Investigation into the rising air pressure inside the door during side impacts

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ABSTRACT:

A crucial point in side impacts is the rapid intrusion of the side structure of the door into the passenger compartment. In the initial stage of the crash it is essential to provide sufficient space between occupant and door trim to enable a proper unfolding of the side airbag. This problem can be alleviated by using the rising air pressure inside the door as an additional input for crash sensing. When combined with the common acceleration sensing on the centre tunnel or B-Pillar it is feasible to increase the sensitivity of the impact detection so that an earlier airbag triggering in side impacts can be achieved. However, because of the introduction of more demanding side impact test configurations this phenomenon still needs to be investigated.

In the early development process side impact simulations are usually employed to estimate the available space for airbag unfolding. But these simulations have shown some discrepancies if kinematics of the door trim intrusion during the airbag unfolding phase is compared to the experiments. This can be attributed to a lack of consideration of the air inside the door. A method to simulate this phenomenon which incorporates fluid-structure interaction is given in LS-DYNA. Recent developments in this software allow the use of an Arbitrary Lagrangian-Eulerian (ALE) solver and therefore make it possible to simulate the airflow inside and out of the door during a side impact. Using this approach, the dynamic pressure distribution inside the door and the loss of pressure due to outflowing air was simulated. Within the scope of this study the predictability of the pressure signal recorded for crash sensing and the additional air-induced intrusion of the door trim which reduces space for airbag unfolding is investigated in comparison to the different side and pole impact experiments.

INTRODUCTION

In view of increasing demands on the predictability and accuracy of side impact simulations, models have become more and more detailed over the years in order to accurately predict the risk of injury to the occupant. However, there is a shortage of information about the influence of air inside the door. In order to provide insight into this phenomenon and to evaluate its importance this phenomenon has been investigated in this study using the ALE capabilities in LS-DYNA. There are two issues which have to be addressed: the pressure distribution and the pressure progression in the initial period of the side impact, and, a more unknown quantity, the effect of the rising air pressure on the door trim kinematics.

NUMERICAL MODEL

The door model used in the present study is based on a full-vehicle FE model that has been used for the structural analysis of various side impact configurations. However, for the investigation into the air induced effects, a sub-system model set up suffices. This has the advantage to considerably reduce the computation time. The sub-system model uses a prescribed structural motion taken from the full-vehicle simulation results. The sub-system model consists of the door structure, the door trim and a selection of the barrier front surface and the relevant vehicle structure supporting the door in the side impact, see Figure 1. Depending on the crash configuration, the associated time-displacement boundary conditions of the vehicle structure supporting the door and of the barrier are added to the model.

Next, an appropriate methodology to model the air inside the door is needed. Therefore the Arbitrary Lagrangian-Eulerian (ALE) formulation in LS-DYNA was chosen. This approach allows material to flow across the element boundaries. Additionally, the elements themselves can be translated or deformed as it is common in the Lagrangian approach. In combination with a penalty based Eulerian-Lagrangian coupling algorithm, the material based on the ALE approach is able to interact with parts of the Lagrangian FE-structure [1].

