Simulation of an Airbag Deployment in Out-of-Position Situation

C. Ruff (vif), A. Eichberger (Magna Steyr), Th. Jost (vif)

Kompetenzzentrum virtuelles Fahrzeug (vif)
Inffeldgasse 21A
8010 Graz
Austria

Abstract:

The common used “Uniform Pressure Method” (UP) is a well-tried method to simulate an airbag deployment in accident cases. Nevertheless, this method indicates rather heavy inadequacies at the examination of the airbag deployment in the first milliseconds. A solution is the airbag deployment calculation by using CFD methods, wherein the calculated gas flow pressure may be applied “correctly” to the airbag shell elements.
This CFD simulation is integrated in LS-Dyna with the so-called Arbitrary Lagrangian Eulerian (ALE) method and in this review the result’s accuracy will be discussed. According to the FMVSS 208, an OoP model will be built-on and comparisons with simulations and tests are done. Another important detail in this labour is the airbag cover examination and the tear seam modelling, as a trivial FE modelling cannot be done due to the very fine mesh. So two possible solutions for tear seam modelling are introduced and discussed. Furthermore considerations concerning the gas generator combustion will also be revealed and an analysis about the impossibility of the direct comparison between gas generator tank test and airbag deployment will be done. At least, some parameters, which take effects in the simulation, are researched and evaluated, so finally an optimized simulation model can be made available for further examinations.

Keywords:

FMVSS 208, 3- and 6yrs dummy, Out-of-Position, airbag deployment, gas generator, airbag tear seam modelling

1 Introduction, motivation

The airbag is a well known and important safety component in passenger vehicles, so nearly every new car is equipped with it. In the US around 2 million accidents with around 42 000 fatalities could be counted in the year 2002. In the EU area it were still 1.5 million accidents with around 40 000 fatalities [1]. It's estimated, that around 2 000 lives have been rescued with help of the airbag. Similar data are estimated for the EU.

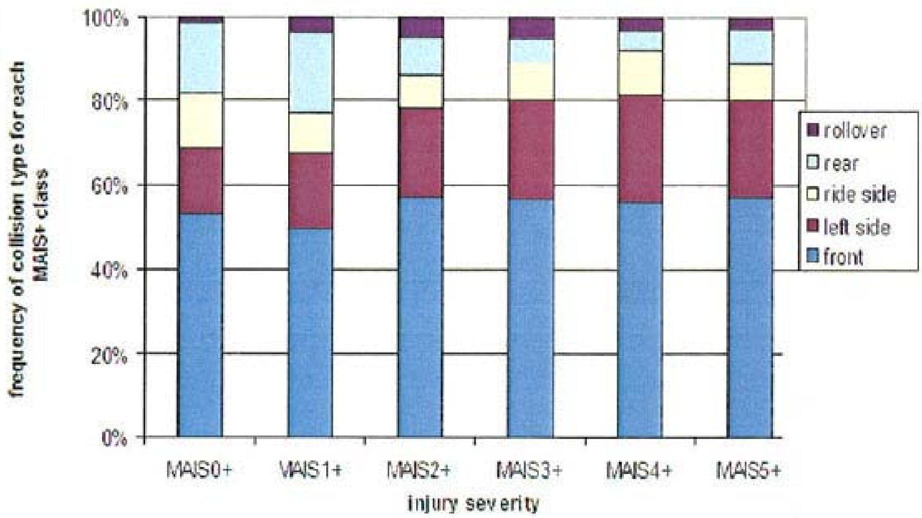

Figure 1: Injury distribution in accident cases

In figure 1 it is not hard to find that the frontal accident is the accident type in that the most occupant injuries can be counted. Next to frontal crashes, side impacts show the highest numbers, followed by rear impact and rollover. So furthermore it seems very reasonable to hold on the combination of the (frontal) airbag in combination with the safety belt and to improve the airbag development.

The methods to simulate an airbag deployment are well known and are used very often at developing a new car. Actually, the so-called „Uniform Pressure" simulation method is a common way to check the occupant injury criteria by simulation. But this method only works for the already full deployed airbag, when the occupant's exposure will happen only while sinking in the already full deployed airbag. In Out-of-Position (OoP) the airbag load to the occupant will happen already in the first milliseconds, while the airbag is deploying. Actually simulation methods do not consider this fact accurately, so wrong simulation results will be the consequence. A way to solve this problem might be the airbag simulation by using gas flow calculations (CFD) methods. Several examinations at this topic have been done already and first results were published [2][3], so further examinations with this new method can be done.
This paper focuses on the so-called Arbitrary Lagrangian Eulerian (ALE) method, which is provided by LS-DYNA®. With this method it is possible to evaluate the gas flow directly from the gas generator and to model the dependence between the gas flow and the (folded) airbag. First steps and possibilities have been introduced already [4][5][7], so the studies discussed in this paper are based on these examinations.
The influence of the airbag cover was unknown at project start, so this model part has been investigated, too. As no reasonable method to model very fine structures (0.1 mm) in a frequently used mesh ambience (15 mm) is known, some workarounds were reflected and investigated in the simulation. Further it is known that different kinds of airbag folding exist, which can cause several deviances at the results.

