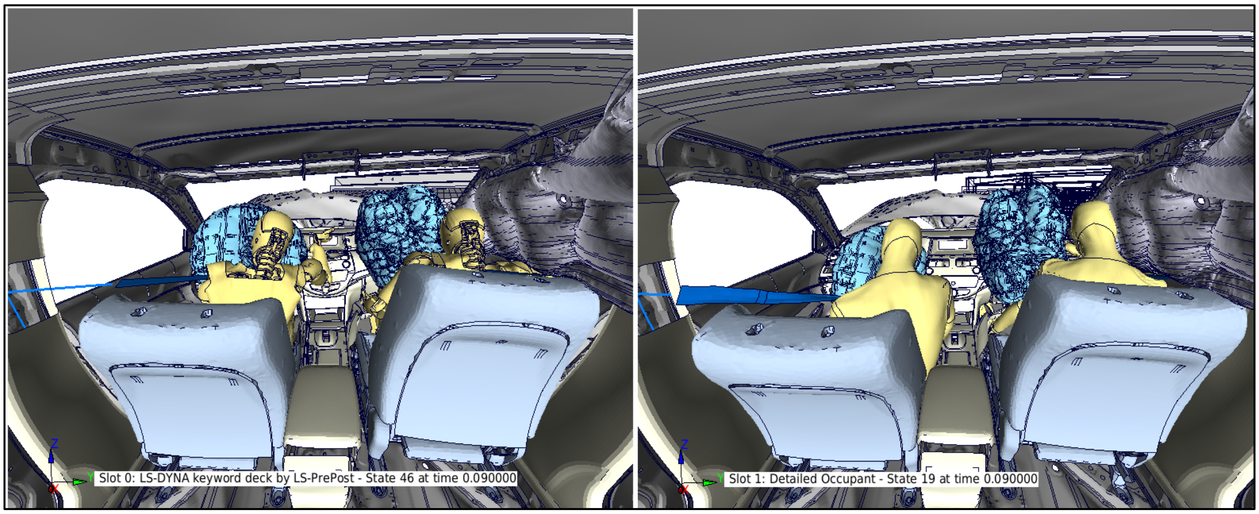


Figure 86: THOR CAE Versus GHBMC Model at 90 ms

At 90 ms the passenger dummy head is in contact with both curtain and front air bag. The passenger dummy continues to move forward toward the center of the dash.

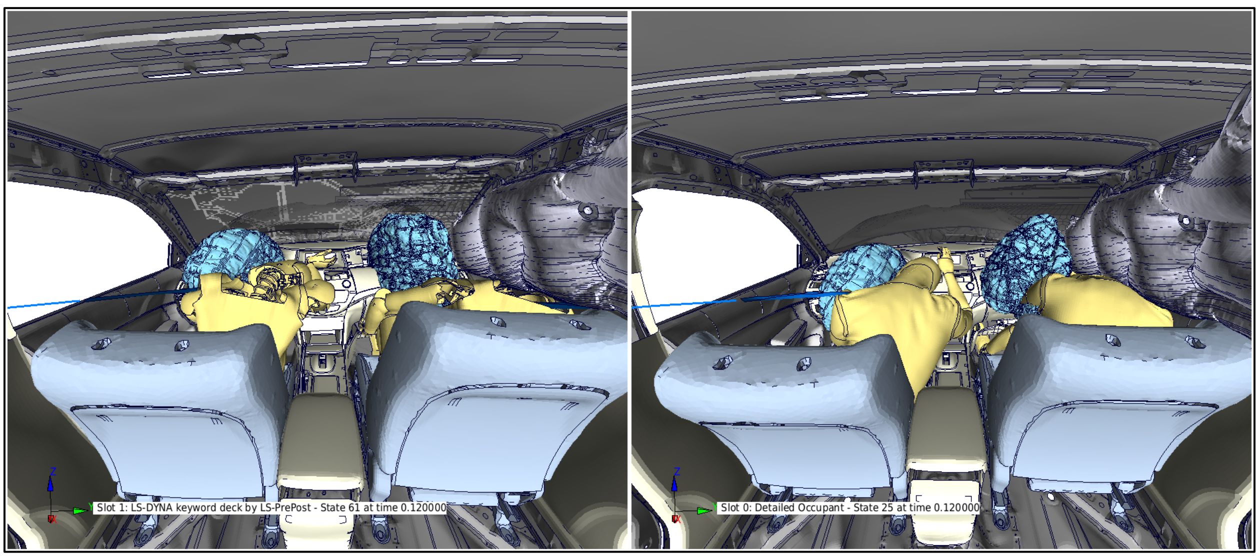


Figure 87: THOR CAE Versus GHBMC Model at 120 ms

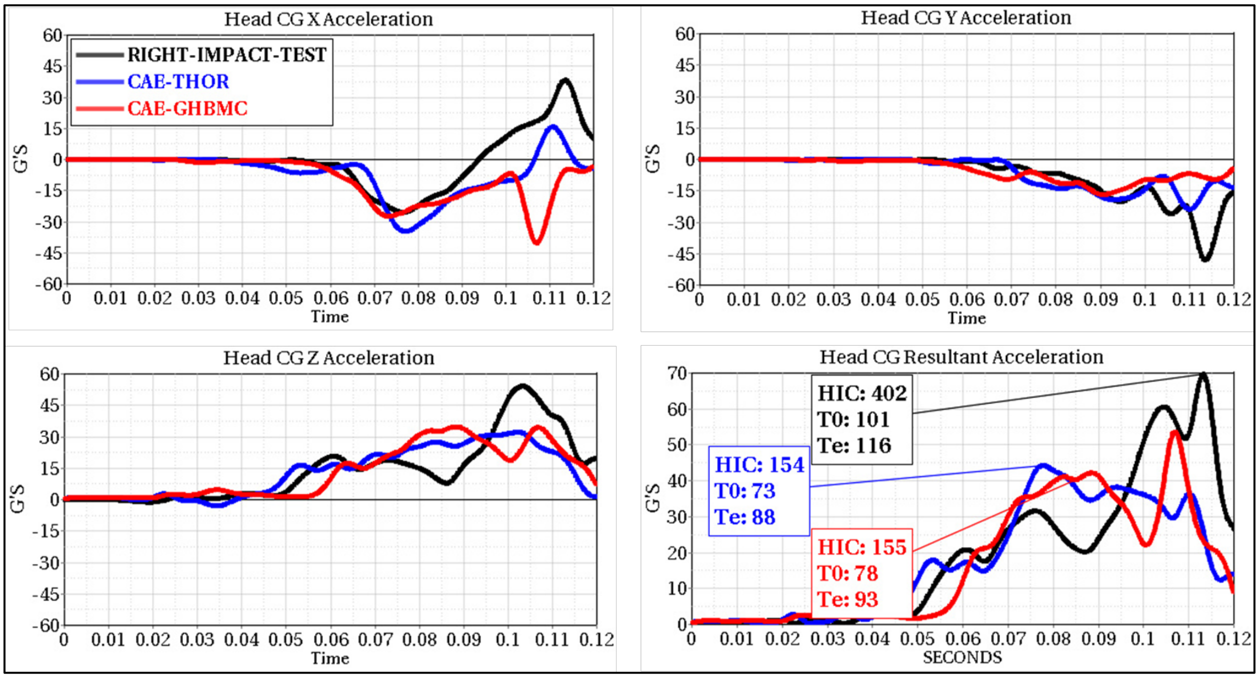


Figure 88: Driver Head CG Acceleration

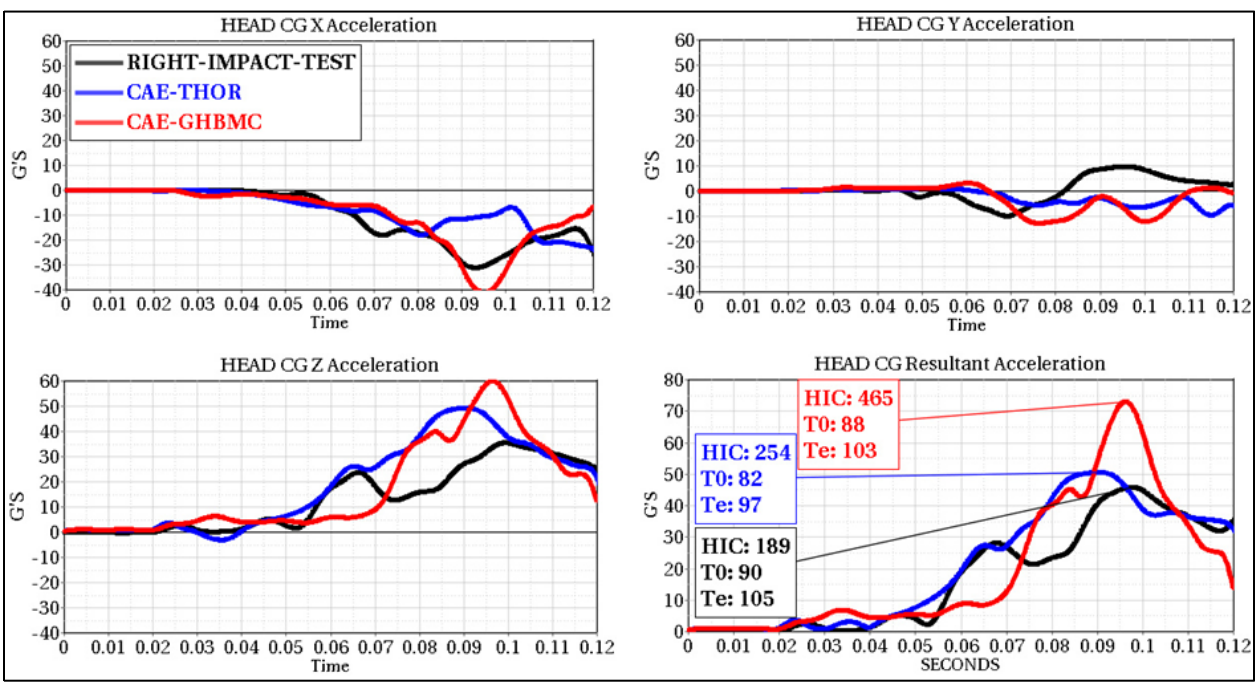


Figure 89: Passenger Head CG Acceleration

Figure 88 and Figure 89 show the head CG acceleration for both driver and passenger. For the driver side, the GHBMC model head CG acceleration shows similar performance as the CAE

THOR dummy. For the passenger side, the GHBMC model recorded a higher HIC value as it experienced higher peak in both X and Z directions.

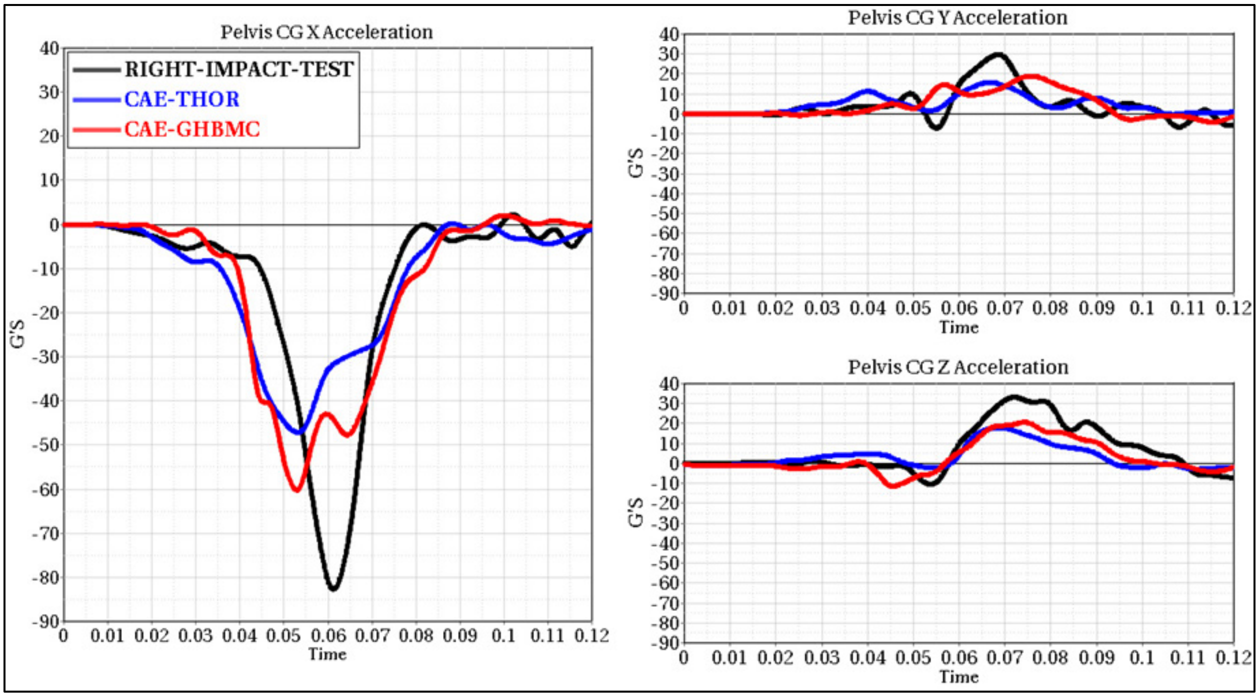


Figure 90: Driver Pelvic CG Acceleration

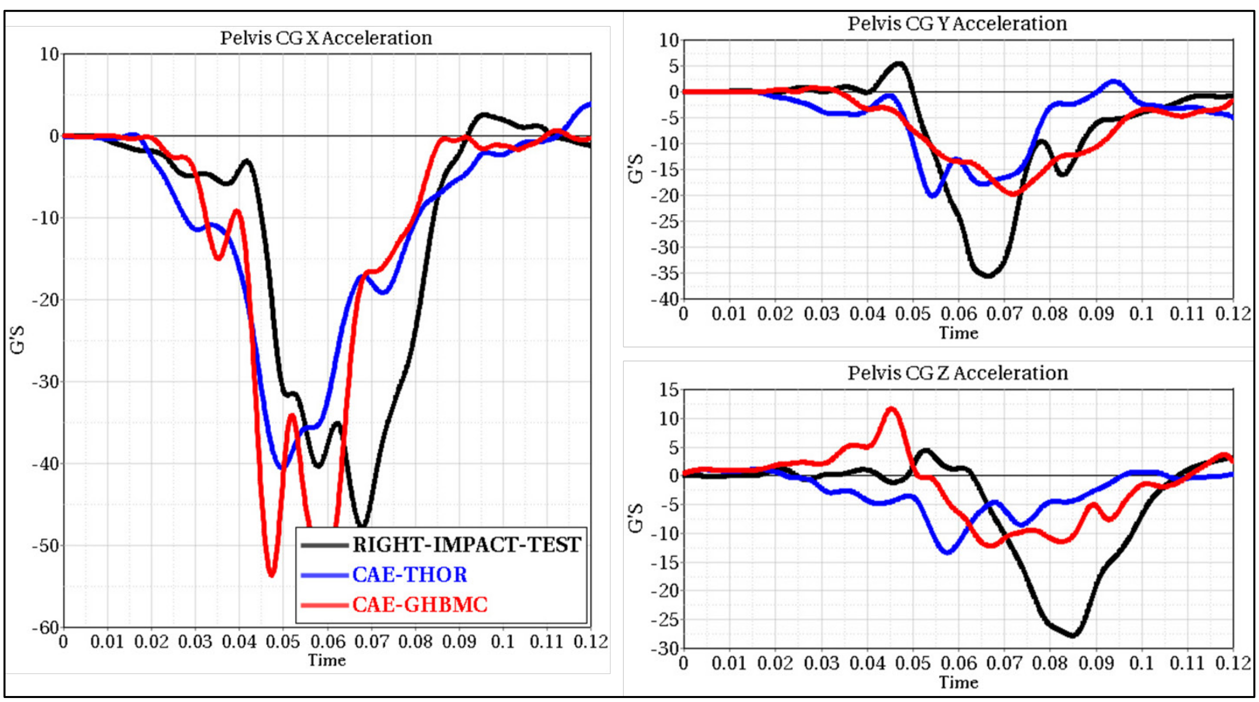


Figure 91: Passenger Pelvic CG Acceleration

Figure 90 and Figure 91 shows pelvic CG acceleration of both driver and passenger. The GHBMC model curves show similar performance compared to the CAE-THOR for both driver and passenger.

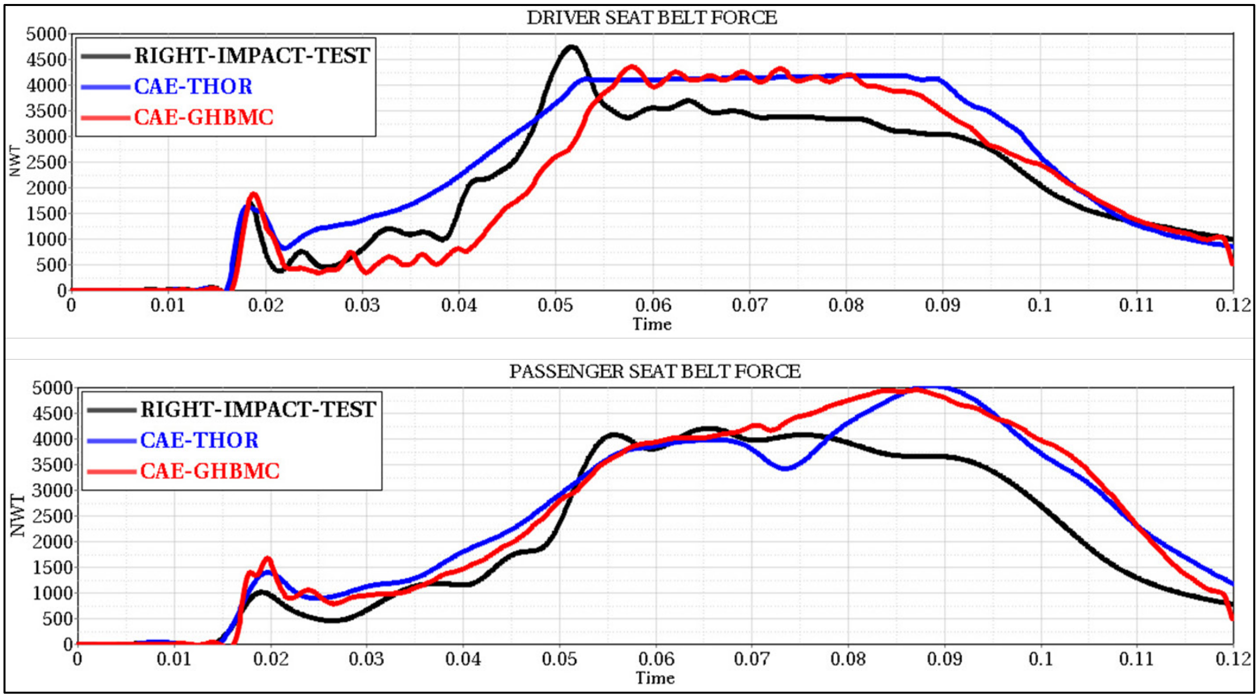


Figure 92: Driver and Passenger Seat belt Force

Figure 92 shows the seat belt force for both driver and passenger. Overall, the GHBMC model curve is very close to CAE-THOR and test in both driver and passenger.

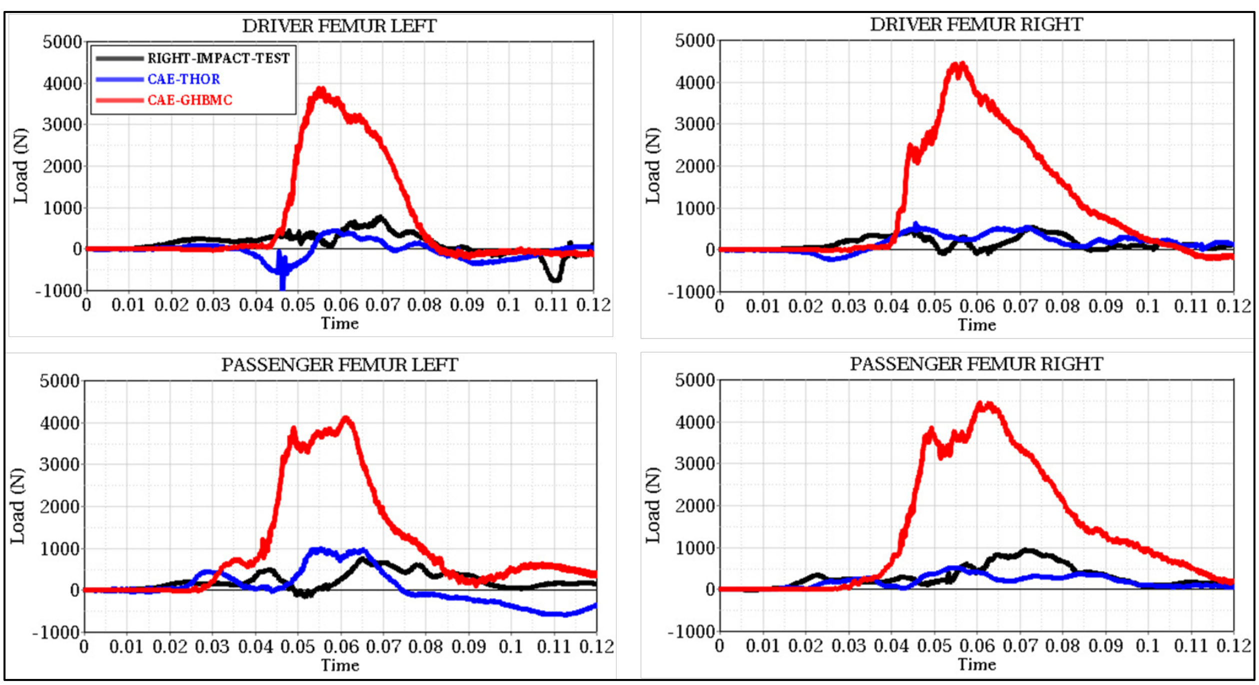


Figure 93: Driver and Passenger Femur Force

Figure 93 shows the femur forces for both driver and passenger. Similar to the left oblique impact load case, the femur load of the GHBMC human body model predicted higher forces going through the femur bone compared to the CAE-THOR model and the test THOR.

5.2.1 Difficulties running GHBMC

The occupant simulation for oblique frontal impact was further carried out by replacing the THOR dummies with human models provided by GHBMC. Similar problems and challenges were faced in running the simulation with human models:

1. Each human model consisted of 2.5 million nodes/elements with numbering range 1,000,000 to 10,000,000. It was extremely difficult to accommodate two human models, one for driver and another for passenger (duplicated driver human model and positioned to passenger side) with LS-DYNA id offset technique.
2. A typical full vehicle FEM nodes/elements id range is from 1,000,000 to 99,000,000, duplicating human model for driver and passenger caused id clash issues due to the wide range of ids in human model.
3. The default unit system was different than EDAG modeling standard unit system. It was quite challenging to perform a unit conversion successfully due to the encrypted parts of the GHBMC human model.
4. Difficulties with renumbering as the encrypted hourglass entities were not accessible to be renumbered.
5. Unlike the THOR dummy model, the human model does not have any dummy tree for occupant positioning. At present there are no direct tools, scripts, or any means available to reposition torso rotation for seat back angle, upper arms, and legs positioning. Executing LS-DYNA simulation for moving limbs or body parts was a very time-consuming task.
6. Several negative volume issues on human model solid parts during simulation after 30 milliseconds of the simulation were encountered.
7. EDAG had to tune the hourglass parameters for the selected parts to make the models run successfully to 120 ms.

6 Appendix

KSS test results are in an appendix:

Appendix - DTNH2216D00006-0002 KSS Accord Restraints System Benchmarking

The following are covered/reported in the above pdf file.

- Review - Overall Plan
- Seat belt Component Testing
- Teardown Analysis – Drive Air Bag/Passenger Air Bag/Side Air Bag/Curtain Air Bag
- Scanning – Drive Air Bag/Passenger Air Bag/Side Air Bag/Curtain Air Bag Cushion
- Drop Tower Test - Drive Air Bag/Passenger Air Bag/Side Air Bag/Curtain Air Bag
- Data Delivered – Scanning and Test Data, Models
- Summary

Feb 8, 2017

Accord Restraints System Benchmarking Test

Agenda

- Review - Overall Plan
- Seatbelt Component Testing
- Teardown Analysis – DAB/PAB/SAB/CAB
- Scanning – DAB/PAB/SAB/CAB cushion
- DropTower Test - DAB/PAB/SAB/CAB
- Data Delivered – Scanning & Test Data, Models
- Summary

EDAG Restraints Benchmarking Test

Seatbelt	04818-T2F-A00ZB / OTR ST, Left *NH598		2		
Actions	Test Description	Test Type	Qty	Sample #	compete
1	Load Limiter (Retrator Pay-Out Test)	Instron	1	#1	23-Nov
2	Webbing Elongation Test	Instron		#1	23-Nov
3	Pre-Tensioner	Sled Stati	1	#2	9-Dec

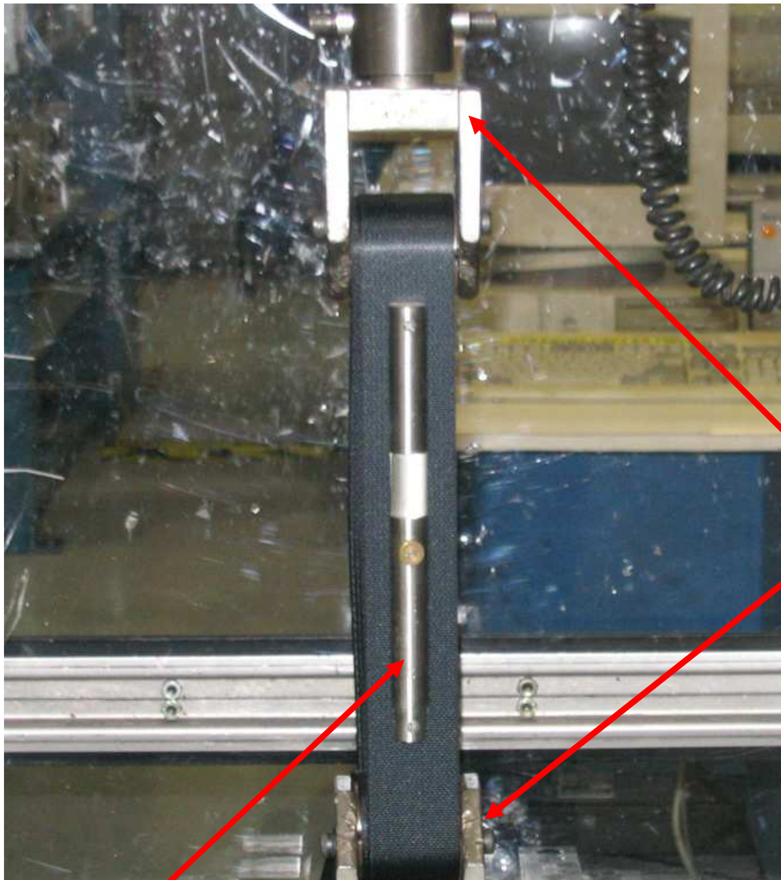
	Ongoing
	Complete

Airbag	Actions	Qty		Timing
DAB	77810-T2A-A81ZA / Module, DriverAir Bag	3		6 weeks
1	Tear Down	1	#1	18-Nov
2	Scan cushion(2d shape)	1	#1	18-Nov
3	Inflator Tank test (pressure, Gas Composition)	1	#1	13-Dec
4	Drop Tower Test w SW	2	#2 & #3	30-Nov
	Folded / Generic Fixture with SW			
PAB	77820-T2A-A71 / Module, Passenger Air Bag	3		
1	Tear Down	1	#1	18-Nov
2	Scan cushion 3d shape (Ping Pong Ball)	1	#1	Complete
3	Inflator Tank test (pressure, Gas Composition)	1	#1	13-Dec
4	Drop Tower Test	2	#2 & #3	9-Jan
	Folded / Generic Fixture Modification			
CAB	78875-T2A-A80 / Module, Left Side Curtain Air Bag	3		
1	Tear Down	1	#1	2-Dec
2	Scan cushion 2d shape	1	#1	9-Jan
3	Inflator Tank test (pressure, Gas Composition)	1	#1	6-Jan
4	Drop Tower Test	2	#2 & #3	9-Jan
	Folded (unfolded) / Generic Fixture Modification			
SAB	78055-T2A-A81 / Module, Left Side Air Bag	3	Sample #	
1	Tear Down	1	#1	9-Dec
2	Scan cushion 2d shape	1	#1	12-Dec
3	Inflator Tank test (pressure, Gas Composition)	1	#1	6-Jan
4	Drop Tower Test	2	#2 & #3	16-Dec
	Folded (unfolded) / Generic Fixture Modification			

