Issues in ALE Simulation of Airbags

A. Chawla[1], S. Mukherjee, J. Jangra
Transportation Research and Injury Prevention Programme
Indian Institute of Technology New Delhi
T. Nakatani
Japan Automobile Research Institute

ABSTRACT

Airbag simulations have emerged as an important means to study their efficiency in occupant safety. The situation where the occupant deviates from the nominal position is commonly referred to as Out Of Position (OOP) situation. The focus in this paper is in developing simulation models that can be used for OOP studies in the future. In order to capture the initial stages of inflation of the airbag in OOP simulations, the focus has now shifted towards discretizing the fluid flow inside the airbag using the Arbitrary Lagrangian Eulerian (ALE) approach. The interaction between the fluid (Eulerian mesh) and the structural elements (Lagrangian mesh) is defined through a coupling. In this work, a description of process for generating the mesh for the folded airbag is presented. Some strategies adopted to resolve penetration and time step issues in folding have been highlighted. The folded airbag is inflated in simulation using both the CV and ALE approach and the results are compared. For validation, the inflation of the airbag was recorded using high speed photography and a tank test conducted to characterise the inflator. The performance of the ALE method and Control Volume method for the purpose of OOP simulations is compared with the experimental observations.

Key Words: Airbags, Eulerian Mesh, Lagrangian mesh, Constant Volume Approach, Aribtrary Lagrangian Euler (ALE) approach, Finite Element Simulations.

INTRODUCTION

With the increase in use of airbags in vehicles, and simulations becoming time and cost effective, airbag simulations have emerged as an important means to study their efficiency in occupant safety. One issue that is of importance in occupant safety is the injuries caused by airbag in cases where the occupant is sitting too close to the airbag. The high momentum jet of gases from the inflator propels the folded airbag and imparts a high velocity fling and can cause injury on contact. This situation where the occupant deviates from the nominal position is commonly referred to as Out Of Position situation or simply OOP. The case of the occupant sitting too far away is also labelled out-of-position, it leads to a different problem that of the airbag deflating before the occupant is restrained. The airbag design should account for this as well, but the focus in this paper is in simulations for the former case, of the occupant coming into contact too soon. Traditionally airbags have been simulated using the Control Volume approach. In the Control Volume model, the pressure inside the airbag is calculated using the mass flow and temperature curves obtained from a tank test. This pressure is assumed to be uniform inside the airbag and thus a uniform force is applied on all the surfaces of the airbag, including those surfaces which are yet not unfolded. Control Volume approach is hence analogous to a lumped parameter model in which the flow of inflating gases inside the airbag is not discretized. The effect of the gas jet from the inflator is not taken in to account in these models. To overcome this shortcoming, jetting is added to control volume models to add a momentum to the airbag in the direction of the jet from the inflator. But even these jetting models are unable to reproduce the initial fling of the airbag as needed in OOP simulations. The pressure in the airbag obtained from the Control Volume approach during the initial stages of deployment of the airbag is under predicted. Therefore the Control Volume Models are not able to capture the initial stages

---

[1] Corresponding Author: Dr. Anoop Chawla, Associate Professor, Deptt. of Mechanical Engineering, IIT Delhi. Tel no.: 011- 26591058, Fax no.: 011-26582053, Email: achawla@mech.iitd.ernet.in

of unfolding of the airbag. In order to capture the initial stages of inflation of the airbag in OOP simulations, the focus has now shifted towards discretizing the fluid flow inside the airbag using the Arbitrary Lagrangian Eulerian (ALE) approach [1][2][3][4][5]. Usually the fluid is modelled using an Euler mesh which is fixed in space, since the Lagrangian elements are not suitable to model high distortions that are present in the fluid. If we go by a purely Euler approach, we must have a very large number of Eulerian elements so that the Eulerian domain can submerge the completely deployed airbag. The size of the Eulerian elements must be kept small at all times even though larger elements are good enough for later stages of simulations. This leads to very long computation times for a purely Eulerian approach. In the ALE method, the Euler mesh can be expanded, as the airbag deploys. This gives us the freedom to keep small Euler elements during the initial stages, and expand them as the airbag deploys. The interaction between the fluid (Eulerian mesh) and the structural elements (Lagrangian mesh) is defined through a coupling. In this work, a description of process for generating the mesh for the folded airbag is presented. Some strategies adopted to resolve penetration and time step issues in folding have been highlighted. The folded airbag is inflated in simulation using both the CV and ALE approach. For validation, the inflation of the airbag was recorded using high speed photography and a tank test conducted to characterise the inflator. The mechanical properties of the fabric was characterised in two orthogonal directions. The performance of the ALE method and Control Volume method for the purpose of OOP simulations is compared with the experimental observations from an airbag inflation test.

