

SIMULATION OF A DETONATION CHAMBER TEST CASE

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Abstract

The purpose of a detonation chamber is to ensure vapor and fragment containment during the destruction of explosive munitions. The toxic vapors generated by the detonation can be vented into a filtration unit. Compared to free air detonations, the use of a detonation chamber reduces the environmental impact of munitions destruction.

The manufacture and testing of a detonation chambers is time consuming and expensive. At present, new designs are mainly based on experience with previous designs and rough estimates. A more accurate and reliable method for predicting a chambers performance would therefore be a significant aid in the design process.

This paper considers the most straightforward method for predicting the performance of a chamber design, which is to simulate a munitions detonation in the chamber. The simulation is accomplished using LS-DYNA's multi-material Eulerian methods.

Introduction

Detonation chambers are used to ensure vapor and fragment containment during the destruction of explosive munitions. The toxic vapors generated by the detonation can be vented into a filtration unit. Compared to free air detonations, the use of a detonation chamber reduces the environmental impact of munitions destruction.

At present, new designs of detonation chambers are mainly based on experience with previous designs and rough estimates. A more accurate and reliable method for predicting a chambers performance would therefore be a significant aid in the design process.

This paper considers the most straightforward method for predicting the performance of a chamber design, which is to simulate a test case where a spherical TNT charge is detonated in the chamber. The simulation is accomplished using the multi-material Eulerian method of LS-DYNA, version 960 (1) (2). (Note: a beta release of version 960 is used.)

Using simulations to predict the performance of detonation chambers must be regarded as an experimental method. The accuracy and usefulness of the method will be determined by comparison with future full-scale tests.

Test case

In the test case a spherical TNT-charge is detonated inside the detonation chamber, Figure 1. After the charge has been ignited the following stages occur:

1. The charge detonates and burns.
2. The charge residue expands and a blast wave is formed.
3. The blast wave expands until it reaches the inner walls of the chamber.
4. A shock wave is formed in the chamber structure due to the impact and reflection of the incoming blast wave. After the first reflection of the blast wave, diffraction and interference together with the interaction with the chamber walls creates a complicated pattern of waves traveling through the chamber.

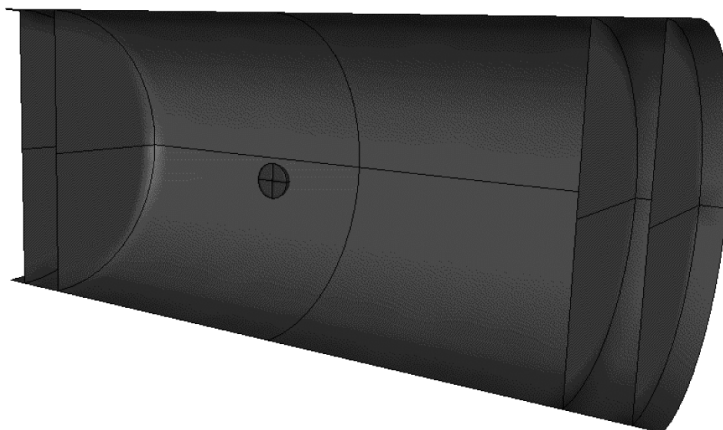


Figure 1 Cross section of a detonation chamber with charge (the diameter of the chamber is 2.4m).

Approach

The simulation of the detonation of a charge in a detonation chamber is a fluid/structure interaction with explosive loading. This type of simulation is very complex and computationally demanding, given the currently available computers.

To simulate the test case the following stages have to be properly modeled

1. Ignition, detonation, and burn of the charge
2. Expansion of the detonation residue/gases and formation of the blast wave
3. Expansion of the blast wave
4. Interaction of the blast wave with the chamber walls, which yields a shock wave in the chamber structure
5. The plastic deformation of the chamber structure.

Using LS-DYNA (1) (2) has from a practical point *the great advantage that the entire simulation can be contained in a single code*. Stages 1-3 are modeled using the multi material Eulerian capabilities, stage 4 using the fluid-structure coupling, and stage 5 using the standard finite method.

For this problem is important to have a smooth and regular mesh, this was accomplished using TrueGrid (6).

Charge explosion

The gases from the detonation will mix with the air during explosion. The multi material solid element (ELFORM=11) allows a mixture of several materials in the same element. LS-DYNA uses an operator split method for integrating the governing equations in their Eulerian formulation.