Seatbelt Component Testing

- Webbing Elongation Test
- Retractor Pay-out Test
- Pre-tensioner(PT) Test

Seat Belt Webbing Elongation Test

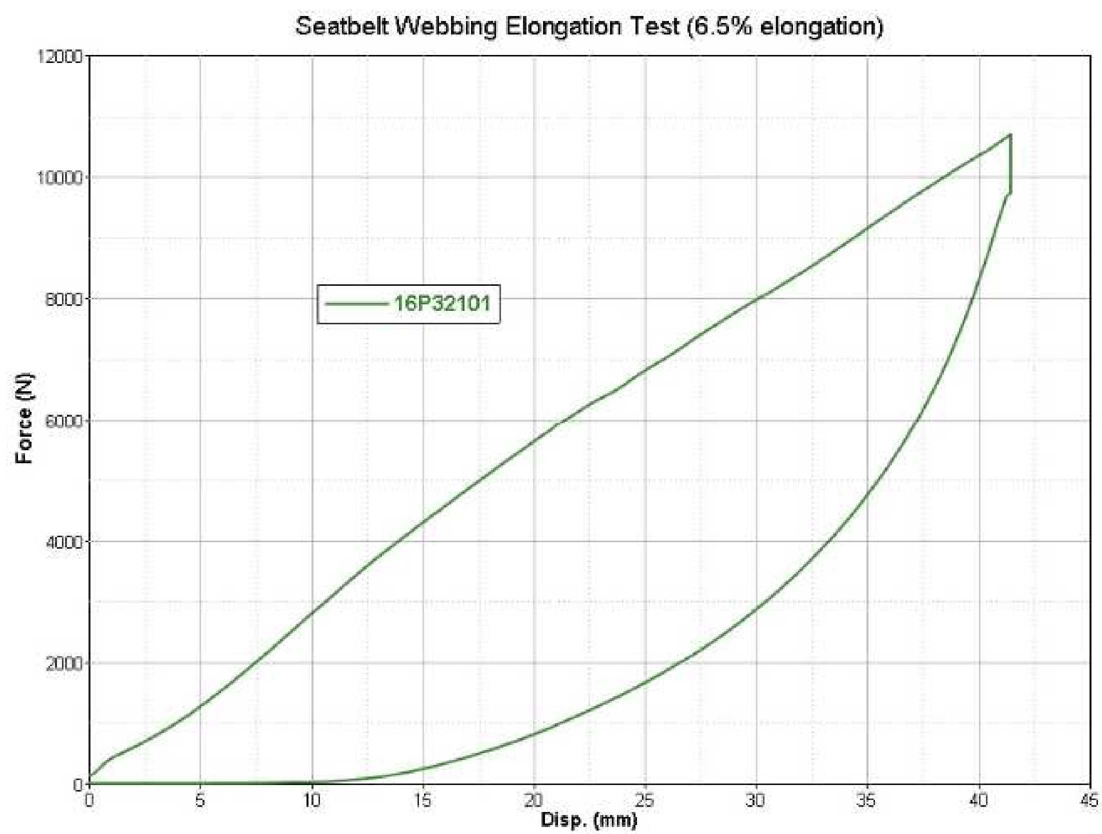


- Seatbelt webbing is anchored at both ends with clamping jaws.
- Clamping jaws are rigidly attached to Instron base plate and crosshead ram.
- A tensile load of 11kN is applied to the test specimen.
- Webbing elongation is read directly from the extensometer.

Clamping jaws

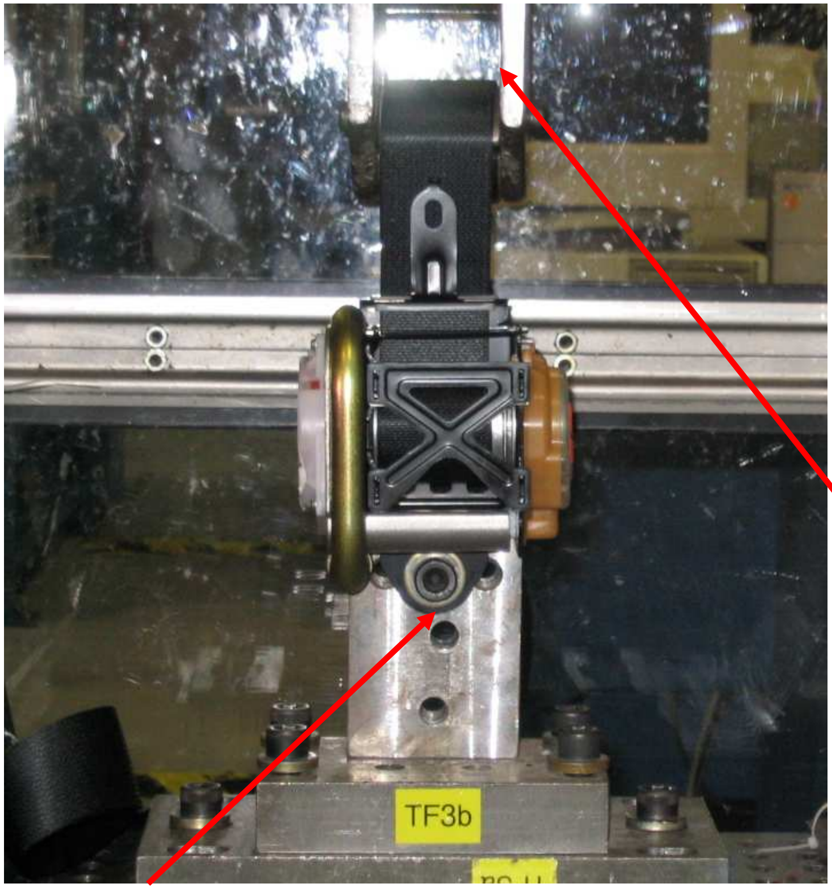
Webbing extensometer

Webbing Elongation Test – MY14 Accord Driver Seat Belt



Webbing extensometer shows 6.5% elongation for Honda Accord driver seatbelt.

Retractor Pay-out (Load Limiter) Test

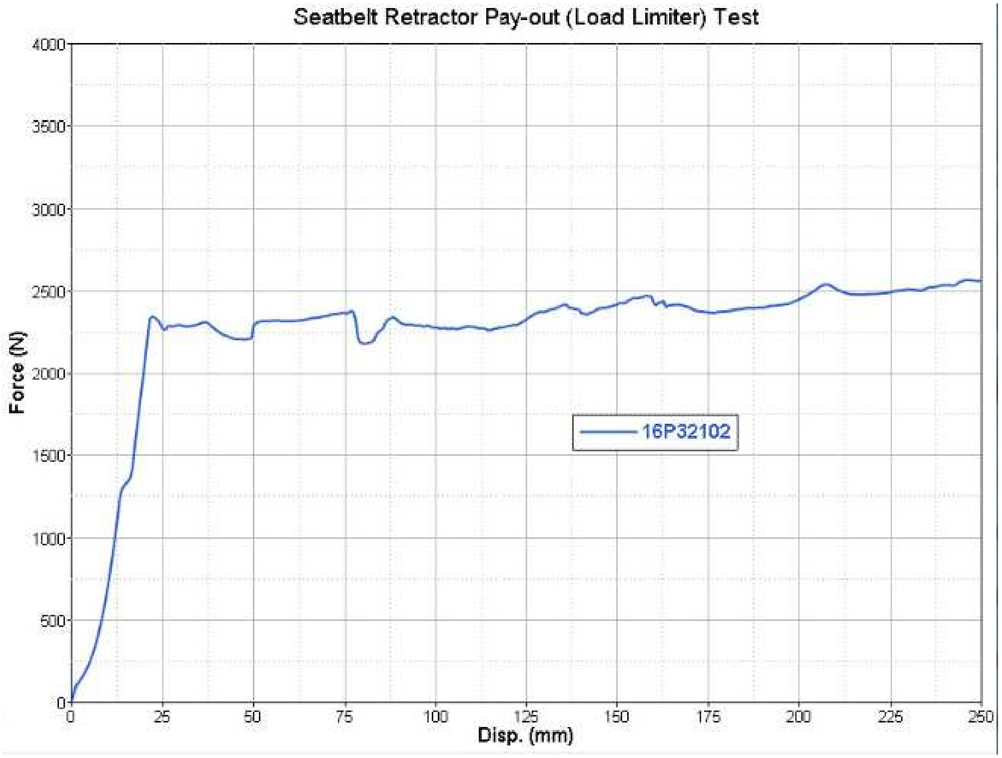


- Seatbelt retractor is bolted at the base and the webbing is clamped in jaws attached to the crosshead ram.
- The crosshead ram is moved upward at 4in.min.
- Load and crosshead ram displacement are recorded.
- webbing spool length should be same as real spool of sled test for 50^{th} ATD (750mm).

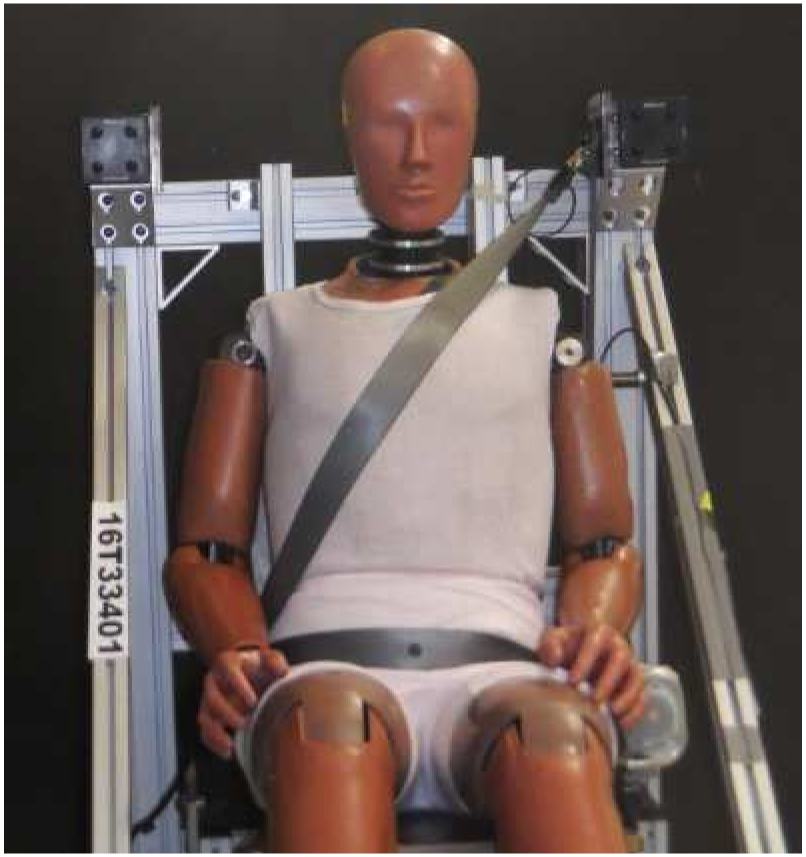
Clamping jaws

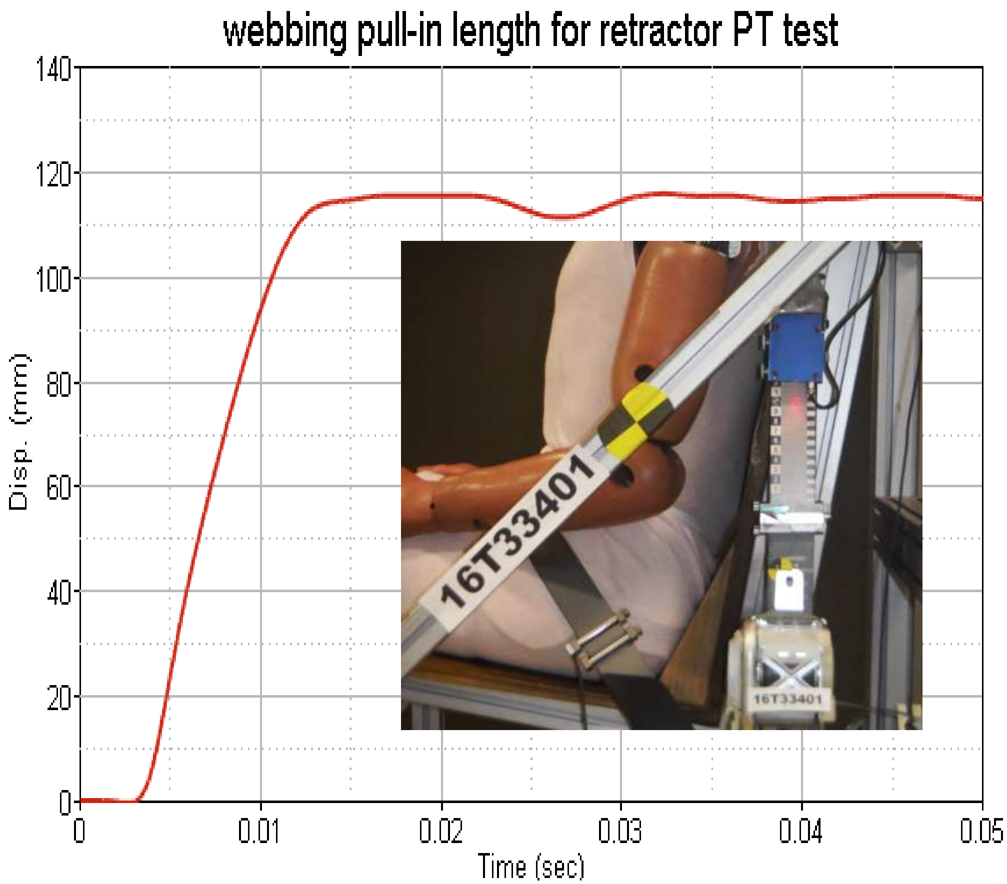
Retractor is bolted to rigid fixture.

Retractor Load Limiter Test – MY14 Accord Driver Seat Belt

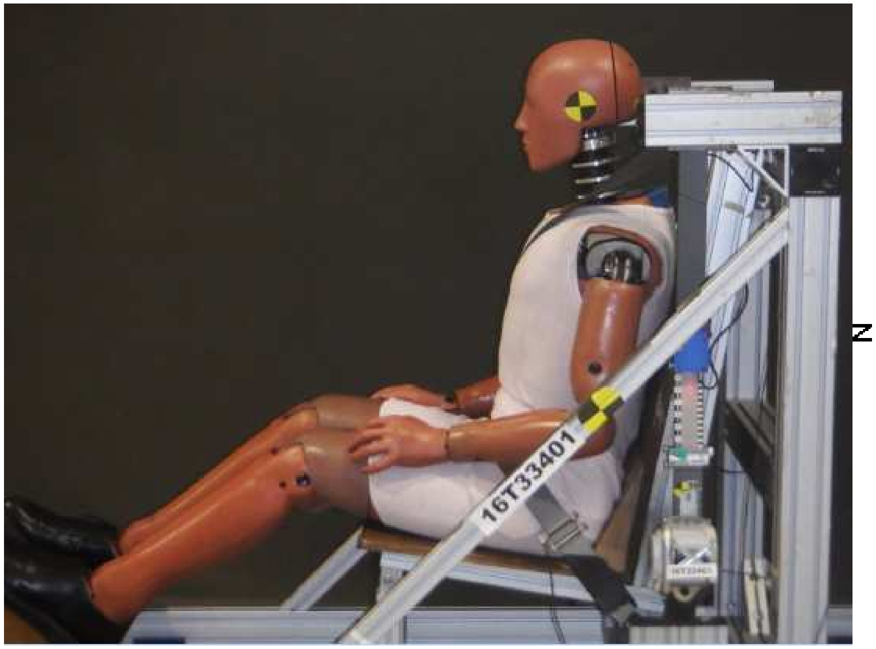


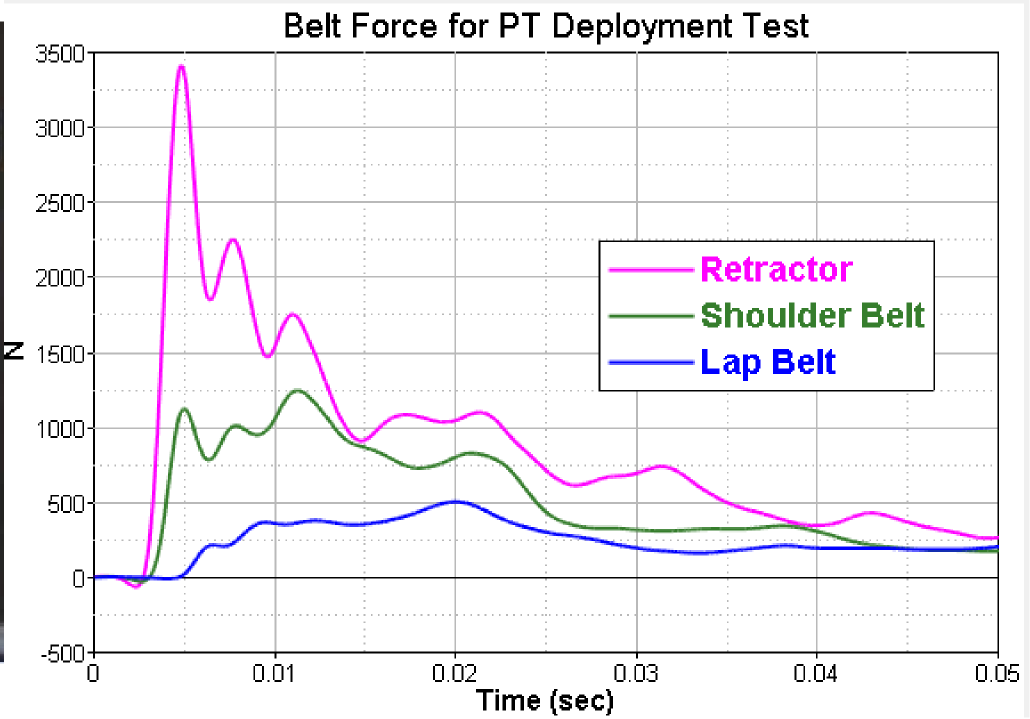
Retractor PT Test – MY14 Accord Driver Seat Belt





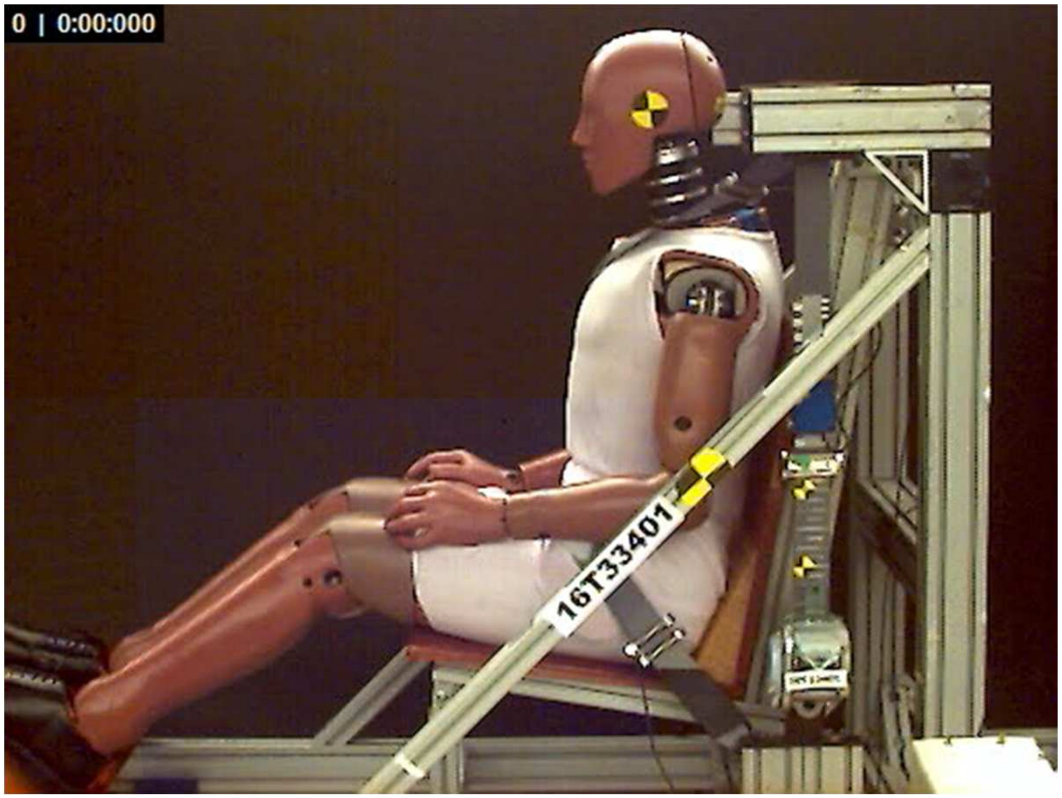
Retractor PT Test – MY14 Accord Driver Seat Belt

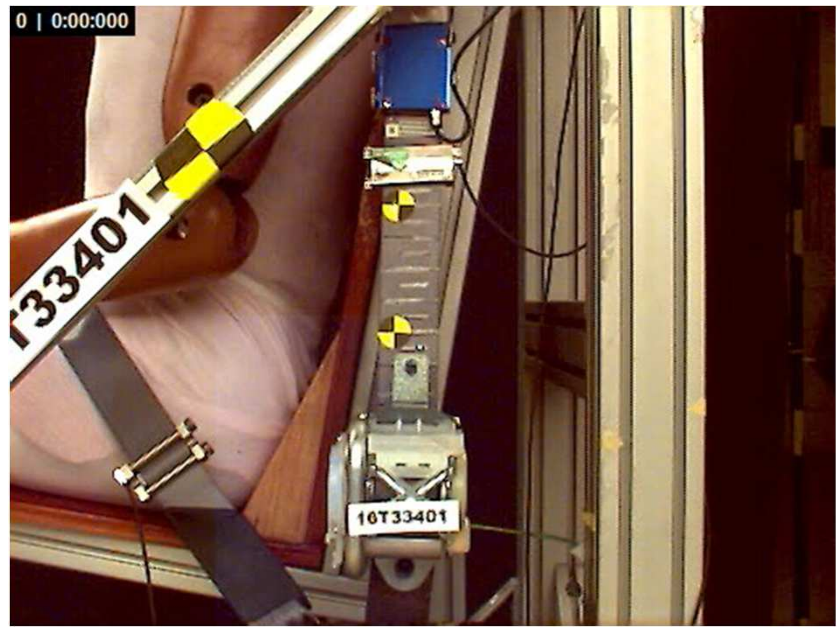




Retractor Pre-tensioner(PT) Test

- Accord Seatbelt Pre-tensioner Test – Animation





Teardown Analysis

DAB / PAB / SAB / CAB

1.0 Driver Airbag Module

Manufacturer:	Takata
Part Number:	77810-T2A-A81ZA
Overall Dimensions:	170mm WIDTH x 166mm LENGTH x 97mm HEIGHT
Mass:	1320 grams
Mounting:	Two side mounted bolts
Assembly process:	1. Place cushion retainer into cushion then fold to create cushion assembly 2. Place cushion assembly onto mounting plate via cushion retainer's studs 3. Secure resulting assembly into DAB cover with rivets 4. Mount inflator on cushion assembly then place horn plate assembly over inflator then secure with pins
Miscellaneous:	Floating module

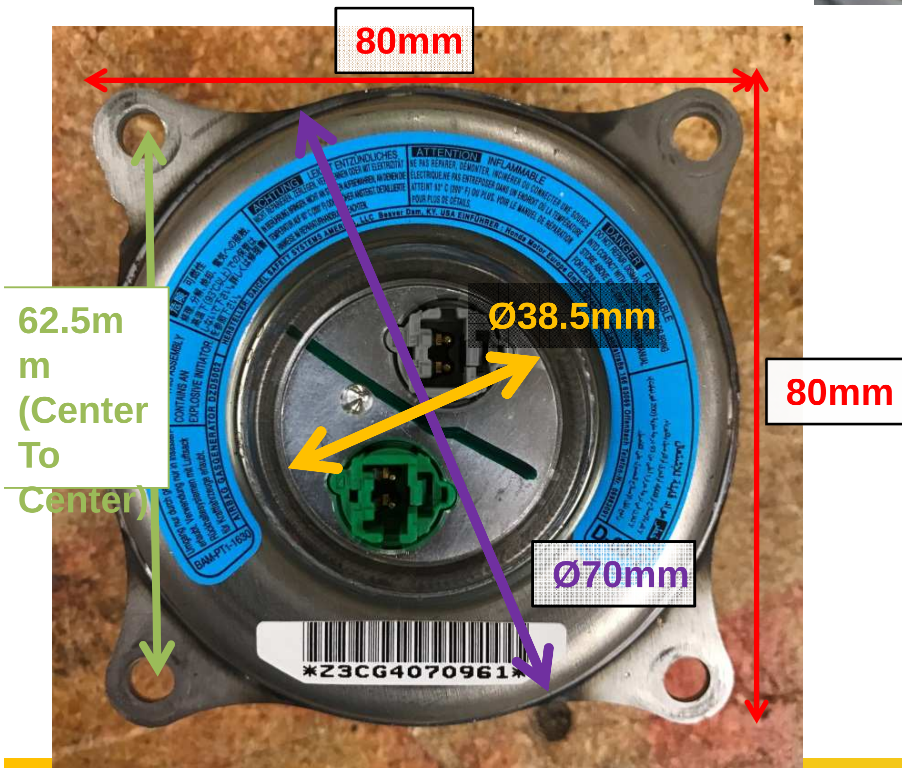


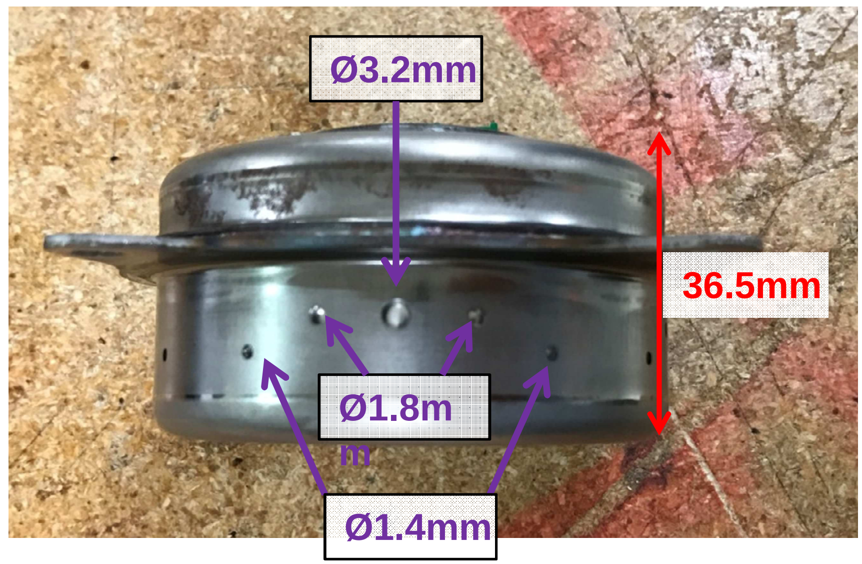
1.1 DAB Module – BOM (Bill of Materials)

