Detailed Passenger Airbag Modelling for Early Stage Events

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1 Introduction

Occupant restraint systems are an essential part of today's vehicles to reduce the injury risk of occupants during collisions. Additionally to In-Position collisions, further requirements influence the performance and design of airbag modules. This can be integrity of airbag housings, of IP covers or the FMVSS208 including Out-of-Position for driver and passenger airbags modules where a detailed modeling of the first milliseconds after TTF is necessary. Since virtual product development is an important part in vehicle development, predictability of airbag modules for In-Position, housing and IP integrity simulation and Out-of-Position is required. In this paper we focus on modeling techniques for simulations of passenger airbag modules during the first phase of deployment and the use of simulation methods in the development process.

To reduce the number of hardware loops, the predictability and robustness of the simulation models have to be guaranteed. Changes in airbag folding or the inflator used have to be captured in the model.

Standard simulation approaches are not sufficient to capture all loads and effects acting in an early state of deployment. Additional correlation tests and advanced modeling techniques have to be implemented to correlate the model at an early state, when first contact between airbag and neighboring parts occur. Basic modifications, for instance changes in inflator gas flow model, detailed airbag folding or airbag shape modeling are required. Recent developments of software tools allow a fast folding simulation of airbags, a pre-requisite for an efficient usage of simulation in product development process. Completed by fluid structure interaction methods, e.g. CPM in LS-Dyna, a realistic gas flow model and hence deployment of the airbag, which captures proper loadings on surrounding parts like airbag housings or dummies, can be achieved.

First, modeling strategies of passenger airbag modules are discussed including detailed analyses of the airbag folding and its deployment. Then, different test settings for a passenger airbag module correlation are summarized. Benefits and limits of the airbag model are presented showing a stepwise increasing complexity of the model. Finally outlook to the field of Out-of-Position simulations for passenger airbags are given.

2 Passenger airbags

2.1 Passenger airbag module setup

Passenger airbag modules include different parts like the airbag fabric, housing, airbag cover and the inflator, see Figure 1. Physical effects like the internal airbag fabric, folding, gas flow of the inflator, material characteristics of the fabric and the housing and the module leakage through vents, seams and the fabric itself determine the module performance.

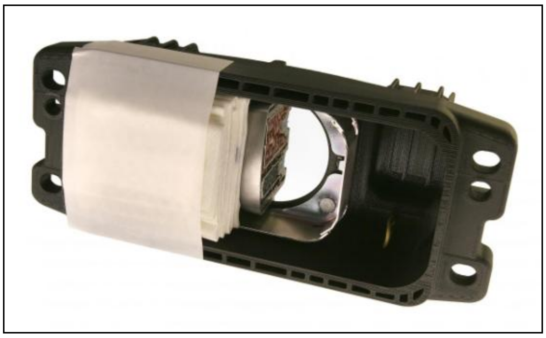

Figure 1: Passenger Airbag Module

2.2 Boundary conditions in Passenger Airbag Module development

Passenger Airbag Modules (PAB) are part of the passive safety system in most vehicles [1]. Legal, consumer and specific OEM requirements affect the development of a Passenger Airbag Module. The following categories summarize those requirements:
- Module integrity which has to be assured for a reliable deployment of the airbag out of the module.
- IP cover opening: During the deployment, the airbag interacts with the IP cover which tears off at a certain reaction force.
- Avoid damage of the wind screen during airbag deployment.
- Out of Position load cases. US legal requirement considers load cases in which dummies do not sit in the nominal position. In such scenarios the airbag interacts with the dummy during deployment. Dummy values must not be exceeded during airbag deployment.
- In Position load cases: Restraint performance of the airbag reduces dummy values in frontal impact crash scenarios.

In this paper, we will focus on the airbag modeling strategy including an approach to separate different physical effects to capture the physical values like airbag pressure, volume and geometry. These values affect the interaction with surrounding parts like the housing, IP or wind screen, especially between “Time to fire” (TTF) and the fully deployed passenger airbag.

