Gas Dynamic Simulation of Curtain Airbag Deployment through Interior Trims

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Abstract

The curtain airbag is usually simulated by a uniform pressure method in which the pressure of the airbag is considered as constant. This is correct when the airbag is fully deployed. However, this assumption is not valid during the curtain airbag deployment phase, where the gas flow passing through each chamber can be clearly seen. Therefore it is impossible to simulate the intermediate sequences of the airbag deployment correctly by using the conventional uniform pressure method.

The gas dynamic module has been made available within LS-DYNA®. This module provides the basic toolset to simulate gas flow. This technique enables us to simulate the gas flow and pressure distributions in detail and enables the correct sequences of the curtain airbag deployment. Interactions between the airbag and interior trims can now be simulated and well understood.

This gas dynamic simulation method can be implemented to identify the potential failure modes of the curtain airbag during deployment through trims in the design development stage of the programme. Therefore, the confidence level for "right first time" curtain airbag deployment can be greatly increased.

Introduction

Curtain airbag has been widely used in the automotive industry to protect occupants in the events of side impact and rollover. In the vehicle, curtain airbag is folded and installed on the cantrail behind roof headliner. When the collision occurs, the curtain airbag is deployed, pushes the headliner out of the way and positions itself between occupant and side windows of the vehicle to protect the occupant. To serve this purpose, in the curtain airbag design there are three key aspects to be considered, curtain airbag component performance; curtain airbag and headliner interaction; and curtain airbag restraint system performance.

In curtain airbag component performance, the detailed airbag design has to be considered. Those include airbag coverage, chamber volume, airbag pressure, tether tension, curtain shrinkage and airbag module integrity, etc. For the curtain airbag and headliner interaction, the headliner and pillar trims have to be engineered for the curtain airbag deploying through the trims cleanly without damage to the bag and to minimize both delay of positioning time and deliver desired emerging airbag kinematics. For restrain system performance, the curtain airbag has to meet the performance requirement of all load-cases with adequate stiffness to protect the occupants.

In the design process, it is important to detect failure modes early enough to avoid expensive tooling changes. Clearly, analytical CAE is the timeliest tool to help the design. Over the years CAE has been widely used in the curtain airbag component design and restraint system performance in the automotive industry. However, due to the complex nature of the system problem, there are less CAE applications in curtain airbag and trims interaction. As a result, intensive hardware tests have to be conducted to ensure clean deployment of the curtain airbag through trim when the prototype trims parts are available. Usually, those tests are only available at later design phase and have very limited practical ability to include parametric robustness evaluations.

The main difficulty for such simulation is that the gas flow from chamber to chamber has to be modelled faithfully as the curtain airbag deployment interaction with the trim occurs in the early stage of the airbag unfolding through inflation. Conventional uniform pressure method does not simulate the unfolding behavior so a gas dynamic method has to be utilized. The multi-layered nature of modern headliner construction must be faithfully modelled. Finally, the overall model with BIW, trims and gas dynamic curtain airbag has to be assembled and debugged to get a working system CAE model.

With LS-DYNA® gas dynamic modules, namely ALE method and CPM method, gas flow in curtain airbag can be simulated. This provides a basic CAE tool kit to enable a detailed CAE study on curtain airbag deployment through trims. This paper describes how Jaguar and Land Rover use such CAE method to detect failure modes and design robust system in curtain airbag deployment through interior trims.

Common Failure Modes of Curtain Airbag and Trims Interaction

To deliver full effective restraint performance, the curtain airbag has to able to deploy through the trim to its full extent without constraint. This deployment has to be robust across environmental conditions e.g. temperature and ageing and robust to design noise factors. Pre CAE toolkit heavy reliance has been placed on physical tests, which are later in programme, so detected failure modes are more expensive to fix.

The common failure modes are curtain airbag hang-up, pillar trim detach, pillar trim broken, etc. Figure 1 shows a typical curtain airbag hang-up during deployment at cold temperature condition. Figure 2 shows a detachment of C-pillar trim during deployment. Figure 3 shows the local trim plastic break.