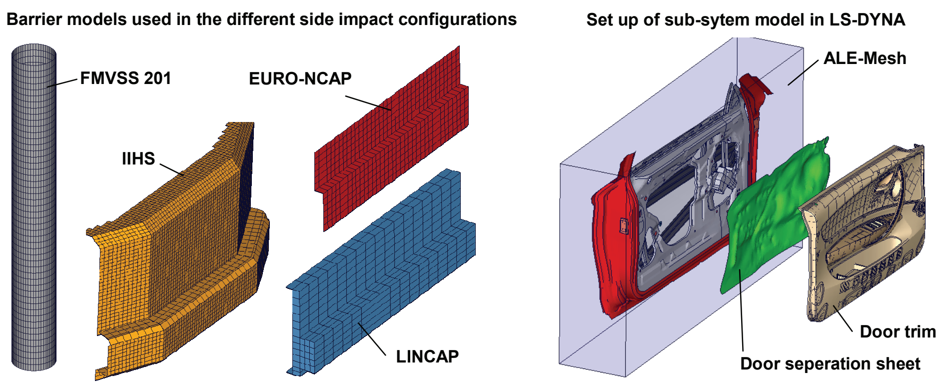


Figure 1: Substructure model setup of barrier, ALE-mesh and door structure

The ALE mesh covers the volume in space that is occupied by the Lagrangian door structure. In order to avoid a computationally intensive calculation, the ALE mesh follows the Lagrangian door structure with a predefined velocity which allows reduction of the overall size of the mesh. The mesh itself is completely filled with air, which is presumed to have ideal properties (pv/T = const.), see Table 1. A mesh size has been chosen which is small enough to enable outflow through the side window aperture in the door frame and to accurately simulate the flow inside the door. This required a total element number of 650000 volume elements. The Eulerian-Lagrangian penalty contact is defined for the whole door structure. Inside the door there are usually two different chambers, the wet area which covers the door beam, the window rails etc. and the inner part of the door which consists of the door trim. These two chambers are separated by a plastic sheet which is adhered to the inner door panel, see Figure 1. This sheet restricts the outflow of air from the wet area towards the door trim and into the passenger compartment. However, air can still flow out through the side window aperture in the door frame.

Density: ρ0	Temperature: T0	Cv	Cp	Pressure: p
1,205 [Kg/m³]	293 [K]	1,005[kJ/kgK]	0,717[kJ/kgK]	0,1016 [MPa]

Table 1: Properties of air used for the ideal gas equation.

NUMERICAL SIMULATIONS

The side impact simulations were performed on the basis of different impact configurations. In total three barrier-to-vehicle simulations were carried out, the European consumer test EURO-NCAP, the US based consumer tests IIHS and the LINCAP test. Additionally, a vehicle-to-pole test according to the Federal Motor Vehicle Safety Standard (FMVSS 201) was simulated. The simulations were executed with a single precision LS-DYNA 971 executable on a dual Opteron 2800 workstation with Linux 10.0. Computation time needed for a 20ms simulation run is about 40 hours. For evaluation of the pressure inside the door, five pressure sensors were uniformly distributed over the interior of the door, see Figure 2. Sensor number 1 coincides with the sensor used in the experiment for pressure sensing.

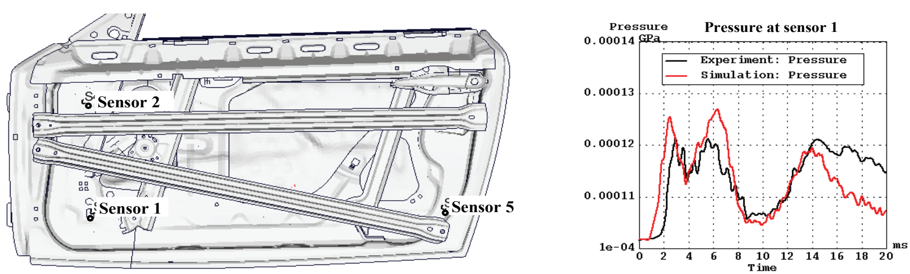


Figure 2: Location of pressure sensors in simulations and experiments.

The following sections will briefly describe the simulation results for the LINCAP side impact. In this test configuration, a moving deformable barrier, which has all wheels rotated at an angle of 27 degrees (crab angle), impacts the vehicle on the drivers side at a 90-degree contact angle.

As illustrated in the diagram in Figure 2 and the illustrations in Figure 3 the pressure inside the door starts to rise in the contact area between barrier-bumper and door outer panel. The generated pressure wave travels from the contact area to other regions of the door at the speed of sound, which is approximately 0.33 m/ms. The ongoing deformation of the door generates a rise in pressure up to a first peak at 2.5 ms. The subsequent decay results from the movement of air to less deformed parts of the door which starts 2 ms after the impact, see Figure 3. At 6 ms deformation in the lower area of the door is completed. From 10 ms onwards the upper part of the barrier strikes the door, causing a further rise in pressure.

