On Airbag Simulation in LS –DYNA with the use of the Arbitrary Lagrangian - Eulerian Method

Authors:

Dmitri Fokin, Nitin Lokhande, Lars Fredriksson
Altair Engineering GmbH, Germany

Correspondence:

Dmitri Fokin
Altair Engineering GmbH
Calwer Str. 7
D-71034 Böblingen
Germany

Tel: +49-(0)7031-620884
Fax: +49-(0)7031-620899
e-mail: fokin@altair.de

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ABSTRACT

In the present paper a basic finite element model of an ALE thorax side airbag with a simplified gas generator will be considered. In particular, it will be discussed how to define boundary conditions and properties of the inflating gas. A possible general approach to ALE airbag validation to fit results of a standard body block test will be described. Finally numerical results for a push-away test for an ALE and corresponding CV airbag will be compared.

INTRODUCTION

Computer simulation is a powerful tool for developing effective airbags for the modern automotive industry. At the present time, almost all airbag calculations are based on the control volume (CV) technique (see e.g. [1]). In the simplest case, for every time step the pressure on the internal surface of the airbag is determined from a given thermodynamic model. Then, pressure is applied as a load to find the airbag shape for the next time step. This approach is quick and gives rather good results for predicting the interaction of the airbag surface with surrounding objects at the later stages of the airbag deployment. However, the pressure constant assumption is not correct in the beginning phase of the airbag motion. To consider this phase more precisely, a more accurate method to describe the interaction between airbag surface, inflow gas and ambient air is needed. One of this formulations based on the Arbitrary Eulerian – Lagrangian (ALE) method is realised in LS-DYNA (see e.g. [2,3]).

The main idea of the ALE airbag application is to model in a precise way the gas generator so that the time consuming process of airbag validation (i.e. calibration of the finite element airbag model against standard test results) can be avoided. In this case an airbag model that provides reliable results for both position and for out-of-position impact cases is obtained. However, to produce a precise gas generator model comprehensive information on its geometry, gas properties etc is needed. This is not always available or is rather difficult to model with the use of a present finite element tools of LS-DYNA. Therefore it is of interest to consider a simplified gas generator model, which provide a prescribed mass flow rate and temperature curve that can be obtained from a standard tank test.

The present paper concentrates on a basic finite element model of an ALE thorax side airbag with simplified gas generator. In particular, it is discussed how to establish boundary conditions and properties of the inflating gas. A possible general approach to ALE airbag validation to fit results of a standard linear body block test is described. Finally numerical results for a push-away test for an ALE and corresponding CV airbag will be compared.

ALE airbag model

General description of the model. A thorax side airbag is taken as a basis for further numerical investigations and comparisons. A general view of the model of the folded airbag is shown in Figure 1. The surface of the airbag (1) consists of two parts represented by fabric materials: the main coated surface and a seam surface where a leakage may occur. There are no vent holes on the airbag surface. The surface is covered with appropriate Lagrangian shell elements. The size of the mesh elements is determined by the properties of the fabric materials, accuracy requirements and simulation time. A reference geometry is used to correct the shape of any elements distorted due to the folding. There is also a housing available in the model which is not shown in the Figure 1. The airbag housing is attached to a stonewall (2) in xz-plane which also prevents motion of the airbag beneath the stonewall.

