



European  
Commission

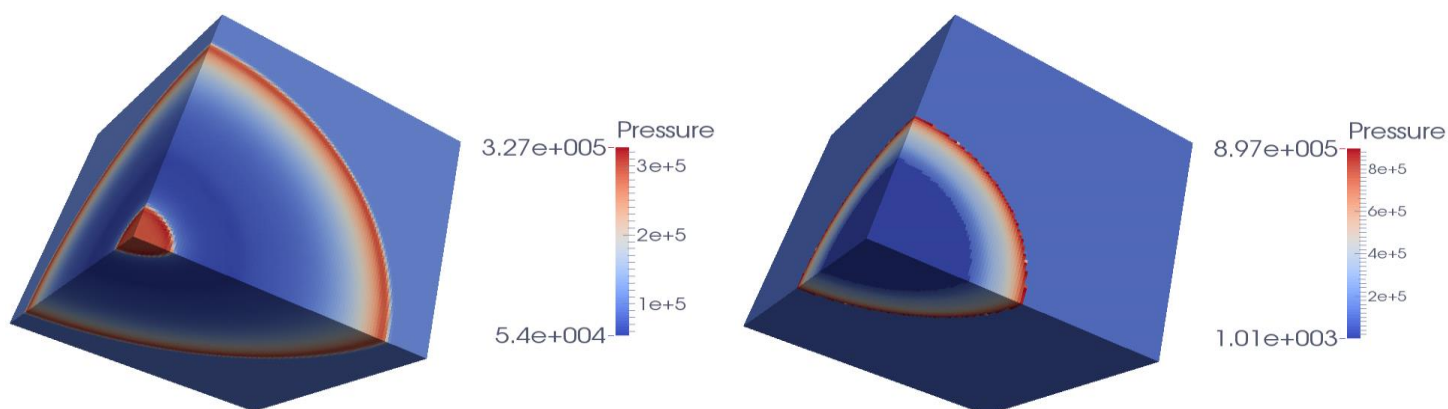
J R C T E C H N I C A L R E P O R T S

# Simulation of blast waves by using mapping technology in EUROPLEXUS

Martin Larcher  
Folco Casadei  
George Solomos

2014

Report EUR 26735 EN  
JRC91102



**EPX**  
EUROPLEXUS Software

Joint  
Research  
Centre

**European Commission**

Joint Research Centre  
Institute for the Protection and Security of the Citizen

**Contact information**

Martin Larcher  
Address: Joint Research Centre, Via Enrico Fermi 2749, TP 480, 21027 Ispra (VA), Italy  
E-mail: [martin.larcher@jrc.ec.europa.eu](mailto:martin.larcher@jrc.ec.europa.eu)  
Tel.: +39 0332 78 9563  
Fax: +39 0332 78 9049

<http://ipsc.jrc.ec.europa.eu/>  
<http://www.jrc.ec.europa.eu/>

This publication is a Technical Report by the Joint Research Centre of the European Commission.

**Legal Notice**

This publication is a Technical Report by the Joint Research Centre, the European Commission's in-house science service. It aims to provide evidence-based scientific support to the European policy-making process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

JRC91102  
EUR 26735 EN  
ISBN 978-92-79-39249-8  
ISSN 1831-9424  
doi: 10.2788/98310

Luxembourg: Publications Office of the European Union, 2014

© European Union, 2014

Reproduction is authorised provided the source is acknowledged.

Printed in Italy

# CONTENTS

1	Introduction.....	2
2	1D calculation.....	4
2.1	Reference model .....	4
2.2	General procedure.....	5
2.3	Writing map files .....	6
2.4	Reading the map file.....	7
3	Examples and results .....	8
3.1	Mapping files .....	8
3.2	Comparison with Kingery curves .....	10
3.3	Alia tests data.....	18
3.3.1	1D simulations to create map file.....	19
3.3.2	3D simulations.....	21
3.4	Simulation of an explosion inside a train .....	23
4	How to use mapping .....	26
5	Conclusions.....	27
6	References.....	28
7	Appendix.....	29
7.1	Creation of a map file .....	29
7.2	map3d test cases .....	29
7.3	alia tests .....	30
7.3.1	Parameter test for creation of mapping file.....	30
7.3.2	Alia simulation with small model .....	31
7.3.3	Alia simulation with full model.....	32
7.3.4	Explosion inside a train .....	33

# 1 Introduction

Finite element or finite volume simulations of the propagation of blast waves by using a model for the explosion of the explosive solid itself require very fine meshes in the explosive material and in the immediately zone around it. Structures may be at a long distance from the source of the explosive and this leads often to very big meshes with many elements. On the other hand, the option of meshing coarsely the explosive leads to results that are not accurate. There are several possibilities to deal with this problem (Figure 1, Larcher, Casadei [10]).

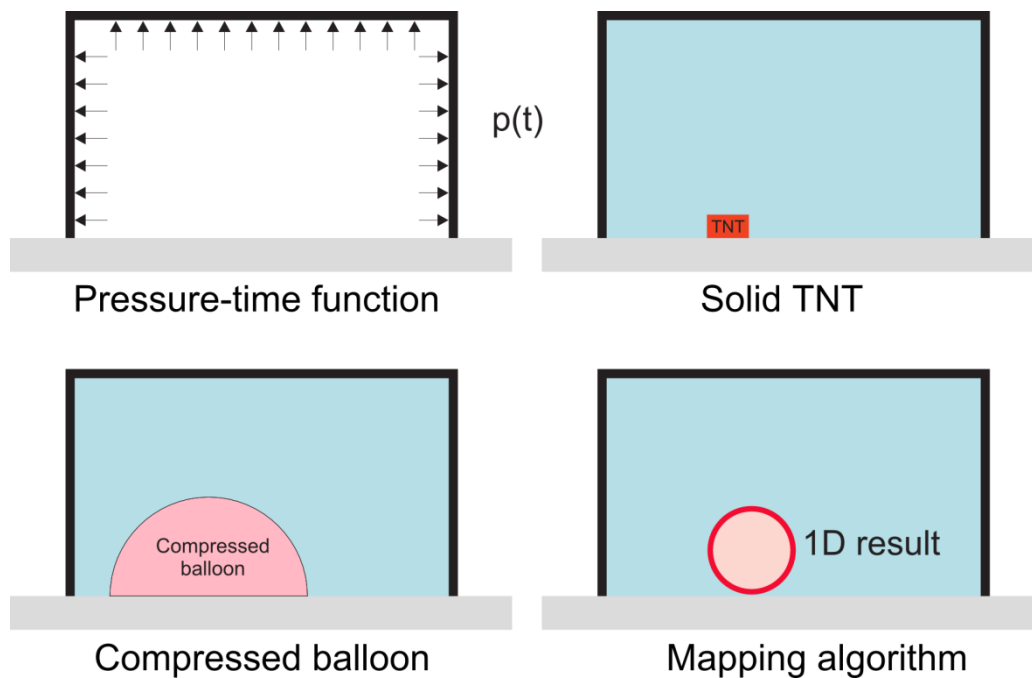


Figure 1: Simulation models for blast waves

The application of a **pressure-time function** on the structures reduces computational costs but it is often not applicable especially when wave reflections, shadowing etc. have to be considered. **The balloon model** (Larcher, Casadei [8]) is sometimes a good compromise. It uses a compressed balloon under high pressure, which is released and forms a pressure wave that is somehow similar to a blast wave. Large 3D calculations with a **solid TNT model** using a JWL-equation can be used but they are more effective when the results of one finer mesh are mapped onto a coarser mesh after some calculation steps. When the blast wave reaches a certain distance to the charge, the small elements inside the charge are not needed any more since the pressure ratio decreases strongly. These small elements result in very small time steps for the full model and the calculation is inefficient in terms of CPU.

In addition, mapping can be seen as a much more general methodology. A fine solid TNT simulation in 1D can be mapped in 2D when the first reflection surface is reached and can be mapped in 3D when the second reflection surface is reached. But also a mapping from 3D to 3D could have advantages in cases with very complex geometries where results of an inner zone can be mapped to a wider zone after reaching the end of the first model. Mapping from one material law to another should also be possible. This could be a possibility in order to eliminate the very sophisticated and time consuming JWL-material which is not needed after a certain time.

Another possibility is layer mapping. If fluid-structure interaction is needed in a case where the wave is nearly plane, i.e. a structure far away from the charge, the blast could be applied on a thin layer of one side of the fluid mesh.

It is very important that not only the pressure and the density (or two other equivalent parameters of the ideal gas equation) are mapped into the other mesh, but also the particle velocity because this plays an important role in a blast wave.

The commercial programs AUTODYN and LS-DYNA both offer in a certain way such mapping technologies. These codes could be used as a reference.

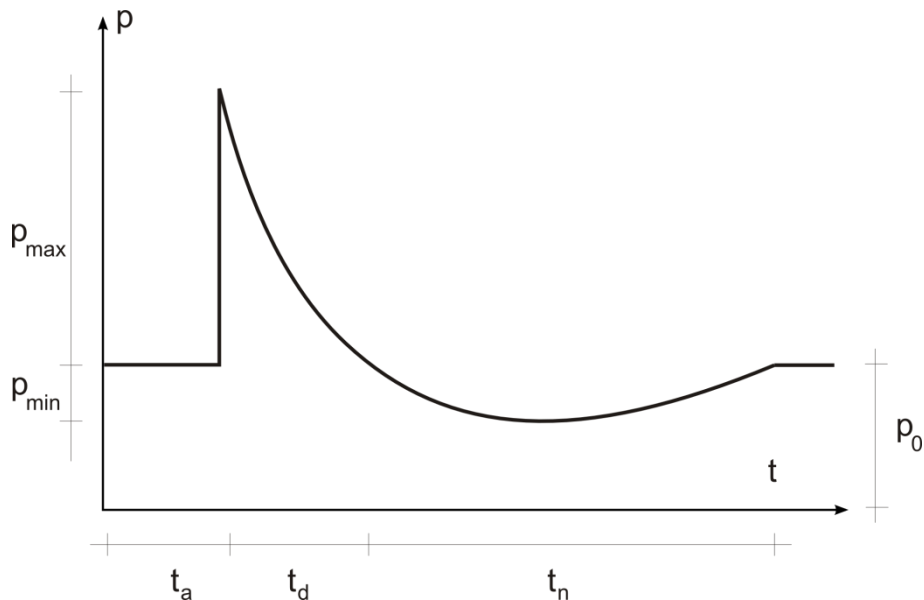
This report presents first the general idea and the implementation of the mapping algorithm in EUROPLEXUS. After that several blast examples computed using the mapping approach, are compared with analytical or experimental results in order to show the capabilities of the method. The results are also compared with the balloon model in order to highlight the advantages and disadvantages of both methods. The report also shows how the mapping can be used in the code, and terminated with some conclusions. The appendix contains all relevant input files of the examples.

## 2 1D calculation

### 2.1 Reference model

1D models are seldom used in EUROPLEXUS. Their capability to describe explosion phenomena is limited, and none of the 1D elements was until now usable together with the JWL material law, which is fundamental to describe detonation effects. All developed models are first validated using a spherical detonation of 1kg TNT whose density is 1.654 kg/dm<sup>3</sup>. This corresponds to a spherical charge with a radius of about 5.2 cm. The detonation wave is compared when it arrives at a distance of 1.0 m from the centre of the charge. No reflections are considered since this will be done later in the 3D calculation.

The form of a detonation wave follows in general the curve given in Figure 2.



**Figure 2: Theoretical pressure-time history for an air blast detonation**

This form can be represented very well for the positive part by the modified Friedlander equation. The measured pressure at a given point can be described by the modified Friedlander equation and depends on the time  $t$  from the arrival of the pressure wave at the point under consideration ( $t = t_0 - t_a$ ), where  $t_0$  is the absolute time

$$p(t) = p_0 + p_{\max} \left( 1 - \frac{t}{t_d} \right) e^{-\frac{bt}{t_d}} \quad (1)$$

The other parameters involved are the atmospheric pressure  $p_0$ , the maximum overpressure  $p_{\max}$ , the duration of the positive pressure  $t_d$  and the decay parameter  $b$ . These parameters can be taken from several analytical-empirical equations like Kingery [5] and Kinney [6]. The parameter  $b$  describes the decay of the curve. Some formulas to calculate this parameter are given in Goel [4].

Table 1 shows the analytical incident wave parameters obtained by the AIRB command in EUROPLEXUS for the given geometry [7]. These parameters can be compared with the numerical ones to validate the models.

**Table 1: Pressure wave for 1 kg TNT @ 1 m according to Kingery [5] and Kinney [6]**

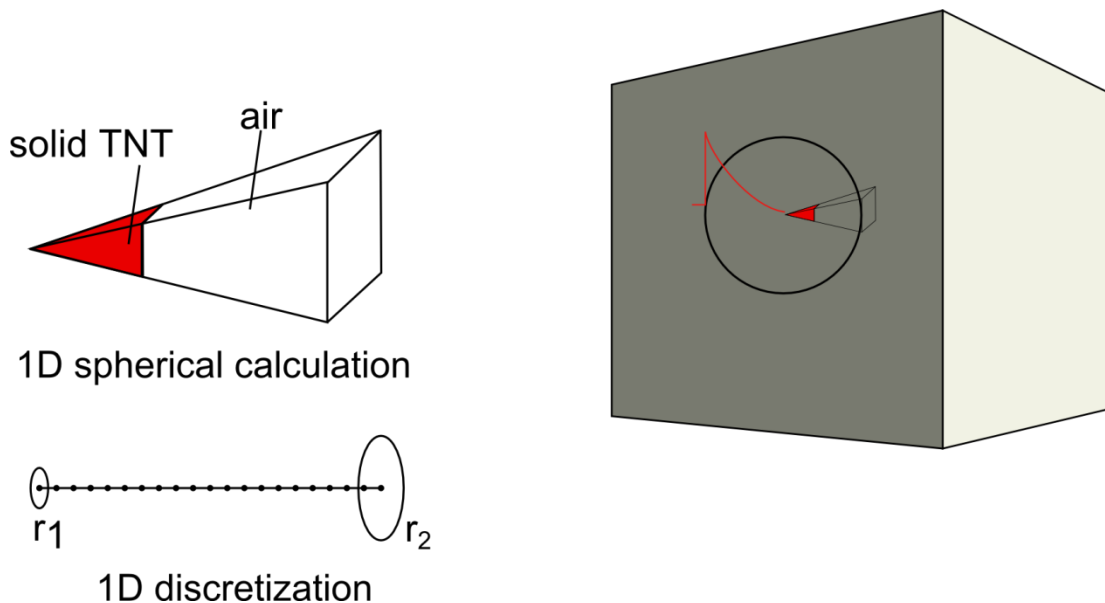
	$p_{\max}$ [Pa]	$t_{\text{start}}$ [s]	$t_d$ [s]	$p_{\text{neg}}$ [Pa]	$t_{\text{neg}}$ [s]	$b$ [-]	$l_{\text{pos}}$
Kingery	0.9349E6	0.5318E-3	0.1795E-2	0.7943E5	0.1201E-1	8.416	0.1745E+03
Kinney	0.9956E6	n.a.	0.5202E-3	n.a.	n.a.	n.a.	n.a.

