A Benchmark Study of the Gas Flow Module

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Abstract

Simple gas flow configurations have been examined to understand and visualize its dynamics.

The main objectives are to get a grip on the required accuracy for specifying boundary conditions in gas flow calculations and to describe local effects numerically, for example pressure waves which were measured in tests. Both, the occurred difficulties and the results will be presented.

To achieve those goals, it is first required to separate the otherwise superimposed effects like time and temperature dependent properties such as inflowing gas, vent hole and folding. This has been done by analysing a tank test model and a flat driver bag respectively. Finally a folded driver side airbag is simulated.

Motivation and Strategy

Forced by the FMVSS 208 duties, a more detailed description of the airbag unfolding process has become indispensable. A comparison between the Madymo uniform pressure model and the gas flow module calculation (version 6.0) of a flat driver bag, pushing away a spherical impact body, shows basic differences in the acceleration of the sphere, especially in the first 12 milliseconds. Figure 1 exposes the deviation of simulation results from measurements.

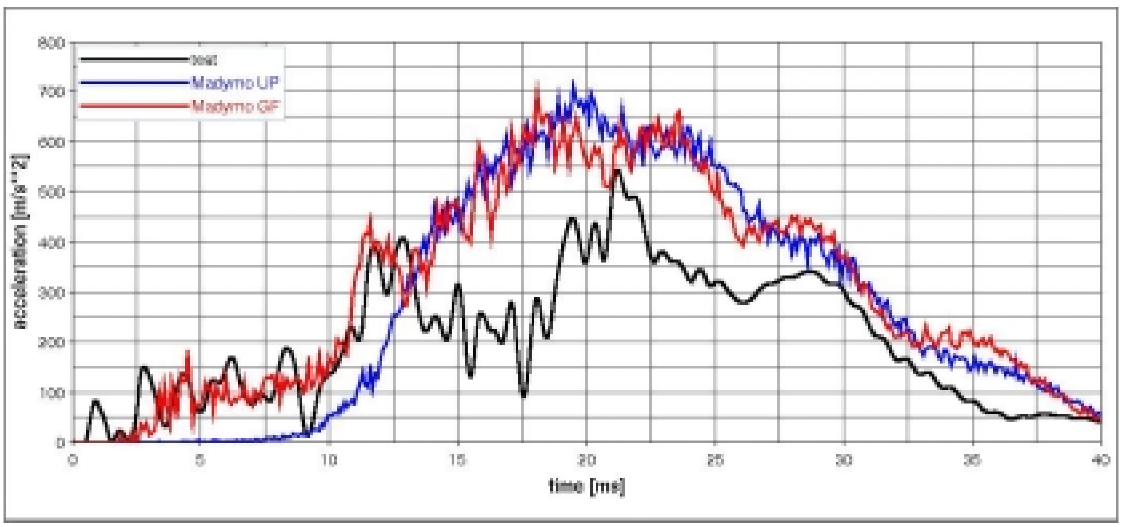
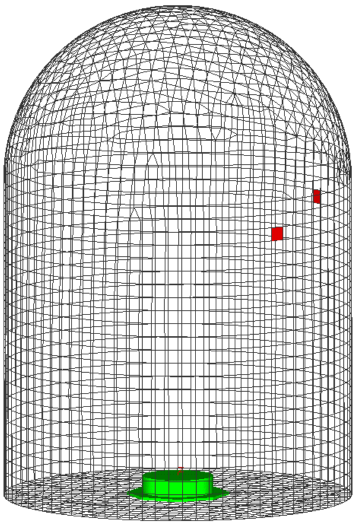


Figure 1: Uniform pressure and gas flow calculations of a flat driver bag in contrast with measurements: acceleration of an impact sphere

Some basic investigations have been started to find out, how to describe the fluid dynamics correctly by using the Madymo gas flow module. This requires the comprehension of several phenomena in the airbag inflating process. In order to separate the effects due to the volume variability, the folding, the fabric property, etc. the tank test has been simulated first.