Due to the improved effects on the occupants in OoP situation, the „stochastic" folding was chosen for the investigated airbag by the manufacturer. It is rather complicated to fold this kind of folding by simulation, so new methods and solutions for the simulated folding had to be found and to be implemented. Several problems with the node penetration were solved, so at least a working simulation method could be obtained.

2 The fundament for the research:

The FMVSS[1] 208 is part of the CFR (Code of Federal Register) in the US that describes how to handle with OoP situations. The 208 standard has been established as traffic accident examinations showed that some cases appeared where the airbag caused lethal injuries to car occupants, especially children and adolescents, due to the deployment. Car manufacturers, which develop cars for the US market, are forced to follow the required specifications (figure 2).

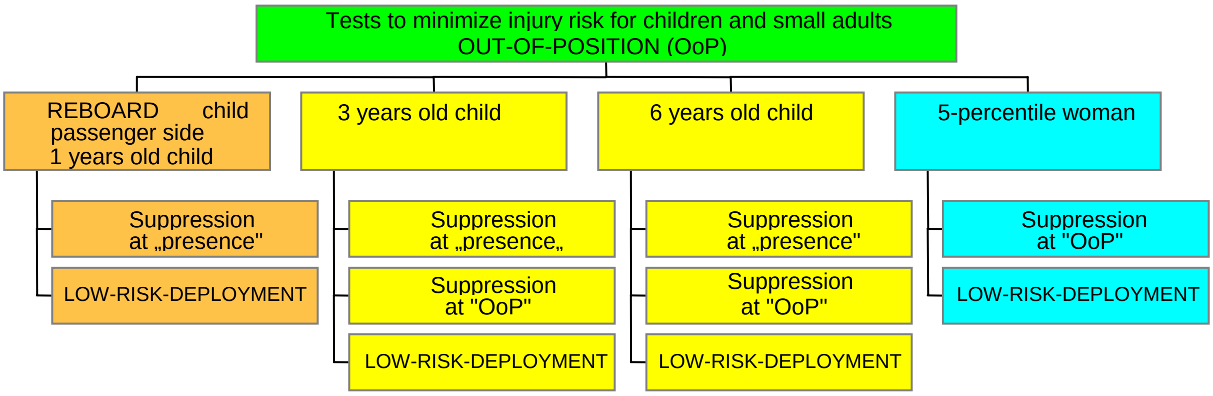

Figure 2: Overview FMVSS 208

In our research we will focus on the 3yrs and the 6yrs child at the passenger side, examining the sub area „low risk deployment". This means, the airbag is designed for a "safe" deployment, when the occupant is "OoP", but the same airbag will also protect the occupant "in position" as well.
Two positions are specified in the FMVSS 208 for the 3yrs and 6yrs child each: One position with the dummy's head at the cockpit and one position with the dummy's chest at the cockpit. In total, four positions are considered. (2x 3yrs and 2x 6yrs).

2.1 Tank test:

When developing new gas generators and airbags, tank tests are performed to obtain the characteristics of the gas generator. In this way different gas generators can be compared by their parameters as burning rate, pressure and temperature increase. These values can be compared to the simulation results and give a first impression about the result's accuracy. Secondly the simulated tank test can be used to realise a precise simulation parameters adjustment to gain better results.

Some gas generator data were delivered by the airbag manufacturer in form of diagrams showing pressure and temperature progression. The manufacturer also delivered gas generator data input for the simulation, which were rechecked in a tank test simulation run. Firstly a shell tank was modelled, surrounded by an Eulerian mesh to ensure the gas flow in the tank (figure 3).

