Benchmark Study on the AIRBAG_PARTICLE Method for Out-Of-Position Applications

Wenyu Lian
General Motors

Dilip Bhalsod
Livermore Software Technology Corporation

Lars Olovsson
IMPETUS Afea

Abstract

The demands for developing safety restraint systems that perform well under Out-Of-Position (OOP) conditions have increased significantly in recent years. At the same time, the development of simulation capabilities for OOP have made progress in most major crash/safety software, such as the coupled Lagrangian-Eulerian approach (here referred to as AIRBAG_ALE) in LS-DYNA® by LSTC. Similar technologies are applied in MSC-Dytran by MSC and Madymo_CFD (Madymo) by TNO. A somewhat different approach is the FPM method in PAMCRASH by ESI. The AIRBAG_ALE capability in LS-DYNA, MSC-Dytran, and Madymo_CFD use loose-coupling techniques to couple the Lagrangian finite element airbag with a flow domain modeled with an Eulerian or ALE description of motion. PAMCRASH uses a particle based Lagrangian method, referred to as the Finite Point Method (FPM), for the description of the gases inside the airbag. All these methods share the same challenges associated with the coupling of the gas flow to folded bags under high speed deployment. Generally, the computations require considerable CPU power. The improved AIRBAG_ALE algorithm was developed in 2004 by Lian, Olovsson and Bhalsod [1]. In the same year, a set of benchmark problems were proposed by Lian at the SAE Conference [2]. A driver side airbag OOP study using AIRABG_ALE was presented in 2004 at LS-DYNA users' Conference [3]. During the last few years, some modeling difficulties using AIRBAG_ALE have been reported. To overcome the difficulties, the Corpuscular Method (here referred to as AIRBAG_PARTICLE) was developed by Olovsson [4].

This study is intended as an evaluation of the accuracy, stability and efficiency of AIRBAG_PARTICLE compared to AIRBAG_ALE in OOP applications. More specifically, in this work the benchmark problems in ref. [2] have been studied using AIRBAG_PARTICLE. The results of AIRBAG_PARTICLE and AIRBAG_ALE are discussed.

Introduction

The development of AIRBAG_PARTICLE was initiated in 2006. The method is described and demonstrated through a set of simple examples (e.g. gas at thermal equilibrium, quick adiabatic expansion, and multiple inflators mixing gases in an S-shaped tank) in a booklet by Olovsson [4]. In addition, sparse results from folded airbag models have been presented at local LS-DYNA® conferences. However, the method still needs plenty of testing and guidelines for how to use it remain to be worked out.

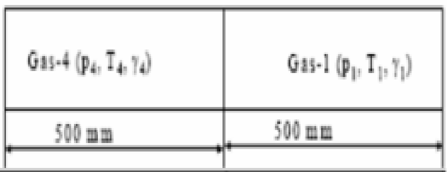
As a contribution to this evaluation process, it was decided to test the method on a set of benchmark problems originally developed by Lian in 2004 [2]. The objective was to compare the AIRBAG_PARTICLE results to those obtained with AIRBAG_ALE. The following benchmark problems have been studied (purpose in parenthesis):

- Shock tube (gas dynamics and equilibrium)
- Tank test (gas mixing and venting)
- Driver side airbag with an OOP pendulum (gas-bag interaction, bag deployment)
- Driver side airbag with a 5th percentile hybrid dummy in OOP-P2 (chest on module) to evaluate airbag unfolding, accuracy, stability, and efficiency for OOP applications.

Each benchmark model and the results are discussed in a separate section. The conclusions and findings of the study are given in the final summary section.

Benchmark I- Shock Tube

A typical shock tube is similar to a very simple stored gas-airbag system. The example simulated here has been taken from a book on gas dynamics [5]. Figure-1 lists the initial conditions together with a diagram of the shock, expansion waves and contact surface of the shock tube. Figure-2 shows the LS-DYNA finite element mesh of the shock tube.



Properties	High pressure side (zone 4)	Low pressure side (zone 1)
Gas	Air	Air
Gas gamma	1.4	1.4
Pressure	500 kPa	20 kPa
Temperature	303 K	303 K
Velocity	0	0

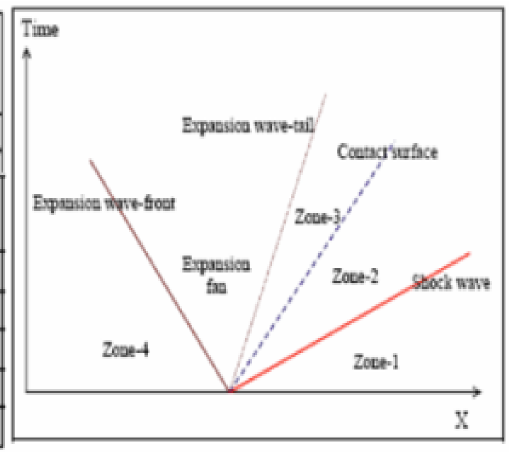


Figure-1. Initial conditions and shock wave diagram of the shock tube.

