

## Simulation of Airbag Deployment Using the Coupled Eulerian-Lagrangian Method in Abaqus/Explicit

### Acknowledgements

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### Summary

The uniform pressure method (UPM) approach to simulating airbag deployment has been widely used in the automobile safety industry. The defining assumption of UPM, specifically that pressure in the airbag is spatially uniform during inflation, makes the approach most applicable for 'in-position' (IP) analyses with fully inflated airbags. In contrast, an analysis may be characterized as 'out-of-position' (OoP) if the occupant interacts with the airbag before it is fully deployed. Prior to complete inflation, large spatial pressure gradients can exist in the airbag, violating the assumptions of the UPM approach.

The advancement of airbag regulations and technology necessitates the consideration of OoP scenarios. An accurate analysis thus requires a tool capable of simulating the flow of gas during the inflation process.

Abaqus/Explicit offers a sophisticated coupled Eulerian-Lagrangian (CEL) technique that can be used to simulate dynamic gas flow in the airbag. The flow-based CEL method offers a more realistic prediction of airbag shape and pressure distribution during all stages of deployment.

### Key Abaqus Features and Benefits

- The Abaqus/Explicit coupled Eulerian Lagrangian (CEL) technique provides the ability to model gas flow in the airbag and include the effects of surrounding air during deployment
- Ability to easily enforce contact interactions between the Lagrangian bodies and the materials in the Eulerian mesh using the powerful and robust general contact algorithm
- Extensive material library to model woven airbag fabrics and gas equations of state

### Background

In the UPM approach to airbag inflation simulation, pressure can vary temporally, but at any instant the spatial distribution of pressure is uniform. The validity of the assumption is greatest at full inflation; therefore UPM is traditionally used for simulating IP load cases where the occupant impacts a completely inflated airbag.

In a static OoP safety test, the engagement of the occupant with the airbag starts when the airbag is only partially deployed. During the initial stages of inflation, large spatial pressure gradients exist inside the airbag; some regions of a tightly folded bag will not "see" the inflator gas before the bag unfolds. The UPM assumption thus breaks down,

