Gas Dynamic Simulation Capability for Side Impact Pressure Sensing Calibration

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1 Abstract

A method has been developed that uses crash simulation models to provide side impact door pressure sensor data to the sensor calibration engineers much earlier than was hitherto possible, thereby affording the opportunity to reduce the time period required for physical sensor calibration in the vehicle development programme.

2 Introduction

Vehicle side impacts must be detected by some sort of sensor in order to trigger the operation of the passive safety systems (i.e. the airbags and seat belt retractors). Ordinarily this is achieved using accelerometers to measure the acceleration of the impacted B-Pillar and sill, the signals from which are filtered and evaluated to determine the severity of the impact. In recent years pressure sensing technology has become widely used. This type of sensor is mounted in the door and measures the change in pressure experienced within the door cavity during a side impact as the door is deformed and its volume reduces. The advantage of pressure sensing is that it allows an impact to be detected earlier than would be possible with only acceleration sensing, and also produces a much smoother output signal.

With the development of the gas dynamic Corpuscular Particle Method (CPM) in LS-DYNA® it is possible to simulate the behaviour of the air within the door cavity during impact and using the pressure output from the simulation models as an input for the sensor calibration work.

3 Methodology and Process Flowchart

The method is developed through component metal box impact and validated through correlations of vehicle tests of two types of vehicles: saloon and SUV.

Impact tests had been carried out on steel boxes with a variety of sizes of hole cut in them to vary the level of venting. Pressure data from these tests was recorded. The strategy was to use this pressure data to validate simulation models of the box impacts by investigating various parameters relating to the CPM implementation, and thereby yield an understanding of the feasibility of using this method for pressure sensing prediction.

Side impact pressure data from two different types of vehicle was then used to validate the CPM pressure sensing methodology in the complete vehicle models. A procedure for assessing the pressure sensor response during side impact then was developed.

Ordinarily, CPM uses temperature and mass flow properties of inflating gases to inject mass into an airbag model, thereby pressurising and inflating the volume. In order to use CPM to model a large static volume at atmospheric pressure which could then be used to measure the pressure response of an impact, the capabilities of the CPM had to be investigated and used in a different way.

Drawing parallels with the usual way of setting up a CPM airbag model, an alternative method of building a large static volume using CPM was developed. Figure 1 shows the methodology development flowchart.

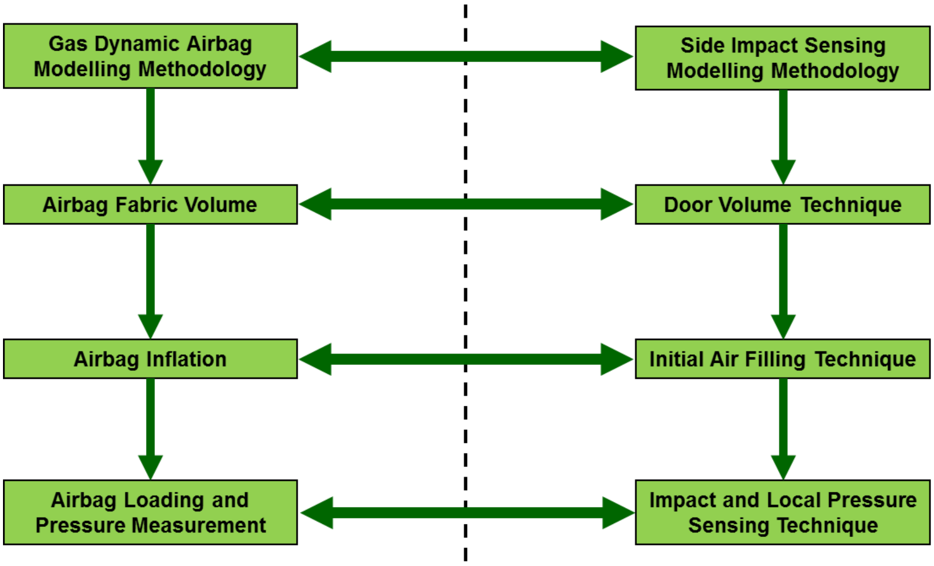

Fig 1: Side Impact Sensing CAE Methodology Development Flowchart

4 Box Impact Tests

Fifteen steel boxes were created with 5 different venting configurations as shown in Figure 2. They were impacted with a cylindrical impactor of 150 mm diameter, whilst 4 pressure sensors recorded the pressure within the boxes. The tests showed pressure increases of between 1 and 10 kPa during impact depending on the configuration of the vent holes.