Figure 1 Common failure mode – curtain airbag hang-up

Figure 2 Common failure mode – C-pillar trim detachment

Figure 3 Common failure mode – local trim break

CAE Gas Dynamic Techniques and Curtain Airbag Model

In curtain airbag simulation, the most common method is the uniform pressure approach with multi-chamber definition separated by interfaces. The uniform pressure theory assumes that at any time step the internal airbag pressure is constant. It is a simplified model with no local gas flow effect. This method is well proven for occupant restraint system performance simulation where by the time occupant head is in contact with curtain airbag, the airbag is already fully inflated. However, when one looks into detailed interaction between airbag and trims during the deployment the local gas flow effect cannot be ignored.

In the recent years, LS-DYNA provides two analytic methods to simulate gas flow features, the Arbitrary-Lagrangian-Eulerian (ALE) approach and Corpuscular Particle Method (CPM). Those two methods have completely different approaches to modeling the gas flow. In the ALE, the inflowing gases and the air volume outside the airbag are modeled with Eulerian solid mesh and the airbag with Lagrangian mesh. The gas dynamic effect is determined by calculating the coupling forces between inflow gas and airbag fabric. While in CPM method, the inflow gases are modeled as molecular particles with kinetic energy. Molecules colliding to the surface of the airbag build up the gas dynamic effect.

The experience of the authors suggests both methods have advantages, disadvantages and limitations. Particularly, the CPM method is still in development. Table 1 lists the comparisons of advantages and disadvantages for both methods.

Table 1 Comparisons of advantages and disadvantages for ALE and CPM

Method	CPU Time	Multi CPU MPP	Easy To Use	Gas Through Small Gap	Satbility	Gas Graphics
ALE	Long	Yes	No	Better	Limited	Good
CPM	Reasonable	Limited	Yes	Limited	Better	Poor

Two JLR programmes have used the gas dynamic methods in the simulation of curtain airbag deployment through trims. One used ALE method and another one the CPM method. In both programmes, the gas dynamic model of the curtain airbag was generated and correlated with static deployment tests. It is very important that the CAE model replicates the correct sequence of the curtain airbag in the physical tests. Figure 4 shows the similar deployment sequence between CAE curtain airbag with gas dynamic features and the physical test. The gas flow bubble starts from gas generator and moves through the chambers. Figure 5 also shows the deployment of CAE with uniform pressure method in which airbag starts unfold everywhere and no gas flow features can be seen. It is clear that uniform method does not replicate the bag inflation and therefore is not suitable to be used for curtain deployment through trims.

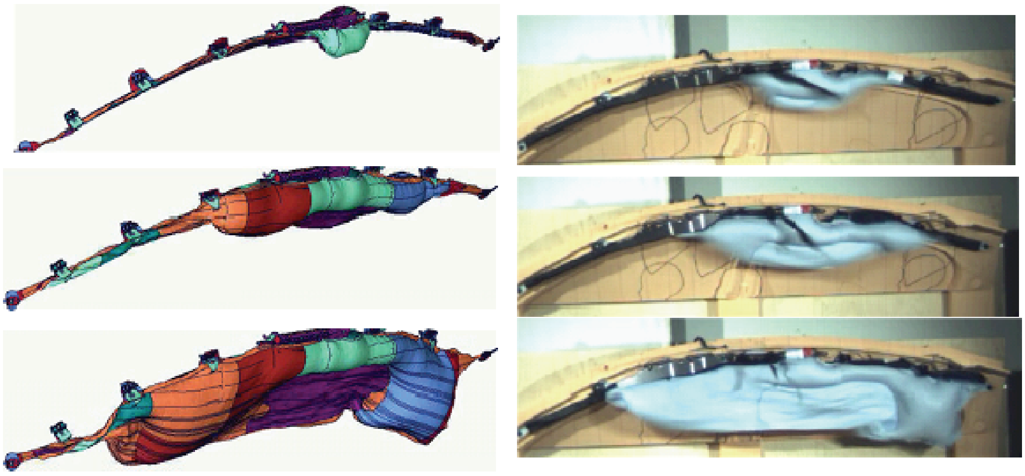


Figure 4 Deployment of CAE curtain airbag with gas dynamic and the physical test.

