Simulation of Curtain Airbag with Arbitrary Eulerian- Lagrangian Method

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Abstract:
Computer simulation is a powerful tool for developing effective airbags for modern automotive industry. At the present time, most airbag calculations are based on a so-called uniform pressure technique. In the simplest case, for every time step the pressure is constant on the internal surface of the airbag and is determined from a given thermodynamic model. An extension of this method is a “multi-chamber” approach, which allows simulating a stepwise constant pressure distribution inside of the airbag. However, in this case additional empirical assumptions on the flow between the chambers should be made. Curtain airbags serve to protect occupants on one side of the vehicle and therefore they have one long dimension and possess many complex interconnected chambers. The inflating gas needs a certain time to flow from the gas generator to the distant airbag chambers. Therefore application of the constant pressure approach for simulation of the curtain airbag development is not always possible.
This paper deals with development and comparison with tests of a curtain airbag numerical model which is based on the Arbitrary Eulerian – Lagrangian (ALE) method in LS-DYNA. The project is performed in the route of virtual prototype program supported by Saab Automobile AB (Sweden). ALE airbag model build is described and discussed. Test results are compared with simulation results.

Keywords: finite element modelling, curtain airbag simulation, arbitrary Lagrangian – Eulerian method

1 Introduction

Computer simulation is a powerful tool for developing effective airbags for modern automotive industry. At the present time, most airbag calculations are based on a so-called uniform pressure technique [see e.g. 1]. In the simplest case we neglect the gas motion inside of airbag and assume that for every time step the pressure is constant on the internal surface of the airbag. It is determined from a given thermodynamic model for given massflow rate and temperature of inflating gas. An extension of this method is a “multi-chamber” approach, which allows simulating a stepwise constant pressure distribution inside of airbag. However, in this case additional empirical assumption on the flow between the chambers should be made.

Curtain airbags serve to protect occupants on one side of the vehicle and therefore they have one long dimension and possess many complex interconnected chambers. The inflating gas needs a certain time to flow from the gas generator to the distant airbag chambers. Therefore application of the constant pressure approach for simulation of the curtain airbag development is not always possible.

To consider this process more precisely, a more accurate method to describe the gas motion and its interaction with airbag surface is needed. One of these approaches based on the Arbitrary Eulerian – Lagrangian (ALE) method is realized in LS-DYNA (see e.g. [2, 3]). This approach is rather time-consuming, but due to its accuracy it is still a benchmark method for other fluid –structure interaction approaches available in LS-DYNA.

Present paper deals with development and comparison with tests of a curtain airbag numerical model based on ALE method. The project is performed in the route of virtual prototype program supported by Saab Automobile AB (Sweden).

2 ALE Airbag model

ALE airbag model consists of two parts: airbag finite element (FE) model and ALE 3-dimensional cell mesh. Structural calculations are performed in a Lagrangian coordinate system for the FE airbag model, while a fixed (or moving) 3 dimensional Eulerian mesh is used to calculate the gas flow inside of the airbag. Fluid-structural interaction between the airbag surface and the gas flow is determined through a special penalty – type contact.

Each of the parts (airbag and ALE mesh) can be modelled separately, however, not independently from each other. Let us consider the basic considerations that should be taken into account for development of each part of the ALE airbag model.

a)

