

# Integrity Assessment of Passenger Airbag Module Housings

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## Abstract

*A substantial prerequisite for the performance of airbag modules during collisions is the structural integrity of all module components. This paper focuses on integrity assessment of passenger airbag module housings during deployment and the use of adequate simulation methods for this task. In particular an approach is discussed that reduces the required number of hardware test loops by using a complete model of the module including details like the folded airbag and IP. Instead of identification hardware tests, the proposed method allows to calculate the loading parameters of the housing directly within the simulation. This increases accuracy for the analysis of various setups and parameter changes. Mandatory for this approach are efficient airbag folding, realized by pre-simulation, and a high level of predictability of the deployment behavior, where fluid structure interaction methods are applied, i.e. CPM in LS-Dyna.*

## Keywords

Passenger Airbags, Corpuscular method, Airbag folding

## Introduction

Occupant restraint systems are essential parts of today's vehicles to reduce the probability of occupant injuries during collisions. In order to evaluate the restraint performance, computer simulations, sled tests and vehicle barrier tests are conducted for different collision types. Substantial prerequisite is the integrity of the passive safety modules on component level. This paper focuses on integrity of passenger airbag modules during deployment and the use of adequate simulation methods in the development process.

Standard simulation approaches simplify the loads on the module during an airbag deployment to mean pressures and forces. These approximated loads are measured in specific tests and transferred into the simulation models. This approach is well applicable for one specific module. Basic modifications, for instance changes of inflator, airbag folding or airbag shape, require further test series, though.

In order to reduce this additional hardware loops a full simulation of the module is proposed including details like the folded airbag and IP environment. Thus the loading conditions of the housing result directly from simulation, which increases accuracy for the analysis of various setups and parameter changes. Recent development of software tools allows for a fast folding simulation of airbags, a prerequisite for this approach. Complemented by fluid structure interaction methods, e.g. CPM in LS-

Dyna, a realistic gas flow and hence deployment of the airbag and loading of the housing can be achieved.

In this paper, the hardware module setup and functionality is explained. Afterwards different loading situations for a passenger airbag module are summarized. Then focus is put on the airbag deployment. Two modeling strategies are discussed within the development process. Benefits and limits of simplified models are presented. Then improvements by the use of detailed models are described. As one key point, the airbag folding is highlighted. Further, a modular modeling strategy is discussed with identification and correlation of the driving physical effects like the reaction force of the inflator. Finally the paper is closed with an outlook on the utilization of the proposed approach at TRW.

## 1 Passenger airbags

### 1.1 Module setup and functionality

Passenger airbags are part of the passive safety protection system in most vehicles. Parameters like airbag shape, venting, material, inflator performance, etc. are defined with respect to the overall occupant restraint system performance regarding legal, consumer and specific OEM requirements. This includes a sound balance of all restraint components including seatbelt system, seat, instrument panel (IP), knee airbags, etc.

In this paper focus is given on the integrity of the airbag module on component level. Figure 1 shows the main parts of a passenger airbag module. The airbag is a fabric cushion that is folded in a defined way and positioned inside the housing. The folding process comprises flapping, tucking and rolling steps. The inflator provides the gas to inflate the airbag. The housing is a relatively stiff metal or plastic part that can withstand the pressure and force loads during the deployment. After ignition, the airbag cushion deploys in front of the passenger to protect him.

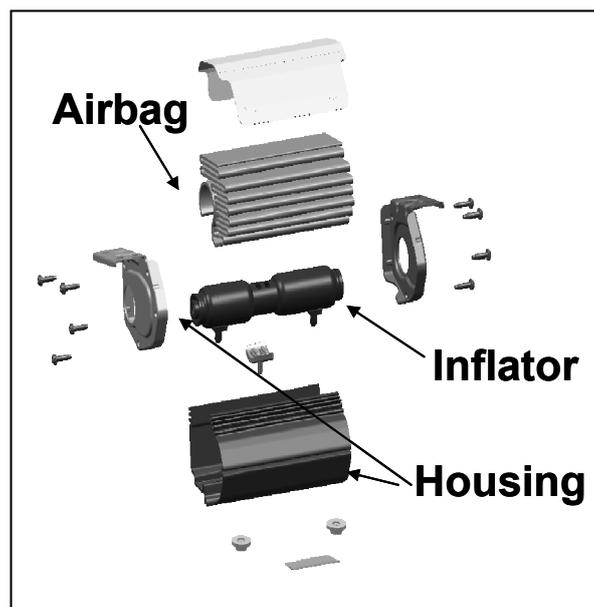


Figure 1: Airbag module

### 1.2 Simulation tasks in product development

During a vehicle crash, the protective function of the passenger airbag module needs to be ensured. This comprises performance of the airbag cushion and integrity of the complete module. Here, implicit and explicit FE simulation methods support the development process:

- Performance of the complete occupant restraint system is assessed and optimized in explicit frontal crash simulations. Correlated passenger airbag models are included in the vehicle model.
- During deployment, the airbag housing is loaded by pressures and forces which could lead to deformation and displacements of the housing within the instrument panel. The most relevant

loads occur in the first 10-15ms after ignition of the inflator. Thus explicit FE models are used to assess the integrity.

- Pre-stresses could occur during molding, assembly or mounting of the module inside the car environment. Here it is essential to identify potential pre-stress with adequate pre-simulations and transfer it to the integrity simulation model.
- Analysis of squeak and rattle behavior during excitation in normal driving on the road. Implicit eigenmode calculations support this task.
- Housings and other mechanical parts are more and more made from plastics for a good balance between strength and weight. This requires to take the molding process into account and combining mold flow analysis with integrity assessment.
- Potentials for further weight reduction can be identified through shape and topology optimizations. Hence, topology and parameter optimization studies are performed.

This overview shows the variety of tasks for simulation in the development process of a passenger airbag module. In the following focus is given on integrity assessment of passenger airbag module housings.

## 2 FE models for integrity assessment

Major loading of passenger airbag module housings occurs in the early phase of airbag deployment. Hence, for housing integrity assessment the focus is on the first 10-15 ms after ignition. In the following the loading situation during that timeframe is explained in more detail. Then the TRW workflow for integrity assessment of module housings is briefly outlined. Finally, the corresponding simulations models are introduced.

### 2.1 Loading situation during deployment

At ignition, an electrical signal fires the inflator. A chemical reaction starts to produce gas that flows over the nozzles into the airbag cushion. The gas is guided and reflected by inner airbag layers and metal retainers. Due to the constraints by housing and IP cover, the pressure inside the airbag raises quickly until it reaches a sufficient level for opening of the tear line in the IP. So far approximately 10ms time elapsed. Then, the airbag starts to deploy out of the housing and positions in front of the passenger. During the unfolding and continued deployment process the pressure level decreases due to the increasing volume of the airbag cushion. In this phase straps, fabric tissue and tethers that determine the shape of the airbag for optimal in position restraint functionality transfer forces locally into the housing at the attachment points. The airbag deployment is finished after approx. 40ms. Now the pressure has reached working level and can protect the passenger in the intended manner during the crash. However, major loading of the housing occurs only in the first 10-15ms.

The described airbag pressure and forces directly act on the module housing and the IP. The forces shortly after ignition are short impulses acting only locally during 2-3 ms whereas the pressure loads range over 5-10ms. The design of cover tear seams influences the level and time history of these loads. Depending on the mounting situation in the IP, the module needs to withstand additional torsion and bending. Hence, robust designs are required. On the other hand, weight reduction desires a good balance to the material used. The definition of a robust low-weight design is a task where simulation can give good support. Current designs using plastic housings require special focus on high and low temperature where the mechanical properties of the materials may change.

### 2.2 Integrity assessment of module housings - Workflow

In order to ensure the integrity of the airbag housing during deployment, TRW focuses on a simulation supported development process. Concept designs of housings are established by the aid of topology optimization, elastic static analysis and Moldflow studies. Thus geometric concepts can be compared and elaborated due to stress profiles. At this is early stage, essential information of the required module dimensions is gained.

As the project evolves, simplified dynamic deployment simulations are performed to choose material, rough rib or beat patterns as well as molding strategies. These simulations consider most important loads like pressures and forces due to airbag deployment. The magnitude of these loads is approximated by data from generic measurements and applied directly on the FE model. In this phase, information on the environment is often limited and therefore worst case assumption upon experience and tests are used. These models are explained in chapter 2.3.

As soon as Finite Element models of the environment, i.e. instrument panel, covers and cross car beams, are available, detailed deployment simulations are possible. Here airbag and inflator are part of the model and the loads directly result from a numerical deployment simulation. Now worst case

assumptions can be released and fine tuning of the module concept is possible. At this point, close interaction between IP supplier and airbag supplier is necessary to analyze module and IP behavior during deployment. This type of model is described in chapter 2.4.