PROCESS FOR GETTING THE FOLDED MESH

The airbag used in the present study is a typical passenger side airbag. It consists of an inflator unit, a small inner chamber and the main airbag. The inner chamber has sideways opening holes which redirects gases from the inflator to enter sideways into the main airbag. The modelling process started from the uninflected fabric which when laid out flat contained many wrinkles and some portions had to be tucked in during the flattening process. So the airbag was meshed along with the wrinkles and tuck-ins. The folding was initially tried by simulating the manual folding process. The mesh of the tucked-in airbag was sandwiched between 4 rigid planes, 2 on each side of the location of the fold. Two of these rigid planes were fixed and the other two were given an angular velocity about the fold line. In simulation, as the rigid planes rotate, the airbag fabric between them would also rotate about the location of the folds, as would happen in a real folding process. This is shown schematically in Figure-1. Correct orientations of the contacting surfaces, planes and airbag fabric had to be maintained. Special attention was paid to define contact surface definitions in these folding simulations.

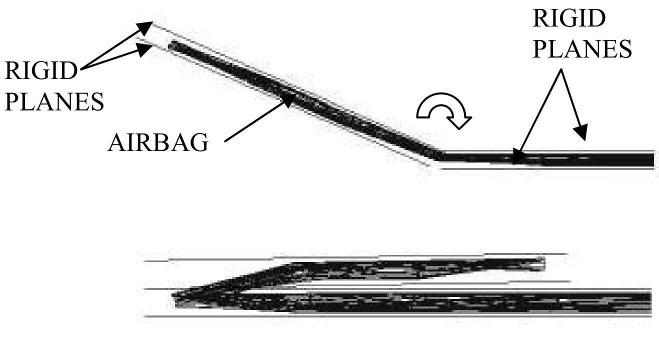

Figure-1 Folding by simulations

This process worked satisfactorily for up to two folds. For more than two folds, the pre-existing double folds had to be constrained inside a rigid box, instead of planes, and this box rotated about the location of the fold. But during the simulation, the earlier folds lost shape and this led to a distorted mesh. Another approach tried was to make the already existing two folds rigid and then rotate them about the location of the third fold. This led to penetration problems that could not be resolved. The manual mapping method [6] was tried. It proved to be a very efficient and an effective way of creating the folded airbag mesh. In this method, the tucked-in airbag was meshed so that apart from random free mesh, nodes were mapped at the location of the folds. In this method systematic delineation of the airbag surface into multiple logical patches is required prior to meshing the surfaces so that nodes are mapped at all the fold locations, through all the fabric layers. Following this, nodes on one side of the fold were given a rotation of 180 degrees and the nodes at the location of the fold were given a rotation of 90 degrees as shown with exaggerated interlayer thickness in Figure-2**.** This creates a reasonable fold, but a few penetrations between layers of fabric at the location of the fold appear. Inspecting the fold layer by layer, and manually relocating the penetrating nodes removed the penetrations. This corrective process is shown schematically in Figure-3**.**