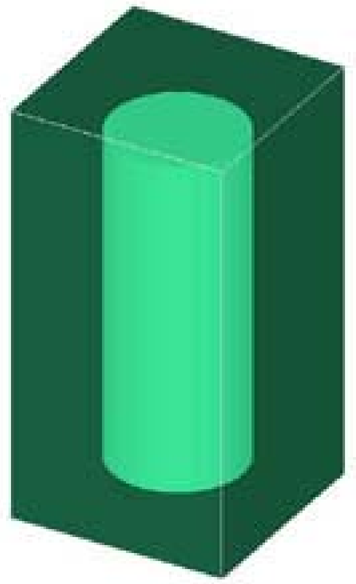

Figure 3: Simulation model gas tank test

Three Eulerian material definitions were assigned to the Eulerian mesh: Ambient air (outside the tank), ambient air (inside the tank, no connection to the air outside the tank) and the airbag gas, generated by the gas generator (inside the tank, mixing up with the air during the burning process). The measure points were taken at the top and the bottom of the tank and compared to the test diagrams, which were provided by the gas generator manufacturer. For an

[1] Federal Motor Vehicle Safety Standard

example, see figure 4: This diagram describes the pressure characteristics during burning off the first stage of a two stage gas generator. The second stage is ignited after 100 ms, so it is not displayed at this diagram, as it only describes a time range between 0 and 100 ms.

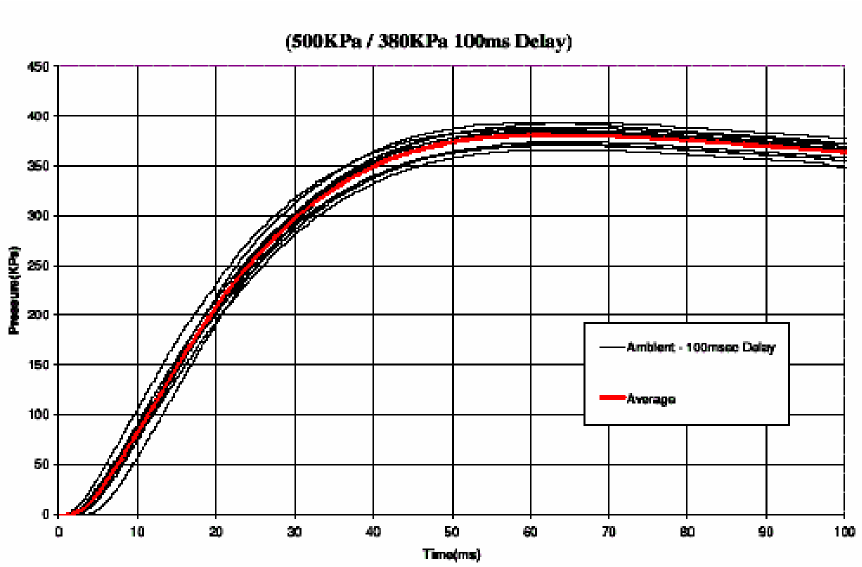

Figure 4: Gas tank pressure curve at ambient temperature and 100 ms delay (Source: Airbag manufacturer)

As it is easily to recognise, the simulation model (results drawn in figure 5) shows similar the same results as the test, so the gas generator input data for the simulation is well adjusted and can be used for the built-up of the next simulation models. One important difference between the tank test and the deploying airbag should be mentioned here: In the gas generator tank test, the volume of the tank is constant. In contrast to this, the airbag's volume is variable during the deployment, so the backpressure in the airbag will not be the same as at the tank test, viewed over the time. This means furthermore, that the gas generator's burning rate is dependent on the backpressure, so the burning rate in the tank test simulation will not be the same as the rate in the airbag simulation. For better results the correlation of the backpressure and the burning rate should be modelled, but actually LS-Dyna and other reviewed simulation software does not support this. Therefore examinations about this are actually in progress [8][9], suitable results are expected in future.

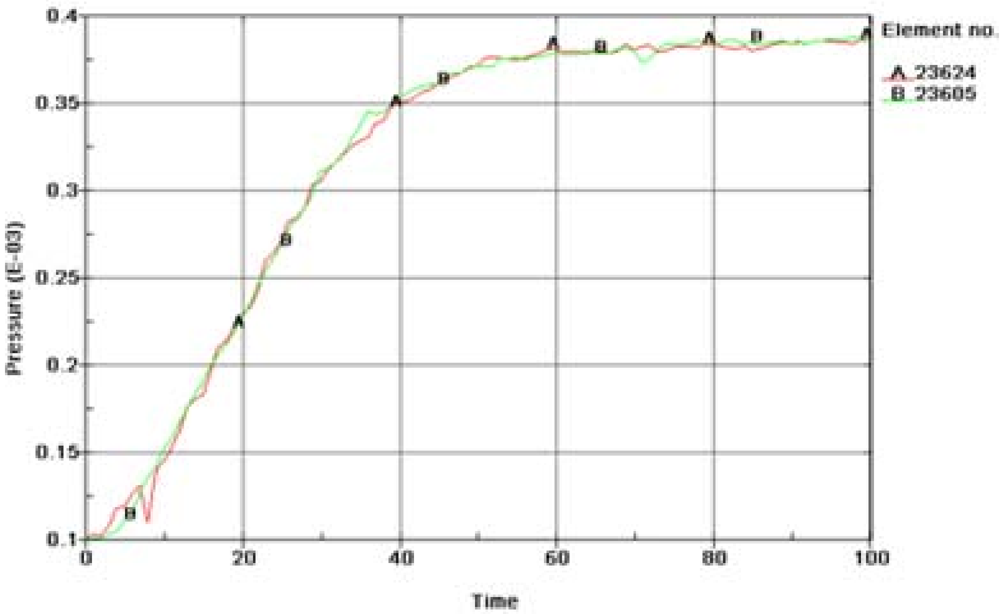

Figure 5: Simulated gas tank test pressure curve at ambient temperature and 100 ms delay