Part Description	Quantity	Material	Weight
DAB Cover Assembly	-	Mixed	171.4 grams
DAB Cover	1	TPO	-
Honda Emblem	1	-	-
Horn Plate Assembly	-	-	234.3 grams
Horn Plate	1	Steel	168.1 grams
Pin Assembly	-	-	-
Pin	3	Steel	47.3 grams (all 3)
Pin Gasket	3	Rubber	1.0 gram (all 3)
Spring rest	3	Plastic	12.8 grams (all 3)
Spring	3	-	4.9 grams (all 3)
Mounting Plate Assembly	-	-	177.4 grams
Mounting Plate	1	Steel	165.7 grams
Horn Plate Studs	3	Steel	-
Attaching plate	1	Steel	11.7 grams
Inflator	1	Mixed	454.3 grams
Cushion Pack Assembly	-	Mixed	273.8 grams
Cushion Retainer	1	Steel	61.1 grams
Cushion Wrap	1	PA – Uncoated	6.1 grams
Lower Panel Assembly	-	PA 66 – Coated	112.4 grams
Lower Panel	1	-	-
Vent / Inflator Opening Reinforcement	1	-	-
Tether Hub	2	-	-
Inflator Opening Reinforcement	1	-	-
Upper Panel Assembly	-	PA 66 – Coated	94.2 grams
Upper Panel	1	-	-
3 Way Tether	1	-	-
Crown Reinforcement	1	-	-
Rivets and Nuts	6	Steel	9.0 grams (all 6)
Total Parts: 21 Total Components: 37			

1.2 Inflator

Part Number:	BAM-PT1-1630
Manufacturer:	Daicel Safety Systems
Description:	Dual Stage
Mass:	454.3 g (pre-deployment)
Dimensions:	80mm LENGTH x 80mm WIDTH x 36.5mm HEIGHT
Barcode Label:	Z3CG4070961



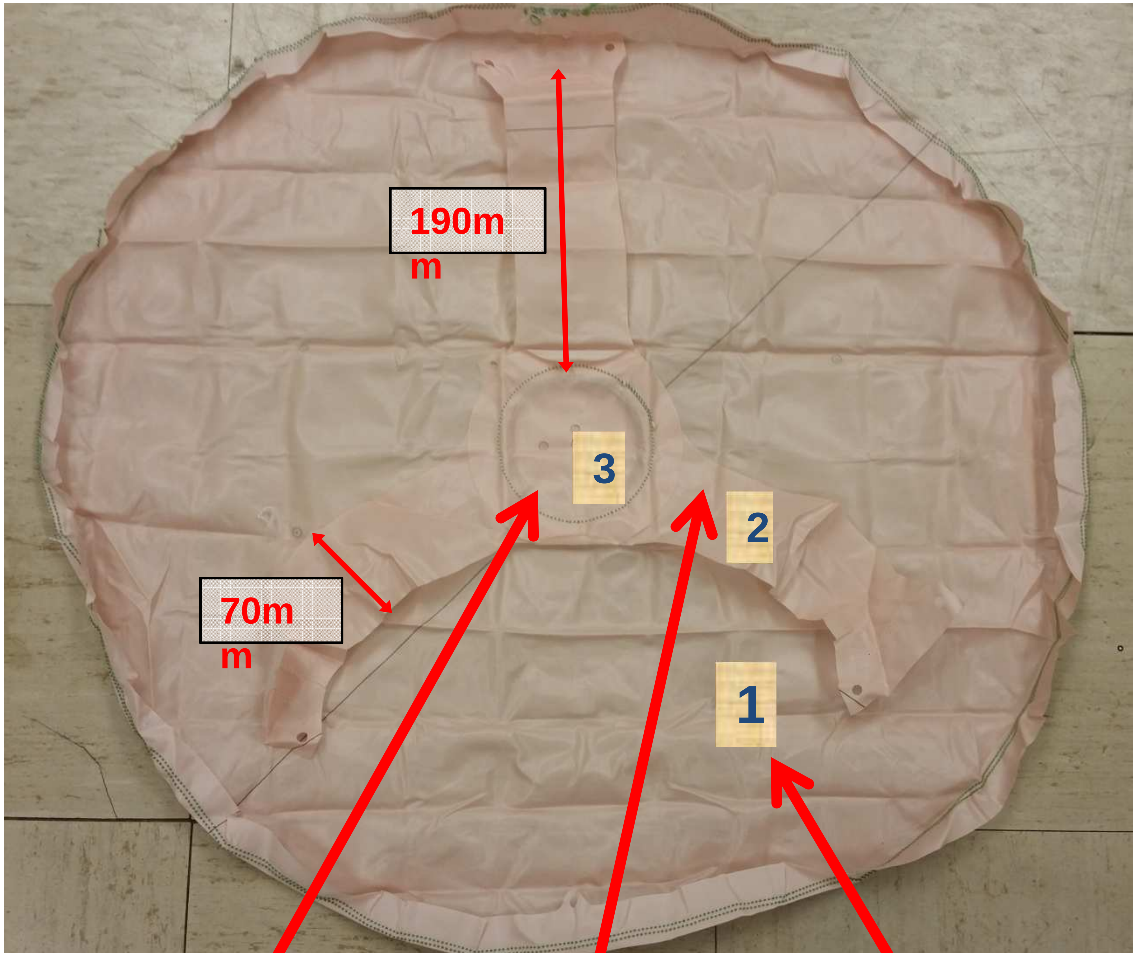


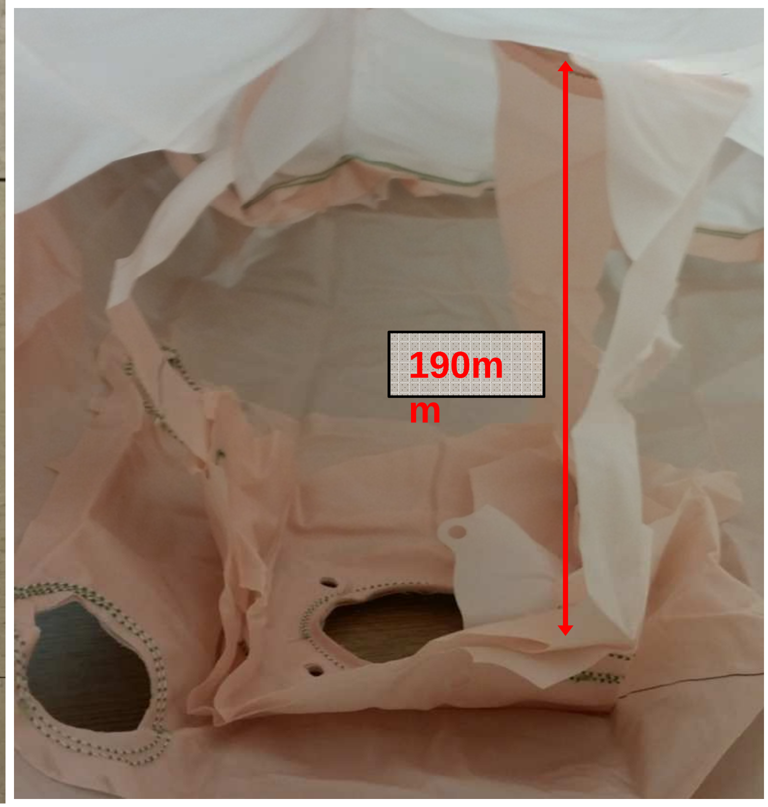
x4

Notes:
- 1.67 mm thick flange
- 4 sets of nozzle array

1.3 Cushion Details (TOP)

- **Effective tether length is 250mm**



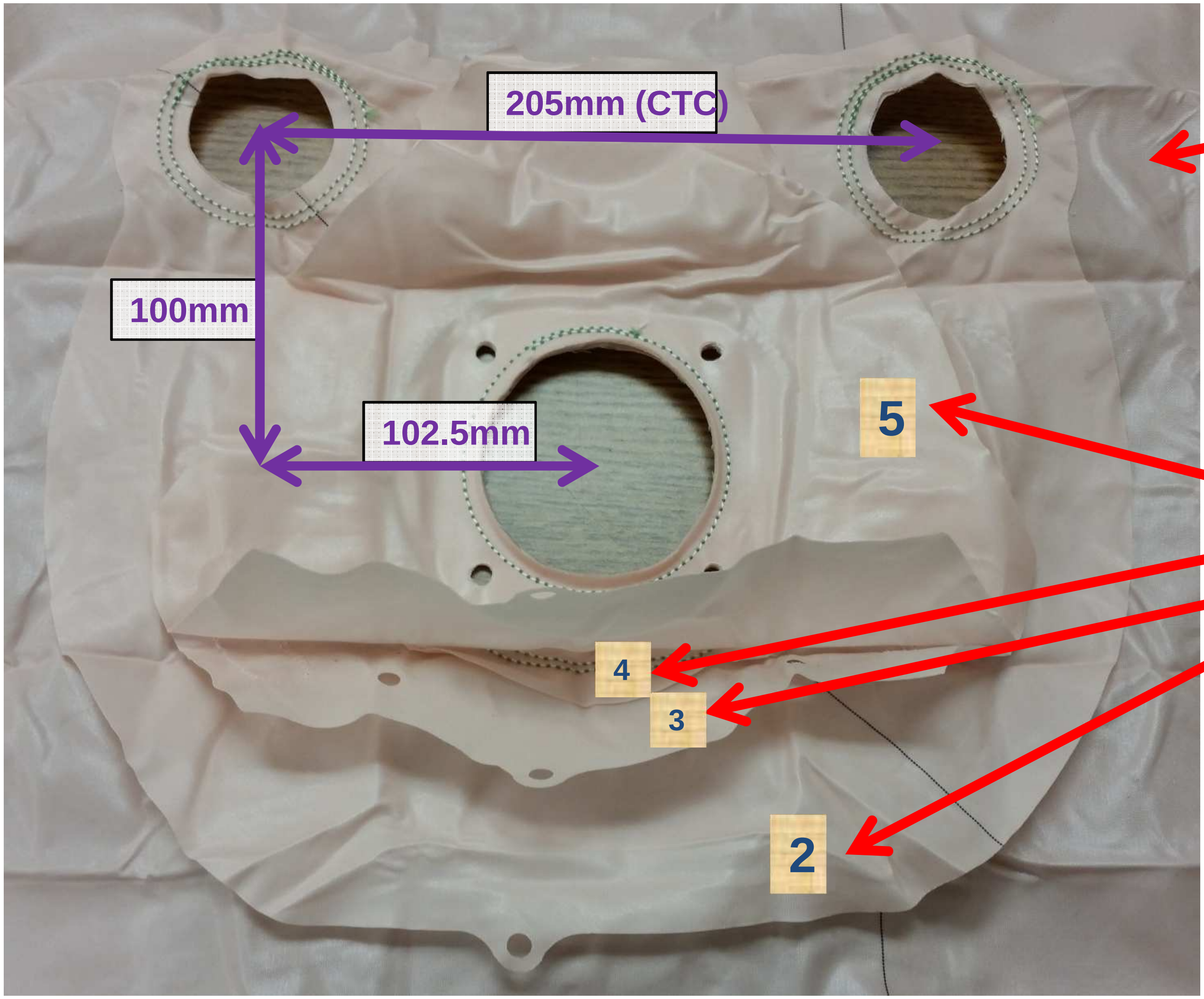


3. Reinforcement

2. Tether

1. Top Panel

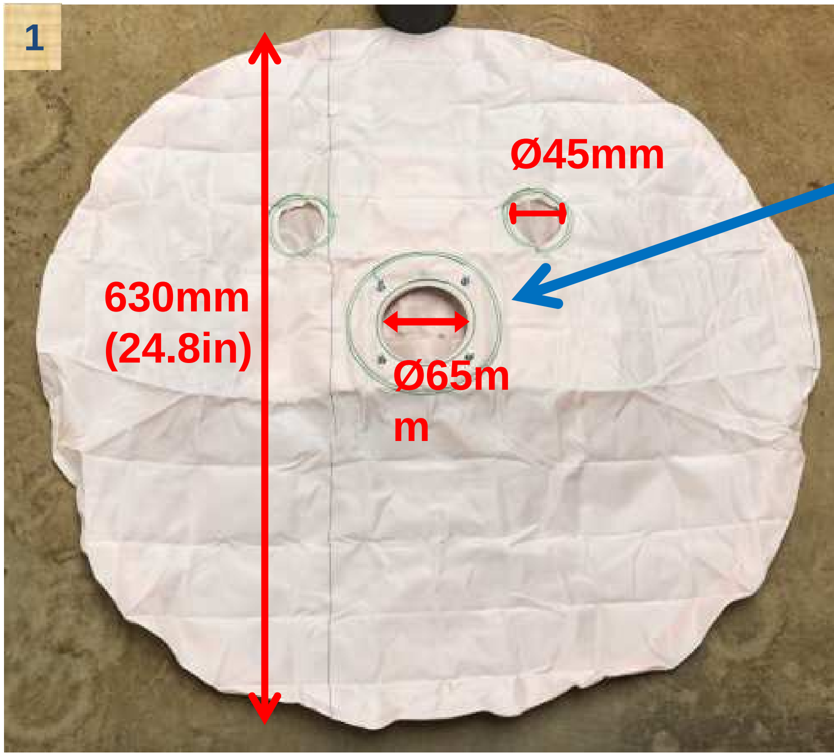
1.4 Cushion Details (BOTTOM)



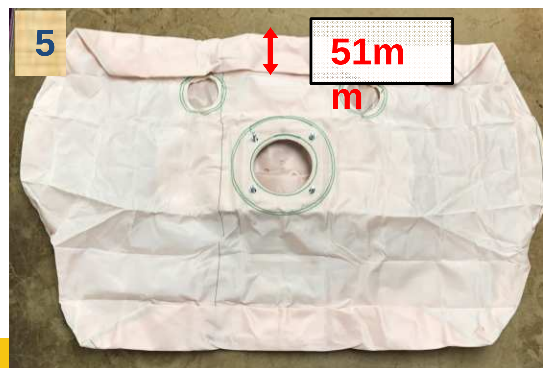
1. Bottom Panel

2, 3, 4, 5. Reinforcements

1.5 Cushion Fold Photographs

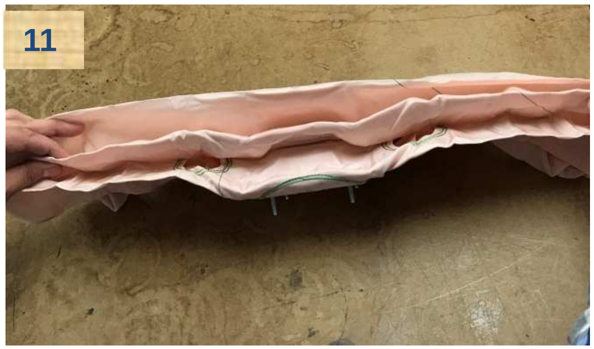


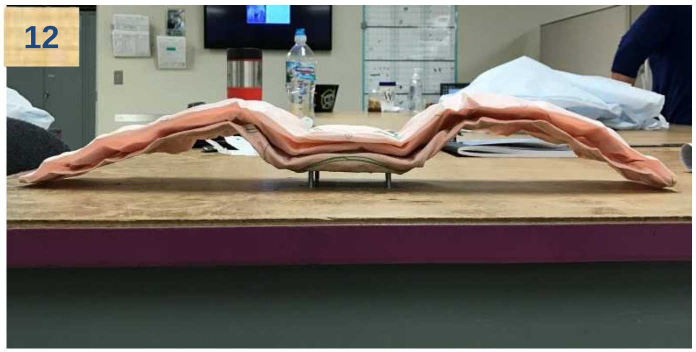
1. Insert retainer into inflator opening and secure with studs

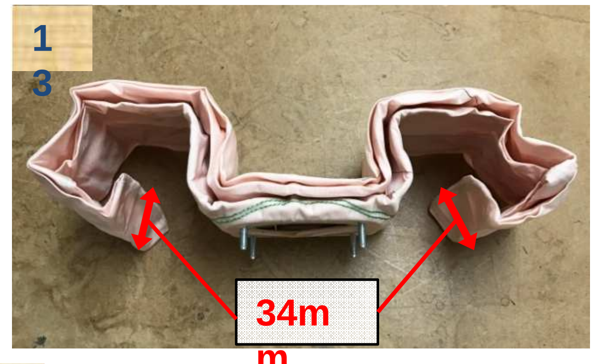


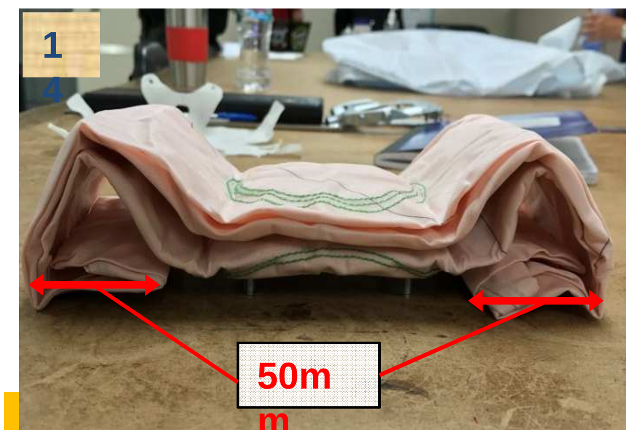
7. Flip horizontal from backside to front side

1.6 Cushion Fold Photographs (Cont'd)









2.0 Passenger Airbag Module

Part Number:	77820-T2A-A71
Manufacturer:	Takata
Mass:	2702.8 grams
Volume:	86 Liters
Cushion Fabric:	Coated PA 66
Venting:	2 x 65mm Discrete Vents
Housing:	Steel
Fold:	Engineered
Inflator:	Tubular Style Dual Stage Output: TBD

2.1 PAB Module - Bill of Materials

Part Description	Quantity	Material	Weight (g)
PAB Module	-	mixed	**2702.8**
Housing Assembly	-	-	1055.8
PAB Housing	1	steel	-
Felt Tape	4	felt	-
Inflator Securing Bracket	1	steel	13.4
Lead Wire	1	-	-
Lead Wire Shielding	1	plastic	2.7
Zip-Tie mounting clips	2	plastic	0.1
Inflator	1	steel	778.9
nuts	4	steel	2
Cushion Pack Assembly	-	mixed	-
Reatiner	1	steel	166.9
Cushion Assembly	1	Coated PA 66	670.5
Total Unique Components: 10			

2.2 Housing

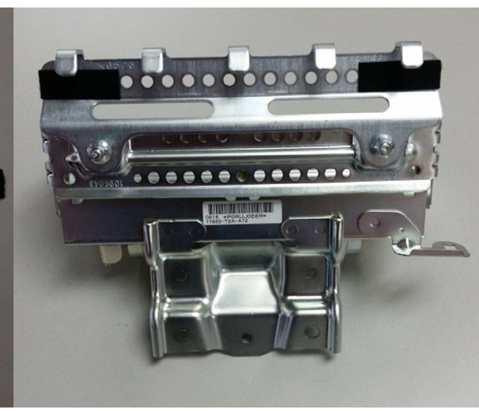
Dimensions:	
Mass:	1055.8 grams
Material:	Zinc coated Steel
Miscellaneous:	Felt tape used 9 pieces of metal staked together

Top

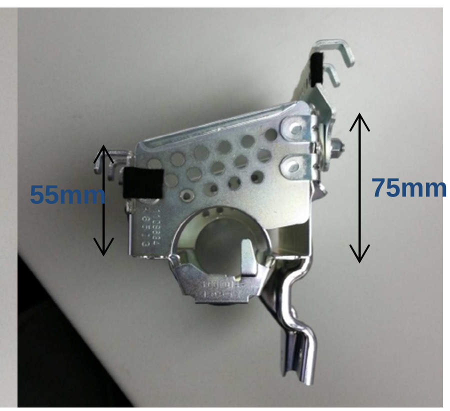
215mm

Front

Rear



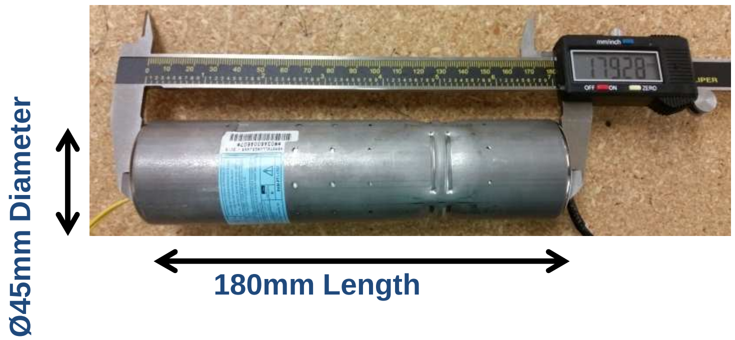
Side

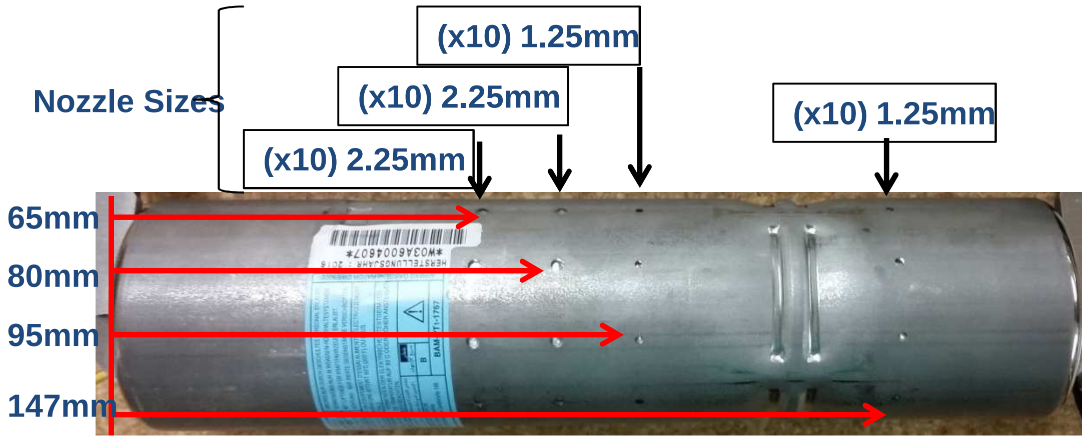


90mm

2.3 Inflator

Manufacturer:	Daicel – DWE 5000
Disc / Canister Style:	Canister
Mass:	778.9 grams
Output:	TBD





2.4 Cushion fold

1) 55mm deep accordion folds in both sides (5 peaks and 4 valleys)

2) Pleats

205mm

3x 60mm

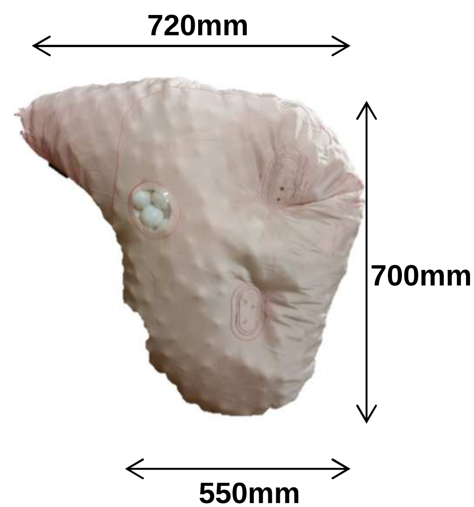
2 x 50mm

70mm

3)Zig-Zag LRD flap, and cushion cover fold attachment

11 x 32mm zig zag folds
1 x 100mm fold

2.5 Inflated Cushion Photographs



3.0 Side Airbag Module

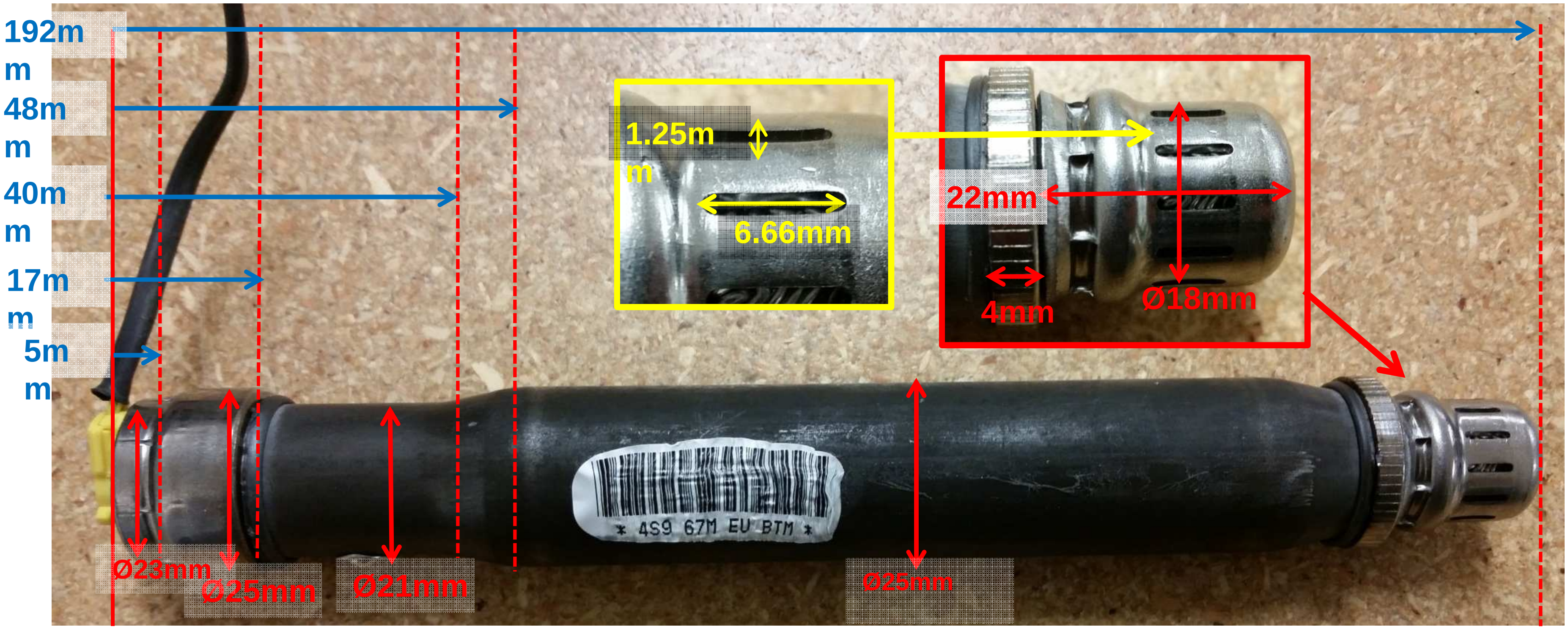
Part Number:	78055-T2A-A81
Manufacturer:	Takata
Module Dimensions:	365mm LENGTH x 95mm WIDTH x 60mm HEIGHT
Cushion Dimensions:	310mm LENGTH x 85mm WIDTH x 50mm HEIGHT
Mass / Cushion Volume:	1073.1 grams / 16 liters

3.1 SAB Module - Bill of Materials

Part Description	Quantity	Material	Weight (grams)
2014 Honda Accord SAB Module	-	Mixed	1073.1
Cover	1	TPO	215.4
Mounting plate	1	Zinc coated steel	125.2
Tape	1	unknown	0.1
Nut	1	Steel	3.5
Inflator assembly	-	Mixed	508.5
Inflator	1	Mixed	-
Lead wire assembly	-	Mixed	-
Wire shield	1	unknown	-
Push pin	6	unknown	-
Lead wire	1	unknown	-
Inflator bracket	1	Steel	163.1
Cushion assembly	-	PA66	219.8
Cushion wrap	1	PA66	-
Main panel	1	PA66	-
Vent reinforcement	1	PA66	-
Secondary chamber	1	PA66	-
Chamber vent reinforcement	2	PA66	-
Heat shield/Diffuser	2	PA66	-
External reinforcement	1	PA66	-
Total unique parts: 16 Total components: 23			