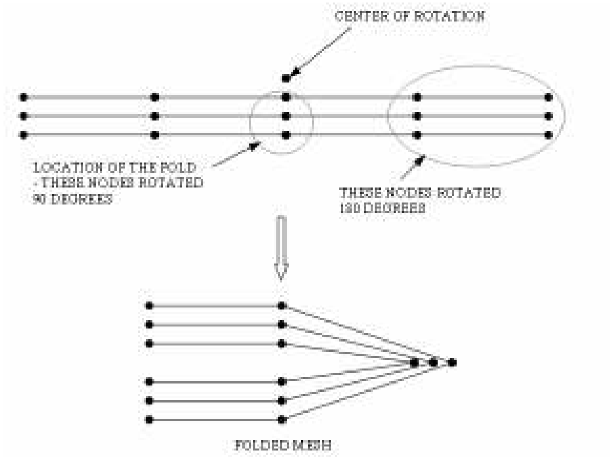

Figure-2 Folding methodology in manual meshing

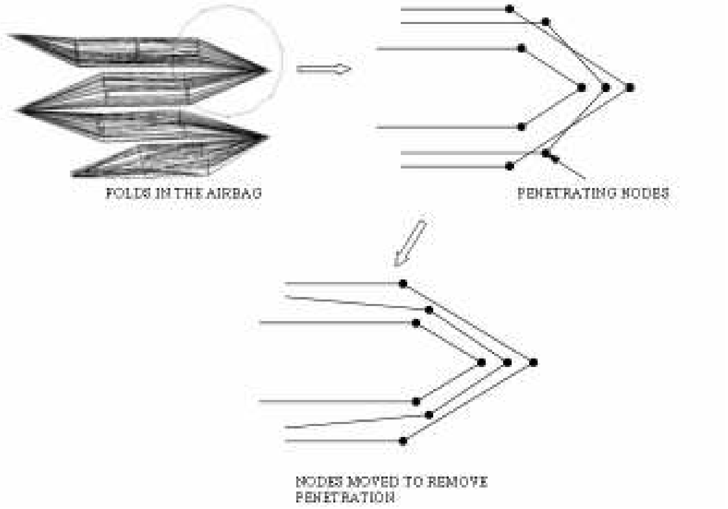

Figure-3 Removing the initial penetration between fabric layers by moving nodes

Using this method, the folded airbag mesh could be created rapidly and systematically. The airbag chosen had an inner chamber inside the main outer bag. This inner chamber of the airbag was also meshed using the same methodology. The mesh of folded inner chamber was placed inside the main airbag. Figure-4 shows how the inner chamber is placed inside the main airbag. The inflated geometry of the inner chamber is shown in Figure-5. The inner chamber has holes (darker patches in Figure-5) and the Lagrangian elements at free edges of the holes ended up having high distortions and therefore causing a drop in the time step. To counter this problem, a dummy fabric, loosely connected the free edges of the airbag was added to this inner layer. This dummy fabric was not included in the contact surface definitions and made completely porous, so that it allows the inflator gases to pass through it unobstructed. Hence the dummy fabric did not affect the airbag mechanics, in any way other than to prevent high distortions at the free edges of the inner chamber.

