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Pressure Sensor Simulation Capability for Side Impact Sensing Calibration

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ABSTRACT

There is a growing interest in using pressure sensors to sense side impacts, where the pressure change inside the door cavity is monitored and used to discriminate trigger and non-trigger incidents. In this paper, a pressure sensor simulation capability for side impact sensing calibration is presented. The ability to use simulations for side impact sensing calibration early in the vehicle program development process could reduce vehicle development cost and time. It could also help in evaluating sensor locations by studying the effects of targeted impact points and contents in the door cavity. There are two modeling methods available in LS-DYNA for predicting pressure change inside a cavity, namely airbag method and fluid structure interaction method. A suite of side impact calibration events of a study vehicle were simulated using these two methods. The simulated door cavity pressure time histories were then extracted to calibrate the side sensing system of the study vehicle. The calibration result shows that both the airbag method and the fluid structure interaction method are capable of predicting the pressure change inside the door cavity for side impact sensing calibration purposes, albeit the former requires much less computer run time than the latter.

INTRODUCTION

Airbags have been widely used in frontal and side impacts to absorb a significant portion of the occupants' impact energy and to protect the occupants from impacting the vehicle interiors directly. Since the space between the occupant and the side structure is very limited compared to the frontal impact case, it requires a rather short sensing time to ensure the side airbags fully deploy in place to protect the occupant. There is a growing interest in utilizing door cavity pressure sensors to meet the side impact short sensing time requirements. With pressure sensors, the pressure in the door cavity is monitored, and the pressure change from any impact or intrusion is used to discriminate between deploy and non-deploy events.

The use of math-based tools has reduced the need for hardware prototyping and testing, which in turn reduces a vehicle's development time and cost. With the increase of model details and complexity, advanced characterization of material and structural behavior, and ever faster computer speed, fidelity and predictability of the crash models have been greatly improved in the last few years. An accelerometer sensor simulation capability has previously been developed and documented in [1, 2, 3, 4, 5, 6, 7]. The introduction of pressure sensors for side sensing impacts also requires such modeling capability to enable a math-based side sensing calibration early in a vehicle program to help the sensing calibration processes before all the test data becomes available. In this paper, a pressure sensor simulation capability for side impact sensing calibration development is presented. The ability to use simulations for side impact sensing calibration development early in the vehicle program development process could reduce vehicle development cost and time. It could also help in evaluating sensor locations by studying the effects of targeted impact points and contents in the door cavity. The vehicle crashworthiness model was originally developed for the LS-DYNA finite element solver. To fully utilize the available model, with some modifications and additions, for our study, we would like to continue the analysis in LS-DYNA Two modeling methods available in LS-DYNA for predicting pressure change inside a cavity, namely an airbag method and a fluid structure interaction method are employed and evaluated.

COMPUTATIONAL METHODS IN LS-DYNA FOR PREDICTING PRESSURE CHANGE

For a belted and in-position occupant, the front airbag will most likely be fully deployed before the occupant impacts the airbag in a frontal impact. Modeling of the front airbag using uniform pressure method, control volume technique [8], is suitable for such a simulation. For out-of-position (OOP) occupants who are near the unfolding airbag, simulating an airbag unfolding during the deployment is critical to predict the occupant kinematics. For such a simulation, the assumption of uniform airbag pressure may yield inaccurate kinematics of an unfolding airbag, while Arbitrary-Lagrangian-Eulerian (ALE) features may be more suitable in simulating such an airbag unfolding and result in better predictions of the occupant injury performance. However, the ALE method requires much more Central Processing Unit (CPU) time.

For simulating the deployment of an airbag, a commonly used modeling technique without jetting is *AIRBAG_HYBRID. It can predict the gas dynamics state of a closed volume. Pressure inside a closed volume will change due to the inflow and outflow of gases, the temperature fluctuation, and the volume change. This feature can be used to predict the overall pressure change for a door being compressed in a side impact and is used in this study and called "airbag method". It is different from modeling a side impact airbag which unfolds during the crash but rather simulates an airbag which already fills the cavity of the front door from the beginning of the simulation and has an initial pressure identical to the ambient air pressure. The pressure change inside the door chamber is much smaller in magnitude than the pressure change of an unfolding airbag.