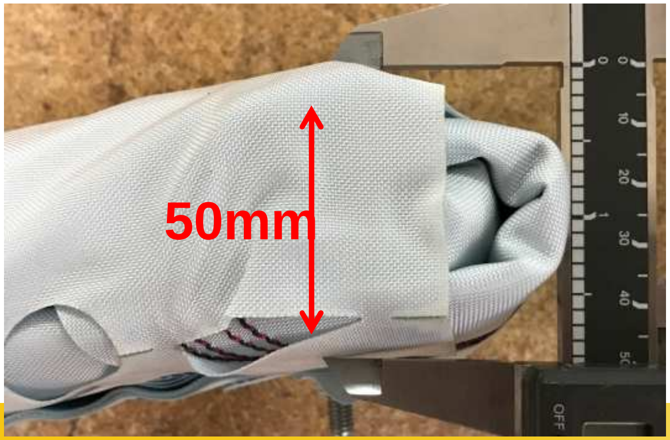
3.2 Inflator

Manufacturer:	Autoliv
Barcode:	Inflator: 4S9 67M EU BTM Wire: R0TP102718B
Mass:	345g
Material:	Mixed
Dimensions:	Length: 1385mm = 192mm(inflator) + 1193mm (wiring) Inflator diameter: Ø21mm-25mm Nozzle(x12) tube diameter: Ø18mm Nozzle(x12): 6.66mm HEIGHT x 1.25mm WIDTH



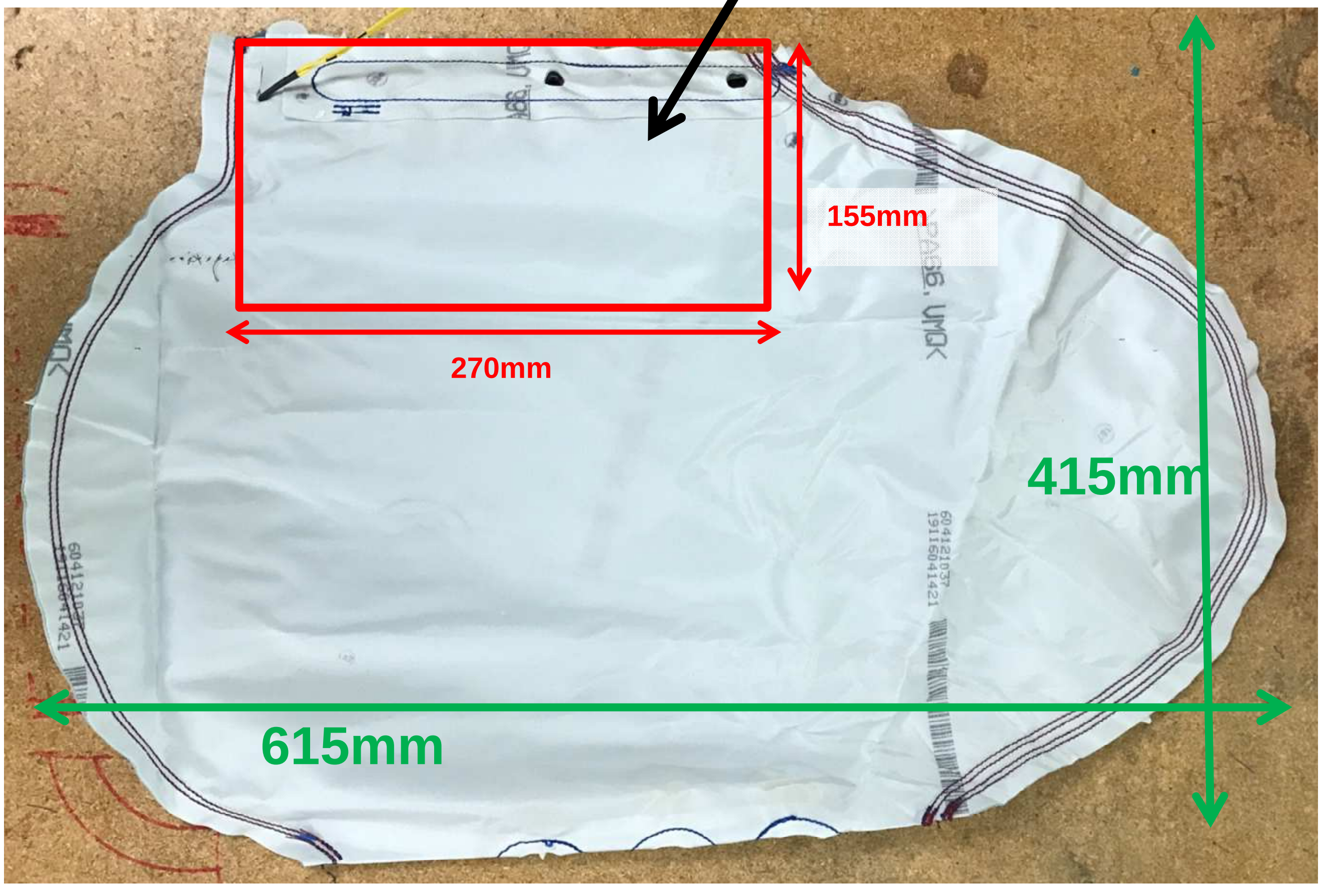
3.3 Cushion Assembly

Dimensions:	Cushion Pack: 310mm LENGTH x 85mm WIDTH x 50mm HEIGHT
Mass:	219.8 grams
Material:	PA66
Fold:	Engineered
Cushion Volume:	16L



3.4 Unfolded Cushion

Heat Shield Location
(around inflator)



3.5 Cushion Fold Photographs

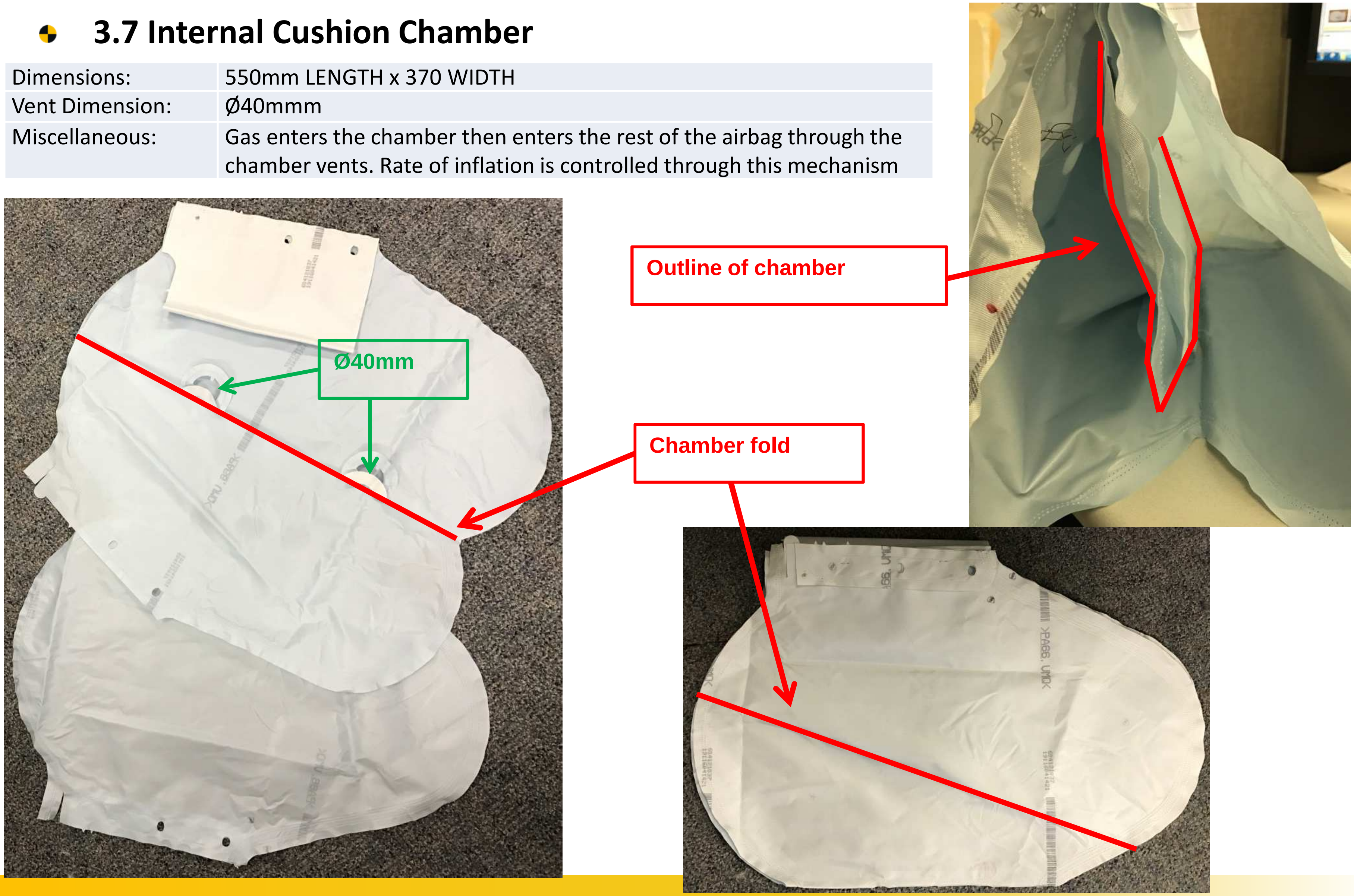
3 Flip horizontal

6 Flip horizontal

- **3.6 Cushion Fold Photographs (Cont'd)**

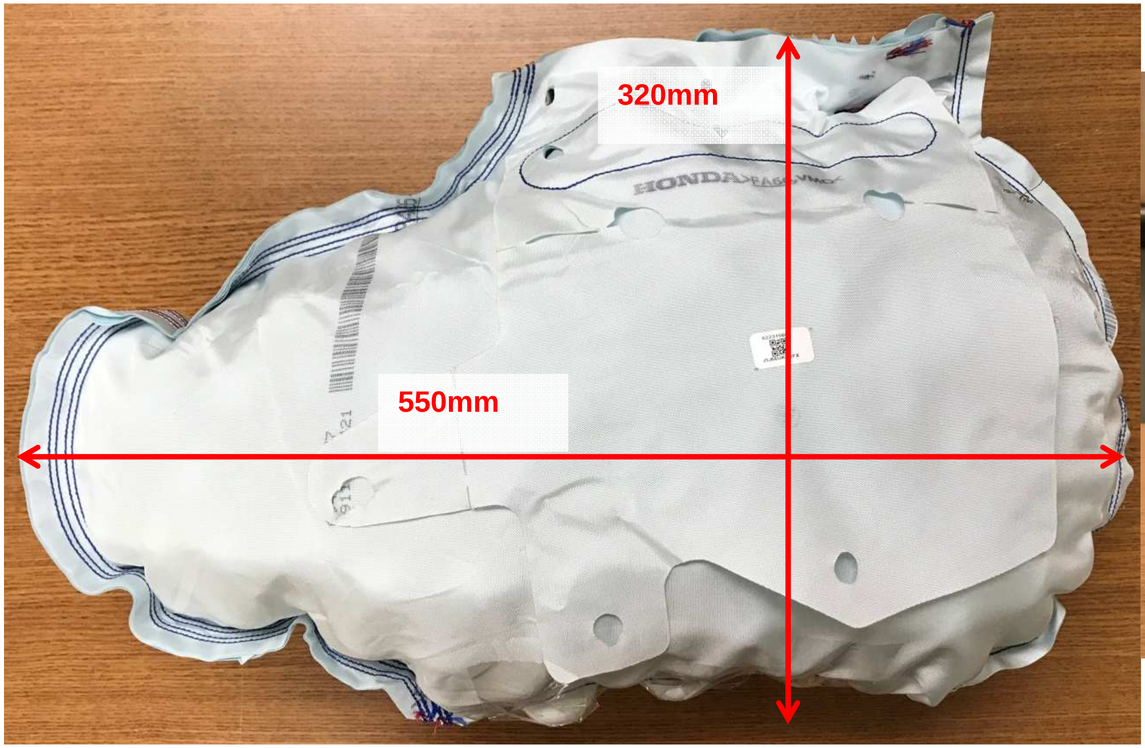
3.7 Internal Cushion Chamber

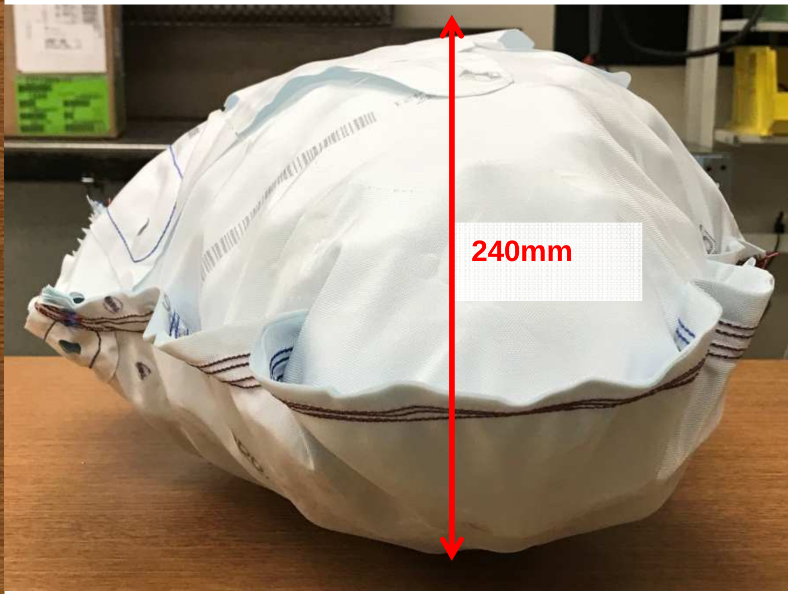
Dimensions:	550mm LENGTH x 370 WIDTH
Vent Dimension:	Ø40mmm
Miscellaneous:	Gas enters the chamber then enters the rest of the airbag through the chamber vents. Rate of inflation is controlled through this mechanism



3.8 Cushion Fill Information

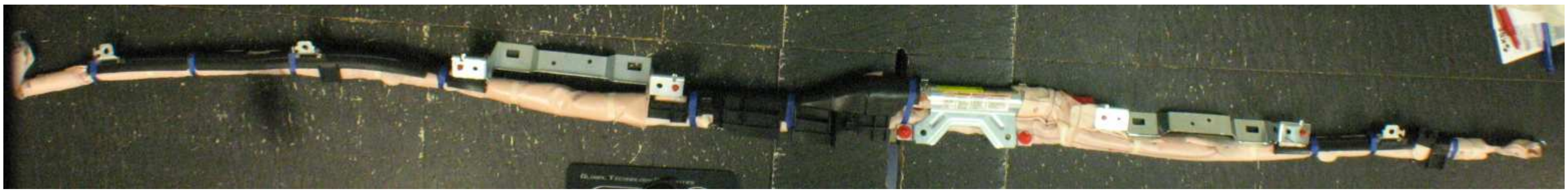
Dimensions:	550mm LENGTH x 320mm WIDTH x 240mm HEIGHT
Cushion Volume:	16L



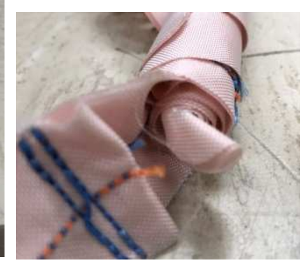


4.0. Curtain Airbag Module

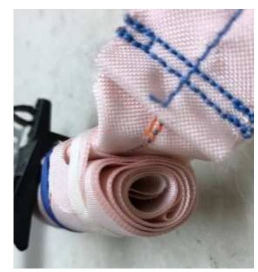
Part Number:	78875-T2A-A80
Manufacturer:	Takata
Inflator Manufacturer:	Daicel
Module Dimensions:	2255mm LENGTH x 95mm WIDTH x 80mm HEIGHT
Cushion Dimensions:	2030mm LENGTH x 710mm WIDTH
Mass / Cushion Volume:	1987 grams / 42 Liters



Cushion Assembly unfolded



A-pillar fold end



C-pillar fold end

4.1 CAB Module - Bill of Materials

Part Description	Quantity	Material	Weight (grams)
2014 Honda Accord CAB Module	-	-	1987
Inflator	1	Steel	487
Oetiker Clamp (34mm)	2	Steel	9.5
Oetiker Clamp (36mm)	2	Steel	9.5
Iinflator Squib Cover	1	Rubber	8
Blue Tape	10	tape	4.3
White Tape	15	tape	3.9
Inflator Mounting Bracket	1	steel	136.6
A-Pillar Ramp	1	TPO	33.2
B-Pillar Ramp	1	TPO	57.8
C-Pillar Ramp	1	TPO	19
Mounting Bracket (Front Row)	1	Steel	158
Mounting Bracket (Rear Row)	1	Steel	149.7
Christmas-tree Style Fastener	4	Plastic	4.4
Cushion Assembly	-	PA66 Si Coated	887.5
Mounting Tab	7	Steel	
Diffuser Assembly	-	PA66 Si Coated	
Main Panel	1	PA66 Si Coated	
External Support Layer	1	PA66 Si Coated	
Heat Shield	1	PA66 Si Coated	
Inboard Panel	1	PA66 Si Coated	
Outboard Panel	1	PA66 Si Coated	
C Pillar Roof Rail Reinforcement Panel	2	PA66 Si Coated	
Inflator Mounting Reinforcement Panel	1	PA66 Si Coated	
Neck Reinforcement Panel	2	PA66 Si Coated	
External C-PillarTether	1	PA66 Si Coated	
External A-Pillar Tether	1	PA66 Si Coated	
Bracket Guard Panel	1	PA66 Si Coated	
Sewing Dart Reinforcement	6	PA66 Si Coated	
Total unique parts: 26			
Total components: 67			

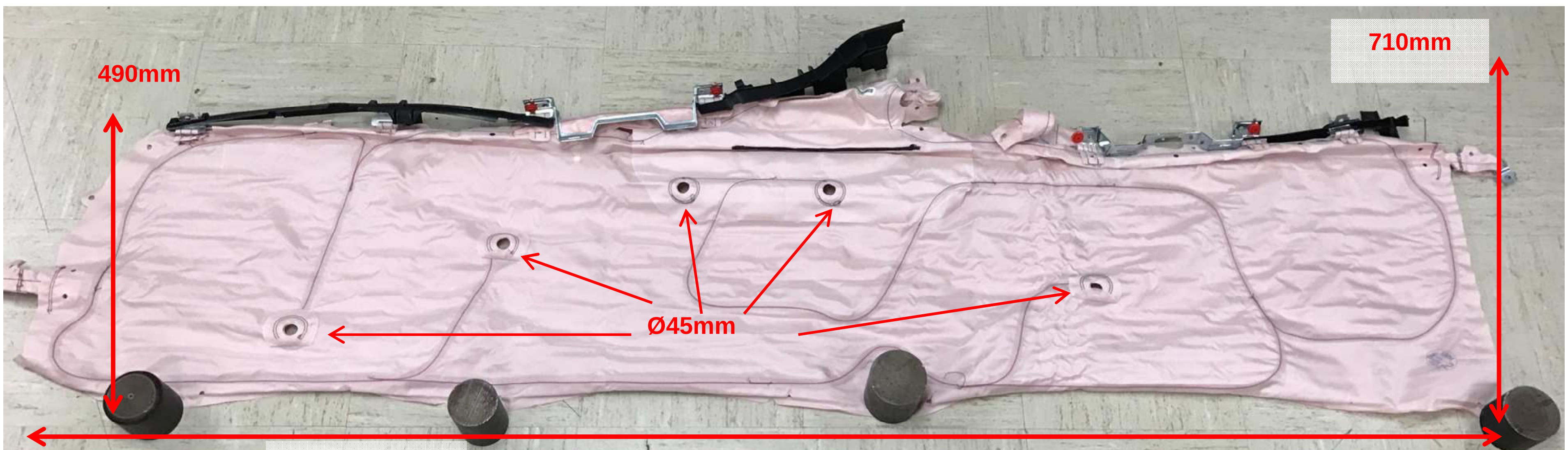
4.2 Inflator

Part Number:	LH2-01-2
Manufacturer:	Daicel
Mass:	487g
Material:	Steel
Dimensions:	285mm LENGTH x Ø30mm DIAMETER Nozzle(x8) diameter: Ø1.5mm
Barcode Label:	LHGH5348621

Ø1.5mm Nozzle(x8)

4.3 Cushion Assembly

Part Number:	2462595 5134957.68 260615MV2E
Dimensions:	2030mm LENGTH x 710mm WIDTH
Mass:	824.6g
Material:	PA66
Fold:	Engineered and rolled
Stitching:	Main: 10 spi (stitches per inch), single needle lock Mounting tab: 11 spi, double needle lock Dart sew: 11 spi, double needle lock Tether: 12 spi, double needle lock Diffuser attachment: 9 spi, single needle lock