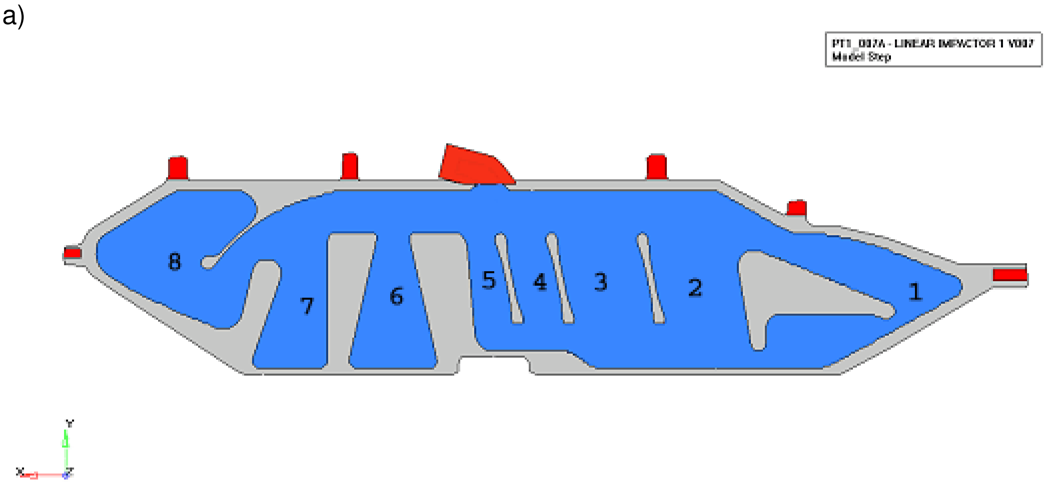

Figure 1: a) Curtain airbag. Blue- airbag chambers 1-8, grey – connecting fabric, red – fixation.

2.1 FE airbag model

Consider first the requirements for the FE airbag model. The model build consists of meshing, folding and bending.

We use a stabdrad curtain airbag as a basis. The airbag is about 2000mm long and 400mm high (Fig. 1) with regular zig-zag folding. Element size of the airbag mesh should be comparable with size of the ALE cells and element size of surrounding components (trim, dummy, etc.) to provide optimal resolution of fluid-structure interaction and structural contacts. For the latter, it is also important that mainly quads are used for meshing the airbag chambers. Triangle elements are allowed on the boundaries of the chambers and on the connecting fabric.

Optimal size of quad element edges can be uniquely determined from the folding plan of the airbag (number of folds, width and height of airbag housing) and requirement for minimisation of the element distortion during the folding. In the present case, the optimal solution of about 5mm element edge size is used. Too small airbag mesh requires too many ALE cells, which increases computation time. Coarse airbag mesh provides higher element distortion during the folding. Fig. 2 shows the meshed airbag surface and the general view of the folded airbag.

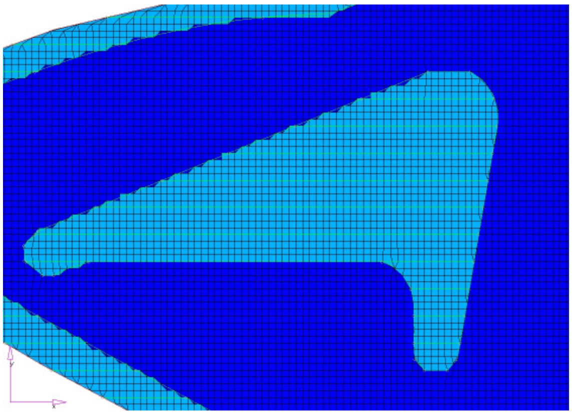

Figure 2: Mesh on the window airbag meshed. Dark blue- airbag chambers, light blue – connecting fabric.

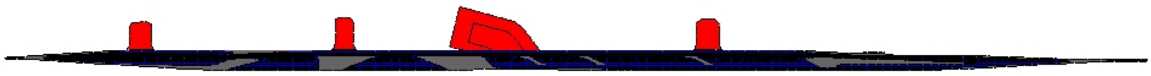

Figure 3: Curtain airbag after folding

Bending of the airbag is a numerical transformation of coordinates of the airbag nodes to fit them into a given airbag housing and surrounding (Fig.4). A special script is developed to perform this transformation with minimal distortion of the element size. Namely the transformation provides a one-to-one correspondence between non-bended and bended airbags in every section perpendicular to the “middle line” of folded airbag. The minimal element length distortions are only allowed along the “middle” line, to fit exactly to the position of the airbag serial fixations.

Optimisation of the element edge size, folding and bending parameters provides a rather small final element distortion. Maximal difference between initial (reference) and final geometries does not exceed 3%.

