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PENETRATOR / SHAPED CHARGE SYSTEM
PART I: SIMULATION OF ASYMMETRICAL EFFECTS

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Aspects of the influence of the casing of a multipurpose round designed as penetrator / shaped charge system have been investigated. The penetrator function demands a heavy casing, and it has long been known that this can give rise to reduced or variable shaped charge performance. The influence of geometrical inaccuracies and fracture of the casing has been studied using hydrocode simulations. Conclusive evidence was found that practically relevant thickness variations could be ruled out as a source of performance reduction. However, fracture of a heavy steel casing can induce lateral jet velocities that are considered to be sufficient for causing severe performance degradation.

INTRODUCTION

The typical application of shaped charges (SC) has been the defeat of main battle tanks (MBT). However, the MBT ceased to be the target of primary interest and structural targets come into the focus. A penetrator / shaped charge system, which stimulated the presented study, was proposed as a multipurpose round. It is intended to act against a variety of targets. Blast-fragment effects defeat structural targets after penetration into the structure, but the performance of the shaped charge should be still sufficient against the MBT.

Figure 1 shows a sketch of a shaped charge integrated into a penetrator. The penetrator function requires a strong steel casing. Jet mass and jet energy are relatively high compared to an unconfined charge, thus one would expect an increased performance. However, it has long been known that heavy confining structures can cause reduced or variable performance of the shaped charge. Two decades ago, Brown et al. [1] presented an exhaustive amount of experimental, analytical and numerical results concerning the effects of the confinement of a shaped charge. We do not attempt to study the subject in general, but concentrate on two problems, whose solution has become feasible due to the progress of computational hardware since the appearance of the cited paper.

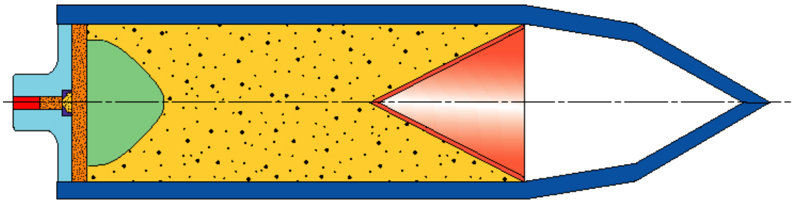

Figure 1. Multipurpose penetrator / shaped charge system.

Based on numerical analysis the present study addresses the following questions related to a penetrator / shaped charge system:

- Does the heavy casing lead to enhanced requirements with respect to the manufacturing accuracy of the casing?
- Is fracture of the casing a possible reason of performance reduction?

Experimental aspects of the penetrator / shaped charge system are discussed in part II of this paper [2].

HYDROCODE SIMULATIONS

Modelling Details

The hydrocode simulations were performed using the Eulerian analysis code NUMHYD [4] on a Windows-PC. This limited the number of computational cells to $5 \cdot 10^6$ and allowed to cover a space of 100 x 200 x 250 mm^3 with a cubical 1 mm mesh. The space was sufficient for the 96 mm calibre shaped charge, but the resolution was too coarse compared to 1.9 mm thickness of the copper liner. To get a reasonable resolution across the liner, the copper was replaced by aluminum of equal weight, but higher thickness. Compared to an earlier study [5], we achieved a considerably higher resolution, but the resulting seven cells across the liner thickness were still not sufficient to accurately model the jet tip formation. Since the asymmetries we wanted to study were related to the casing of the charge, this was judged to be an issue of minor importance. Indeed, we did not find severe lateral velocities of the jet tip in any of our simulations.

Explosive products of TNT/HMX 15/85 were modelled with a JWL equation of state. Solid materials were described by a Mie-Gruneisen equation of state and an elastic-plastic strength model. When the tip of the jet encountered the mesh boundary the mesh was allowed to move with the jet. This kind of adaptive meshing allowed limiting the initial extension of the mesh in order to maximize spatial resolution.

The most important result of a simulation of the asymmetric jet formation process is the lateral velocity profile. To give a rough figure, a lateral velocity of 20 m/s can be typically observed in mass produced precision shaped charges. This lateral velocity is induced during jet formation by asymmetries of generally unknown origin. For precision shaped charges jet break-up has been shown to be only a minor source of lateral particle velocities [3].

Validation Experiment

To check the applicability of the numerical model a shaped charge test was performed. An extremely asymmetrical configuration was chosen (Figure 2), for which we expected clear observations of lateral particle velocities on a flash X-ray (FXR) record (Figure 3).