3 FE model set up for early stage events

A physically correct FE PAB model enables to predict physical parameters like:
- The pressure inside the airbag
- The volume of the airbag
- The reaction forces to the surrounding parts of the airbag

To reach this goal all important physical effects which influence the overall airbag performance have to be captured:
- The inflator provides the whole energy to the airbag. After ignition by an electric signal a chemical reaction produces gas which flows from the nozzle inside the airbag cushion. Depending on the composition of the gas the inflator generates different mass flow and temperature characteristics.
- The outer contour of the airbag which defines the shape after deployment. It also gives the volume.
- The internal geometry and parts of the airbag. These are important to guide the hot gas inside the folded airbag. They affect the airbag deployment.
- The airbag folding. Depending on the folding the regions which deploy first are defined as well as the direction of deployment and hence the resultant reaction forces on the housing, IP, wind screen and first contact with dummies.
- The material characteristics of the airbag (and the housing) influence the shape, pressure and volume of the airbag respectively the stiffness of the housing.
- The leakage of gas affects the performance especially for In-Position. But also during deployment gas is leaking throughout vents, seams and airbag fabric.

For early stage events especially the internal parts (explained in chapter 3.1.), the airbag folding (chapter 3.2) and the gas input of the inflator (chapter 3.3) are of importance.

3.1 Airbag contour and internal parts

The airbag shape is driven by the contour of the IP and the angle of the wind screen. Furthermore the available packaging space and the inflator performance influence the contour of the shape.
Straps are applied to reduce the airbag volume or to change the shape. The so called calzone is a cylindrical piece of fabric which is wound up around the inflator to guide the gas into the outer regions of the airbag. The strap and the calzone are shown in Figure 2.

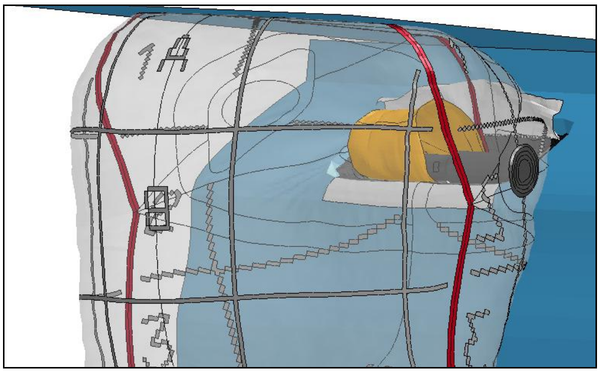

Figure 2: FE model of a deployed passenger airbag

3.2 Airbag folding

Especially for early stage events it is highly recommended to investigate the folding procedure in detail and spend some time to set up a realistically folded airbag module. The folded airbag has to be free of intersections and penetrations and must not show a high level of initial energy. A virtual folding table is set up to pre-simulate the folding process in detail. Figure 3 shows several intermediate steps of a folding simulation: (a) the airbag is positioned flat on the virtual folding table, lower panel is rolled and tucked into the housing (b) and in (c) one can see the final folded passenger airbag after the zig-zag-fold of the upper panel.
To assure that the final folding has a good quality and comparability with reality, a 3D computer tomography has been performed for the hardware. The result shows a good conformity for some important features of the airbag like the positions of the upper and lower roll fold and the calzone.

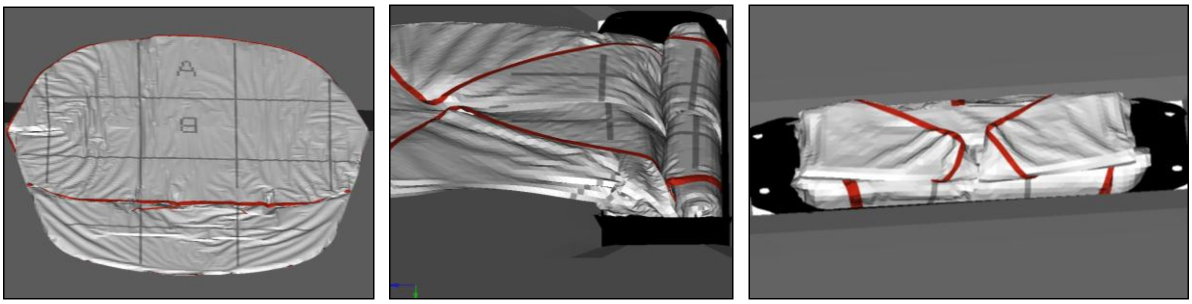

Figure 3: Folding sequence of a passenger airbag, (left) positioning, (middle) roll fold lower panel, (right) zig-zag-fold upper panel

3.3 Inflator data

Before modeling the gas flow into the airbag cushion, the inflator input data has to be verified. The general approach is a tank test. The inflator is placed in a tank with a predefined volume; a sensor measures the pressure inside the tank after the inflator is ignited. In a semi-empirical approach the measured p(t) curve is used as an input together with the gas composition to generate a mass flow versus time and a temperature versus time curve. Gas composition, mass flow and temperature curves act as input for the simulation [2], [3].
Furthermore the gas deployment into the airbag cushion has to be modeled. Therefore it is necessary to capture the gas flow characteristics into the airbag cushion. It has to be assured, that the gas flow behaves realistically, starting from the inflator nozzles into the neighboring parts. So the airbag is

deployed step by step. A uniform pressure approach is not sufficient for that, because it applies the same pressure in the whole airbag equally. The CPM method in LS-DYNA [4] allows the required behavior instead. The gas molecules are discretized with a limited amount of particles that carry averaged gas properties.