The following numerical values used for the Eulerian/ALE solver were changed from their default values

- **NADV=1** An advection is performed every timestep.
- **METH=2** The Van Leer + half index shift method is used to perform the advection. This is currently the most accurate method available in LS-DYNA.

4.1 Air

The air in the chamber is modeled as an inviscid ideal gas. The expansion of the blast wave is assumed to be an adiabatic process, which results in the following equation of state for the air

$$p = (\gamma - 1) \frac{\rho}{\rho_0} E$$

where ρ is the density and E the internal energy per initial volume. The material data used for the air are given in Table 1.

Table 1 Material data of Air.

Initial density ρ_0	1.293 kg/m ³
Initial pressure	1 Bar
Ratio of specific heats (γ)	1.4

The *MAT_NULL material and *EOS_LINEAR_POLYNOMIAL equation of state in LS-DYNA are used to express the above constitutive relations.

4.2 Charge

The properties of the TNT explosive are taken from (5), Table 2.

Table 2 Material data of TNT explosive.

Density	1630 kg/m ³
Detonation velocity	6930 m/s
Chapman-Jouget pressure	21.0 GPa
Internal energy density (E0)	7.0 GPa

The explosive is ignited at the center and a “programmed burn” model is used with a “burn fraction” enhancement, material *MAT_HIGH_EXPLOSIVE_BURN with option BETA=2 and *INITIAL_DETONATION. In this model the ignition time of a particle in the explosive is equal to its distance to the ignition point divided by the detonation velocity.

The evolution of the explosive after ignition is described by the Jones-Wilkins-Lee (JWL) equation of state, *EOS_JWL, which defines the pressure as

$$p = A \left(1 - \frac{\omega}{R_1 V} \right) e^{-R_1 V} + B \left(1 - \frac{\omega}{R_2 V} \right) e^{-R_2 V} + \frac{\omega E}{V}$$

where V is the relative volume, E the internal energy density per initial volume, and the constants in the case of TNT are given in Table 3; see Table 2 in (5).

Table 3 Material constants of the JWL EOS for TNT.

ω	0.30
A	371.213 GPa
B	3.2306 GPa
R_1	4.15
R_2	0.95

Chamber structure

Plate steel is used in the chamber. An isotropic linear hardening material model is used; typical material data is given in Table 4. Fully integrated shell elements were used, ELFORM=16 together with the default hourglass control.

Table 4 Typical material properties of plate steel.

Yield strength	460 MPa
Young’s Modulus	220 GPa
Density	7800 kg/m ³
Poisson’s ratio	0.3
Hardening modulus	500 MPa

Fluid-structure interaction

The Euler and Lagrange elements at the air and chamber-wall interface are coupled using a penalty method, *CONSTRAINED_LAGRANGE_IN_SOLID (CTYPE=4). This coupling method has the advantage that it gives complete freedom to create an optimal mesh for both the Lagrangean and Eulerian domains, compared to alternative coupling methods.

Convergence study: 3D shell chamber

To get an idea of what an appropriate element size is, a simple detonation chamber model was created with three different mesh densities. An illustration of the chamber is given in Figure 1.

Due to the symmetry only an eighth of the chamber was modeled. An illustration of the base model with the coarsest mesh is given in Figure 2. Two additional models were then created by dividing each original element into 8 pieces. Even though the models are quite large they ran quickly, the model with 198144 elements took 10h to complete 6 ms simulation time on a Compaq DS10 (equivalent to a 1.3GHz Pentium 4).

A graded mesh was used to capture the large pressure gradients at the beginning of the simulation, Figure 4. Considering the large difference in mesh density the difference in result is remarkably small, see Table 5.

7.1 Energy dissipation

There is a certain leakage of energy, which probably is due to the advection step, Table 5. The energy leakage is greatest at the beginning of the simulation, when there are sharp pressure gradients, see Figure 5. Typically, around 20-30% of the initial energy in the detonation was lost in this manner. Refining the mesh only seems to lessen the energy loss to a certain degree.