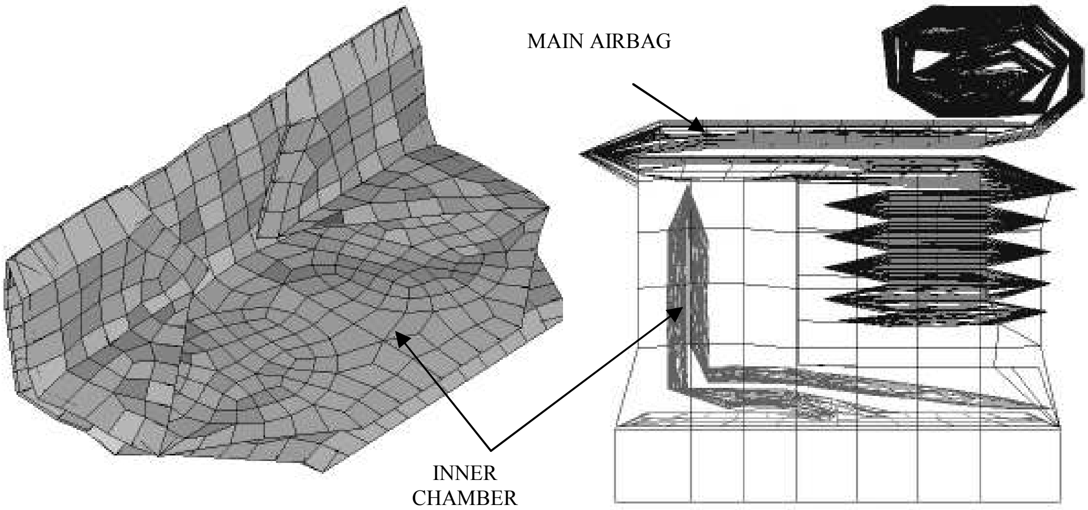

Figure-4 Folded mesh of the inner chamber placed inside the main airbag

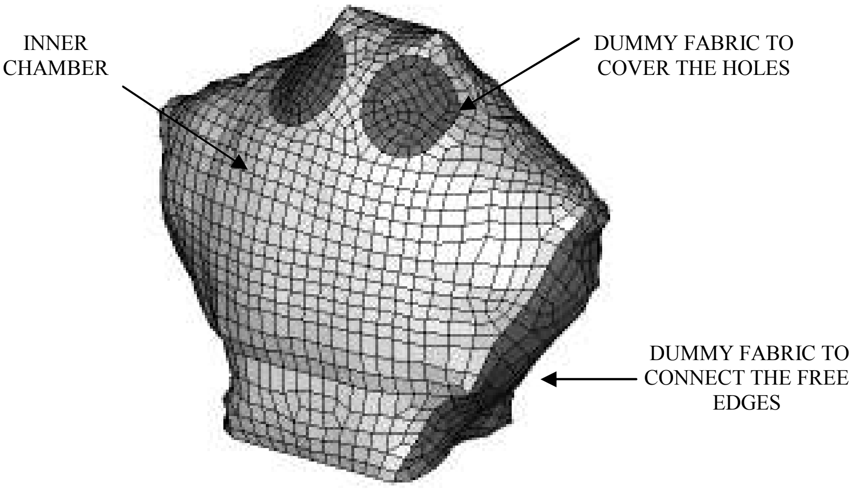

Figure-5 Inner chamber (in completely deployed state) with the dummy fabric

THE CONTROL VOLUME SIMULATIONS

The Control Volume (CV) Models work on a lumped parameter fluid pressure driven approach i.e. they assume a uniform pressure inside the airbag and ignore any pressure variation or flow within the airbag. But during the initial stages of deployment of the airbag, the constant pressure assumption is not valid. In spite of this obvious limitation, Control Volume models are used, as they are computationally economic and standard crash situations do not involve OOP contacts. Hence in OOP cases, where the dummy comes in contact with the airbag during the early stages of deployment, the fidelity of Control Volume models are limited. One adaptation to improve the CV model predictions for the initial deployment stage is to add jets to mimic the effect of the momentum of the fluid emerging from the nozzles of the inflator. But in these jetting models, only the surfaces that are in line of sight of the virtual origin of the jets have an increased force applied. This is hence not capable of simulating the redirection of gas, for example, when it hits an obstacle [4]. As mentioned earlier, in the airbag used in the present study, the gases from the inflator initially enter an inner chamber. The gases then flow into the main airbag from the holes and side openings in this small chamber in to the main airbag. Therefore when we attempted to model the current airbag using the control volume jetting options, the jet impacts only the inner chamber and the jet effects are effective only in the inner chamber since the outer airbag fabric is not in line of sight of the jet. Therefore, the "control volume with jetting" severely under-predicts the pressure in the airbag and hence is not suitable in the present case.

THE ALE TANK TEST SIMULATIONS

An initial step in airbag simulations is to validate against a tank test data in order to characterize the inflator correctly. The tank test records the pressure variation at the tank wall with time. The inputs required by the simulation are the mass-flow rate, density and velocity of the gas exiting the inflator. Modelling the tank test was not an issue for the CV approach as the problem is mathematically simpler and there are pull down menus in most packages to model the inflator, given the tank test results. Using the assumption of constant inflator temperature, conservation of mass and the equation of state, the problem can be reduced to one of three unknowns to satisfy two equations, viz.: -

$$\dot{m} = \rho A V$$

and

$$p = \rho R T$$

where $\dot{m} =$ mass flow rate of inflating gases

$\rho =$ Density of inflating gases

$A =$ Inflator exit area

$V =$ Velocity of inflating gases

$p =$ Pressure of inflating gases

$R =$ Universal Gas Constant

$T =$ Temperature of inflating gases

In the LS DYNA package for example, the ALE_TANK_TEST option calculates the time dependent density and velocity inputs. When the tank test was simulated using the ALE approach by incorporating an airbag of the same dimension as the tank, the pressure history of the tank test was not reproduced. It was seen that the point source input option (SECTION_POINT_SOURCE_MIXTURE option in LS DYNA) allowed greater control and by iterating over the inlet air temperature curve, the inflator was characterized so as to match the simulation results with the experimental tank test. The number of point sources is also a factor and eight point sources were used to model the inflator corresponding to the holes actually present in the inflator. Figure-6 shows a comparison of the tank pressure history obtained from simulations with that recorded in a tank test experiment.