Note that the discussion in the following focuses on the load cases and required information. Basic prerequisite is to determine suitable FE cards for the material data. Here it is crucial to take strain rate and temperature dependency into account.

## 2.3 Simplified models

### 2.3.1 Model Setup

The finite element model comprises housing and inflator, see Figure 3. Pressure is applied on segments of the walls of the housing. Forces and torsional moments are applied on the centre of gravity of the inflator. These inflator loads are called backforce. Fixations are realized by idealized constraints at the screws. The resulting pressure on the housing and reaction forces of the inflator are measured by load cells in specific hardware tests. Often a conservative approach is chosen in early phases, where worst case values for internal pressure, backforce and fixation of the model are used. Moreover, several input curves from different inflators can be taken from tests with different inflators. All tests are performed at low, room and high temperature.

For the FE solution an explicit solver is applied. Shell elements or 10-node tetra elements are utilized. The material data takes temperature and strain rate dependency into account. The simulation model is of low complexity and can be created fast. The overall computing time is low. For plastic housings the explicit mechanical analysis is augmented by a MoldFlow simulation that shows the position of weld lines and gives an indication on fiber distribution.

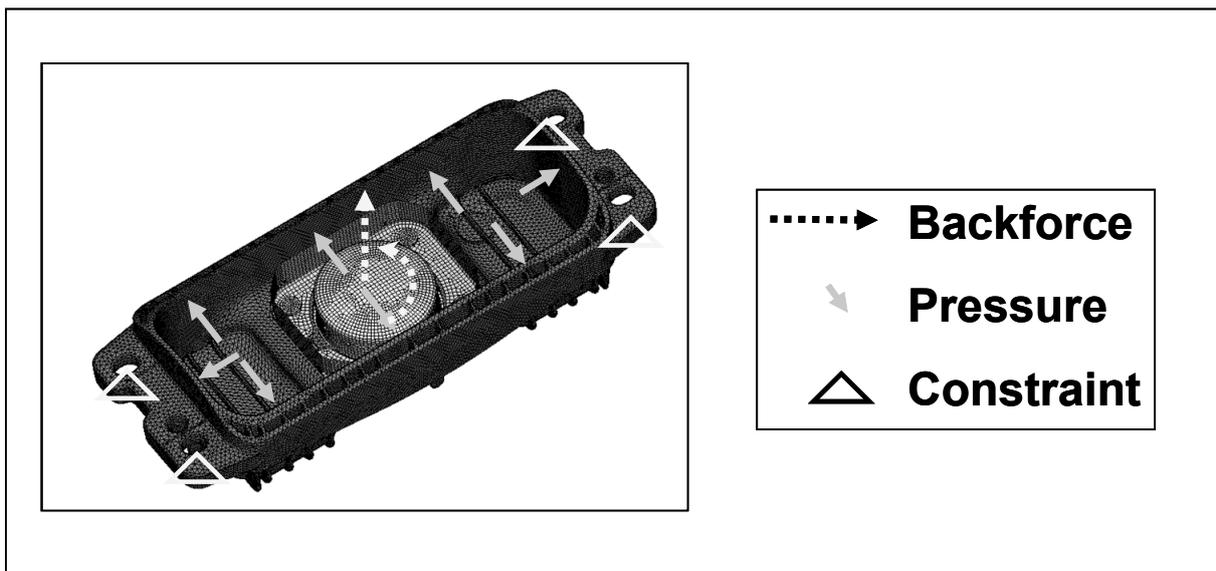


Figure 3: Simplified models

For simplified models, simulation indicates peak stresses and critical areas. Hence, rib patterns and reinforcements can be defined and materials can be selected. In case of plastic housings, molding strategies can be defined. Kinematics is of limited predictability since the constraints do not account for the exact mounting situation in the instrument panel.

Main advantage of this approach is to improve the housing geometry rapidly at an early stage of the project with limited input on the vehicle environment like brackets, instrument panel or the tear seam of the cover.

A drawback of the described approach is that some generic hardware tests are required to approximate the loads acting on the housing. The airbag is folded inside a simplified buck and load cells record the forces acting on idealized walls. Parameter variations like different inflator types or folding sequences cause changes in internal pressure and backforce and, hence, specific tests.

### 2.3.2 Considering pre-stress

Mounting the inflator results in pre-stresses in the housing. This reduces the safety margin within the subsequent deployment tests. Pre-stresses can be taken into account by an implicit pre-simulation. In a first implicit step, the screws are mounted on the bolts of the inflator. Here a solid mesh is necessary. The resultant deformation and stresses are directly transferred as initial condition into the second explicit step, a simplified deployment simulation. Figure 3 shows this approach.