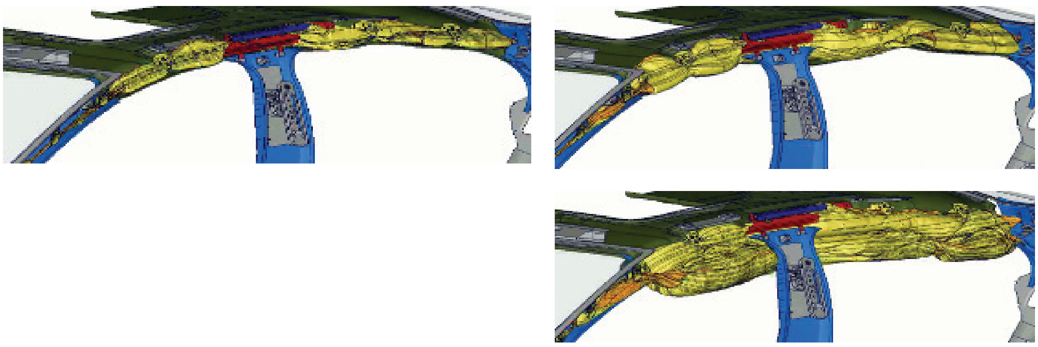


Figure 5 Deployment of CAE curtain airbag with uniform pressure method

Trim Material Characterization

Pillar trims are usually made of plastics and headliner is of multi-layer material with fibers, foams and cloth or leather trimming. In order to capture the correct response of headliner and pillar trims during the curtain airbag deployment, accurate trim material characterisation is essential.

Samples of trim plastics have been tested in tensional tests with different strain rates and Dynatup drop tests at different temperatures. The test data have been analysed and correlated in component CAE models to generate correct material cards in LS-DYNA for the trims in the model of curtain airbag deployment through trims. Figure 5 shows the typical tensional test curves and correlation. Figure 6 shows the typical Dynatup test curves and correlation.

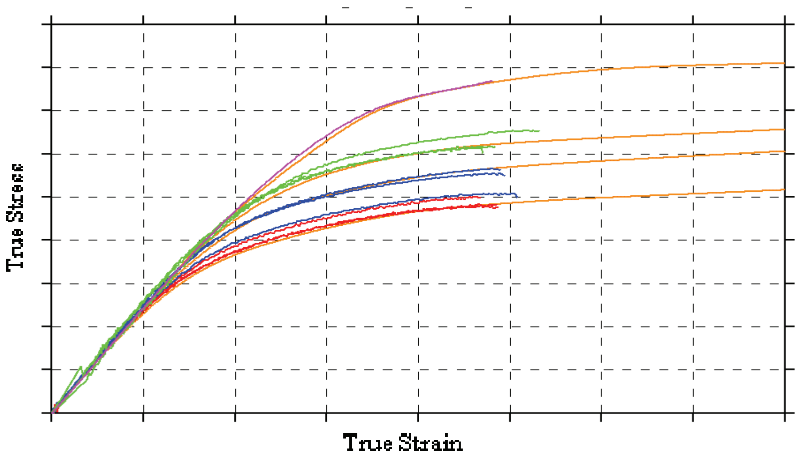


Figure 5 Typical tensional test curves with different rates and correlation

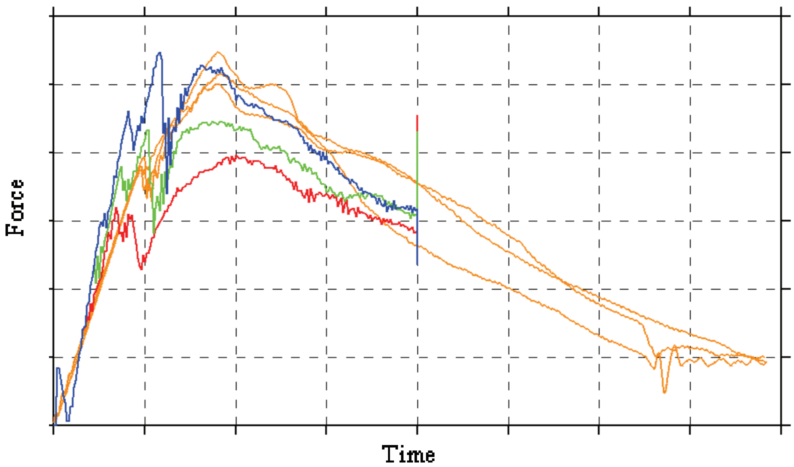


Figure 6 Typical Dynatup test curves and correlation

Samples of headliner material have also been tested in tensional and bending tests at different temperatures. The test data have been analysed and correlated in component CAE models to generate correct material cards in LS-DYNA for the headliner in the model of curtain airbag deployment through trims. Figure 7 shows the typical tensional test curve and correlation. Figure 8 shows the typical bending test curve and correlation