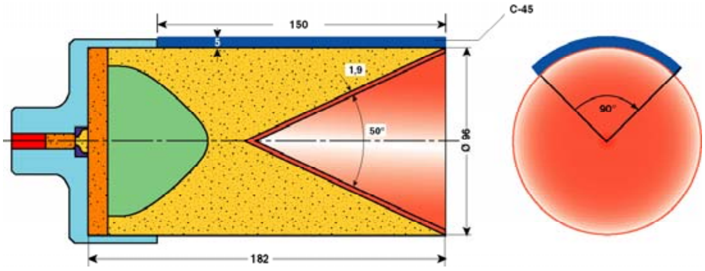

Figure 2. Test configuration with an extremely asymmetrical casing.

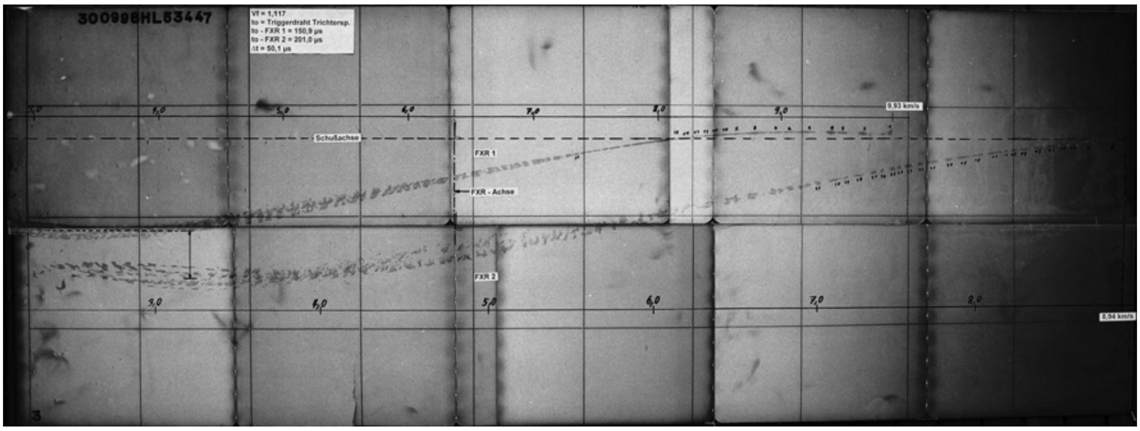

Figure 3. Double exposure FXR record of the validation experiment.

A time sequence of the numerical simulation is shown in Figure 4. The calculated shape of the jet is displayed in Figure 5. In accordance with the FXR record the tip region appears straight. The maximum deflection can be observed near the rear part of the jet. Calculated lateral velocities are displayed in Figure 6. The resolution of the numerical model was not sufficient to reproduce the complex splitting of the jet particles behind the tip region.

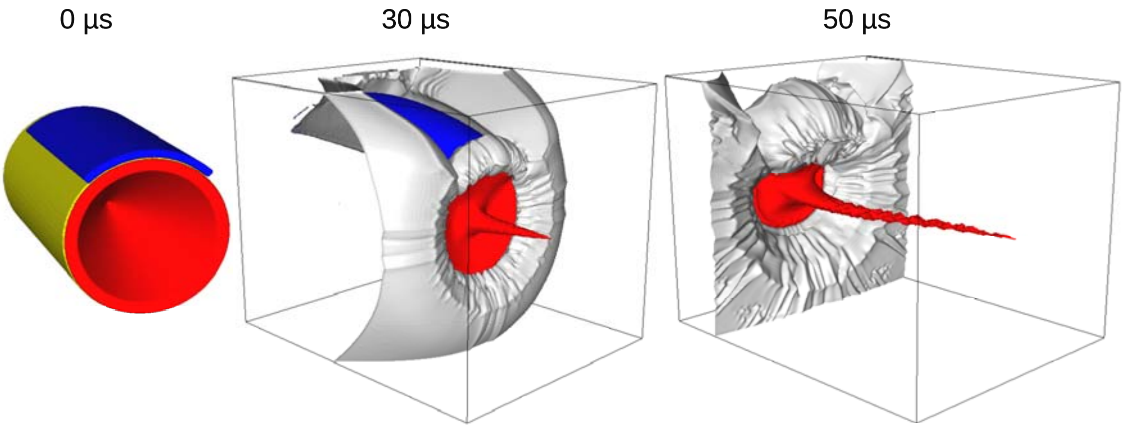

Figure 4. Material surfaces of the numerical model at times t = 0 µs, 30 µs and 50 µs. The outlines demonstrate the translation of the mesh with the tip of the jet.

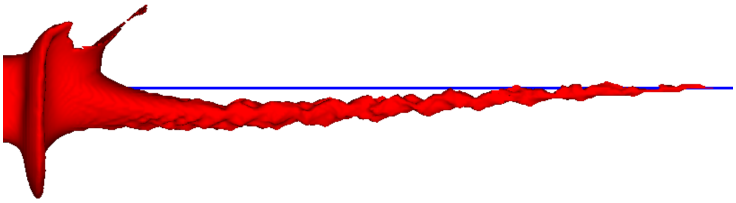

Figure 5. Shaped charge jet deflection at 50 µs compared to the charge axis.