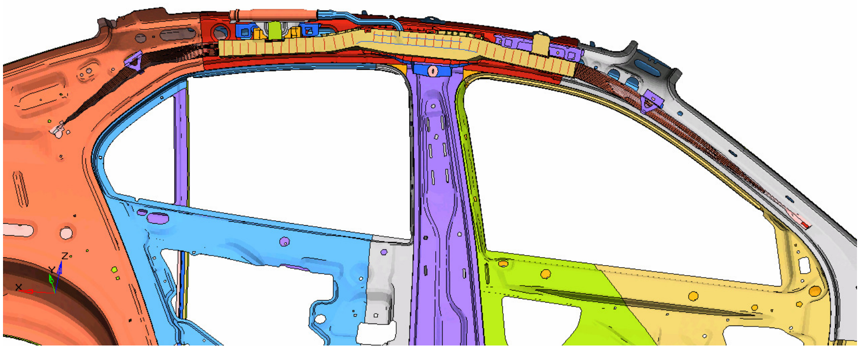

Figure 4: Curtain airbag after bending is integrated into the actual body-in-white surrounding

2.2 ALE mesh model

Choice of a proper ALE cell mesh has major influence to the stability, calculation time and quality of ALE simulation. Let us discuss some considerations to ALE mesh choice. Suppose that, when the airbag is filled with the gas, it is approximately 200mm thick. This approximate thickness can be initially estimated, for example, from simple uniform pressure airbag simulation. It is useful because the ALE cell mesh should envelope the airbag at every moment. In addition to this there should exist a “margin of safety” between airbag surface and boundary of the ALE mesh. Theoretically the size of the mesh is determined by the smallest characteristic size in the airbag model, e.g. by the distance between the airbag layers which is about 0.3mm. For complex folded airbags the distance can be even smaller. Suppose we have an ALE mesh with 0.3mm cell size. For the airbag under consideration this brings about 5.925.925.925 cells. Of course it is impossible to use such a mesh. At the present time, a realistic number of the cells should not exceed about 1.000.000 cells to get an “overnight” solution.

There exists two ways to overcome the difficulty. First is to use a so called expanded ALE mesh. In this case an initially fine and uniform mesh is expanding as the airbag blows up. It is a rather efficient way because the mesh generation is simple and quick. The main negative point is that airbag characteristics (e.g. pattern of unfolding, pressure inside of airbag) are very much dependent on the centre, rate and direction of the expansion. Variation of these parameters (say, due to additional obstacle, trims, dummies) may change completely the simulation results. A more expanded mesh results in a much “softer” airbag. Variation of the expansion parameters requires a new validation of complete ALE airbag model.

The other approach is to use a fixed 3-dimensional mesh with local “dense” regions with finer cells e.g. near initial position of unfolded airbag. This way of mesh creating is more time-consuming. However, it allows creating a rather small 3-dimensional mesh with 200.000- 300.000 cells which makes ALE airbag simulation rather stable and more appropriate in the sense of calculation time. This way is used in the present study.

The ALE mesh depends on the initial airbag configuration. For a so called push-up test, the airbag initially lies on a flat table. Therefore the ALE mesh should provide an increased cell density towards the table (Fig. 5). Of course, the maximal vertical height of the mesh should be big enough to envelope the airbag during the entire simulation.

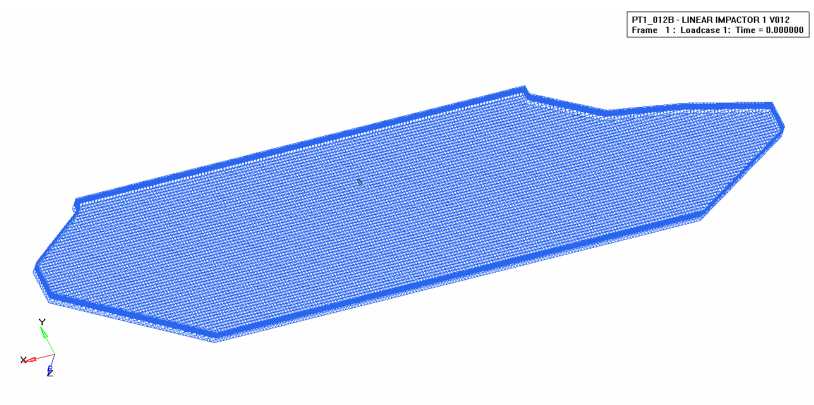

Figure5: ALE mesh for a push-up test. Increased mesh density towards the flat table. ALE mesh with approx. 150.000 cells