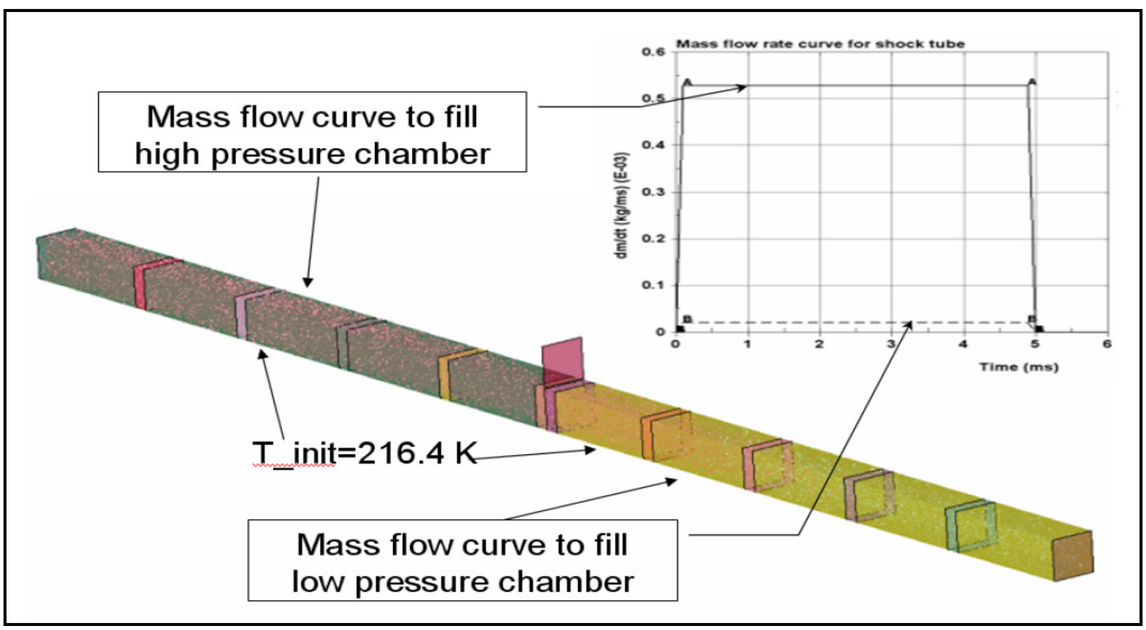


Figure-2. Shock tube mesh (30x30x1000 mm) and initial conditions

The shock tube was modeled as a $30x30x1000mm^3$ rigid tube with 10mm shell element mesh size. The initial conditions were obtained by injecting gas through 18 point sources distributed along the shock tube. The initialization process was defined to last for 5ms. The diaphragm was modeled by declaring the divider as an internal part that was rapidly removed at 5ms using *BOUNDARY_ PRESCRIBED_MOTION. The simulations were compared with analytical results with 5ms time shift (accounting for the initialization process). Ten 10mm wide rings with different part ID's were defined along the tube for monitoring the pressure (part pressures are written to the binout file that can be processed by LS-PREPOST).

An AIRBAG_ALE model of this shock tube was defined by maintaining most of the information and parameters of the AIRBAG_PARTICLE model. The Eulerian mesh size was set to 5mm. Figure-3 is a snap shot of the shock tube flow at 5.5ms (using gas fraction in AIRBAG_ALE and particles in the AIRBAG_PARTICLE model).

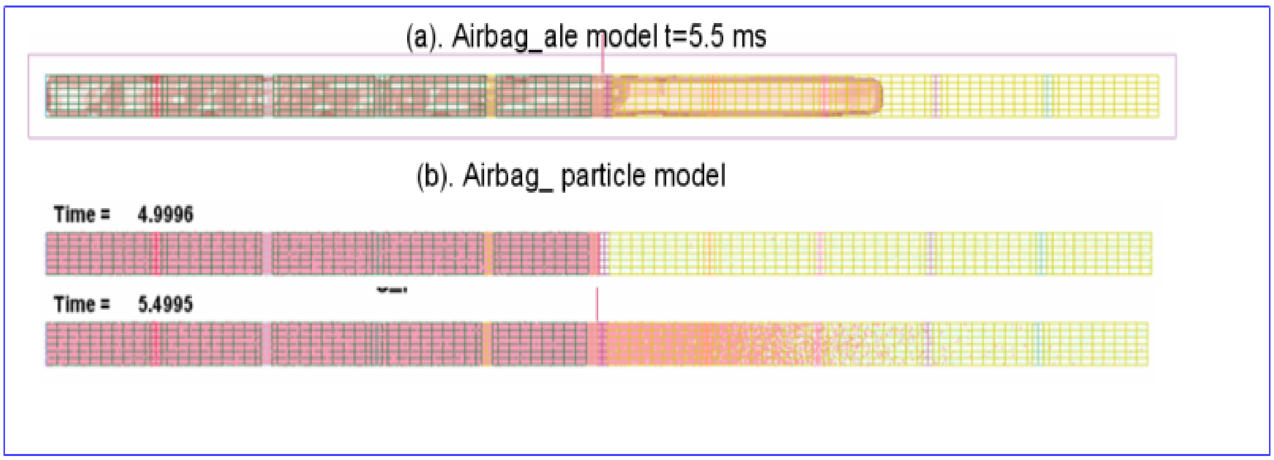


Figure-3. Shock tube at t=5.5 ms AIRBAG_ALE and AIRBAG_PARTICLE methods

The number of particles for this example was chosen at 20,000 and 100,000. The time steps size was set to roughly 1µs. For numerical accuracy reasons, the particles should not be allowed travel more than a small fraction of the shock tube diameter every time step. Large time steps reduce the particle-particle collision frequency. In addition, second order temporal errors in the particle-structure contact implementation will lead to an underestimation of the pressure.

Figure 4 to Figure-6 shows the pressure time histories from AIRBAG_ALE model and AIRBAG_PARICLE models with NP=20,000 and NP=100,000. With the number of particles set to NP=20,000 in this example, each cm^3 contains by average roughly 22 particles. By increasing the total number of particles to NP=100,000 (roughly 110 particles/cm^3) the results were much smoother.