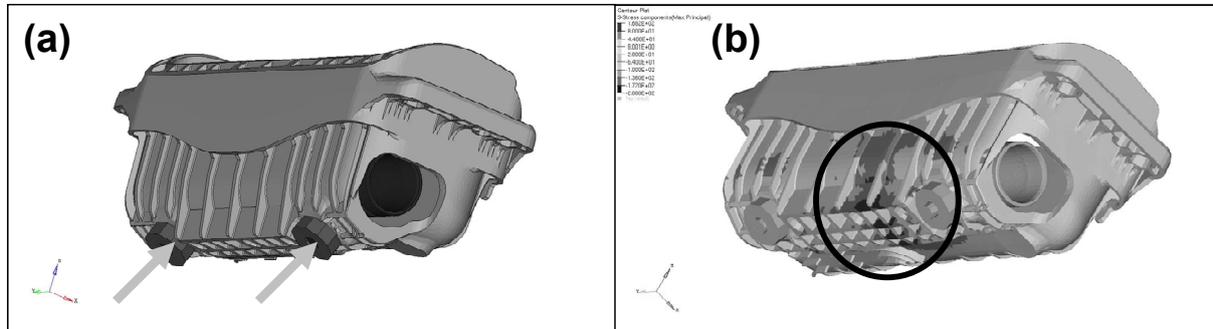


Figure 3: (a) Implicit simulation: Mounting screws on inflators bolts (b) Resultant Pre-stresses

## 2.4 Detailed airbag models

### 2.4.1 Model Setup

In detailed models the loads acting on the housing are internal loads and therefore part of the solution. For example pressure applied on the housing results from a deployment simulation of the airbag and not from prescribed curves as used in the simplified models. Main parts of detailed models are:

- Folded airbag inside the housing,
- Gas flow method to allow for fluid structure interaction,
- Instrument panel and bracket,
- Cover with tear seam including failure

Figure 4 shows a model and a snapshot from the deployment simulation. Rotation of the whole module around the cross car beam and deformation due to pressure load and backforces can be seen in simulation.

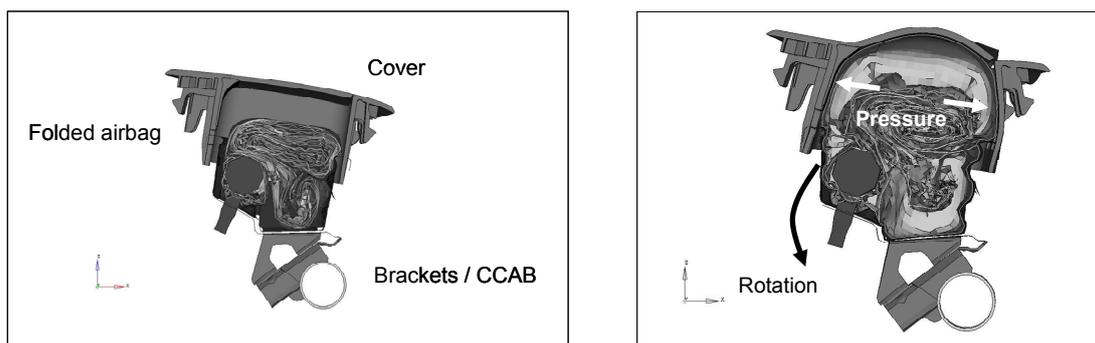


Figure 4: Detailed model: Before (left) and during deployment (right)

The folded airbag cushion model is placed inside the housing. In detailed models, solid elements are required for the other parts of the module. A minimum of three layers of elements over thickness is common for housing walls or the cover. Material cards for tear seams include a failure criterion to show proper opening behavior.

### 2.4.2 Airbag folding and gas flow modeling

One of the crucial parts is the FE model of the folded airbag. It needs to be free of intersections and penetrations and must not show high initial energies. Also, it has to be built up in an efficient way to

allow parameter variations and has to guarantee a high level of predictability of the airbag deployment. Currently, folding is carried out by pre-simulation. The layout of the fabric is meshed and placed onto a virtual folding table. Each folding step is represented by virtual tools that are added sequentially. Examples are flap folds and roll folds. Hardware dimensions are transferred into parameters of these tools. Figure 5 shows several steps of a folding simulation: (a) the folding table with tools, (b) and (c) demonstrate parts of a flap and roll fold. Final step is a relaxation of the FE mesh which results in a penetration free energetic stable mesh.