3.4 Material characteristics

Airbag fabrics are made of thin, soft filaments, taken to fibers, which are woven. The small dimension of airbag thickness compared to the dimensions in plane allows a certain test approach which neglects the effect over fabric thickness, but considers the two webbing directions, warp and weft.
Two tests, the biaxial test and the picture frame test were implemented to determine the anisotropy stiffness of the fabric and the shear stiffness, respectively. Both tests are shown in Figure 4.

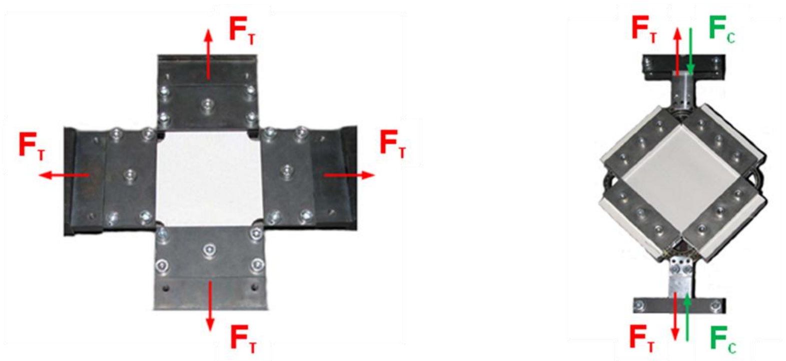

Figure 4: Biaxial test (left) and picture frame test (right)

3.5 Definition for airbag seam leakage

In LS-DYNA, several gas leakage options are available. Here the pressure rate dependent leakage FVOPT=7 or 8 in the *MAT_FABRIC card is used. This allows an m*(p)-function to be defined as input for leakage through seams and/or fabric for a defined part.
In Figure 5, the test rig to determine the mass flow versus pressure function is shown.
We define an exactly known seam line in a simplified airbag. It has to be assured that no other leakage occurs. Now we define a pressure which should inject the airbag. During the whole injection, gas is leaking throughout the seam. As soon as the working pressure is reached the pressure regulation fills in exactly the amount of gas which is leaking throughout the airbag seam. In the volume flow measurement the gas flow over time is measured. We will redo this approach in steps of 0.05bar for all important pressure levels which can be reached during airbag deployment phase. All these values can be converted into the required m*(p)-function for the code.

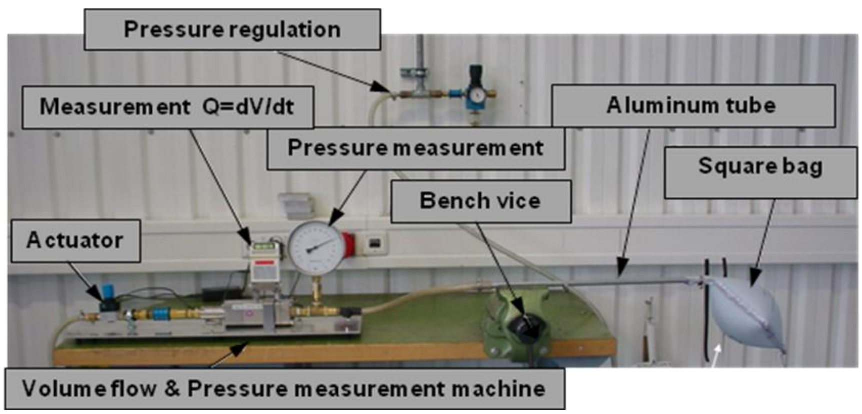

Figure 5: test rig to measure the mass flow throughout an airbag seam

All in chapter 3 described effects have to be implemented into the FE model to assure a proper deployment behavior of a folded passenger airbag.