Another example is the curtain airbag hanging free in the window opening (Fig.6). In this case the dense region should follow the initial airbag position. The ALE mesh should envelope the airbag at each moment of the simulation. The airbag “envelope space” is determined as a space that contains every airbag shape during the complete simulation with a certain “margin of safety”. At the first approximation, the possible airbag shapes can be estimated from simple uniform pressure simulation.

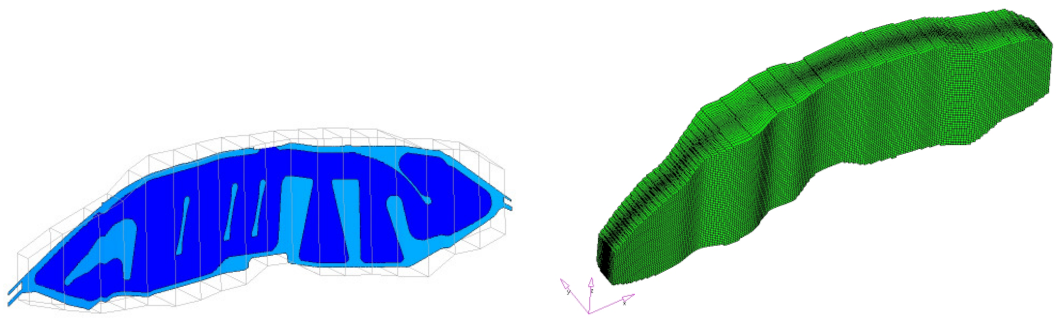

Figure 6: ALE mesh for a bended curtain airbag (not folded) in window opening. Denser mesh follows the initial position of the airbag. Mesh fills the airbag envelope space (grey wire frame lines). ALE mesh with approx.250.000 cells

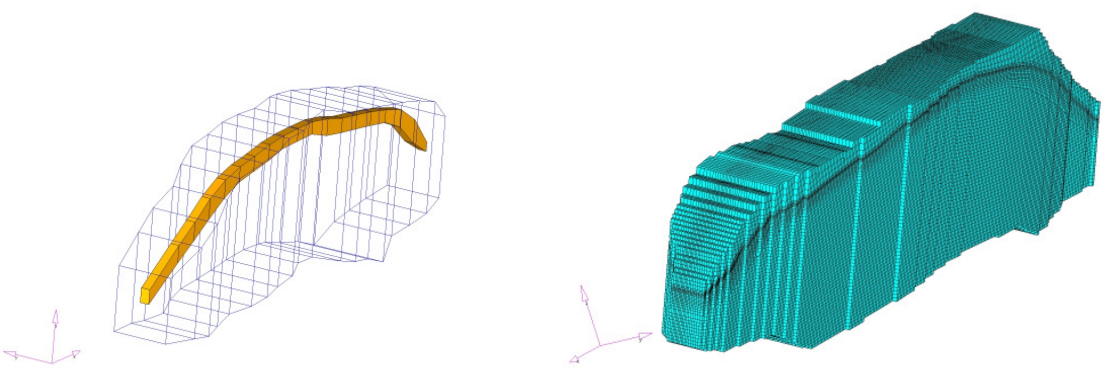

Figure 4: Airbag envelope space (blue wire frame lines) and initial position of the folded airbag (yellow box). Corresponding ALE mesh is denser near the initial position of the folded airbag. Mesh fills only the airbag envelope space. ALE mesh size is approx. 300.000 cells

A more complex example is the folded and bended airbag in the housing above the window opening. The denser region of the ALE mesh lies around the initially folded airbag. The corresponding airbag envelope space is shown in Fig. 4.

Generation of the airbag “envelope space” is performed automatically. A non-uniform ALE mesh with corresponding densities is generated and then cut according to the corresponding envelope space.