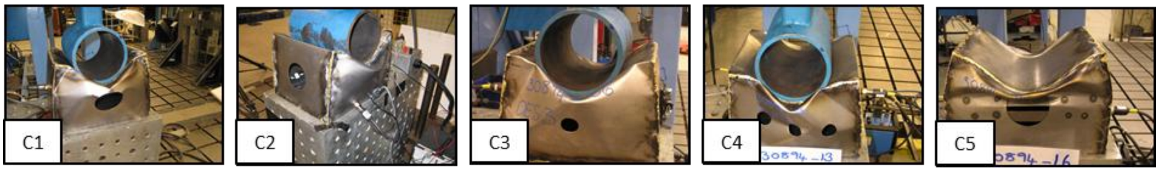

Fig 2: Box impact test configurations

5 Methodology Development - Box Impact Modelling

5.1 Parameters Study

A simple box model was created. This model needed to be made aware of the atmospheric pressure inside and outside of the box. Unlike an airbag, the static box had no inflator in reality, as atmospheric pressure is always present. CPM uses particles to represent dynamic fluid behaviour within the volume, whilst a general atmospheric pressure is applied from the outside to the elements forming the boundary of the volume definition. Particles can escape from the volume through vents when the volume is compressed.

There are two options in LS-DYNA that take into account the initial conditions of a volume using particles: one that uses the control volume (CV) method (IAIR = 1) and one that uses the particle method (IAIR = 2). As the dynamic behaviour of fluid within the door was expected to be of key importance from the outset, the CV method would not be suitable.

The IAIR = 2 option allows particles to be distributed throughout the volume by seeding particles on the faces of the elements defining the volume and letting these particles diffuse through the volume during an initialisation phase, so that by the end of this initialisation phase particles are evenly distributed and the pressure is uniform throughout the volume. Extra simulation time must be allowed for in order to run the initialisation and the impact event must be delayed so that it begins once initialisation has finished.

The particle method permits the definition of local sensors to measure pressure at specific points within a model, much like a sensor in a physical test will measure only the pressure local to its mounting point. A CPM sensor is a region in which all particles that are contained within or pass through it are used to calculate the local pressure.

Three different sensor sizes (2 spherical and 1 cylindrical) and three different numbers of particles were used to define a range of particle densities, whilst four sensors in the box measured the pressure during initialisation. The sensor responses were assessed using the matrix in Figure 3:

Initial Box Volume (L)	No. of particles	Initial Particle Density (-/L)	Sen. radius (mm)	Sen. length (mm)	Sen. Vol. (L)	Particles per sensor
12	100000	8333	10	0	0.004	35
12	100000	8333	25	0	0.065	545
12	100000	8333	25	50	0.098	818
12	500000	41667	25	50	0.098	4091
12	2500000	208333	25	50	0.098	20453

Fig 1: Particle sensitivity matrix

Four sensors were positioned in different faces and recorded the pressure (Fig 2). Increasing the number of particles encompassed by the sensor showed the level of resolution achievable (
Fig 3).