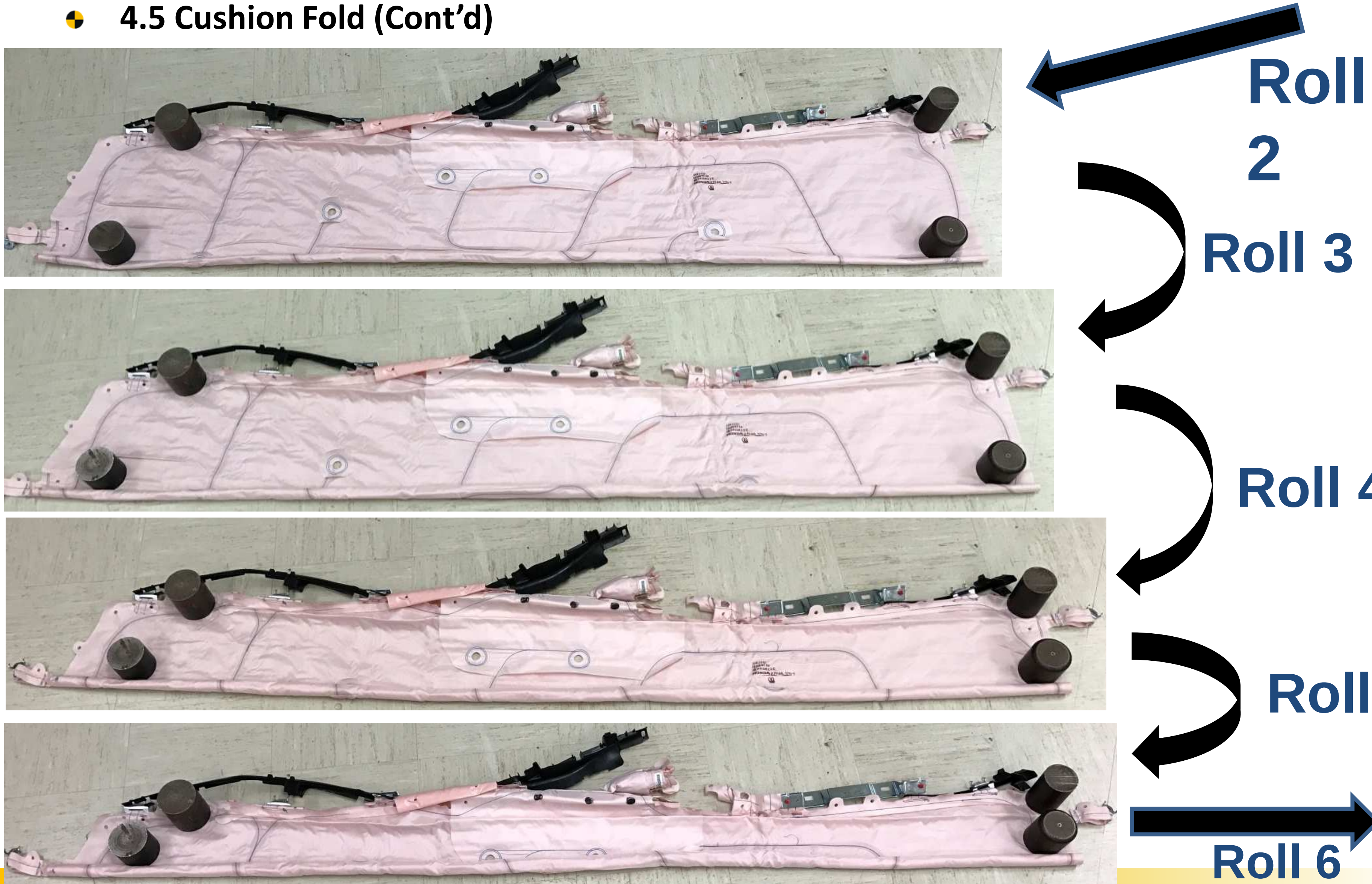
4.4 Cushion Fold

20mm Fold

Roll 1

Roll 2

- **4.5 Cushion Fold (Cont’d)**



- **4.6 Cushion Fold (Cont'd)**

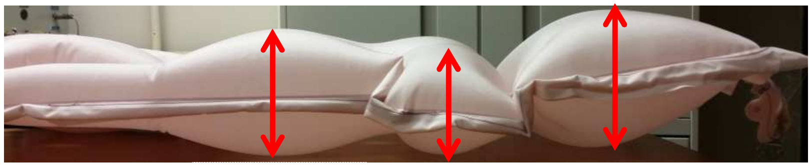
Roll 6

25mm zig-zag Fold

Roll 7

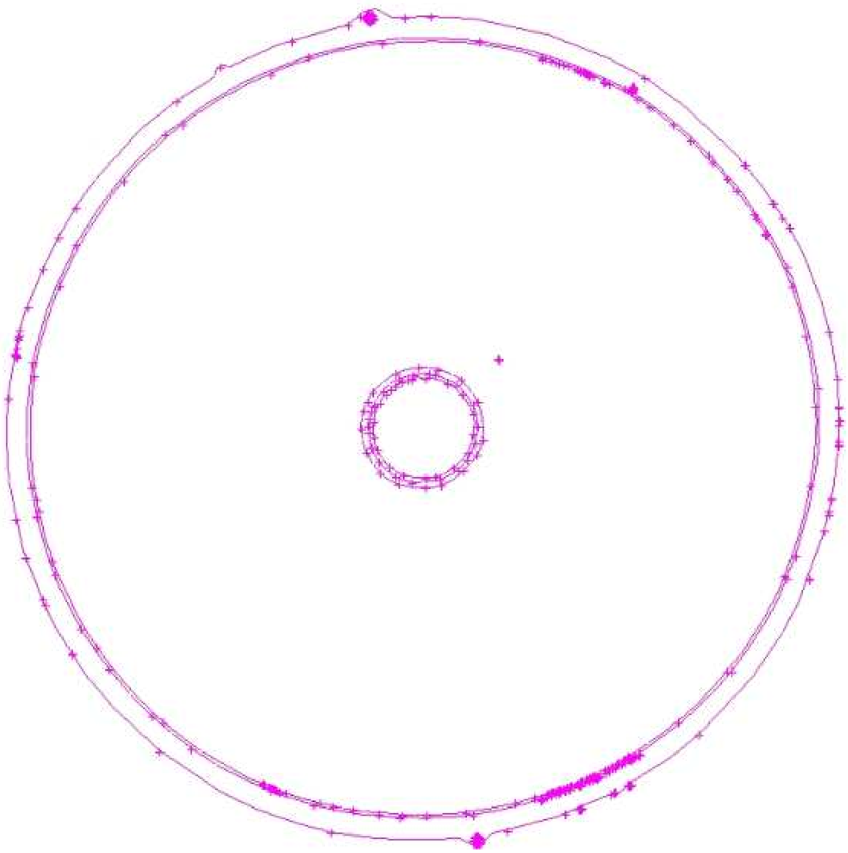
4.7 Inflated Cushion Photographs

Cushion Volume = 42 Liters

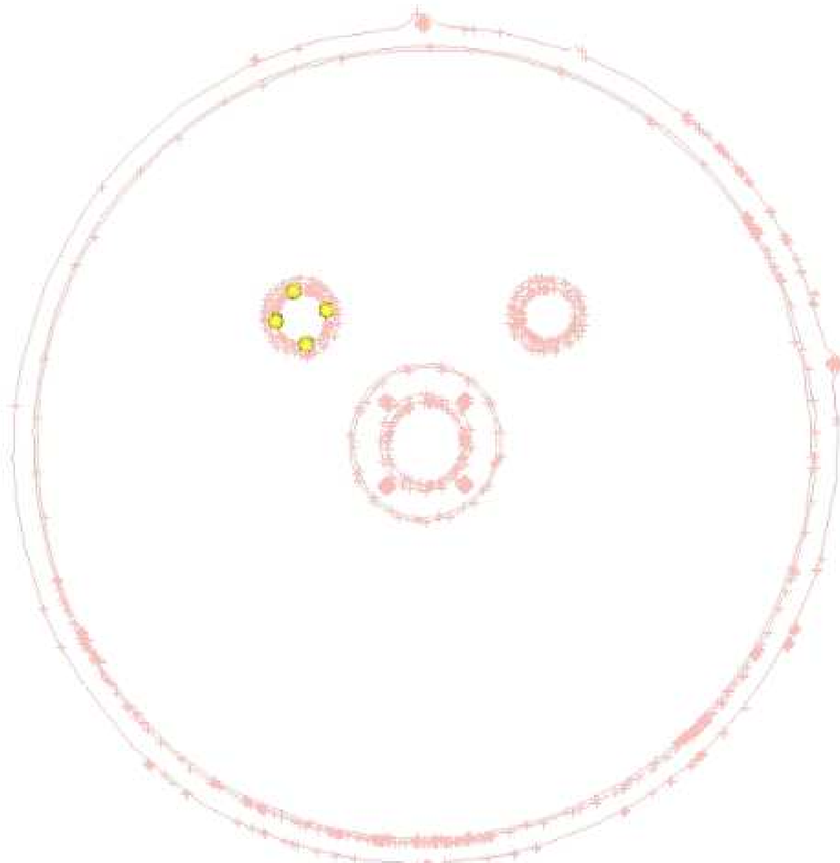


Cushion Scanning – DAB / PAB / SAB / CAB

- **DAB Cushion Scanned Data – Top / Bottom Panel**



Top Panel



Bottom Panel

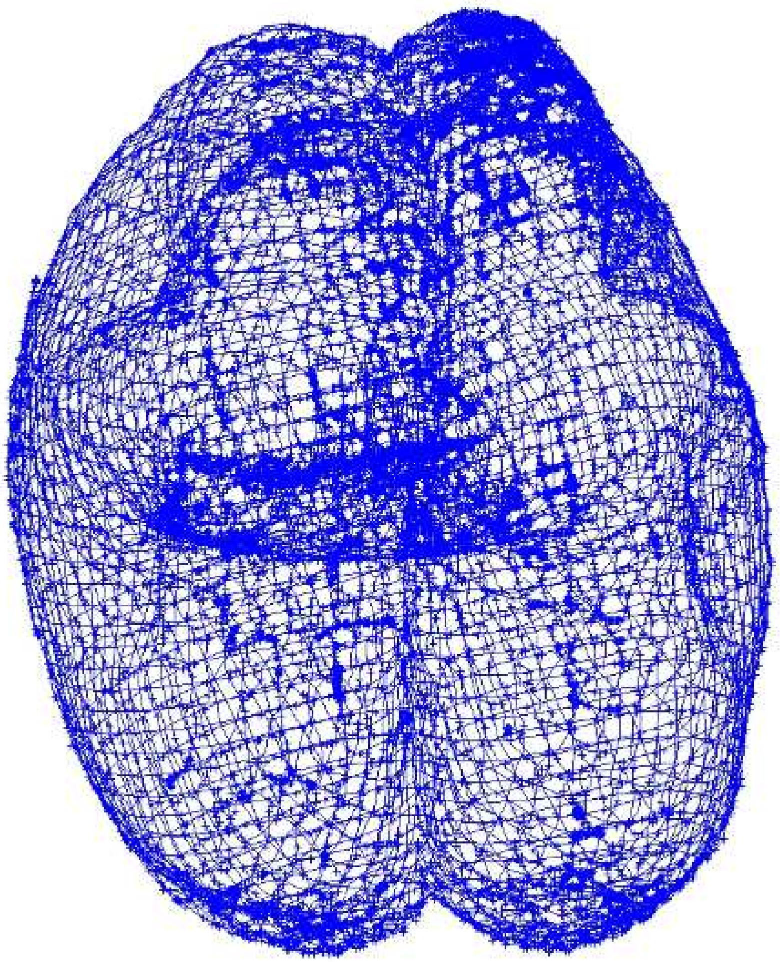
CAD Data for Scanning - DAB Cushion

pics_DAB_Top_panel_pieces_#1_2_3.jpg

pics_DAB_Bottom_panel_pieces_#4_5_6_7_8.jpg

- Accord DAB Botton Panel piecel#4.igs
- Accord DAB piece #3 reinf.igs
- Accord DAB piece #5.igs
- Accord DAB piece #6.igs
- Accord DAB piece #7.igs
- Accord DAB piece #8.igs
- Accord DAB piece#2 teather.igs
- Accord DAB Top Panel piece#1.igs
- pics_DAB_Bottom_panel_pieces_#4_5_6_7_8.jpg
- pics_DAB_Top_panel_pieces_#1_2_3.jpg

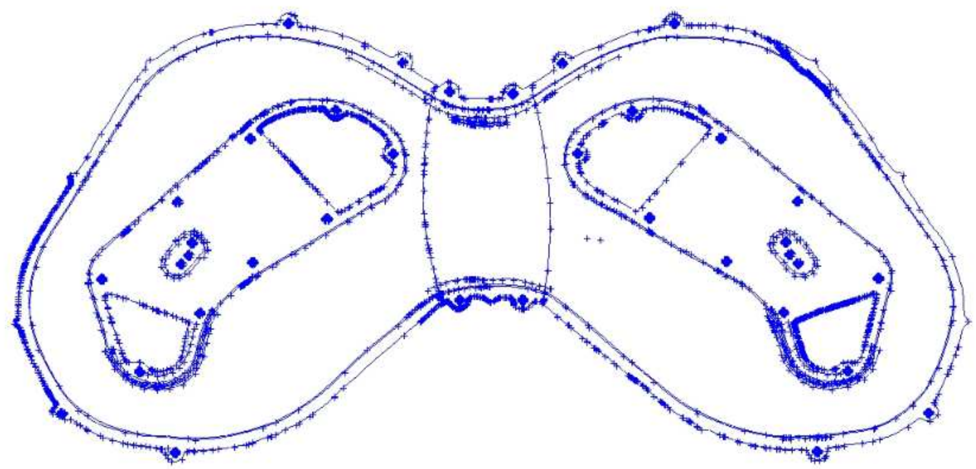
PAB Cushion Scanning



3D Scanned CAD

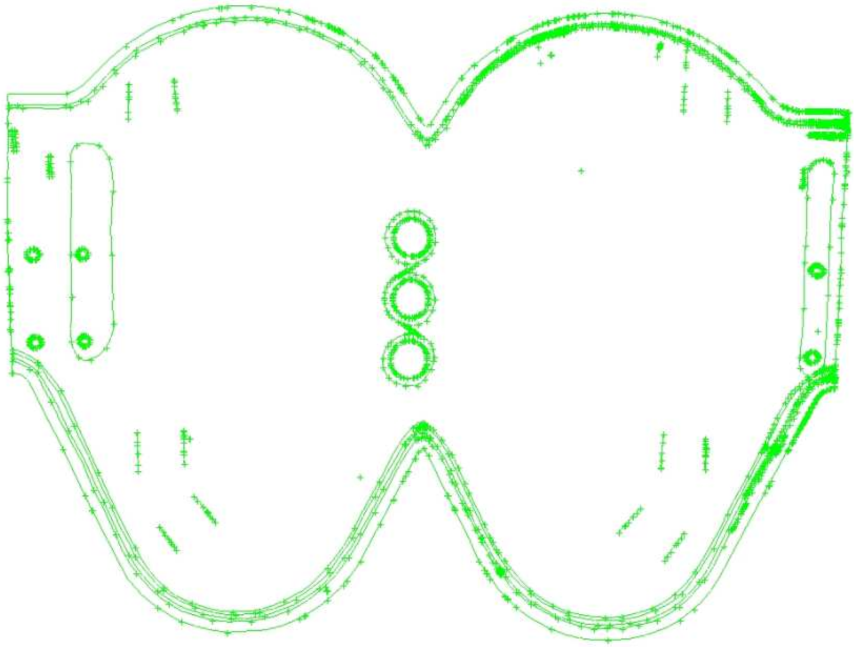
Picture

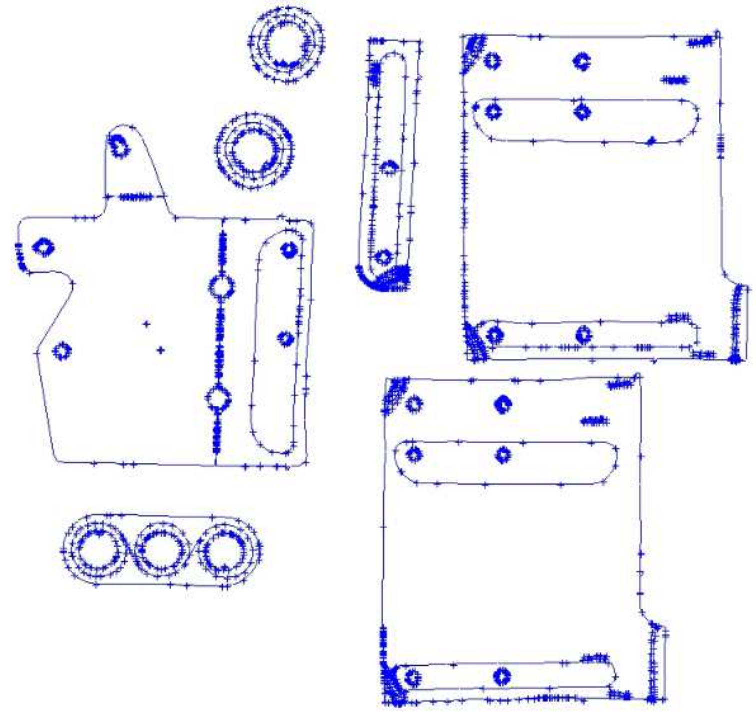
- **CAD Data for Scanning - PAB Cushion**



Accord PAB piece #2.igs
Accord PAB piece #3-#10.igs
Accord PAB piece #7.igs
Accord PAB piece #12-#16.igs
Accord_PAB_3D_scanned point data 111416.igs
Honda PAB 3D Cushion Point Cloud 120716.igs

- **CAD Data for Scanning - SAB Cushion**



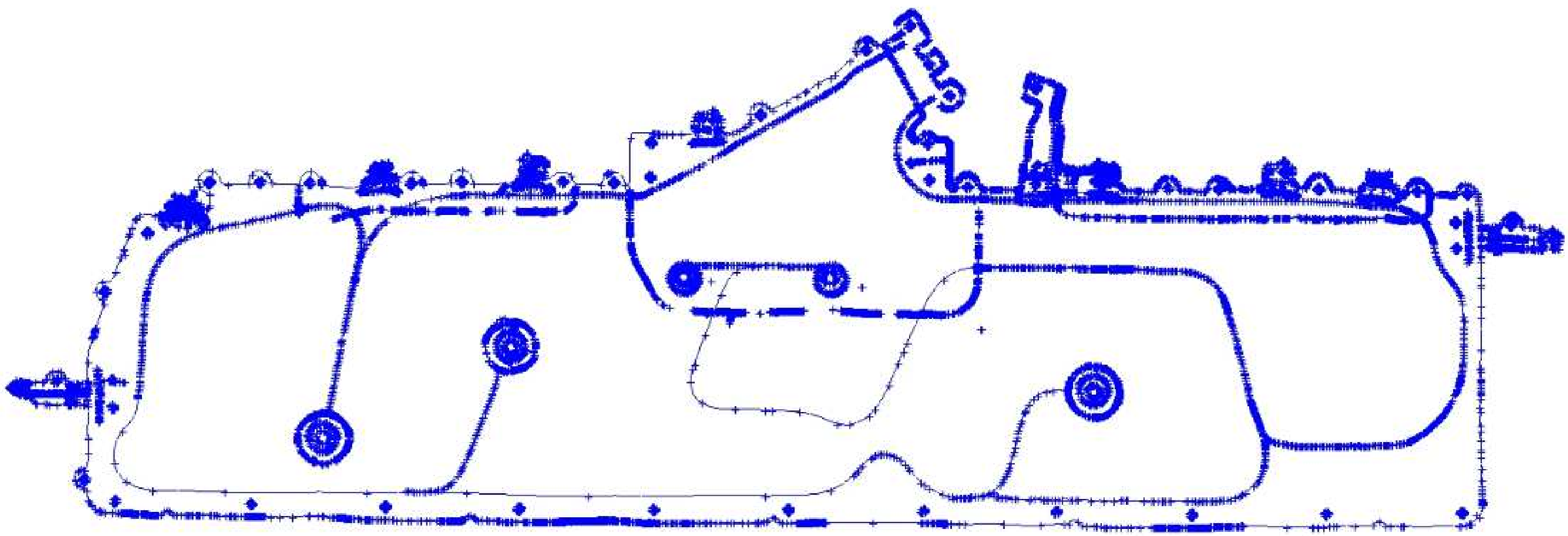


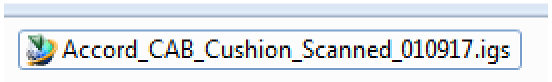
Main Panel

SAB - Internal chamber #5.igs
SAB - Main panel #3.igs
SAB - all other pieces .igs

Other Panel Pieces

- **CAD Data for Scanning - CAB Cushion**

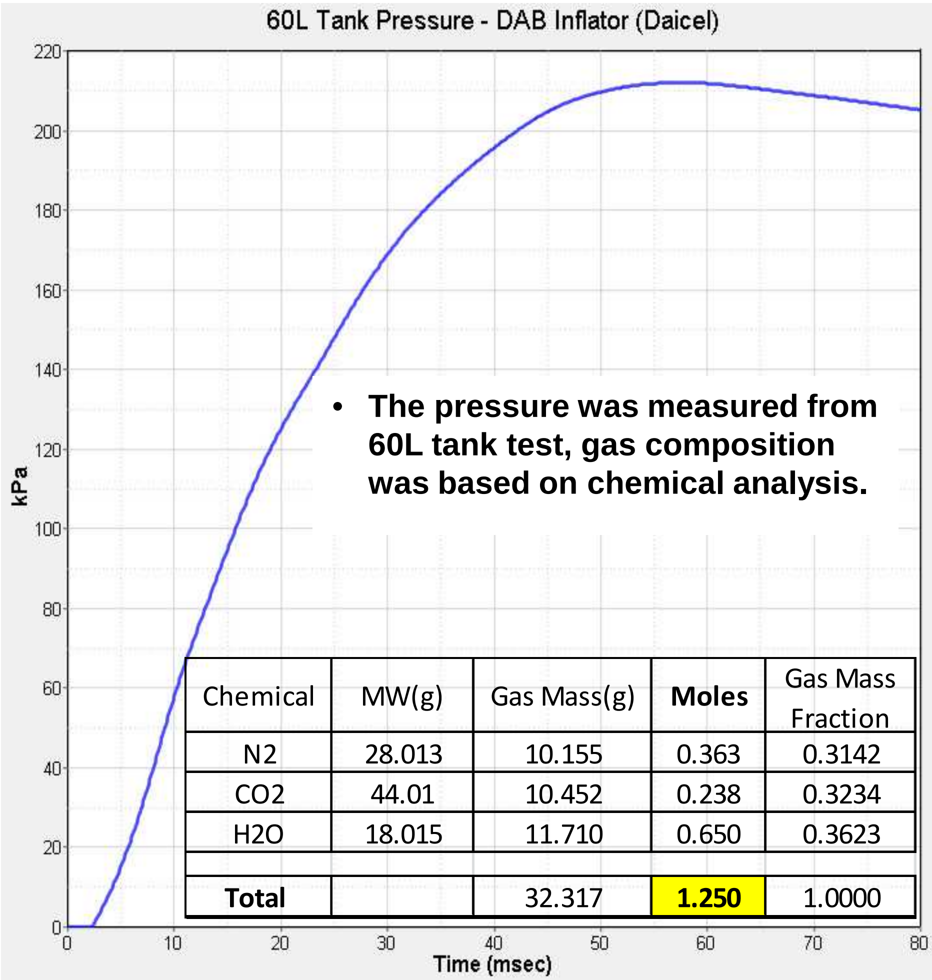




Inflator Analysis

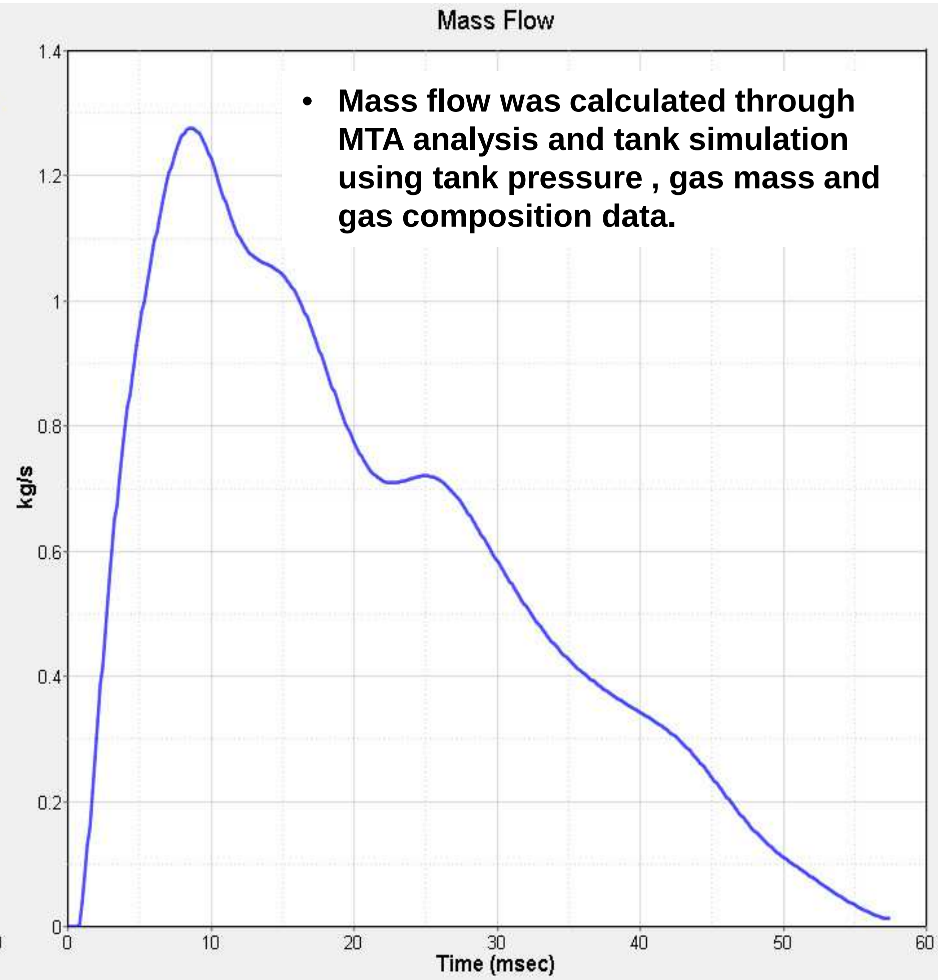
- Accord DAB Inflator : Daicel ZD2-160_200, 454g, Dual Stage

- DAB Inflator (Daicel ZD2) : Tank Pressure / Mass Flow / Gas Composition (Full Output)



- **The pressure was measured from 60L tank test, gas composition was based on chemical analysis.**

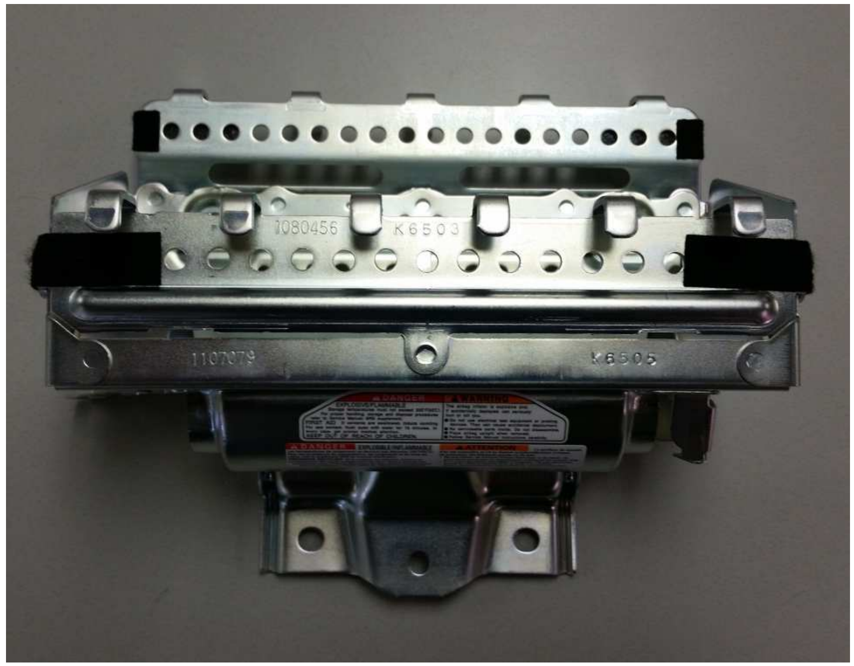
Chemical	MW(g)	Gas Mass(g)	**Moles**	Gas Mass Fraction
N_2	28.013	10.155	0.363	0.3142
CO_2	44.01	10.452	0.238	0.3234
H_2O	18.015	11.710	0.650	0.3623
Total		32.317	**1.250**	1.0000



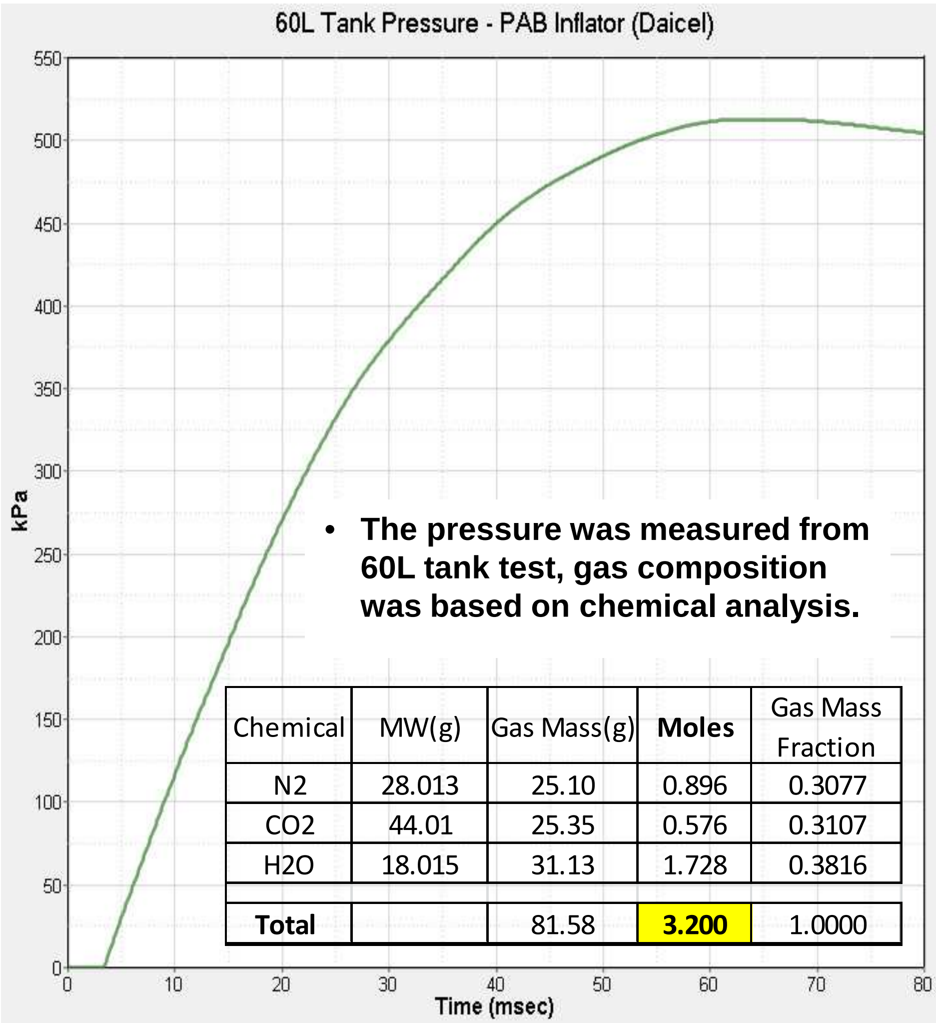
- **Mass flow was calculated through MTA analysis and tank simulation using tank pressure , gas mass and gas composition data.**

PAB Inflator

- Accord PAB Inflator : Daicel DWE-5000(WE390-500), 779g, Dual Stage

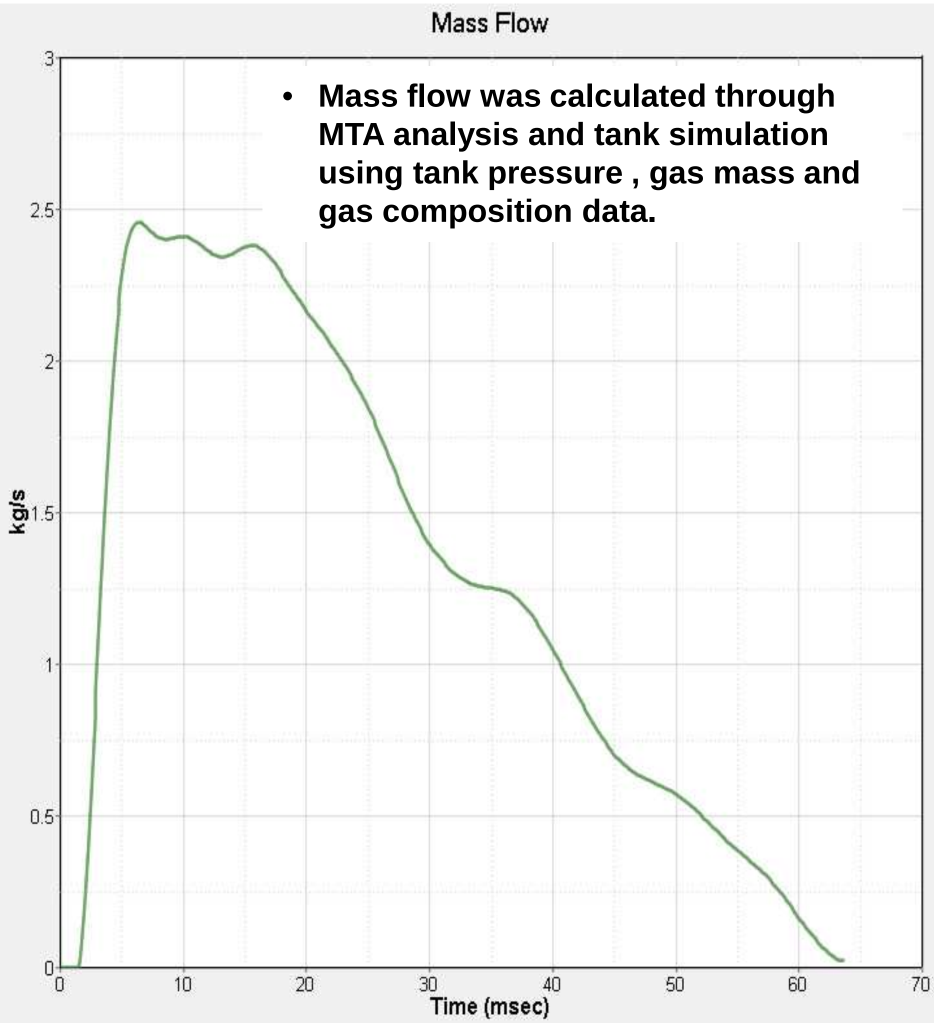


- PAB Inflator (Daicel DWE-5000) : Tank Pressure / Mass Flow / Gas Composition (Full Output)