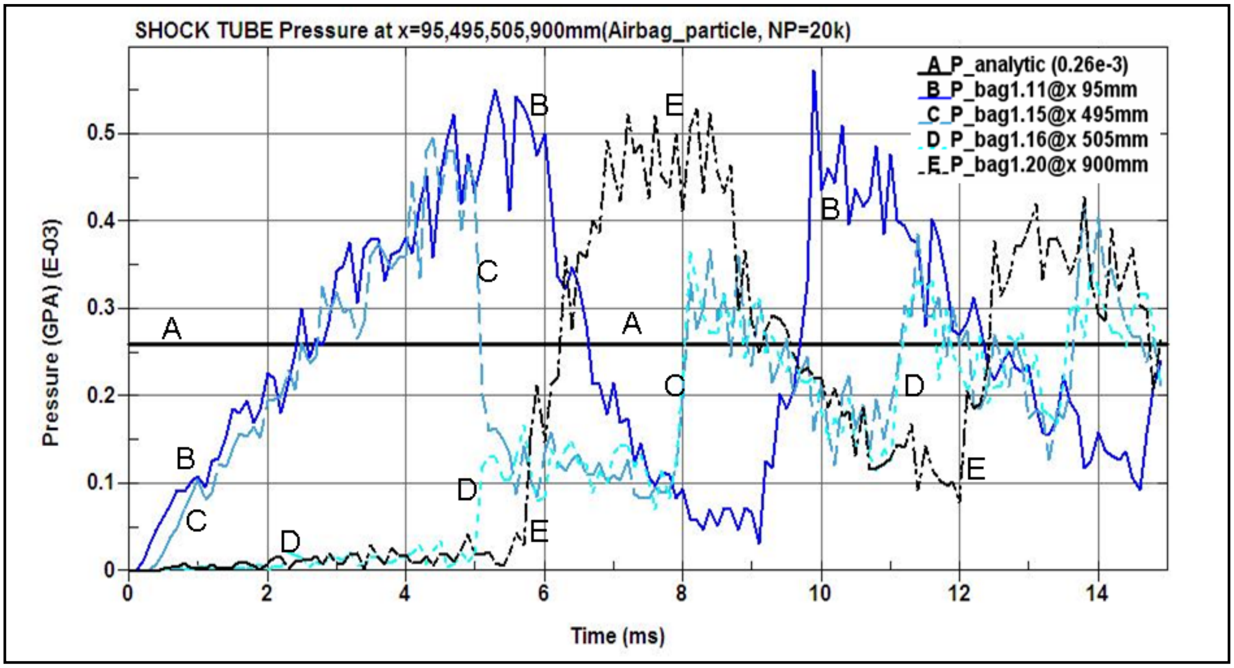


Figure-4. Simulation results of AIRBAG_PARTICLR with NP=20,000

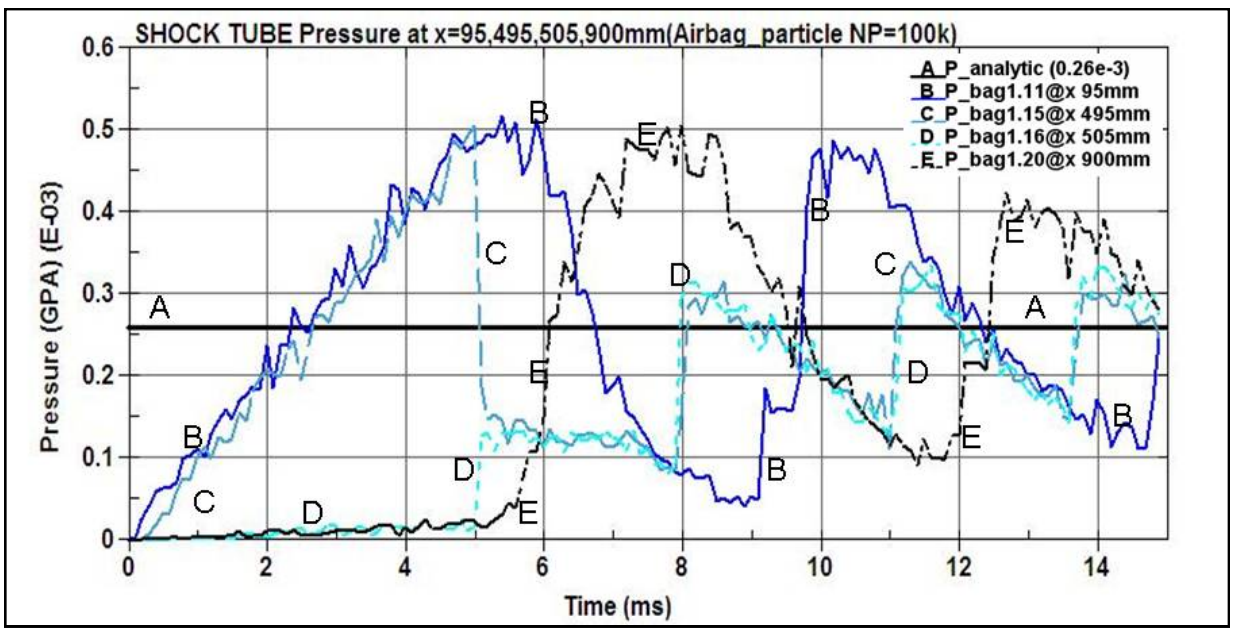


Figure-5. Simulation results of AIRBAG_PARTICLR with NP=100,000

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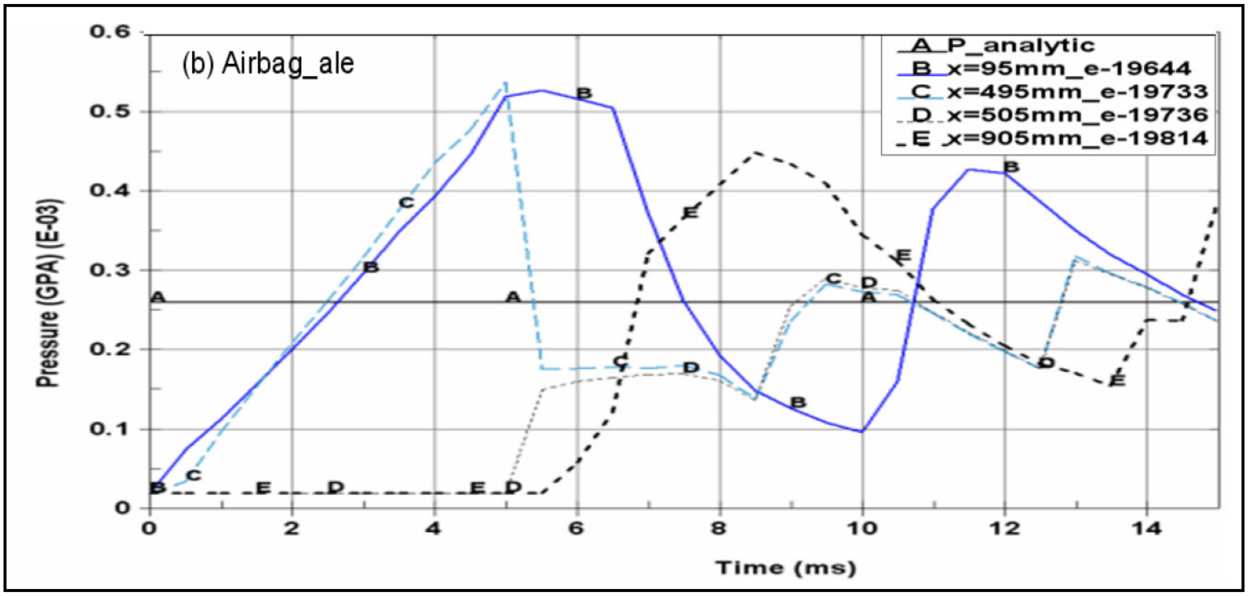


Figure-6. Simulation results of AIRBAG_ALE

The results show that, even with as small average particle to particle distance as 2mm (NP=100,000), the results of AIRBAG_PARTICLE are noisier than those of AIRBAG_ALE. In fact, noise is inherent to the method as pressure is built up by discrete particle-structure impacts. Further, using the AIRBAG_PARTICLE approach pressure waves are generally dissipated faster than when using AIRBAG_ALE.