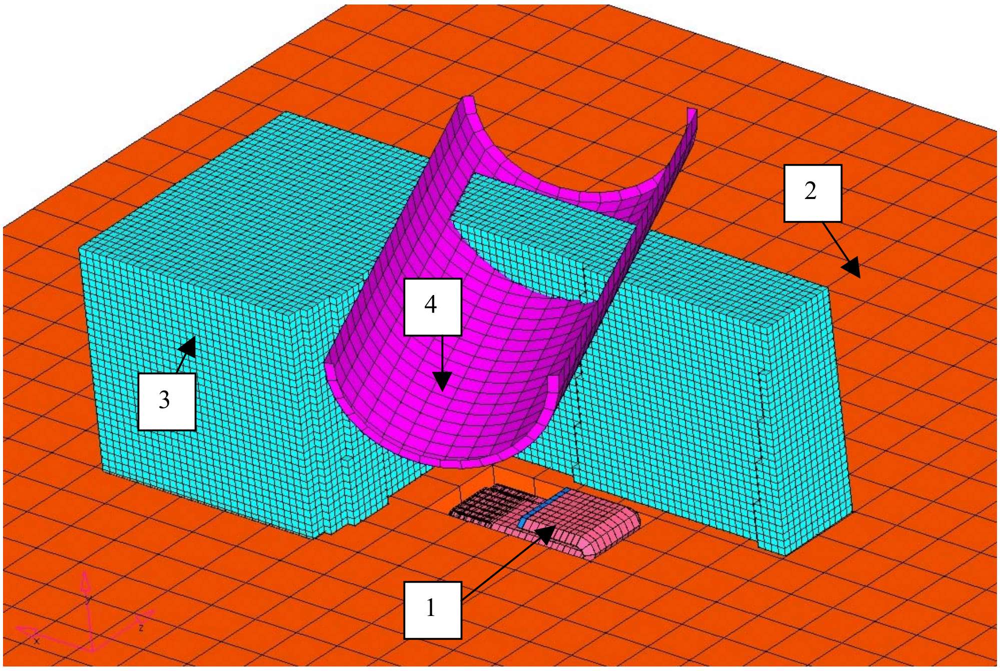

Figure 1 Principal ALE airbag model. (1)- airbag (housing is not shown), (2) – stonewall, (3) – Eulerian mesh (shown with cut of slice), (4) – impacting body

Air outside of the airbag. It is assumed that air outside of the airbag is an ideal gas with constant C_p and C_v values, under standard atmospheric pressure, temperature and density. To describe motion of the air outside of the airbag and the gas inside of the airbag we introduce an Eulerian mesh (3) (only part of the mesh is shown in Figure 1). This mesh is large enough to include the entire deployed airbag and consists of brick elements with one-point ALE solid section. The size of the brick elements is set to be approximately the size of the shell elements on airbag surface in order to provide a proper interaction between the airbag surface and the gas flow.

Inflator model. Figure 2 shows a simplified gas generator model. The inflator (1) is modelled with brick elements (one-point ALE solid section, pressure outflow) which are the part of the general Eulerian mesh and lie near the inflator opening of the airbag. To prevent the gas from leaking outward of the airbag an additional rigid housing (2) is introduced. The gas is assumed to be one component and ideal with constant values of C_p and C_v. In LS-DYNA 970 the properties of the inflator should be determined by temperature $T(t)$ and relative volume function $V(t) = \rho_0 / \rho(t)$, where ρ_0 is some reference density and $\rho(t)$ is the inflator gas density as function of time t. Then the pressure of the inflating gas is determined from a given equation of state. If the pressure in the inflator elements is higher than the pressure in elements nearby, then there is a gas flow outward of the inflator.

To make the inflator model more accurate we constrain the nodes on the lower surface of the inflator and prescribe the flow direction on the upper