For fluid-structure interaction problems, ALE has been used to simulate fuel sloshing in a fuel tank [9]. ALE has also been applied to study the interaction of an out-of-position occupant with an inflating airbag. The ALE method is used in this study for its ability to accurately predict pressure variation within a closed volume and for its relative familiarity to the crash community versus other similar methodologies, like Lagrange, SPH (Smoothed Particle Hydrodynamics), or Eulerian formulations.

EXAMPLE FOR COMPARATIVE STUDY

ALE METHOD

There are many variables in LS-DYNA that can affect the accuracy of a simulation. We will look into all the parameters in LS-DYNA and study their effect on the simulation results. Since our study objective is to analyze door cavity pressure change from side impacts, simple component simulations were conducted to understand the effect of pressure change due to impact speeds, leakage area, and pressure wave traveling path. A simple circular tank was generated with an opening vent hole on the top surface, and struck by an impactor with 5 kg mass and 10m/s initial velocity, as shown in Figure 1. A rigid wall is placed behind the tank to support it from moving away from the impactor during the impact. A rectangular vent hole, size of 28.9mm × 70.7mm, is created on the top surface, shown in Figure 2, so that the air can leak out when the pressure inside is greater than the ambient pressure. To study the effect of the parameters used in LS-DYNA, the pressure change inside the tank is monitored in our simulation, with one measurement point on the impact side and the other measurement point on the non-impact side. Air flow in the cavity resulting from the impact is shown in Figure 3. Based on this investigation, a proper set of variables will be determined initially and then further adjusted in full vehicle simulations to achieve acceptable full vehicle model correlations.

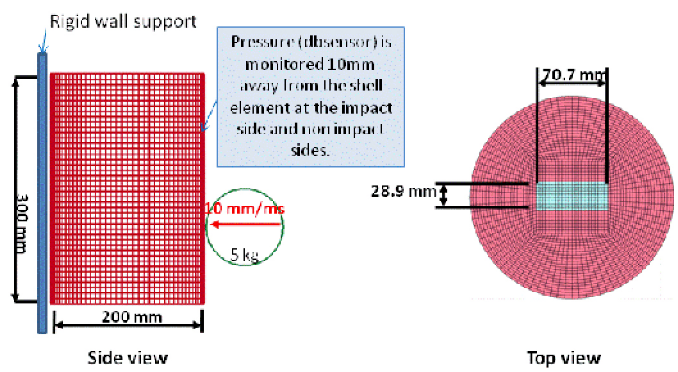

Figure 1. Example of the comparative study

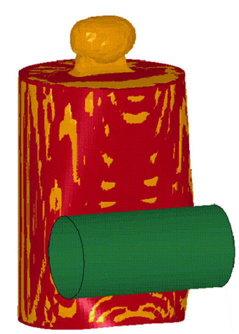

Figure 2. Deformation of the tank from impact and the air flow out of the compressed tank