2.2 Airbag folding:

Actually four methods to fold an airbag are known. These methods differ in the quantity of work for folding and occupant safety during the deployment process. A short introduction is now given to raise the understanding for the finally chosen method:

Leporello-Folding: This kind of folding was used in earlier times and is quite simple to handle, as the airbag is folded by hand and lumped together from the side. This causes a self blockage of the airbag, because the inflowing gas pressure affects only till the next folding line. So the airbag gas will flow abruptly to the next folding lines, this leads to the so-called “punch-out” effect and the occupant will obtain a higher force load.

Ring-Folding: The airbag fabric is arranged circular around the gas generator, so the airbag deploys mainly to the side and without self-blockage. This leads to lessened occupant force loads.

Accordion-Folding: Here the airbag fabric is folded as like an accordion around the gas generator. Similar as like as the R-Folding the airbag deploys during the gas flow more to the side and does not experience a self-blockage, too.

Stochastic-Folding: This is a “chaotic” airbag folding, where only few rules are applied to the folding. Here the airbag deploy direction depends on his manufacturing process, this means, how it was folded into the gas generator; e.g. the airbag case.

More information about these four folding methods and their effects to the occupant can be found in the dissertation of Mao [6].

As the best results were expected with the stochastic folding, the airbag manufacturer decided to use this folding and the simulation model was build up with this folding, too. As the manual work is a rather complicated process, firstly it was necessary to decompose these steps, so that they can be built up easily in the simulation. Five simulation decks were created, each with its special subtask of airbag folding. After solving every simulation deck, the nodal coordinates were taken from the final result file and implemented in the next simulation deck, so at least the complete airbag folding process could be mapped with less costs.
For a small insight, the last (and biggest) of these five steps is described consecutively. It starts with the already pre-folded and gentle into the folding machine pressed airbag fabric (see figure 6, “0 ms”).

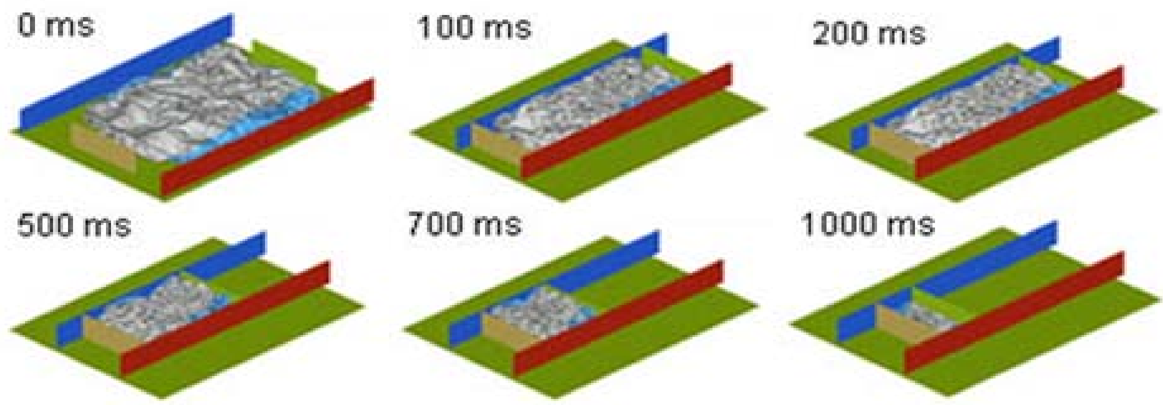

Figure 6: Airbag folding process: Folding machine last step

Firstly the long sliders drive together and start to compress the fabric. The up arching of the fabric is here prevented by using a cover disc (not shown in figure 6). After the long sliders movement stops, the short sliders movement (at the top and bottom of the airbag) starts (150-900 ms) and the airbag is “folded“. At end of the movement the airbag fabric is compressed by moving down the cover disc (after 900 ms) finally. With this step the folding is completed and the nodal coordinates can be extracted.

As the folding process is complicated and interminable, high focus to the contacts should be concentrated. A good and robust contact card is very important, as the FE airbag consists of more than 24 000 nodes. Only a single penetrated node would corrupt the model, because this leads to leakage and the airbag will not deploy as expected. Calculation time on a cluster with 8 CPUs was around 6-7 days.