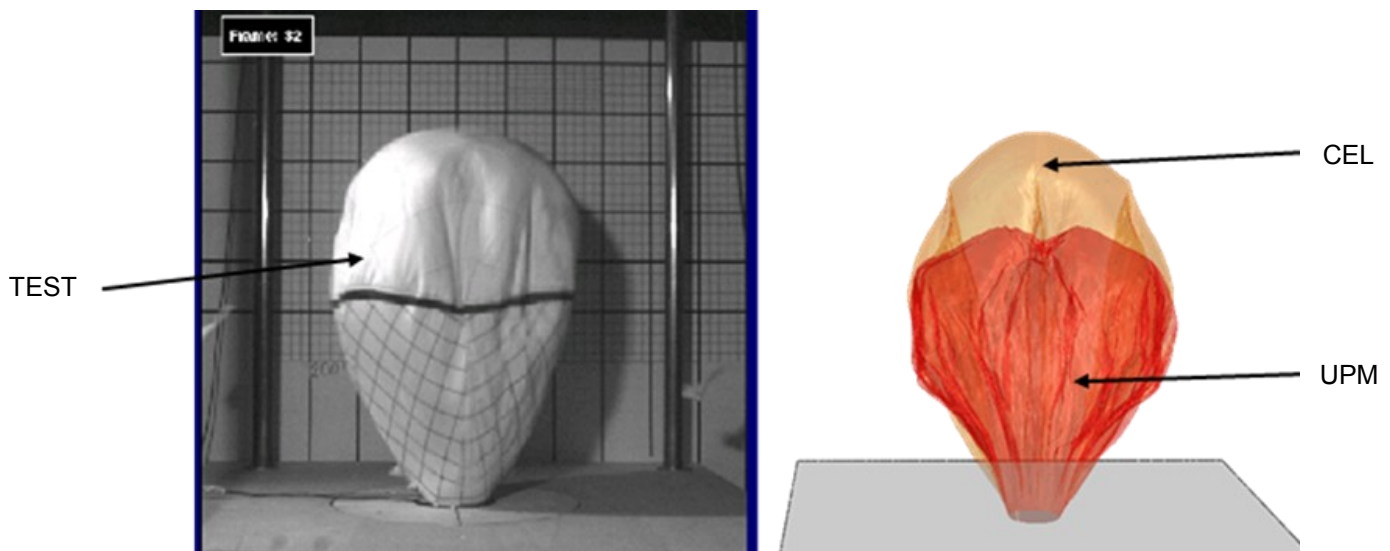


Figure 1: A folded airbag deployment at 16 ms: Test, CEL & UPM simulation approaches

and the motion of the gas in the airbag must be considered for such cases. The coupled Eulerian-Lagrangian (CEL) technique provides a higher fidelity approach by simulating the gas flow inside the airbag. Consequently, this method predicts a more realistic deployment and computes the spatial and temporal pressure history inside the airbag accurately, even during the early stages of inflation. Figure 1 compares the predicted shape of an initially folded airbag at 16 ms using the two approaches.

### Working Group Airbag

In the late 1990s, German automobile manufacturers formed a 'working group' to evaluate and develop a common methodology for out-of-position simulations [1]. The working group used a standard 60-liter driver airbag model for evaluating different simulation techniques. Two versions of the driver airbag, flat and folded, were used for the evaluations. The same two working group airbags are used for the present demonstration of the CEL method in Abaqus/Explicit.

The test configuration consists of a freely suspended hemispherical headform which is in initial contact with the airbag (Figure 2). During deployment, the airbag pushes the headform, and the acceleration is measured and correlated against the test data.

### Finite Element Analysis Approach

The Lagrangian airbag is discretized with membrane elements. The fabric constitutive model is anisotropic and nonlinear, and captures the independent loading and unloading mechanical response of a woven material in each of the three component directions: fill, warp, and shear.

In a traditional Lagrangian analysis nodes are fixed within the material, and the elements deform as the material

deforms. Lagrangian elements are always 100% full of material, so the material boundary coincides with an element boundary. By contrast, in an Eulerian analysis nodes are fixed in space, and material flows through elements that do not deform. Eulerian elements may not always be completely full of material; many may be partially or completely void. The Eulerian mesh for these simulations is a simple grid constructed to extend well beyond the Eulerian material boundaries, giving the material space in which to move and deform.

The airbag inflator is represented by a number of nodes at locations that approximate the inflow points. A vector is specified at each of the inflator nodes to represent the direction of the gas inflow. The velocities at the nodes of the inflator elements are obtained by solving the momentum equations based on the input mass flow rate, area, and the direction vector. The temperature and the mass flow rate of the gas entering the airbag is specified at the inflator nodes as a function of inflation time. In the experiment, the inflator gas composition changes with time, but in the simulation the inflator gas composition is assumed to be constant.

An Eulerian element can contain multiple materials at the same time. The Eulerian volume fraction (EVF) is computed for each material at every time increment, and based on the EVF, the material surfaces for every element are determined. These Eulerian material surfaces can interact with Lagrangian surfaces, such as the airbag. The Eulerian domain is initially filled with air. When the inflator fires, the gas fills the airbag and pushes the air out. Abaqus/Explicit general contact captures both the Lagrangian contact and the Eulerian-Lagrangian contact. The latter is defined only between the inflator gas and the airbag. No contact is defined between the outside air and the airbag. It is safe to assume that the air cannot re-enter the airbag due to the high inflation pressure.