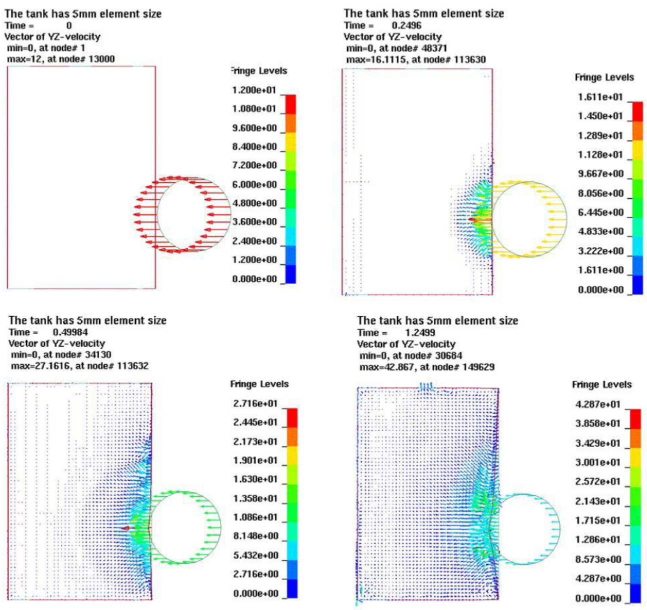

Figure 3. Air flow from the impact by using the ALE method

MESH SIZE OF AIR USING THE ALE METHOD

The mesh size of air in the simulations can affect how much of the air leaks out of the cavity and how the fluid and the structure interact in the simulations. In our example, the tank shell elements have a mesh size of 7 mm. The vent hole on the top surface has about the same width of 30mm as the side window opening between the door outer and inner panels [10]. In a real vehicle door there are other relatively large holes on the side of the door inner panel, however, a durable plastic sheet is generally used to cover the door inner panel to prevent the water from coming into the door trim and into the occupant compartment, so the holes are not considered as vent holes.

In Figures 4 and 5, the air ALE mesh sizes are varied between 10mm, 7.5m, 5mm, and 3mm with two coupling methods between the fluid and the structure, both tension and compression (by setting DIREC=1 in *CONSTRAINED_LAGRANGE_IN_SOLID) and compression only (setting DIREC=2). From the pressure changes in these figures, we conclude that we need to have an ALE mesh size of 5mm (or smaller) with at least 6 elements across the vent hole for such a simulation. An element size of 3mm will require many more elements and more CPU time. The conclusion of the ALE mesh size study in our example is in agreement with the recommendation from Livermore Software Technology Corporation (LSTC) that 6 elements across the vent hole [12] are required to accurately simulate fluid flow through a hole. Since the air and the structure interaction in side impact prior to the side airbag deployment time is mainly in compression, which is not like a fuel sloshing problem, setting DIREC=2 is adequate for most of the crash sensing simulations. If there is an unreasonable response after the pressure peak, as shown in Figure 5 for the 10 mm ALE mesh size, coupling both compression and tension between the ALE and the structure can help to eliminate it. To avoid larger noise in the simulation, it is also recommended that the pressure measuring point should be 10 mm off the shell surface, as shown in Figure 6.

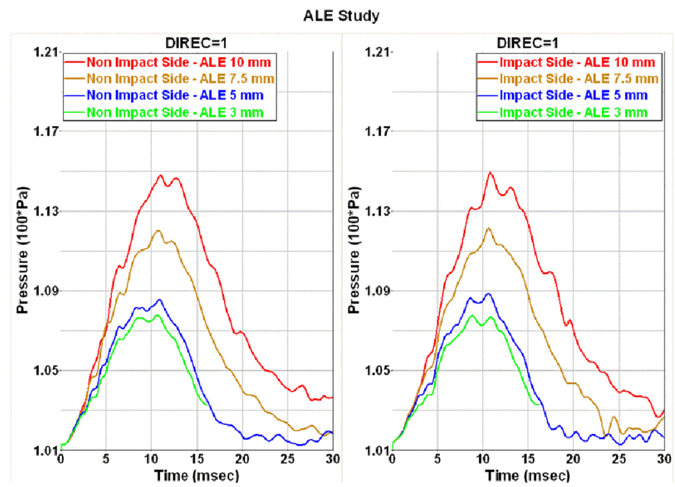

Figure 4. ALE mesh size study using both compression and tension coupling method (DIREC=1) with structure

