Consideration of Shock Waves in Airbag Deployment Simulations

Doris Rieger
BMW Group

ABSTRACT

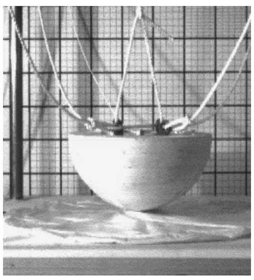
When the inflation process of a simple flat airbag was simulated with the MADYMO gas flow module, the resulting bag oscillation frequency was observed to be too high in comparison to hardware tests. When the damping force of the surrounding quiescent air was included in the simulation, the observed oscillation frequency of the bag was found to correlate better with hardware tests. The investigation was taken further by positioning a pendulum above the flat airbag. One would expect good correlation of the bag oscillation behaviour between test and 'quiescent-air-simulation' to continue, however this was not found to be the case. In order to understand and quantify the relevant physical effect of the discrepancy in bag-oscillation-correlation, the shock waves that hit the pendulum and bounce back towards the bag must be taken into account. Software requirements for an accurate simulation were investigated by comparing numerical results with simplified models from literature.

Important results of the study include:

- shock waves and their reflections can be described well with the MADYMO gas flow code.
- the amount of energy dissipated by shock waves is small.
- the effect of shock wave reflections off a spherical impact body (e.g. pendulum) causes a significant pressure increase inside the airbag chamber.

INTRODUCTION

A configuration suitable for basic investigations with the MADYMO gas flow module is an unfolded driver airbag with a pendulum positioned as shown beside. (details described in [4]). After the inflator is triggered the airbag expands due to the inflowing gas, forcing the pendulum upwards. The measured acceleration of the sphere is drawn with the solid black line in Figure 1.



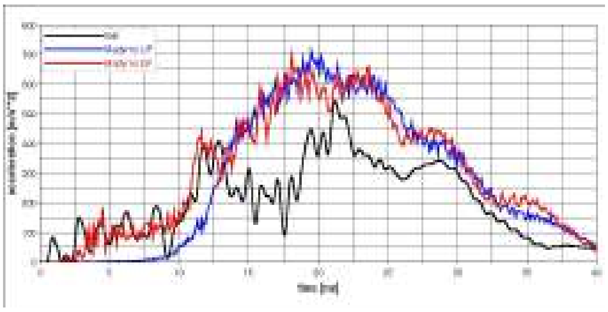


Figure 1: Uniform pressure and gas flow calculations of a flat driver bag in contrast with measurements: acceleration of an impact sphere.

Results of MADYMO uniform-pressure and MADYMO gas-flow simulations are also plotted in Figure 1. While the phase of acceleration during the first 12 ms is well described by the gas flow module, correlation thereafter is poor. This region of poor correlation is characterized by bag oscillations between plate and pendulum.

Basic simulations with only a flat bag positioned in an additional gas flow region (representing the surrounding environment) showed that the damping effect of the ambient air had a significant influence on the bag oscillation behaviour. With this result one would expect that in the configuration of a flat bag with a pendulum positioned above, the movement of the bag between the plate and sphere should also be described correctly when damping of the environment is taken into account. However, with a second CFD grid in the outer region around the airbag, the high frequencies in the pendulum acceleration merely became smooth and three low frequency oscillations observed in the test (see Figure 1) could not be predicted in the simulation. The global maximum in the acceleration curve was also still too high.

An aim of the investigation was to analyse the surrounding environment in detail and determine if shock waves (possibly not taken into account by the software) could be responsible for the poor test correlation. When an airbag moves impulsively, shock waves are generated in the quiescent surrounding and travel upwards. They are reflected off the pendulum back to the airbag. This reflection process repeats, each time under new thermo-fluid-dynamical conditions.