Tank Test

In real tests, the inflator is located in the tank as shown in Figure 2a. The two red elements mark the position of the redundant pressure sensors. For simplification and to reduce the computational costs, only the pure tank skin is regarded. The gas flow into the tank volume is modelled by defining several inflators directly in the Madymo input file. Each of them represents one opening of the inflator housing (red arrows in Figure 2b).



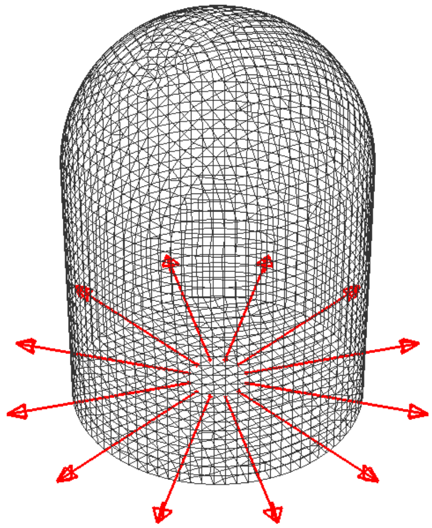


Figure 2: a) Inflator positon in the tank test b) Tank model

In order to define the sensitivity of gas flow calculations towards inflator input data, two possible combinations of mass flow, temperature and gas mixture are used in this study. The simplest and most common technique is the evaluation of tank pressure measurements with the Average Temperature Method (ATM). This algorithm for mass flow calculation requires the output gas composition to be given (normally constant over time) and assumes a constant gas temperature at the inflator exits. The second kind of input data was ascertained by analysing a complete inflator combustion simulation. This implies, temperature and gas composition are also time varying variables. The results of both simulations are shown in Figure 3.