2.3 Gas generator model

Proper modelling of airbag gas generator and ALE mesh near the gas generator is an important part of the ALE airbag modelling. Standard gas generator data (massflow rate for every gas component, temperature curves) are usually obtained from a tank test. It is known, that the definition of ALE airbag gas generator requires more data (e.g. velocity of the gas jet) than for usual uniform pressure airbags. However, it is rather difficult to get any additional information about the gas generator. Therefore it is assumed that the gas jet velocity is proportional to the total massflow rate received from the tank test, and the maximal velocity is about 100mm/ms.

The first several milliseconds of ALE airbag calculations may run unstable due to high massflow rates from point sources that model the gas generator. At the moment LS-DYNA does not account for the ALE component velocities in the time step control. Therefore special attention should be paid to the proper distribution and configuration of ALE cells near the gas generator. In the present case, the gas generator sources are positioned in the middle of ALE cells and airbag surface is modified to provide several cells between airbag layers (Fig. 5) to let the gas flow develop during the first 1-2 ms of the simulation.

Gas generator jetting is also an important issue for the beginning phase of the simulation. In the test, the jetting is very well visible, especially for the cases when the airbag is not folded (push-up tests, blow up test). There is an option available in ALE airbag card that determined the direction of the gas, flowing from gas generator. However, this option does not allow a stable jet. The “numerical” jet disperses after few ALE cells even for a rather fine mesh. Therefore a proper pattern of point sources are used to simulate the jet.

a) b)

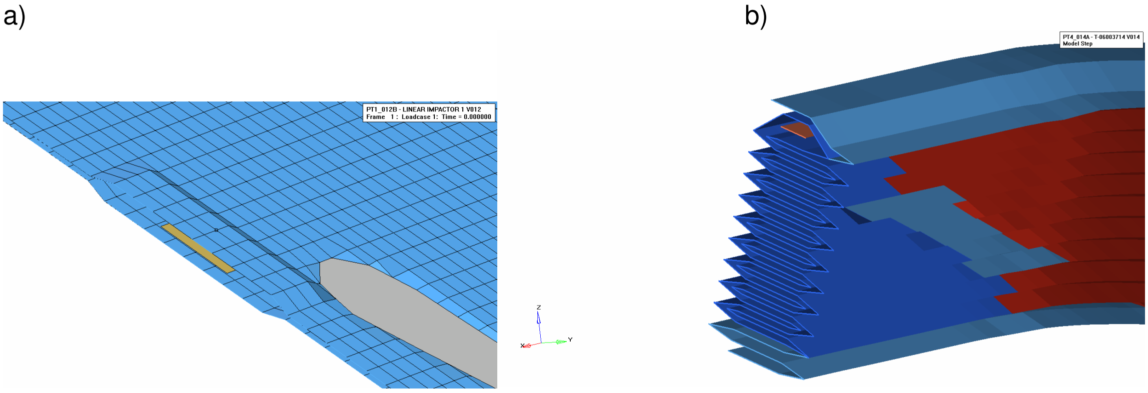

Figure 5: Gas generator model for unfolded airbag a) and folded airbag b). Airbag layer are moved from each other to let several ALE cells between

3 Comparison with tests

Following tests are performed to investigate the correlation with the simulation

- push-up test (2 variants)
- inflation test
- test with a trim

Results of the first two tests are discussed below

3.1 Push-up test

The push-up test is a basic airbag test which is used to investigate airbag performance and stiffness at the early stage of the airbag inflating. The unfolded airbag is positioned on a rigid table with standard fixations (Fig. 6). A rigid impactor initially lies on the airbag and is pushed away after actuation of the gas generator. Acceleration of the impactor is measured and video is recorded with 2 high speed cameras. Two positions of the impactor are chosen to control the airbag stiffness at different places:

- impactor to driver compartments (chambers 3-5)
- impactor to passenger compartment (chamber 7-8).
-

A specific feature of curtain airbag is that due to its length (appr. 2000mm) there is a visible gas “wave” (e.g. boundary between airbag regions inflated with gas and empty regions) spreading from the gas generator to every chamber of the airbag. In the simulation it is important to obtain a correct timing of this wave. Comparison shows that for both initial impactor positions, the wave timing correlates well with test. However, the rear chamber 8 in simulation is inflated later than in the test. This can be explained by a rather thin and long sleeve leading to the chamber 8.