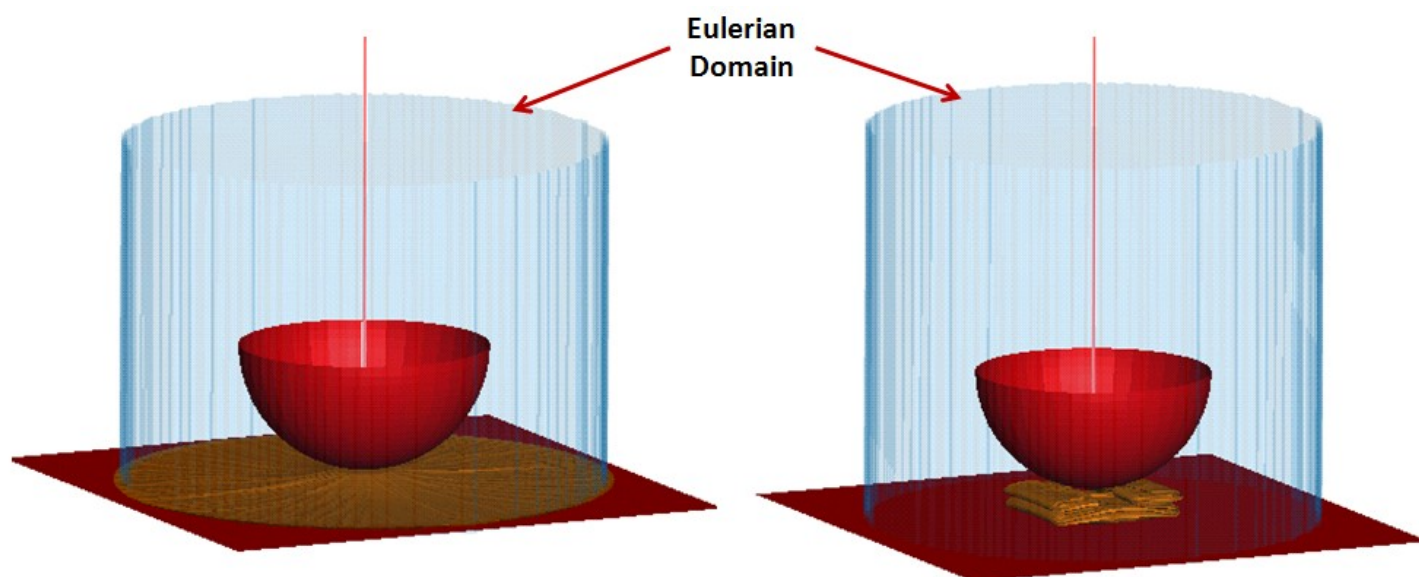


Figure 2: Initial configurations of flat (left) and folded (right) airbag simulation models