With the end of the simulated folding the compressed airbag still contains high element stresses, which, if the airbag would be built-in into the cockpit at this time, would cause a self-deployment only due to those stresses. So these element stresses need to be reduced in another step.

2.3 Airbag covers:

A new approach to model the airbag's tear seam behaviour should be obtained.
A typical example for a invisivble airbag cover tear seam can be seen in figure 7. A carrier made of plastic materials like ABS or PP is weakened along a predefined opening line by tiny holes (diameter of around 0.1 mm) generated by a laser device. This carrier part is covered by a layer which typically consists of a plastic, leather or textile sheet. This sheet accounts for the optical appearance of the interior and is usually supported by a thin layer of foam (for haptical reasons), It is impossible to model the laser holes with a FE mesh, because that mesh would contain too small elements which would result in numerical problems (time-step, etc.). So two other possibilities were analysed and checked for accuracy of the result.

Figure 7: Invisible airbag cover - driver and passenger airbag (source: Mercedes)

The first alternative is the tear seam modelled by plastic shells, which will deform under force influence and failing at reaching a specified limit. In figure 8 the tear seam is marked with a red line and the plastic shells, which will approximate the tear seam, are marked with white shells.

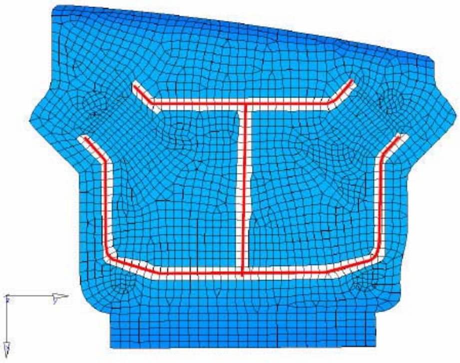

Figure 8: FE Airbag cover model (plastic shells)

The second alternative is the tear seam modelling by using beam elements, which are used to connect the opposite covers (a scheme is drawn in figure 9). A force is assigned to these beam elements. With reaching the force limit the beam element fails and is taken out of simulation by the solver, so the covers can move free at the local point of the beam failure. The beams length ΔL is zero, so the opposite shell elements touches each along their edge(s) (at the figure drawn not correct to set the details more clear).

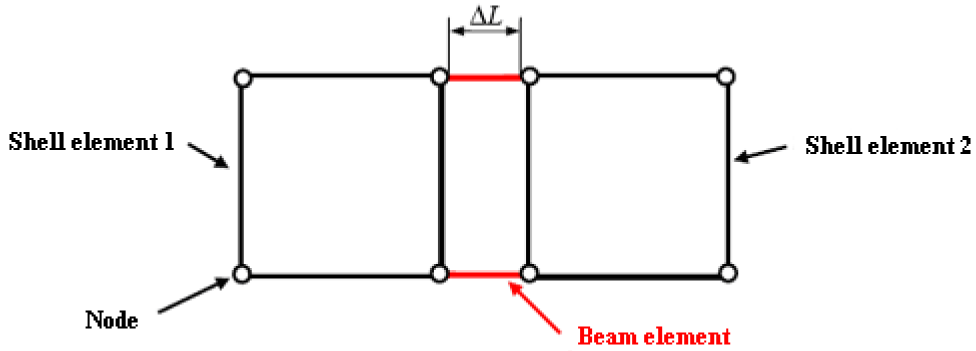

Figure 9: Scheme airbag cover modeling by using beam elements

Figure 10: Airbag cover impact test

Both described methods were reviewed and compared to tests, which were accomplished at the same time. The tests were done with so-called impactor tests. A specially prepared airbag cover part, fixed to the ground and positioned vertically, was penetrated with an accelerated impactor (see figure 10). At the moment hitting the cover backside, the stamp reaches a velocity of 6.2 m/s.

Between the impactor and the force generator a force measure element is mounted and the force plot is recorded over the impactor way and time, so in the diagram the opening force can easily be differed in the tear seam force and the fabric force (see figure 11):