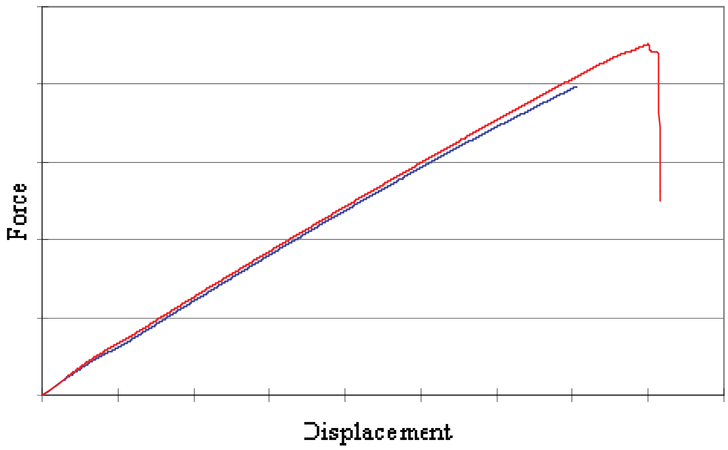


Figure 7 A typical tensional test and correlation

Figure 8 A typical bending test and correlation

Failure Mode Avoidance

In early design phase failure mode detection pre prototypes is difficult, detected failures are easier to fix. On the other hand, in the late design phase it is easy to find the failure mode as physical parts are available but it is expensive to fix. It is clear that the purpose of CAE application in the design is to find the failure mode and fix it in the early design phase.

With repetitive gas flow curtain airbag model and validated headliner and trim material properties, sub-system CAE model of curtain airbag deployment through trims can be assembled and debugged. The model can be used for early design failure mode detection with CAE engineers working alongside interior trim CAD engineers to fix the failure modes identified by virtual CAE model.

Figure 9 and 10 illustrate two common failure modes detected by CAE model for airbag hang-up at B-pillar area and C-pillar detachment. Recommendations have been made to CAD engineers to avoid such failures.

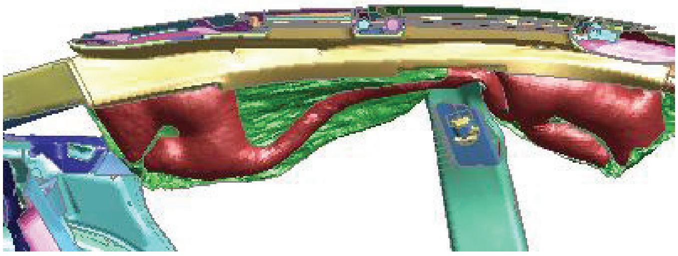


Figure 9 Failure mode identification – B-Pillar hang-up

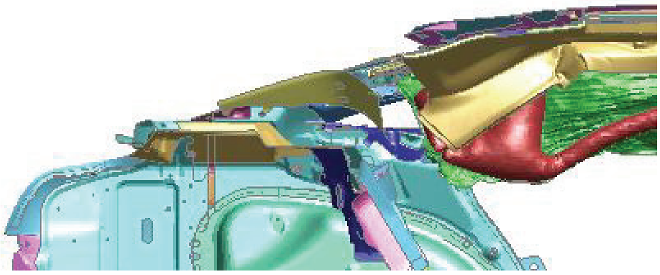


Figure 10 Failure mode identification – C-Trim detachment

Figure 11 shows another example where CAE helps IHI bracket design. In an early iteration of the bracket, there was a potential failure that a corner of the metal bracket ruptures the airbag fabric. This was only identified by using gas dynamic CAE model (uniform pressure model cannot detect).