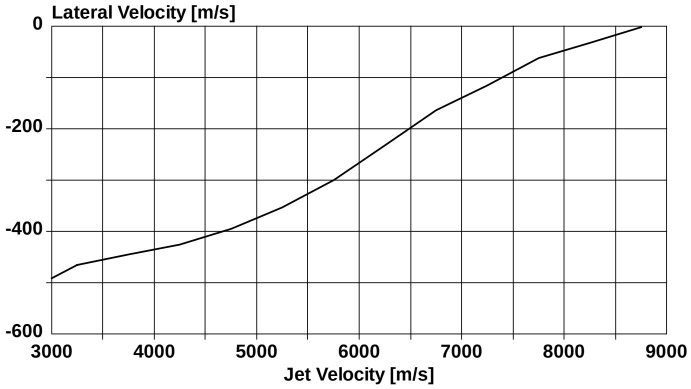

Figure 6. Calculated lateral velocity profile for the validation experiment.

Casing Thickness Inaccuracies

A series of simulations was carried out to study if geometrical inaccuracies due to the manufacturing process could be a relevant source of jet disturbance, especially for heavily confined charges. A constant excess thickness over a 90° sector of the casing was modelled as shown in Figure 7.

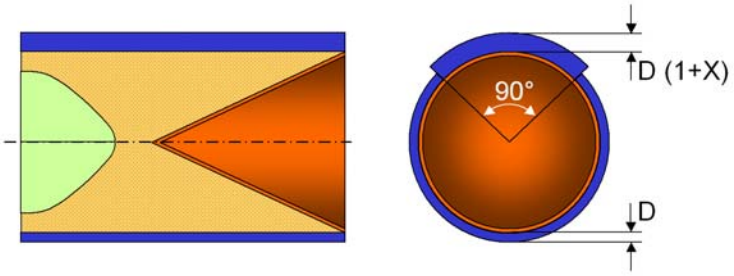

Figure 7. Sketch of the simulated configurations with excess thickness X applied to a 90° sector of steel casing with thickness D.

Calculated lateral velocity profiles in Figure 8 show a nearly undisturbed tip region. Jet parts with velocities between 3000 m/s and 6000 m/s obtain the maximum lateral velocity. According to Figure 9 the lateral velocity with a D = 5 mm steel casing is approximately proportional to the excess thickness X. Varying the casing thickness at a constant excess thickness of 20 % led to the lateral velocity curve given in Figure 10.

In practice the manufacturing tolerances for a charge casing will be surely less than 0.05 mm, which means X = 1% in our example. This would give rise to a lateral velocity of only 2 m/s, a value which would be hardly detectable in experiments and which is definitely acceptable for any shaped charge.

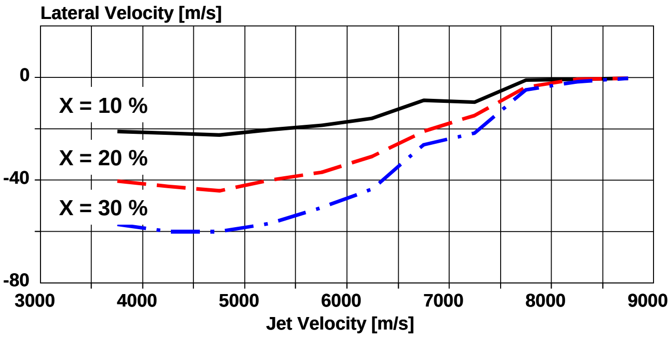

Figure 8. Calculated lateral velocities versus jet velocity for a steel casing with D = 5 mm and various excess thickness ratios X.

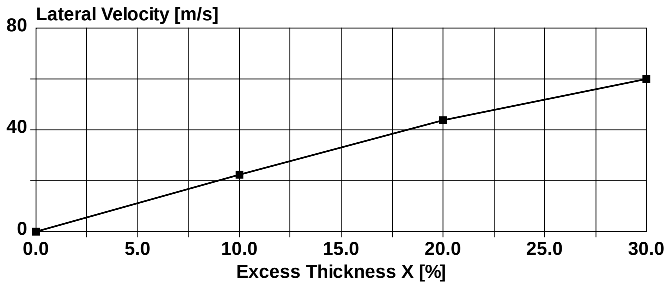

Figure 9. Maximum absolute lateral velocity as function of the excess thickness X for a D = 5 mm steel casing.