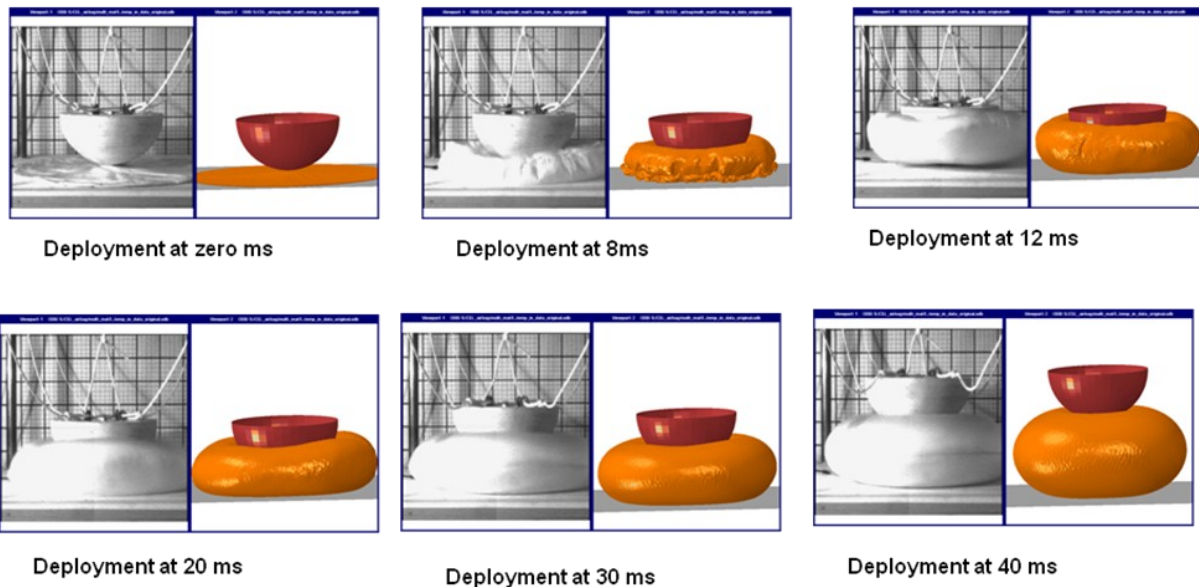


Figure 3: Flat airbag deployment, experimental results and CEL prediction

### Results and Conclusions

A 5 mm uniform Eulerian mesh is used for both models. Figures 3 & 4 display the comparison of the working group flat and folded airbag experimental deployment with the CEL predictions. Figure 5 shows the comparison of the headform acceleration for the flat and the folded airbag simulations respectively. For both airbag models, the acceleration history as well as the airbag deployment correlates reasonably well with the experiment.

It is clear from Figure 5 that the UPM approach does not capture the acceleration history well during the initial

stages of deployment. The initial peak as well as the maximum peak acceleration is more accurately captured in the CEL simulations. In both the airbag models, the CEL simulation better captures the oscillations in acceleration plots.

The above correlation between the experiment and the CEL method demonstrates that Abaqus/Explicit is capable of predicting realistic results even in the early stages of the airbag deployment; hence, this method can be successfully used for the out-of-position load cases.