- **The pressure was measured from 60L tank test, gas composition was based on chemical analysis.**

Chemical	MW(g)	Gas Mass(g)	**Moles**	Gas Mass Fraction
N2	28.013	25.10	0.896	0.3077
CO2	44.01	25.35	0.576	0.3107
H2O	18.015	31.13	1.728	0.3816
Total		81.58	**3.200**	1.0000

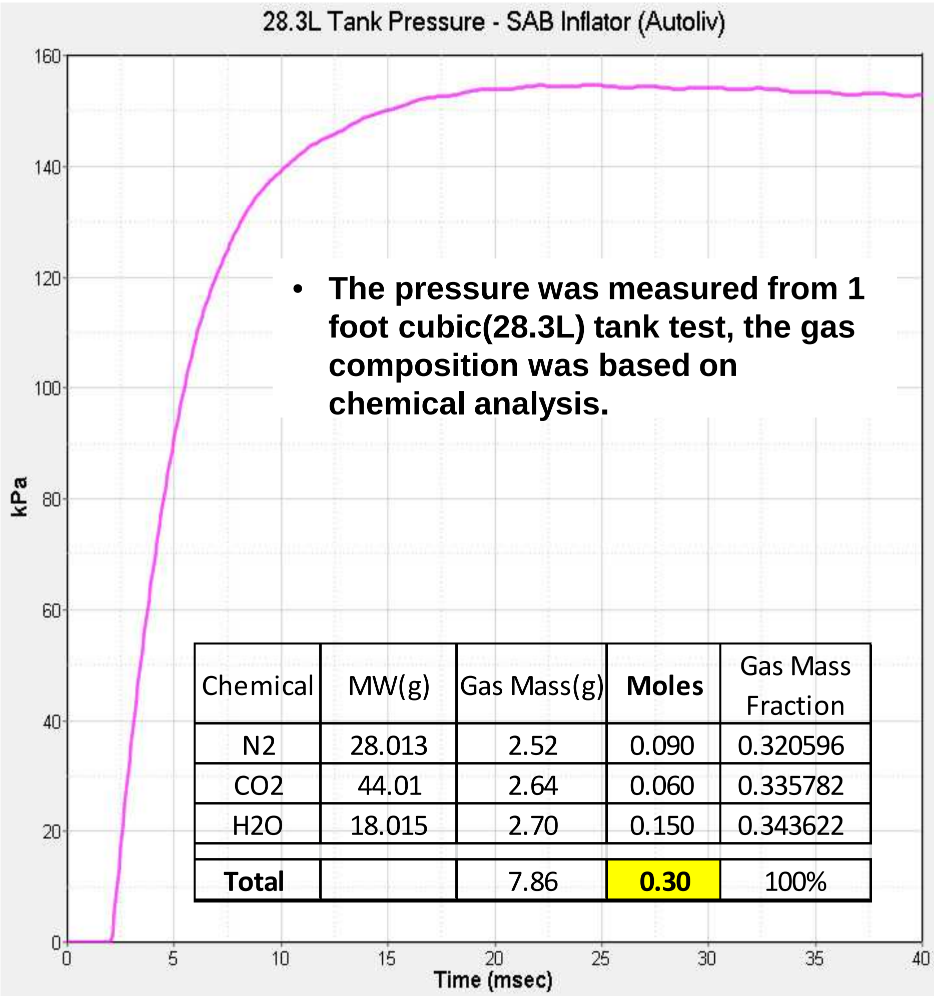


- **Mass flow was calculated through MTA analysis and tank simulation using tank pressure , gas mass and gas composition data.**

- Accord SAB Inflator : Daicel (4S9 67M EU BTM, 345g, Autoliv)

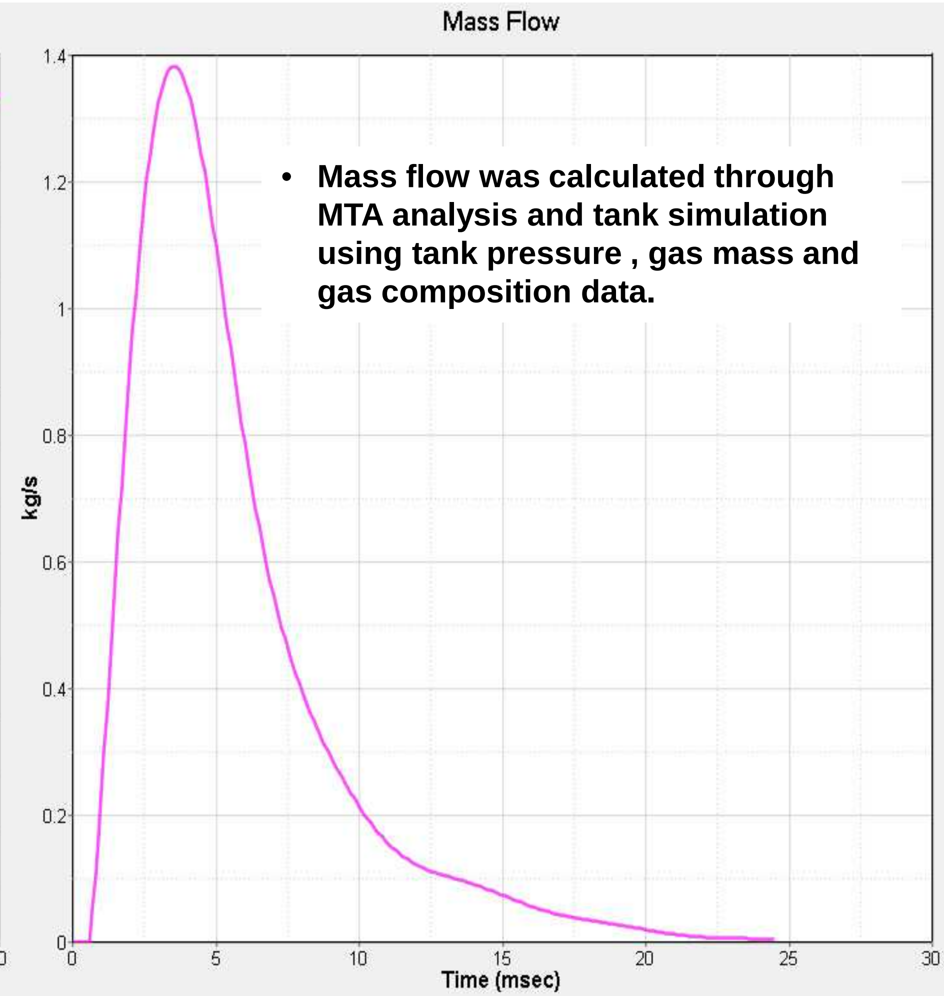
Chemical	MW(g)	Gas Mass(g)	**Moles**	Gas Mass Fraction
N2	28.013	2.521170	0.090000	0.320596
CO2	44.01	2.640600	0.060000	0.335782
H2O	18.015	2.702250	0.150000	0.343622
Total		7.864020	**0.30**	100%

SAB Inflator (Autoliv Production) : Tank Pressure / Mass Flow / Gas Composition



- **The pressure was measured from 1 foot cubic(28.3L) tank test, the gas composition was based on chemical analysis.**

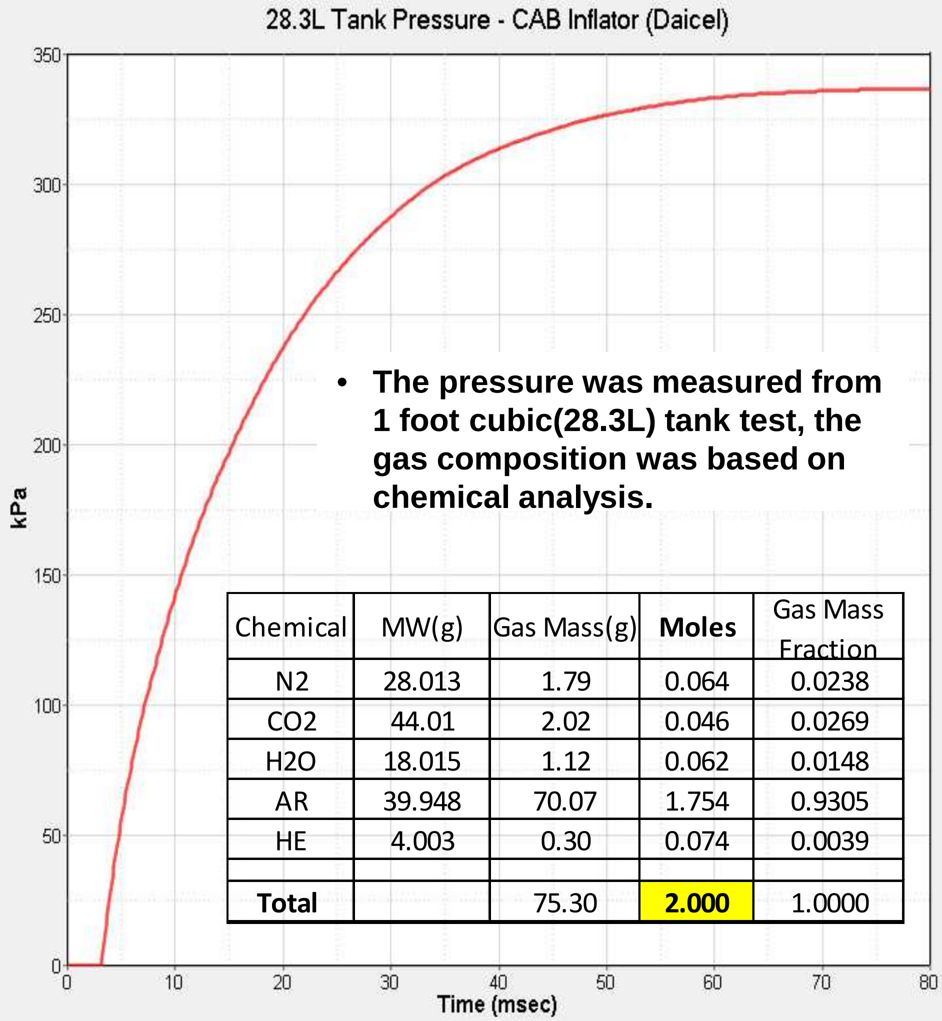
Chemical	MW(g)	Gas Mass(g)	**Moles**	Gas Mass Fraction
N2	28.013	2.52	0.090	0.320596
CO2	44.01	2.64	0.060	0.335782
H2O	18.015	2.70	0.150	0.343622
Total		7.86	**0.30**	100%



- **Mass flow was calculated through MTA analysis and tank simulation using tank pressure , gas mass and gas composition data.**

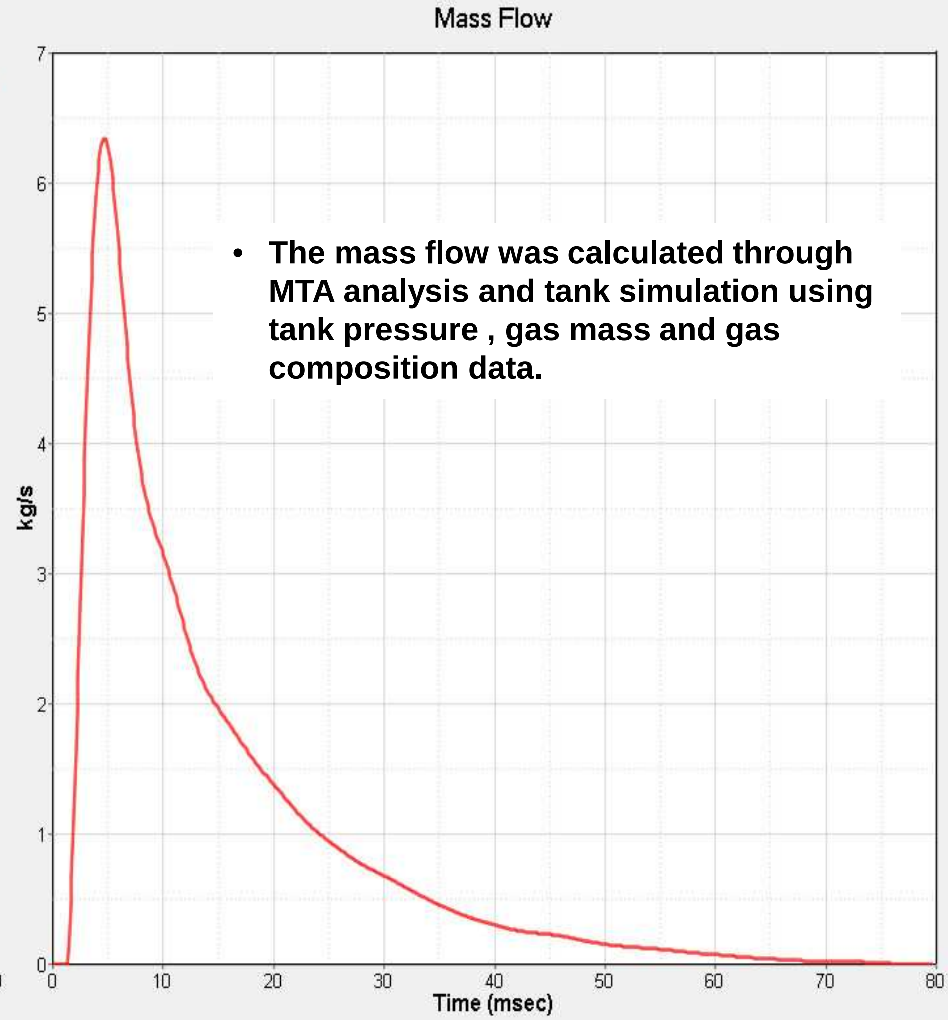
- Accord CAB Inflator : Daicel LH2-01-2(LHGH5348621), 487g

- CAB Inflator (Daicel LH2-01-2) : Tank Pressure / Mass Flow / Gas Composition



- **The pressure was measured from 1 foot cubic(28.3L) tank test, the gas composition was based on chemical analysis.**

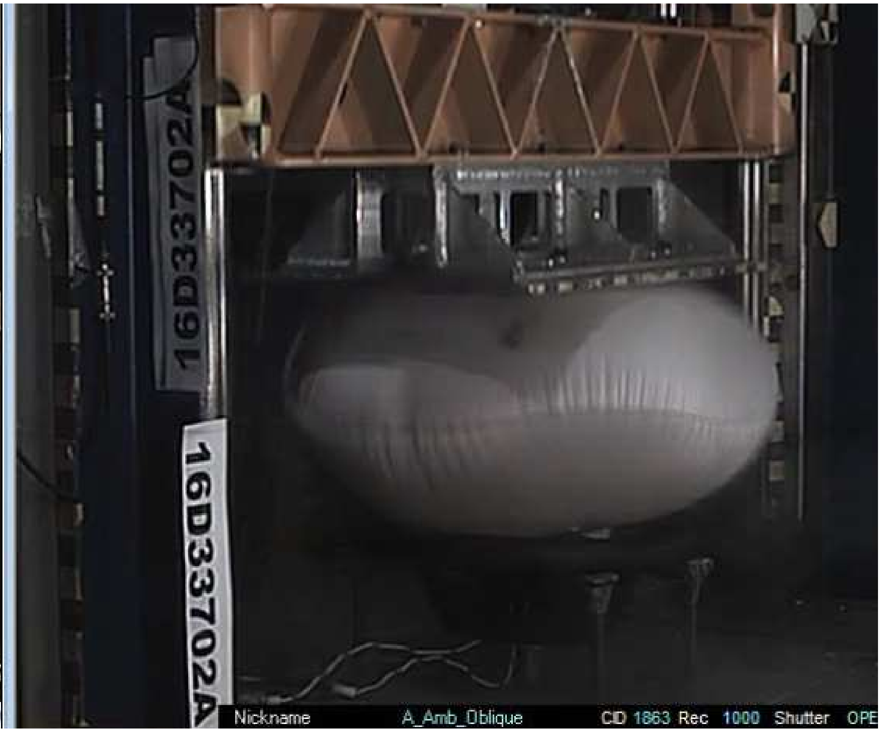
Chemical	MW(g)	Gas Mass(g)	**Moles**	Gas Mass Fraction
N2	28.013	1.79	0.064	0.0238
CO2	44.01	2.02	0.046	0.0269
H2O	18.015	1.12	0.062	0.0148
AR	39.948	70.07	1.754	0.9305
HE	4.003	0.30	0.074	0.0039
Total		75.30	**2.000**	1.0000



- **The mass flow was calculated through MTA analysis and tank simulation using tank pressure , gas mass and gas composition data.**

DropTower Test

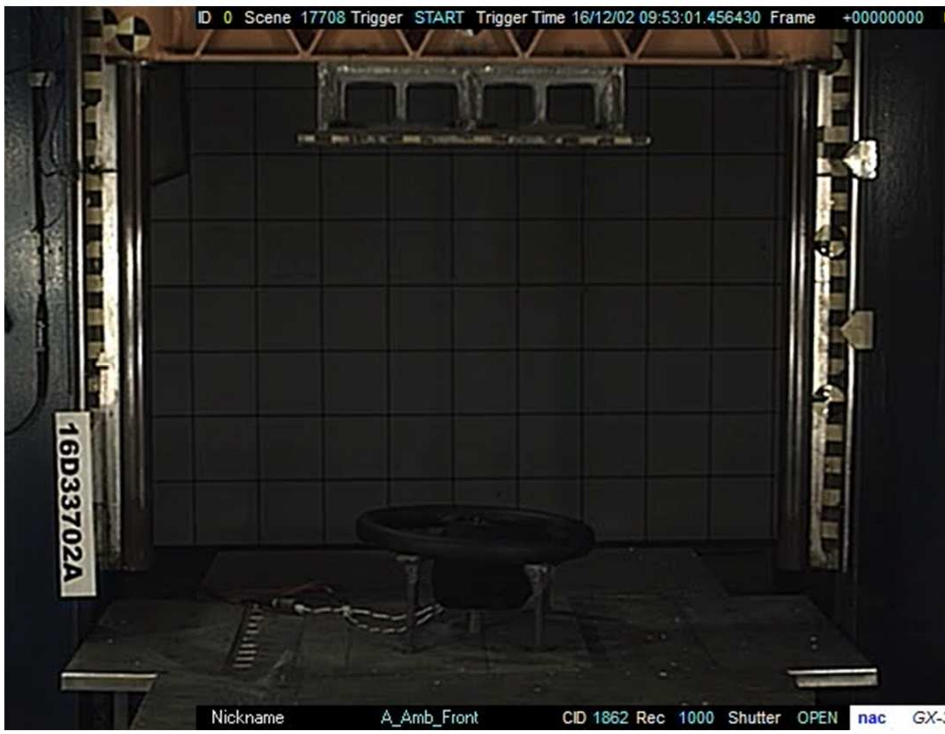
Accord DAB DropTower Test Setup



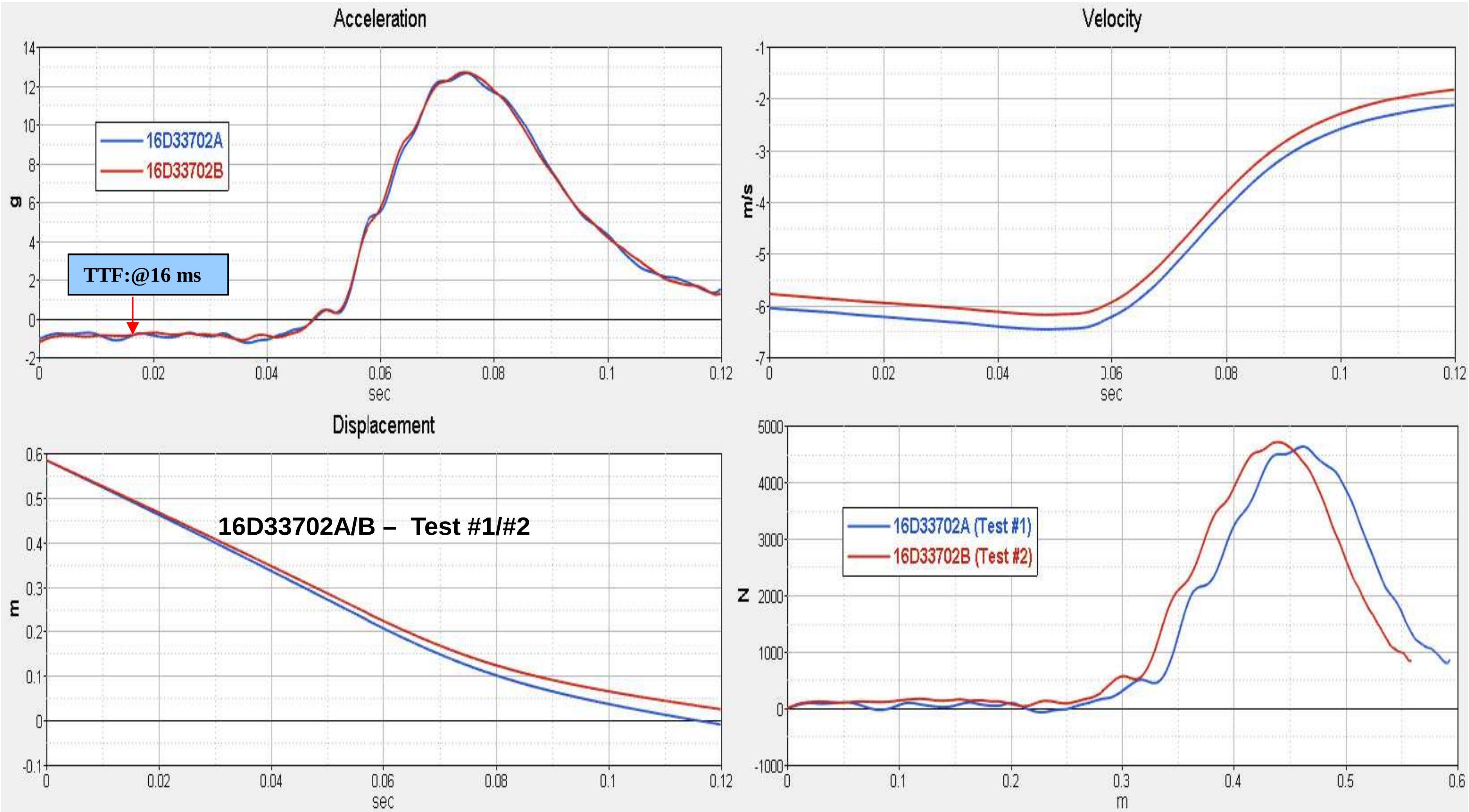
DT Test Spec.
- **Drop mass : 34.5 kg**
- **Impact Velocity : 6.5 m/s**
- **Inflator Output : Full Output**
- **Aibag TTF : 16ms**
- **Accord Steering Wheel**

Accord DAB Configurations
- **Inflator : Daicel (dual stage)**
- **Fabric : 470dtex coated PA6.6**
- **Tether Location : 4 & 8 & 12 O’clock**
- **Tether Length : 250 mm**
- **Discrete Vent Size : 2 x 40mm**