## 2.2 General procedure

The following variables are needed to map a blast wave from one model to another:

- Pressure (scalar)
- Density (scalar)
- Particle velocity (vector)

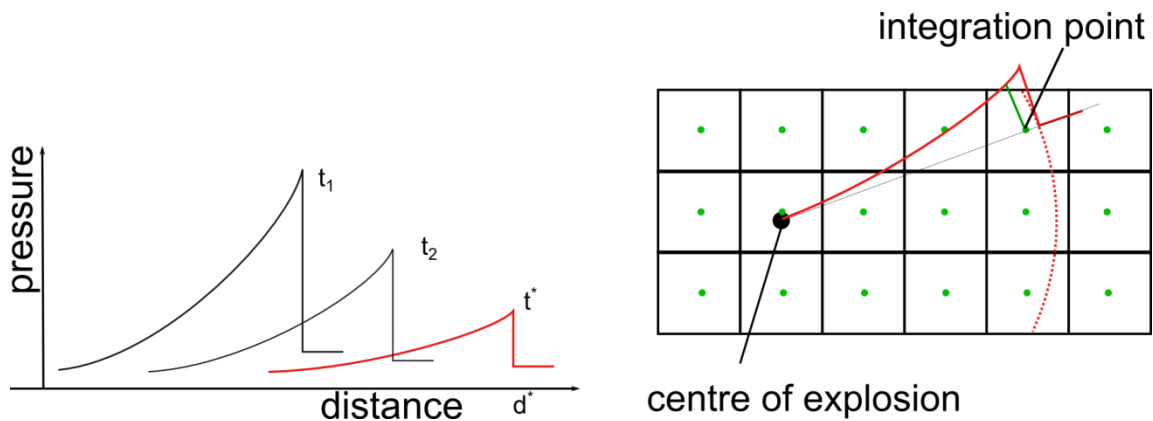
Pressure and density are related to the element and are stored in the ECRO variables. The particle velocity is calculated in the elements in case of cell centred finite volumes and on the nodes in case of finite elements and node centred finite volumes. The idea is to write the three variables in an output file that can be read during a subsequent calculation and mapped onto another mesh.



**Figure 3: General mapping procedure; 1D (left) to 3D (right)**

Figure 3 shows the general procedure. A 1D calculation with JWLS material law for the explosive and the air is performed. The boundary condition is chosen in such a way that the model represents a spherical configuration. Tube (or bar) elements with an increasing radius are used to model this

behaviour. When the pressure wave reaches a certain distance to the centre the mapping file is written. This information is mapped into the 3D configuration (Figure 3, right hand side).



**Figure 4: Interpolation of the blast wave parameters for a certain element / integration point**

Several procedures are possible to calculate the blast wave parameters in a certain element. An averaged value is more difficult to implement. Therefore, the value of the parameters at a certain point (integration point) is interpolated between from the parameter-distance curves of the mapping file (Figure 4). The same procedure is used for the particle velocity at the nodes.

In case of mapping from 2D or 3D a more sophisticated interpolation procedure must be used.

As it will be seen later on, the use of cell centred finite volumes with suitable parameters is recommended since finite elements results in more inaccurate pressure waves in case of detonations.

### **2.3 Writing map files**

The map data is written in a separate mapping file. This file contains in the first header line the following information

Dimension	Up to now only 1D is possible
Time	Arrival time at the point where it is written
Points	Number of points n for which the output is written

The following lines are repeated n times and contain the following information separated by blanks:

Distance	Distance from the centre to the point where output is written
Pressure	Pressure at this point in the units of the calculation
Density	Density at this point in the units of the calculation
Particle velocity	at this point in the units of the calculation. Three directions are given. For 1D the second and the third dimension of the particle velocity are 0.



The format of these files is kept as general as possible in order to allow further developments for other cases.

The output of the file is done by defining an additional ECRI command in the input file. This ECRI command defines the distance from the charge at which the pressure should be monitored. In addition a critical value of the pressure is given. When this pressure value is reached at the defined point, the map file is written. The `FREQ` parameter of ECRI should be defined to 1 in order to check the pressure at each time step. The following input line could for example be used:

```
ECRI ... FICH MAPB DIPR 1.0 PCHE 1.5e5 FREQ 1
```

Internally, the values of pressure, density and internal energy are calculated so that mapping can be used both for finite elements and finite volumes. Mapping from one type of fluid formulation to another one (finite elements, finite volumes) is possible. However, it is strongly recommended to use finite volumes for the calculation of the map files since the results are much more accurate.

## **2.4 Reading the map file**

The map file described in the previous section is read by using the keyword `INIT MAPB`. The number of points where the information about the blast wave is stored is in most cases much bigger than the one used in the 3D file. The map file is therefore first read and stored. Three subroutines are used in order to compute the values for the 3D model. `MAP_BLAST_ELEMENT` calculates the pressure and the density for finite elements as well as for finite volumes. `MAP_BLAST_ELEMENT_V` calculates the fluid velocity for finite volumes. `MAP_BLAST_NODE` calculates the velocities of the fluid at the nodes for finite elements. All these subroutines use a generic subroutine `GET_MAP_VALUE` that interpolates the needed value from the map file.

### 3 Examples and results

#### 3.1 Mapping files

In a first step the blast wave due to the detonation of a charge of 1 kg TNT is mapped into different geometries. The map file is checked against the Kingery-data to ensure that the mapping is done with reasonable input data from the map file.

The map file is created by using a 1D model made of finite volume elements (TUVF). This element is used with a linearly increasing diameter in order to get a cone-type geometry. Finite Volumes have at their borders fixed (reflecting) boundary conditions. Therefore, this model represents a cone with symmetry conditions in all directions (spherical symmetry). The JWLS material is used for the explosive as well as for the air with the parameters given in Table 2. This is done for simplification since multi-material simulations are much more complicated to perform. The JWL equation can also describe the behaviour of the air. Probably this is numerically not effective but it is more robust. Since the calculation time of the 1D model is very small, efficiency is not important at this stage.

**Table 2: Parameters for the JWL equation for TNT**

Parameter	Description	Parameters for explosive	Parameters for the air
A (Pa)		3.738e11	3.738e11
B (Pa)		3.747e9	3.747e9
R1		4.15	4.15
R2		0.90	0.90
beta		0.25	0.25
ro	density	1630	1.3
eint	current internal energy per unit mass	3.68e6	2.1978E5
omeg	specific heat ratio	0.35	0.35
d	detonation speed	6930	-

Figure 5 shows the result of the 1D calculation (file map1d.epx in the appendix). It can be seen that the mapping file can represent the pressure-distance curve quite well. The comparison is done in such a way that the wave at a similar distance is compared (i.e. the time of the pressure distance curve is taken from the Kingery data). The accordance decreases when the distance to the charge is getting larger. The negative phase is not represented by the Kingery data. Therefore, this part cannot be compared. Several formulas for the negative phase are given in Larcher [7]. The values are shown in

Table 3. The numerical results from the 1D calculation show a relatively good agreement with the data from the literature.

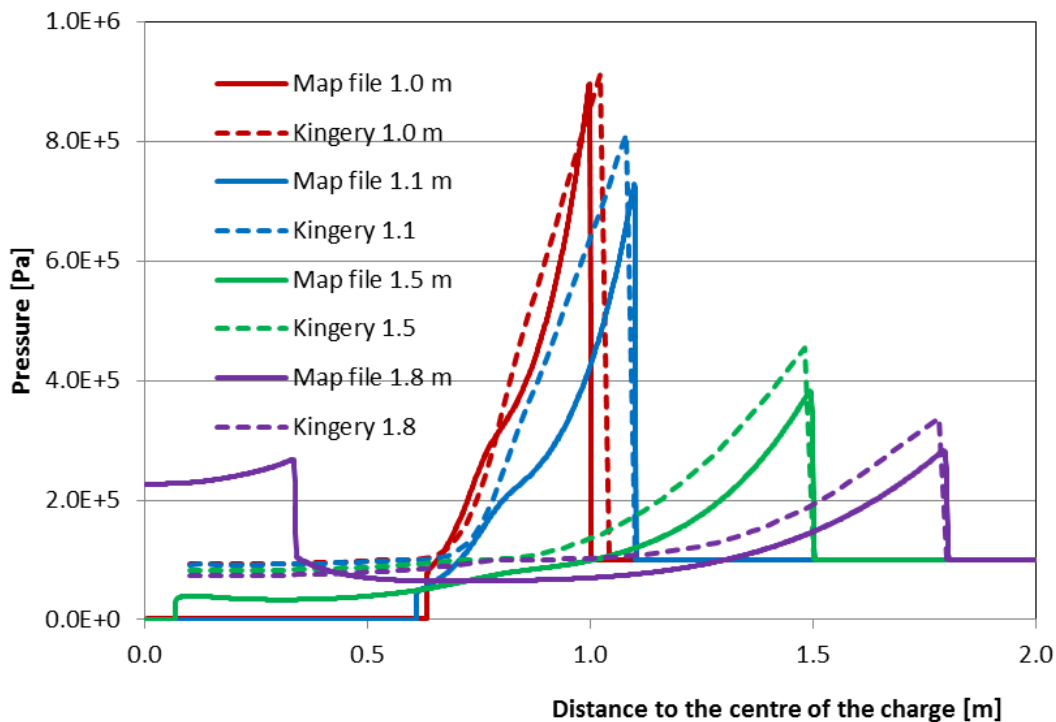
**Table 3: Pressure wave for 1 kg TNT @ 1 m according to Kingery [5] and Kinney [6] and Larcher [7]**

	$p_{\max}$ [Pa]	$t_{\text{start}}$ [s]	$t_d$ [s]	$p_{\text{neg}}$ [Pa]	$t_{\text{neg}}$ [s]	b [-]	$l_{\text{pos}}$
Kingery	0.9349E6	0.5318E-3	0.1795E-2	0.7943E5	0.1201E-1	8.416	0.1745E+03
Kinney	0.9956E6	n.a.	0.5202E-3	n.a.	n.a.	n.a.	n.a.
Map file	0.897E6	0.5615E-3	0.688E-3	0.64827E5	0.189E-2	-	-

As shown in Cullis [3] a shock wave is reflected also at the charge centre. The part after the peak drops at a certain point nearly to zero. This wave travels towards the centre of the charge and results in a large pressure that can even reach the same magnitude as the peak pressure of the first blast wave at the same time.

This effect can be very well represented with the numerical simulation as it can be seen in Figure 5 for the situation at a propagated distance of 1.8 m. Kingery data can also not represent this behaviour since this behaviour is not included in the modified Friedlander equation.

It has also been checked that the angle of the cone of the 1D model that is used for this type of simulations has no significant influence on the pressure-distance curve.



**Figure 5: Comparison of the mapping file for 1 kg TNT**

### **3.2 Comparison with Kingery curves**

The mapping files are used in order to map the 1D pressure-distance curve into 3D cubical cells of air and several modelling approaches are tried. It is very early found that the case with finite elements (map3d) is not stable and terminates at a certain point by reaching a too small time step. This was observed in several test cases where the pressure became too high in one particular element and therefore the time step size decreased too much. Since the results were much more successful with finite volumes, no further investigations with finite elements were done. It is generally not recommended to use the mapping algorithm with finite elements.

Table 4 shows the models used for comparison. For all models three symmetry planes are used in order to reduce the numerical costs, thus only 1/8 of the reality is built up in the numerical model. The symmetry conditions must be considered in the two numerical models (finite elements, finite volumes) in a different way. While for the finite volumes the boundary condition is reflecting, the boundary condition for finite elements is absorbing.

The mapping file from the previous section is used where a charge of 1 kg TNT is modelled. The element size in the 1D calculation is 1 mm, i.e. the charge consists from 30 elements. The total length of the 1D model is 3 m. The mapping file is written when the blast wave reaches 1 m distance from the charge. This is the case 0.571 ms after the start of the detonation.

The mapping builds up the charge in the 1D calculation with spherical symmetry. Further attention in case of the mapping algorithm is not needed since the pressure is mapped and not the charge. For the bubble model the total charge must be divided by 8 in order to consider the right amount of explosive.

**Table 4: Models for comparison of mapping algorithm with analytical data from Kingery**

Model	Length	Element type	Element size [m]	Number of elements	Calculation time
Map3d	5 m	FE (CUBE)	0.10	125000	termination
Map3dvfcc	5 m	VF (CUVF)	0.10	125000	401 s (0.01 s)
Map3dvfcc_fine	5 m	VF (CUVF)	0.05	1000000	5509 (0.01 s)
Map3dvfcc_fine_fine	2 m	VF (CUVF)	0.02	1000000	3464 (0.003 s)
Map3dvf_bub	5 m	VF (CUVF), bubble model	0.10	125000	338 s (0.01 s)
Map3dvf_bub_fine	5 m	VF (CUVF)), bubble model	0.05	1000000	6610 s (0.01 s)
Map3dvf_bub_fine_fine	2 m	VF (CUVF)), bubble model	0.02	1000000	5235 (0.003 s)

For the finite volume modelling Map3dvfcc\_fine\_fine Figure 6 shows the situation at the beginning of the 3D calculation (time is reset to zero) when the 1D blast wave is mapped to the 3D fluid volume. It can be seen that the resolution of the pressure wave is very fine. The thickness of the shock front with the maximum pressure is small as is actually observed in reality. Inside the sphere of the high pressure wave the pressure falls below the atmospheric pressure (underpressure). This negative phase results in a reflection at the central point of the charge as it can be seen in Figure 7. The resolution of the positive pressure wave at this time ( $t=1$  ms) is still very good.