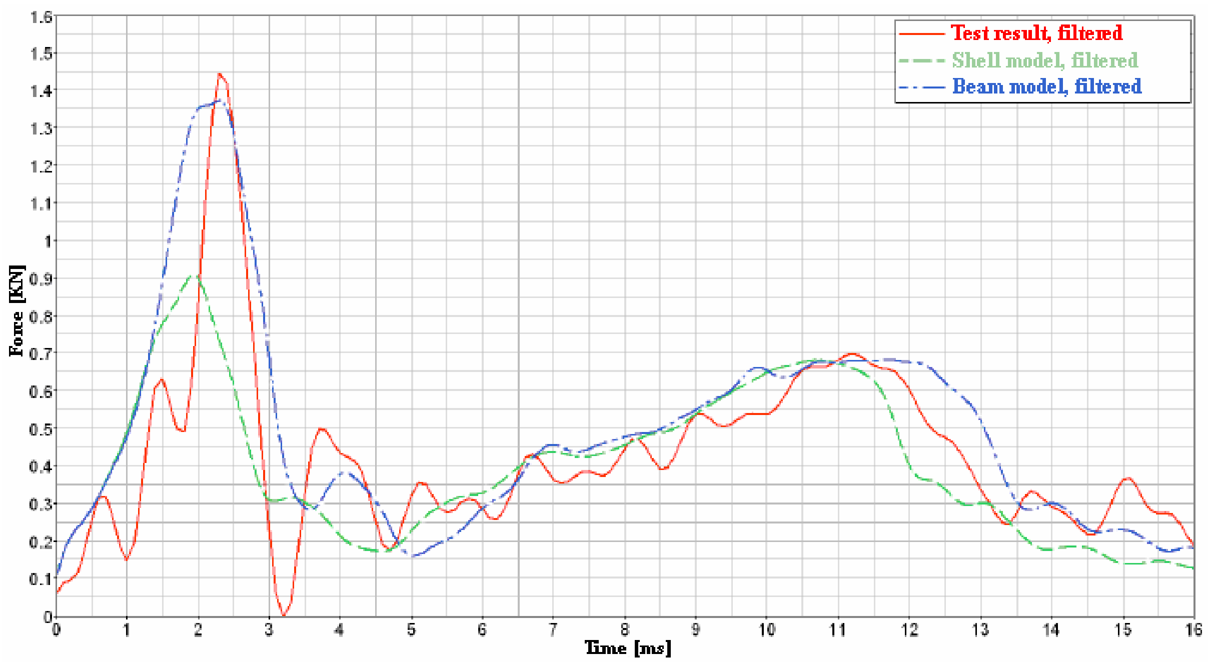

Figure 11: Airbag cover FE model: Comparison shell / beam model to test

The first peak at 3 ms and the following curve decay is caused by the tear seam failure. Then, beginning at 5 ms, the fabric force raises slowly up to its peak at 11 ms – at this moment the fabric starts to rip and the stamps penetrates the whole airbag cover finally. When comparing the shell model to the beam model, we recognize an improved accordance of the beam model to the test, especially around the time range 2-3 ms. As it was not possible to gain more suitable results with the shell model, the beam model was used in further follow for implementing the airbag cover model into the whole cockpit model.

3 Airbag validation:

After achieving these fundamentals we are now able to start to mock-up the complete airbag model and then in a further step to validate the airbag. Two options were reviewed and discussed.

3.1 Inverted head impact test

This is a pendulum test, where the head of the pendulum rests on the folded airbag. The other end of the pendulum is fixed to a framework and can rotate around it. When igniting the gas generator and deploying the airbag, the pendulum is loaded and catapulted away. The resulting forces and accelerations are recorded (three tests were solved).
Three further tests without airbag cover were also done to determine the difference between existing cover and missing cover. No significant deviances were recognized, so it can be assumed, that the main force is caused by the airbag itself. Unfortunately, the simulation did not hit the test results, as the gas generator modelling with LS-Dyna does not include the calculating with the airbag backpressure (+applied pendulum), so the gas generator's burning rate is not variable according to the backpressure. So another method to validate the airbag was tried.

3.2 Impactor test

This test consists of a 50 kg dummy-impactor, which is shot against a deploying airbag. When the airbag is fully deployed, the impactor hits the airbag with a velocity of around 5 m/s. Aim of this test is the evaluation of the airbag's ability to "slow down" the occupant.
Firstly this validation was tried out with the uniform pressure method (UP), as this is an approved and fast simulation method. Comparing the simulation to the test, it was with some modifications possible to gain a suitable result. The calculating time is with a few hours CPU time for a simulation range from 0 to 300 ms very acceptable.
As our attention is concentrated more to the gas flow method, a second simulation deck containing the ALE method was attached. For calculation this deck needs much more time compared to the UP method, around 7 days on a 8 CPU cluster must be set for the same simulation range till 300 ms. The results are regrettably not as good as with the UP simulation, so the reasons were investigated. One reason might be the Eulerian mesh, as it was modelled rather raw to save CPU time. Another reason might of course be found in a suboptimal calculation code, so newer revisions may prove improved results (latest version used for these examinations is LS-Dyna 9.70 Rev. 6763.169).