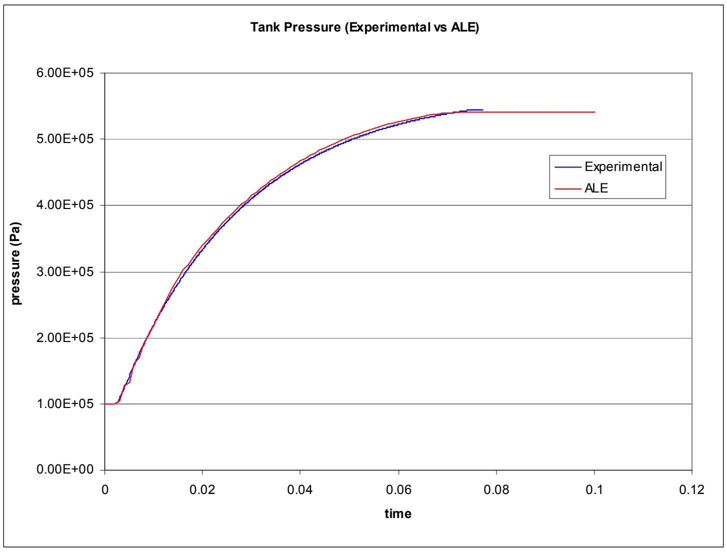

Figure-6 Tank Pressure comparison of ALE tank test simulations with the experiment

A point to note about the tank test simulations was that the inflator was “characterized” numerically so that the results from the finite element model matched with the experimental results. Hence the numerical model of the inflator may or may not have a mapping to the thermodynamics of the inflator. But the results from numerical model match with the experimental results Another issue worth a mention is that, as with most physical systems, the ALE approach is unstable with step inputs. This leads to leakage of fluid past the solid boundaries even if coupling is defined. Our experience was that in LSDyna version 960, a ramp over about 20 time steps (for all inputs that have to be modelled as instantaneous changes) stabilises the simulation and limits leakages to small levels. In LSDyna 970 however, an explicit definition of steps to ramp-over was not needed.

THE ALE AIRBAG SIMULATIONS

After characterizing the inflator by simulating the tank test, this inflator model was used to simulate the airbag by the ALE approach. The structural parts of the airbag were modelled as a Lagrangian mesh and the fluid was modelled by an ALE mesh. The mesh of the folded airbag was submerged in an Eulerian domain of more than 100,000 elements. In order to better simulate the flow of the gases during the initial stages of inflation, initially the size of the Eulerian mesh was kept small in the direction normal to the backing surface. As the airbag inflated, this Eulerian mesh was expanded in that direction to twice its size. In order to define the interaction between the structure (airbag) and the fluid (inflating gases), LS DYNA provides algorithms for fluid structure interaction (FSI). Since the structural (airbag) parts are modelled in Lagrangian domain, and the fluid is modelled using moving Euler (ALE) approach, these algorithms provide mechanisms for coupling between the Lagrangian and the Eulerian domain. The Euler domain is fixed in space and the structure can move freely in this Eulerian domain. Forces are transferred between the fluid and the structure through a penetration penalty based contact algorithm in which penalties are used to calculate forces between interacting (penetrating) Lagrangian and Eulerian domains.

RESULTS

Figure-7 shows the comparison of experimental airbag shape recorded at 2000 fps with the Control Volume and ALE prediction. Differences are significant till the first 20 ms in terms of the height gained, lateral expansion and overall shape. Beyond 20 ms, the ALE and CV prediction is similar. The observed prediction of an initial fling is missed by the Control Volume method but captured by the ALE simulation. In the control Volume method, the gas pressure starts acting uniformly on all the airbag surfaces, even the folded portions, where there is no gas initially. Hence, the ALE method is able to predict the shape of the airbag during the initial stages of the inflation better. However after the airbag has completely unfolded, the pressure becomes more or less uniform throughout. Hence during the later stages, in the completely deployed state, both the CV as well as the ALE method yields acceptable results.

