PERFORMANCE OF KINETIC ENERGY PROJECTILE - NUMERICAL AND EXPERIMENTAL STUDY

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Effect of Yaw and Obliquity on Penetration

- High velocity kinetic energy long rods are one of the most important munitions of the main battle tank.
Passive armor

- One way to protect a tank against a kinetic energy long rod is to configure a series of thin plates as passive armor.
- These plates are generally oblique.
- This target is capable of breaking the rod.
The penetration process of a rod while penetrating a thin and oblique target is characterized by the following factors:

- erosion at the nose of the rod (large plastic strain)
- rotation and bending of the rod
- long rod breakage
- interaction between the broken parts and the target

Yaw worsens the above phenomena
The goals of the present work

- To build a numerical simulation of the penetration process.
- Validation of the numerical model with experimental results.
- Using the model to study the influence of the initial yaw on projectile penetrability.
- Using the numerical model to design an improved projectile.
Obliquity is the angle between the velocity vector of the rod and the normal to the target.
Yaw is the angle between the velocity vector direction of the rod and its axis of symmetry.
Initial Yaw Sign

Negative initial yaw angle

Positive initial yaw angle

Zero initial yaw angle
EXPERIMENTS
The tungsten-alloy long rod penetrates the thin steel target

- $V = 1600 \, m/s$
- $\approx 700 \, mm$
- $L/D = 30$
- $65^\circ$
- $50 \, mm$
Experimental Results

Initial yaw $\approx 0^\circ$

X-Ray image of the rod after penetration

$V = 1600\ m/s$

simulation
Experimental Results

Initial yaw ≈ 1°

X-Ray image of the rod after penetration
Experimental Results

Initial yaw \(\approx -1^\circ\)

\(V = 1600 \, m/s\)

X-Ray image of the rod after penetration
Experimental Results

It is apparent that:

- the rod was bent and its nose was broken
- for a negative initial yaw angle the rod bends up
- for a positive initial yaw the rod bends down
- for a zero initial yaw the bending is minimal
NUMERICAL SIMULATION
Numerical Simulation

A three-dimensional time-dependent finite element numerical simulation (MSC/DYTRAN) was performed in order to emulate the penetration process of the rod during and after target penetration.
Numerical Simulation

- Lagrangian explicit model.
- Adaptive contacts to model the rod - target interaction
- A nonlinear, plastic material description with isotropic hardening:
  \[ \sigma_y = \sigma_0 + \frac{E}{E - E_h} \varepsilon_p \]
- A polynomial equation of state:
  \[
p = \begin{cases} 
  a_1 \mu + a_2 \mu^2 + a_3 \mu^3 + (b_0 + b_1 \mu + b_2 \mu^2 + b_3 \mu^3) \rho_0 e & \mu > 0 \\
  a_1 \mu + (b_0 + b_1 \mu) \rho_0 e & \mu \leq 0
  \end{cases}
  \]
  \[, \mu = \frac{\rho}{\rho_0} - 1\]
A failure criterion model in the form of a user written subroutine was added to the MSC/DYTRAN code:

- it depends upon the state of the material in the element (stress, strain, pressure …)
- it is based on two types of material failure:
  - erosion failure
  - static maximum plastic strain failure
Numerical Simulation

$V = 1600 \text{ m/s}$

Initial yaw $= 0^\circ$
Numerical Simulation

Initial yaw = 1°

Experiment
Numerical Simulation

Initial yaw = -1°

$V = 1600 \ m/s$
The bending process:

- enlarges the hole crater in the target
- decreases the rod velocity
- diverts the direction of the penetrator

In addition, for none zero initial yaw values:

- the side of the rod pointing in the direction of its velocity is damaged. (This side is in greater contact with the target because of the velocity direction).
The overall results are a weakening of the rod and a decrease in its ability to penetrate a series of plates following the original thin plate target.

For large yaw angles the bending of the long rod will cause it to break into several pieces.