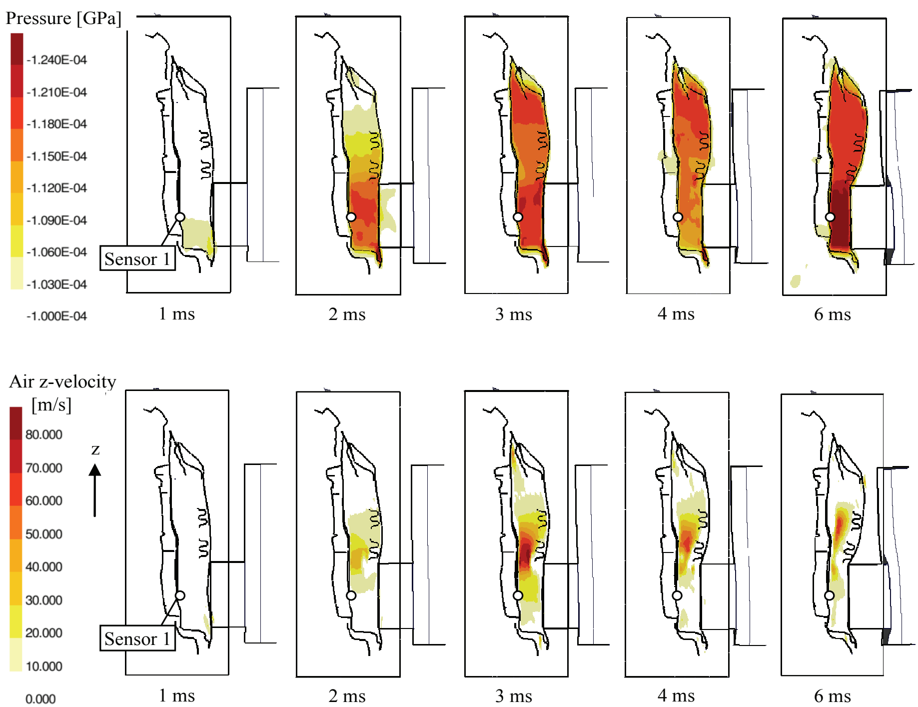


Figure 3: Pressure distribution and air flow at the location of sensor 1 in the LINCAP Side Impact.

Note that in order to achieve a reasonable agreement of the pressure signal between experiment and simulation, the inner parts of the door need to be integrated into the Eulerian-Lagrangian penalty contact. The lower door beam for example, affects to some extent the upward movement of air underneath itself. In the period from 5 ms to 13 ms there is a considerable amount of outflow through the side window aperture of the door frame. After that the upper door reinforcement panels are deformed and thus prevent the outflow through the window aperture of the door frame, see Figure 4. If this is not taken into consideration, level and progression of the pressure signal will be different.

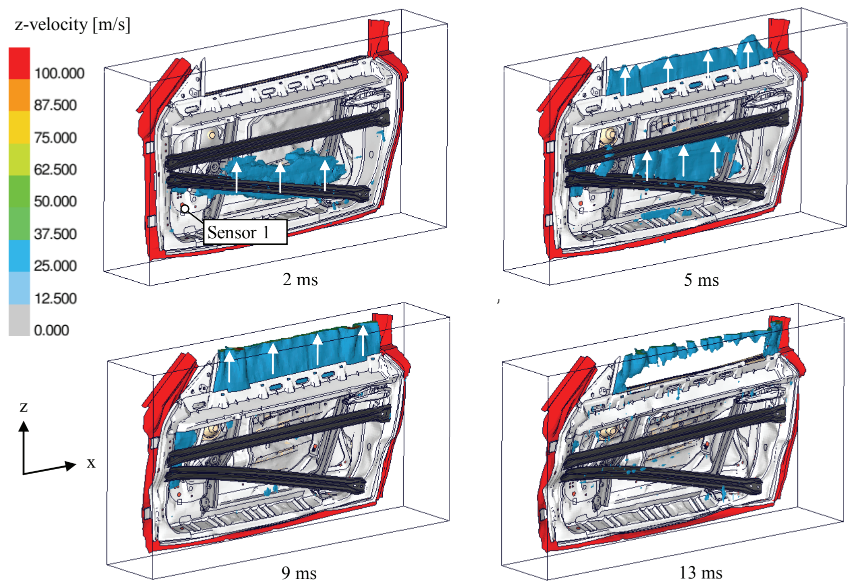


Figure 4: Iso-surface of z-velocity indicating flow of air inside and out of the door.

Next, the pressure signal for 3 different locations within the door was compared, see Figure 5. As expected, the first peak in pressure is delayed for sensor 2 in the upper door region due to the later arrival of the pressure wave which travels with the speed of sound. In the area of sensor 5, which is located close to the stiff B-pillar, the deformation of the door is less severe and the initial thickness of the door is larger. For this reason the pressure signal at this position differs from the other locations. The equalization of pressure at different locations needs a flow of air particles inside the door, which takes place at velocities of up to 50 m/s.