When using AIRBAG_PARTICLE energy is conserved and, hence, the final equilibrium pressure in the shock tube was correctly predicted. The CPU time for a 14ms AIRBAG_PARTICLE run with NP=100,000 and time step size 1µs was 2 hours, while the CPU time for the AIRBAG_ALE run with element size 5mm and time step size **0.6e-3 ms** was 3.5 hours on an XP workstation.

Benchmark III- 100 Liter Tank Test

For a 100 liter tank test problem, the original tank mesh, inflator mass flow rate (MFR) and temperature curves from reference [2] were used. In this tank test model, the vent area was 1963mm^2 (50mm diameter vent). The Discharge coefficient C_d in AIRBAG_PARTICLE was set to 1. Two testing configurations were modeled: one was a closed tank test and another was a tank test with one 50mm diameter vent. The default number of particles (NP=200,000) was used in both simulations.
Figure-6 shows the tank model, the plots of inflator MFR and temperature curve. Figure-7 shows the tank pressure correlations of both AIRBAG_ALE [2] and AIRBAG_PARTICLE. AIRBAG_PARTICLE correlated the tank pressures very well for both tank test configurations.

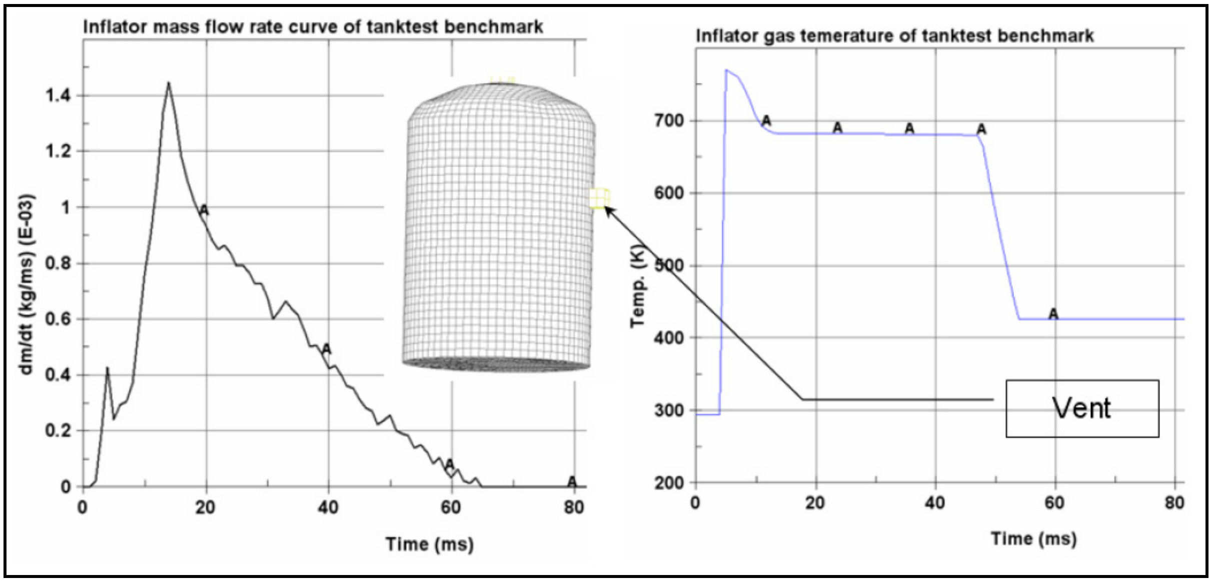


Figure-6. Mesh and inflator inlet curves of the tank test benchmark problem.

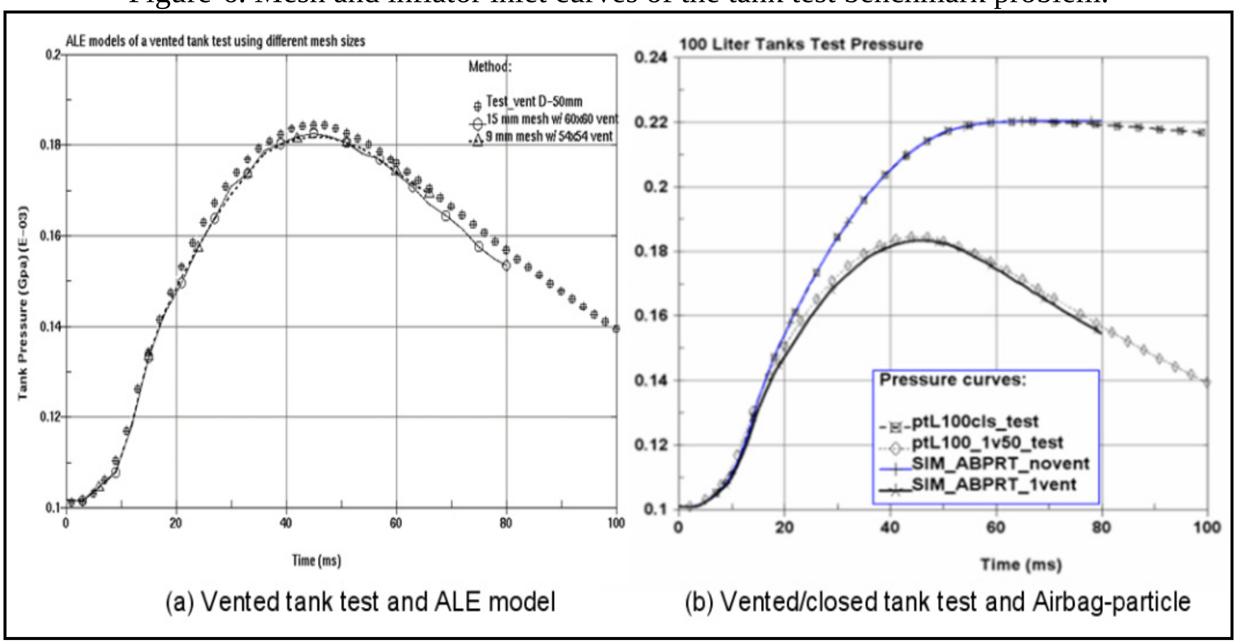


Figure-7. Model correlations for the tank test benchmark problem.

Benchmark IV- Driver Side Airbag OOP Pendulum

The airbag pendulum OOP benchmark problem was chosen to examine the accuracy of the gas-airbag interaction under OOP conditions. This problem was studied using general ALE capabilities and a gas mixture model in reference [2] and using AIRBAG_ALE in reference [1, 3]. In this study, the original folded AIRBAG_ALE model with an OOP pendulum in reference [3] was used. Only the AIRBAG_ALE keyword command was changed to AIRBAG_PARTICLE. Only few modifications were necessary. All the inflator gas properties, orifice directions and areas, the mass flow rate, and gas temperature were maintained directly from AIRBAG_ALE. Figure-8 shows the model set up.

