Coupled Eulerian-Lagrangian contact modeling for airbag deployment simulation

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Abstract: *The coupled Eulerian-Lagrangian (CEL) method in Abaqus/Explicit is essential in component design of head protection systems at BMW Group as it allows an accurate modeling of the gas behavior. However, due to the nature of the algorithm, the modeling of the contact between inflator gas and airbag membrane is a challenging task. Using conventional modeling techniques, two airbag membrane sections are not able to separate again, as soon as they come into contact, as the membrane elements are embedded into Eulerian cells entirely filled with inflator gas. The proposed modeling approach overcomes this severe contact issue and allows separation of the membranes after having been in contact. The method has successfully been applied for airbag deployment simulations within the development process at BMW Group.*

Keywords: *Coupled Eulerian-Lagrangian, CEL, Airbag, Passive Safety, Crash*

1. Introduction

Besides an optimized structural behavior of the car, the restraining system is an essential component of the passive safety concept of modern passenger cars. A restraint system consist of a belt with a pretensioning and load limiter device and a number of airbags (SRS: supplemental restraint system).

Initially introduced in 1974 by General Motors, these systems became mandatory for the driver and the front seat passenger in 1997 in the United States. Today's cars are equipped with driver and front seat passenger airbags, knee, side and head airbags. Beyond that, pedestrian protection airbags (PPA) are available.

The effectiveness of an airbag system is determined by a number of parameters such as size, shape, pressure, ignition point (time to fire), and others. The optimization of the entire restraint system requires an even larger number of parameters (e.g. time of pretensioning, belt force limit). In order to ensure an optimal interaction of these components, all of these parameters need to be optimized. With regard to time and cost efficiency, this task has to be done with simulations. Consequently, only a reduced number of tests is needed for calibration and validation purpose.

2. Airbag Modeling

An airbag simulation model mainly contains the following parts: the bag itself, the inflator device and the gas to fill the airbag. The inflator device is usually modeled as a small rigid body and will not further be discussed here. The modeling of the inflator gas depends primarily on the airbag deployment method used in the simulation.

2.1 The Bag

The bag is modeled by membrane elements defined with **`*FABRIC`** material model. Besides the visible part of the bag there are several non-visible parts inside. Examples for the latter are rebound straps to ensure an optimal shape of the deployed airbag and fabric diffusors which guide the gas flow to ensure a time-controlled inflation of different parts of the airbag. Depending on the application, all these components have to be modeled and considered.

The folded airbag configuration is associated by a reference mesh (initial metric) with **`*INITIAL CONDITIONS, TYPE=REF COORDINATE`**, in order to consider strains due to the folding process.

During the inflation, complex contact behavior has to be considered (with activated edge contact) which increases the computational load.

2.2 Airbag deployment method

For the modeling of the inflator gas, two different approaches are available:

1. The uniform pressure method (UPM)
2. The coupled Eulerian-Lagrangian method (CEL)

2.2.1 Uniform Pressure Method

In case of the UPM a pressure load is be applied on the inside of the airbag. It varies in time, but is uniform in space. The pressure load is applied by the **`*FLUID CAVITY`** technology. This leads to a physical behavior only at the end of the deployment phase. In reality, there are one or more concentrated jets of the inflator gas at the beginning of the deployment, which results in a significant pressure gradient inside the bag.

This method is acceptable, if the occupant hits the airbag at the end of the deployment process and there are no other components of the car interacting with the airbag during the deployment. The validity depends on the crash load case and the distance between occupant and airbag.

This method is very attractive due to its numerical efficiency. In fact, there is no noticeable increase in computational effort.

2.2.2 Coupled Eulerian-Lagrangian Method

Using the CEL method, the actual gas behavior can be modeled. Specifically, the jetting out of the inflator device, varying gas pressure and different pressure loads on the bag can be considered. This allows the simulation of airbags, which are in contact with the occupant during the inflation process and airbags hitting obstacles (e.g. part of the seats, trim parts, etc.) during deployment. For example, these situations can be observed for curtain airbags, for pedestrian protection airbags, or for out of position investigations of front seat airbags.

The drawback of this method are its high computational costs and its challenging handling of the contact modeling.

Modeling the gas using a conventional Lagrangian finite element method is not feasible due the large deformations of the gas. Therefore an Eulerian approach is used by Abaqus/Explicit. This method can be understood as a Lagrangian body, which undergoes a limited amount of deformation during a small number of increments. Depending on the deformation, or the number of increments, an update procedure is carried out. It resets the deformed mesh to the original, undeformed configuration and maps the material state to a new mesh configuration. This allows the material to flow though the mesh, comparable to an Eulerian point of view. This leads to a situation, where the surface of a body is not aligned to surfaces of the elements. In order to allow a smooth movement through the fixed mesh, every element (Eulerian cell) stores a so-called element volume fraction value for every material inside this Eulerian cell. This element volume fraction has to be mapped during the update process as well. The Eulerian region (meshed region with Eulerian cells) has to cover all the space where the Eulerian material is expected to be during the simulation. This results in a huge number of the Eulerian elements depending on the size of the airbag. The additional number of elements for the Eulerian region as well as the numerical cost of the mapping process and the contact algorithm increase the computation load of an airbag deployment simulation with the CEL method.