The rate of the outflowing air through the side window aperture in the door frame is governed by the corresponding seal, the crushing window and the deformation of the door outer panel. A simulation of these details would mean an enlargement of the model size and would therefore increase calculation time to an impractical amount. Instead, the importance of this kind of outflow has been evaluated by comparing the influence of different side window apertures in the simulation. As can be seen in Figure 6, a restriction of any outflow leads to a higher pressure level at later times, whereas an opposite effect can be noticed if the side window aperture is slightly enlarged. In a further simulation the door separation sheet was omitted. This has only a minor effect on the pressure level, provided that the door trim does not separate from the door structure (which would lead to additional outflow of air).

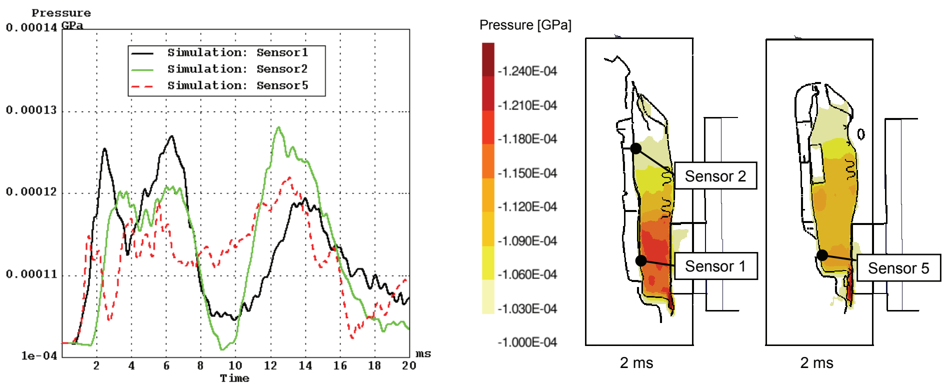


Figure 5: Differences of pressure level at different locations within the door.

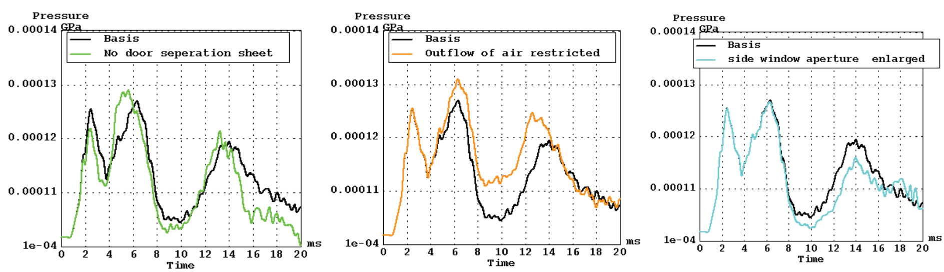
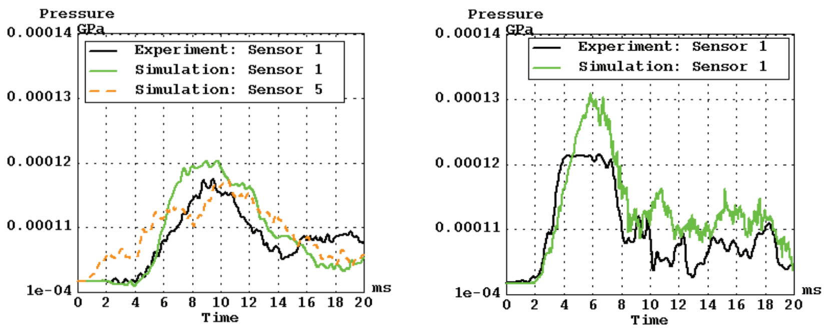


Figure 6: Sensitivity of pressure signal against some model modifications.

Finally the pressure signal in two further crash test configurations was compared, see Figure 7. In both, the onset of rising pressure is accurately predicted. In the pole impact configuration (FMVSS 201), the door outer panel can undergo a pressure driven ballooning, if it is separated from the door beams to which it is glued. If this happens, the pressure level inside the door will be slightly lower. A lack of agreement between experiment and simulation at later times might also be attributed to a different deformation behaviour of the barrier model used, or due to the missing airbag model in simulations, as mentioned earlier.

In the pole impact configuration the pressure onset varies clearly between locations, as the pole strikes the door outer panel at a position more closely positioned to the B-pillar of the vehicle. The pressure wave therefore needs a different time span to reach sensor 1 and 5 in the door, see Figure 7a.



(a) FMVSS201 Pole Impact (b) IIHS Side Impact

Figure 7: Comparison of pressure inside the door in different crash configurations.