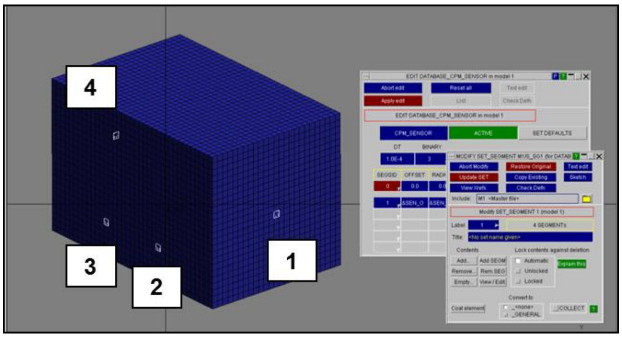

Fig 2: Box sensor locations

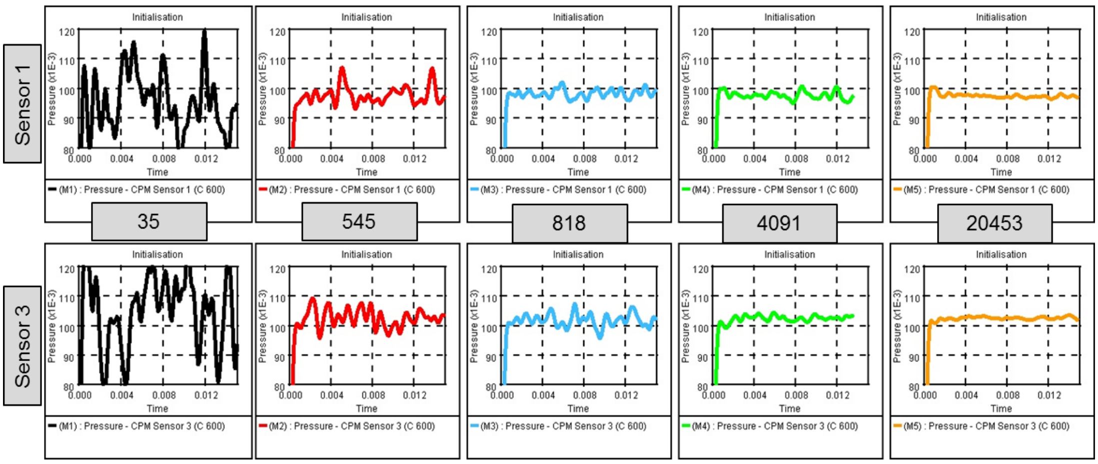

Fig 3: Sensor sensitivity results

The greater the number of particles covered by the sensor volume, the less noisy the pressure reading. Even though the box is static and at atmospheric pressure, a certain level of noise is evident in each case, becoming less significant as the number or particles encompassed by the sensor increases. 4,000+ particles give a reasonably smooth pressure reading, although depending on geometry this may not always possible to achieve however, but a value of a least 1,000 should be aimed for.

The difference in equilibrium pressures shown by the sensors is a result of the sensors being on the CPM domain decomposition boundary, and can be overcome by modification of the domain decomposition parameters, or by the inclusion of the NP2P parameter in the *CONTROL_CPM card in future versions of LS-DYNA.

5.2 Box Impact Correlation

Analysis of the box impact test data showed pressure rises of between 1 kPa and 10 kPa depending on the venting configuration. Models of the five box designs and the cylindrical impactor were created. Local pressure sensors were defined and positioned according to the tests, with most designs featuring two on the back and one on each end face. Vent holes were covered with nulls shells created in a separate part, to which venting was specifically applied in the *DEFINE_CPM_VENT card, and the internal baffles in box design C5 were defined as internal components within the *AIRBAG_PARTICLE card.

The same vent efficiency was applied to all models. The models were allowed to initialise before the impact occurred, and the pressure responses from the impact simulations were recorded. As expected, particles could be seen exiting the volume through the vent(s) as the box was impacted.

The simulation results shows that the pressures profiles measured in the physical box tests can be reasonably well modelled as shown in Figure 6 as an example.