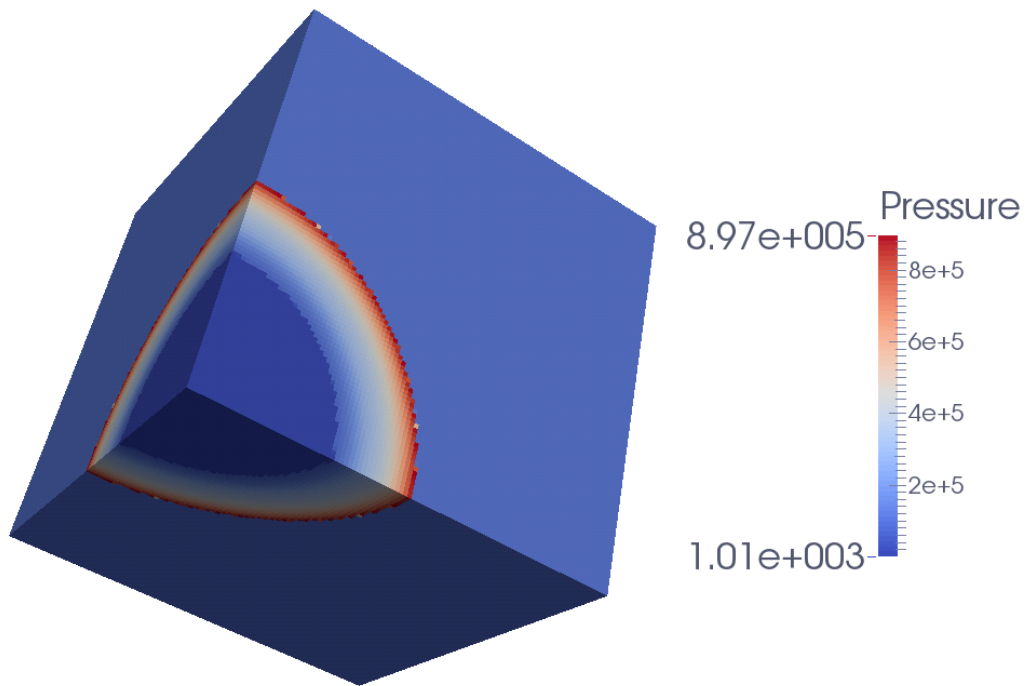


Figure 6: map3dvf\_fine\_fine immediately after the mapping ( $t=0$  ms + 0.57 ms mapping). Blast front has reached a distance from the charge of 1 m.

---

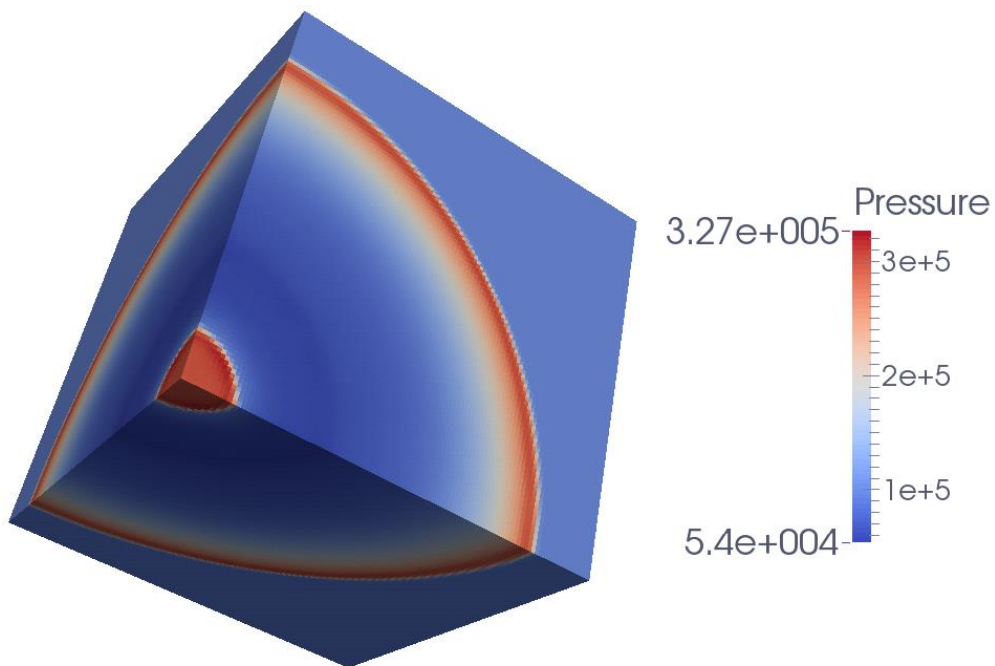


Figure 7: map3dvf\_fine\_fine at  $t=1$  ms + 0.57 ms mapping

---

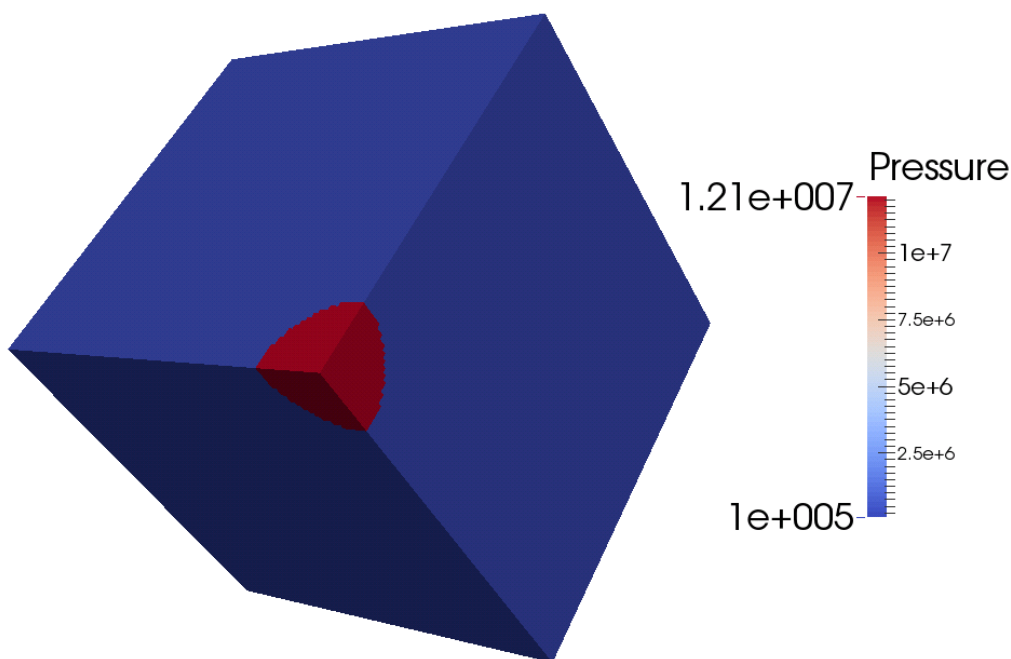
The third possibility, which has been tried out, to impose in a fluid a blast pressure wave is the so-called compressed balloon or bubble model [8]. A sphere with a radius much higher than the one of the

explosive if filled with compressed gas that is then released. The pressure wave resulting from that pressure release can describe a blast wave quite well especially when the pressure of the compressed air is fitted by comparing the resulting pressure-time curves with the ones of experimental data.

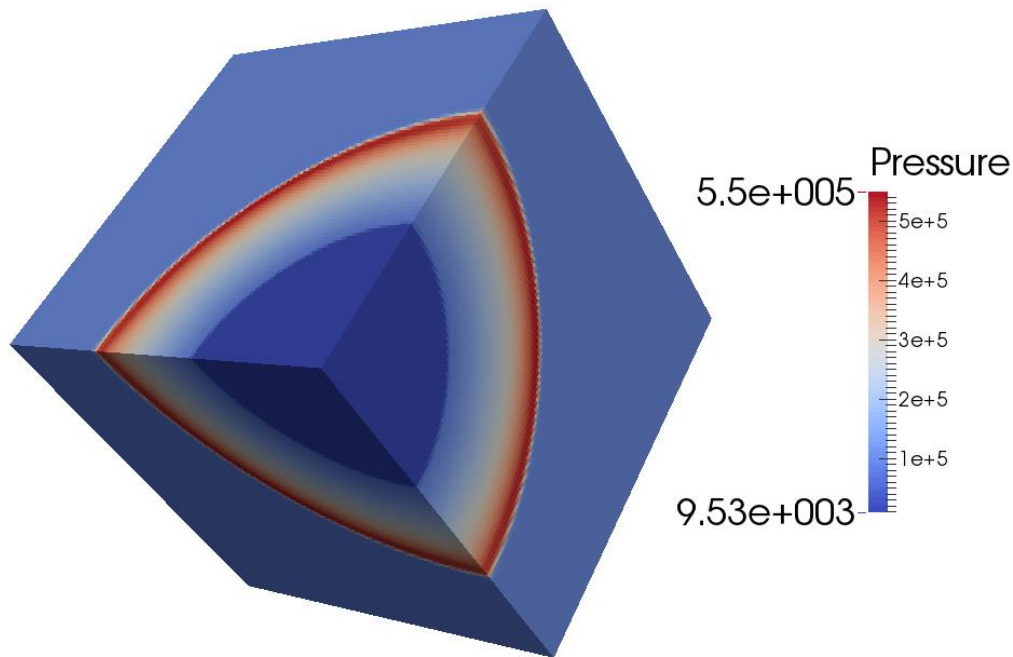
Figure 8 shows the bubble model after filling the bubble with the compressed air. It is obvious that the main idea is similar to the mapping algorithm but the bubble model uses a constant pressure instead of the physical pressure-distance relation that is derived by a numerical 1D pre-calculation.

The comparison between Figure 7 and Figure 9 shows the advantage of the mapping algorithm. The pressure wave at the time  $t=1$  ms is much more pronounced for the mapping algorithm than for the bubble model. This corresponds much better with the physical pressure-time curve as it can be seen in Figure 10 and Figure 11.

The triggering of the two models is different. The arrival time of the blast wave in case of mapping algorithm (3D model) can be determined by adding the time that the wave needs in the 1D model. In case of the balloon model the arrival time can be estimated by using the arrival time at the radius of the balloon. This time can be calculated using Kingery formulas (AIRB).



**Figure 8: map3dvf\_bub\_fine\_fine bubble filled with compressed gas ( $t=0$  s + 0.1 ms bubble)**



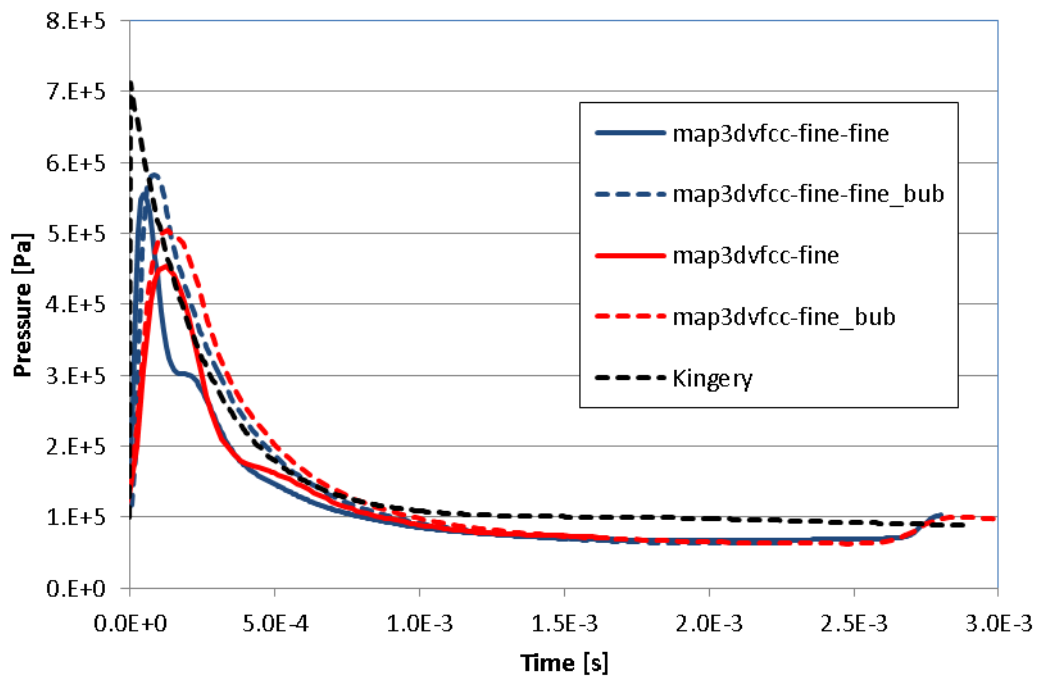
**Figure 9: map3dvw\_bub\_fine\_fine at t=1 ms + 0.1 ms bubble**

In Figure 12 and Figure 13 the maximum pressures of all models are compared against the empirical values from Kingery. As expected the numerical simulations underestimate the pressure waves since numerical simulations are a kind of filter or damping for high frequencies. This means that the blast wave is smoothed in each step of the calculation. The results of the bubble model are slightly better in comparison to the Kingery values. This is also clear since the compressed pressure in the balloon has initially been calculated in such a way that the pressure wave can best represent the empirical data. For the mapping the blast wave is filtered much longer and therefore the pressure wave is slightly smaller than the bubble one. Nevertheless, the mapping algorithm can represent also the maximum pressure over distance function for that charge size. The finer the mesh is (for bubble or mapping model), the better the results are. This is also evident since the high frequency filtering is then smaller.

The pressure-time curves shown in Figure 10 and Figure 11 indicate also some slight differences between the two models. The peak pressure is slightly smaller for the mapping algorithm due to the fact that the bubble model uses a correction factor to get better results. This correction is obtained by fitting the numerical results to Kingery's empirical data. Kingery's empirical data are very smooth since only an exponential equation is used to describe the decay of the pressure (modified Friedlander equation (1)). In reality, the physical process is much more complicated e.g. includes a negative phase and reflections of the negative wave at the centre. This process cannot be described neither with Kingery's formulation nor with the bubble model. A comparison with experimental values would most probably be more similar to the mapping results, especially the pressure history after reaching the peak.



The curves in Figure 10 and Figure 11 are moved in such a way that the blast wave arrives always at  $t = 0$  ms to allow a comparison between all models. The numerical arrival times can also be compared here more in detail. For the bubble model, the arrival time at the maximum radius of the bubble is about 0.09 ms (from AIRB). The time for the wave to reach the distance of 1.2 m is about 0.75 ms resulting in a total arrival time of 0.84 ms. For the mapping model, the time of the wave to reach the map point (1 m distance from the charge) is about 0.57 ms. The time of the wave in the 3D model to reach the 1.2 m distance is 0.2 ms corresponding in total to an arrival time of 0.77 ms. The empirical arrival time that can be calculated for a distance of 1.2 m with AIRB is about 0.75 ms and corresponds quite well with the one of the mapping model but slightly worse with the one of the balloon model.



