# INTRODUCTION TO NUMERICAL ANALYSIS OF DIRECTED FRAGMENTATION WARHEADS

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*Abstract*

*The aim of the paper is to presents one of the possible approaches to the numerical analysis of the behaviour of directed fragmentation war heads. These kinds of warheads consists of: metallic or composite cover, explosive material and a driven and fragmentation liner. The explosives are initiated by a booster causes driving the liner in a few milliseconds up to about 900 m/s. The liner fragments into many parts during this intensive and dynamic load. The fragments move in a cone which dimensions depend on the warheads shape and mechanical parameters of others warheads parts. All of the warheads elements are selected to meet the assumed parameters. The fragments velocity, their mass or geometric dimensions and cone angle are the most important parameters of the warheads fragments. Such a warhead, in the initial phase of the liner driving can be numerically modelled in the field of the continuum damage mechanics. Such a description is presented in other papers. This approach in a further phase of driving cause the increases of inaccuracies. Therefore, this paper proposes the use of ALE and FSI approach to describe the behaviour of the fragmentation warheads. A three-dimensional numerical model of the directed fragmentation warheads was made in the MSC Patran, and the dynamic phenomena analysis used a nonlinear finite element method implemented in the LS-Dyna program.*

**Keywords:** *finite elements method, dynamic, directed fragmentation warheads*

## 1. Introduction

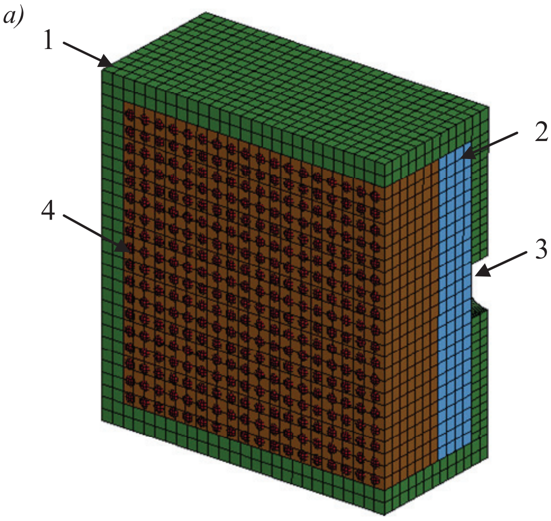
Directed fragmentation warheads consist of a few parts: metallic or composite cover, explosive material and a driven and fragmentation liner. The liner is suitably shaped. The explosive is used for rapid, dynamic liner driving. A proper shape of liner, case and selection of explosive makes it possible to control the angle of dispersion and energy of the warhead parts. Fragments energy can also be controlled by appropriate selection of the mass of the explosive and its parameters characterizing demolition properties. Selection of the initial detonation point, and the shape of both the case and the liner enable shaping the fragmentation process as well as further fragments driving. Both of these features allow achievement of required parameters of the fragments (velocity – energy, cone angle in which fragments move, spatial distribution of fragments).

The initial phase of driving such a system can be modelled using computer methods of mechanics in approximation of continuum mechanics. Such approximation was used by, inter alia, Prof. Jach while modelling the behaviour of directed fragmentation warheads in axisymmetric approximation [3]. However, the accuracy of this description decreases with development of the phenomenon. Individual parts of the warhead form a cloud of fragments, i.e., small parts. Therefore, the error of such an approach increases with the process of liner fragmentation and fragments driving. Another possibility, used in this paper, is the approach applying ALE and FSI for warhead and liner fragmentation modelling. In this approach, individual elements of the liner are described with the use of equations of continuous medium mechanics in Lagrange formulation.

However, the resin, joining individual fragments, is described with equations of continuous medium mechanics in Euler formulation. A large number of fragments used in such systems requires the application of a large number of finite elements. Such an approach, in its initial phase of description, is equivalent to the first of the described possibilities of modelling the warhead fragmentation. However, in further phases of the driving phenomena, it should allow obtainment of the results closer to reality.