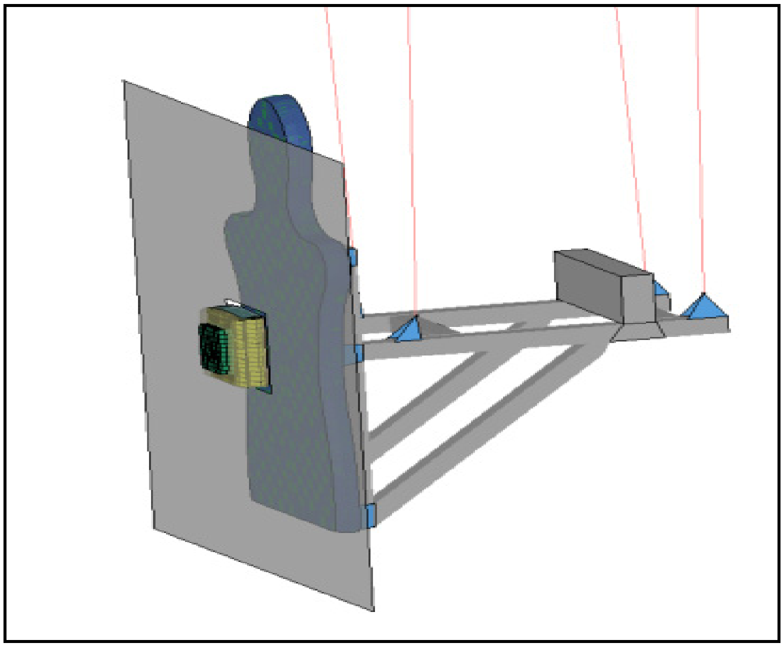


Figure-8. Driver side airbag pendulum OOP set-up.

The default number of particles (NP=200,000) were kept and the time scale factor was set to 0.8. For an event time of 50ms, the AIRBAG_PARTICLE model ran for 4.5 hours on an XP workstation (1 CPU) while the AIRBAG_ALE model with mesh size 15mm needed 10.5 hours. Figure-9 is a comparison of the acceleration from simulation vs. three tests.

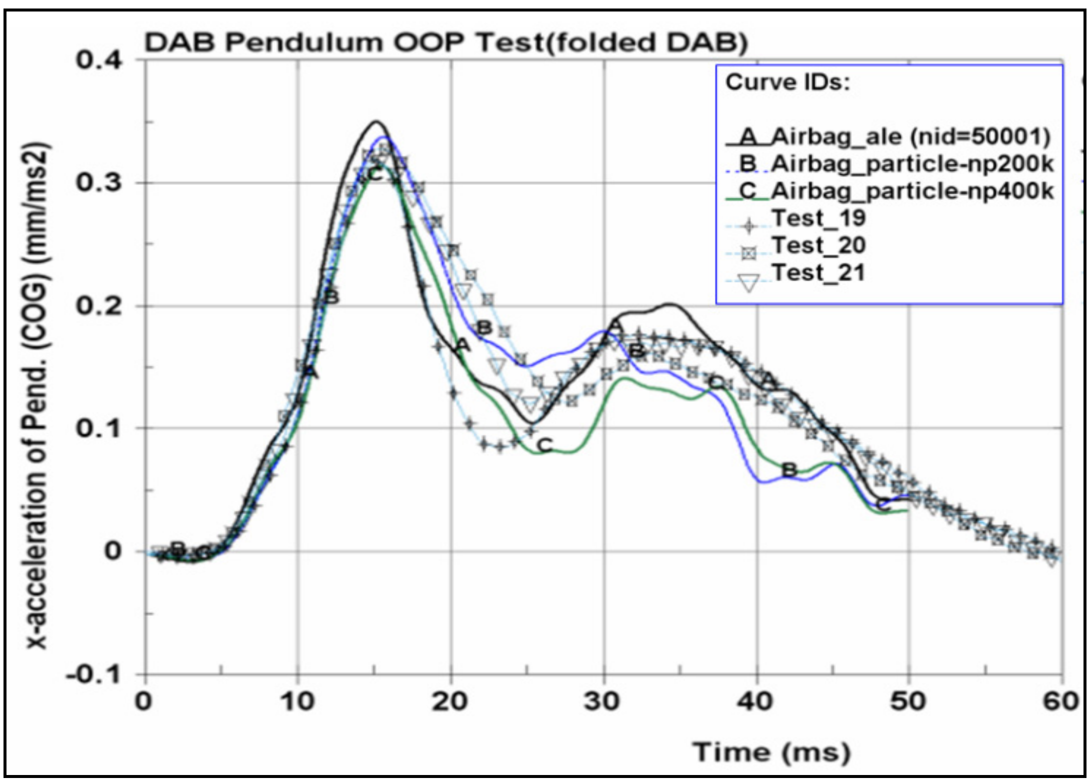


Figure-9 Pendulum acceleration correlations

Figure-10 shows a comparison of bag pressure and leakage of obtained with AIRBAG_ALE and AIRBAG_PARTICLE (NP=200,000 and NP=400,000).

