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Military Applications of Explosive Propulsion

Explosive propulsion has the significant role both in civil and in military applications. In this paper different geometrical configurations, which find their applications in practice, are studied mainly through determination of terminal velocity of liners achieved during explosion. Use of formulae, for studied geometrical configurations, in design of selected military items is presented. These formulae are the basic ones for design and optimisation of conventional warheads, anti-tactical ballistic missiles warheads, fuzes, etc.

Keywords: *Physics of explosion, explosive propulsion, warhead, fuze.*

1. INTRODUCTION

The explosive propulsion is the part of physics of explosion which is dealing with acceleration of objects by detonation of an explosive charge. It finds its applications in many civil and military fields. As civil applications we′ll mention explosive clading and forming of metals, explosive welding of similar and dissimilar metals, etc.

Military applications are numerous: *high-explosive (HE) warheads (directed energy*: shaped charge, hemi charge and explosively formed penetrator and *omni-directional*: fragmentation and blast), *anti-tactical ballistic missiles (ATBM) warheads, fuzes*, etc. In laboratories plane metal plates are accelerated by detonations of explosive charges in their contact in order to get shock waves that can be conveniently used as laboratory tools to study the equations of state of materials at extremely high pressures and temperatures, and their behaviour at high rate of loading.

In this paper we′ll consider some formulae and their modifications for one-dimensional geometry. Their military applications are specially concerned.

2. EXPLOSIVELY DRIVEN LINERS

2.1. Introduction

Explosively driven liners movements, their destruction and fragments fly are carried out on the account of energies which are released during explosive detonations. A velocity of liner driven by explosive covered from all sides (for example, a sphere or a long cylinder) can be determined from the energy equation [1, 2]:

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$$E_s + E_k + E_p + E_d + \frac{m_m v^2}{2} = m_e Q \ , \qquad (2.1)$$

where are: E_s -energy transferred to surrounding media of liner (air, water, ground), E_k - kinetic energy of deto-nation products, E_p - internal (potential) energy of detonation products, E_d - energy used for plastic deformation of liner, m_m - liner mass, v - liner velocity, m_e - explosive charge mass, Q - explosive heat of explosion.

Based on this energy equation, and very often in connection with equation of momentum balance, different models are developed. Today the Gurney model is the most often used for various applications. British physicist Ronald W. Gurney developed a couple of simple ideas into a way to estimate the velocity of explosively driven fragments. Although shock waves played a very important part in the transfer of energy from the detonation of confined explosives to the surrounding metal ammunition cases, the assumptions Gurney made in his model to provide mathematical tractability had nothing to do with shock mechanics. Gurney assumed that:

1. detonation of a given explosive releases a fixed amount of energy per unit mass which winds up as kinetic energy of the driven inert material (often metal) and the detonation product gases (he neglects energies E_s, E_p and E_d); and
2. those product gases have a uniform density and linear one-dimensional velocity profile in the spatial coordinates of the system.

The physical justification of these assumptions may be thought of as follows. The first assumption is equivalent to an expectation that the efficiency of energy transfer to the metal will be consistent, regardless of the geometry or massiveness of the confinement of the explosive. This assumption turns out to be good one as long as there are no significant "end losses" of gases, which cause the gases to expand in a direction not contemplated in the one-dimensional model. The second assumption corresponds to a condition where there is opportunity for multiple shock reverberations in the gas space while the confinement is still intact, in which case the gas state inside the case tends toward constant density and a linear velocity profile. Both assumptions break down when the case mass is relatively light, because there is insufficient time for reverberations within the gas to drive toward steady expansion within the gas space; the result is that the case is then driven faster than the Gurney model predicts.

The Gurney model may be applied to any explosive/metal system with a cross-section admitting one-dimensional translation motion of the metal typically normal to its surface, regardless of the direction of detonation propagation. The one-dimensional geometries considered are planar, cylindrical, and spherical. By applying the principles of conservation of energy and conservation of momentum to selected control masses, the equations for the asymptotic velocity of the liners may be derived. In the cases where a symmetry boundary falls within the definition of control mass, as in symmetric sandwich and exploding cylinder and sphere, only the equation for conservation of energy is needed. When no symmetry boundary is defined, or when the boundary falls outside the control mass, an equation for conservation of momentum must be developed.