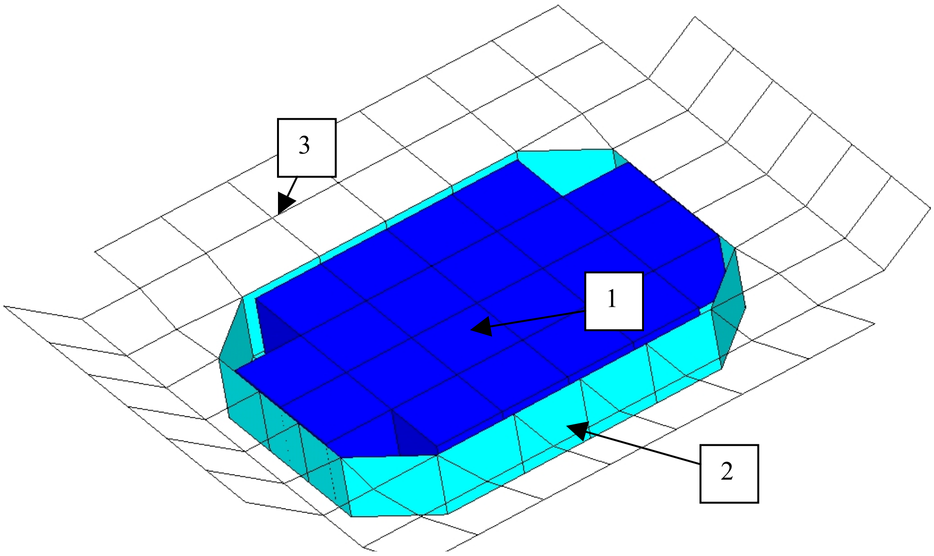

Figure 2 Simplified gas generator model. (1) – inflator brick elements. (2) –additional housing to prevent the inflating gas from leakage, (3) – airbag surface

surface of the inflator (see Figure 2). Then the mass flow rate can be calculated rather exactly from the integral

$$\dot{M}(t) = \iint_S \rho \vec{v} \vec{n} dS \,, \quad (1)$$

where $\vec{n}$ and $\vec{v}$ are the normal and velocity vectors on the upper inflator surface S. It should be noted that the present inflator model is very simplified. In reality, for example, there can be many inflator openings and inflow gas directions. Thus the area S and inflow direction $\vec{n}$ should be considered as average parameters that may be calibrated to achieve better correspondence with experimental data.
For CV airbag models the dynamics of the inflow gas is fully determined by its mass flow rate $\dot{M}(t)$ and temperature $T(t)$. These data are calculated with a certain approximate approach from pressure measurements obtained from a tank test. It is interesting to note that the tank test itself can also be modelled rather well with the use of ALE method [4]. This could provide us with more exact information about inflow gas properties. In the present case we assume that the functions $\dot{M}(t)$, $T(t)$ are prescribed. A typical distribution $\dot{M}(t)$ is shown in Fig. 3 with a solid line 3.

Velocity of the inflating gas. In the ALE approach, the velocity module of the inflating gas is determined in the course of the solution and can not be prescribed arbitrary. For example, for the case of the ideal adiabatic gas the flow velocity module v is connected with the temperature through Bernoulli equation

$$\frac{v^2}{2} + C_p T = C_p T_* \,. \quad (2)$$

Here T_* is a stagnation temperature of adiabatic gas flow. For non-adiabatic gas flow the connection between flow velocity module and thermodynamic parameters (temperature, pressure etc.) is more complicated. Nevertheless, the velocity still can not be given as an independent boundary condition because this introduces a local discontinuity in solution. This discontinuity may not be evident for coarse Eulerian

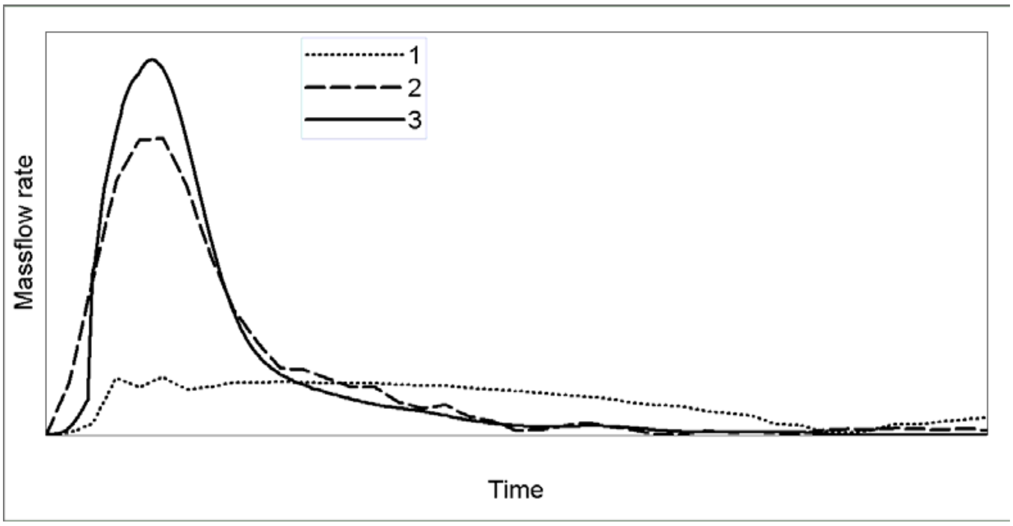

Figure 3 Mass flow rate distribution. 1 – corresponds to constant density distribution of the inflating gas, 2 – corresponds to the density distribution (3), 3 – desired mass flow rate.

mesh, but for a fine mesh it may bring numerical instability to the solution process. It has to be noted that, in contrast to the velocity module, the direction of the inflating gas velocity can be prescribed.