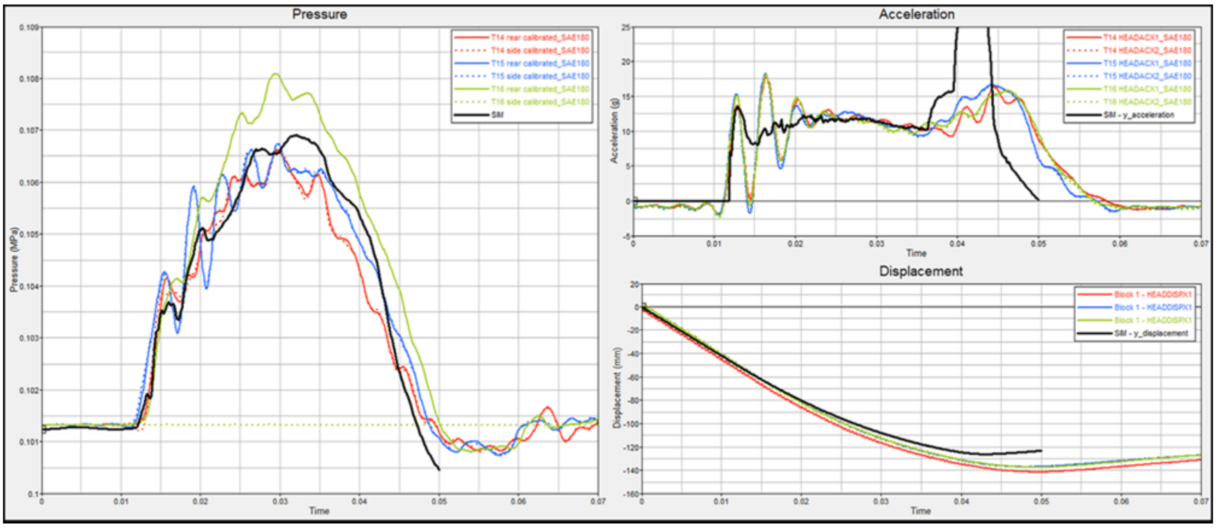

Fig 4: Box impact simulation example

6 Methodology Validation - Vehicle Side Impact Correlation

As stated before, side impact pressure data from two different vehicles (saloon and SUV) was available. The data was used to validate the pressure sensing method to a level where it could predict the pressure response seen in the tests.

6.1 Door Volume Creation

To create door volume for pressure sensor modelling, parts formed the door cavity are coated in null shells and the null shell parts define the closed volume. This would allow the user to be selective about precisely how the door volume is defined. A low stiffness and low density null material was created, along with a thin section and all of the parts required for the CPM volume definition were coated in null shells.

The use of a null shell coating permitted more flexibility in the door volume definition. For example, in the SUV case the door inner panel also includes the window frame structure as shown in Figure 7, but this could be omitted for the CPM volume definition. Likewise, flange overlaps could be simplified in the sports car case without modifying the original models.

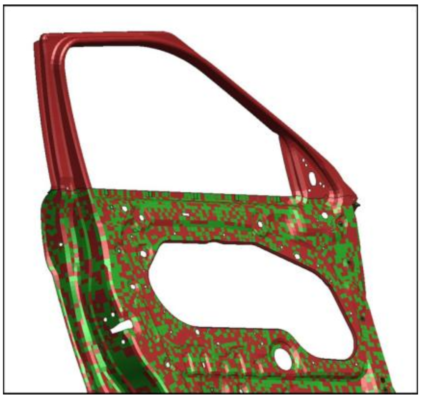

Fig 5: CPM volume definition using null shells

Internal components such as window guides, impact bar, electric motor and door lock were coated in null shells so they could be represented in the door volume definition too. Holes in the panels were filled in with null shells in a separate part as shown in Figure 8.