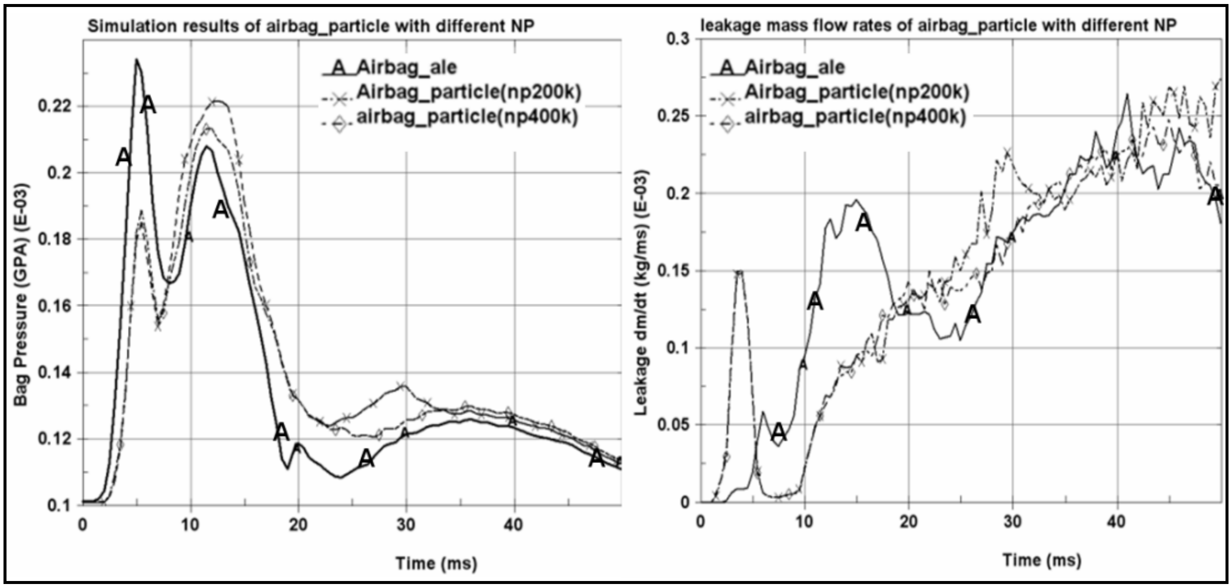


Figure 10. Comparisons of airbag pressure and leakage mass flow rates

Comparing the pendulum acceleration obtained with the two methods, it was found that AIRBAG_PARTICLE was better than AIRBAG_ALE at predicting the first peak (time=0.20 ms). However, with NP=200,000, the pendulum acceleration curve profile of was not as good as the one obtained with AIRBAG_ALE. By increasing the number of particles to NP=400,000, better correlations for the pendulum acceleration were obtained and the bag pressure and leakage mass flow rate were much closer to those of the AIRBAG_ALE model.

Benchmark V- Driver Side Airbag 5th% Dummy OOP

The application studied here, shown in Figure-11, was a 5th% Hybrid III dummy under a driver side (chest on module position) an ISO standard OOP condition. The airbag and inflator were the same as the one used in the pendulum OOP study. Just as in the pendulum OOP example, the original AIRBAG_ALE model used in reference [3] was converted to an AIRBAG_PARTICLE model by substituting a few lines in the inflator definition. The definitions of gas properties, mass flow rate, temperature, and inlet jets definitions (jet directions and areas) were retained from the AIRBAG_ALE model. Figure-11 shows the model set-up and deformed shapes at time=36ms.

Figure-12 shows the comparisons of the simulation results of the two methods. A 60ms run of the AIRBAG_PARTICLE model ran for 18 hours on an XP workstation, while the AIRBAG_ALE model needed 28 hours on a single CPU XP workstation.

Overall, the results obtained with AIRBAG_PARTICLE were very comparable to those of the AIRBAG_ALE method. Both methods are capable of simulating airbag deployment under OOP conditions. With the same venting and inflator parameters, the airbag in AIRBAG_PARTICLE simulations seem softer than when using AIRBAG_ALE, especially in the presence of venting leakage.

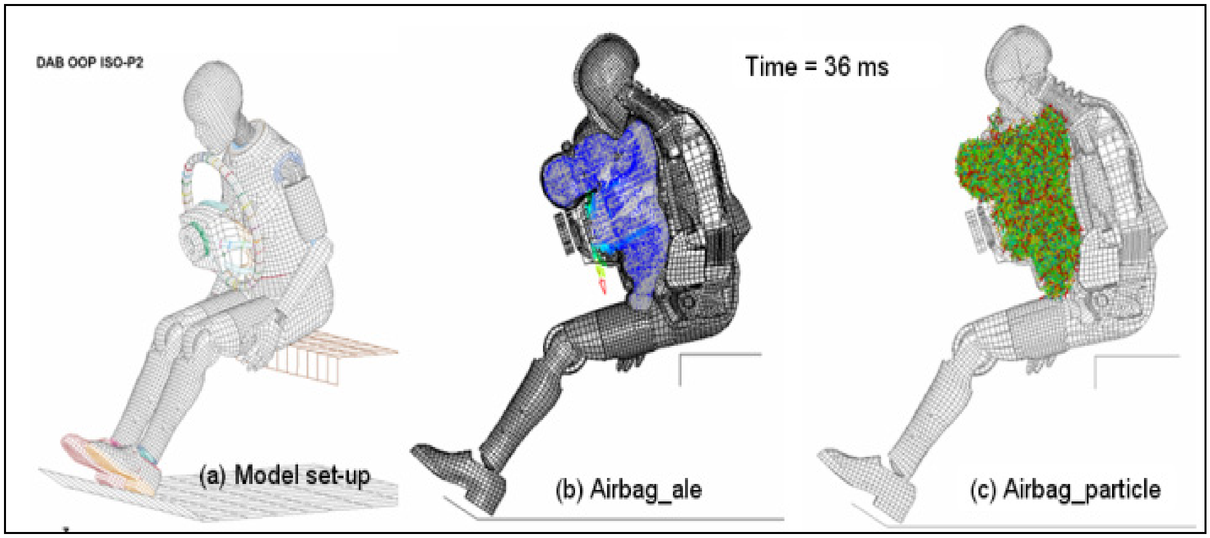
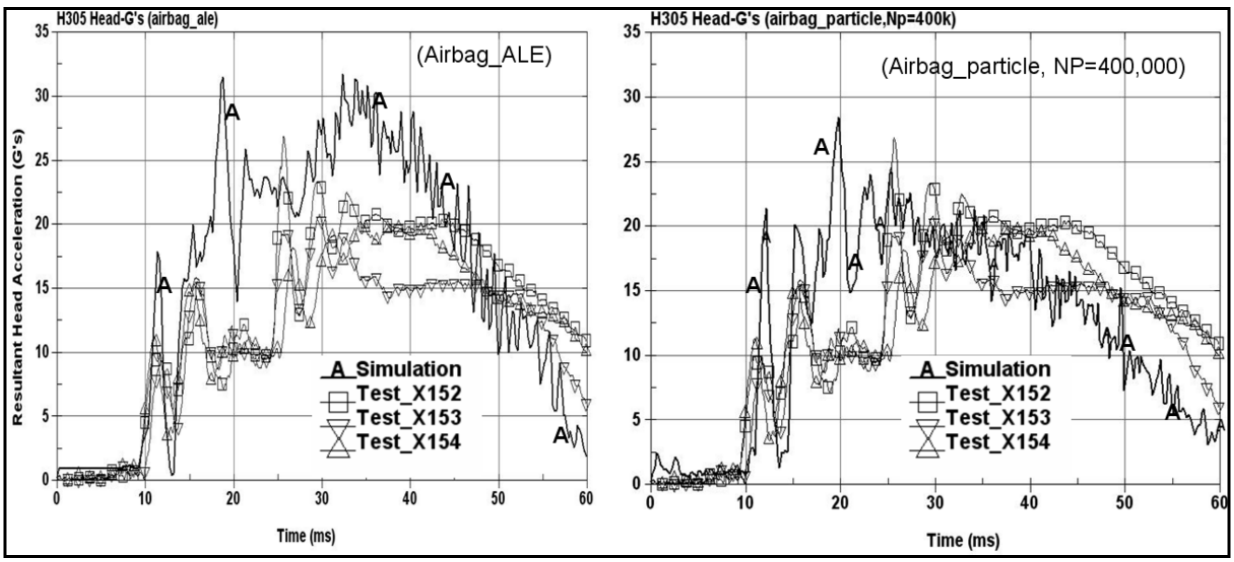
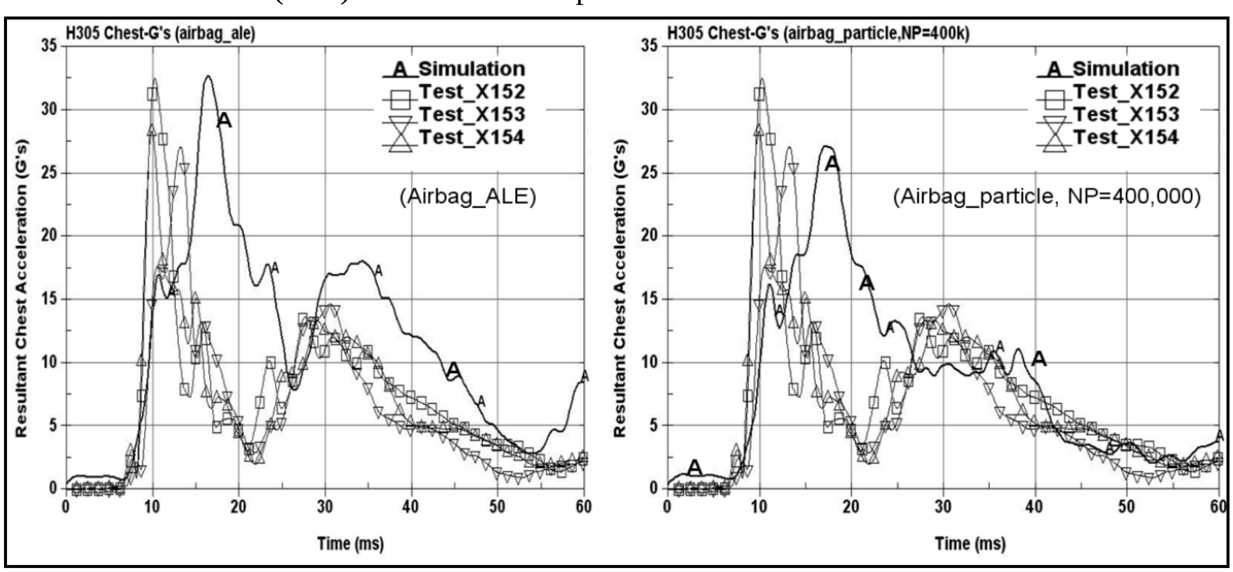