**Figure 10: Pressure history for the comparison between mapping and bubble model at a distance of 1.2 m. The starting time is set to the arrival of the wave in order to make it comparable.**

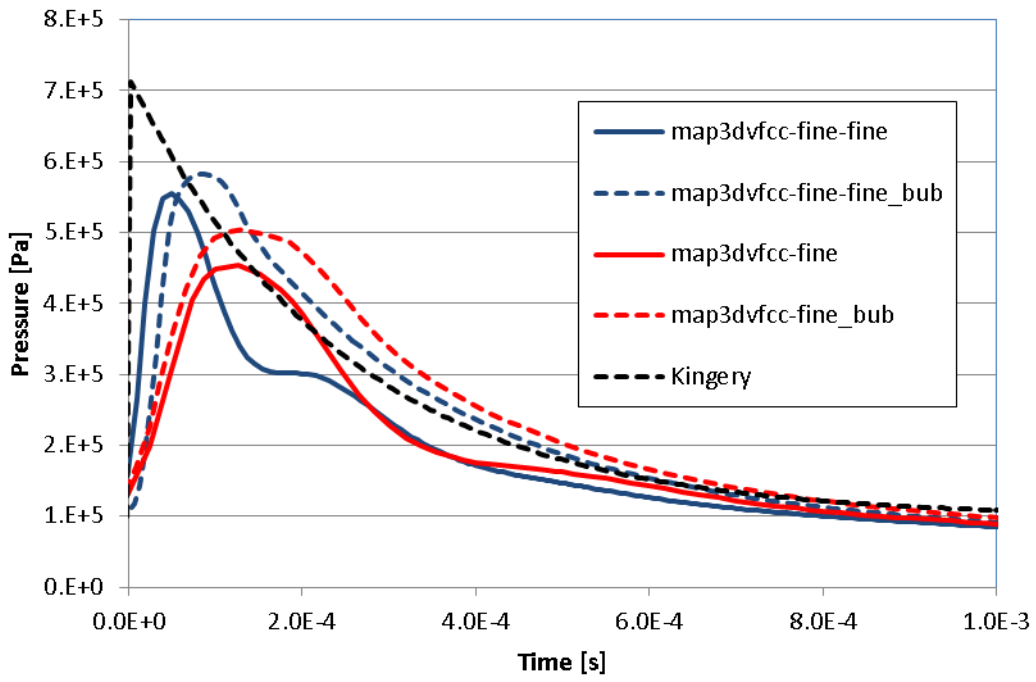


Figure 11: Pressure history for the comparison between mapping and bubble model at a distance of 1.2 m, detail

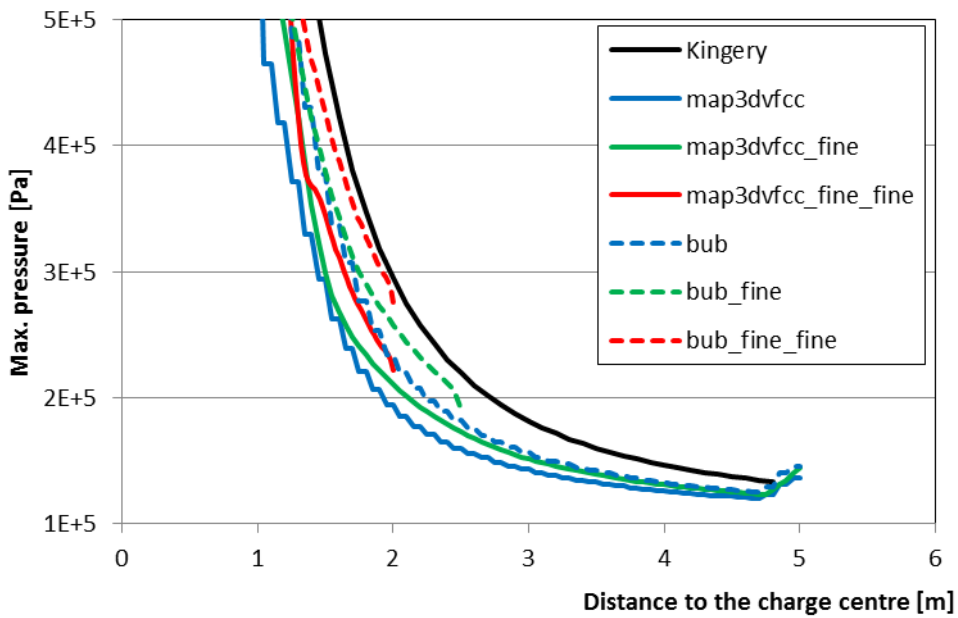


Figure 12: Comparison of the pressure-distance curve for a charge of 1 kg TNT equivalent

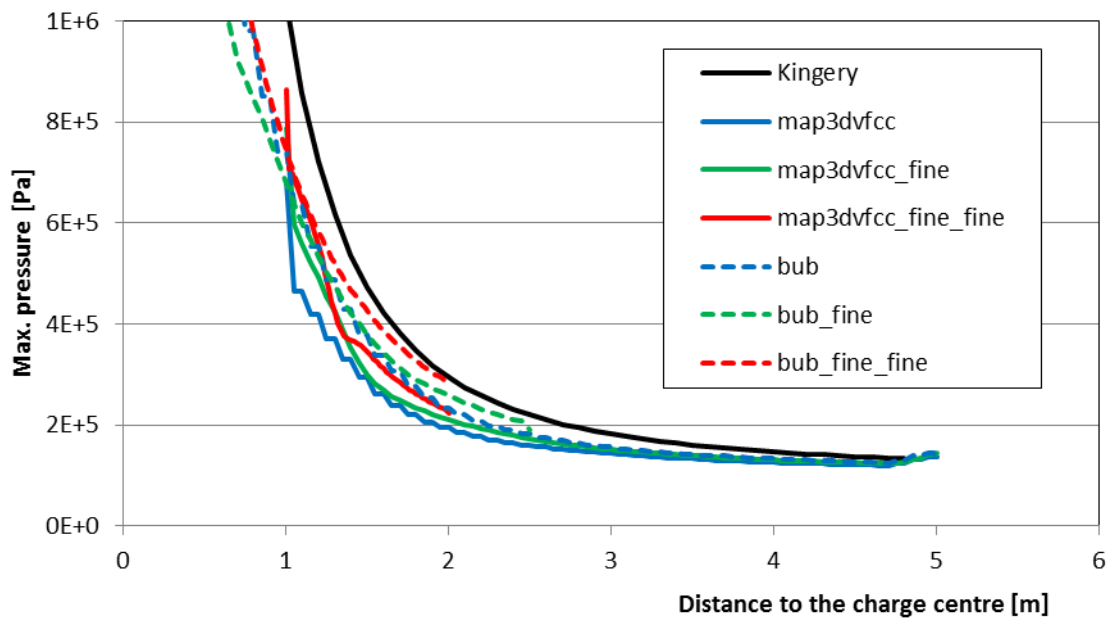


Figure 13: Comparison of the detailed pressure-distance curve

Also the impulse-distance curve is an indicator of how well a numerical model can represent the development of a blast wave. In Figure 14 the impulse-distance curves of the mapping method are compared with the bubble method and with the empirical values also from Kingery. It can be seen that the impulse is better represented by the bubble method. The reason is that the pressure wave is represented in a much sharper way in case of the mapping algorithm which together with the lower peak pressure produce a smaller impulse value. In case of the bubble model the numerical impulse is fit to the Kingery curves by using a correction parameter. Therefore, the bubble model can represent the impulse better, although the correction factor does not have any physical background.

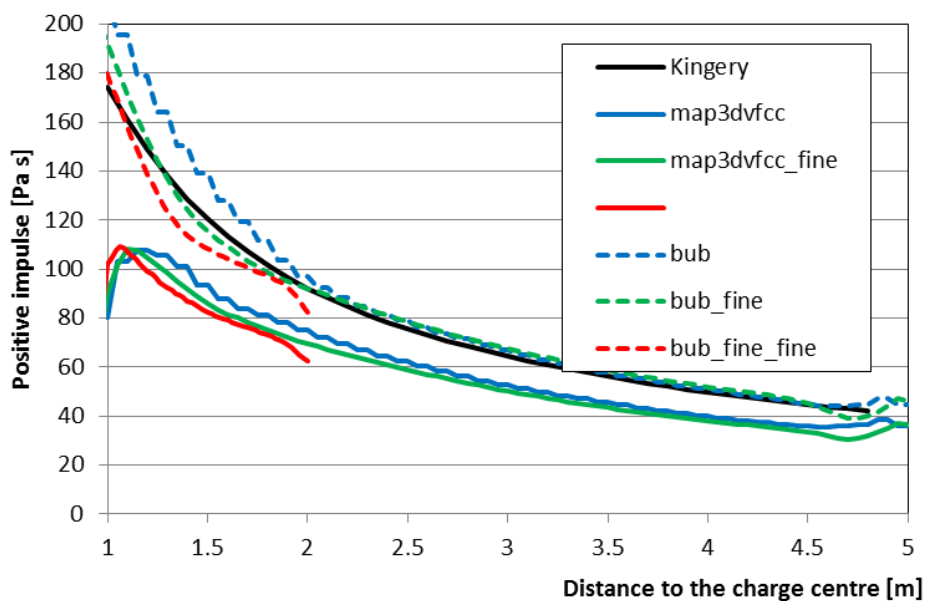


Figure 14: Comparison of the 1 kg TNT: impulse-distance curve

The calculation time needed is (except for the very coarse mesh) slightly smaller for the mapping technology. This was not foreseeable since the bubble model has at least at the beginning a more uniform pressure field than the mapped model. Nevertheless, this fact could be an additional advantage of the mapping technology if this difference can be confirmed by other comparative calculations.

### 3.3 Alia tests data

The next comparisons are done with data from a real experiment. As in a previous report [8], the experiment of Alia [1] has been used since it provides blast data that show also a reflection on a surface (Figure 15).

The experiment uses a charge of 227 g C4, which corresponds to a charge of 268 g TNT equivalent. Three symmetry planes can be considered in order to reduce the computational costs, i.e. 1/8 of the reality is modelled.

The previous report shows results from solid TNT and bubble models testing several parameters. The comparison should be completed here by adding the mapping model results.

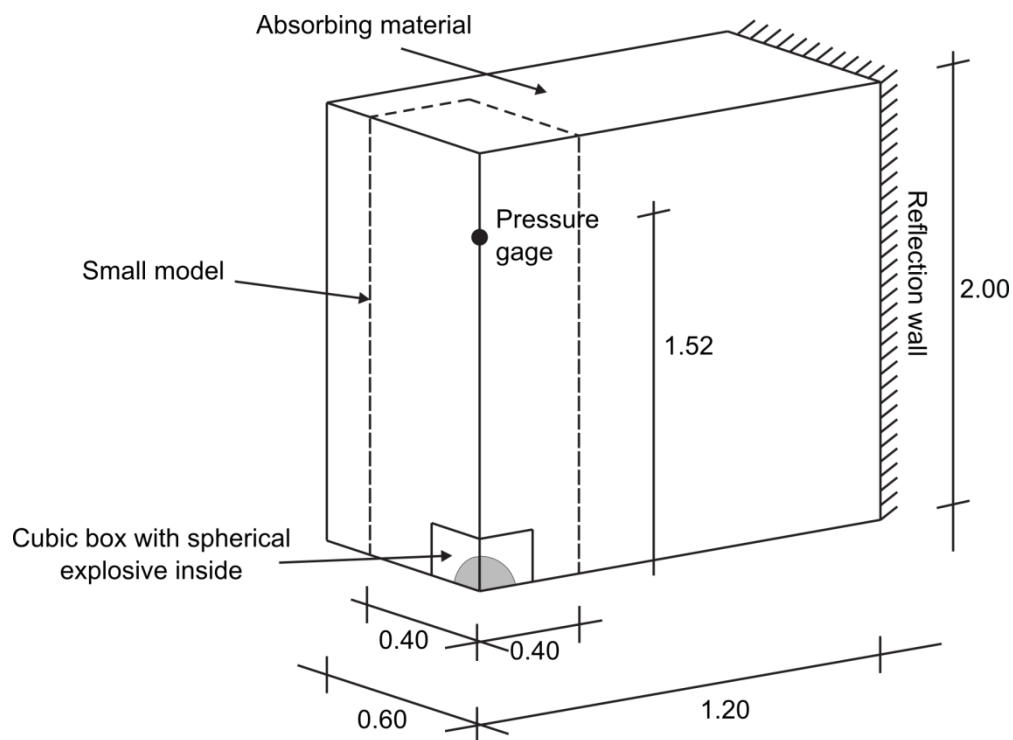
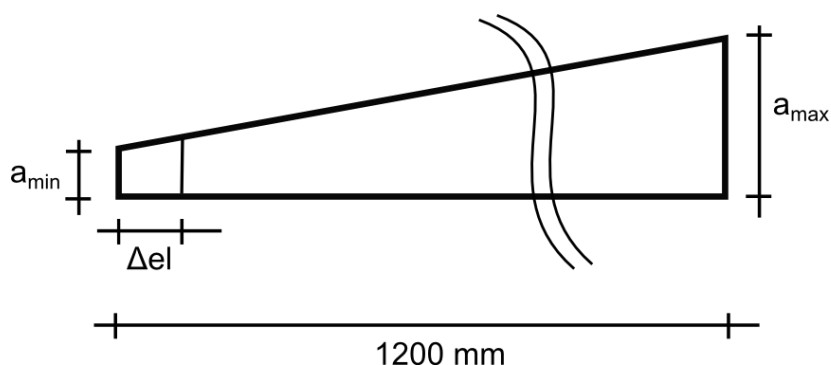


Figure 15: Experimental setup of the experiment of Alia [1]

### 3.3.1 1D simulations to create map file

In the first step, the mapping file is created. The first simulations of that problem get about 15 % lower peak pressures in comparison to Kingery's empirical values. To understand this difference several parameters are changed in order to identify substantial influences on the pressure values.