In the following section, firstly results of an analytical evaluation of the energy loss due to shock wave generation are given. Simplified ramp models are then investigated to find out the capability of shock wave reflection calculations with the MADYMO gas flow module. Indeed, there is a publication on shock wave reflections in a tube simulated with AUTODYN (Century Dynamics)[2]. AUTODYN is the software from which the MADYMO gas flow module originates. However, because of the loss of full boundary functionality in the application for airbag simulations (see [2] for more details), it is necessary to test the performance of the gas flow module in situations where shocks appear. To this end, a ramp model (well described in reference [1]) is used to investigate the behaviour of the MADYMO model. Finally, shock wave reflection and resulting pressure distribution at the spherical impact body are shown.

MAIN SECTION

ENERGY LOSS DUE TO SHOCK WAVE GENERATION

The following considerations are based on an isolated airbag, flat or folded, without an impact body. From test video the velocity of the airbag fabric was visually extracted and the induced shock Mach number calculated based on a piston model (see Figure 2, details in reference [1]). In this simplification, the fabric is treated as a piston moving a tube with constant velocity, generating a shock wave which travels into the quiescent medium air.

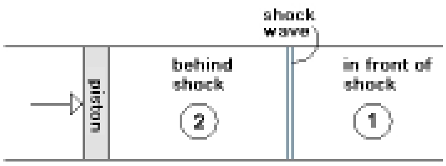


Figure 2: piston model.

Further assumptions made are a constant heat capacity (in spite of a temperature jump across the shock wave) and slip conditions at the tube walls. The calculated Mach numbers are slightly above one: 1.07 for a flat bag and 1.11 for a Leporello folded bag ([5]). This confirms the conjecture that shock waves are generated. The enthalpy difference between the regions in front of and behind the shock wave is very small, namely less than 2.5 % of supported inflator enthalpy in both airbag configurations. Thus, the obvious conclusion is that the influence of a shock wave travelling away from the bag is negligible. The effect of a shock wave reflected off an impact body is given in the following subsection.

RAMP REFLECTION

Shock wave reflections at ramps with two different angles are investigated first in order to compare simulation results with reflection patterns described in literature. Grid resolution and orientation are then changed.

Simulations are all carried out within a tube where a piston with a constant velocity of 100 m/s generated a shock wave in the initially quiescent fluid Argon. This velocity corresponds to the movement of the fabric layers of a folded airbag installed in an I-Panel. The inert Argon gas ~~is~~ was chosen instead of air because its specific heat capacity can be treated as a constant.

Principal patterns

Two primary reflection patterns dependent on ramp slope are described in reference [1]. The aim is to find a good correlation between simulation and theory for “Single Mach Reflection” (SMR) at small angle of gradients and “Regular Reflection” (RR) at steep ramps.

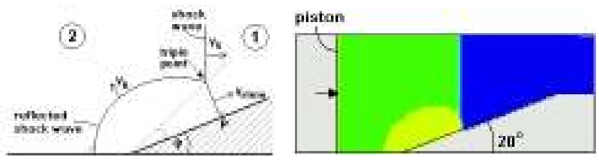


Figure 3: Single Mach Reflection (SMR) at small angle of gradients in theory (left) and pressure distribution created with MADYMO gas flow simulation (right).

SMR (see Figure 3, left) is characterized by a curved shock front. A Mach stem is built that moves up the ramp at higher speed than the undisturbed shock. The length of the stem grows linearly with time and respectively with the distance from the corner, so the triple point that connects front, stem and reflected wave moves along a straight line. The pressure plot on the right side (Figure 3) shows the characteristic details of a SMR pattern.

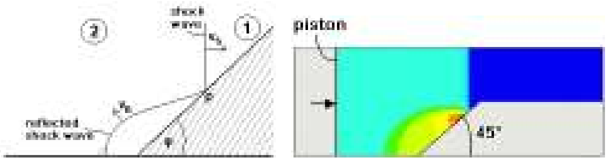


Figure 4: Regular reflection pattern at steep ramps – in theory (left) and pressure plot with MADYMO gas flow data (right).

In the RR pattern described in the literature there is no stem. The connection point between shock front and reflected wave lies on the ramp (see Figure 4, point P).