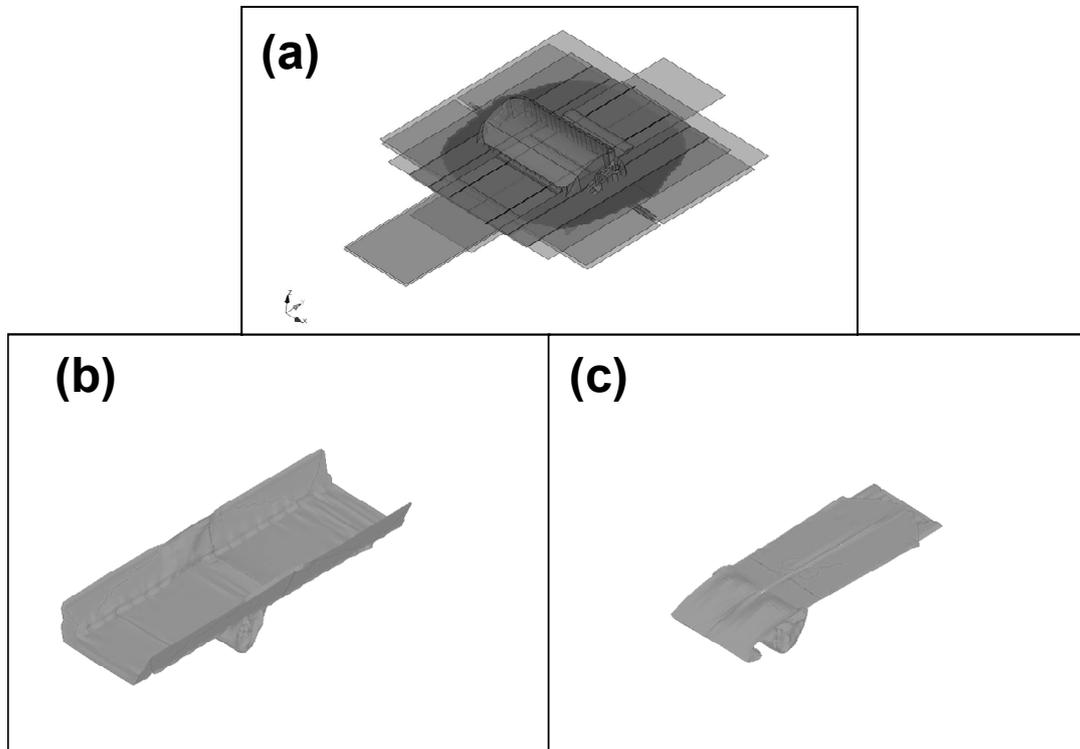


Figure 5: Virtual airbag folding, (a) folding table overview, (b) flap fold, (c) roll fold

The initial effort to setup a virtual folding table is high. However, once completed, it allows for a fast change in variations of the folding sequence and bag shapes. For example, tool dimensions and number of roll folds are parameterized. New bag shapes need only to be placed inside the folding table and the folding simulation needs to be re-run.

To obtain proper airbag deployment behavior, a gas flow method is required. This allows the different portions of the folded airbag cushion to deploy sequentially, starting at the inflator. Standard uniform pressure approaches deploy the airbag equally in all parts of the cushion and thus are not recommended for early deployment assessment. In LS-DYNA, the CPM method is available [1]. All gas molecules are reduced to a limited amount of particles that carry averaged gas properties. Near the inflator, the nozzles need to be defined for gas inlet. Figure 6 shows the setup of the model. All interior fabric parts of the airbag and metal fixation brackets are considered.

#### 2.4.3 Correlation of loads

In order to give an indication of the correlation of detailed models, exemplary backforce prediction is compared to tests. This impulse is measured by a load cell and may result in several kilo Newtons.

To model this effect, the IMOM option of the CPM method is activated. It assigns the reaction force of the gas outflow at the nozzle to the inflator. Torques and forces are transferred into the inflator and consequently over the screws into the housing.