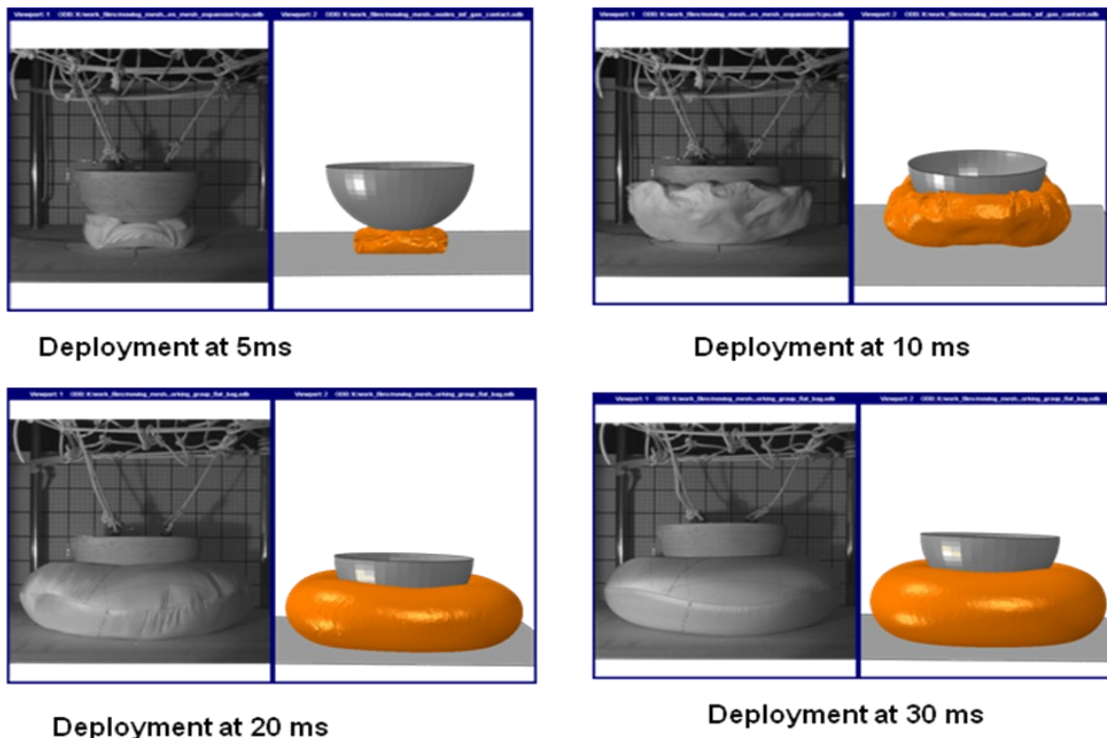


Figure 4: Folded airbag deployment, experimental results and CEL prediction

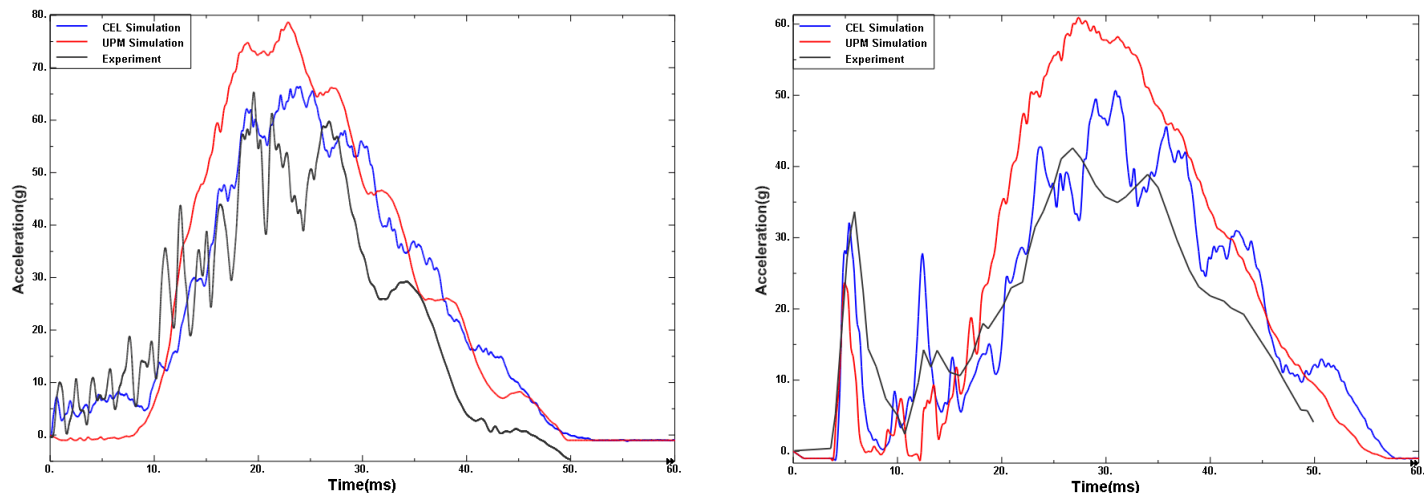


Figure 5: Headform acceleration for the flat (left) and the folded (right) airbags

## References

1. Benno Beesten, Andreas Hirth, Robert Reilink, Rolf Remensperger, Doris Rieger, Gunther Seer, "OOP-Simulation—A tool to design airbags? Current Capabilities in Numerical Simulation," *Technical Report, OOP Simulation Working Group of German Automobile Manufacturers*, 2004.
2. Isheng Yeh, Li Chai and Nripen Saha , "Application of ALE to airbag deployment simulation," *Int. J. Vehicle Safety*, Vol. 1, No. 4, 2006

## Abaqus References

For additional information on the Abaqus capabilities referred to in this document please see the following Abaqus 6.11 documentation references:

- Abaqus Analysis User's Manual
  - 'Eulerian Analysis,' Section 14.1.1
  - 'Eulerian Elements,' Section 31.14.1
  - 'Eulerian surface definition,' Section 2.3.5
  - 'Defining general contact interactions,' Section 34.4.1

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