## 2. The model of directed fragmentation warhead

The model of directed fragmentation warhead consists of three basic parts previously mentioned: the case with the explosive and the liner shown in Fig. 1. The liner consists of metal balls (5.5 mm in diameter) embedded in the resin (Fig. 1b). In the presented model (half the real system), the number of balls was 1620 and the number of finite elements for their description – 74520. The balls were given parameters corresponding to the RIGID type material and steel density.



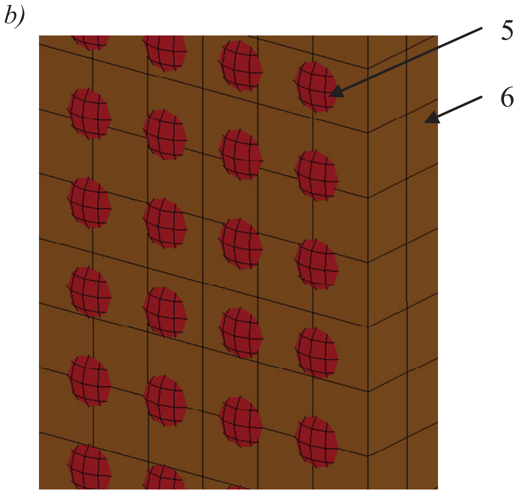




*Fig. 1. The model of directed fragmentation warhead: warhead (a), and liner (b): 1 – case, 2 – explosive, 3 – fuse place, 4 – liner, 5 – balls, 6 - resin*

Mechanical properties of the case made of St3 steel were described using a simplified Johnson-Cook type material [2]. This model correctly reproduces the behaviour of the described material during dynamic interaction with high strain rates, strains and temperature effects. Parameters used in simulation taken from the literature [7] are shown in Tab. 2.

Due to low strength of resin, the description of its properties has been simplified and described in the presented model with the use of the material applied for liquid description.

During simulations, the influence of explosive selection on the whole process was investigated. For this purpose, two commonly used explosives C4 and TNT were selected. The detonation process was described using programmed burn model approximations [5, 6], and the behaviour of detonation products was described with the JWL (John, Wilkins, Lee) equation [2, 8]:

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

where:

$V = \rho_0 / \rho$,

$\rho_0$ – initial density,

$\rho$ – density of detonation products,

$A$, $B$, $R_1$, $R_2$, $\omega$ – values constant.

*Tab. 2. Material parameters for the case [7]: ρ – density, E – Young's modulus, V – Poisson's ratio, A, B, N, C – material constants, $\varepsilon_f$ –plastic strain at failure*

| $\rho$ [kg/mm$^3$] | $E$ [GPa] | $V$ [–] | $A$ [GPa] | $B$ [GPa] | $N$ [–] | $C$ [–] | $\varepsilon_f$ [–] |
|---|---|---|---|---|---|---|---|
| 7.89E–06 | 210 | 0.3 | 0.365 | 0.51 | 0.9 | 0.0936 | 0.3 |

The values constant of the JWL equation for TNT and C4 are presented in Tab. 3 [8].

*Tab. 3. The values constant of the HE and the JWL equation for TNT and C4 [8]: ρ – density, D – detonation speed, PCJ – C-J pressure, A, B, $R_1$, $R_2$, ω – equation of state constants*

| HE type: | High Explosive | | | JWL equation of state | | | | |
|---|---|---|---|---|---|---|---|---|
| | $\rho$ [kg/mm$^3$] | D [mm/ms] | PCJ [GPa] | A [GPa] | B [GPa] | $R_1$ [–] | $R_2$ [–] | ω [–] |
| C4 | 1.6E–06 | 8000 | 28 | 609 | 12.95 | 4.50 | 1.4 | 0.25 |
| TNT | 1.6E–06 | 6900 | 18 | 373 | 3.75 | 4.15 | 0.9 | 0.35 |

In the model, air around the warhead was taken into consideration for the results refinement (Fig. 2). The behaviour of air has been described with the Mie-Gruneisen equation [2, 4]:

$$p = p_0 + \gamma \rho E \,, \tag{2}$$

where:
$p$ – pressure,
$p_0$ – initial pressure,
$\gamma$ – Gruneisen coefficient,
$\rho$ – density,
$E$ – specific internal energy.
The following values constant in the equation (2) [6]: $\gamma = 1.4$, $\rho = 1.185$ kg/m$^3$, $p_0 = 1013$ hPa.