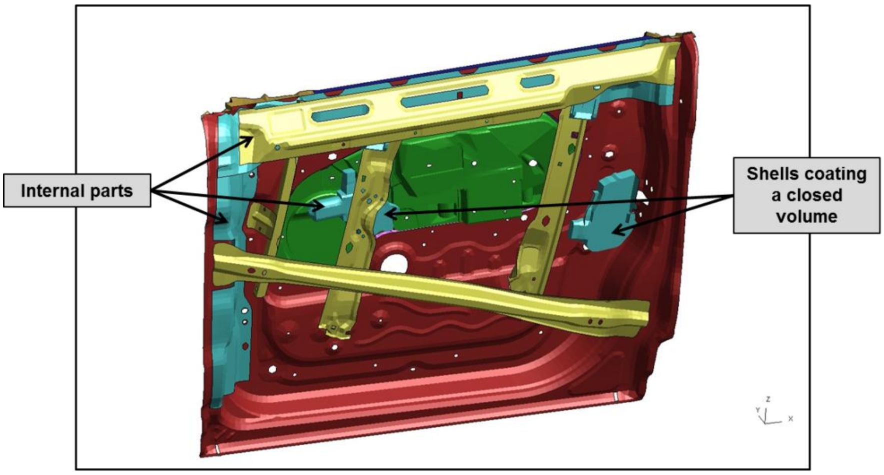

Fig 6: Internal components of the door volume

6.2 Initial Air Filling

Before model submission, it was necessary to adjust the position of the impactor to allow the door volume to undergo an initialisation phase before the impact begins. Duration of 10ms was used for the initialisation, after which the particle distribution and pressure readings were checked to ensure that the pressure had stabilised at atmospheric pressure and that the particles were uniformly distributed through the volume. Figures 9 and 10 show the initial air filling and stabilised pressure plot.

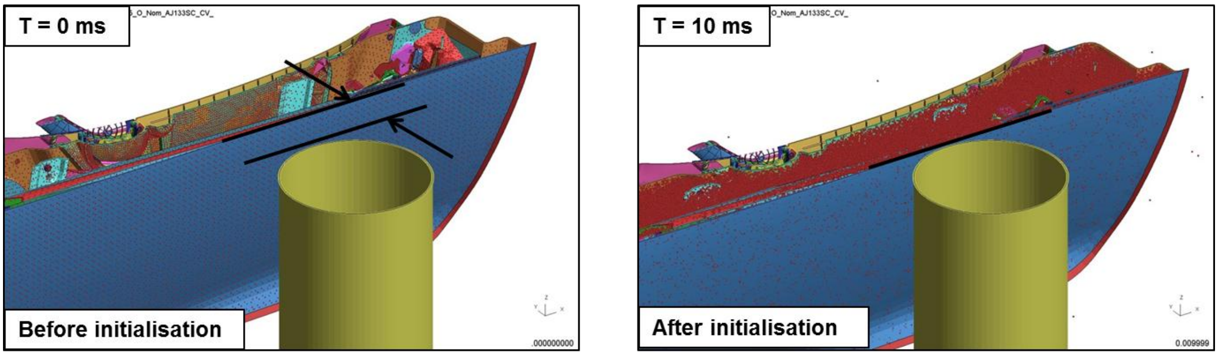

Fig 97: Particle initialisation

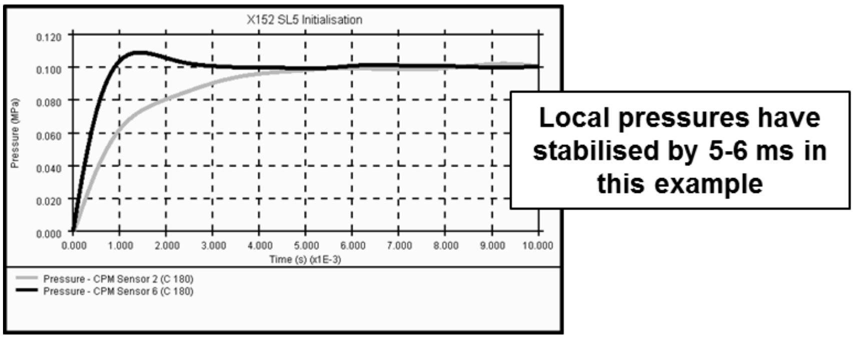

Fig 10: Pressure initialisation

6.3 Validation Results

Eight load cases were analysed for each vehicle to assess the performance of the door pressure prediction. They were:

- FMVSS 214 Angled Pole Impact - 50%-ile
- FMVSS 214 Angled Pole Impact - 5%-ile
- IIHS Side Impact Barrier
- USNCAP Crabbed FMVSS214 Barrier
- No Fire Non-Crabbed FMVSS214 Barrier
- Must Fire Crabbed FMVSS214 Barrier
- Angled Pole Impact – 5%-ile Pole Position
- Angled Pole Impact – 50%-ile Pole Position

Figure 11 shows CAE models of SUV and saloon in side impact pressure sensing simulation.

Figures 12-15 show the level of correlations achieved using the method developed above for SUV vehicle. Figures 15-19 shows the correlations for saloon vehicle.