Figure 16 shows the shape and dimensions of the 1D model. To get a spherical symmetry a cone is built using 1D elements. This means that the cross section of the elements is increased linearly with the distance to the centre. Since a cross section of 0.0 for the inner element is not possible in the recent EUROPLEXUS code, a small enough value should be used, which however is not too small to cause the premature termination of the calculations. In addition to the element size the minimum and the maximum cross sections are changed for the parameter study. The parameters for the different runs are given in Table 5.



**Figure 16: Dimension of the model that is used to create the mesh file**

One of the runs was not completed properly. The element size was too big and the calculation stopped due to negative energy in one element. The peak pressures of all the other simulations were quite similar except for the model map\_para6. In this model the maximum cross section was chosen to high. This resulted in a configuration that cannot be seen as a spherical condition and is therefore not considered.

A very small influence of the element size on the peak pressure is found. map\_para4 produces the highest and sharpest peak pressure. The needed calculation time for all models is very small. Even the very fine model with  $\Delta el=0.1$  mm and 20000 elements uses only 20 minutes of CPU time.

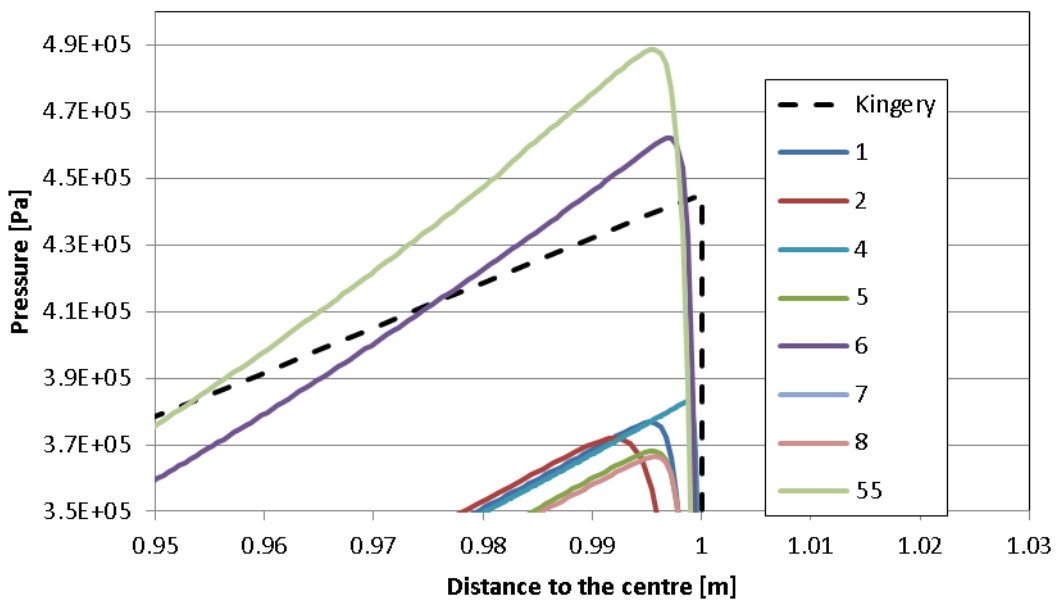
In comparison with the empirical data from Kingery the current results for the peak pressure are smaller (Figure 17). There are several possible reasons for this difference. The used 1D finite volume implementation can until now be used only under first order formulation in space and time, and this can result in smaller peak pressure values. In addition, the values of Kingery have been mainly obtained using very large explosions and theoretically scaling them down to small events. It is not clear if these values fit also very well the small charges. Bogosian et al. [2] presented a comparison of

Kingery's data with data from several other sources and experiments. The comparison showed that these data systematically underestimated Kingery's data values.

**Table 5: Parameter study to create the map file**

Model	Element length $\Delta el$	Truncated cone: min dimension ( $a_{min}$ )	Truncated cone: max dimension ( $a_{max}$ )	Vfcc options	Result
map_para1	0.5 mm	25e-6	0.05 m	6	
map_para2	1.0 mm	25e-6	0.05 m	6	
map_para3	2.0 mm	25e-6	0.05 m	6	Tilt
map_para4	0.1 mm	25e-6	0.05 m	6	
map_para5	0.5 mm	25e-6	0.1 m	6	
map_para6	0.5 mm	25e-6	0.01 m	6	
map_para7	0.5 mm	25e-6	0.05 m	3	
map_para8	0.5 mm	5e-6	0.05 mm	6	

Figure 17 shows that all pressure results are slightly lower than Kingery's data but they are all very similar. Therefore, the map file created by the model map\_para1 is used for the mapping.



**Figure 17: Pressure-distance curve of map files (Table 5)**

### 3.3.2 3D simulations

The results of the 1D simulations were next mapped into a 3D model. This model has an (hexahedral) element size of 2 cm. Two different models are used: a small model (Figure 15) and a full model with 44400 and 284400 elements, respectively. To see the influence of the region where the mapping is applied, the simulations are performed with four different configurations each with a different distance of the blast wave to the centre when the blast wave is mapped. This distance varies from 0.2 m to 1.1 m. The models can be compared with the results from the previous report [8] where a bubble (balloon) and a solid TNT model have been used. All model configurations are presented in Table 6.

**Table 6: Parameter study for mapping of Alia experiment**

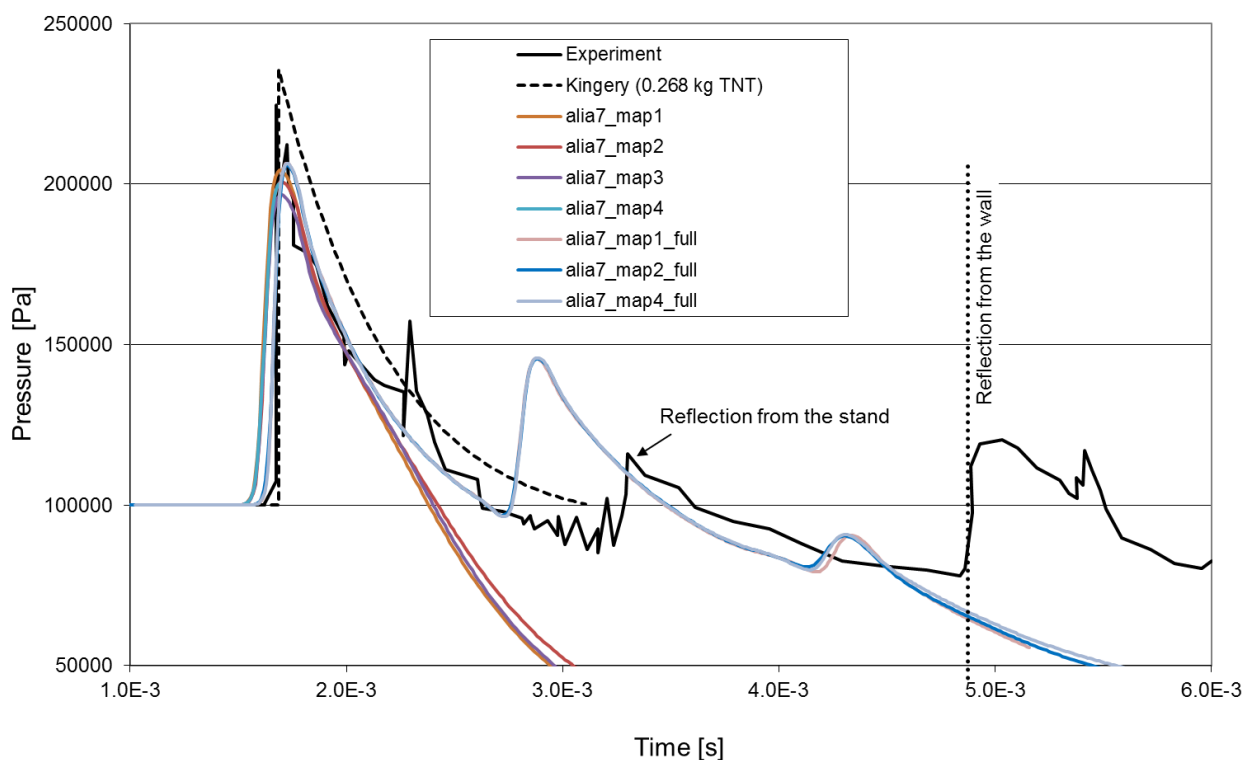
Model	Mapping of blast wave at	Small/full model	Element size	End of calculation (3D)	Calculation time (3D)
alia7_map1	0.4 m	small	2 cm	3.00 ms	99 s
alia7_map2	1.0 m	small	2 cm	3.00 ms	87 s
alia7_map3	0.2 m	small	2 cm	3.00 ms	107 s
alia7_map4	1.1 m	small	2 cm	4.00 ms	101 s
alia7_map1_full	0.4 m	full	2 cm	5.00 ms	1074 s
alia7_map2_full	1.0 m	full	2 cm	5.00 ms	853 s
alia7_map3_full	0.2 m	full	2 cm	5.00 ms	1051 s
alia7_map4_full	1.1 m	full	2 cm	4.00 ms	1031 s
alia_bubb4	bubble	small	2 cm	3.00 ms	156 s
alia_bubb7	bubble	full	2 cm	6.00 ms	1524 s
alia7	Solid TNT	small	2 cm	3.00 ms	2252 s
alia20	Solid TNT	small	1 cm	3.00 ms	36334 s

Figure 18 indicates that the differences in the pressure-time histories for the different starting points of the mapping (distance of the initial blast wave from the centre) are very small. This means first, that the meshes are sufficiently small and represent the blast wave development accurately enough and

second, that the mapping can also be done shortly before the point where the first reflection takes place. The calculation time of the 3D model is then smaller. This distance is here 1.2 m.

While the first peak pressure is represented quite well, the reflections “from the stand” and from the wall cannot be described accurately enough in the full models. Both reflections reach the investigated point (pressure gage) earlier and in the case of the reflection from the wall the pressure value is substantially smaller than the experimental one. Nevertheless, the fundamental behaviour is well described. Clearly the small model can capture only the initial features of the pressure record.

Also Alia [1] shows a difference of the arrival time of the blast wave between the experiment and the numerical simulations. While the experiment shows the arrival of the blast wave at about 1.5 ms the arrival time in the numerical simulations are about 0.5 ms later. To allow a better comparison of the numerical and the experimental results, all curves are moved to a similar arrival time of 1.5 ms.

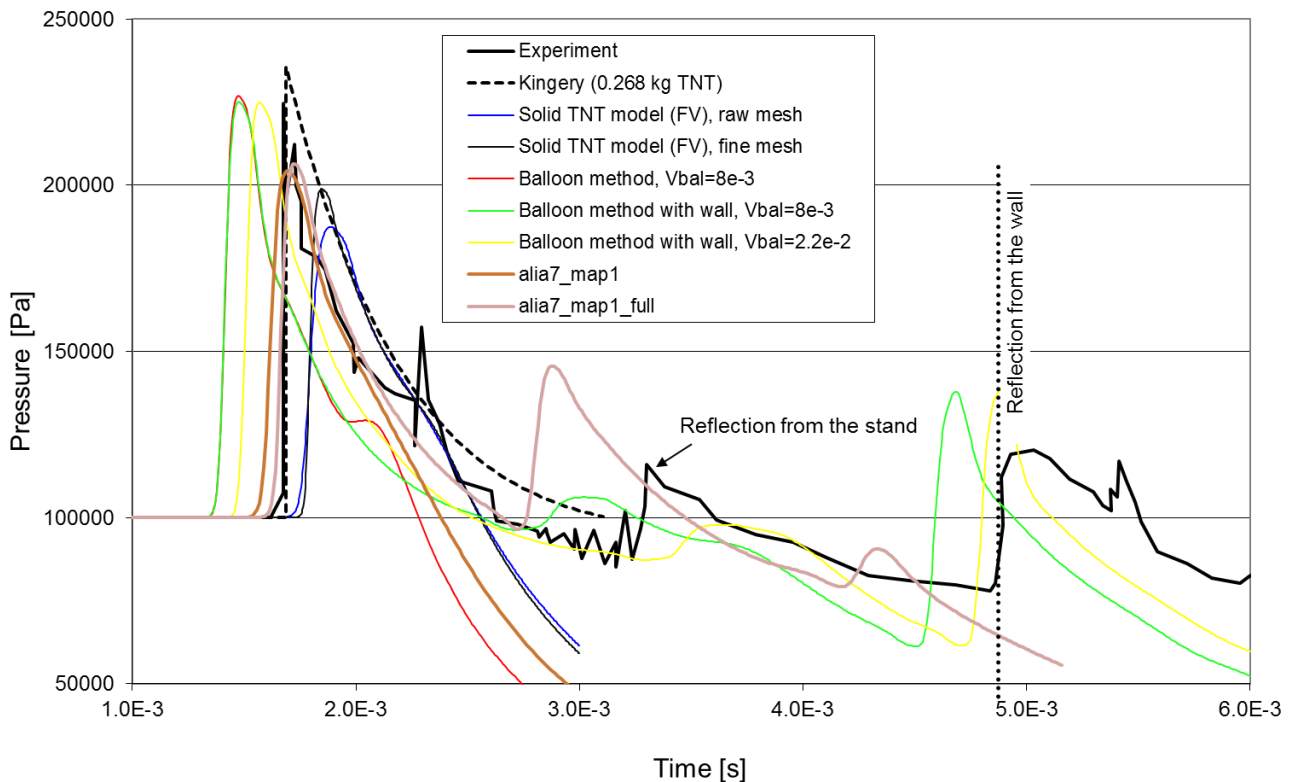


**Figure 18: Pressure history for Alia experiment: comparison of mapping parameters (Table 6)**

When the results of the mapping models are compared with the bubble and solid TNT models (Figure 19) it can be seen that the peak-pressure arrives earlier for the bubble model and is slightly higher. This results most probably from the effects already mentioned for the calculation of the mapping file. The peak pressure in the solid TNT model is slightly smaller, most probably since the element size inside the explosive was not small enough. The results of the small model are all quite similar except the already mentioned difference for the reflections for the mapping model.



Since the results are quite similar the calculation time can be compared in order to choose the appropriate simulation model. The solid TNT models have a very high computational cost but they are only used for calculating the small model. The calculation time for the full model is too long. In comparison, the mapping simulation runs much faster. The calculation time of the bubble model is slightly higher than the one of the mapping model. If the calculation time for creating the map file is added, the computational costs are most probably of the same order of magnitude. The two models (mapping and bubble) will be compared with their advantages and drawbacks in the conclusions section.