With the element volume fraction at hand, free surfaces of the body are computed and used for visualization purposes and for contact calculations. This contact couples the Eulerian (inflator gas) and the Lagrangian (airbag and rest of the car) parts of the model. Since the computed free surfaces are approximations, the contact algorithm is quite complex and the modeling becomes very challenging.

3. Contact Issues in CEL Method

As previously described, the element volume fraction quantity is used to compute free surfaces of the Eulerian parts. This approach has to consider a number of implementation dependent requirements.

In situations, where Eulerian cells are filled with inflator gas from two sides, no contact surface is computed in case of an element volume fraction larger than 0.5. This situation is illustrated in Figure 1. On the top and on the bottom of the Eulerian mesh, two different airbag chambers can be seen. These chambers are connected with a single layer of airbag membrane. In the contact area of the two chambers, the contact issue can be observed.

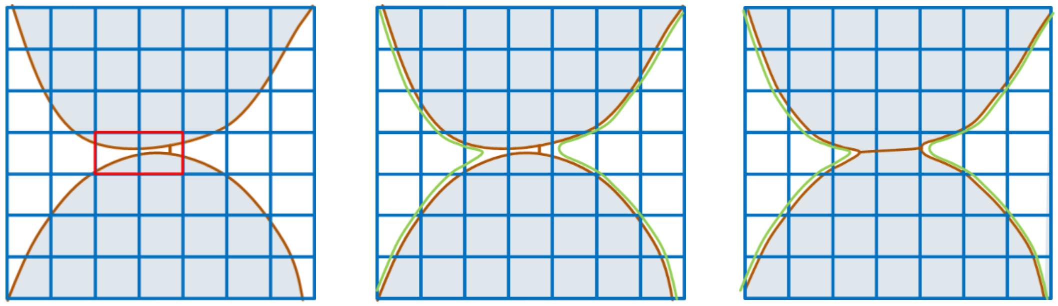

Figure 1. Schematic visualization of neighboring airbag chambers.
Left: Red Euler cells are filled more than 50% with inflator gas.
Middle: No inflator gas contact surfaces in involved Euler cells.
Right: Airbag chambers stick together. (Horz 2015)

The reason is the mismatch in size of the thickness of the airbag membrane and the size of the Eulerian cells. This insight leads to an improved modeling technique which can be used to resolve this issue.

4. Improved Contact Modeling Technique

As mentioned above, the reason for the contact issue is the small thickness of the airbag membrane compared to the Eulerian cell size. To achieve a correct contact situation, the Eulerian cell should be smaller than the thickness of the airbag membrane. Unfortunately, this is not feasible due to the resulting numerical cost.

Instead of reducing the size of the Eulerian cells, the contact thickness of the airbag membrane could be increased with **`*SURFACE PROPERTY ASSIGNMENT, PROPERTY=THICKNESS`**. But this would lead to severe contact intersections at the beginning of the simulation due to the folded configuration of the airbag.

The final idea of the modeling technique follows the approach of modifying the contact thickness. To overcome the contact intersections of the folded airbag, we followed the *divide and conquer* paradigm. The airbag membrane is used to impose the contact between airbag and surrounding parts and airbag membrane self-contact. No modifications are necessary for the contact thickness of the airbag membrane. In order to handle the contact between airbag and the inflator gas the membrane elements are overlaid with additional surface elements. The contact thickness of the surface elements is increased to be thicker than half of the Eulerian cell size. Moreover, an offset fraction is defined, causing the additional contact thickness to be effective at the outside of the airbag only.

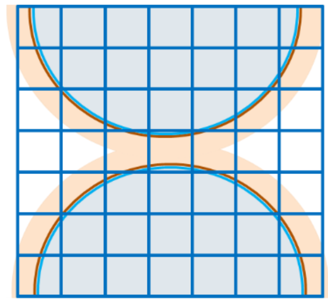

Figure 2. Schematic visualization of the improved modeling technique. The contact thickness with offset of the additional surface elements can be seen. (Horz 2015)

This configuration leads to a situation, in which the inflator gas is in contact with the surface elements inside the airbag in the same way as in conventionally modelled airbags. Inflator gas from outside (from the neighboring airbag chamber) contacts the surface elements with a distance defined in the contact thickness (see Figure 2).

4.1 Additional Remarks

4.1.1 Contact Exclusions

A number of additional contact exclusions need to be introduced. First, the inflator gas is only in contact with the overlaying surface elements. Second, no self-contact and no contact between the surface elements and the rest of the model are allowed.

In case of **`*CONTACT INCLUSIONS, ALL EXTERIOR`**, a contact exclusion between the inflator gas and the rest of the model except the surface elements needs to be defined. This can be achieved by the definition of a default all-exterior surface and the subtraction of the surface elements:

```
*SURFACE, NAME=Surf_SurfaceElements, TYPE=ELEMENT
SurfaceElements
*SURFACE, NAME=Surf_AllExterior, TYPE=ELEMENT
,
SURFACE, NAME=Surf_AllExterior_without_SurfaceElements, COMBINE=DIFFERENCE
Surf_AllExterior, SurfaceElements
```

4.1.2 Surface Polarity

In conventional modeling techniques **`*CONTACT FORMULATION, TYPE=POLARITY`** is used to limit the contact computations between airbag and inflator gas to the inside of the airbag. In the presented approach, the contact between the surface elements from the inside and the outside of the airbag is essential. No surface polarity is used.