- Accord DAB DT Test – Cushion Kinematics

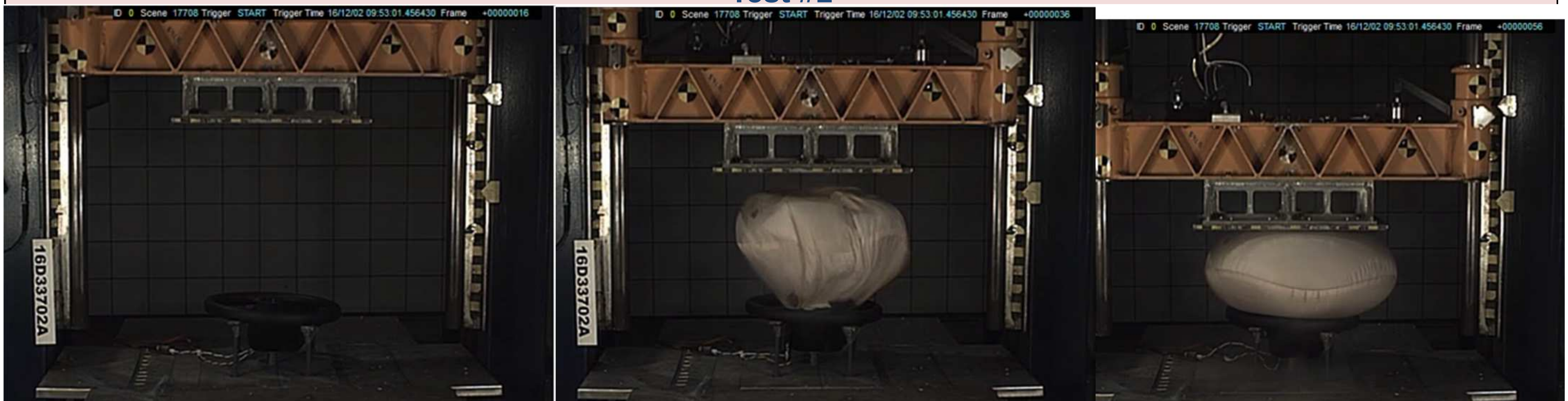


Test Result - Accord DAB DropTower Test

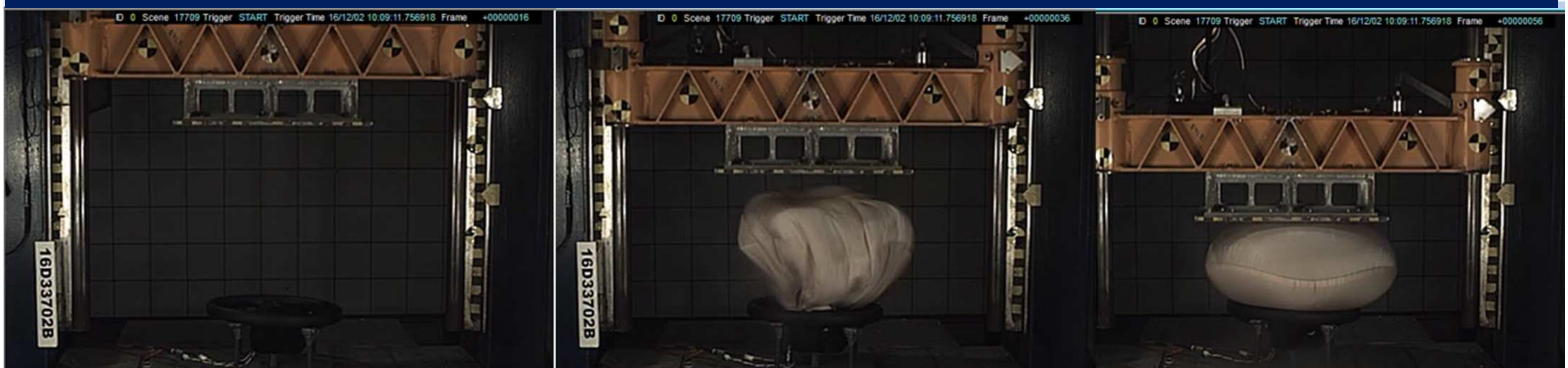


Cushion Kinematics – DAB DT Test

Test #1



@TTF+0ms	@TTF+20ms	@TTF+40ms



Test #2

Cushion Kinematics – DAB DT Test

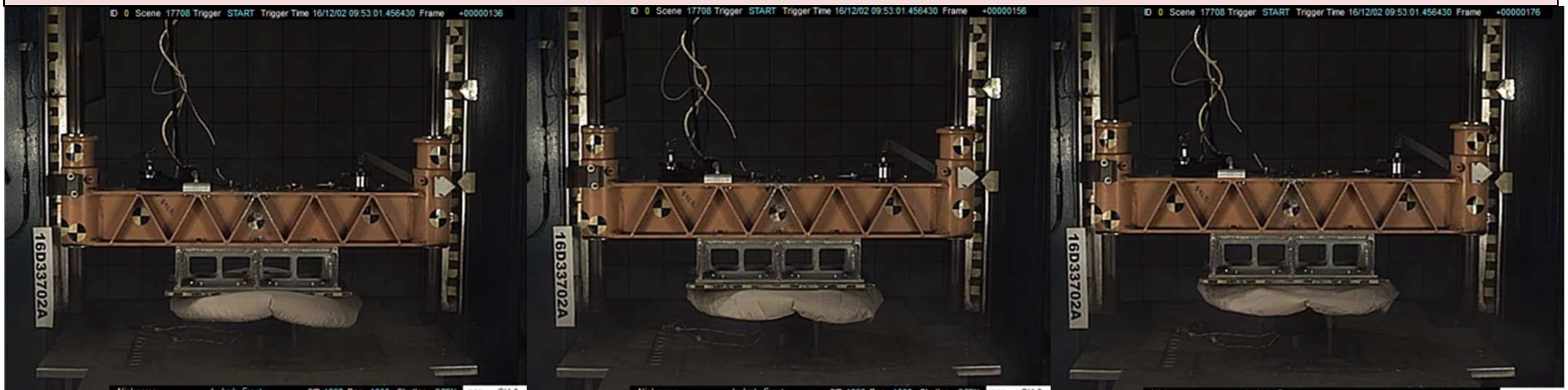
Test #1

@TTF+60ms | **@TTF+80ms** | **@TTF+100ms**

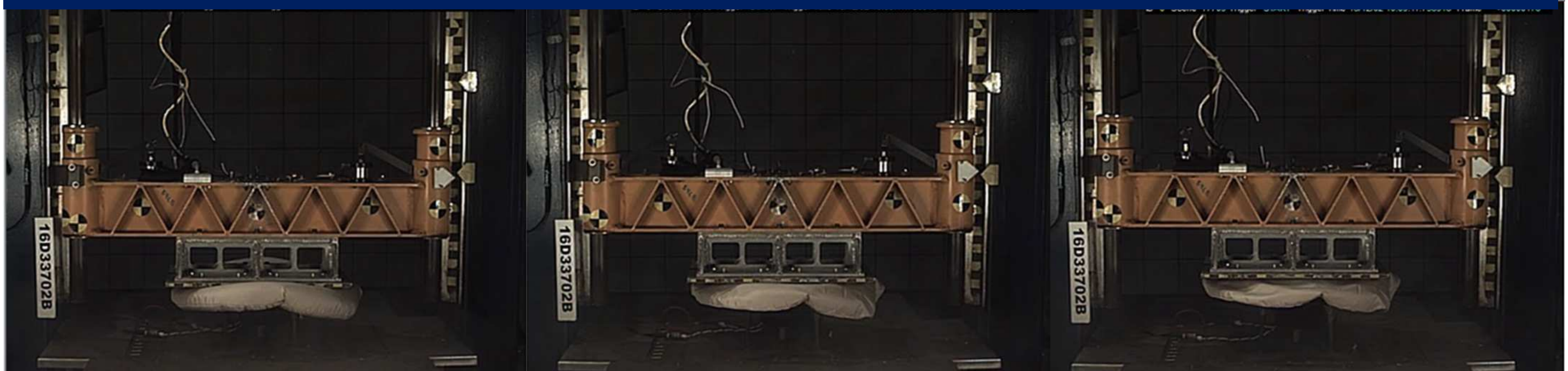
Test #2

Cushion Kinematics – DAB DT Test

Test #1



@TTF+120ms **@TTF+140ms** **@TTF+160ms**



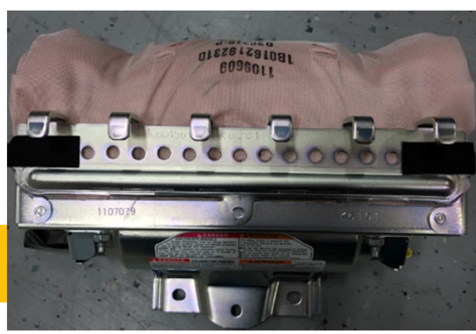
Test #2

- Accord PAB DT Test Setup

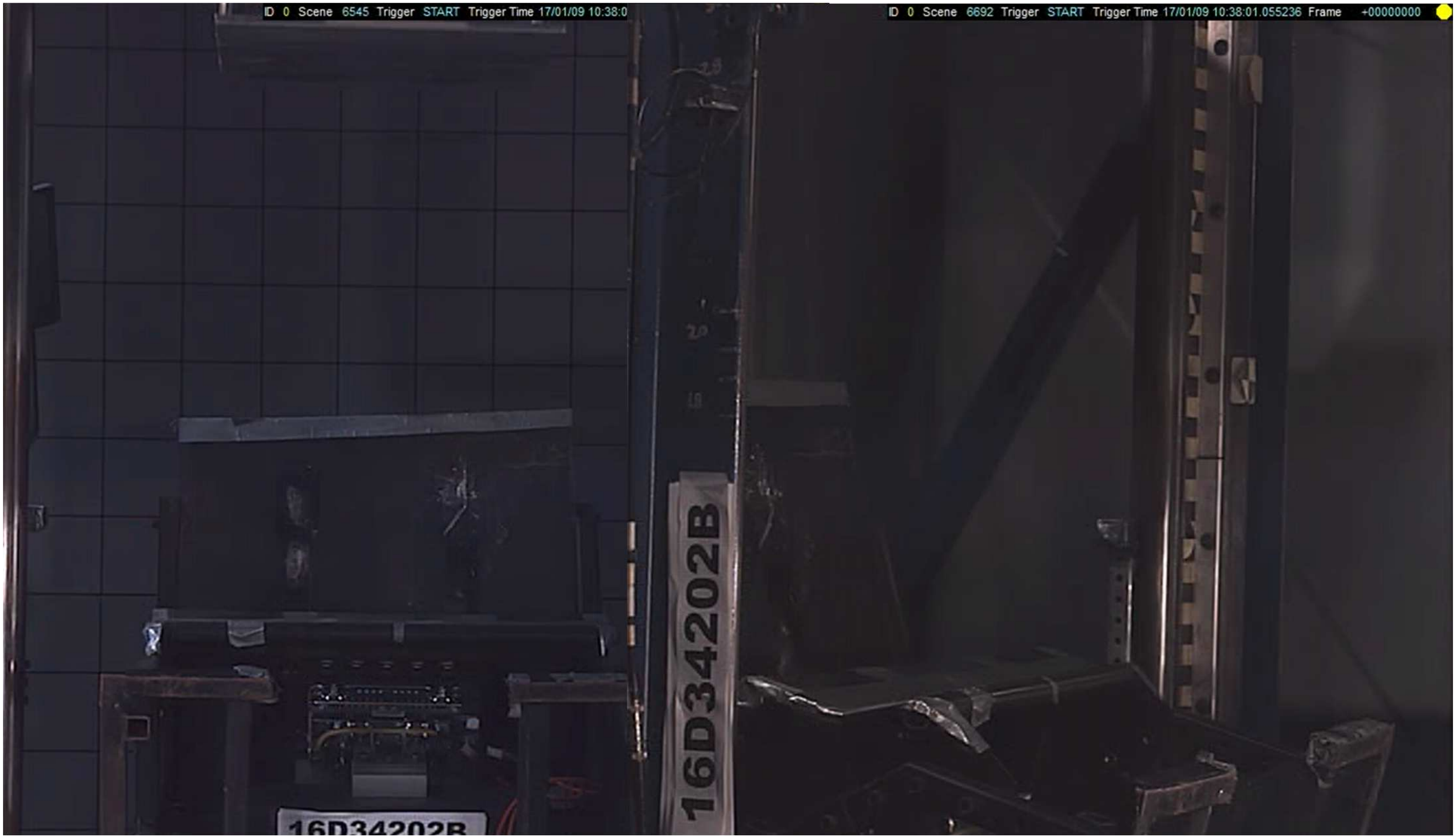
PAB DT Test Spec.

- **Drop mass : 36.3 kg**
- **Impact Velocity : 5.4 m/s**
- **Inflator Output : Full Output (5ms delay)**
- **Aibag TTF : 33ms**

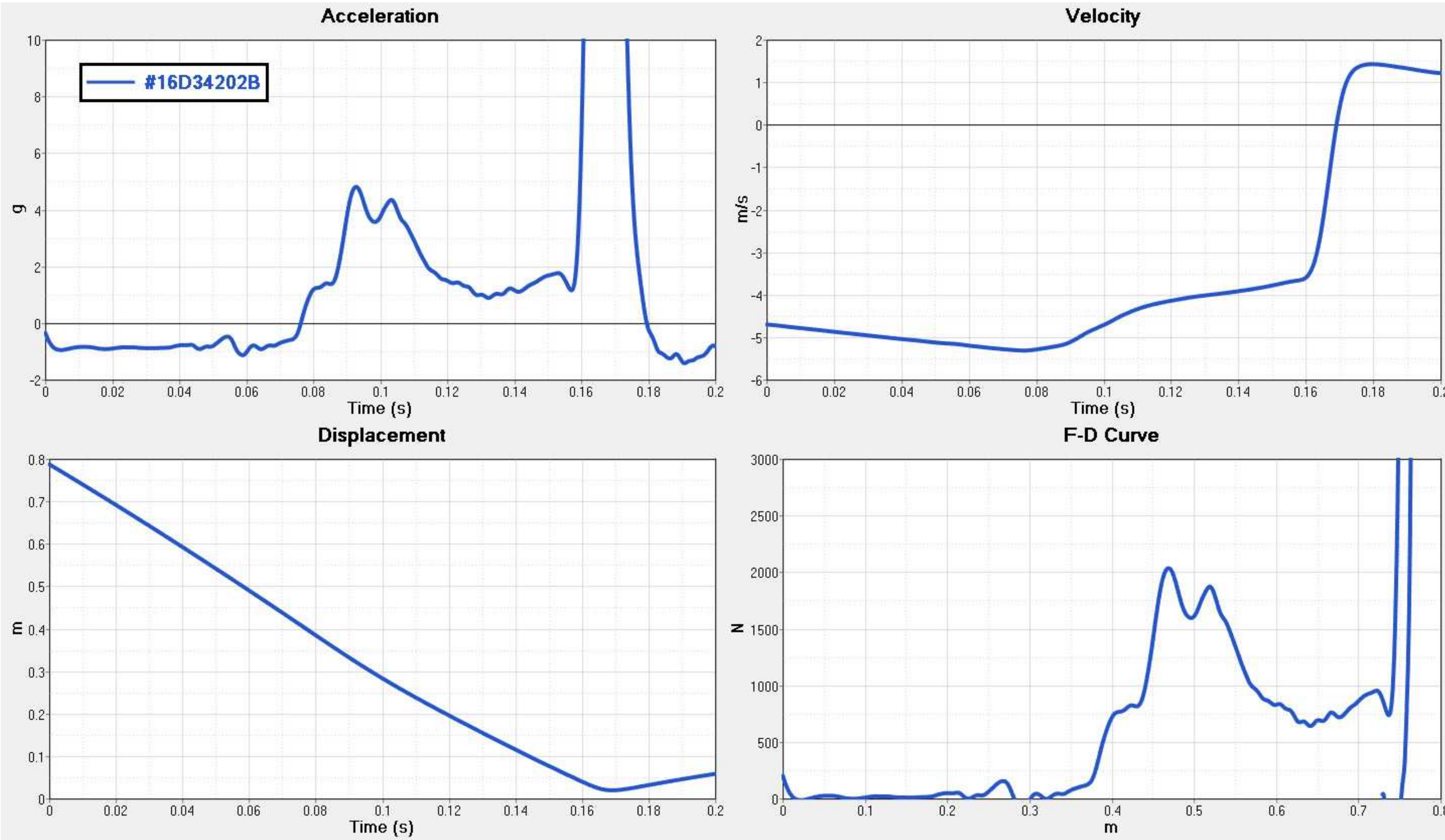
PAB DT Test – Modification of Fixture



- Accord PAB DT Test – Cushion Kinematics



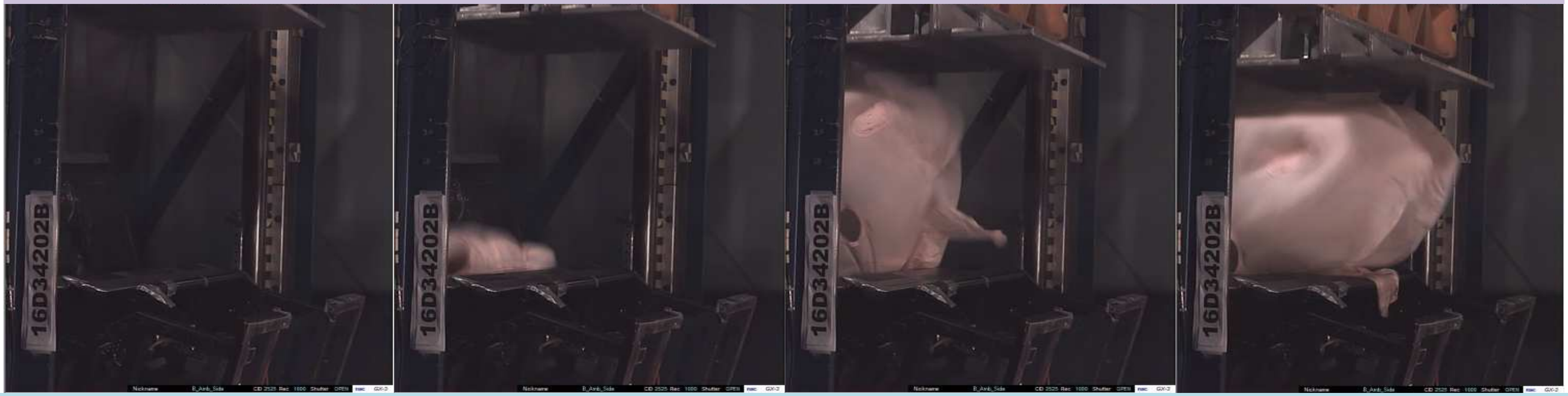
- Accord PAB DT Test – Test Result



- Accord PAB DT Test – Cushion Kinematics

Front View

@TTF+0ms	@TTF+10ms	@TTF+20ms	@TTF+30ms

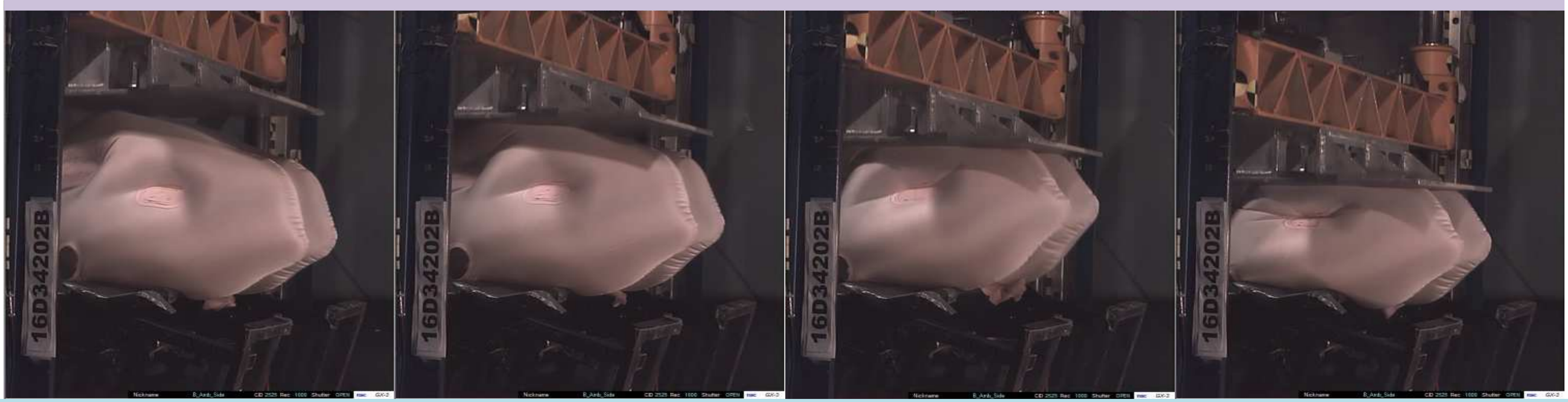


Oblique View

- Accord PAB DT Test – Cushion Kinematics (Cont'd)

Front View

@TTF+40ms	@TTF+50ms	@TTF+60ms	@TTF+80ms



Oblique View

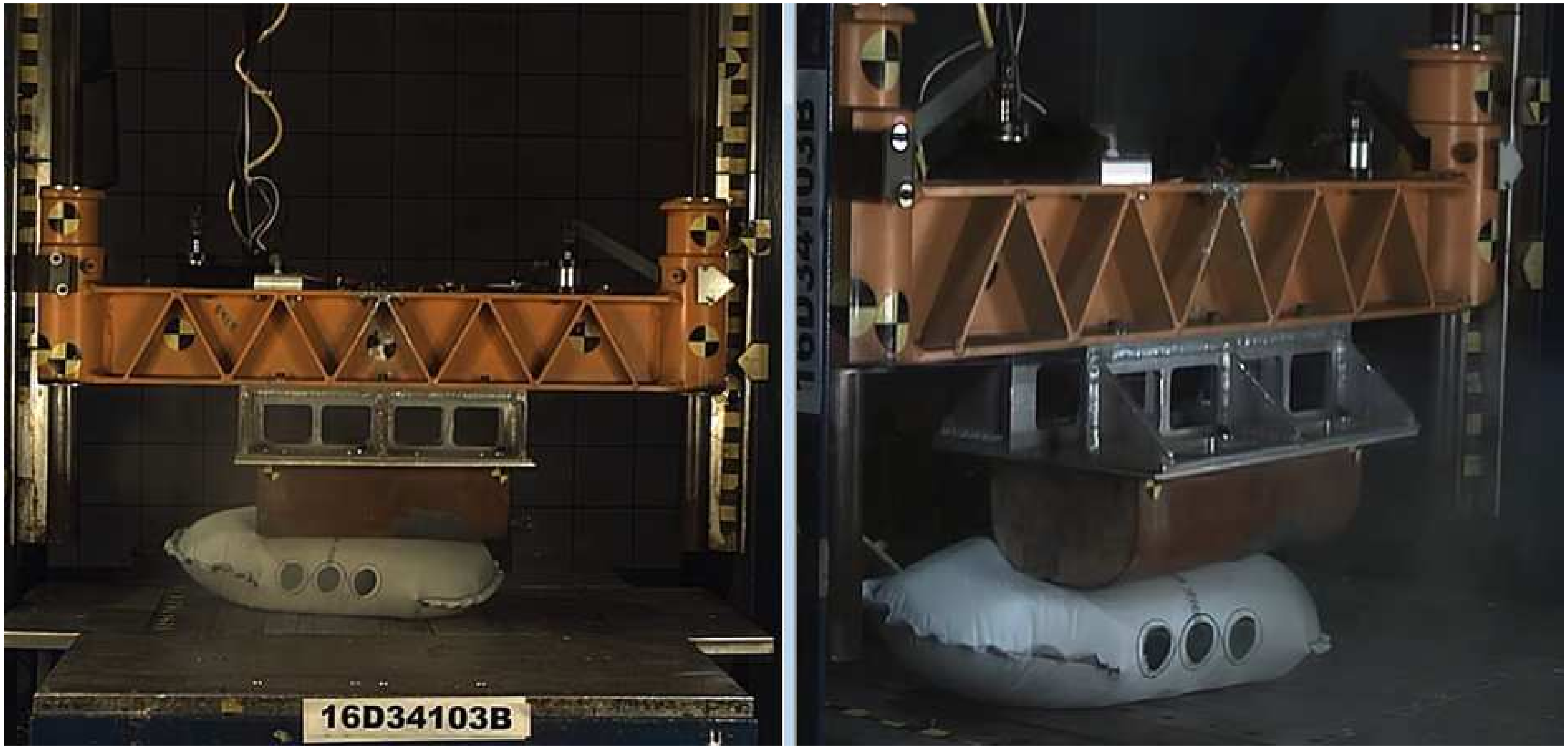
- Accord PAB DT Test – Cushion Kinematics (Cont’d)

Front View

@TTF+100ms	@TTF+120ms	@TTF+140ms	@TTF+160ms

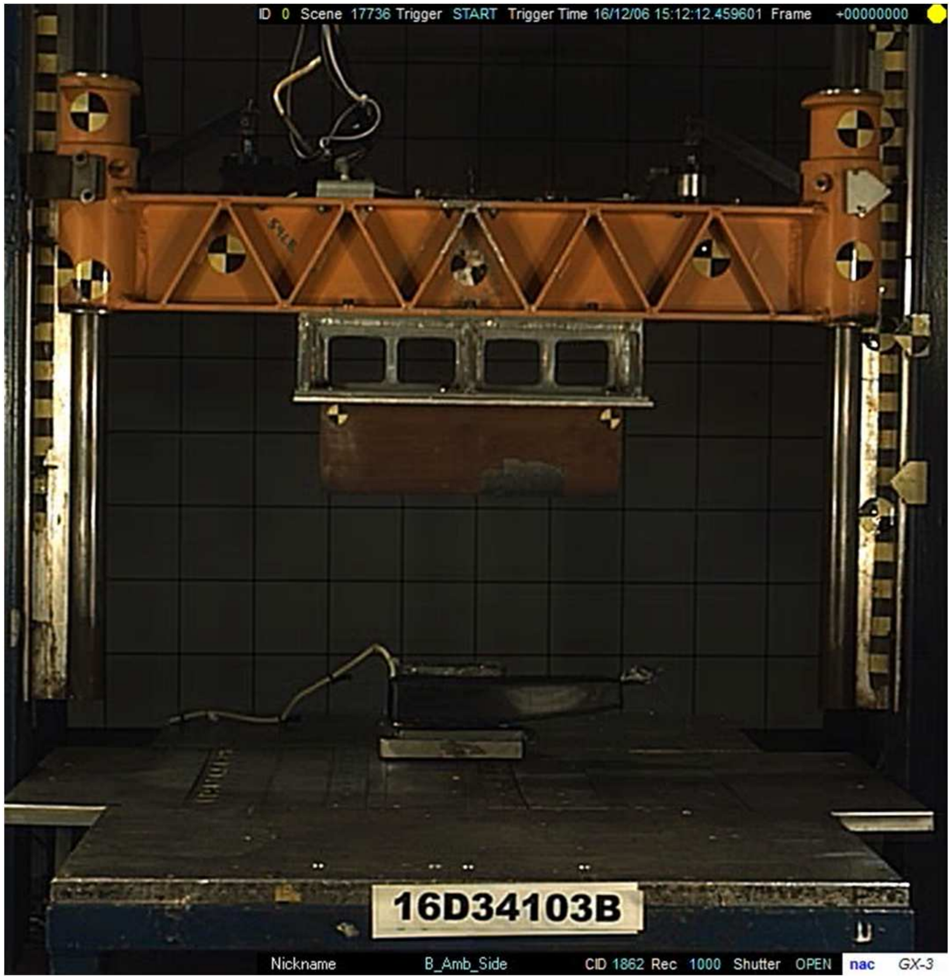
Oblique View

- Accord SAB DT Test Setup

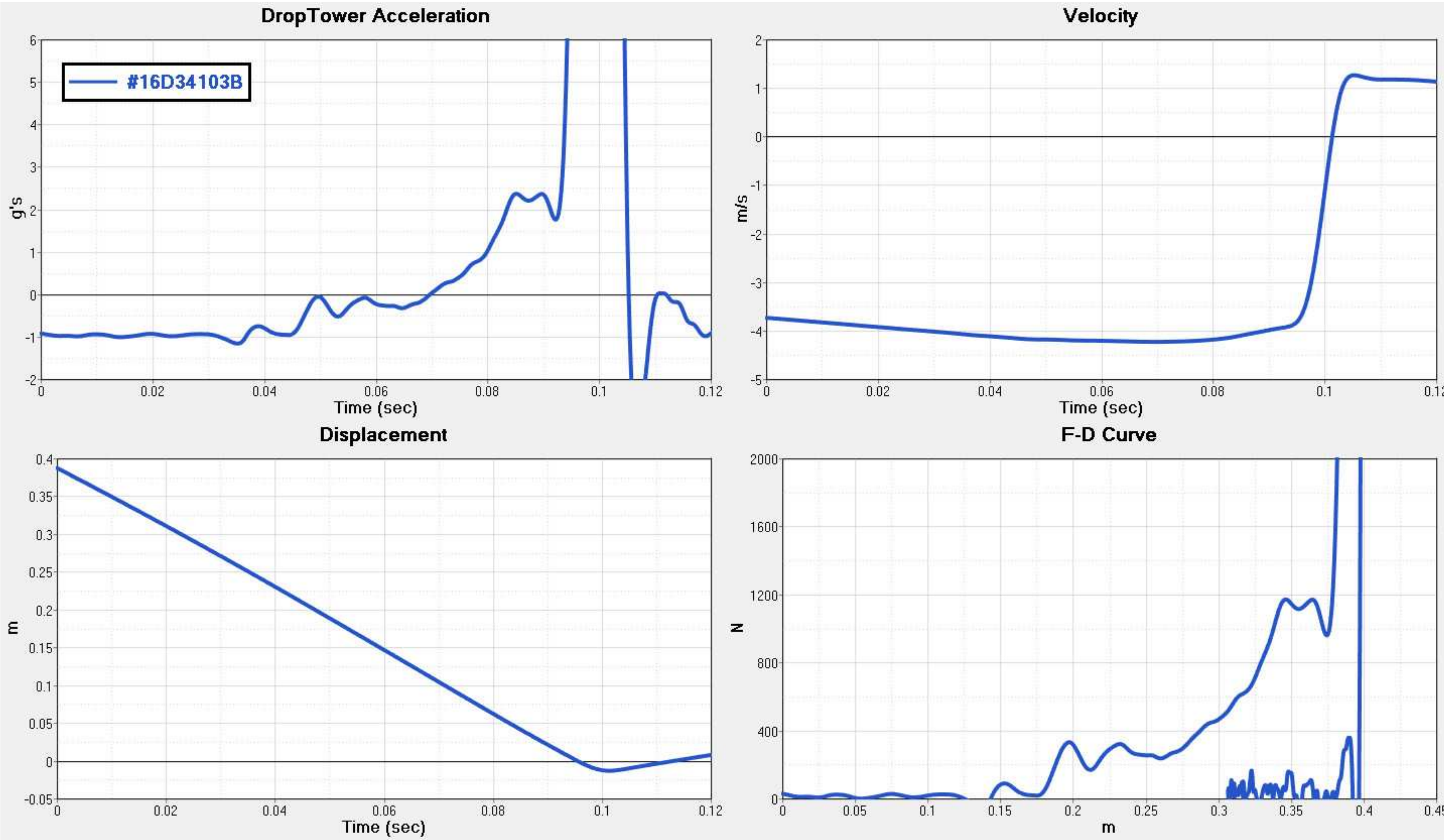


SAB DT Test Spec.
- **Drop mass : 35 kg**
- **Impact Velocity : 4.1 m/s**
- **Airbag TTF : 36ms**