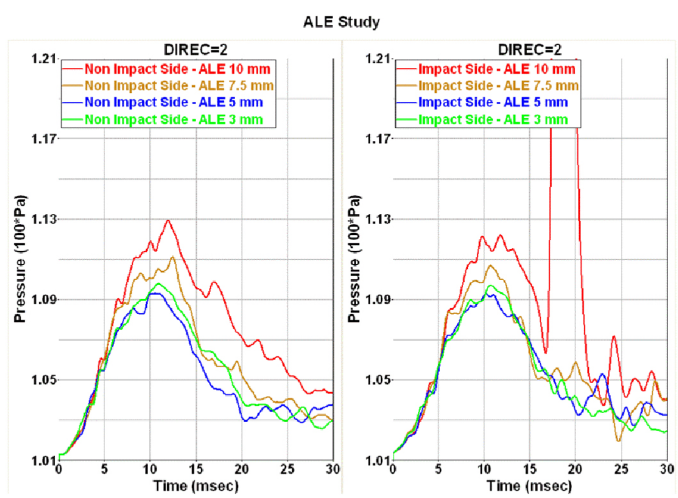

Figure 5. ALE mesh size study using only compression coupling method (DIREC=2) with structure

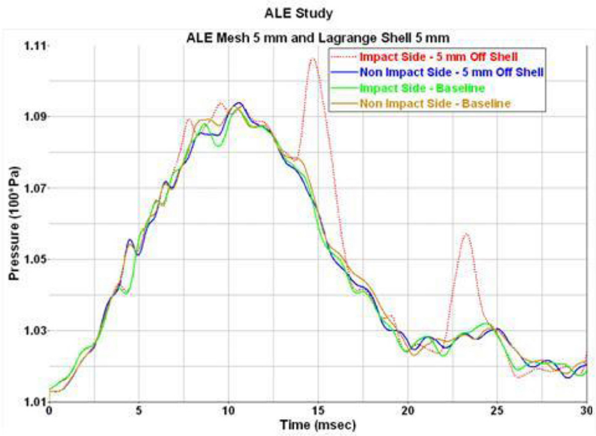

Figure 6. Sensor distance off the structure surface study - The baseline model has the measuring point off the shell surface by 10mm. With the 5 mm distance off the shell surface, the signal gets noisy.

AIRBAG METHOD

The *AIRBAG_HYBRID option in LS-Dyna is used in our study. The same ideal air properties used in the ALE method are used here as well. We adjust the airbag vent discharge coefficient in the *AIRBAG_HYBRID so that the pressure history obtained from the simulation has the best match of the peak pressure and overall pressure profile. The orifice coefficient is a function of the geometry of the vent hole and the pressure difference [11]. An orifice coefficient of 0.40 is consistently used in the full vehicle simulations as well. The comparison of the two methods, airbag method and ALE method, is shown in Figure 7. The pressure history from the ALE method shown in Figure 7, is the averaged pressure from the impact and the non-impact sides. From these two simulations, the uniform pressure airbag method has a slight delay in ramping up the pressure before the peak.

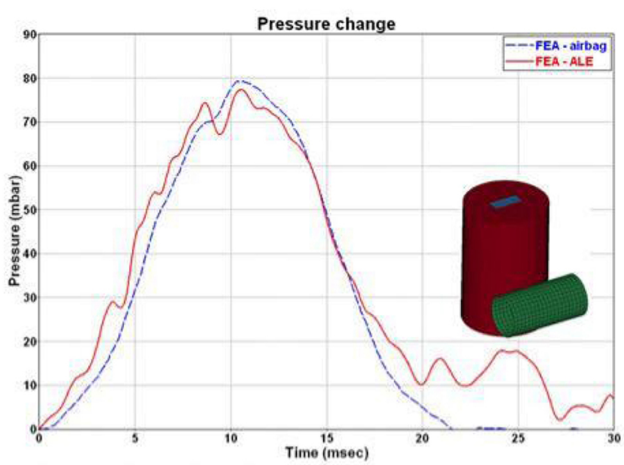

Figure7. Airbag versus ALE modeling method

FULL VEHICLE SIMULATION FOR SIDE IMPACT SENSING CALIBRATIONS

For the full vehicle analysis, it is necessary to determine the air leakage passage from the door cavity in an impact. The air flows out of the door cavity mainly from the aperture where the side door window slides between the door inner and outer panels. To discount the thickness of the window and allow enough width for air to escape out of the aperture, two thirds of the aperture is defined as the vent hole, while the rest of the gap is blocked in the model. After balancing the need to have at least six ALE elements across the vent hole, the total venting area in the simulation model is the same as the real vehicle. As shown in Figure 8, additional null material is used to cover the holes that exist in the door inner and outer panels as well as a possible gap between inner and outer panel because both the airbag and the ALE methods require an enclosed volume.

