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NUMERICAL SIMULATION OF THE TUMBLING EFFECT OF SMALL CALIBER PROJECTILES INTO BALLISTIC SOAP

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ABSTRACT

Most of the projectiles used in modern military small arms are spin-stabilized bullets. They are designed in such a way that stability in the air (i.e. the bullet's longitudinal axis tends to point into the general direction of movement), is achieved by forcing the projectile through a rifled barrel resulting in a projectile spinning at high speed around its longitudinal axis. When such a projectile penetrates a medium like human body soft tissue denser than air, it looses stability and tumbles, causing a large wound cavity with great damage. For better understanding of the tumbling effect, an investigation has been made in order to simulate and predict with Autodyn-3D the response of a dense target material subjected to 7.62mm NATO ammunitions impact. For validation purpose, a series of experimental tests were conducted consisting of firing the spherical bullets into ballistic soap [1]. Soap, although it has plastic behavior, was selected because of the fact that the temporary cavity remains visible after the penetration process. That is not the case for an elastic medium where the cavity closes up.

The well-known gyroscopic stability factor (Eq. 1) [2] in the air $(S_g > 1)$ shows that they are many parameters that may influence the tumbling effect. Obviously, the passage from one medium to a denser one will lessen the stability condition and create early instability. This is particularly true as the soap density is about 1000 times greater than the air density $(\rho_{soap} > \rho_{air})$.

$$s_g = \left(\frac{2}{\pi} \cdot \frac{I_a}{I_b} \cdot \frac{I_a}{d^3}\right)\left(\frac{\omega_a}{v}\right)^2 \left(\frac{1}{\rho}\right)\left(\frac{1}{C_{M_\delta}}\right) \tag{1}$$

As soap is an opaque material, it was not possible with our lab facilities to 'follow' the projectile motion during the penetration process. Therefore, numerical simulations were compared with analytical model [3] given by (Eq. 2-3) as no experimental data was

available for comparison purpose. Nevertheless the cross-section of the soap material target after the firings reveals that two cavities were formed and the projectile ended up with the base frontward (Fig. 1), observation made also in [3-4].

$$\ddot{x} = -C_0\, C_{Do}\left(1 + C_1 \sin^2 \delta\right)\, \dot{x}^2 \tag{2}$$

$$\ddot{\delta} = C_2 \sin\delta\, \dot{x}^2 - C_3 \sin(2\delta)\, \dot{x} - C_4\, \dot{\delta} \tag{3}$$

with δ the yaw angle, x the position of the center of mass with respect to a transversal axis in the projectile base plane, C_{Do} the equivalent zero yaw drag coefficient. The coefficients C_0, C_1, C_2, C_3 and C_4 are considered to be constant within the specified velocity range.

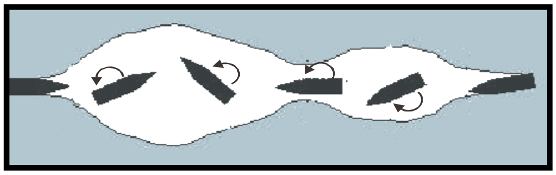

Figure 1: Penetration mechanism and formation of the cavity

For simulations, the gyroscopic effect was not taken into account. Soap material was characterized in [1] using spherical bullets. As the projectile did not deform nor break after the firings, it was modelled as a rigid projectile. In order for the projectile to start tumbling numerically, a small yaw angle (3°) at impact was introduced in the numerical simulations (otherwise, the projectile would never become instable numerically and would never start tumbling). Satisfying results have been achieved especially for the velocity profile (Fig. 2-left). Note that the numerical simulation picks up the tumbling effect (rotation of the projectile in the target material) (Fig. 2-right).

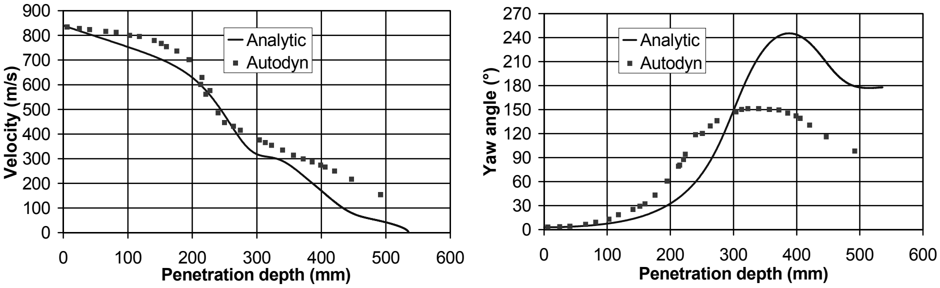

Figure 2: Comparison between numerical simulations and analytical modeling

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