Thus the velocity $v(t)$ of the inflating gas, generally speaking, can not be given independently from the density distribution $\rho(t)$. The velocity distribution should be more or less consistent with the density distribution to avoid significant discontinuities in the solution.

How to provide a given mass flow rate. Let us consider an example. The density of the inflating gas is assumed to be constant (this curve is shown with dotted line 1 in Figure 4). Then calculation of ALE airbag will give average velocity distribution of the inflating gas as shown in Figure 5 with the dotted line 1. Corresponding mass flow rate is depicted in Figure 3 with dotted line 1. It is obvious that the values as well as the shape of the obtained mass flow rate curve is different from the desired one.

In order to evaluate an appropriate distribution of density $\rho(t)$ which provides the given mass flow, we assume for a moment that the flow through the upper surface of the inflator is adiabatic, uniform and directed along the upper surface normal. Then from Eqs. (1), (2) the following formula for $\rho(t)$ can be obtained:

$$\rho(t) = \frac{\dot{M}(t)}{S\sqrt{2C_p(T_* - T(t))}}.$$

This expression can provide an indication of what the density curve of the inflating gas should look like. However, for $\dot{M}(t) \to 0$ it follows $T(t) \to T_*$ and hence a singularity $0/0$ occurs. This singularity can be resolved only if the mass flow rate and temperature are prescribed with sufficient accuracy so that their derivatives can be calculated. This is usually not the case. Therefore, the following representation of the density with an offset is used:

$$\rho(t) = \rho_1 + \frac{\dot{M}(t)}{S\sqrt{2C_p(T_* - T(t))}}. \tag{3}$$

Here the unknown parameters ρ_1 and T_* can be used as calibration parameters to reach the prescribed mass flow rate $\dot{M}(t)$.

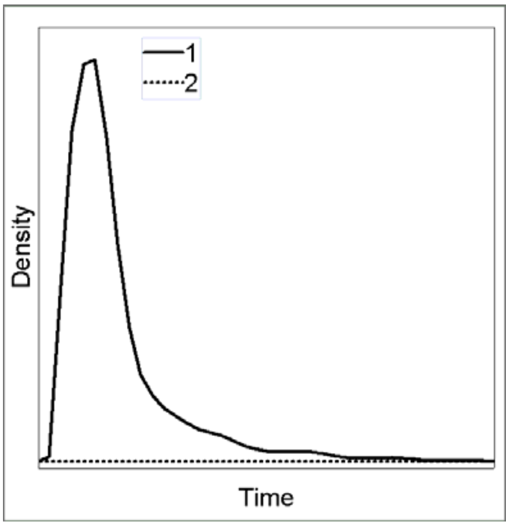

Figure 4 Density of the inflating gas
1 – density from Eq. (3),
2 – constant density

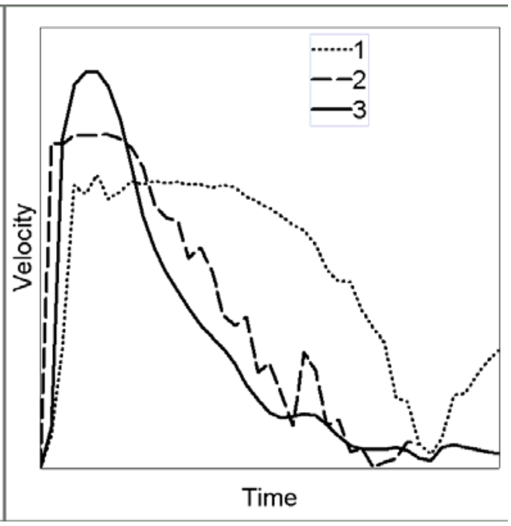

Figure 5 Velocity of inflating gas corresponding to 1- constant density, 2- density from Eq. (3), (3)- corrected velocity to reach the prescribed mass flow rate