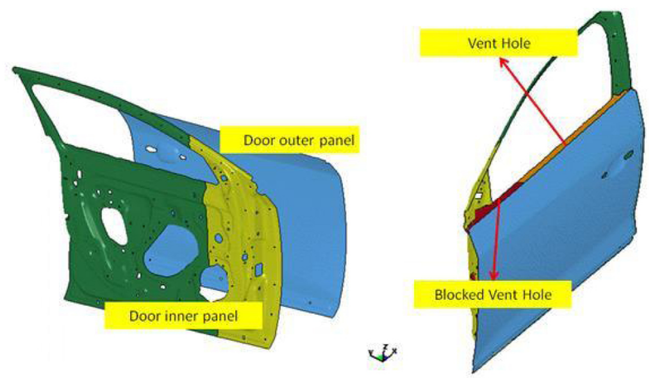

Figure 8. Side door inner and outer panels with holes and the vent hole between the panels

Table 1 lists the side impact sensing calibration matrix. The events include three high speed MDB (moving deformable barrier) impacts, two oblique pole impacts, and two low speed MDB impacts. The target airbag triggering times were determined by sensing performance engineers to ensure timely deployment of the airbag for occupant protection. Other immunity tests, such as door slams, hammer blows, bicycle hits, curb impacts, etc., are not included in this study.

Table 1. Side sensing calibration simulation matrix.

Simulation Condition	Speed (km/h)
MDB1	62
MDB2	50
MDB3	50
Oblique pole (Front row 50th/5th)	32
Oblique Pole (Front row 50th)	16
MDB1	16
MDB3	16

BASELINE VEHICLE MODEL

The baseline FEA model was originally developed to evaluate structural and occupant performance. Since it is critical to have a good vehicle model for sensing simulation for the first few milliseconds, the velocity correlation of the vehicle model at the B-pillar and at the center of gravity of the MDB was verified as shown in Figure 9. The intruding velocity at the mid-section of the B-pillar correlates very well with the available tests.

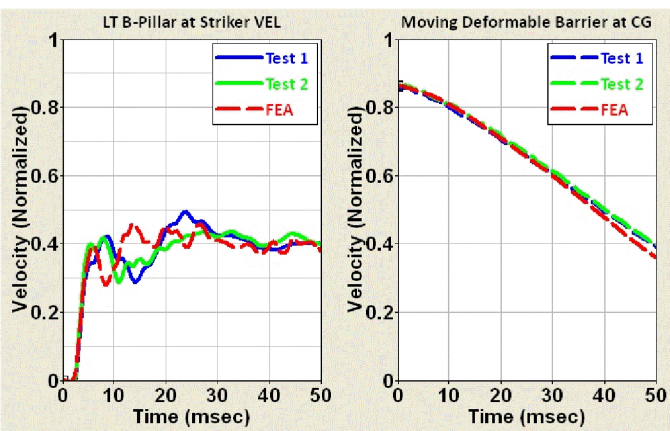

Figure 9. Velocity correlation of the vehicle model at B-pillar and at the MDB1 center of gravity, test condition MDB1

After checking the structure velocity and MDB velocity correlations, the model is accepted, and we proceed to apply the pressure modeling technique and conduct the simulations. The pressure sensor for this test condition is placed on the inside of the door outer panel. Correlation of the ALE and the airbag method simulation results are shown in Figure 10. Both of the simulations show acceptable agreement before the pressure reaches its peak. After the door chamber pressure reaches the peak, the ALE method has a better overall correlation than the airbag method. However, the pressure profile after the airbag deployment target time of 6ms would not be used in the sensing calibration development. It would be more important in the case of no-deploy events since the entire pressure profile may be needed in the sensing calibration development to ensure that the pressure profile does not cross specified thresholds.