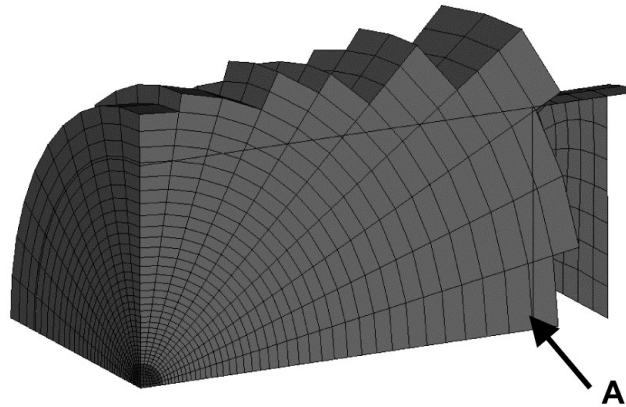


Figure 2 3D convergence study, course mesh.

Table 5 Results from 3D convergence study.

Mesh	# elements	Max disp. node A (mm)	Max eff. plastic strain	Energy dissipation
1	3096	41.8	1.1	29%
2	24768	41.2	1.0	26%
3	198144	40.9	1.3	21%

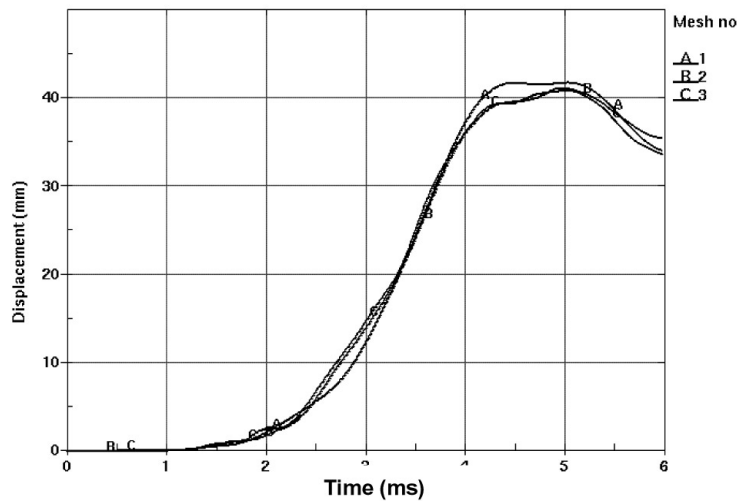


Figure 3 Displacement of the point A.

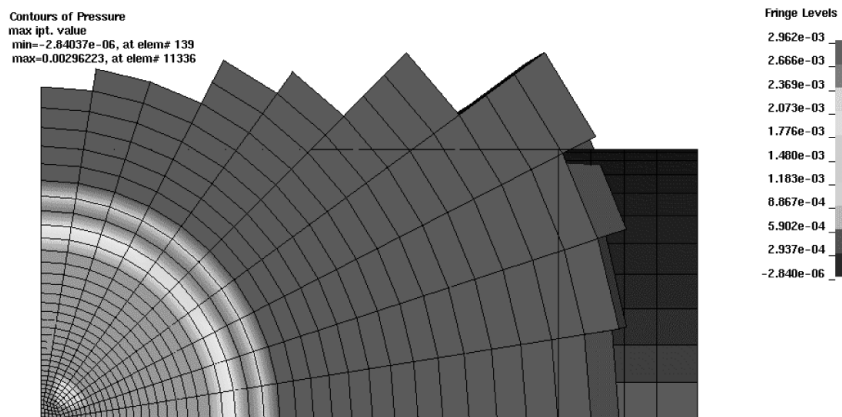


Figure 4 Pressure distribution at t=0.3 ms.