- Accord SAB DT Test – Cushion Kinematics



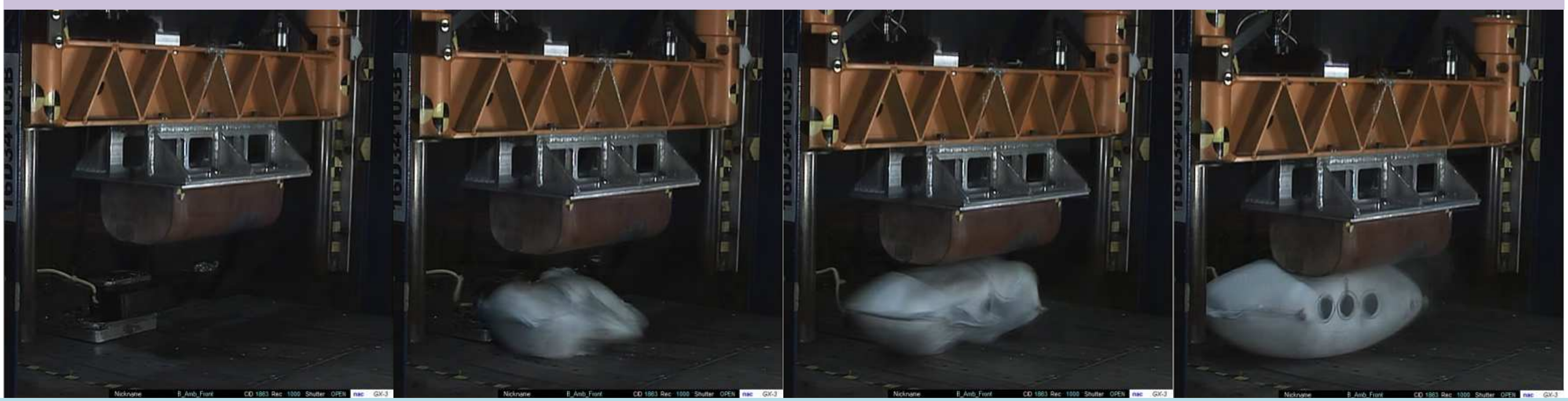
- Accord SAB DT Test – Test Result



- Accord SAB DT Test – Cushion Kinematics

Front View

@TTF+0ms	@TTF+5ms	@TTF+10ms	@TTF+15ms

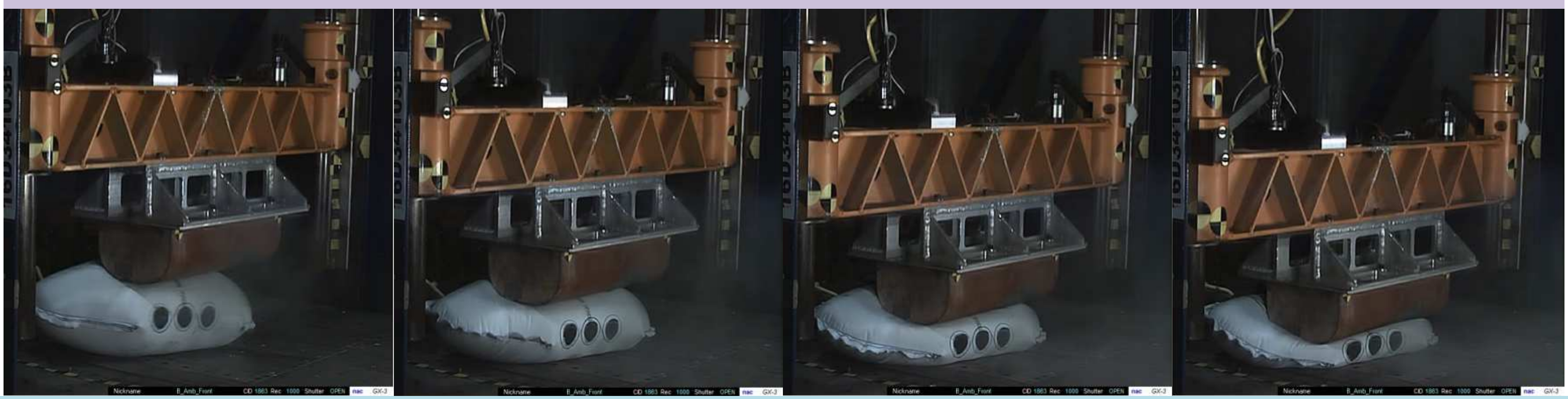


Oblique View

- Accord SAB DT Test – Cushion Kinematics (Cont'd)

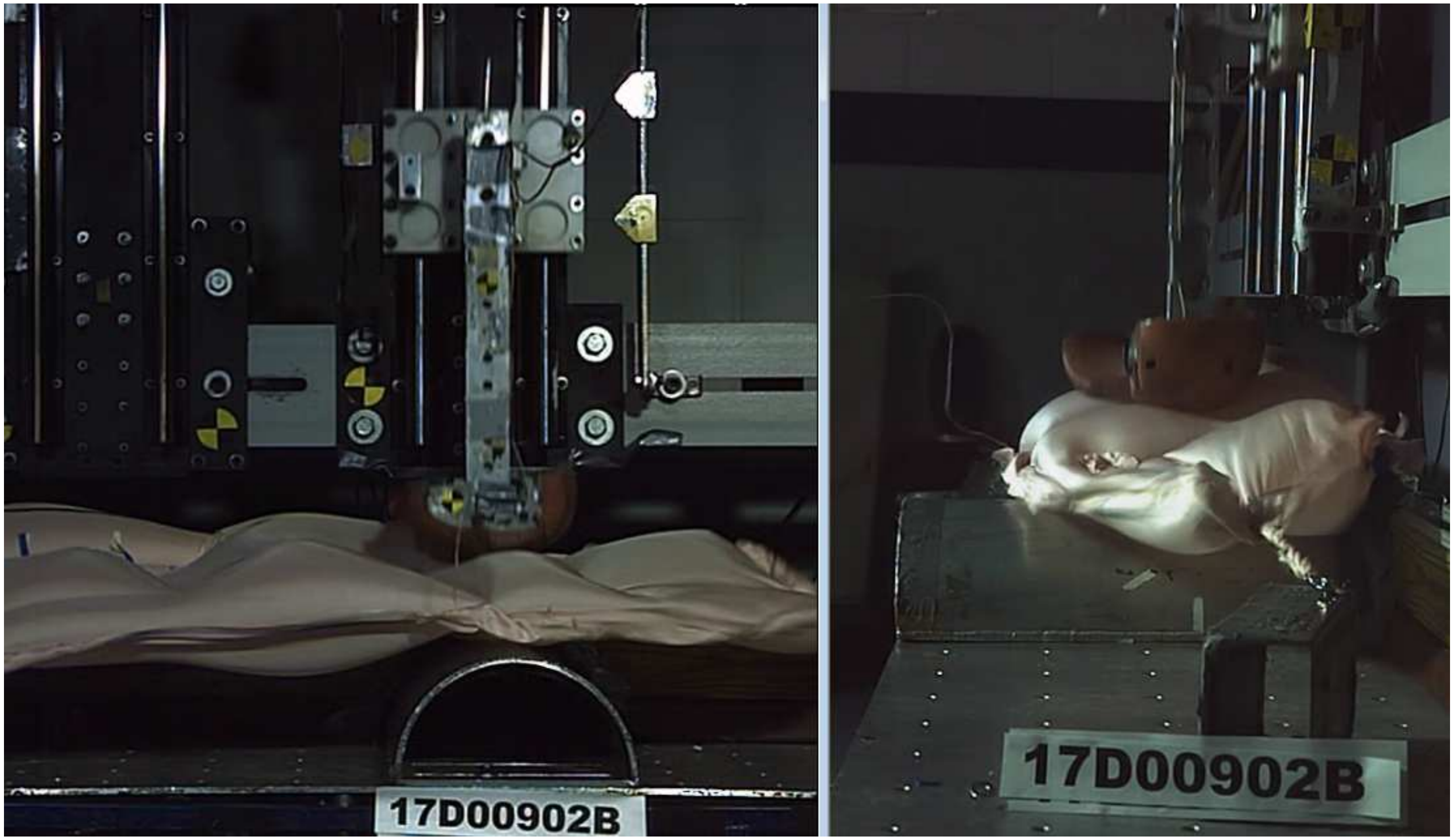
Front View

@TTF+20ms **@TTF+30ms** **@TTF+40ms** **@TTF+50ms**



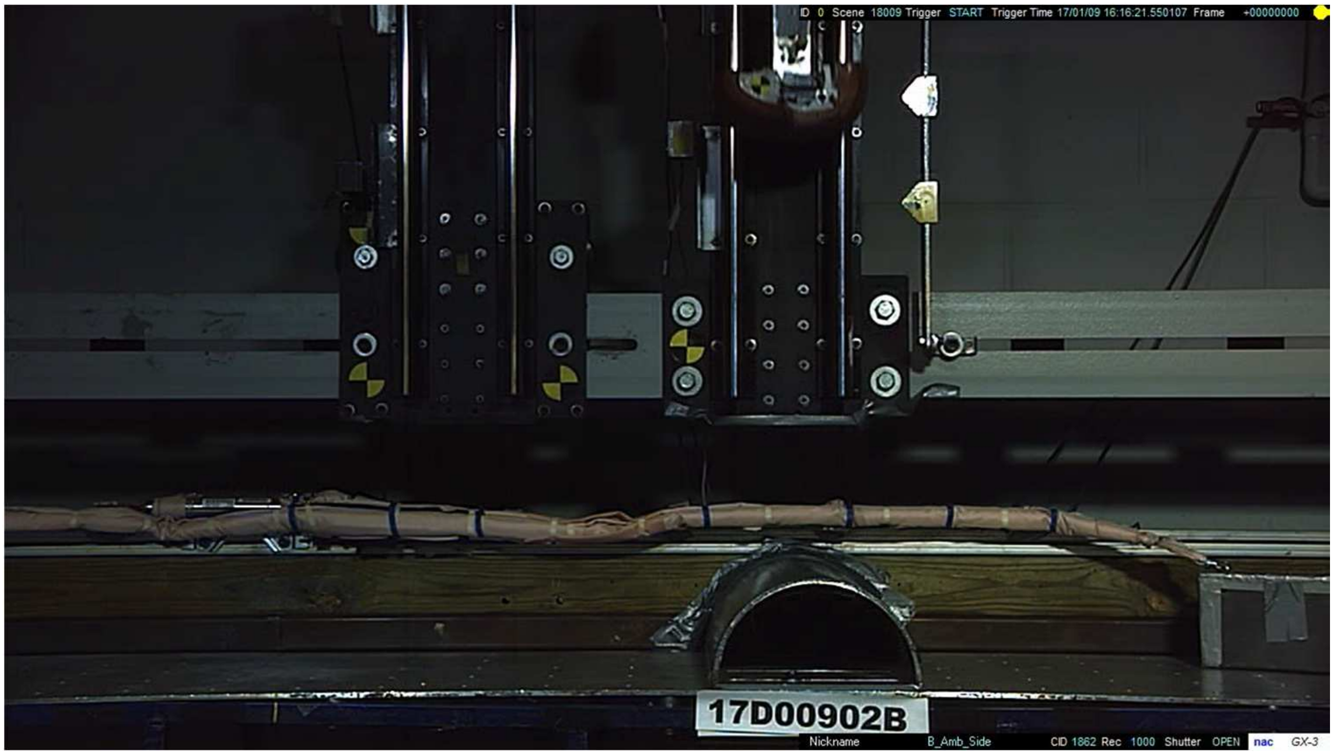
Oblique View

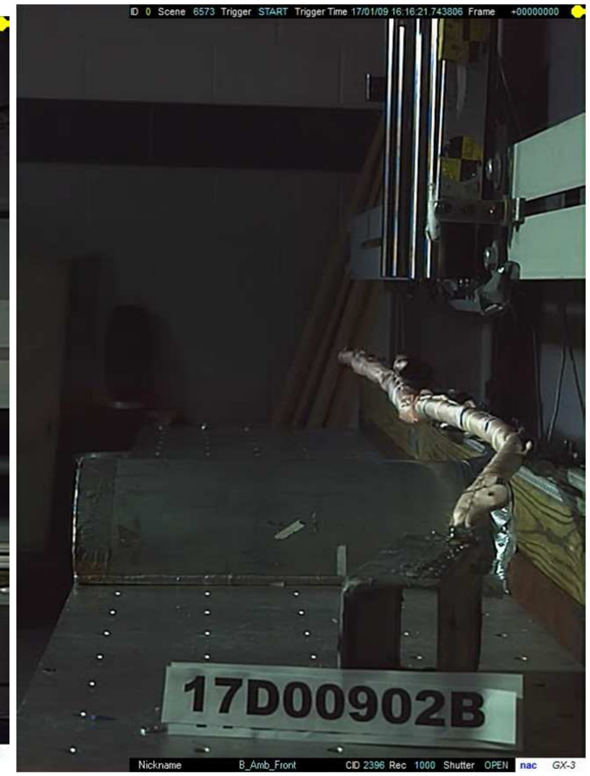
- Accord CAB DT Test Setup



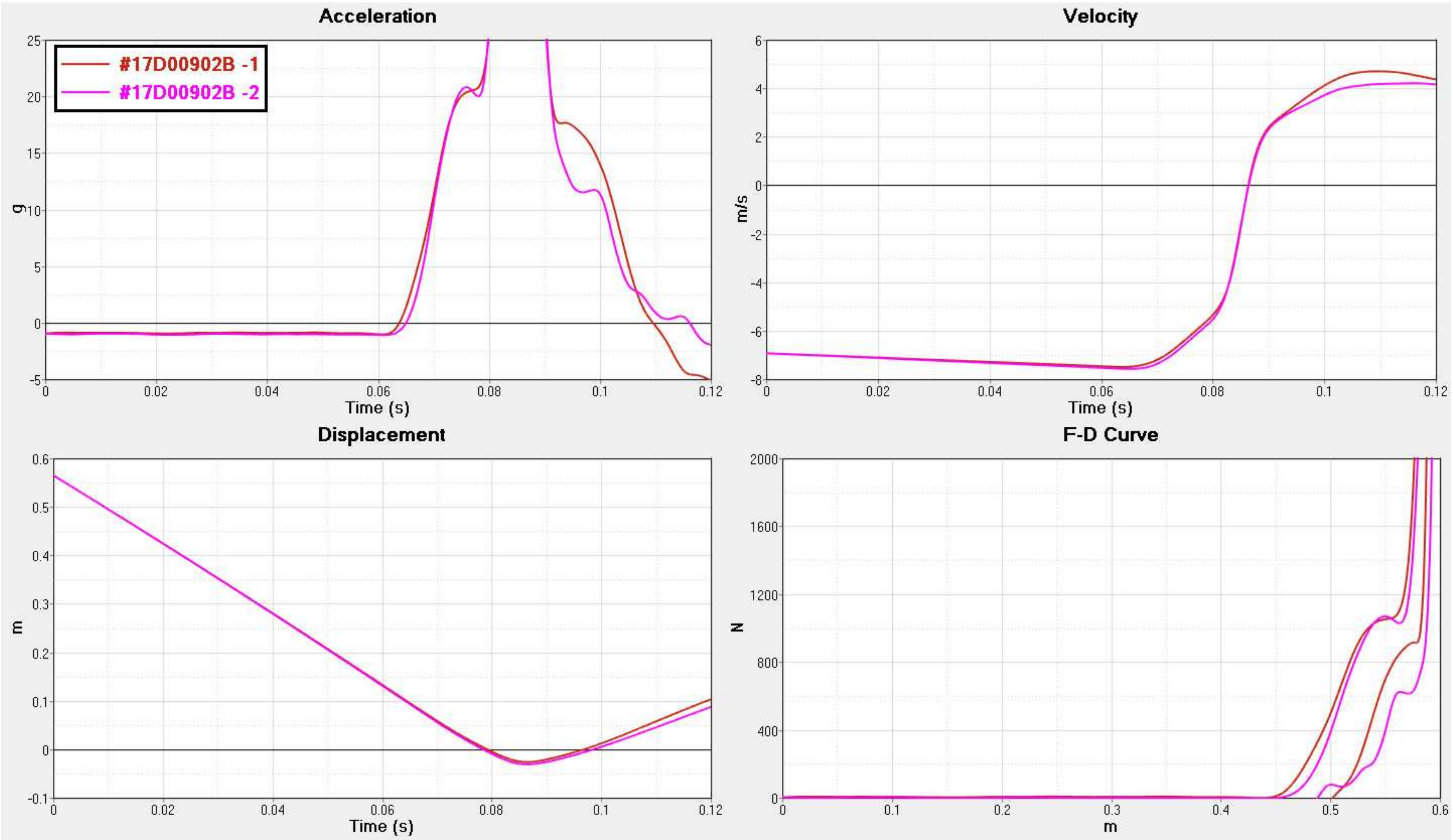
CAB DT Test Spec.
- **Drop (headform) mass : 5.0 kg (11 Lbs)**
- **Impact Velocity : 7.5 m/s**
- **Airbag TTF : 30ms**

- Accord CAB DT Test Video



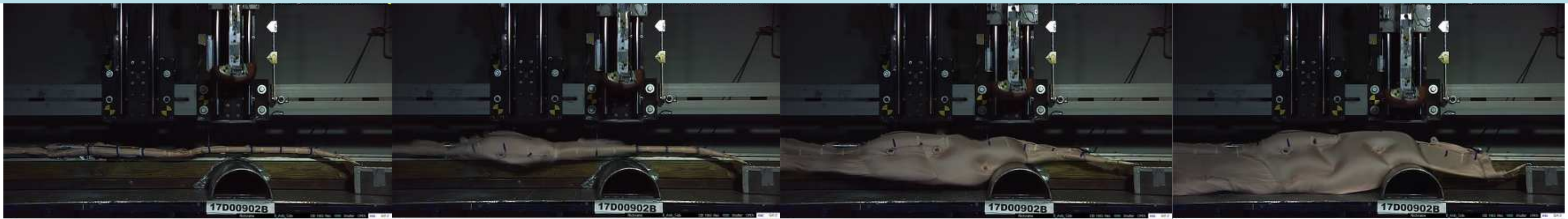


- Accord CAB DT Test – Test Result



- Accord CAB DT Test – Cushion Kinematics

Side View



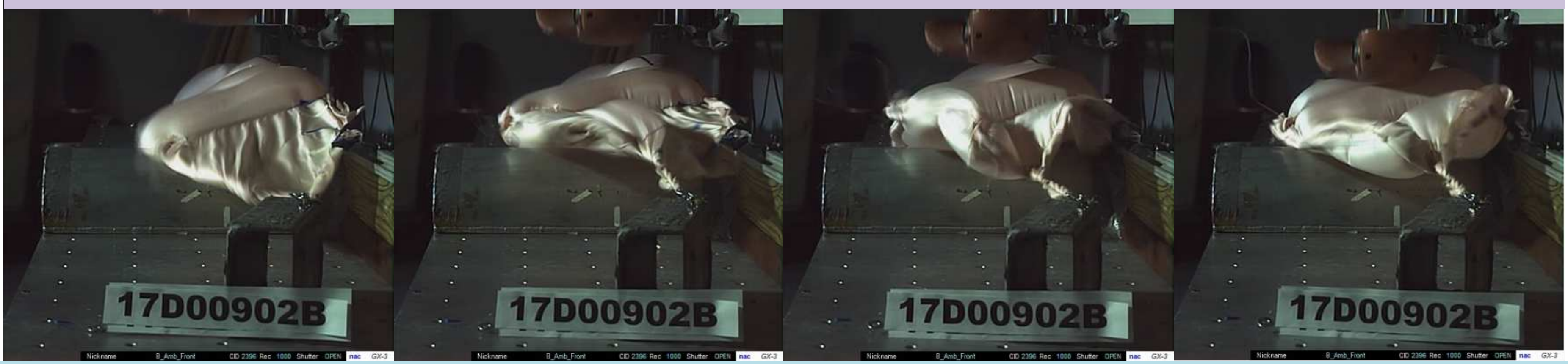
@TTF+0ms	@TTF+5ms	@TTF+10ms	@TTF+15ms

Front View

- Accord CAB DT Test – Cushion Kinematics (Cont'd)

Side View

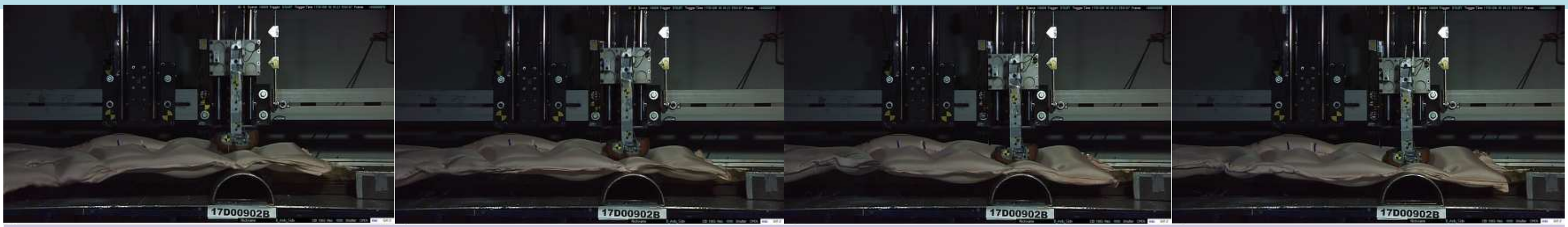
@TTF+20ms	@TTF+25ms	@TTF+30ms	@TTF+35ms



Front View

- Accord CAB DT Test – Cushion Kinematics (Cont'd)

Side View

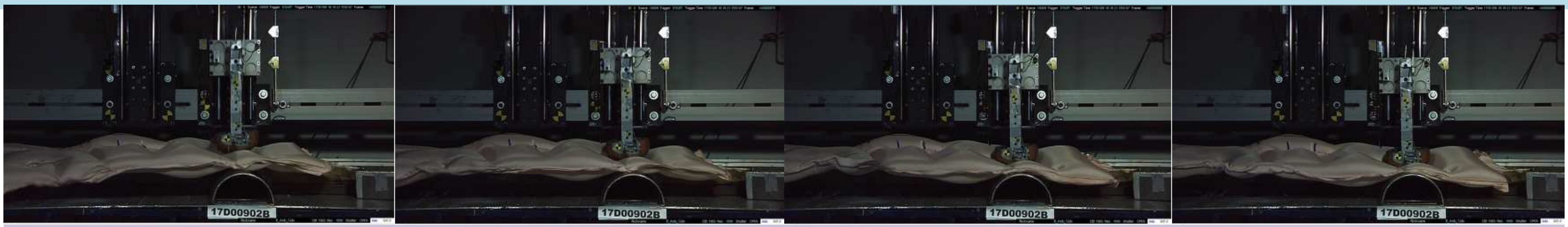


@TTF+40ms	@TTF+45ms	@TTF+50ms	@TTF+55ms

Front View

Accord CAB DT Test – Cushion Kinematics (Cont'd)

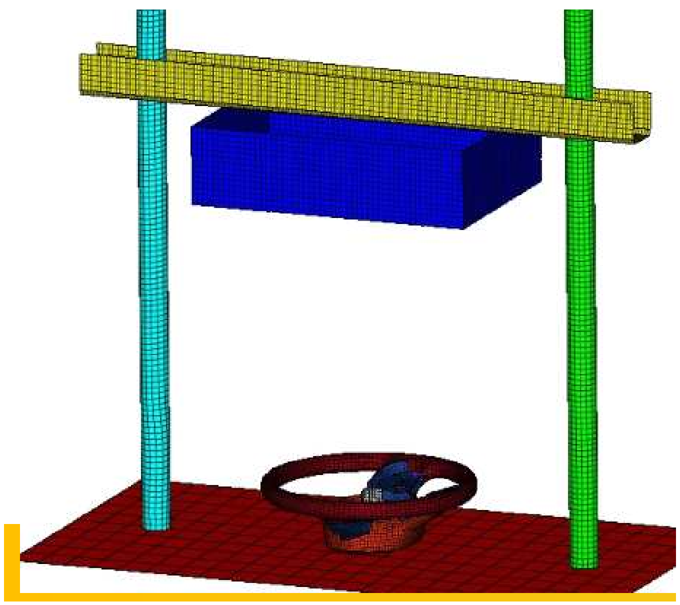
Side View

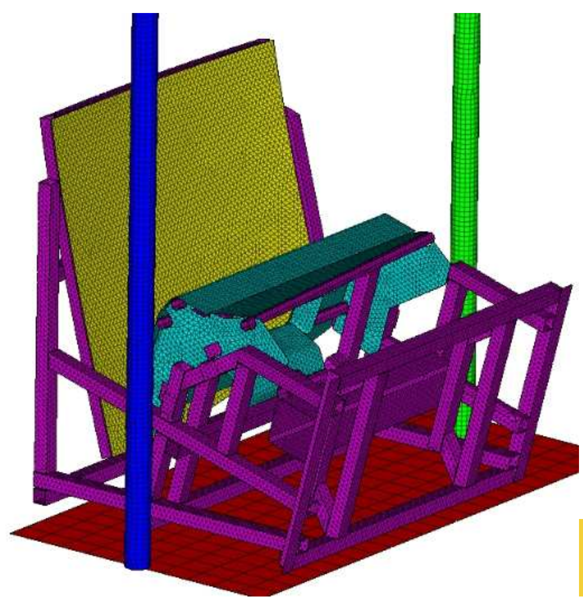


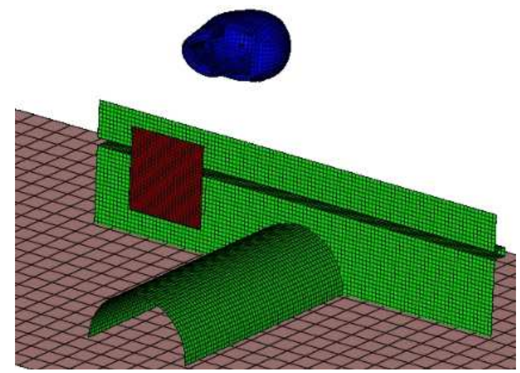
@TTF+40ms	@TTF+45ms	@TTF+50ms	@TTF+55ms

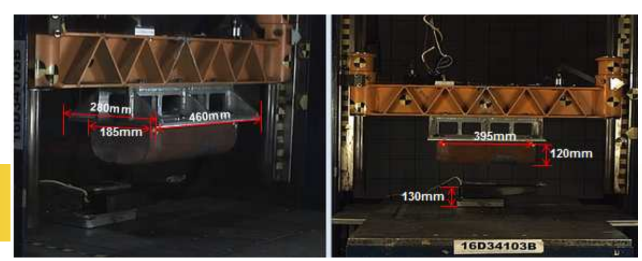
Front View

- Seatbelt Test Data – Reatractor/Webbing ElongationF-D curve, PT stroke and force curve
- Scanning CAD data / Pictures for DAB/PAB/SAB/CAB cushion
- Teardown analysis data – DAB/PAB/SAB/PAB module
- Inflator – mass flow & temperature curve for DAB/PAB/SAB/CAB inflator
- DT test data - DAB/PAB/SAB/CAB acceleration/velocity/displacement curve / test videos
- LS-Dyna models for generic DAB/PAB/CAB droptower, and SAB Impactor geometry data









Summary

- The seatbelt component test provided that MY14 Accord driver seatbelt had the 6.5% webbing elongation, 2.5 kN CFR load-limiter, and 115mm stroke retractor pre-tensioner.
- The teardown analysis for DAB/PAB/SAB/CAB was performed successfully as scheduled.
- The CAD(iges) data for DAB/PAB/SAB/CAB cushion pieces were delivered.
  .
- The PAB DT test was challenging due to the modification of IP fixture for reaction surface
- The tank test and gas analysis were conducted by KSS inflator team in Lakeland, FL.
- The LS-Dyna models for generic DAB/PAB/CAB droptower test environment were provided.
- The DT test data and test videos were delivered.

Q & A

★★★★★

DOT HS 812 545
August 2018

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

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