Conclusion: With the described inverted head impact test and the „normal" impactor test it was not possible to validate the airbag in a satisfactorily way. The main reason might be found in the „static" gas generator, this means, the modelled gas generator always provides the same mass flow rate, independent of the airbag backpressure. Only a "dynamic" gas generator, where mass flow can be coupled in dependence to the backpressure might be able to provide accurate results.

4 Implementation (Full Model):

As already mentioned in Chapter 2, four different test positions are examined (3yrs with head and chest at cockpit, 6yrs with head and chest at cockpit). At first, the position "3yrs with head on cockpit" was chosen to implement the single components. It consists of the positioned 3yrs child dummy, the folded airbag with its chassis and gas generator, airbag covers, cockpit, windscreen, seat and of course the Eulerian mesh for the fluid calculation (see figure 12). The Eulerian mesh is here displayed transparent.

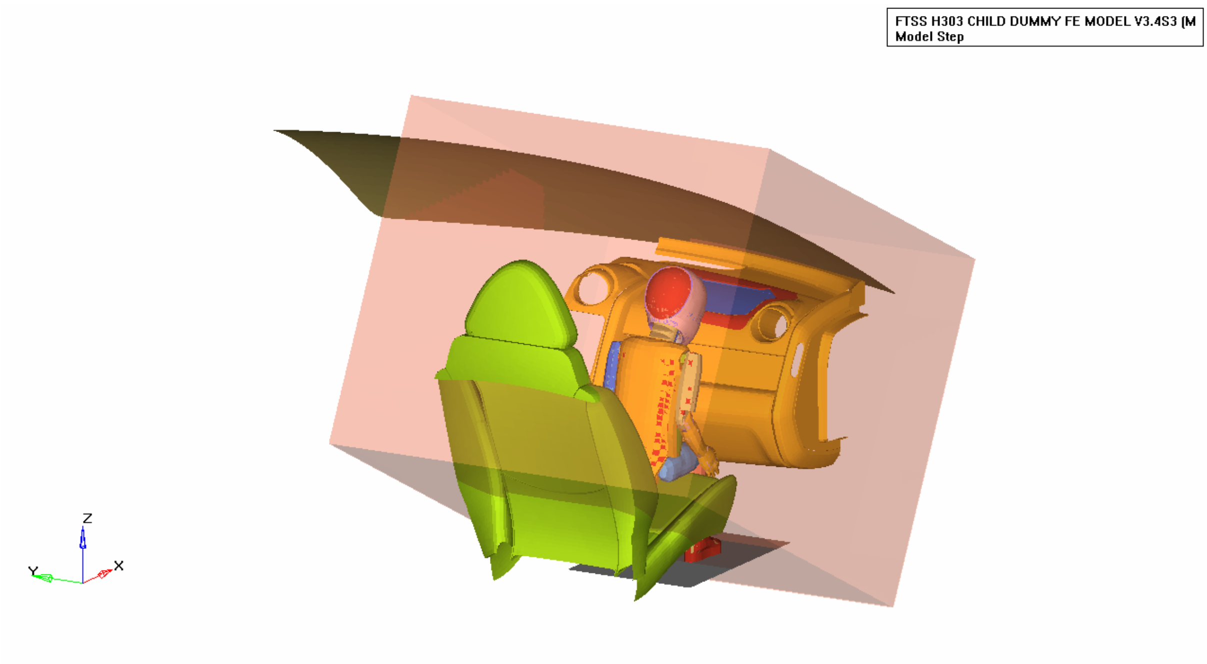

Figure 12: 3yrs dummy with head at cockpit, complete simulation model

In the test runs the dummy position was measured exactly and protocols were penned, so the dummy in simulation model could be positioned and checked for the exact position rather easily. The whole simulation model consists of around 413 000 nodes and 401 000 elements (shells, solids, beams) and runs from 0 to 50 ms. A calculation time of around 90 hours (~ 4 days) on a 8 CPU machine must be assumed for this model. After applying some optimisations (parameter adjustments) to the model, accurate results are achieved (see figure 13-15).