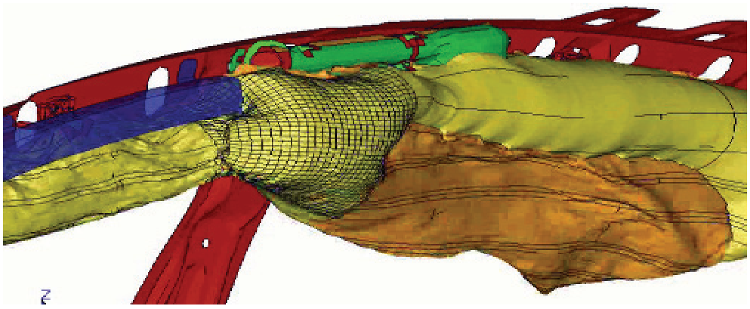


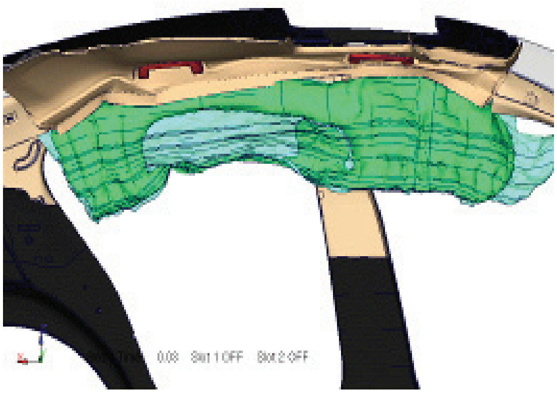
Figure 11 Failure mode identification – IHI bracket

The true power of this analysis is the ability to develop and assess and rank the influence of empirically understood design guidelines such as stiffness of headliner material, headliner and trim overlap tolerance etc. Design For Six Sigma Studies using this technique are allowing engineers to guides design studio development of good designs at the clay stage and define ideal ranges of the design parameters to be recommended to the CAD designers.

The CAE model is also being used for the robustness analysis of clean curtain airbag deployment through trims, this is the only practical (and cost effective) means assess different design variables and noise factors. This allows informed decision making to assess the plurality of design solutions available to achieve target functional performance.

Clean Curtain Airbag Deployment Through Trims

Through the design phase, a virtual CAE model has been intensively used to achieve robust design of curtain airbag deployment. It has been a great success that with the help of CAE clean deployment of curtain airbag through trims has been achieved in physical tests with various conditions. No major design issues have been identified. Figure 12 demonstrates the CAE prediction and one of the physical tests.



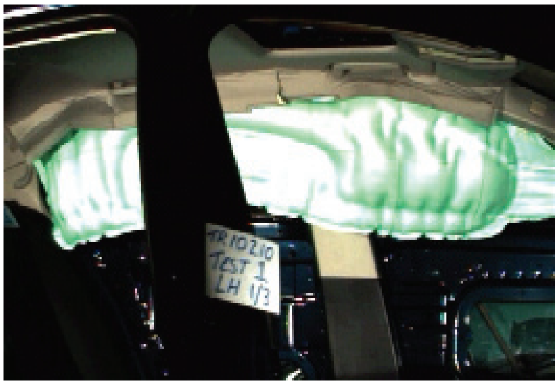


Figure 12 Clean deployment – Right First Time

Conclusions

With help of the state-of-the-art CAE gas dynamic techniques, complicated interaction between curtain airbag and interior trims during various deployment conditions can be simulated. Potential failure mode can be identified and fixed in the early design phase. The CAE technique has been successfully applied to a vehicle program and has demonstrated its ability to deliver curtain airbag deployment through trims Right First Time.

Current gas dynamic method in LS-DYNA is still developing and the limitations of the code constrain the wider application of the gas module. Therefore the authors urge the code developers to continue code development to improve the software in following areas to meet the demands of industry application:

(1) Improve code capability of modeling gas flow and distribution through channels, such as lance in curtain application.
(2) Extend the code application into multi-CPU MPP version and ensure the code is bug-free and stable.
(3) Improve quality of the gas flow graphics.

References

(1) Jerry Longland and Bill Feng, “The practical and simulated development of lower risk airbag system at Jaguar and Land Rover”, presentation at “Airbag 2006”, Karlsruhe, Germany, 2-4, December 2006
(2) Bill Feng, S. Al-Samarae, “ Application of gas dynamic method in development of airbag module.”, presentation in No. 6 LS-DYNA Forum, Frankenthal, Germany, 11-12 October 2007
(3) A. Hirth, A. Haufe & L. Olovsson, “Airbag simulation with LS-DYNA past-present-future” , presentation in No. 6 LS-DYNA Forum, Frankenthal, Germany, 11-12 October 2007.