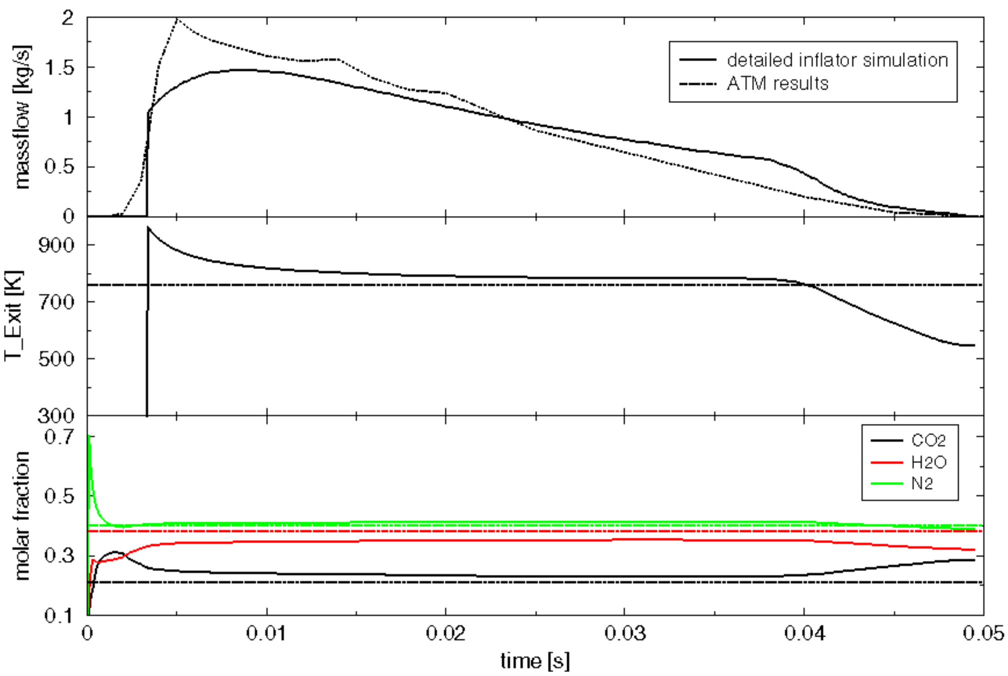


Figure 3: Two kinds of inflator input data

Over a wide range, the molar fraction and the temperature curve shapes are nearly constant and the ATM assumption seems to be justified. However, in the beginning the mass flow rate becomes overestimated, at the end it is underestimated. These are the time ranges where the computed tank pressure curves differ. Figure 4 shows the measurements compared with the results in one specific euler cell, which is located at the same height as the pressure sensors in the tests. In the first 15 milliseconds (on condition of a fine enough grid resolution), the pressure waves are exactly described with the completely time dependent input data. It might be a benefit to use detailed input data for further calculations, particularly with regard to out of position simulations, where the first few milliseconds are very important.

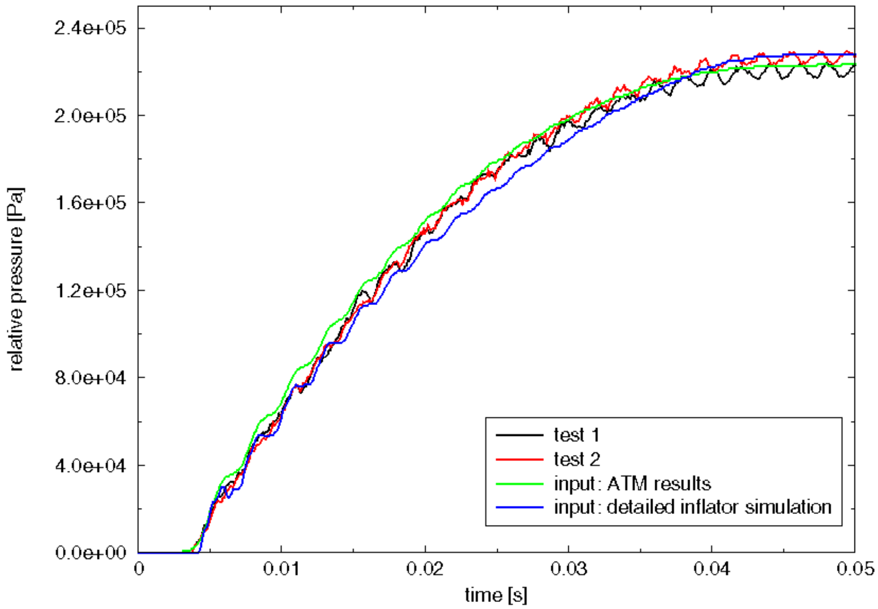


Figure 4: test and simulation results

Flat driver airbag

For more understanding, the influence of the following effects is investigated with the flat driver airbag model:

1. Does the completely time dependent input data also lead to different results, when applied to a more complex model and compared to the ATM input data?
2. How does the grid resolution influence the velocity field distribution?
3. Are there differences between calculations over one and two CPUs?

Like in the previous section the numerical model is based on a test configuration.