For example, solid line 1 in Figure 4 shows a density distribution from Eq.(3) with specially chosen parameters ρ_1 and T_*. Calculation of ALE airbag has given the corresponding velocity distribution of the inflating gas (dashed line 2 in Figure 5). The mass flow rate is presented in Figure 3 with dashed line 2. A much better resemblance with the desired mass flow rate (solid line 3 in Figure 3) could be seen here.
To provide exactly the desired mass flow velocity of the inflating gas is calculated from Eq. (2):

$$v(t) = \frac{\dot{M}(t)}{S\rho(t)}. \tag{4}$$

This velocity is shown in Figure 5 with the solid line 3. It is not exactly consistent with the chosen density distribution (solid line 1 in Figure 4), but it differs not very much from the exactly consistent velocity distribution, shown in Figure 5 with dashed line 2. Therefore, if this velocity distribution is prescribed to the nodes of the inflator elements, then the numerical discontinuity could be expected to be rather small. At the same time exactly the desired mass flow rate is provided.

Leakage through airbag surface can be modelled by prescribing the dependence of gas velocity through airbag surface as function of local pressure difference inside and outside of the airbag $v_{leak} = f(\Delta p)$. This curve should be given from experimental data. If not, it can be used as a calibrating tool to achieve a better correspondence with experiments. In the simplest case this relationship is linear:

$$v_{leak} = k\Delta p \quad (5)$$

However, it should be noted that application of the leakage option in the ALE method requires rather exact calculation of pressure inside and especially outside of the airbag. The latter is not always possible because the accuracy of pressure calculation outside of the airbag is strongly affected by the boundary of the Eulerian mesh. To make the calculation more precise a larger mesh should be used which leads to significant increase of the calculation time.

It should be also noted that presently it is only possible to model the leakage through the airbag surface as a whole. This may result in the lack of accuracy when modelling a coated airbag. However it is probably not so drastic for the beginning phase of the airbag deployment when the leakage is not very strong: recall that time period is the main area of interest for ALE calculations.

Validation of the gas generator model and leakage parameter

Body block test. Figure 1 shows a standard configuration of airbag which will deploy and hit a rigid body (4) with prescribed mass and inertial properties. The body moves along the y- axis starting from a given position with a prescribed initial velocity in negative y- direction. This is a finite element model of a typical body block test. Acceleration of the body as function of time, is an important kinematic characteristic of the airbag. A solid line in Figure 6 shows the experimentally obtained acceleration curve.

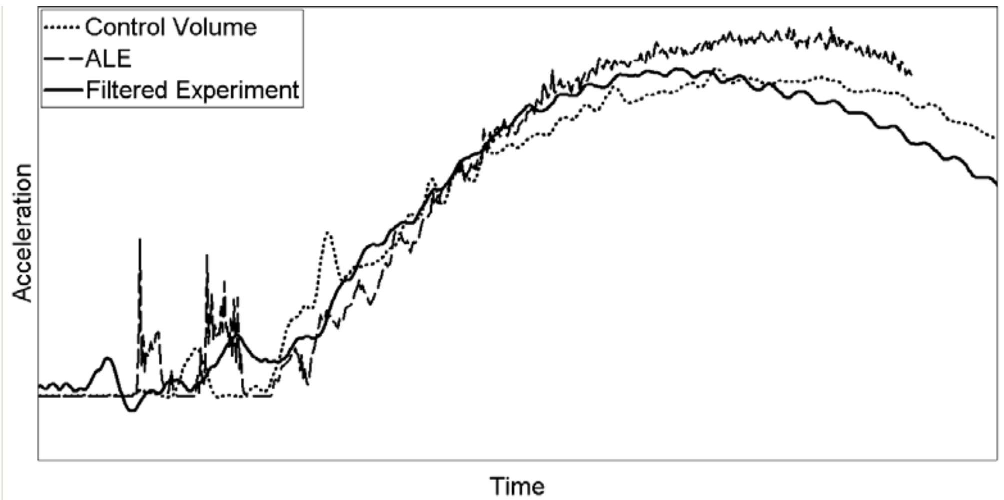

Figure 6 Acceleration curves for body block test

The usual approach to validation of a finite element model of a CV airbag involves finding scaling parameters for leakage and temperature curves. As previously discussed, for the ALE airbag model the density of the inflating gas is the control function that is used to provide the given mass flow rate. If the density curve is taken from Eq. (3) then we have two control parameters ρ_1 and T_*.