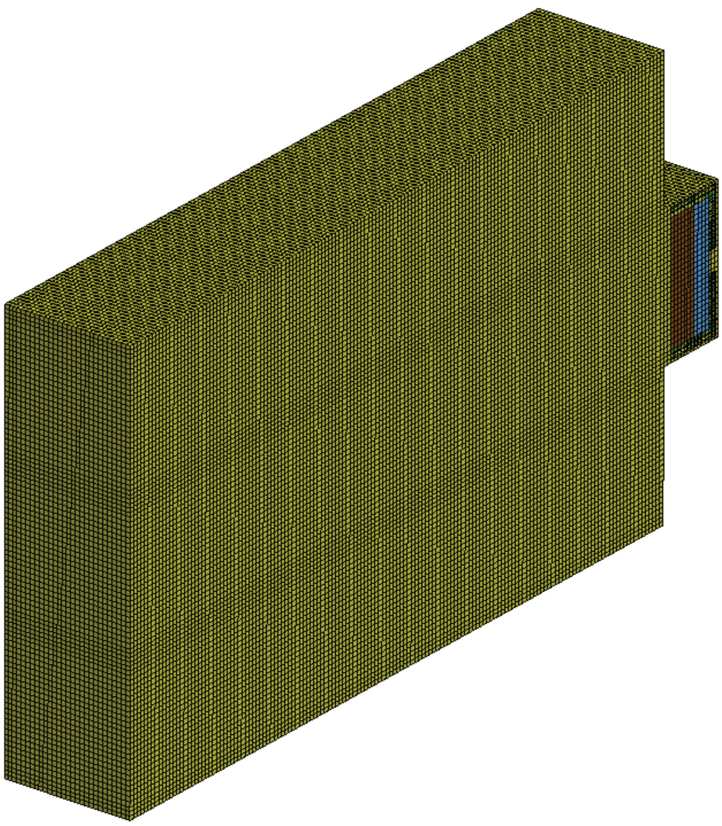


*Fig. 2. The directed fragmentation warhead model with air*

## 3. Numerical analyses

Numerical analysis results of directed fragmentation warheads behaviour are presented below in their original, the most important phase lasting approximately 1 ms. At this time, the explosive is detonated, what results in, inter alia, fragmentation of the case. This process is shown in Fig. 3 and 4. When the trinitrotoluene is used, the case undergoes fragmentation only up to the time of 0.4 ms. This process is longer for TNT and lasts for approximately 1 ms.