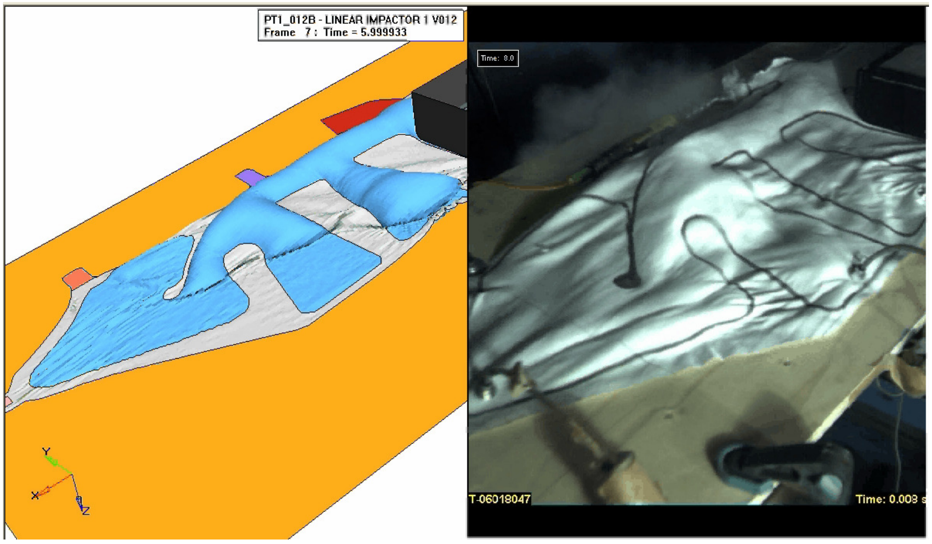

Figure 6: Push- up test after 6ms. Imactor to the driver compartment.

Comparison of impactor accelerations is shown in Fig.7. For the case of the impactor to the driver compartment (thin curves), the timing and the maximum of the acceleration curves correspond well to each other. It can be noted that in simulation the initial acceleration peak is higher that in the test. For the case of the impactor to the passenger compartment (thick curves) the correspondence between test and simulation curve is worse. Simulation shows a much higher acceleration peak. This can be explained by the fact that in the simulation, chamber 7 of the airbag, which is initially under the impactor, does not inflate properly.

Perfect correlation of “timing” for both acceleration curves can be noted. Interaction between airbag and impactor starts exactly as in the test. Correspondingly the time delay, i.e. the time that the gas “wave” needs to travel from gas generator to the rear compartments, is represented well.