The next control parameter is the value k in Eq. (5) which determines the leakage properties of the airbag surface and should be calibrated to achieve experimental acceleration curve of the body. Thus, we have an ALE airbag model with 3 parameters.

At the first step parameters ρ_1 and T_* are chosen to prescribe the density distribution from Eq. (3) so that the corresponding mass flow for the ALE airbag calculation would be as close to the desired one as possible. Then from Eq. (4) a velocity distribution of the inflating gas is calculated which provides only a small discontinuity of the numerical solution and gives exactly the desired mass flow rate.

The next stage involves calibration of the leakage coefficient to achieve a better correspondence with the experimental acceleration curve. The resulting curve obtained for the ALE airbag is presented in Figure 6 with a dashed line. Here for comparison also the acceleration curve for corresponding CV airbag is shown.

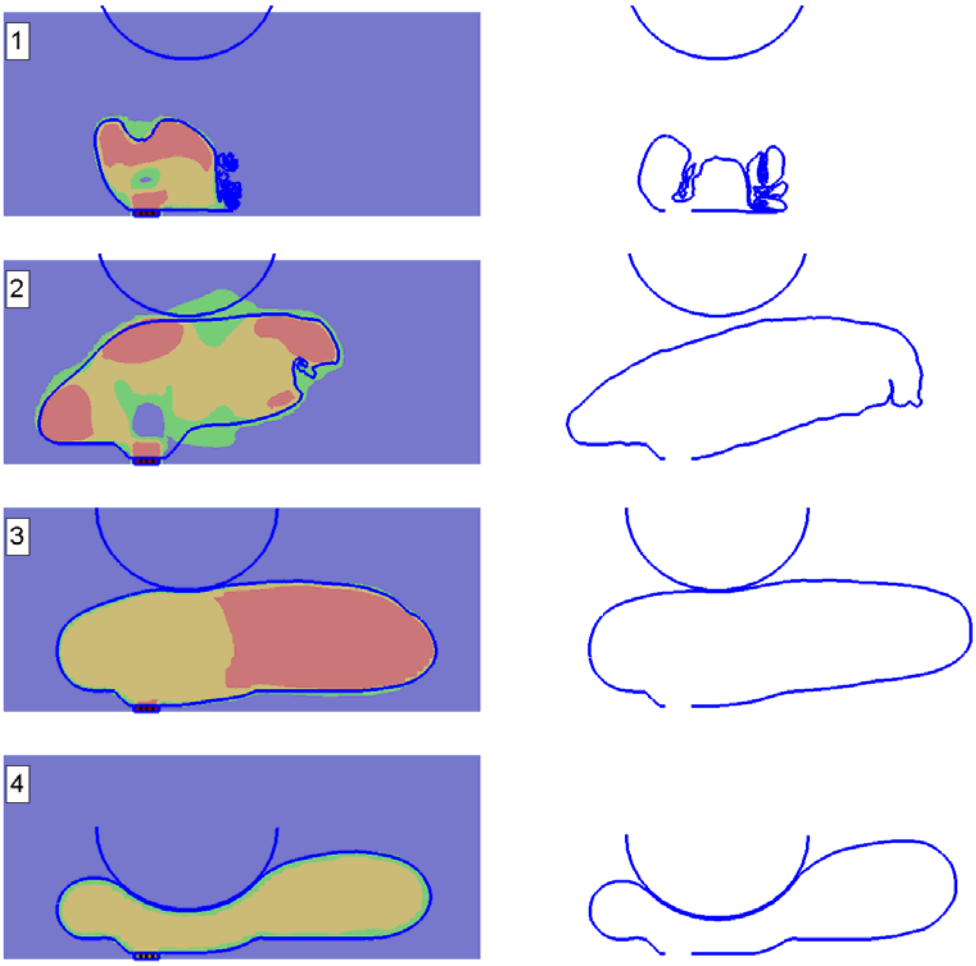

Figure 7 Comparison of the motion of section of ALE airbag (left) and CV airbag (right) for several time steps. For ALE calculation pressure contour plot for the gas and the air is shown