4.1.3 Contact Thickness Reduction

In case of a large contact thickness compared to an element size, Abaqus/Explicit reduces the contact thickness automatically. This can be avoided by **`*CONTACT CONTROLS ASSIGNMENT, CONTACT THICKNESS REDUCTION = NOPERIMSELF`** for regions with no self-contact. Depending on the airbag mesh size and the contact thickness used for the surface elements, this is important for proper results.

4.1.4 *TIE instead of sharing nodes

For the first approach, the membrane elements and the surface elements use the same nodes. Despite different elements used for surface definition, the resulting surfaces are the same for Abaqus/Explicit. Assigning surface properties to one surface affects the properties of the other surface in the same way. Different contact thickness definitions are not possible. This can be resolved by using different, but coincident nodes and defining a tie constraint between the airbag membrane and the surface elements.

5. Example

In this example the simulation model of a curtain airbag is used. The model is quite challenging with respect to the contact issue described above. This airbag is composed by a number of chambers sticking together during the deployment phase. Figure 3 shows the entire airbag and a detail with the contact issue.

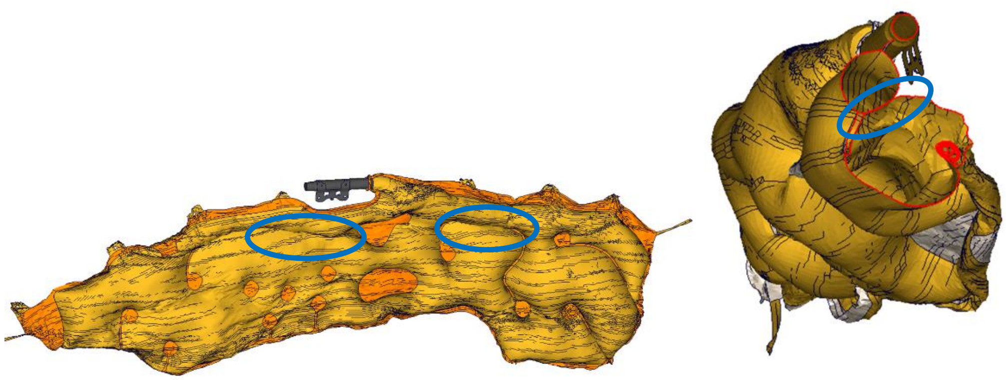

Figure 3. Curtain airbag during deployment phase. The sticking chambers can clearly be seen. (Horz 2015)

Figure 4 shows the same position as the left picture in Figure 3 with different contact thickness settings. In this example 5mm CEL element mesh is used. With 5mm and 3mm contact thickness, the airbag deployment could be simulated in a robust way without sticking of neighboring chambers. With 2mm contact thickness, some chambers still stuck together.
As a general rule of thumb, the surface thickness has to be more than a half of the size of the

representative Eulerian cell. This prevents the Eulerian cells to be filled more than 50%. In our example, this is true for a surface thickness of 3mm.

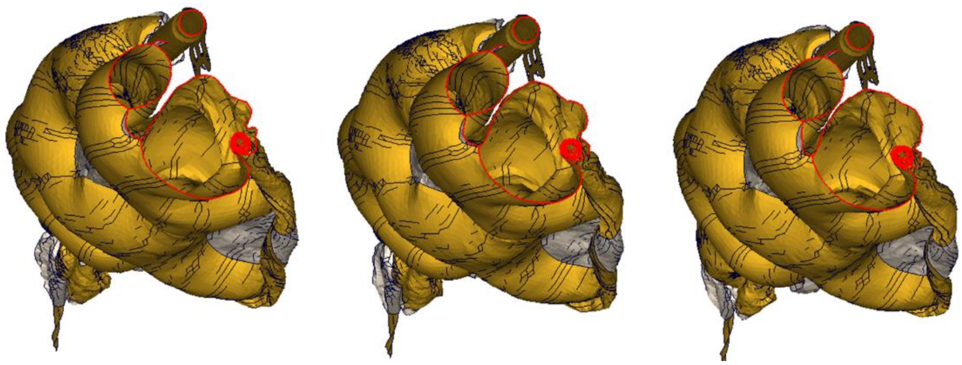

Figure 4. Same position as in Figure 3 with different contact thickness settings for the surface elements (5mm, 3mm, 2mm) for 5mm CEL element size. (Horz 2015)

6. Summary

With this workaround at hand, the airbag deployment of multi-chamber airbags and self-contacting situations can be simulated in a robust way. The additional preprocessing effort is relatively small.

7. References

1. Horz, S., “CEL Contact Issue - Sticking of Airbag Chambers: Workaround”, TECOSIM internal report, 2015.