4 Model correlation

To correlate the FE model a test scenario has to be chosen, which captures all important phases during an airbag deployment. At TRW three test procedures were defined, each one for a specific period of time during deployment:

- 0-10ms after ignition: Here mainly the reaction forces from the airbag on the housing and the IP cover are of interest.
- 10-40ms after ignition: After opening the cover, the deploying airbag and, depending on the design, also the cover hits the wind screen.
  Afterwards the airbag interacts with the dummy in so called “Out-of-Position” load cases.
- 40-…ms: In this time range usually the so called “In-Position” load cases occur. The airbag is fully deployed and the dummy is restrained by the airbag.

4.1 Test scenario for 0-10ms after ignition

In [1] a detailed description is given how models have to be prepared and set up to correlate at the time between 0 and 10ms after ignition. The so called “Wall-Segment” test device is used to correlate the passenger airbag on reaction forces acting on the housing. Doing small modification to the test rig, also an IP cover can be implemented to the test set up. In Figure 6 the reaction forces on housing and the inflator are shown. The airbag pressure is applied to the wall segments of the housing. Additionally, reaction forces and torsion moments are acting to the centre of gravity of the inflator.
Hence it is very difficult to measure reaction forces directly to the housing; we replace the walls by steel plates with load cells mounted behind the walls. During airbag deployment, the forces applied to the walls are transferred to the load cells which give the F(t) function from the test. In the FE model we use the folded airbag and place it into the rig of rigid plates which have just one degree of freedom perpendicular to the plate. When deploying the airbag the F(t) function can be plotted from the simulation model which can be compared to the test scenario. Figure 7 shows the test rig and the simulation model as well as the reaction forces on the wall segments.

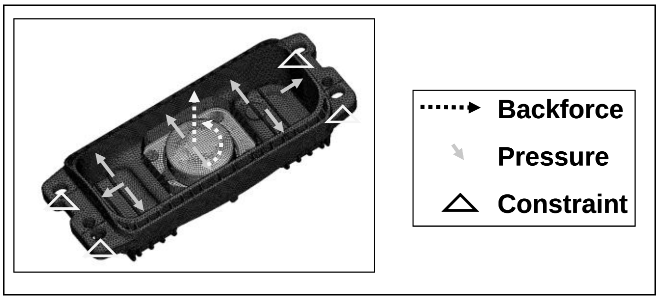

Figure 6: Sketch of reaction forces and torsion moments acting on housing

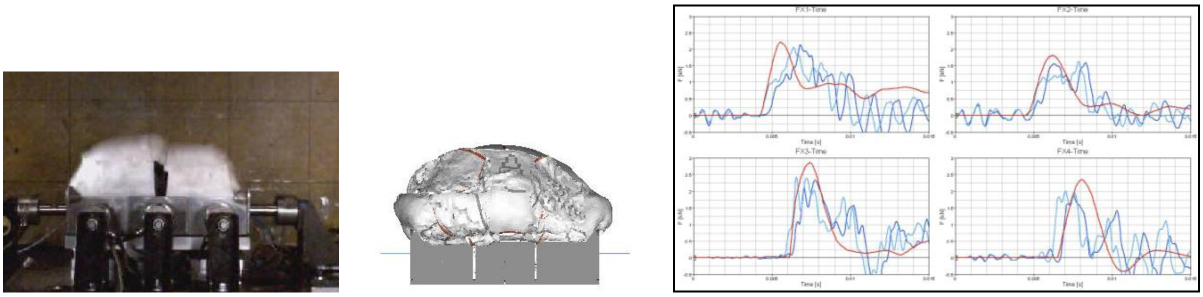

Figure 7: Test rig (left), simulation model (middle) and back forces (right)

4.2 Test scenario for 10-40ms after ignition

This test scenario represents a simplified Out-of-Position test scenario.
A 1DOF wooden plate is positioned right in front of the deploying airbag. It is pushed away, when the cushion hits the plate. A load cell measures the kinematic values of the pushed plate like displacement

and acceleration. Additionally a pressure measurement is implemented into the airbag module. During airbag deployment it is important to capture the energy absorption of with or without IP cover. Doing some small changes in the test rig, an IP cover can be attached to the device. In Figure 8 the test rig, the simulation model and kinematic curves are shown.