The transition from SMR to RR depends on the velocity behind the shock: it occurs, when the Mach number in region (2) (see Figure 3 and Figure 4) becomes equal to 1, calculated in a coordinate system relating to point P. In the investigated channel with a piston velocity of 100 m/s the transition is expected for a ramp angle greater than 27 degrees. In principle both flow patterns are depicted at ramps with 20 and 45 degrees in MADYMO simulations. A detailed view on the wave shapes is given in the following subsection.

<u>Grid variation</u>

In the simulations the RR pattern differs from the shape described in literature. Depending on grid resolution used there is a stem which decreases in length as grid resolution is made finer. The significant difference is that the SMR pattern has constant length as the shock moves up the ramp (see Figure 5).

The number of cells is varied only in the vertical (y) direction. The simulations are performed quasi-two-dimensionally with two cells in the z-direction.

Direction	x	y			z
Cell numbers	300	50	100	150	2
Cell size (mm)	1.76	4.08	2.02	1.34	200

Table 1: Variation of cell edge lengths.

Cell numbers and sizes are the same in the 20 degree ramp model, where the SMR pattern can clearly be seen in Figure 6. The triple points move along the straight lines.

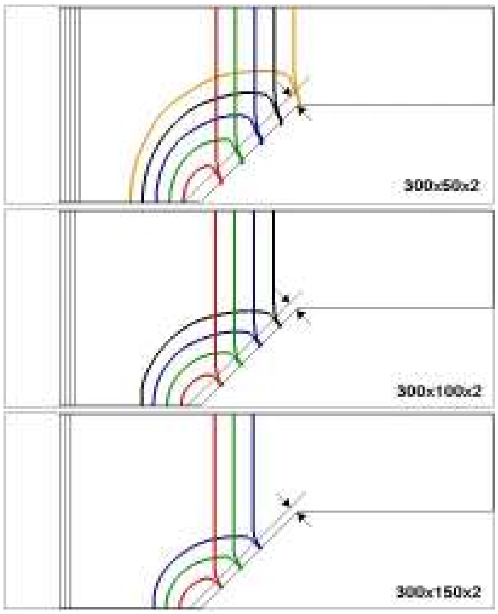


Figure 5: 45 degree ramp: shock contours in the course of time (red: 55 µs, green: 60 µs, blue: 65 µs, black: 70 µs) calculated with different cell numbers.

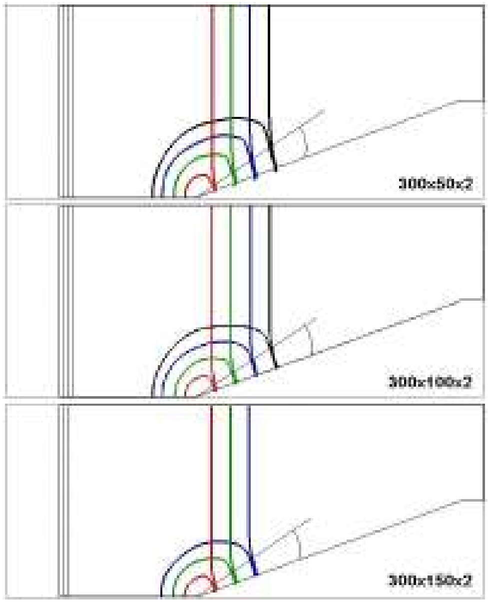


Figure 6: 20 degree ramp: shock contours in the course of time (red: 55 µs, green: 60 µs, blue: 65 µs, black: 70 µs) calculated with different cell numbers.

A comparison of pressure contour lines at one point in time gives information about the influence of grid size on the shape of the reflected shock wave (see Figure 7): the difference between coarse and fine grids is bigger for the 45 degree ramp.

A comparison of the numerically calculated velocity of the plain shock with the analytical value gives a deviation of 1.3 %, which is considered acceptable for airbag simulations.