There is a rather good correspondence between ALE calculation and experimental data. Particularly, there are two acceleration peaks that are clearly evident at the beginning of the body block test for both the experimental and ALE curves. At the same time it can be noted that the maximum of the ALE curve is about 7% higher and is shifted to the right in comparison with the experiment. This can be explained by the insufficiently accurate leakage modelling. Namely the leakage curve was taken in linear form (see Eq. (4)). Moreover it was supposed that the whole airbag surface is porous. Nevertheless, the general correspondence in the practically important beginning time period is good.
Figure 7 shows a section of the airbag calculated for some consequent time moments with ALE method (left) and CV method (right). For the ALE calculation also distribution of pressure inside of the airbag is presented. Frame 1 demonstrates that the topology of the unfolding is very different for the ALE and CV airbag models. Namely, for the CV method the whole airbag surface starts to inflate because the pressure is acting everywhere from the very beginning. For the ALE airbag only the part of the airbag contacting with the inflating gas is unfolding. As the gas fills up the whole airbag volume the difference in the airbag shapes become smaller, although still the pressure inside of the ALE airbag is not a constant (Frames 2 and 3). After some more time the behaviour of the airbags becomes practically identical (Frame 4). It is also important to note that the pressure of the air outside of the ALE airbag is not constant and changes as the airbag moves.

Push-away test. For this test the rigid body is positioned very close to the airbag and has zero initial velocity. As the airbag starts to unfold, it pushes the body away. The main characteristic of interest in the experiment is the acceleration of the body as function of time. For this test we had no experimental data, so the numerical results obtained for CV and ALE airbags are compared to each other. Resulting acceleration curves are shown in Figure 8.

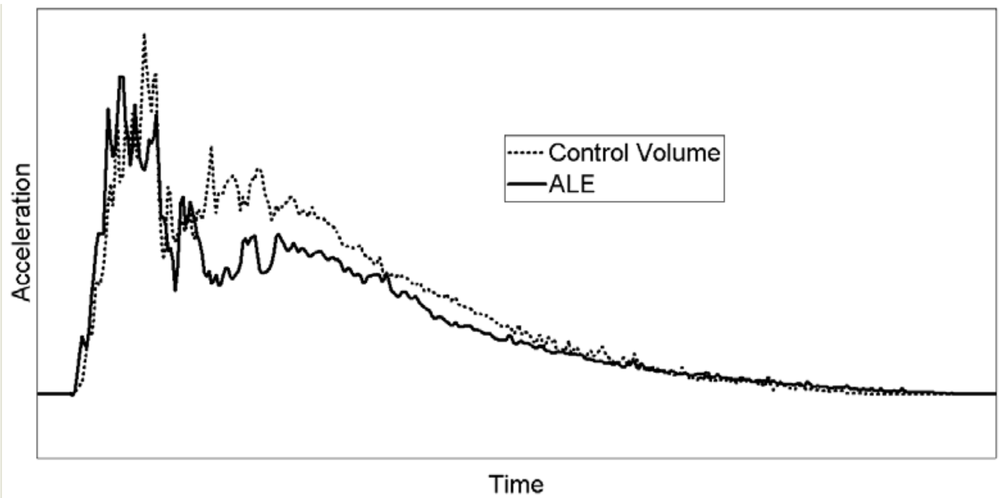

Figure 8 Acceleration curves for push-away test

It can be seen that both curves are more or less identical at the beginning, although, the first acceleration peak comes earlier in the ALE airbag. At the later time stages the CV airbag calculation has shown rather higher accelerations compared to the ALE airbag calculations (up to 40%).