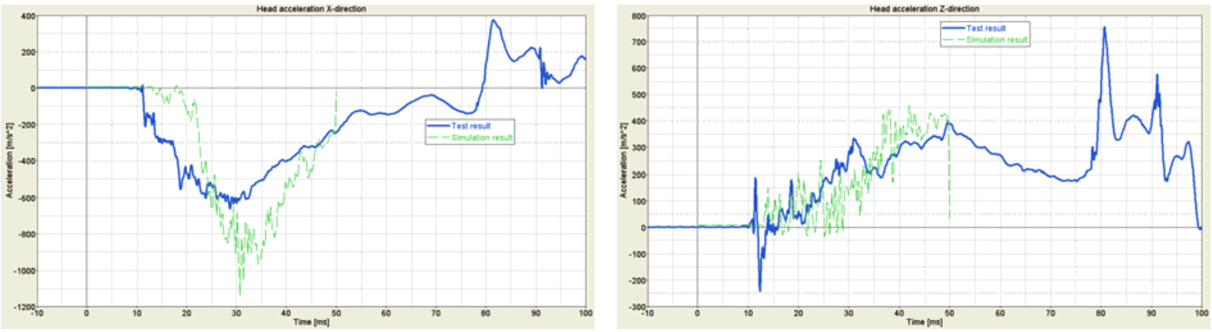

Figure 13: Head acceleration in X- and Z-direction

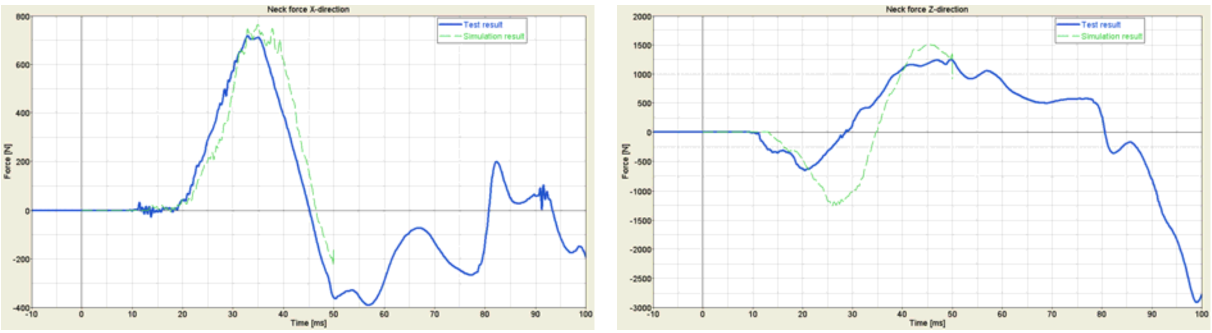

Figure 14: Neck force in X- and Z-direction

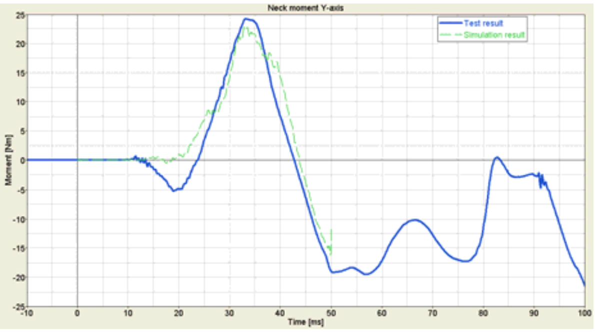

Figure 15: Neck moment around Y-axis

Only the head acceleration in X-direction (figure 13) and the neck force in Z-direction (figure 14) does not fit to the test line very well. With this optimised model it's possible to examine little model deviations, for example another dummy position or another airbag folding and its effects. Huge model deviations cannot be examined, as they depend on the effect of the airbag backpressure to the burning rate. As this accomplishment is very important, but cannot be modelled with this version of LS-Dyna, we will need to wait for improved solver solutions.

5 Parameter study:

To estimate the influence and dependence of several parameters on the simulation results, some considerations about significant parameters were done and ranked on their (assumed) priority. A so-called parameter matrix was generated, the simulation decks were varied by these parameters and the results were evaluated. Some important, examined parameters may be listed for example consecutively:

- friction between airbag and dummy
- dummy's head tilt
- gas generator performance
- tear seam force
- airbag folding
- size of Eulerian mesh
- dummy's position

In conclusion the parameter with the biggest influence was found in the gas generator performance – this means, more gas generator „power“ leads to more curve amplitude and vice versa. The second important parameter is the dummy position; every position change leads (as expected) to different results. The other parameters do not show great influence on the results.

6 Conclusion, forecast:

Usage of the ALE method is a good approach to simulate the first milliseconds of airbag deployment, as this method provides more accurate results than the UP method. The modelling, especially of the airbag folding, must be done very carefully and little deviants can lead to different results. Effects on the dummy position must be taken into account and it is advised to verify these deviants by tests. The calculation time is not negligible as the ALE method needs around 90 hours, compared to the 6 hours with the UP method.
The biggest disadvantage of the ALE method is the „static” gas generator mass flow, as the solver does not take the backpressure into account. Surely, in future improvements will be done in the solver code, but actually OoP simulations are afflicted with this inadequacy.
This method is, however, a first starting to investigate OoP problems by simulation. Model variations (in a small range) can be done and evaluated, but the simulation results always need to be fused by tests. With rising CPU power (dual core, quad core) it will be possible to establish this method more and more as it promises more accurate results compared to the UP method.

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