The pressure inside the door does also have an influence on door kinematics. Roughly estimated, a pressure increase of 10 - 20 kPa inside the door leads to an overall force of 5 - 10 kN on the entire door trim surface. This has a significant effect on the intrusion of the door trim into the passenger compartment. Figure 8 illustrates the door trim intrusion with and without consideration of the influence of air pressure.

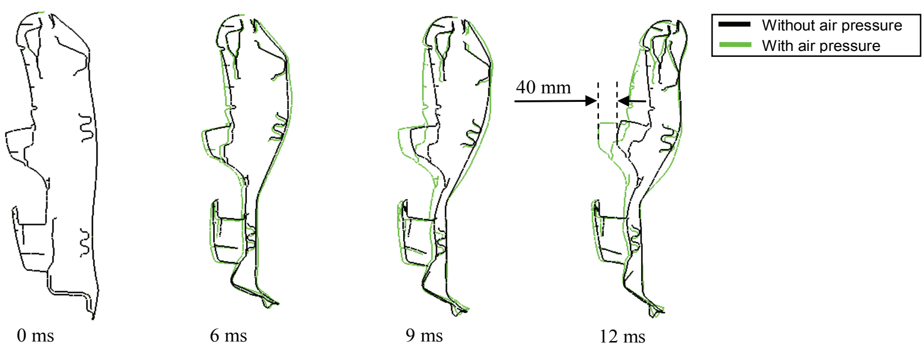


Figure 8: Influence of air pressure on door trim kinematics in the LINCAP side impact.

In our experience this effect is often noticed, if the door trim kinematics in experiments and ordinary simulations (without consideration of air) are compared. There is always an earlier and more severe intrusion of the door trim in the experiment. Certainly, this also depends on the door design, the location of attachment points of the door trim and the crash test configuration.

After that an acceleration gauge was placed at the rear side of the armrest in an IIHS side impact experiment in order to check the additional air induced intrusion of the door trim. Double integration of the signal into displacements shows that the armrest is displaced by the air pressure up to a time of 11 ms but is after this pushed back to the door inner panel by the airbag, see Figure 9. As a result from 11 ms onwards, the experimental curve deviates from the simulation in which no airbag is used. Crash test films have shown, that the airbag is fully deployed after 14 ms. The airbag therefore seems to be able to push back the door trim to a considerable amount during the unfolding process. The simulations have been carried out with and without influence of air pressure. Without considering air pressure the simulated time displacement curve is considerably delayed.

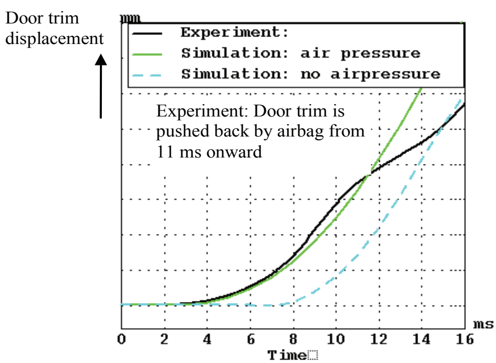


Figure 9: Armrest displacement in experiment (with airbag) and simulation (without airbag) in the IIHS side impact.

In vehicles where the gap between occupant and door trim surface is closer, it will be interesting to analyse whether the additional pressure induced intrusion of the door trim has an influence on the airbag unfolding. However, once the airbag is inflated into the gap between dummy and door trim, the airbag should be able to push back the door trim, on account of its much higher internal pressure. A numerical investigation into this matter would need an airbag model which takes into account the air flow inside the airbag, which is possible by using the ALE approach in LS-DNYA.

SUMMARY AND CONCLUSIONS

The investigation into the rising air pressure inside the door gives insight into many interesting physical phenomena related to flow of air inside and out of the door frame. The method of using the Arbitrary Lagrangian-Eulerian formulation in LS-DYNA to model the air is capable of predicting the air pressure inside the door in a variety of side impact configurations with reasonable agreement. It is also shown that simulations can further assist by checking the suitability of different sensor locations as they can provide information about the varying pressure progression at these locations. An additional effect of the rising air pressure is the increased intrusion of the door trim into the passenger compartment. This effect is accurately predictable by simulations, as a comparison of door trim displacement with experiments proved. In the present study the interaction between airbag and door trim has not been investigated in simulations. But experimental measurements show that the airbag is able to push back the door trim mainly during the unfolding process. However, in vehicles where the gap between the occupant and the door trim is closer than in the present study it will be of interest to simulate the interaction of the unfolding airbag and the door trim in simulations. Here the ALE method could also be used to model the airbag inflation process.

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