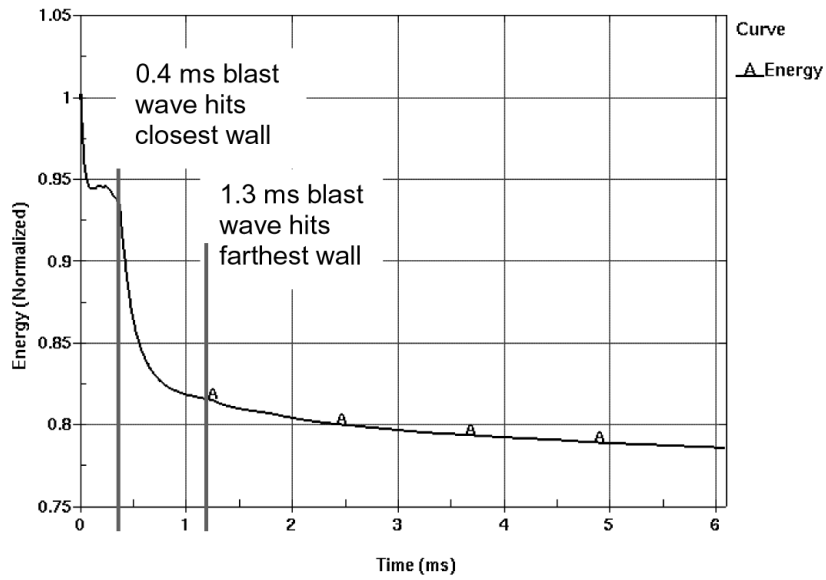


Figure 5 Energy dissipation in mesh #3.

Application example: Spherical detonation chamber

A typical application example is the spherical detonation chamber shown in Figure 6. The simulation can give insights that are difficult to obtain in a physical test, e.g. how the stresses are distributed in the flanges during the event; Figure 7.

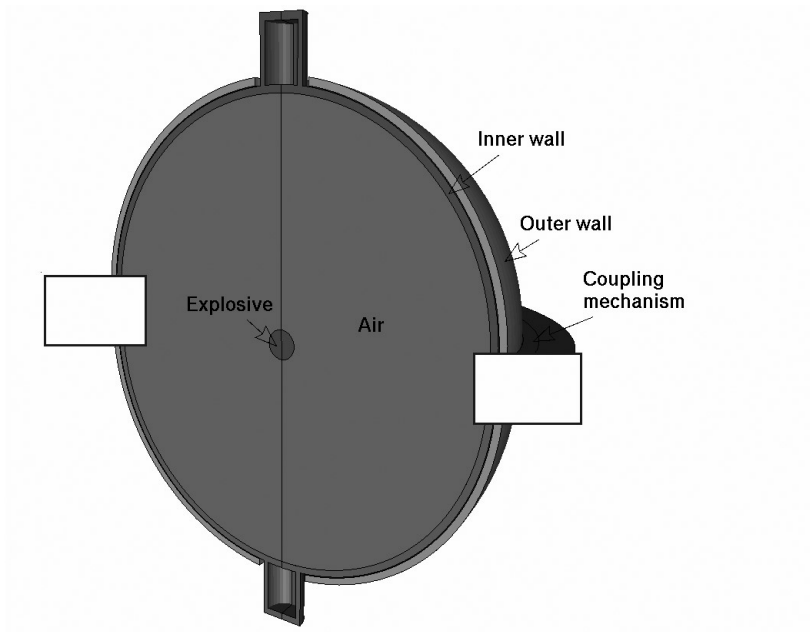


Figure 6 Spherical detonation chamber.

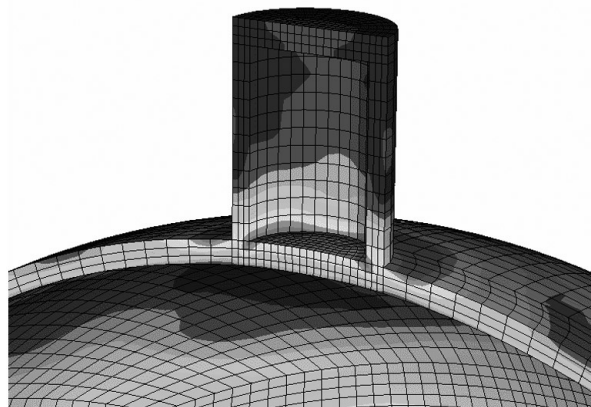


Figure 7 Effective stress in the top of the chamber 1ms after ignition

Conclusions

The presented results demonstrate that from a practical point it is easy to perform a simulation of a fluid/structure interaction with explosive loading, using version 960 of LS-DYNA. This opens a new area of applications for LS-DYNA.

However, it cannot be neglected that this type of simulation is very complex from a theoretical point of view. Further, the methods (the multi material Eulerian method and the fluid/structure coupling) used to perform the simulations are still under active research. It is fair to say that the simulation of fluid/structure interaction is still an "emerging technology" (at least in the civil industry). This means that the results must be critically evaluated until enough experience with the method has been gained, i.e. comparisons are made with experiments.

That there are unresolved issues is indicated for instance by the results in Section 7, which show a numerical dissipation of energy. The dissipation seems to be only marginally reduced when increasing the mesh density.

References

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