**Figure 19: Pressure history for Alia experiment: comparison with previous results (Table 6)**

### **3.4 Simulation of an explosion inside a train**

In order to test the mapping algorithm also for larger structures the simulations of explosions inside trains (previous report [9] and publication [11]) were repeated and instead of the bubble model the mapping technology is used. The model consists of a regular fluid mesh with a mesh size of 10 cm. The structure is built from stiff beam elements and weaker shell elements for the structural surface. The same geometry as reported in the previous work [9] is used.

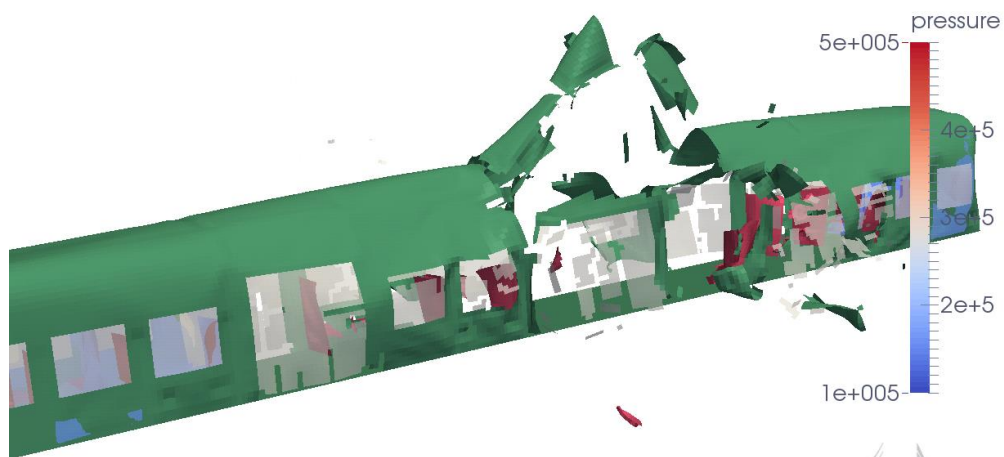
The charge is detonated inside the train. A charge with 9 kg TNT equivalent is used which correlates to a rucksack bomb.

The charge is first calculated in a 1D mesh and then mapped into the 3D case. The 1D calculation uses 9 kg TNT equivalent (radius of the spherical charge of 11 cm) and a total length of the 1D model of 1 m. The element size in that model is 1 mm. In that way, the charge is represented by 110 elements. The mapping file is written when the blast wave arrives a distance of 1 m from the charge centre. This corresponds to the distance of the train structure to the charge.

In comparison to the calculation with the compressed balloon the 3D calculation is quite unstable. At some points the time step size drops to  $1e-8$  s while for the beginning and for several periods in between the parts with small time step sizes the time step size is in the range of  $1e-6$  s. This very small time step occurs only in one or some elements. There could be two reasons:

1. Mapping is an exact physical model. That means that the pressure wave is reflected inside the charge after some time. That leads to very high pressures and with them the time step size decreases a lot.
2. Some of the elements with very small time step sizes are along the boundary condition. It could be that the boundary condition has some problems with very high pressures. This phenomenon should be checked with additional models.

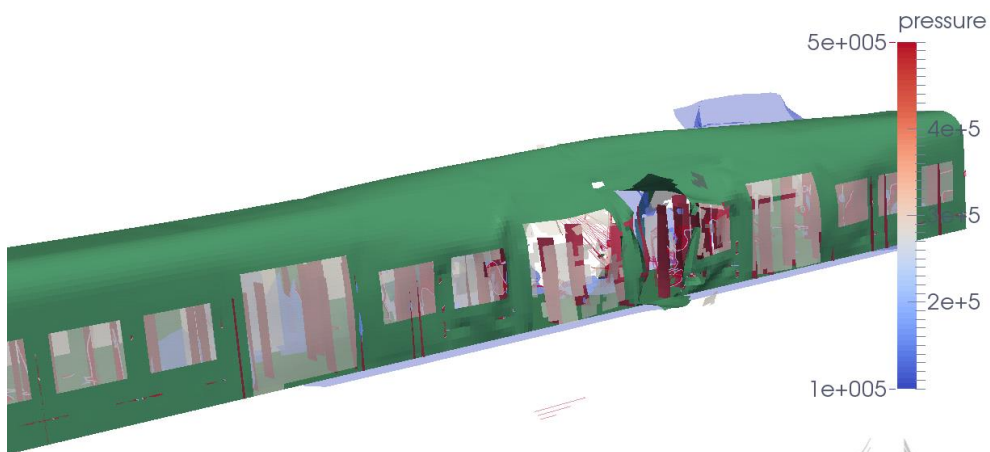
Nevertheless, the calculation results in a deformed and partly failed train carriage, as it can be seen in Figure 20 (bottom). The comparison between balloon and mapping method shows that the displacements in case of the mapping method are smaller. It cannot be stated which one of the approaches provides a better solution due to the lack of possibilities to compare these results with real experimental data.



**EPX**  
EUROPLEXUS Software



JOINT RESEARCH CENTRE



**EPX**  
EUROPLEXUS Software



JOINT RESEARCH CENTRE

**Figure 20: Comparison of the displacements and the failure of the train carriages using balloon (top) and mapping (bottom) method**

## 4 How to use mapping

In order to facilitate the use of the mapping technology the most important steps are presented here:

- Create a 1D mesh for the calculation of the data to be stored in the mapping file. This calculation should be done using 1D finite volume elements (TUVF). The element size can be very small such the calculation time of the 1D problem is typically very short. A discretization of about 50 elements in the charge could be an indicative value.
- The cone-type geometry for the 1D model should be used, as shown in the examples in the appendix. The mapping file is written by using the command MAPB in the ECRI command. The propagated distance of the mapped blast wave from the centre must also be given. This should be chosen in such a way that no reflections have occurred yet. The distance should also be chosen as long as possible in order to reduce the computational cost of the 3D model.
- The mapping file must be read by using INIT MAPB. The centre of the spherical blast wave can be indicated by using POS. The 3D model should also be modelled with finite volumes since they appear to provide the best description of the blast wave development. Finite elements often reduce the blast wave too much. FCONV 6 (HLLC-solver) is recommended for the 1D as well as for the 3D model.
- The simulation time of the 3D model starts again with zero timing. In order to get the time from the initiation of the explosion the time indicated in the mapping file must be added to the current one.

## 5 Conclusions

The report presents the mapping method that can be used to simulate the development of blast waves in the air very effectively. The idea is to do a 1D simulation with a very fine mesh for the explosive and the air until the blast wave reaches the first obstacle. Just before the wave reaches this obstacle the wave is mapped into a 3D mesh (in the future also 2D meshes would be possible).

This procedure provides a physically based approach to speed up the simulation of blast wave development. In comparison to other methods (bubble method, solid TNT method, AIRB) several advantages and drawbacks can be summarized.

Mapping is physical while the bubble model is only an approximation. In both cases a pressure field is applied on the fluid elements. While for the bubble model the pressure is constant and no particle velocity is considered the mapping considers the pressure-distance curve and also the particle velocity. Nevertheless, the bubble model is easier to use and easy to adapt to other charges and distances. For the mapping algorithm two runs are needed. It is slightly more complicated to perform and to adapt to other parameters (e.g. charge size). The description of the wave after the peak pressure is better in case of the mapping model but it shows slightly smaller peak pressures most probably due to first order approach in 1D.

Solid TNT models are very expensive. To reach appropriate values very small elements are needed at least in the explosive and around it. Also if bigger elements are used in zones with a smaller pressure ratio (far field of the explosion) the time step is very small. The results are not better than the one of the mapping method. Full solid TNT models use mainly the JWLS material law for the explosive as well as for the air. The additional terms for the calculation of the explosive are only needed during the explosion effect. Afterwards this terms results in unnecessary numerical costs.

In summary, the mapping method is an additional method in EUROPLEXUS that can be efficiently used to simulate the development of air blast waves.

## 6 References

- [1] A. Alia and M. Souli. High explosive simulation using multi-material formulations. *Applied Thermal Engineering*, 26:1032–1042, 2006.
- [2] D. Bogosian, J. Ferritto, and Y. Shi. Measuring uncertainty and conservatism in simplified blast models. In *30th Explosives Safety Seminar*, Atlanta, Georgia, 2002.
- [3] I.G. Cullis. Blast waves and how they interact with structures. *Journal of the Royal Army Medical Corps*, 147:16–26, 2001.
- [4] Manmohan Goel, Vasant Matsagar, Anil Gupta, and Steffen Marburg. An abridged review of blast wave parameters. *Defence Science Journal*, 62(5):300–306, 2012.
- [5] Charles N. Kingery and Gerald Bulmash. Airblast parameters from TNT spherical air burst and hemispherical surface burst. Technical report, Defence Technical Information Center, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, 1984.
- [6] Gilbert F. Kinney and Kenneth J. Graham. *Explosive Shocks in Air*. Springer, Berlin; Heidelberg; New York; Tokyo, 1985.
- [7] Martin Larcher. Pressure-time functions for the description of air blast waves. Technical Report JRC46829, Joint Research Centre, Ispra, Italy, 2008.
- [8] Martin Larcher. Simulation of air blast waves in urban environment. Technical Report JRC43400, Joint Research Centre, Ispra, Italy, 2008.
- [9] Martin Larcher. Simulations of a metro carriage exposed to an internal detonation. Technical Report JRC50327, 2009.
- [10] Martin Larcher and Folco Casadei. Explosions in complex geometries - a comparison of several approaches. *International Journal of Protective Structures*, 1(2):169–195, 2010.
- [11] Martin Larcher, Folco Casadei, Georgios Giannopoulos, George Solomos, Jean-Luc Planchet, and Anne Rochefrette. Determination of the risk due to explosions in railway systems. *Journal of Rail and Rapid Transit*, in press:1–10, 2011.

## 7 Appendix

### 7.1 Creation of a map file

1 kg TNT equivalent in 1 m distance

#### bm\_flu\_map1.dgibi

```
TITRE 'raccord TUBM et VF' ;
OPTION DIME 3 ELEM CUB8 ;
option sort 'map1d.msh' ;
*
tl_tnt = 0.052;
* about 1 kg tnt (0.96 kg)
tl_air = 1.948;
origine = 0. 0. 0. ;
pt0 = origine plus (0 0 0) ;
pt1 = pt0 plus (tl_tnt 0 0) ;
pt2 = pt1 plus (tl_air 0 0) ;
tu_tnt = pt0 DROIT 52 pt1 ;
tu_air = pt1 DROIT 1948 pt2 ;
cl_2 = MANU POI1 pt2 ;
*
tube = tu_air et tu_tnt;
mesh = tube et cl_2;
*
sortier mesh;
fin;
```

#### bm\_flu\_map1.epx

```
Bench to test writing of the map file
ECHO
  CAST FORM mesh
  TRID euler
GEOM
  TUVF tube
TERM
COMP
  DIAM CONE D1 0.000025 D2 0.05
  ORIG LECT pt0 TERM LIST LECT tube TERM
MATE
*jwl air
  JWLS a 3.738e11 b 3.747e9 r1 4.15 r2 0.90
  omeg 0.35 ros 1630 BETA 0.25
  ro 1.3 pini 1e5 eint 0.21978e6 pref 0
  LECT tu_air TERM
*
  JWLS a 3.738e11 b 3.747e9 r1 4.15 r2 0.90
  omeg 0.35 d 6930 BETA 0.25
  ro 1630 pini 1e5 eint 3.68e6 pref 0
  xdet 0. ydet 0. zdet 0.
  LECT tu_tnt TERM
LINK BLOQ 1 LECT pt0 pt2 TERM
ECRI
  FICH PVTK FORM TFRE 1.0e-4 VARI ECRO VCVI
  FICH MAPB MSPA DIPR 1.0 PCHE 1.5e5 FREQ 1
  FICH ALIC tfre 1e-4
  FICH ALIC TEMP tfre 1e-6
  poin lect 1 term
  elem lect 1 26 45 50 52 60 500 1000 1500
term
OPTI notest noprint
  cstab 0.9 LOG 1
VFCC FCONV 6 ORDR 2
CALC tini 0 nmax 30000 tfin 2.0e-3
*
SUITE
Post-treatment
RESU ALIC TEMP SORT GRAP
AXTE 1.0 'Time [s]'
Cour 1 'VF 1 ' ecro comp 1 elem lect 1 term
Cour 2 'VF 26 ' ecro comp 1 elem lect 26 term
Cour 3 'VC 45 ' ecro comp 1 elem lect 45 term
Cour 4 'VF 60 ' ecro comp 1 elem lect 60 term
```

```
Cour 5 'VF 500'ecro comp 1 elem lect 500 term
Cour 6 'VF 1000' ecro comp 1 elem lect 1000
term
Cour 7 'VF 1500' ecro comp 1 elem lect 1500
term
TRAC 1 axes 1.e-5 'pressure (bar)'
TRAC 2 axes 1.e-5 'pressure (bar)'
TRAC 3 axes 1.e-5 'pressure (bar)'
TRAC 4 axes 1.e-5 'pressure (bar)'
TRAC 5 axes 1.e-5 'pressure (bar)'
TRAC 6 axes 1.e-5 'pressure (bar)'
TRAC 7 axes 1.e-5 'pressure (bar)'
```

### 7.2 map3d test cases

#### map3d-fine-fine.dgibi

```
OPTI echo 1;
OPTI dime 3 elem cub8;
DENS 0.02;
sizx = 2.0;
sizy = 2.0;
sizz = 2.0;
p0 = 0 0 0;
x0 = (sizx) 0. 0.;
y0 = 0. (sizy) 0.;
z0 = 0. 0. (sizz);
*volume of the air
vol0 = p0 droi x0 tran z0 volu tran y0 coul
bleu;
*bubble
ages = vol0 enve;

a_absol = p0 droi x0 tran z0 plus y0;
a_abso2 = p0 droi y0 tran z0 plus x0;
a_abso3 = p0 droi x0 tran y0 plus z0;
a_abso = a_absol et a_abso2 et a_abso3;

a_symm1 = p0 droi x0 tran z0;
a_symm2 = p0 droi y0 tran z0;
a_symm3 = p0 droi x0 tran y0;
a_fsr = a_symm1 et a_symm2 et a_symm3;

elim (ages et a_abso et a_fsr);

geom_new = (vol0 et a_abso et a_fsr);

TASS geom_new;
OPTI sauv form 'map3d-fine-fine.msh';
sauv form geom_new;
fin;
```