Control Volume Experiment ALE
0 ms

Control Volume Experiment ALE
4 ms

Control Volume Experiment ALE
6 ms

Control Volume Experiment ALE
8 ms

Control Volume Experiment ALE
10 ms

Control Volume Experiment ALE
14 ms

Control Volume Experiment ALE
20 ms

Control Volume Experiment ALE
60 ms

Figure-7 Comparison of actual airbag shape with Control Volume and ALE method

The video image of the experimental inflation was tracked to determine the height of the airbag while it inflated. Figure-8 shows a comparison of the height of the inflating airbag with the Control Volume and ALE simulations. The peak of the ALE simulation lags the experimental inflation by 4 ms while that of the CV simulation lags by 12 ms. The airbag volume-time history predicted by the two approaches is shown in

Figure-9 and is the nearly the same for both methods. However, the peak pressure in the airbag in the first few milliseconds shown in Figure-10 shows that the prediction by the ALE method is nearly 850 kPa, whereas the CV method predicts a lower pressure of 220 kPa. Therefore the control volume method might under underestimate the injury to an OOP Occupant. In the later stages of deployment, when the airbag unfolds completely, the pressure inside the airbag is more or less uniform. Hence lumped parameter approach used by CV model is valid in the later stages of deployment and both the ALE and the CV methods give similar pressures after the first 10 ms.