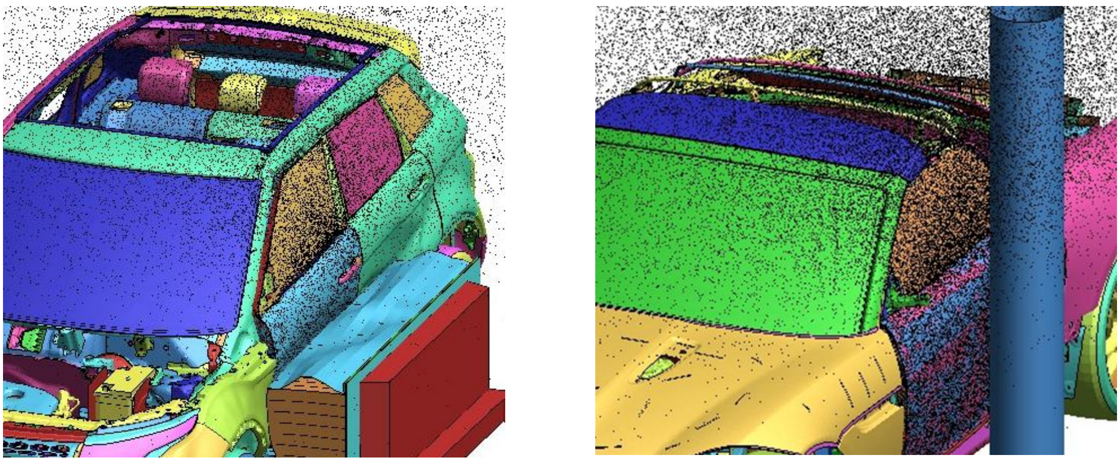

Fig 11: CAE Models for SUV and Saloon

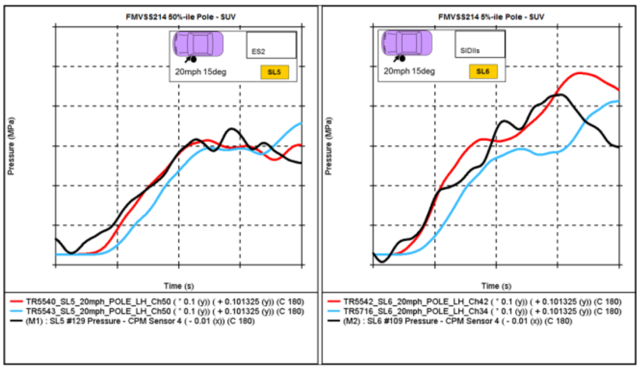

Fig 12: FMVSS 214 Pole Tests - SUV

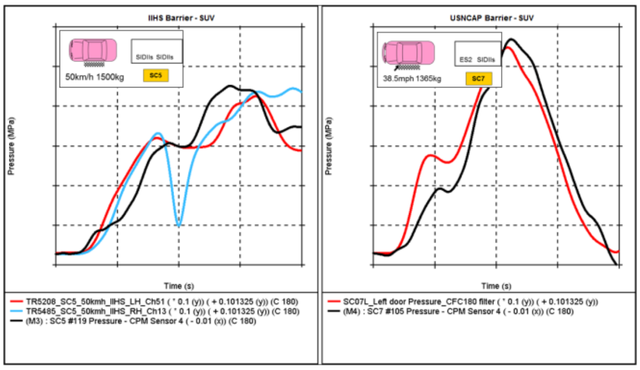

Fig 13: Barrier Tests - SUV

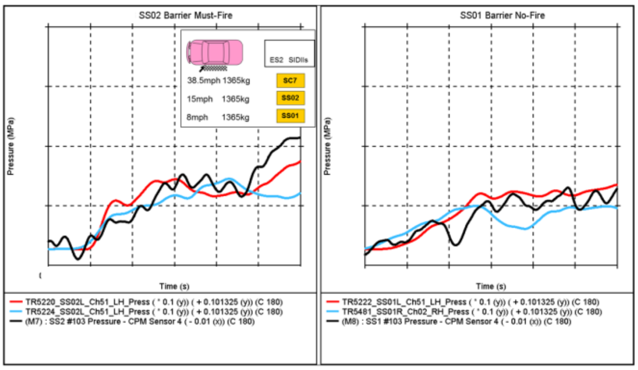

Fig 14: Barrier Tests: Must Fire and No-Fire - SUV

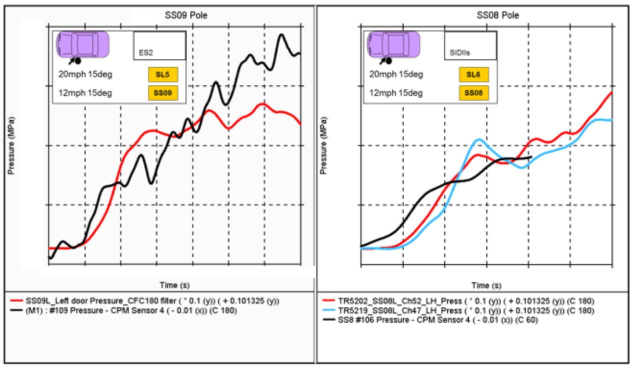

Fig 15: Pole Tests: Must Fire and No-Fire - SUV

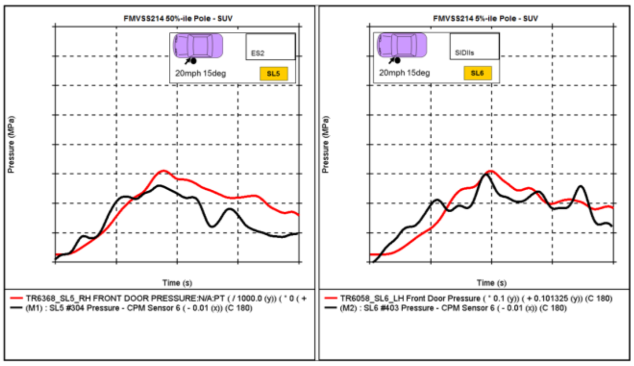

Fig 16: FMVSS 214 Pole Tests - Saloon

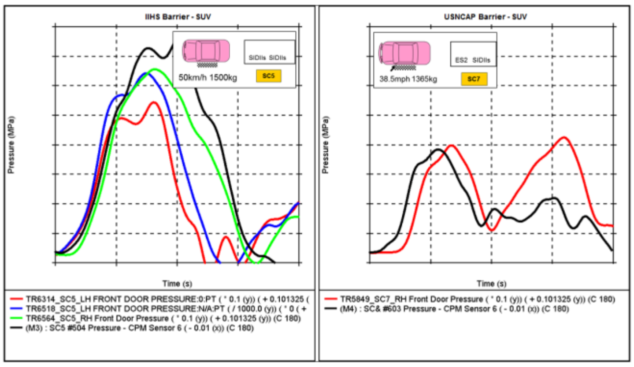

Fig 17: Barrier Tests - Saloon

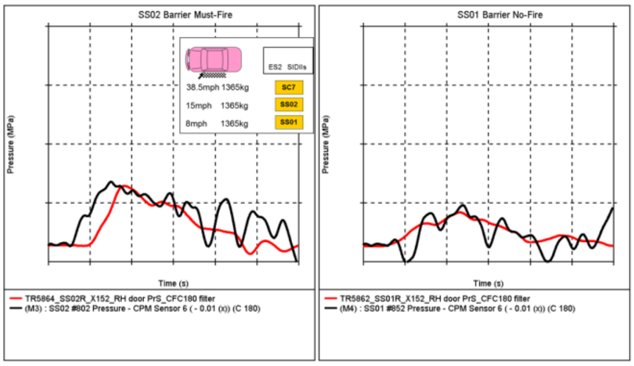

Fig 18: Barrier Tests: Must Fire and No-Fire - Saloon

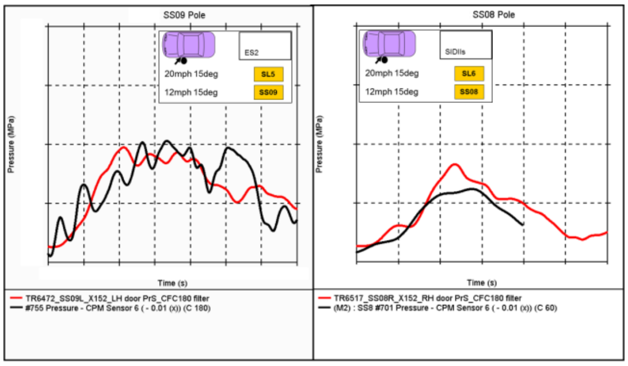

Fig 19: Pole Tests: Must Fire and No-Fire - Saloon

The pressure rise rate and peak pressure for both types of vehicles are well predicted by the method using the same set of correlation parameters. For sensing purpose, pressure rise rate and peak pressure are two important control factors. By discussing the CAE results with