#### map3dvfcc-fine-fine.epx

```
Titel
ECHO
CAST 'map3d-fine-fine.msh' vol0
TRID EULER RISK
OPTI TOLC 1e-1
$
GEOM CUVF vol0 TERM
COMP
  GROU 1 'x1' LECT vol0 TERM COND NEAR POIN
  0.0 0.0 0.5
  NGRO 1 'ns1' LECT vol0 TERM COND LINE X1
  0.1 Y1 0.1 Z1 0
  X2 0.1 Y2 0.1 Z2 5.0 TOL 0.01
*
MATE
$ air
  GAZP RO 1.3 PINI 1E5 GAMMA 1.35 PREF 1e5
  LECT vol0 TERM
INIT MAPB 'map1d.map' POS 0 0.0 0.0
ECRI FICH ALIC TEMP TFREQ 2e-6
  ELEM LECT 60 x1 TERM
```

```

POIN LECT ns1 TERM
FICH PVTK TFREQ 1.0e-4 VARI ECRO CONT VCVI
RISK
$
OPTI NOTE LOG 1 STEP IO
CSTA 0.50 VFCC
VFCC
FCONV 6
ORDRE 2 OTPS 2
RECONS 1
LMAS 3 LQDM 3 LENE 3
KMAS 0.75 KQDM 0.75 KENE 0.75
CENER
$
CALC TINI 0 TEND 3e-3 PAS1 1.E-8
*=====
SUIT
POSTTREATMENT FROM ALICE TEMPS FILE
$
ECHO
$
RESU ALIC TEMP GARD PSCR
*
OPTI PRIN
SORT GRAP
*
AXTE 1.0 'Time [s]'
*
COUR 1 'x1' ECRO COMP 1 ELEM LECT 60 TERM
*
trac 1 axes 1.0 'PRESS. [PA]'
list 1 axes 1.0 'PRESS. [PA]'
FIN

```

### map3dvfcc-fine-fine-bub.epx

```

Titel
ECHO
! VERI
* CONV WIN
CAST 'map3d-fine-fine.msh' vol0
TRID EULER RISK
OPTI TOLC 1e-1
$
GEOM
CUVF vol0
TERM
COMP
GROU 12 'x1' LECT vol0 TERM COND NEAR POIN
0.0 0.0 0.5
      'x2' LECT vol0 TERM COND NEAR POIN
0.0 0.0 1.0
      'x3' LECT vol0 TERM COND NEAR POIN
0.0 0.0 1.5
      'x4' LECT vol0 TERM COND NEAR POIN
0.0 0.0 2.0
      'x5' LECT vol0 TERM COND NEAR POIN
0.0 0.0 2.5
      'x6' LECT vol0 TERM COND NEAR POIN
0.0 0.0 3.0
      'x7' LECT vol0 TERM COND NEAR POIN
0.0 0.0 3.5
      'x8' LECT vol0 TERM COND NEAR POIN
0.0 0.0 4.0
      'x9' LECT vol0 TERM COND NEAR POIN
0.0 0.0 4.5
      's1' LECT vol0 TERM COND BOX X0 0 Y0
0 Z0 0
                                DX 0.1
DY 0.1 DZ 5.0
      'bubb' LECT vol0 TERM
              COND SPHE R 0.35 XC 0.0 YC
0.0 ZC 0.0
      'flui' LECT vol0 DIFF bubb TERM
NGRO 1 'ns1' LECT vol0 TERM COND LINE X1
0.1 Y1 0.1 Z1 0
                                X2 0.1 Y2 0.1
Z2 5.0 TOL 0.01
*

```

```

MATE
$ air
GAZP RO 1.3 PINI 1E5 GAMMA 1.35
PREF 1e5
LECT flui TERM
BUBB MASS 0.125 ! must be 1/8 - symmetry
LECT bubb TERM
ECRI FICH ALIC TEMP TFREQ 2e-6
ELEM LECT 60 x1 x2 x3 x4 x5 x6 x7 x8
x9 s1 ns1 TERM
POIN LECT s1 ns1 TERM
FICH PVTK TFREQ 1.0e-4 VARI ECRO CONT VCVI
RISK
$
OPTI NOTE LOG 1 STEP IO
CSTA 0.50 VFCC
VFCC
FCONV 6
ORDRE 2 OTPS 2
RECONS 1
LMAS 3 LQDM 3 LENE 3
KMAS 0.75 KQDM 0.75 KENE 0.75
CENER
$
CALC TINI 0 TEND 3e-3 PAS1 1.E-8
*=====
POSTTREATMENT FROM ALICE TEMPS FILE
ECHO
RESU ALIC TEMP 'map3dvfcc-fine-fine_bub.alt'
GARD PSCR
*
OPTI PRIN
SORT GRAP
AXTE 1.0 'Time [s]'
*
COUR 1 'x1' ECRO COMP 1 ELEM LECT 60 TERM
trac 1 axes 1.0 'PRESS. [PA]'
list 1 axes 1.0 'PRESS. [PA]'
FIN

```

## 7.3 alia tests

### 7.3.1 Parameter test for creation of mapping file

#### map\_para1.dgibi

```

TITRE 'raccord TUBM et VF' ;
OPTION DIME 3 ELEM CUB8 ;
option sort 'map_paral.msh' ;
*
tl_tnt = 0.034;
* about 268 g tnt
tl_air = 1.966;
origine = 0. 0. 0. ;
pt0 = origine plus (0 0 0) ;
pt1 = pt0 plus (tl_tnt 0 0) ;
pt2 = pt1 plus (tl_air 0 0) ;
tu_tnt = pt0 DROIT 68 pt1 ;
tu_air = pt1 DROIT 3932 pt2 ;
cl_2 = MANU POI1 pt2 ;
*
tube = tu_air et tu_tnt;
mesh = tube et cl_2;
sortier mesh;
fin;

```

#### map\_para1.epx

```

VF
ECHO
CAST FORM mesh
TRID euler
GEOM
tuvf tube
TERM
COMP

```



```

DIAM CONE D1 0.000025 D2 0.05
ORIG LECT pt0 TERM LIST LECT tube TERM
MATE
*jwl air
  jwls      a 3.738e11    b 3.747e9    r1 4.15
r2 0.90
      omeg 0.35    ros 1630    BETA 0.25
      ro 1.3      pini 1e5      eint
0.21978e6  pref 0
      LECT tu_air TERM
*
** Le TNT :   on donne directement ro = ros
*             avec ignition au point P7
*             la vitesse de detonation est celle de
Chapman-Jouguet
*
  jwls      a 3.738e11    b 3.747e9    r1 4.15
r2 0.90
      omeg 0.35    d 6930      BETA 0.25
      ro 1630     pini 1e5      eint
3.68e6     pref 0
      xdet 0. ydet 0. zdet 0.
      LECT tu_tnt TERM
LINK BLOQ 1 LECT pt0 pt2 TERM
ECRI
  FICH MAPB MSPA DIPR 1.0 PCHE 1.5e5 FREQ 1
  FICH ALICE tfreq 1e-4
  FICH ALICE TEMPS tfreq 1e-6
  poin lect 1 term
  elem lect 1 26 45 50 52 60 500 1000 1500
term
*
OPTI notest noprint
      cstab 0.9
*
VFCC ! DUMP
      FCONV 6 ORDR 2
*
CALC tini 0    nmax 30000    tfin 2.0e-3
*
SUITE
Post-treatment 1
RESU ALICE TEMPS
SORT GRAP
AXTE 1.0 'Time [s]'
*
Courbe 1 'VFCC 1 '      ecrou comp 1 elem lect 1
term
Courbe 2 'VFCC 26 '     ecrou comp 1 elem lect
26 term
Courbe 3 'VFCC 45 '     ecrou comp 1 elem lect
45 term
*
Courbe 31 'VFCC 60 '    ecrou comp 1 elem lect
60 term
Courbe 4 'VFCC 500 '    ecrou comp 1 elem lect
500 term
Courbe 5 'VFCC 1000 '   ecrou comp 1 elem lect
1000 term
Courbe 6 'VFCC 1500 '   ecrou comp 1 elem lect
1500 term
TRACE 1 axes 1.e-5 'Pression (bar)'
TRACE 2 axes 1.e-5 'Pression (bar)'
TRACE 3 axes 1.e-5 'Pression (bar)'
TRACE 31 axes 1.e-5 'Pression (bar)'
TRACE 4 axes 1.e-5 'Pression (bar)'
TRACE 5 axes 1.e-5 'Pression (bar)'
TRACE 6 axes 1.e-5 'Pression (bar)'
*
SUITE
Post-treatment 2
RESU ALICE
SORT GRAP
AXTE 1.0 'Time [s]'
*
SCOUR 99 '0.05ms' ECRO COMP 1 T 0.05e-3 SAXE
1.0 'ABSC' LECT tube TERM
SCOUR 100 '0.1ms' ECRO COMP 1 T 0.1e-3 SAXE 1.0
'ABSC' LECT tube TERM

```

```

SCOUR 101 '0.2ms' ECRO COMP 1 T 0.2e-3 SAXE 1.0
'ABSC' LECT tube TERM
SCOUR 102 '0.4ms' ECRO COMP 1 T 0.4e-3 SAXE 1.0
'ABSC' LECT tube TERM
SCOUR 103 '0.5ms' ECRO COMP 1 T 0.5e-3 SAXE 1.0
'ABSC' LECT tube TERM
SCOUR 104 '1.0ms' ECRO COMP 1 T 1.0e-3 SAXE 1.0
'ABSC' LECT tube TERM
TRACE 99 100 101 102 103 104 TEXT axes 1.0
'Pression (Pa)'
*
SCOUR 200 '0.1ms' VCVI COMP 1 T 0.1e-3 SAXE 1.0
'ABSC' LECT tube TERM
SCOUR 201 '0.2ms' VCVI COMP 1 T 0.2e-3 SAXE 1.0
'ABSC' LECT tube TERM
SCOUR 202 '0.4ms' VCVI COMP 1 T 0.4e-3 SAXE 1.0
'ABSC' LECT tube TERM
SCOUR 203 '0.5ms' VCVI COMP 1 T 0.5e-3 SAXE 1.0
'ABSC' LECT tube TERM
SCOUR 204 '1.0ms' VCVI COMP 1 T 1.0e-3 SAXE 1.0
'ABSC' LECT tube TERM
TRACE 200 201 202 203 204 TEXT axes 1.0
'Particle velocity (m/s)'
*
TRACE 100 axes 1.0 'Pression (Pa)'
TRACE 101 axes 1.0 'Pression (Pa)'
TRACE 102 axes 1.0 'Pression (Pa)'
TRACE 103 axes 1.0 'Pression (Pa)'
TRACE 104 axes 1.0 'Pression (Pa)'

```

FIN

## 7.3.2 Alia simulation with small model

### alia\_map.dgibi

```

*Construction d'une sphere a partir d'un cube
opti dime 3 elem cub8;
*Nombre de bisections
nel0 = 7;
nel1 = 7;
*Cote du cube intermediaire
r0 = .25;
sizeex = 0.0323;
sizeai = 0.14;
width = 0.4;
height = 2.0;
dini = 3.141*sizeex/(4.*nel0);
dfin = 3.141*sizeai/(4.*nel0);
*Reference
o0 = 0. 0. 0.;
x0 = (sizeex) 0. 0.;
xa0 = 0 (sizeex) (sizeex);
xb0 = (sizeex) (sizeex) (sizeex);
xc0 = (sizeex) 0 (sizeex);
xd0 = 0 0 (sizeex);
y0 = 0. (sizeex) 0.;
z0 = 0. 0. (sizeex);
x1 = (sizeai) 0. 0.;
y1 = 0. (sizeai) 0.;
z1 = 0. 0. (sizeai);
c0 = x0 plus y0 plus z0 / 2.;
c1 = x1 plus y1 plus z1 / 2.;
symp1 = (sizeex/2.) (sizeex/2.) (sizeex/2.);
symp2 = (sizeai/2.) (sizeai/2.) (sizeai/2.);
*Cube intermediaire (centre=o0 et arete=r0)
vol0 = o0 droi nel0 x0 tran nel0 z0 volu tran
nel0 y0
      coul bleu homo o0 r0;
vol10 = o0 droi nel0 x0 tran nel0 z0 volu tran
nel0 y0
      coul bleu homo o0 0.2;
cub0 = (o0 droi nel0 y0 tran nel0 x0)
      et (o0 droi nel0 z0 tran nel0 y0) et
      (o0 droi nel0 x0 tran nel0 z0)
      syme 'POINT' symp1 homo o0 r0;
cub1 = (o0 droi nel0 y0 tran nel0 x0)

```

```

    et (o0 droi nel0 z0 tran nel0 y0) et
    (o0 droi nel0 x0 tran nel0 z0)
    syme 'POINT' symp1;
cub2 = (o0 droi nel0 y1 tran nel0 x1)
    et (o0 droi nel0 z1 tran nel0 y1) et
    (o0 droi nel0 x1 tran nel0 z1)
    syme 'POINT' symp2;
*Projection sur la sphere de rayon unitaire
spe1 = cub0 proj 'CONI' o0 'SPHE' o0 x0;
spe2 = cub2 proj 'CONI' o0 'SPHE' o0 x1;

*Remplissage
vol1 = cub0 volu nell spe1 coul vert;
vol1 = vol1 et vol0;
vol2 = spe1 volu 'DINI' dini 'DFIN' dfin cub2
coul bleu;

x2 = (width) 0. 0.;
y2 = 0. (width) 0.;
z2 = 0. 0. (height);
dw = 20;
dh = 100;
air = o0 d dw x2 tran dh z2 volu
    tran dw y2 coul bleu;

vges = (air);
elim vges 1e-6;
afull = enve vges;

kod1 = faux;
kod2 = faux;
kod3 = faux;
kod4 = faux;
REPE I0 (NBEL afull);
    symm = faux;
    xx yy zz = coor (bary (afull ELEM QUA4 &I0));
    SI ( xx < 0.0001 );
    si (kod1);a_symmx=(a_symmx et (afull ELEM
QUA4 &I0));
    sinon; a_symmx = afull ELEM QUA4 &I0;kod1 =
vrai;
    fins;
    symm = vrai;
    FINS;
    SI ( yy < 0.0001);
    si (kod2);a_symmy=(a_symmy et (afull ELEM
QUA4 &I0));
    sinon; a_symmy = afull ELEM QUA4 &I0;kod2 =
vrai;
    fins;
    symm = vrai;
    FINS;
    SI ( zz < 0.0001);
    si (kod3);a_symmz=(a_symmz et (afull ELEM
QUA4 &I0));
    sinon; a_symmz = afull ELEM QUA4 &I0;kod3 =
vrai;
    fins;
    symm = vrai;
    FINS;
    SI (symm NEG vrai);
    si (kod4);a_abso=(a_abso et (afull ELEM
QUA4 &I0));
    sinon; a_abso = afull ELEM QUA4 &I0;kod4 =
vrai;
    fins;
    FINS;
FIN I0;

fp1 = vol0 poin proche (0.0 0.0 1.52);
fel = vol0 elem contenant fp1;

mesh = (vges et a_abso et a_symmx et a_symmy et
a_symmz et fel);

TASS mesh;
OPTI sauv form 'alia_map.msh';
sauv form mesh;