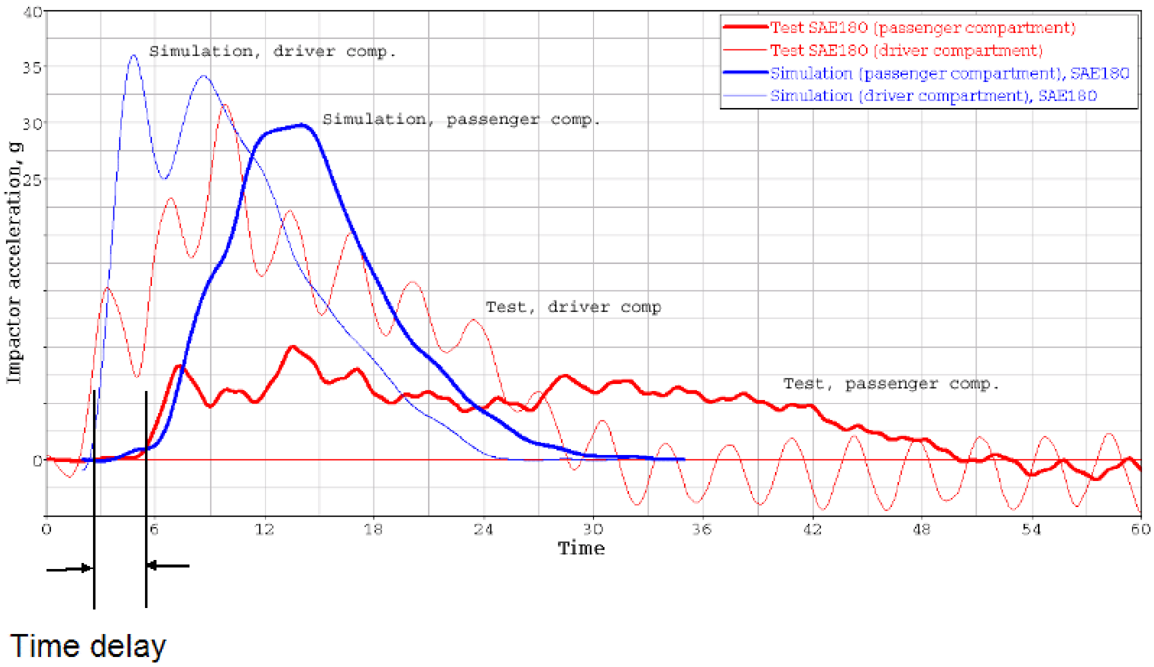

Figure 7: Push- up test. Comparison of the impactor accelerations. Impactor to the driver compartment (thin curves), impactor to the passenger compartment (thick curves)

3.2 Inflation test

Configuration of the inflation test is shown in Fig. 8. The airbag is fixed at its standard places to the body-in-white without trim parts. The main purpose is to compare the visual correspondence of the airbag blow-up between test and simulation.

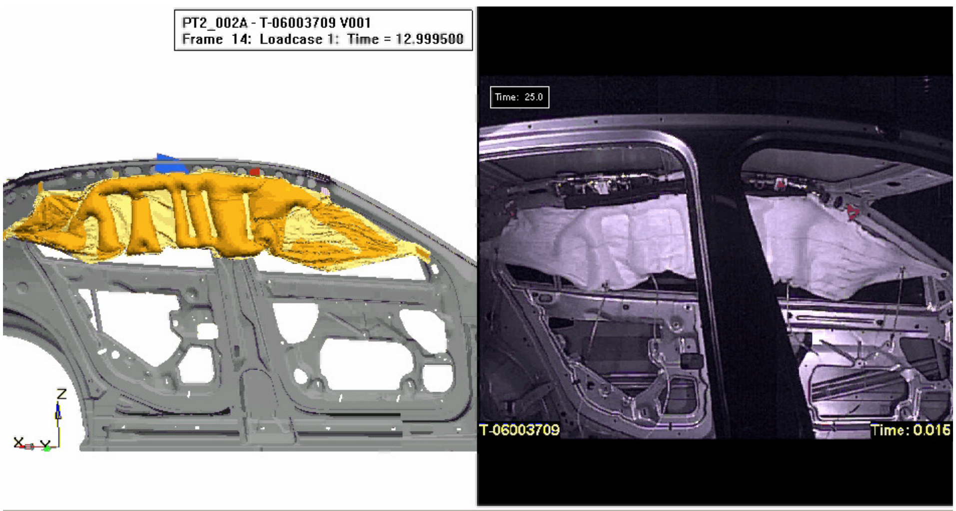

Figure 8: Blow up test. Comparison simulation and test after 13ms

The general visual correspondence between test and simulation is good including the timing of the gas “wave” inflating the airbag. Similarly to push-up tests some discrepancies are found only for the rear chamber 8 which is filled later that in the test.

4 Conclusions

The ALE method is a robust approach for curtain airbag simulation. It creates a realistic motion of the inflating gas and the airbag unfolding pattern, which compares visually well with tests. However, the build and further debugging of an ALE airbag model is a rather complicated and time consuming procedure that requires certain expertise. A significant drawback of the method is sensitivity of simulation results to the ALE mesh (e.g. in the case of expanding mesh). The cell size has to be small enough to avoid this sensitivity. Applications of ALE mesh with many millions cells may help to overcome this difficulty, but it is out of the computational and memory capabilities of many modern computers.

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5 Literature

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