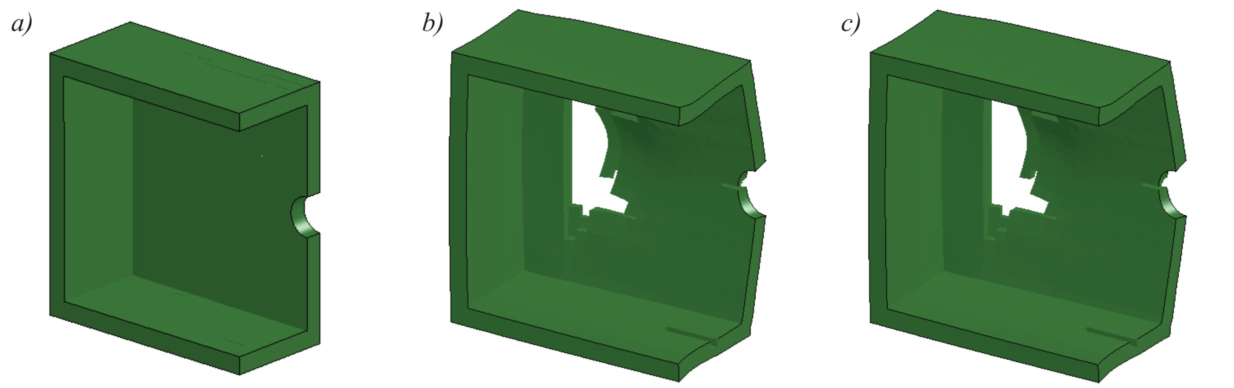



*Fig. 3. Case fragmentation – explosive TNT: t = 0 (a), t = 0.2 ms (b), t = 0.4 ms (c)*

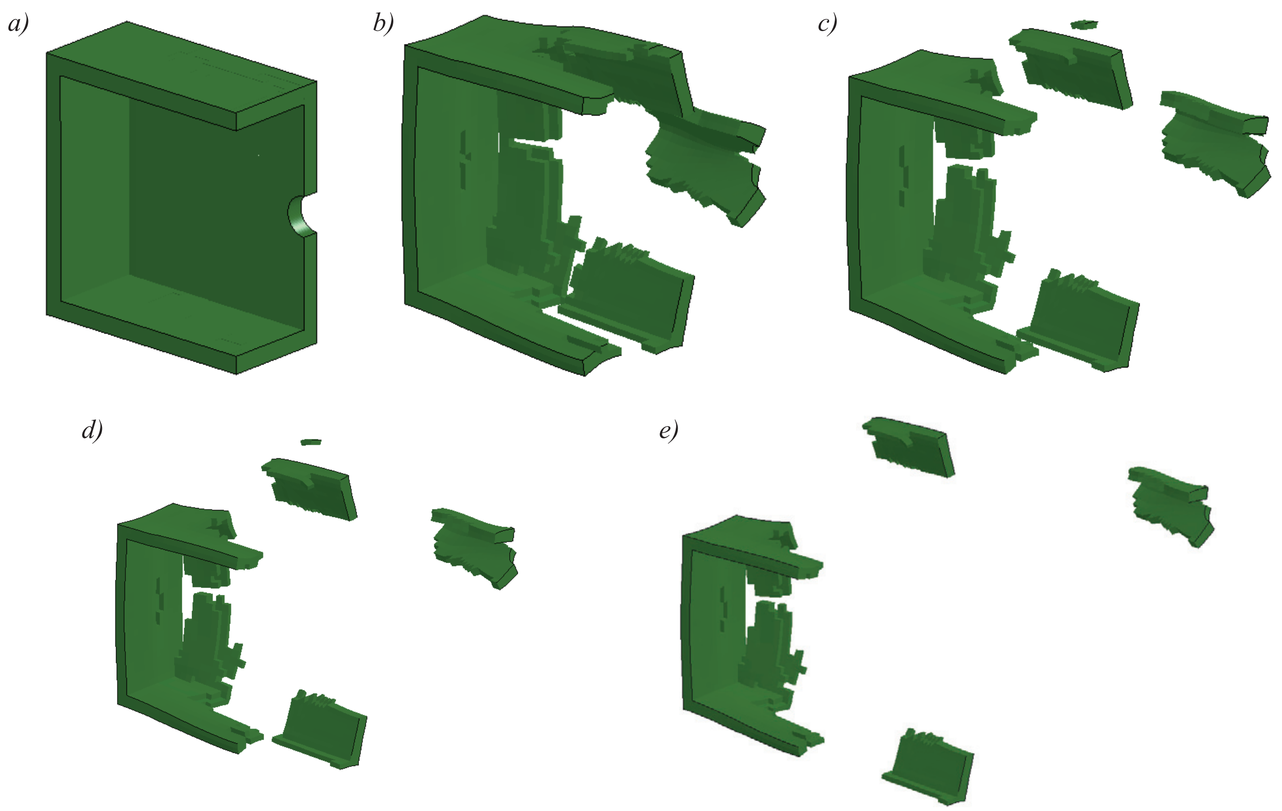



*Fig. 4. Case fragmentation – explosive C4: t = 0 (a), t = 0.2 ms (b), t = 0.4 ms (c), t = 0.6 ms (d), t = 1 ms (e)*