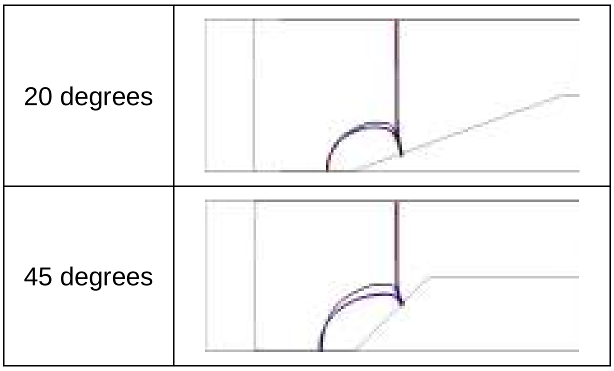


Figure 7: shock pattern at t=65 ms (black: 300x50x2, blue: 300x100x2, red: 300x150x2)

In an airbag simulation the bag material crosses the CFD grid cells at an infinite number of angles and does not move only parallel to the grid lines as treated in the previous simulations with a forced constant piston velocity in x-direction. To investigate the effect of this on results, the grids are rotated in such a way that the x- and y-directions are oriented parallel and perpendicular to the ramp.

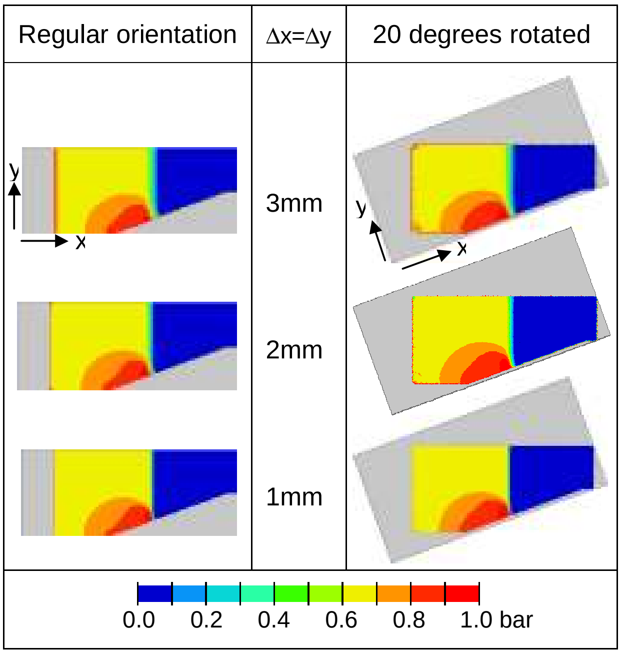


Figure 8: Effect of grid orientation on pressure distribution in the 20 degree ramp model.

It was found that the 20 degree ramp results for both grids are in good agreement (see Figure 8). This is not the case for the steeper ramp (see Figure 9) where the pressure level behind the shock front is 0.1 bar higher than with the regular grid. Obviously 45 degrees is the most critical angle, but this effect must be kept in mind when complicated geometries are investigated.

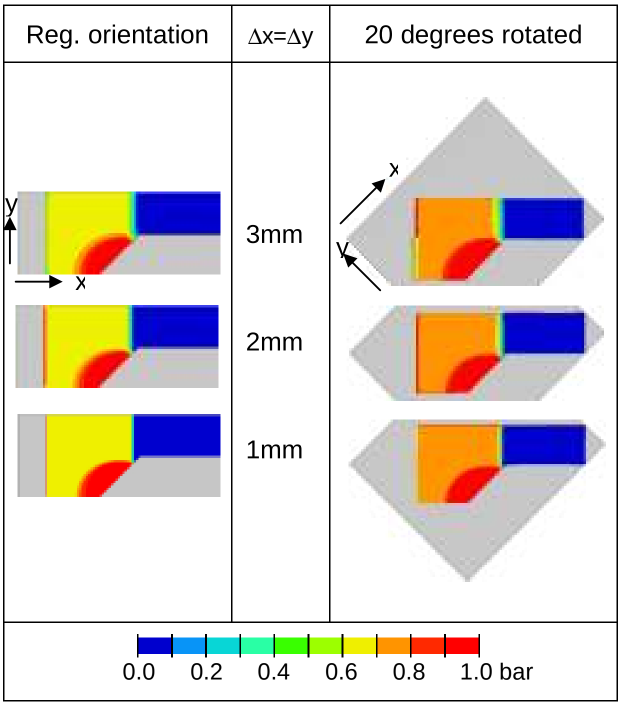


Figure 9: Effect of grid orientation on pressure distribution in the 45 degree ramp model.