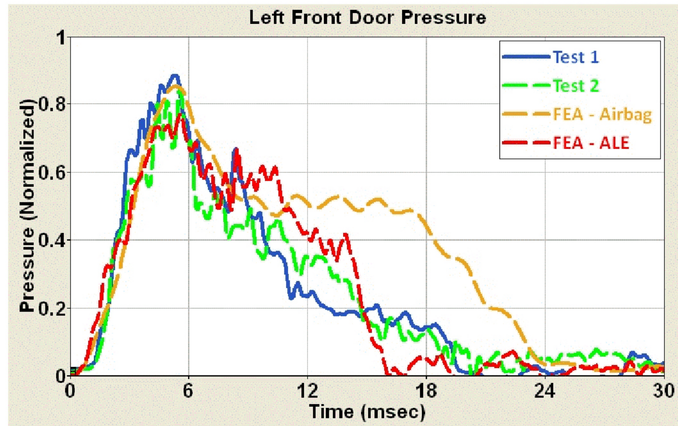

Figure 10. Pressure change from two tests and two simulations, one using the airbag method and the other one using the ALE method

Using the ALE method, the ALE mesh can move with the door during the side impact by defining *ALE_REFERENCE_SYSTEM_GROUP and *ALE_REFERENCE_SYSTEM_NODE. The ALE mesh can expand and rotate with the structure in such a way that it does not require additional 1 million huge ALE elements to allow for the structure to flow through the ALE mesh to study the interaction. This expanding and rotating feature works very well for folded front or side airbag deployment simulation. A folded airbag will deploy and expand into the space, without much rotation. That works well for side door impacts until the door deforms and rotates severely. The three selected nodes cannot represent the deformation state of the door and the ALE mesh can no longer cover the structure, this generally happens after 30 milliseconds. Some of the side impacts cannot be simulated to the specified termination time because the ALE mesh can no longer contain the structure, and the simulations become unstable. However, the simulated signals are still long enough to be useful for side impact sensing calibration purposes.

To monitor the pressure change at different locations, four pressure sensors were placed on the front door inner panel for a second side impact test, as shown in Figure 11. This side impact simulation was conducted and the pressure change at the four locations from ALE and airbag methods are plotted, together with the test results, in Figure 12. For the airbag method, the pressure history is identical for all four points, which is unlike the ALE method. The pressure history at the point 2 is lower than the test before 5 milliseconds. This difference can be attributed to the size of the vent hole above the sensor location, which is larger in the simulation model than in reality, while the other one third of the aperture above the point 4 is blocked artificially. With 5 mm ALE mesh size, one cannot accurately simulate the air flowing out of the small window aperture. The pressure change correlation at the point 1 seems to be slightly more accurate than at the other locations in this simulation. The velocity history of the structure at the B-pillar is shown in Figure 13. After correlating the model with both high speed impact tests, we then proceed to simulate the rest of the sensing events, and results of the simulations are shown in Figures 14, 15, 16.

Comparing results from all the simulations and the tests, we conclude that the correlations of the pressure change before reaching peak pressure for both methods are acceptable. The pressure profile of the airbag method is slightly delayed compared to both the tests and the ALE method. The initial phase of the pressure ramp up inside the door cavity is most important in determining when to deploy the airbags. The quality of the correlation between simulations and tests can also be judged by whether the airbag deployment times using the simulation data match the deployment times using the test data. If this is the case, it demonstrates that the combination of simulated door pressure signal and acceleration signal at the SDM is capable of predicting the measured deploy times from the tests.