This reduction of acceleration is in line with observations done during several projects at Altair Engineering; the CV approach overestimates the acceleration after the initial acceleration phase.
Figure 9 shows sections of the airbag calculated for some consequent moments in time with ALE methods (left) and CV method (right). For the ALE calculation the distribution of pressure inside of the airbag is also presented. Frame 1 demonstrates that the unfolding topology is rather different with the ALE and CV airbag models. At the later stages of the deployment process the geometry of the airbag sections become more similar to each other. At the same time it can be seen that the pressure inside of the ALE airbag is still not constant everywhere. Namely, it is lower under the body (Frame 3). This is can be an explanation why the body accelerations provided by ALE airbag are lower at the later stages of the impact.

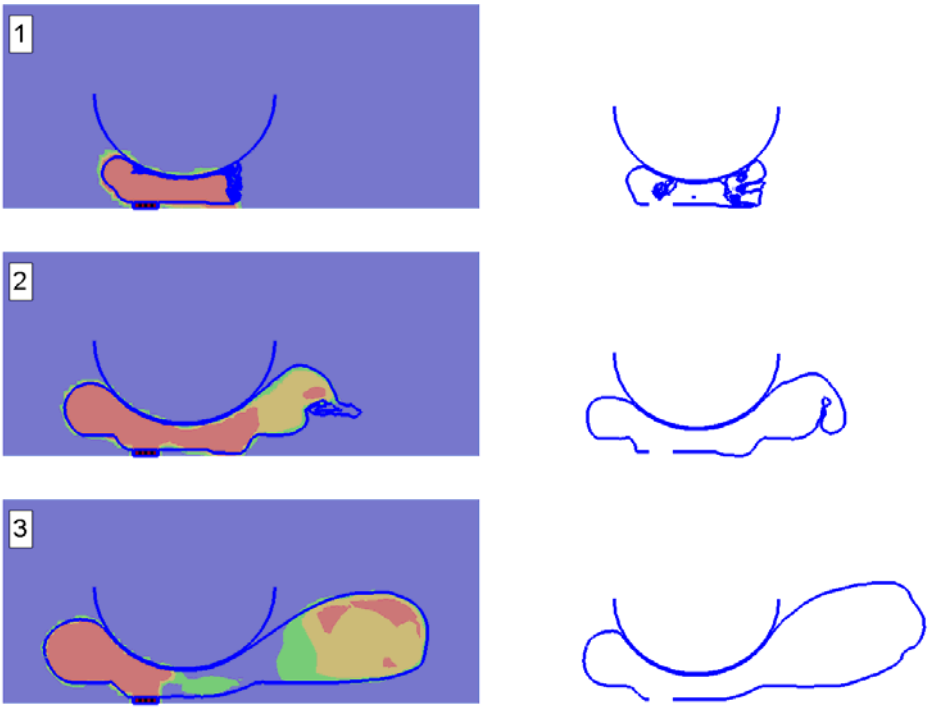

Figure 9 Comparison of the motion of section of ALE airbag (left) and CV airbag (right) for several time moments for push-away test. For ALE calculation pressure contour plot for the gas and the air is shown

Comments and conclusions

We see that even a simple gas generator model constructed with the minimal amount of experimental data allows us to obtain rather realistic results for ALE airbag deployment and impact simulation. For this paper it was decided to concentrate on the detailed description of the ALE airbag model and additional examples might be shown in the Conference presentation.
As already noted the ultimate goal of ALE airbag calculation is to simulate airbag deployment without prior validation of the complete airbag model. Only gas generator model and fabric material data must be validated.

However, this requires more comprehensive information on the inflating gas properties (tank test data) and gas generator geometry. An approach to get this information could be to simulate the tank test itself. Also, it should be noted that presently calculation of the ALE airbag is time consuming. One of the ways to overcome this problem is to use the ALE airbag calculation only at the early time stages of the deployment process (e.g. first 20 ms) and then switch to the CV method. Although this question is left to future LS-DYNA developers.
Postprocessing of the ALE calculation results presented here was performed with the use of Altair® HyperWork® 6.0 postprocessor which provide complete support to all ALE options available in LS-DYNA 970, including fluid-structure interaction data in the “dfsi” database file.

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