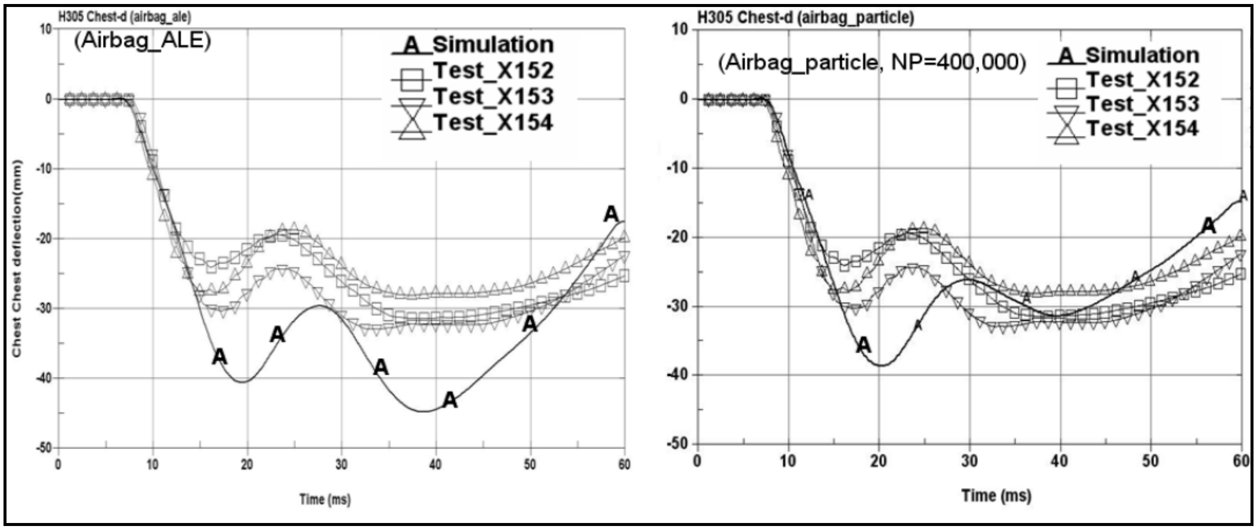
Figure 11. H305 dummy OOP model set-up and deformed shape at t=36 ms.



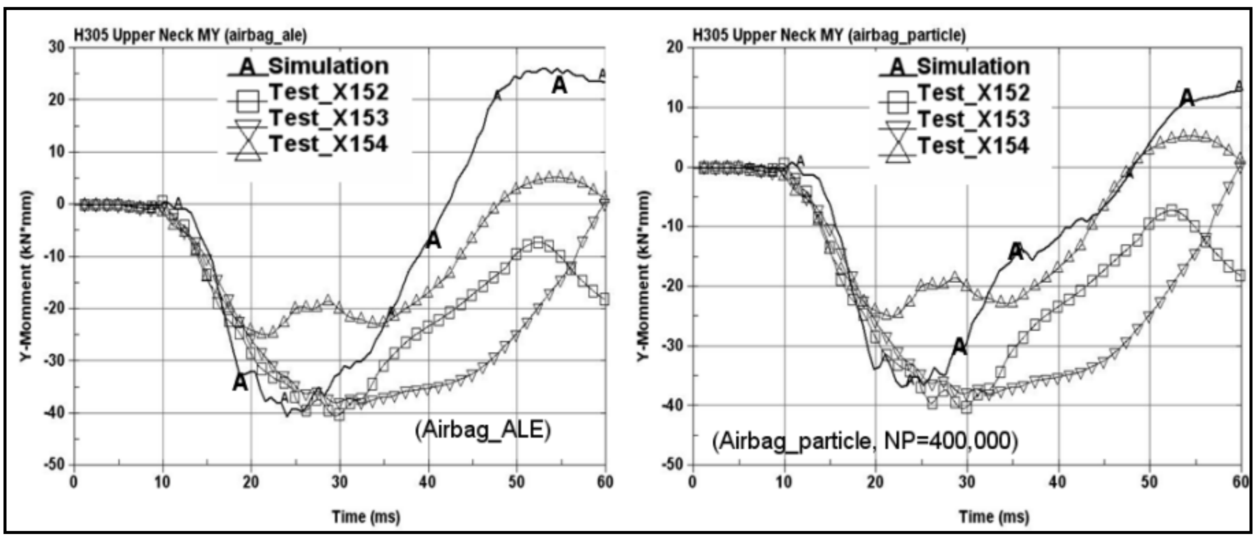
(12-a). Correlation comparisons of head accelerations