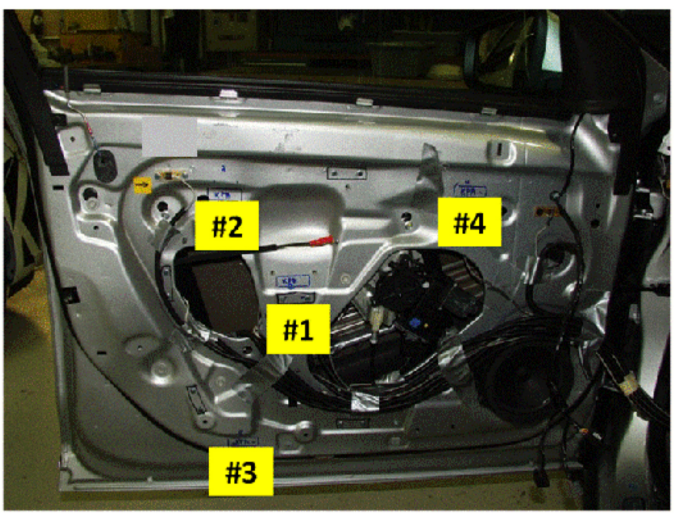

Figure 11. Pressure sensor locations for MDB2 side impact test

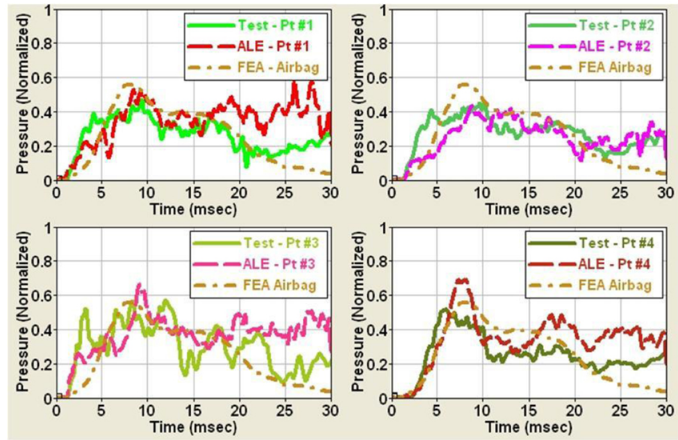

Figure 12. Pressure signals from the simulations and the test at four different locations on the front door inner panel

