SIMULATION AND MEASUREMENT OF FRAGMENT VELOCITY IN EXPLODING SHELLS

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Abstract. This paper presents simulations of initial velocity distribution of fragments for non-trivial shapes of casing in exploding shells, using a semi-empirical computational model. The key to the proposed approach is the use of transformation of a general geometrical shape to a hollow sphere followed by an application of Gurney principles in the transformed domain. The model is validated against an analytical model for a finite cylindrical charge bounded by a cylindrical shell and identical end-plates. A computation for 105-mm shell with steel casing and aluminium fuze illustrates aspects involved in reliable comparisons of fragmentation models against a standard trial data. Further, a simple and inexpensive experimental procedure based on a pin gauges measurement is described. Measurements obtained for short cylinders and an 81-mm mortar bomb are compared with numerical predictions. The described model responds to the need for an improved, fast assessment tool applicable to practical designs involving geometrically complex multi-material shells. The results highlight a requirement for quality experimental data obtained for complex shapes.

INTRODUCTION

The purpose of a fragmenting warhead is to generate multiple fragments with adequate mass and velocity to damage target(s) within its intended lethal zone. There is a need to predict the velocity of the fragments not only for assessing the potential effect of the munition, but also to allow an assessment of its hazard in a credible accident. Although advanced numerical methods are currently available for fragmentation prediction, these can be time-consuming to learn and require lengthy computation. However, the greatest difficulty in obtaining a reliable computation using advanced numerical models lies in their requirement to use a set of complex input parameters which in the case of exploding shells are not readily (if at all) available. A designer of fragmenting shells is ultimately interested in the impact of the fragment. In order to compute trajectories of a large number of fragments (tens of thousands for naturally fragmenting shells) an initial velocity distribution must be known.

In contrast, this study aims at developing a fast analytical method for predicting fragment initial velocity in axis-symmetrical warheads. This information can be used in the assessment of the overall lethality of fragmenting warheads, and for further semi-analytical analysis or as an input to an advanced numerical code.

FRAGMENTATION MODEL

Since the first equations for prediction of fragment velocity for a sphere and an infinitely long cylinder based on the empirical data were formulated by Gurney [1], a range of equations valid for other simplified shapes have been proposed, for example, in various references. [2,3] For more complex shapes the formulation of an analytical equation becomes increasingly difficult. Occasionally, methods approximating a real shape by an infinite cylinder are used for estimation, not withstanding the consequent introduction of approximation errors and ignoring kinetic energy loses in fuze and base regions. Some other reported techniques divide a warhead into a set of short cylindrical segments and use the Gurney equation for every segment in turn. Such approaches need to be used with care as they are limited by the recognition that the Gurney equation is only valid for long cylinders.

For the calculation of fragment velocity of each element, we used an approach that closely follows Jayaratnam [4] but is modified to account for a possible change in density for each segment of the casing. Firstly the shell shown in Figure 1a is transformed, using a form of simplified conformal mapping, into a hollow sphere shown in Figure 1b. During the transformation the following are preserved: high explosive charge mass, casing total mass, and the surface area of the interface between casing and high explosive. If the radius of the hollow is b, and the transformed thickness of the charge is d as indicated in Figure 1b, such that the radius of the sphere is $d+b$, then:

$$b = \left\{ \left(\frac{S}{4\pi} \right)^{3/2} - \left(\frac{3C}{4\pi\rho_C} \right) \right\}^{1/3} \tag{1}$$

$$d = \left(\frac{S}{4\pi} \right)^{1/2} - \left\{ \left(\frac{S}{4\pi} \right)^{3/2} - \left(\frac{3C}{4\pi\rho_C} \right) \right\}^{1/3} \tag{2}$$

where: b is the radius of the hollow core, d the radius of the spherical charge minus the radius of the hollow core, S the total surface area of explosive in the warhead, C the mass of explosive, and ρ_C the density of explosive.

Each point of the inside of the casing (x,y) transforms to a point on the surface of the sphere represented by the angle α, given by:

$$\alpha = cos^{-1} \left\{ 1 - 2\left(\frac{S_\alpha}{S} \right) \right\} \tag{3}$$

where α is the angle subtended by point in sphere to centre of sphere with horizontal, and S_α the total surface area of explosive up to point (x,y).

At each point the thickness of the shell t_x transforms to t_α. Posing a condition that the total mass of the ring element of

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