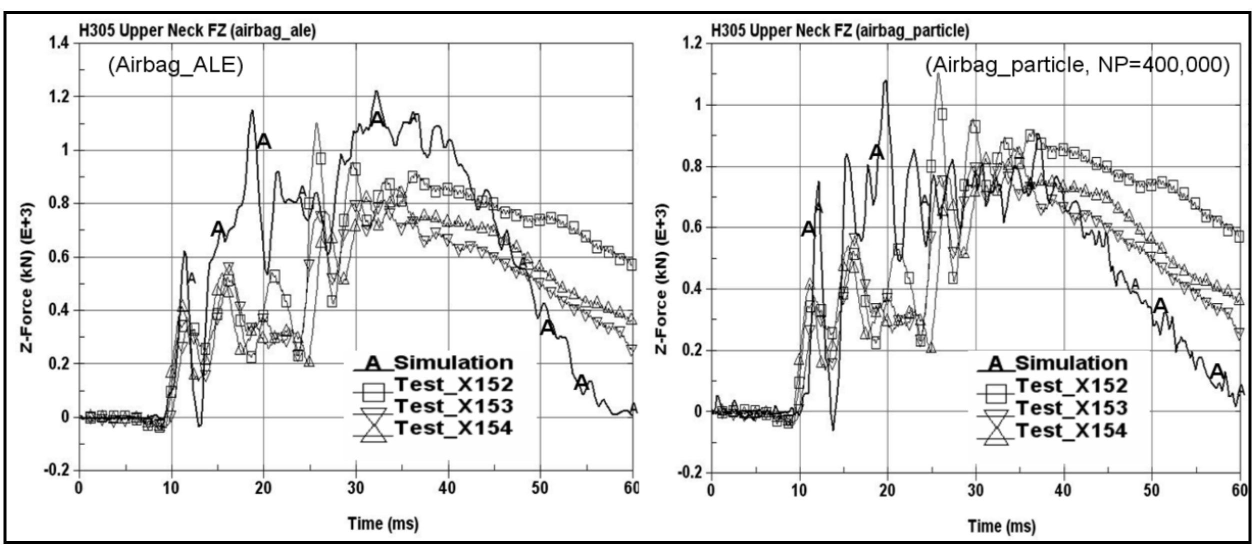
(12-b). Correlation comparisons of chest accelerations



(12-c). Correlation comparisons of chest deflections



(12-d). Correlation comparisons of upper-neck y-momentums



(12-e). Correlation comparisons of upper-neck Z-forces

Figure-12. Simulation result comparisons of airbag_ale and airbag_particle methods.

Discussion on Simulation Results and Summary

Findings and conclusions from this benchmark study:

- From the shock-tube problem, it was noticed the time step size may be a critical factor in narrow pipe-shaped flow domains. The average particle velocity times Δt should be much smaller than the characteristic size of the gas container. In the shock tube problem the characteristic size is 30mm. The root mean square velocity of the particles is roughly 500m/s at 300K. Hence, a time step size around 1μs should be OK.
- The number of particles will affect the accuracy of the simulations. The fewer number of particles, the nosier results are to be expected. From the shock tube results, it was found that AIRBAG_PARTICE is more dissipative than the AIRBAG_ALE method.
- The current AIRBAG_PARTICLE method simulates tank tests very well. Here AIRBAG_ALE is somewhat limited due to the inability to mix initial gas in the tank. *airbag_advanced_ale does have provision for considering initial air in the tank, but this option was not used in this study.
- From pendulum OOP and drive side airbag OOP examples, we found that the venting flow of the AIRBAG_PARTICLE model is slightly higher than what one obtains with AIRBAG_ALE.
- In general, AIRBAG_PARTICLE uses less CPU time than AIRBAG_ALE.
- AIRBAG_PARTICLE does not have any difficulties to interact with tethers inside an airbag. This often causes problems in AIRBAG_ALE models.
- Both AIRBAG_PARTICLE and AIRBAG_ALE models have similar input deck cards. Two models can easily be translated from one to the other.
- AIRBAG_PARTICLE and AIRBAG_ALE produced similar results in the tested benchmark problems. Overall, both methods were very comparable in all the benchmark problems.
- AIRBAG_PARTICLE models may encounter accuracy problems in vented airbag models in the later stage of the simulations due to fewer numbers of particles remaining inside the bag.

Acknowledgement

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References

1. Wenyu Lian, Lars Olovsson, Dilip Bhalsod “DEVELOPMENT OF CFD CAPABILITY FOR AIRBAG OUT-OF-POSITION APPLICATIONS”, Proceedings of HT-FED2004-56044, 2004 ASME Heat Transfer/Fluid Engineering Summer Conference, July 11-15, 2004, Charlotte, NC, USA.
2. Wenyu Lian, “Development of Benchmark Set for OOP Simulation Capability,” SAE paper No. 2004-01-1628, SAE World Congress, Detroit, March 8-11, 2004.
3. Wenyu Lian, Dilip Bhalsod,” Study of a Driver Airbag Out-Of-Position Using ALE Coupling”, 8th International LS-DYNA Users Conference, May 3rd-5th, 2004, Dearborn, MI, USA.
4. Lars Olovsson,”Corpuscular Method for Airbag Deployment Simulations in LS-DYNA”, ISBN 978-82-997587-0-3, May, 2007.
5. James, E. A. John, “Gas Dynamics”, second edition, Allyn and Bacon, Inc., 1984.