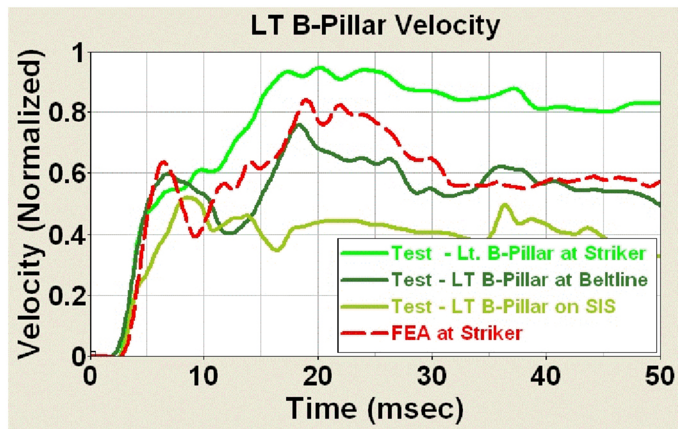

Figure 13. Velocity history of the MDB2 simulation

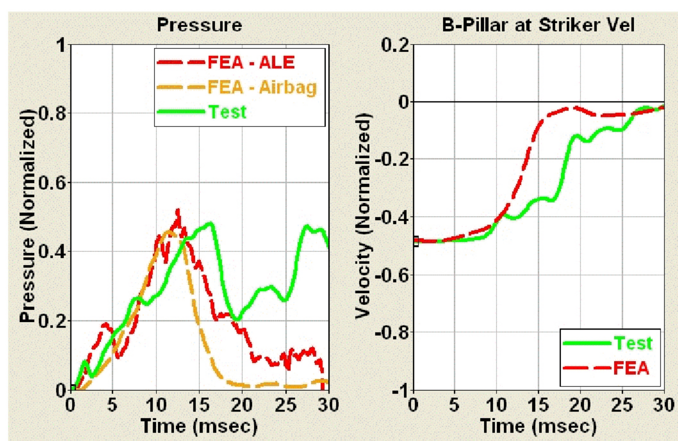

Figure 14. Oblique pole impact 32kph for the 50th

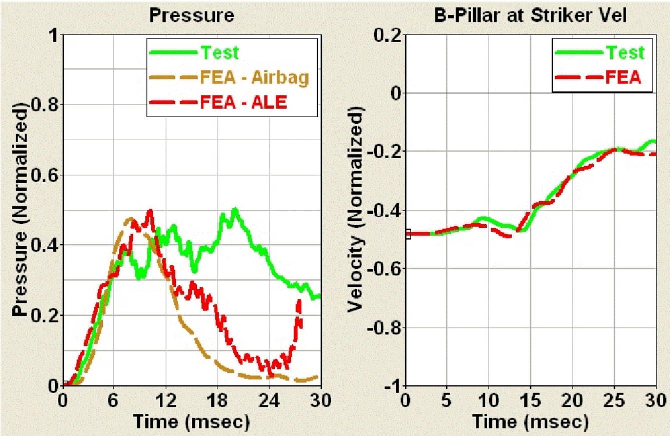

Figure 15. Oblique pole impact 32kph for the 5th

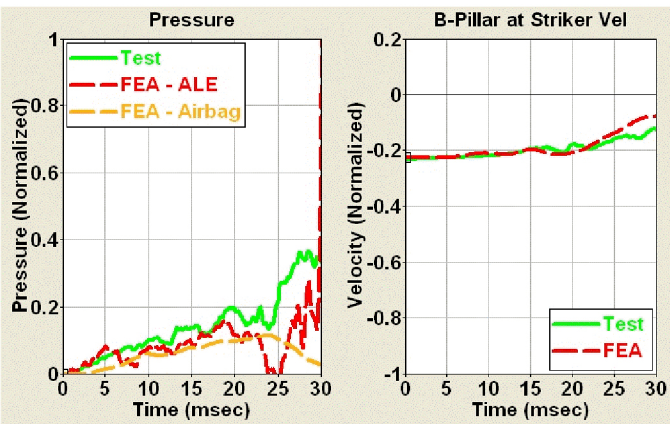

Figure 16. Oblique pole impact 15kph

SIDE IMPACT SENSING CALIBRATION

Results of the FE analysis, pressure signal in the left front door, and acceleration signal at the SDM (Sensing Diagnostic Module) on the center tunnel, along with airbag deployment target times were sent to the sensing supplier for sensing calibration development. Results of the airbag deployment times from the simulations and the tests are shown in Table 2. It suggests that an initial sensing calibration based on FE analysis is feasible for an early vehicle development process using either one of the two LS-DYNA finite element methods described in this report (ALE method or airbag method).

Table 2. Calibrated airbag deployment times for the simulations of ALE and airbag methods

Test Condition	Speed (kph)	Airbag deployment time difference from target (ms)	
		ALE	Airbag
MDB1	62	+2*	+2
MDB2	50	+1.75	+1
MDB3	50	+1.25	+1
Oblique Pole ($50^{th}/5^{th}$)	32	+0.5/0	+1
Oblique Pole (50^{th})	15	+9.5	+1.25/0
MDB1	16	0	+6.75
MDB3	16	0	0

**positive means that the simulation has the deployment time later than the test*

SUMMARY/CONCLUSIONS

The ALE method requires more CPU time than the airbag method, but predicts more accurate results in the early phase when the pressure ramps up, and it also simulates local pressure variation, whereas the airbag method can predict only the average chamber pressure.

For side impact sensing calibration development with the vehicle model, we demonstrated that both the ALE method and the airbag methods can be used to simulate the pressure change inside the door cavity with acceptable correlation. A 16kph low speed MDB1 and - MDB3 tests are used as the immunity events for the calibration. A total of eight simulated events are used for calibration development. All simulated events, with either the ALE method or the airbag method, predict the deployment times with good accuracy.

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