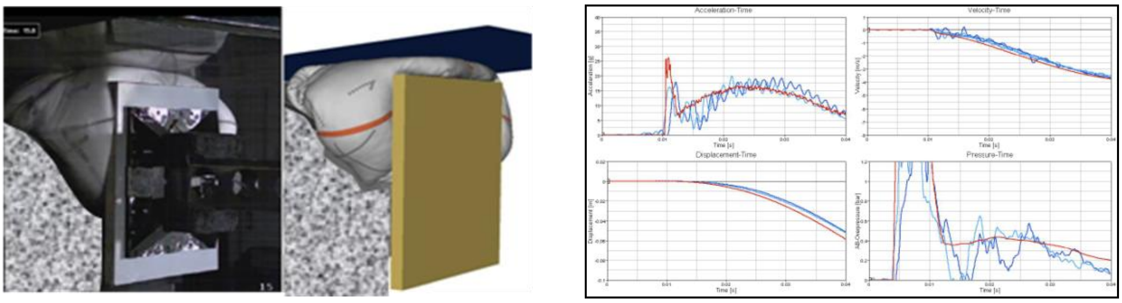

Figure 8: Test rig (left), simulation model (middle) and impactor results (right)

4.3 Test scenario for 40-…ms after ignition

Instead of placing the plate in front of the airbag, it can also be positioned far away from the airbag and moving towards it during the airbag deployment. The plate hits the airbag with a predefined velocity at a predefined time. The simplified linear impactor test represents In-Position load cases. Hence this scenario is beyond early stage events, it is just taken to complete the picture of the model quality.

5 Out-of-Position simulations

All described modelling techniques in chapter 3 and test scenarios in chapter 4 will lead to a very detailed, good correlated airbag model. This model can be used for integrity assessment or IP cover opening simulations as well as for OoP simulations. To assure a good predictability for OoP some additional boundaries have to be captured:

- A high quality model of the IP regarding tearing failure, material characterization and contact behavior between airbag and IP.
- A high quality of the FE dummies and the seat. Both have to capture the correct material characteristics including bending effects or the compression/squeezing behaviour, good internal contact definitions, the correct mass distribution and, especially in dummy models, the same geometrical dimensions as in hardware.
- The correct position of the dummy in the car environment. This has to include the COG, H-Point and important angles of the head or the chest, for instance. A presimulation to position the dummy into seat might be necessary to fulfil both, the COG and the H-point.
- Correct friction values between the different contact partners, for instance airbag-dummy, airbag-wind screen, airbag itself, airbag-IP, dummy-IP, etc. have to be used. A dynamic effect of friction has to be considered.

A simulation was performed for child dummies, the 3-Year old and the 6-Year old dummy, respectively. The 3-Year old was positioned chest on IP while the 6-Year old was positioned head on IP. Especially for the 6-Year old dummy, the correct positioning inside the BIW is very important including a presimulation to squeeze the dummy into the seat cushion and to position it correctly according the required angles for head and chest. This is important to receive a correct splitting of reaction forces and moments in x- and z-direction.

In Figure 9 simulation results for 3-Year-old dummy with chest on IP were compared to test results. Figure 10 shows the 6-Year-old dummy with head on IP. Blue lines show the test results, the red line shows the simulation.

Both simulations show a qualitative good predictability - capturing the first peak, the general behaviour of the curves compared to test and the maximum level of the measured values.

However there are open points to be clarified to further improve this approach:

- The correct position of the dummy has to be taken from test and has to be applied to the simulation. Positioning parameters like the COG, H point, head and chest angles have to be captured exactly like in the test set up.

- The airbag folding process has to be further improved regarding process time.
- The efficiency of the whole process has to be improved.