2.2. Symmetric geometries

In this paper we refer to the mass of the explosive charge m_e, and the mass of liner or liners as m_m or m_n, where m_m is the liner mass which velocity we are concerned with, and m_n is tamping mass. Naturally, in the case of planar geometry we speak of a mass per unit area, whereas in the case of cylindrical geometry we are referring to a mass per unit length.

Let us illustrate Gurney's approach by considering *the symmetric sandwich*, in which a slab of explosive is confined by a metal layer of same mass on each side. In figure 2.1 is a diagram of the control mass used for the symmetric sandwich, where X refers to the Lagrangian position. The vertical dimension and that normal to the plane of the paper are assumed to be infinite in length so that edge effects can be ignored. The X-axis is taken to be normal to the metal surface, and it is assumed that the metal moves in this direction. This assumption is valid when the detonation wave parallel to the X-axis, and is only slightly in error when the detonation travels perpendicular to the X-axis.

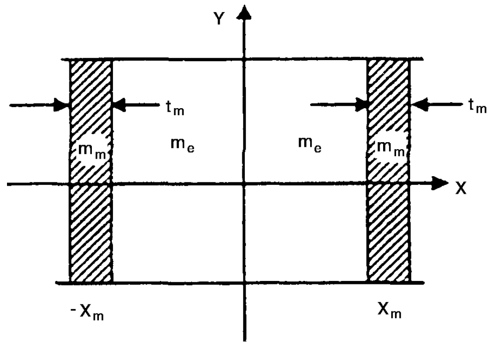

Figure 2.1 Control mass used for the symmetric sandwich

If we use the Gurney assumption that the explosive material velocity v_g is proportional to the distance from the symmetry boundary X=0, we have:

$$v_g(X) = \frac{X}{X_m} v_l \ , \tag{2.2}$$

where v_l is the terminal, rigid-body speed of the metal liner and is also the speed of the gaseous explosion products in contact with the liner. The liner and explosive mass per unit area are defined as

$$m_m = \rho_m t_m \ , \tag{2.3}$$

and

$$m_e = \rho_e X_m \ , \tag{2.4}$$

respectively. The equation for the total kinetic energy per unit area of the control mass E_{ke} may be written as

$$E_{ke} = \int_0^{X_m} \frac{1}{2} \rho_g v_g^2(X) \mathrm{d}X + \int_{X_m}^{X_m+t_m} \frac{1}{2} \rho_m v_l^2 \, \mathrm{d}X \ , \tag{2.5}$$

The equation (2.5) may be integrated using the definitions in equations (2.2), (2.3), and (2.4). So we get:

$$2\,E_{ke} = (\frac{1}{3} m_e + m_m) v_l^2 \ , \tag{2.6}$$

If we define E as the kinetic energy per unit mass of explosive, or E_{ke} / m_e, the equation (2.6) simplifies to:

$$\frac{v_l}{\sqrt{2E}} = \left(\frac{m_m}{m_e} + \frac{1}{3} \right)^{-1/2} \ , \tag{2.7}$$

where the term $\sqrt{2E}$ is an explosive material constant with units of velocity, or the Gurney velocity of the explosive. It is the single material constant needed to estimate the ability of an explosive to launch a mass of material. The different ways for calculation of Gurney velocity for explosives are discussed in [3].

Using the same procedure we get the Gurney equations for a exploding cylinder and sphere:

Cylindrical case:

$$\frac{v_l}{\sqrt{2E}} = \left(\frac{m_m}{m_e} + \frac{1}{2} \right)^{-1/2} \ , \tag{2.8}$$

Spherical case:

$$\frac{v_l}{\sqrt{2E}} = \left(\frac{m_m}{m_e} + \frac{3}{5} \right)^{-1/2} \ , \tag{2.9}$$

The variations of normalised liner velocities with m_m / m_e for the symmetric sandwich, cylinder and sphere are shown in figure 2.2.

2.3. Asymmetric geometries

For one-dimensional geometry that do not contain a symmetry boundary within the control mass, the equation for conservation of momentum is used to determine the material location in the gas explosive products that experiences, on average, no change in position. The approximation of a linear velocity distribution in the gas explosive products is then used to integrate the energy equation.