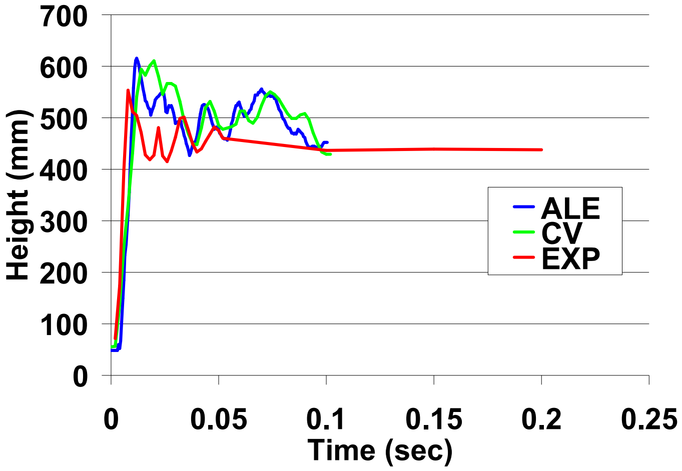

Figure-8 Comparison of height of the airbag in the side view

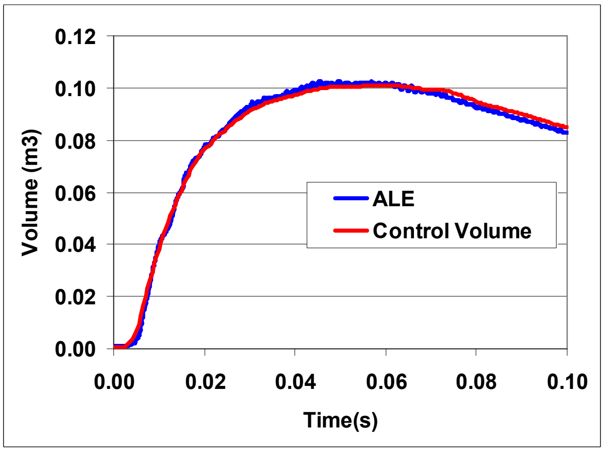

Figure-9 Airbag Volume using ALE and Control Volume Methods

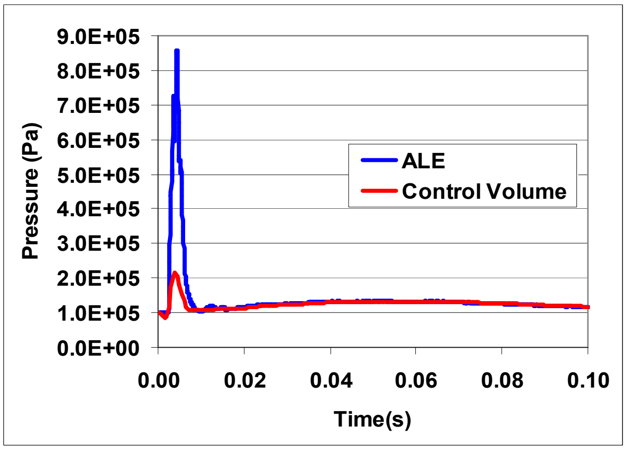

Figure-10 Airbag Pressure using ALE and Control Volume Methods

CONCLUSIONS

Some issues in the process for generating the mesh for the folded airbag have been discussed with strategies adopted to resolve penetration and time step issues highlighted. The folded airbag inflation has been simulated using both the CV and ALE approach using the same fold pattern, airbag material and tank test data. The process of developing an ALE inflator model from tank test inputs was seen to require an iterative procedure. The performance of the ALE method and Control Volume method for the purpose of OOP simulations is compared with experimental results. Comparison of the unfolding pattern and sequence visually indicates superior correlations of the ALE simulations with the experimental inflation sequence in the fling stage with respect to the CV simulations. The unfolding obtained from the CV model lags the experimental and ALE inflation prediction. This was verified by quantifying the airbag height with time in experiment and in simulation. The ALE simulation but not the CV simulation captures the sideways fling caused by the inner layer deflecting the airflow. The results indicate that the CV approach underestimates the airbag pressures in the first 10 ms. Predictions for pressures are similar once the airbag has deployed. One may conclude that an ALE model is needed to study contact with the airbag before it is fully deployed. The computation time for the CV simulation was 1.5 hrs for 100 ms on a 2.4 GHz machine with 2GB RAM. The corresponding ALE simulation ran for about 15 hrs. In view of the additional computation and modelling burden, we also conclude that CV simulations should be preferred if the study is for contact after the airbag has inflated fully, which is the case for many studies.

REFERENCES

1. Cirak F., Radovitzky R., “A New Lagrangian Eulerian Shell Fluid Coupling Algorithm based on Level Sets”, Proceedings of the 44th AIAA/ASCE/ASME/AHS Structures, Structural Dynamics, and Materials Conference, Norfolk, VA, April 2003.
2. Zhang H., Raman S., Gopal M., Han T., “Evaluation and Comparison of CFD Integrated Airbag Models in LS-DYNA, MADYMO and PAM-CRASH”, SAE World Congress, Detroit, Michigan, March 2004.
3. Haufe A., Weimar K., Gohner U., “Advanced Airbag Simulations Using Fluid-Structure-Interaction and the Eulerian Method in LS-DYNA”, 1st NAFEMS CFD-Seminar, Wiesbaden, Germany, April 2004.
4. Marklund P.-O., Nilsson L., “Simulation of Airbag Deployment Using a Coupled Fluid Structure Approach”, 7th International LS-DYNA Users Conference, Detroit, USA, 2002.
5. Marklund P.-O., Nilsson L., “Optimization of Airbag Inflation Parameters for the Minimization of Out of Position Occupant Injury”, Computational Mechanics, Volume 31, pp. 496-504, 2003.
6. Zhang D., Cooper J., “Folding of 3D Airbags Used in Restraint System Simulation”, 5th MADYMO Users Meeting of the Americas, Troy, Michigan, October 2003.

List of Captions:

Figure-1 Folding by simulations

Figure-2 Folding methodology in manual meshing

Figure-3 Removing the initial penetration between fabric layers by moving nodes

Figure-4 Folded mesh of the inner chamber placed inside the main airbag

Figure-5 Inner chamber (in completely deployed state) with the dummy fabric

Figure-6 Tank Pressure comparison of ALE tank test simulations with the experiment

Figure-7 Comparison of actual airbag shape with Control Volume and ALE method

Figure-8 Comparison of height of the airbag in the side view

Figure-9 Airbag Volume using ALE and Control Volume Methods

Figure-10 Airbag Pressure using ALE and Control Volume Methods