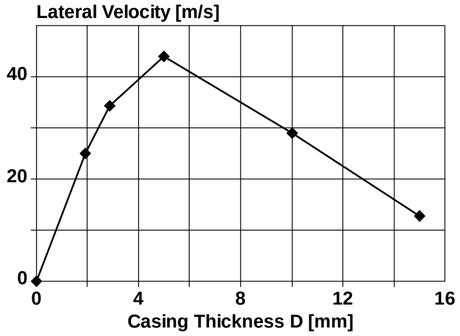

Figure 10. Maximum absolute lateral velocity as function of the casing thickness D at constant excess thickness X = 20%.

Casing with Simulated Built-In Fracture

Fracture of the casing is generally a random process, which necessarily introduces deviations from rotational symmetry. To study the possible effects of asymmetrical break-up of the casing, a series of simulations was performed. To start from a definite problem the break-up was modelled by initially built-in air gaps (Figure 11).

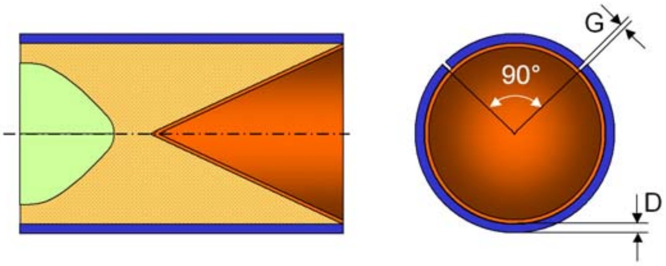

Figure 11. Sketch of the simulated configurations with an air gap G = 2 mm at the edges of a 90° sector of a steel casing with thickness D.

The calculated lateral velocity profiles are shown for various casing thicknesses in Figure 12. Again the jet tip is not disturbed by the asymmetry, but large parts of the jet obtain a nearly constant lateral velocity. The lateral velocity increases with the casing thickness (Figure 13). The magnitude of the lateral velocity is in a range where it could significantly degrade the penetration capability of a jet. For a thin aluminum casing, as it is typical for a shaped charge integrated into a missile, we would not expect a considerable effect on jet formation from the break-up of the casing. But for the heavy casings, which are typical for the intended use in a penetrator, asymmetrical break-up could be responsible for comparatively high lateral jet velocities.

The simulations do not answer the question, if a brittle casing is favorable over a ductile casing. For the ductile casing we would expect some expansion before breakup occurs, thus possible asymmetries develop far from the liner. On the other hand a brittle breakup into many small pieces may be closer to the desired rotational symmetry.

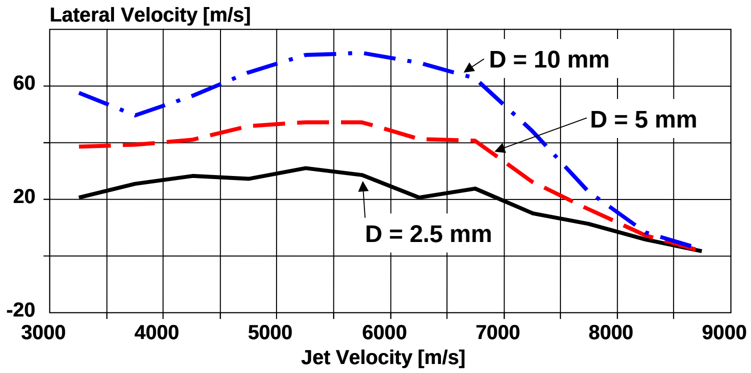

Figure 12. Calculated lateral velocity profile for steel casings with thickness D and built-in air gaps.

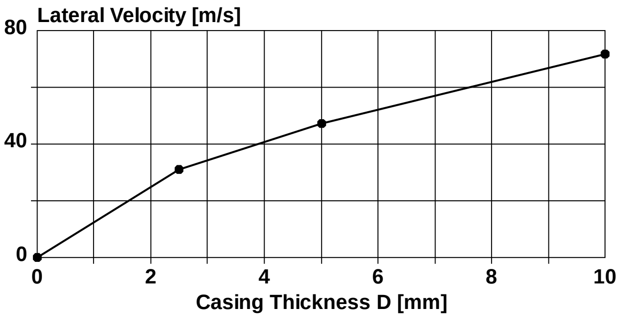

Figure 13. Maximum absolute lateral velocity as function of the casing thickness D with built-in air gaps.

CONCLUSIONS

Two possible effects of a heavy steel confinement on shaped charge performance have been studied numerically:

- casing thickness variations caused by the manufacturing process
- fracture of the casing

We found that manufacturing tolerances can be ruled out as a source of performance reduction. We proved this for thick steel casings, but doubtlessly this statement will hold for any kind of material and any casing thickness. However, considering fracture we found that large lateral jet velocities can be induced, which can lead to severe performance degradation.

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