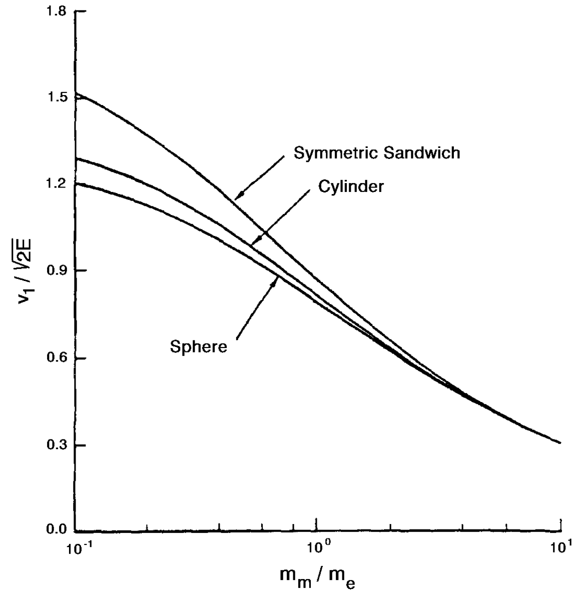

Figure 2.2 Variations of the normalised liner velocities with liner-to-charge mass ratios for the symmetric sandwich, cylinder and sphere

For *the asymmetric sandwich*, or plane parallel plates, a diagram of the control mass is shown in figure 2.3. The velocity in the gas explosive products is expressed as

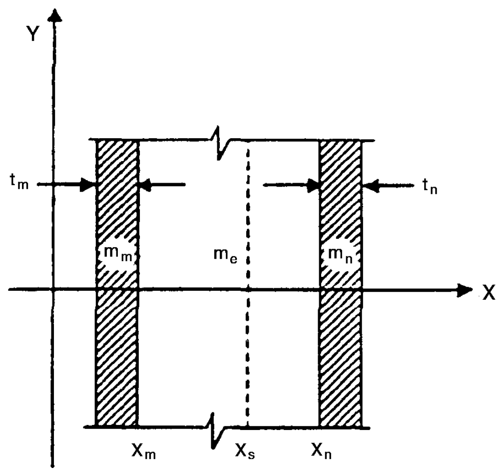

Figure 2.3 Control mass used for the asymmetric sandwich.

$$v_g(X) = v_m \frac{X - X_s}{X_s - X_m} , \tag{2.10}$$

for the left-moving portion, and

$$v_g(X) = v_n \frac{X - X_s}{X_n - X_s} , \tag{2.11}$$

for the right-moving portion.

Using the equations for conservation of momentum for left-moving and right-moving portions, eliminating the pressure impulse term, and solving for X_s, the location of the stationary surface, we have:

$$X_s = \frac{X_n^2\left(\frac{1}{2} + \frac{m_n}{m_e}\right) - X_m^2\left(\frac{1}{2} + \frac{m_m}{m_e}\right) - X_m X_n\left(\frac{m_n}{m_e} - \frac{m_m}{m_e}\right)}{(X_n - X_m)\left(\frac{m_m}{m_e} + \frac{m_n}{m_e} + 1\right)} \tag{2.12}$$

Using the equation for conservation of energy, we get:

$$\frac{v_m}{\sqrt{2E}} = \left\{\frac{m_m}{m_e} + \frac{m_n}{m_e}\frac{(X_n - X_s)^2}{X_s^2} + \frac{1}{3}\frac{X_s}{X_n}\left[1 + \frac{(X_n - X_s)^3}{X_s^3}\right]\right\}^{-1/2} \tag{2.13}$$

The form of the equation (2.13) is well suited to directly reveal the effect of a change in configuration (e.g., m_m / m_e or m_n / m_e) upon the velocity imparted to metal. The figure 2.4 is a plot of the proportionate velocity increase of plate with mass m_m due to tamping for various ratios m_m / m_e. The figure illustrates that tamping a relatively heavy charge ($m_m / m_e = 0.2$) increases the velocity of plate with mass m_m very little, while adding tamping to a light charge ($m_m / m_e = 5$) increases the velocity considerably, particularly in the range $m_m / m_e < 5$.