```

## alia7\_map1.epx

```

alia1 - finite volume with mapping
ECHO
CAST 'alia_map.msh' mesh
TRID EULER
OPTI TOLC 1e-1
*
GEOM
    CUVF air
    CL3D a_abso
TERM
*
MATE
    GAZP          RO 1.3    PINI 1E5    GAMMA 1.35
    PREF 1e5
    LECT air TERM
    CLVF ABSO RO 1.3 lect a_abso term
INIT MAPB 'map1d_al.map' POS 0 0.0 0.0

ECRI FICH ALIC TEMP tfreq 3e-6
    ELEM LECT 3404 fel TERM
    FICH ALIC TFRE 5E-5
    FICH PVTK TFREQ 1.0e-4 VARI ECRO CONT VCVI
RISK
*
OPTION NOTEST PASAUTO
*
    CSTA 0.50 VFCC
    VFCC
        FCONV 6
        ORDRE 2 OTPS 2
        RECONS 1
        LMAS 3    LQDM 3    LENE 3
        KMAS 0.75 KQDM 0.75 KENE 0.75
        CENER
*
OPTI NOTE LOG 1
CALC TINI 0 TEND 3e-3
=====
SUIT
Post-treatment (time curves from alt file)
ECHO
*
RESU ALIC TEMP GARD PSCR
SORT GRAP
AXTE 1.0 'Time [s]'
*
COUR 4 'fel' ECRO COMP 1 ELEM LECT 3404 TERM
trac 4 TEXT axes 1.0 'Pressure [Pa]'
list 4 TEXT axes 1.0 'Pressure [Pa]'
fin

```

## 7.3.3 Alia simulation with full model

### alia\_full.dgibi

```

*ALIA model with the air upto the wall.
opti dime 3 elem cub8;
*Nombre de bisections
sizeai = 0.1;
nbel_bub = 5;
widthx = 1.2;
widthy = 0.8;
height = 2.0;
*Reference
o0 = 0. 0. 0.;

*Remplissage
x2 = (widthx) 0. 0.;
y2 = 0. (widthy) 0.;
z2 = 0. 0. (height);
dwx = 60;
dwy = 40;
dh = 100;
air = o0 d dwx x2 tran dh z2 volu
    tran dwy y2 coul bleu;
vges = air;
elim vges 1e-6;

```

```

afull = enve vges;

kod1 = faux;
kod2 = faux;
kod3 = faux;
kod4 = faux;
kod5 = faux;
REPE I0 (NBEL afull);
  symm = faux;
  xx yy zz = coord (bary (afull ELEM QUA4 &I0));
  SI ( xx < 0.0001 );
  si (kod1);a_symmx=(a_symmx et (afull ELEM
QUA4 &I0));
  sinon; a_symmx = afull ELEM QUA4 &I0;kod1 =
vrai;
  fins;
  symm = vrai;
  FINS;
  SI ( yy < 0.0001);
  si (kod2);a_symmy=(a_symmy et (afull ELEM
QUA4 &I0));
  sinon; a_symmy = afull ELEM QUA4 &I0;kod2 =
vrai;
  fins;
  symm = vrai;
  FINS;
  SI ( zz < 0.0001);
  si (kod3);a_symmz=(a_symmz et (afull ELEM
QUA4 &I0));
  sinon; a_symmz = afull ELEM QUA4 &I0;kod3 =
vrai;
  fins;
  symm = vrai;
  FINS;
  SI ( xx > (widthx-0.0001));
  si (kod4);a_fix=(a_fix et (afull ELEM QUA4
&I0));
  sinon; a_fix = afull ELEM QUA4 &I0;kod4 =
vrai;
  fins;
  symm = vrai;
  FINS;
  SI (symm NEG vrai);
  si (kod5);a_abso=(a_abso et (afull ELEM
QUA4 &I0));
  sinon; a_abso = afull ELEM QUA4 &I0;kod5 =
vrai;
  fins;
  FINS;
FIN I0;

```

```

fp1 = vges poin proche (0.0 0.0 1.52);
fel = vges elem contenant fp1;

```

```

mesh = (vges et a_abso et a_symmx et a_symmy et
a_symmz
et a_fix et fel);

```

```

TASS mesh;
OPTI sauv form 'alia_full.msh';
sauv form mesh;
mess (nbel (mesh));
mess (nbno (mesh));
mess (mesu (bub));

```

### alia\_map1\_full.epx

```

alia1 - finite volume with mapping
$
ECHO
CAST 'alia_full.msh' mesh
TRID EULER
OPTI TOLC 1e-1
*
GEOM
  CUVF air
  CL3D a_abso
TERM
*
MATERIAU

```

```

GAZP RO 1.3 PINI 1E5 GAMMA 1.35
PREF 1e5
LECT air TERM
CLVF ABSO RO 1.3 lect a_abso term
INIT MAPB 'map1d_a1.map' POS 0 0.0 0.0

ECRI FICH ALIC TEMP tfreq 3e-6
ELEM LECT 3404 fel TERM
FICH ALIC TFRE 5E-5
FICH PVTK TFREQ 1.0e-4 VARI ECRO CONT VCVI
RISK
  GROU 1 OBJE 'air' LECT air TERM
*
OPTION NOTEST PASAUTO
*
CSTA 0.50 VFCC
*
VFCC
  FCONV 6
  ORDRE 2 Otps 2
  RECONS 1
  LMAS 3 LQDM 3 LENE 3
  KMAS 0.75 KQDM 0.75 KENE 0.75
  CENER
*
OPTI NOTE LOG 1
CALC TINI 0 TEND 5e-3
*
=====
SUIT
Post-treatment (time curves from alice temps
file)
ECHO
*
RESU ALIC TEMP GARD PSCR
SORT GRAP
AXTE 1.0 'Time [s]'
*
COUR 4 'fel' ECRO COMP 1 ELEM LECT 3404 TERM
trac 4 TEXT axes 1.0 'Pressure [Pa]'
list 4 TEXT axes 1.0 'Pressure [Pa]'
fin

```

## 7.3.4 Explosion inside a train

### map\_9kg\_1m.dgibi

```

TITRE 'raccord TUBM et VF' ;
OPTION DIME 3 ELEM CUB8 ;
option sort 'map_9kg_1m.msh' ;
*
tl_tnt = 0.11;
* about 9 kg tnt ( kg)
tl_air = 1.89;
origine = 0. 0. 0. ;
pt0 = origine plus (0 0 0) ;
pt1 = pt0 plus (tl_tnt 0 0) ;
pt2 = pt1 plus (tl_air 0 0) ;
tu_tnt = pt0 DROIT 110 pt1 ;
tu_air = pt1 DROIT 1890 pt2 ;
cl_2 = MANU POI1 pt2 ;
*
tube = tu_air et tu_tnt;
mesh = tube et cl_2;
*
sortier mesh;
fin;

```

### map\_9kg\_1m.epx

```

Calculation of the blast wave in 1 m distance
with a charge of 9 kg TNT
*
ECHO
  CAST FORM mesh
  TRID euler

```

```

GEOM TUVF tube
TERM
*
COMP
  DIAM CONE D1 0.000025 D2 0.05
  ORIG LECT pt0 TERM LIST LECT tube TERM
MATE
*jwl air
  JWLS a 3.738e11 b 3.747e9 r1 4.15 r2 0.90
  omeg 0.35 ros 1630 BETA 0.25
  ro 1.3 pini 1e5 eint 0.21978e6 pref 0
  LECT tu_air TERM
*
  JWLS a 3.738e11 b 3.747e9 r1 4.15 r2 0.90
  omeg 0.35 d 6930 BETA 0.25
  ro 1630 pini 1e5 eint 3.68e6 pref 0
  xdet 0. ydet 0. zdet 0.
  LECT tu_tnt TERM
LINK BLOQ 1 LECT pt0 pt2 TERM
ECRI
  FICH PVTK FORM TFRE 1.0e-4 VARI ECRO VCVI
  FICH MAPB DIPR 1.0 PCHE 1.5e5 FREQ 1
  FICH ALIC tfre 1e-4
  FICH ALIC TEMP tfre 1e-6
  poin lect 1 term
  elem lect 1 26 45 50 52 60 500 1000 term
*
OPTI notest noprint
  cstab 0.9 LOG 1
VFCC FCONV 6 ORDR 2
CALC tini 0 nmax 30000 tfin 2.0e-3
FIN

```

## train\_madrid\_21\_vf.epx

```

train
*-----
ECHO ! comment
CAST 'train_madrid21_vf.msh' mesh
EROS 0.5
*-----Problem type
TRID ALE RISK
*-----Dimensioning
DIME
  NALE      1 NBLE      1
TERM
*-----Geometry
GEOM
  DKT3 s_tri
  Q4GS sall wall seats hb1 doors
  POUT segm segm_top
  CUVF vol0
  CL3D ages
TERM
*-----Geometric complements
COMP EPAI 3.E-3 LECT sall s_tri TERM
  4.E-3 LECT seats TERM
  6.E-3 LECT wall TERM
  1.E-2 LECT doors TERM
  1.E-1 LECT hb1 TERM
TERM
  GEOP QUEL VX 0 VY 0 VZ 1
  AIRE 7.6E-4 IY 80.1E-8 IZ 8.49E-8 HY
0.023 HZ 0.04 R 3.41e-2
  LECT segm TERM
  RECT VX 1 VY 0 VZ 0
  AY 0.06 AZ 0.03
  LECT segm_top TERM
  EROS 0.0 LECT wall doors TERM
*-----ALE
GRIL LAGR LECT sall s_tri wall doors seats hb1
TERM
  EULE LECT vol0 TERM
*-----Material data
MATE GAZP      RO 1.3      PINI 1E5      GAMMA 1.35
PREF 1e5
  LECT vol0 TERM

```

```

VM23 RO 7800. YOUNG 2.1E11 NU 0.333 ELAS
1.2E8
  FAIL VMIS LIM1 1.6E8
  TRAC 2 1.2E8 1.1E-3 1.6E8 0.13
  LECT sall s_tri seats TERM
  VMIS ISOT RO 2700 YOUNG 7E10 NU 0.3 ELAS
200E6 FAIL 1 LIM1 2.1e8
  TRAC 2 200e6 2.85e-3
  250e6 0.23
  LECT segm segm_top TERM
GLAS RO 2500 YOUN 7E10 NU 0.23 CORR 16.0
  FAIL PSAR LIM1 159.6e6
  LECT wall doors TERM
VM23 RO 1400.0 YOUN 4E7 NU 0.3
  ELAS 10E7
  FAIL PEPS LIM1 0.2
  TRAC 1 10e7 0.25
  LECT hb1 TERM
  CLVF ABSO RO 1.4 LECT ages TERM
*-----Boundary conditions
LINK DECO FLSW STRU LECT sall s_tri wall doors
seats hb1 TERM
  FLUI LECT vol0 TERM
  FACE
  HGRI 0.14
  R 0.10
  BFLU 2
  FSCP 0
BLOQ 123 LECT a_fix TERM
INIT MAPB 'map_9kg_lm.map' POS 0.6 0.75 10.2
*-----Outputs
ECRI
  FICH ALIC TEMP FREQ 1
  elem lect 244397 term
  FICH PVTK tFREQ 1e-3 VARI ECRO CONT DEPL
FAIL RISK
GROU 6
  OBJE LECT sall s_tri TERM
  OBJE LECT wall doors TERM
  OBJE LECT segm segm_top TERM
  OBJE LECT vol0 TERM
  OBJE LECT seats TERM
  OBJE LECT hb1 TERM
*-----Options
OPTI NOTE
  NF34
  csta 0.25
  LOG 1
VFCC
  FCONV 6
  ORDRE 2 OTPS 2
  RECONS 1
  LMAS 3 LQDM 3 LENE 3
  KMAS 0.75 KQDM 0.75 KENE 0.75
  CENER
*-----Transient calculation
CALC TINI 0 TFAI 1e-9 TEND 40.E-3
FIN

```

Europe Direct is a service to help you find answers to your questions about the European Union  
Freephone number (\*): 00 800 6 7 8 9 10 11

(\* ) Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

A great deal of additional information on the European Union is available on the Internet.  
It can be accessed through the Europa server <http://europa.eu/>.

#### **How to obtain EU publications**

Our priced publications are available from EU Bookshop (<http://bookshop.europa.eu>),  
where you can place an order with the sales agent of your choice.

The Publications Office has a worldwide network of sales agents.  
You can obtain their contact details by sending a fax to (352) 29 29-42758.

European Commission

**EUR 26735 EN – Joint Research Centre – Institute for the Protection and Security of the Citizen**

Title: Simulation of blast waves by using mapping technology in EUROPLEXUS

Authors: Martin Larcher, Folco Casadei, George Solomos

Luxembourg: Publications Office of the European Union

2014 – 32 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424

ISBN 978-92-79-39249-8

doi:10.2788/98310

#### **Abstract**

Finite element or finite volume simulations for the development of blast waves by using a model for the explosion of the solid itself need very fine meshes in the explosive and in the zone around the explosive. Structures may have a long distance to the source of the explosive. This leads often to very big meshes with many elements. The explosive is meshed often only coarse and therefore the results are not very accurate. There are several possibilities to deal with this problem.

Large 3D calculations with a solid TNT model using a JWL-equation can be used but they are more effective when the results of one finer mesh could be mapped in a coarser mesh after some calculation steps. When the blast wave reaches a certain distance to the charge, the small elements inside the charge are not needed any more since the pressure ratio is decreased strongly. These small elements results in very small time steps for the full model. The report shows the implementation of the mapping algorithm in EUROPLEXUS and several validation tests of the method.

## JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

*Serving society  
Stimulating innovation  
Supporting legislation*