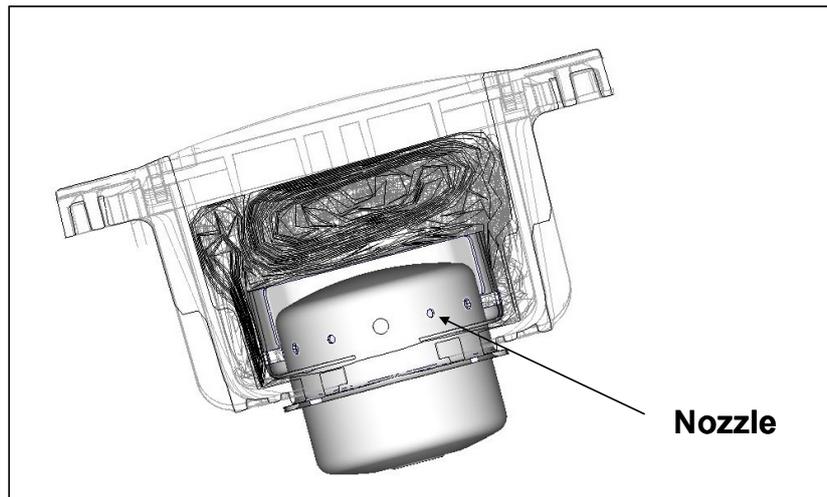


Figure 6: Details of inflator model for CPM approach

For model validation stand alone tests of the inflator together with the airbag have been performed. Figure 7 shows simulation result versus test. The timing and magnitude of the force peak were captured both in vehicle X and Z direction (Y direction is almost zero). Hence the modeling of the inflator is considered to apply the correct force on the housing in the simulation model.

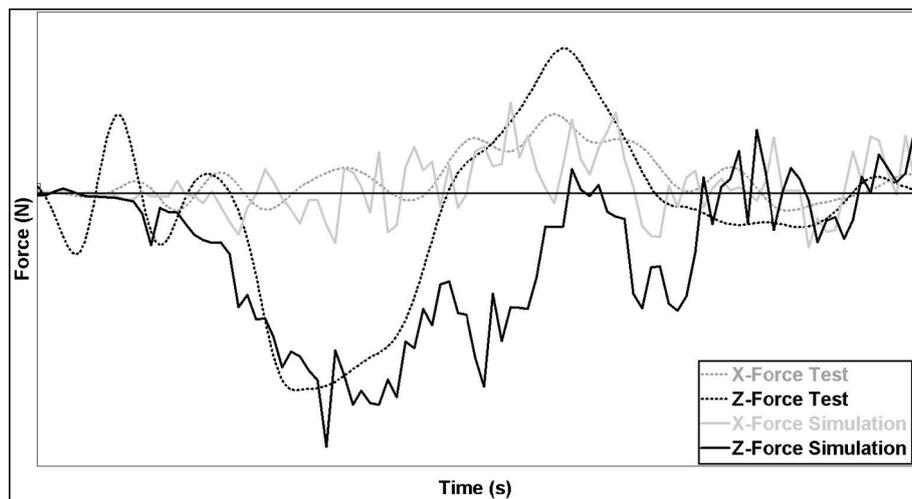


Figure 7: Backforce - Test vs. Simulation

#### 2.4.4 Use of detailed airbag models

Detailed models can be used to evaluate peak stresses, critical areas and kinematics of the module. Since the complete module is considered in the model including folding of airbag, reaction forces due to gas flow, fixation situations in the IP and resistance of the opening of the cover tear seam, parameter variations can be carried out virtually and hardware loops can be reduced. Parameterized virtual folding tables and databases for inflator data allow for efficient analysis of various loading conditions for housing and cover. Thus, optimization and robustness assessments of the modules can be conducted per simulation.

Due to the high modeling effort and computing time, this approach is only applicable after the vehicle environment and interface to the module is settled. In particular, a detailed model cannot overcome lack of information. This requires a closed interaction between suppliers and OEMs.

### 3 Summary

Current passenger airbag module development requires efficient tools that allow an assessment of component integrity with a low number of hardware prototypes. For integrity assessment during airbag deployment, two approaches were discussed: reduced models in the early project phase and detailed models in later phases. Powerful simulation methods for fluid structure interaction and airbag folding allow for detailed models that capture the important mechanical effects during airbag deployment. It was indicated that these methods are able to predict measurement results. They can be applied for parameter variations during housing development with a reduced number of required hardware tests. The current strategy using these two types of models in the development process at TRW was presented, advantages and drawbacks were discussed.

### 4 Literature

- [1] L.Olovsson, Corpuscular method for airbag deployment simulations in LS-DYNA, Report R32S-1 IMPETUSafea AB, ISBN 978-82-997587-0-3, 2007