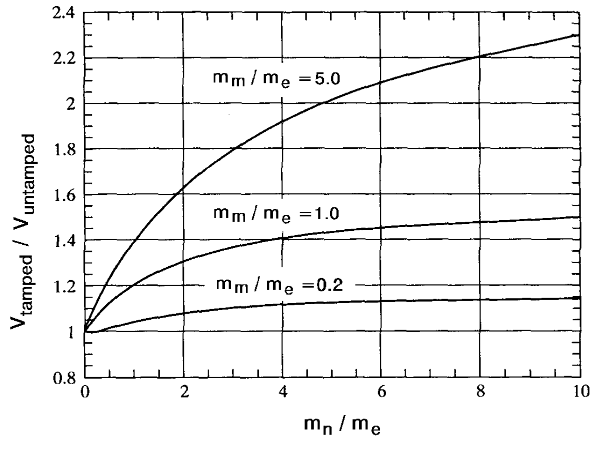

Figure 2.4. Gain in velocity of plate with mass m_m due to tamping factor m_m / m_e.

The plate velocities, obtained from the equation (2.13), were found in reasonably good agreement with experimental values at relatively high charge to metal mass ratio ($m_e / m_m \geq 0.2$). To solve this problem, we use the concept of uniform pressure (density) and particle velocity of detonation products between flyer plates as shown in figure 2.5 for calculating their final velocities at low m_e / m_m. Using equations for conservation of energy and momentum, and the polytropic equation of state for the detonation products, we get:

$$v_m = \left[\frac{2}{k-1}\frac{p_y}{\rho_y}\right]^{1/2}\left[\left(\frac{m_m + m_{em}}{m_e}\right)\left(1+\frac{m_m + m_{em}}{m_n + m_{en}}\right)\right]^{-1/2} \tag{2.14}$$

$$v_n = \left[\frac{2}{k-1}\frac{p_y}{\rho_y}\right]^{1/2}\left[\left(\frac{m_n + m_{en}}{m_e}\right)\left(1+\frac{m_n + m_{en}}{m_m + m_{em}}\right)\right]^{-1/2} \tag{2.15}$$

where k is the polytropic exponent, p_y is the uniform pressure, ρ_y is the uniform density, m_{em} is the mass of detonation products moving with the velocity v_m, and m_{en} is the mass of detonation products moving with the velocity v_n.

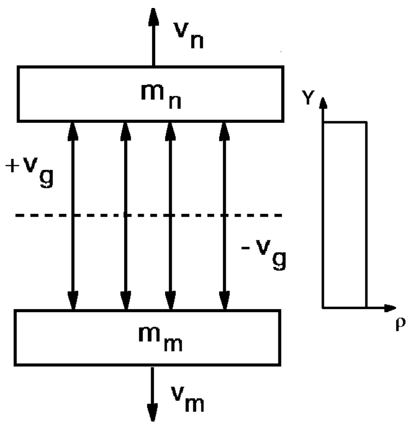

Figure 2.5. Variation of density and particle velocity of detonation products

From previous equations we can consider the case when one plate is of infinite mass. That plate acts as a rigid boundary. The velocity of the other plate can be obtained by substituting m_n=∞, m_{em}=m_e, m_{en}=0, and v_n=0 in the equation (2.14). So we get:

$$v_m = \left(\frac{2}{k-1}\frac{p_y}{\rho_y}\right)^{1/2}\left(1+\frac{m_m}{m_e}\right)^{-1/2}, \tag{2.16}$$

The open-face sandwich shown in figure 2.6 is another example of asymmetric geometry. Using common procedure we get for that case:

$$v_m = \sqrt{2E}\left[\frac{(1+2m_m/m_e)^3+1}{6(1+m_m/m_e)}+\frac{m_m}{m_e}\right]^{-1/2}, \tag{2.17}$$

Interesting results about velocity of a plane metal plate placed at the end of a cylindrical explosive charge are given in [4].

The principal motivation for analysing *imploding geometries* is to model the acceleration of the liner in shaped charge operation. The control volume used to derive formulas for imploding geometries is shown in figure 2.7.