PENDULUM REFLECTION

Here, the reflecting body in the piston model is replaced with a half sphere to represent reflected shock waves in the flat bag configuration with pendulum. The piston simplifies the airbag membrane elements and moves again with a constant velocity of 100 m/s.

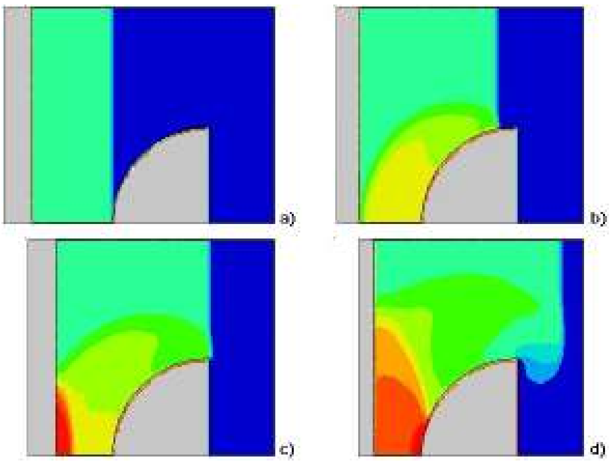
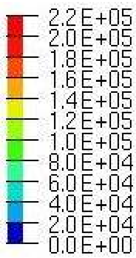


Figure 10: Shock wave reflections at a half sphere: a) planar front reaches sphere, b) reflected wave hits piston, c) reflection at the piston and interaction with the initial reflected wave, d) second sphere reflection and planar front behind the sphere.

The pressure levels (according to the simulation results in Figure 10) are shown in the legend beside. With a maximum of more than 2 bars it is apparent that that the effect of shock reflections cannot be neglected. In Figure 10 four snapshots are depicted: a) the planar front arrives at the spherical body, b) the reflected wave moves upstream and approaches the piston, c) total reflection at the piston leads to a superposition of upstream and downstream waves, the planar front reaches the edge of the half sphere, d) a second reflection occurs at the sphere.



CONCLUSION

The shock wave simulation results gave a good correlation with the reflection patterns described in literature when the grid resolution was fine enough. In the extreme case of a grid rotated at 45 degrees a higher pressure level was left behind the shock. Therefore, care must be taken in a quantitative evaluation with complex geometries where shock waves move in that direction through CFD cells.

The results presented also demonstrated the need to take the reflection of shock waves into account in basic experiments. It is anticipated that the motion of a flat airbag being inflated into a pendulum would be more severely affected by the reflecting shock than for a folded airbag. The extent to which the shock wave reflections have an effect on the oscillation frequency must be investigated with further simulations. This is planned with the next MADYMO version, where improved outflow boundary conditions are implemented. With current software the CFD grid region around the airbag has to be very large to avoid shock waves reaching the computational boundaries and causing error. Because of the fine grid resolution needed this cannot be achieved at present with acceptable calculation costs.

ACKNOWLEDGMENTS

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REFERENCES

1. Emanuel, G., ”Gasdynamics: Theory and Application”, AIAA Education Series, 1986
2. Happee, R., Rekveldt, M., Schoenmakers, F., “Advanced Airbag Modelling for Side Airbags and OOP using MADYMO”, VDI, 2003
3. MADYMO V6.2 Manuals, TNO MADYMO BV, Delft, The Netherlands, June 2004
4. Rieger, D., “A Benchmark Study of the Gas Flow Module”, 9th International MADYMO User Conference, Como, Italy, October 2002
5. Rieger, D., “Capability of Simplified Folded Airbag Models in Gasflow Simulations”, 9th European MADYMO User Conference, Brussels, Belgium, October 2003