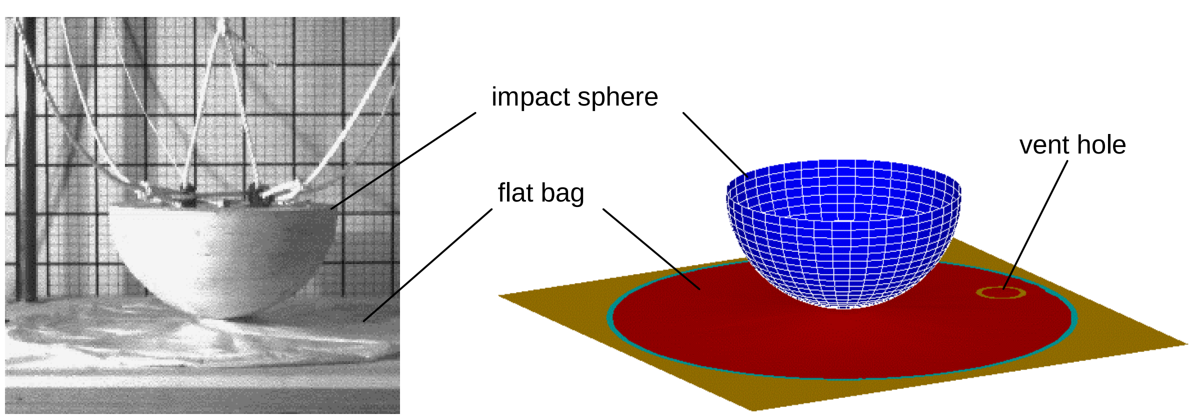


Figure 5: a) Test configuration **b) Model**

The following numerical results are investigated by an initial impact sphere position of 100 mm above the bag surface. During the first 6 ms no contact between bag and sphere takes place.

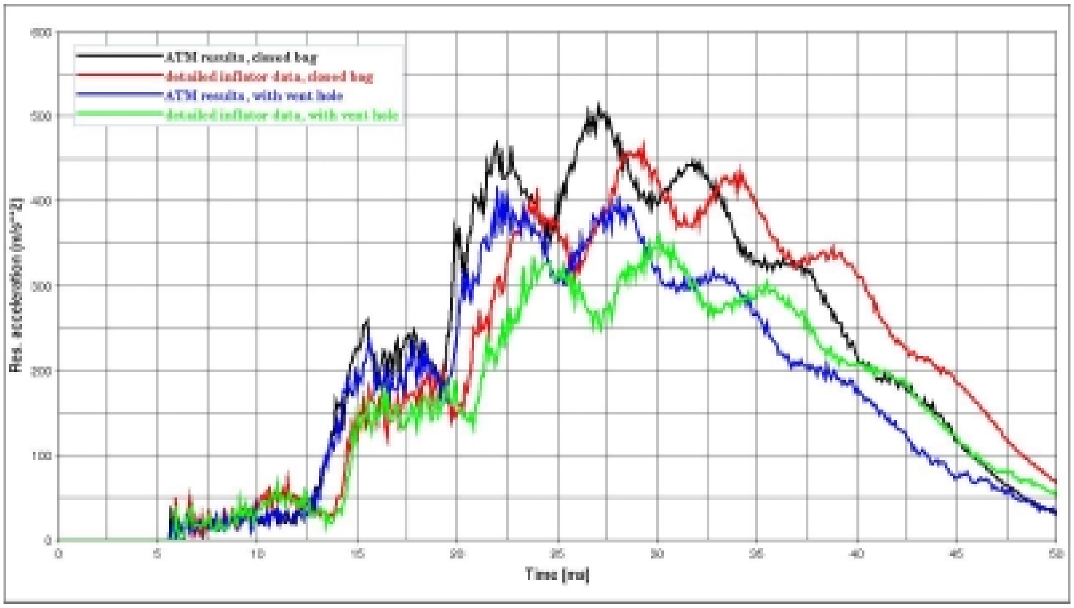


Figure 6: Resulting impact accelerations of simulations with two kinds of input data for a vented and a closed bag (grid 40x40x20)

Even with an initial impact sphere position of 100 mm, there are differences between the resulting accelerations, computed with the two kinds of input data. The ATM results lead to a higher maximum value a few milliseconds earlier.

A comparison with test measurements show, that at this moment the process cannot be described correctly with the detailed input data either. Figure 7 shows a different increase of acceleration over the first 15 ms and a dissimilar oscillation frequency after 25 ms.