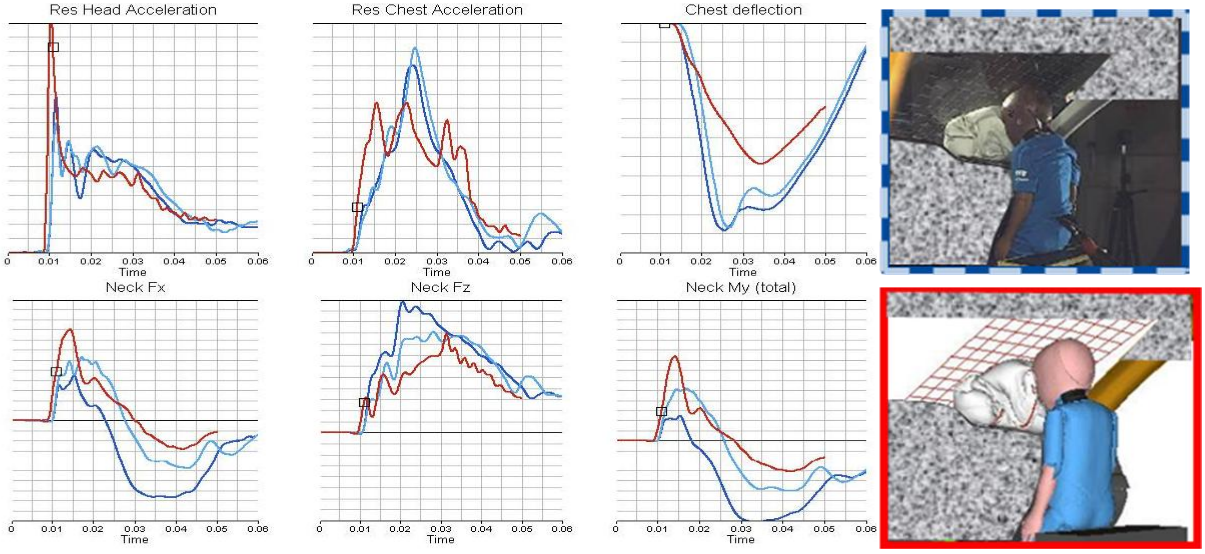

Figure 9: OoP simulation for 3-Year old dummy with chest on IP

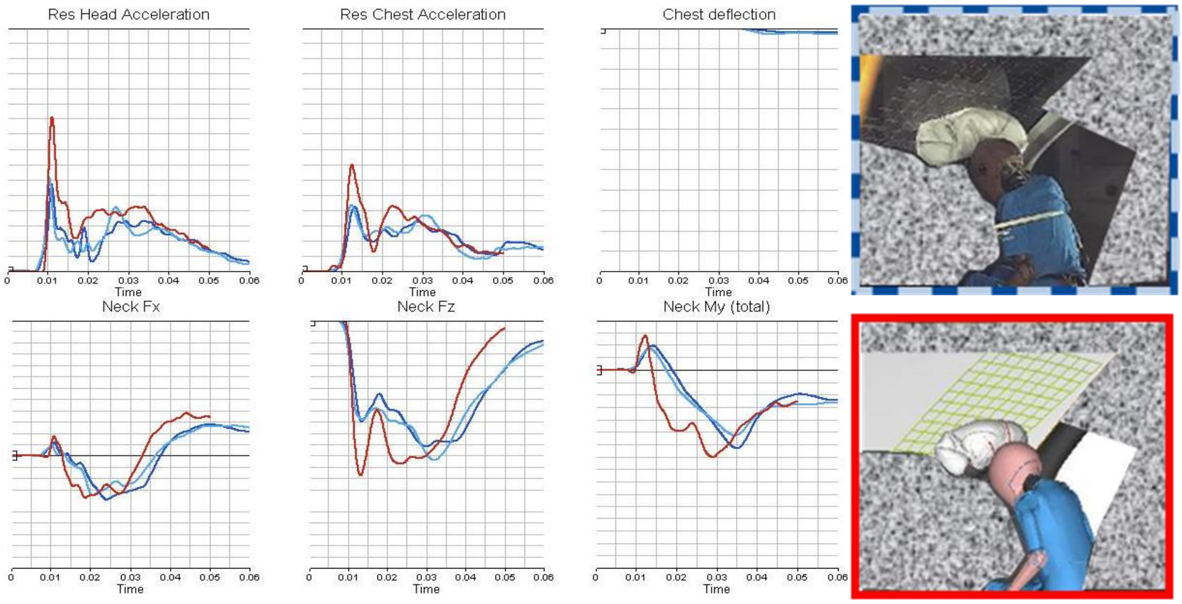

Figure 10: OoP simulation for 6-Year old dummy with head on IP

6 Summary

In today's development process the simulation driven support is increasing more and more. To assure a good quality in predictability, detailed airbag modelling is necessary, especially for development of IPs, housing assessment or Out-of-Position. An approach which separately models the most important effects for these so called early stage events is given. This approach captures the inflator data including a fluid structure interaction and the airbag folding in a very detailed manner. Furthermore the material characterisation and an approach to measure the seam leakage were presented. Before the model is implemented into a complex system of different interacting parts, simple test scenarios for model verification were discussed. On one hand the Wall-Segment test with focus on housing integrity assessment and IP cover opening was shown. On the other side, a Push-Away test was presented giving the energy impact at an early phase of airbag deployment. To assure that the model will also work under In-Position, a State of the Art Linear Impactor test set up was discussed. Finally the model which was taken as an example was put into an Out-of-Position environment to show the current possibilities and limits.

7 Literature

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