The balls reach maximum speed of 550 mm/ms when they are driven by C4 detonation products. The angle of balls dispersion is equal to 92° in the horizontal plane and 102° in the vertical plane (Fig. 6).

In the situation when the balls are driven by TNT detonation products, they reach maximum speed of 350 mm/ms (Fig. 7). For the used TNT, the angle of balls dispersion is equal to 88° in the horizontal plane and 32° in the vertical plane (Fig. 8).

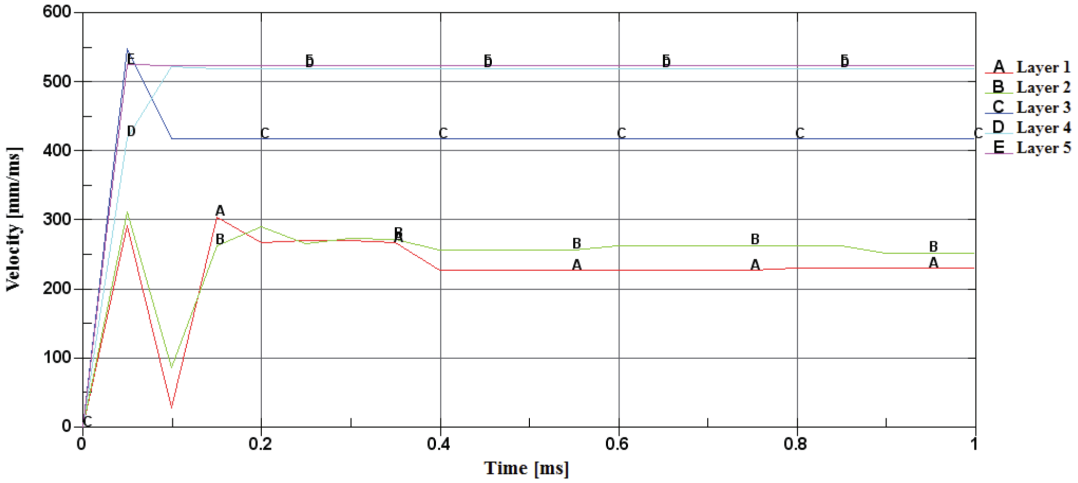



Fig. 5. Balls velocity – explosive C4

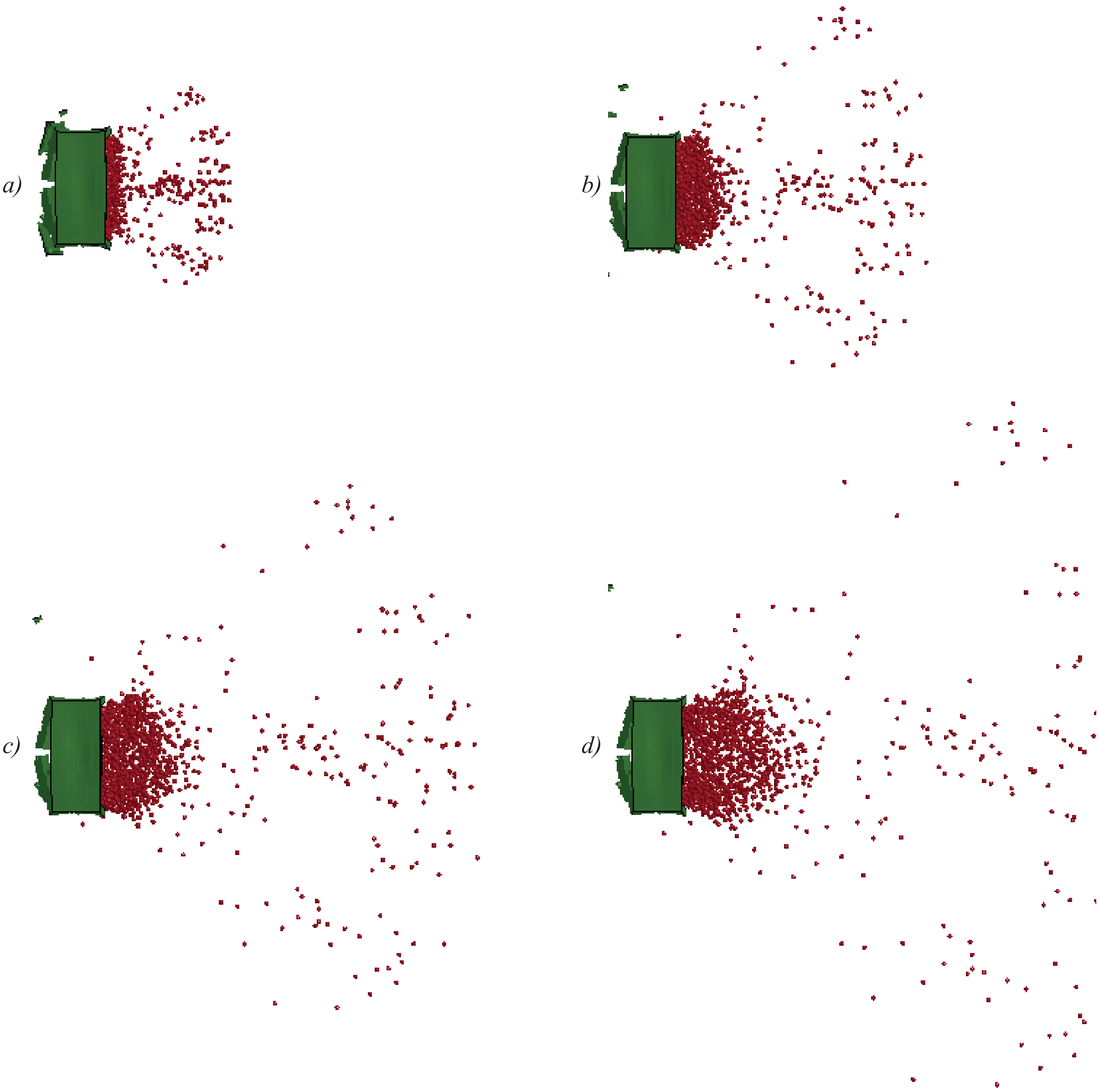



Fig. 6. The angle of balls dispersion (vertical plane) – explosive C4: t = 0.25 ms (a), t = 0.5 ms (b), t = 0.75 ms (c), t = 1 ms (d)