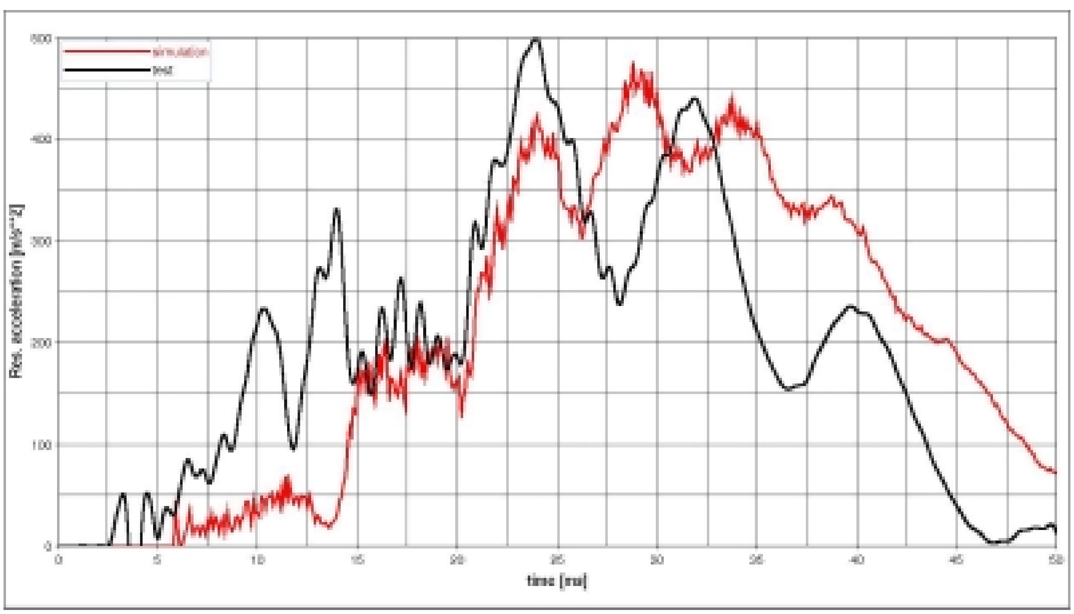


Figure 7: Comparison of test and simulation data (closed bag model with detailed inflator data)

To answer the question about the needed grid accuracy and the validity of the results different euler mesh resolutions were tested (Table 1). It was expected that the maximum gas flow velocity will converge to the speed of sound (for given gas composition and temperature, approx. 620 m/s).

Instead, an increase of the maximum velocity occurs in the vicinity of the inflator openings together with the number of initialised cells. This effect has to be investigated more precisely in the future.

Grid definition	Used cells (initialisation)	Total CPU time (rounded)	Maximum Velocity	
			Red. Inflator hole diam	Regular diameter
20x20x10	957	1.5 h (50 ms)	289.0	287.0
40x40x20	5835	4.5 h (50 ms)	617.0	609.0
60x60x30	17637	10.5 h (20 ms)	730.0	720.0
80x80x40	39584	32.5 h (20 ms)	846.0	818.0
100x100x50	74748	46.3 h (6 ms)	-	907.0

Table 1: Interdependence of grid resolution and the maximum speed in the gas flow region

Not only the criterion maximum speed in the flow region indicates a correct solution to the problem. Table 2 shows the speed in the active cells for four time points in the y-z-slice through the evaluation region. The air bag shapes differ obviously.

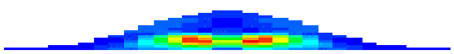
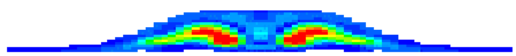
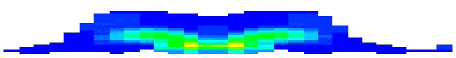
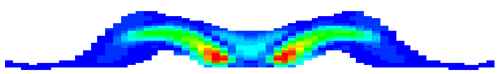
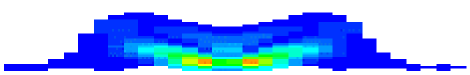
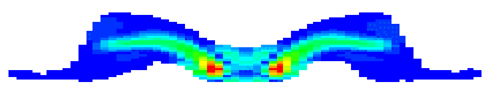
Time	Grid 40x40x20	Grid 80x80x40
3 ms		
4 ms		
5ms		
6 ms		