sensor calibration suppliers and running the sensor algorithms, the CAE data provides very similar fire times to those calibrated through physical tests data.

7 Extended Applications

The method developed above can be also used for two following extended applications.

7.1 Trim Ballooning

It was noticed that air pressure inside the door cavity can have an influence on the intrusion of the trim during impact. The air pressure forces the trim to intrude earlier, in some cases by 30 mm at 16ms, as shown in Figure 20. This was verified by comparing the CAE model with physical tests. Early inboard movement of trim due to ballooning reduces the gap between the door trim and seat, which is critical for side airbag deployment. Taking into account the door cavity pressure would improve the accuracy of the side impact CAE models.

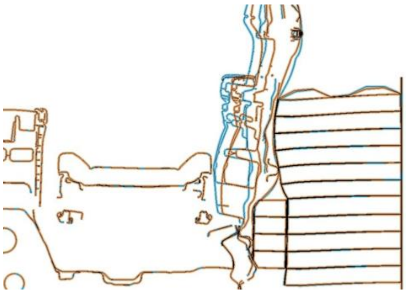

Fig 20: Trim Ballooning Effect

7.2 Sensor Location Study

It has been noted that the proximity of the sensor influences the magnitude of the pressure signal. As the method provides local pressure measurement, it can be used to predict the pressure response in different positions and assess the optimal position in which to locate the sensor. This gives the sensing team a virtual toolset to optimise the sensor location in the early design phase. Figure 21 shows the variation in pressure response to sensor location.

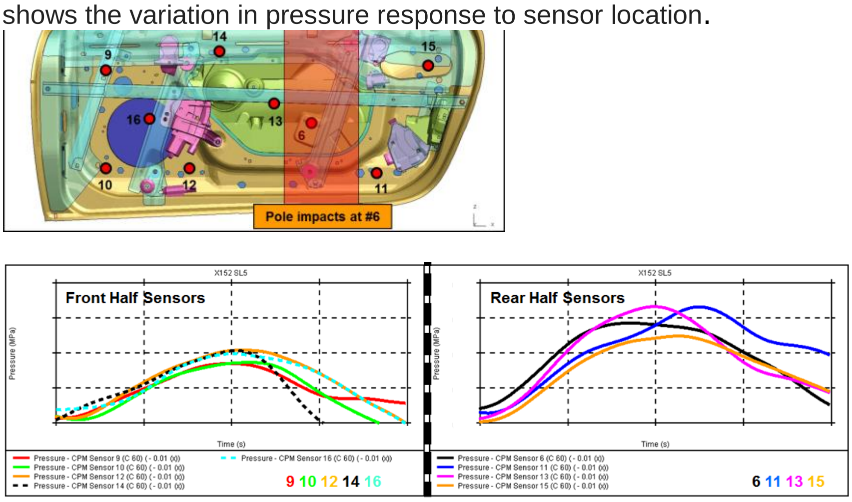

Fig 21: Sensor Locations

8 Summary

The method developed through this work has shown that it is possible to obtain a reasonable prediction of the pressure rise within the door cavity of different vehicles during the onset of an impact for a variety of load cases. These predicted pressures can be used by the sensor calibration team to begin setting sensor threshold values much earlier than they would otherwise be able to, thus affording the opportunity to save weeks of calibration time and also potentially remove several vehicles from the crash program.

9 References

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