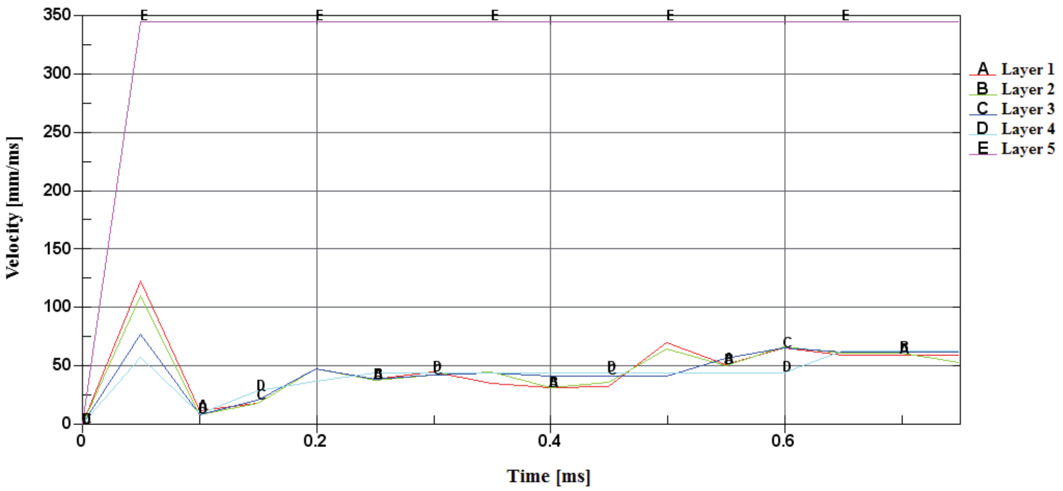



*Fig. 7. Balls velocity – explosive TNT*

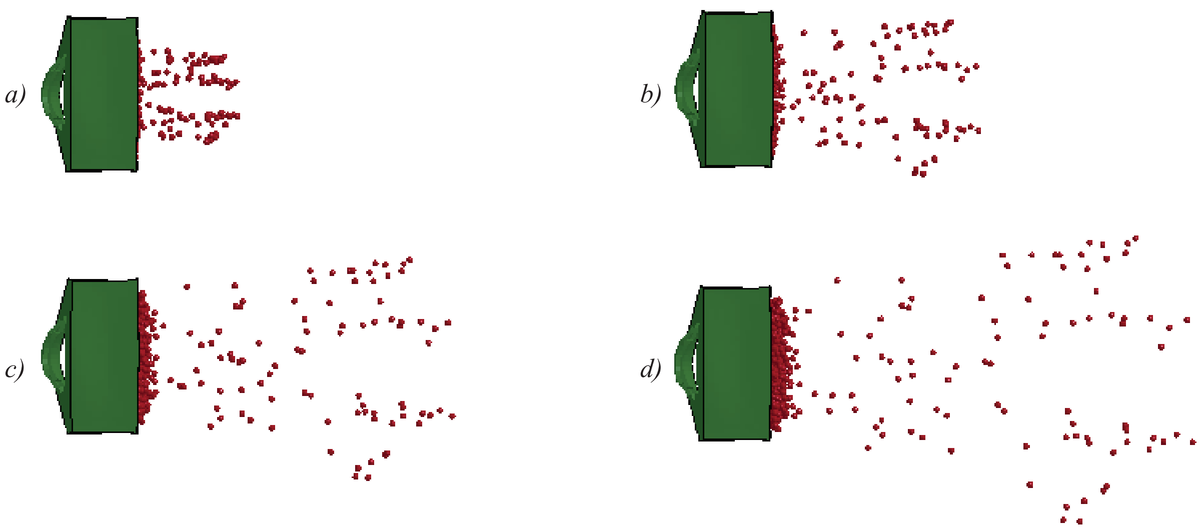



*Fig. 8. The angle of balls dispersion (vertical plane) – explosive TNT: t = 0.25 ms (a), t = 0.5 ms (b), t = 0.75 ms (c), t = 1 ms (d)*

Much lower speeds and angles of balls dispersion are achieved in case of TNT use (Tab. 4).

*Tab. 4. Velocity and angles of balls dispersion*

| HE type: | maximum velocity | vertical plane of balls dispersion | horizontal plane angles of balls dispersion |
|---|---|---|---|
| C4 | 550 mm/ms | 114° | 104° |
| TNT | 350 mm/ms | 88° | 32° |

## 4. Summary

The paper presents the preliminary results of computer modelling of the directed fragmentation warheads. To describe the process of its operation ALE and FSI approach are used. It allowed for a better description of the process. It also caused problems with proper operation of contact that occurs between many elements of the system under consideration. It resulted in a significantly lower speed of the inner layers of the balls.

Despite the existing problems, it seems that such an approach is accurate. It properly describes the process of case fragmentation and liner driving. The value of their velocity corresponds to real tests.

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