Table 2: Speed in the range 0 – 600 m/s

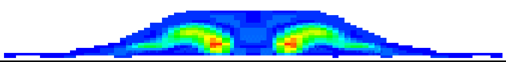
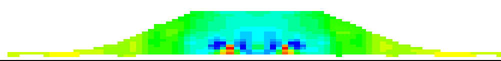
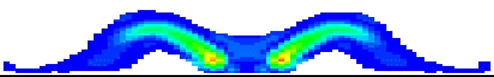
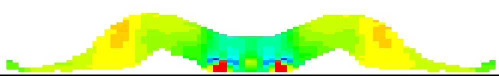
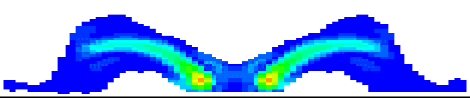
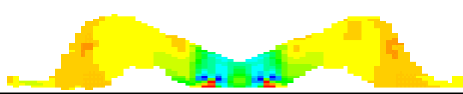
Time	Speed (0-900 m/s)	Pressure (0.5e5 – 1.2e5 Pa)
3 ms		
4 ms		
5 ms		
6 ms		

Table 3: Speed and pressure (grid 100x100x50)

To reduce computation time, a calculation over two CPUs is tested. Figure 8 shows, that the difference in the resulting impact sphere accelerations between one CPU and two CPUs is higher than the noise of the x- and y-acceleration components individually.

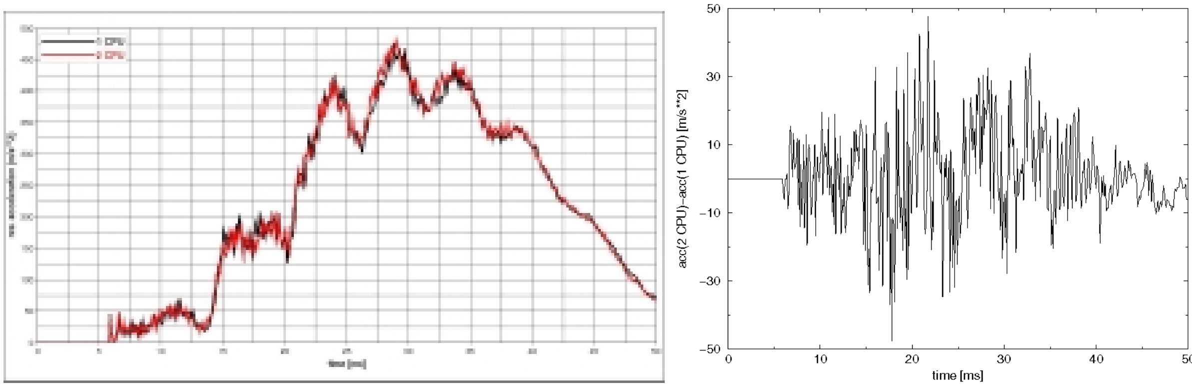


Figure 8: a) resulting acceleration with 1 and 2 CPU **b) differences of the accelerations**

Unfolding of a driver airbag

The unfolding of a driver airbag works well for a pure bag without any components like inflator housing or sheets for gas deviation. With a modified mesh, that contains the inflator housing outline, tangling of several nodes occurred. Some efforts will be necessary to improve the model.

Figure 9: Folded bag without any components and with inflator housing outline. The flow direction at the points of inflator definition is marked by the red lines.

Summary and Consideration

The simulations of the tank test model have proved, that the detailed inflator data give more accurate results than the ATM data. This is also found in the more complex airbag model.

To depict the inflation process correctly, it is important to take care of the euler grid resolution. With respect to the flat bag a perfect grid is not found yet.

If the multi CPU option is used to reduce the computation time, one has to take in consideration, that the results will not be identical.

With the standard release 6.0.1 it is not possible to store additional gas flow data in the Madymo output files. A special executable supplied by TNO allows to save not only pressure and temperature but also gas velocity, mass and density in each euler cell. Post processing with regard to the gas dynamics (for example the creation of vector plots in intersection planes) has to be done with MAPPK after preparing the files with scripts.

Finally I’d like to thank Mr. Andreas Hirth (DaimlerChrysler) for the collaboration and the assignment of the test results.