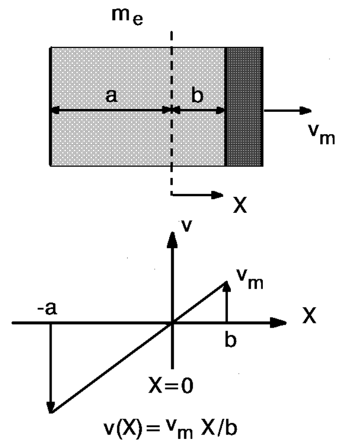

Figure 2.6. Open-face sandwich configuration with assumed velocity distribution

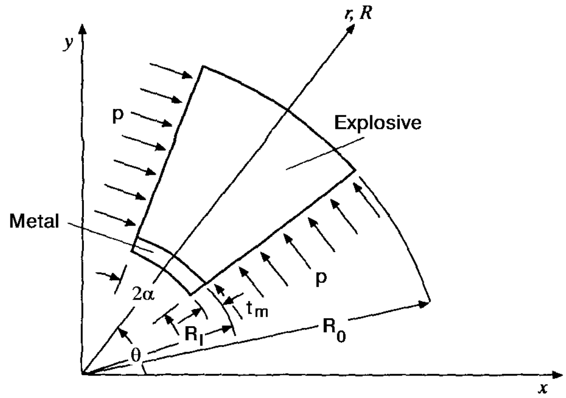

Figure 2.7. Control volume for imploding geometries

The final velocity of the metal liner in this case is:

$$v_m = \frac{1}{1+\frac{m_m}{m_e}}\left[-\frac{\Psi}{m_e}+\left(\frac{2E(\frac{m_m}{m_e}+1)}{\eta(\frac{m_m}{m_e}+1)-1}-\frac{\Psi^2}{m_e^2}\frac{1}{\eta(\frac{m_m}{m_e}+1)-1}\right)^{1/2}\right] \tag{2.18}$$

where

$$\eta = \frac{3}{2}\frac{3\beta^2+4\beta+1}{4\beta^2+4\beta+1}, \quad \beta = R_0/R_I, \quad \Psi = \int_0^\infty \int_{R_I}^{R_0} p(R,t)\,\mathrm{d}R\,\mathrm{d}t.$$

Note that as R_I and R_0 both approach infinity, this formula approaches the classical formula for the open-face sandwich. Usually for Ψ the next approximation is used:

$$\Psi \cong K\, p_{CJ}\, \tau^*(R_0 - R_I)\left(\frac{R_0}{R_I}-1\right), \tag{2.19}$$

over the range 1.25 ≤ R_0/R_I ≤ 1.72, K is constant which value is 0.933, and τ^* is a characteristic time given by formula:

$$\tau^* = \frac{0.912 m_m v_m + 0.207}{p_{CJ}}, \tag{2.20}$$

where p_{CJ} is the Chapman-Jouget pressure.

For imploding cylinders with exterior confinement, the location the zero-radial-velocity position, R_s, is evaluated by solving a cubic equation:

$$R_s^3 + 3R_s\left[(R_0+R_I)\frac{\rho_e}{\rho_{CJ}}\left(\frac{m_m}{m_e}R_0 + \frac{m_n}{m_e}R_I\right) + R_I R_0\right] - -3(R_I+R_0)R_I R_0\left[\frac{2}{3}+\frac{\rho_e}{\rho_{CJ}}\left(\frac{m_m}{m_e}+\frac{m_n}{m_e}\right)\right]=0 \tag{2.21}$$

The imploding liner velocity is then given as:

$$\frac{v_m}{\sqrt{2E}} = \left[\frac{m_m}{m_e} + \frac{m_n}{m_e}\frac{(R_0-R_S)^2}{(R_s-R_I)^2} + \frac{1}{6}\frac{(R_S-R_I)(3R_I+R_S)}{\left(R_0^2-R_I^2\right)} + \frac{1}{6}\frac{(R_0-R_S)^3(3R_0+R_S)}{\left(R_0^2-R_I^2\right)(R_S-R_I)^2}\right\}^{-1/2} \tag{2.22}$$

In similar manner, using the fourth-polynomial equation for hypothetical stationary surface R_S, we get the equation for estimating the velocity of imploding liner *of imploding sphere with exterior confinement*:

$$\frac{v_m}{\sqrt{2E}} = \left\{\frac{m_m}{m_e} + \frac{m_n}{m_e}\frac{(R_0-R_S)^2}{(R_S-R_I)^2} + \frac{1}{10}\frac{R_S-R_I}{\left(R_0^3-R_I^3\right)}\cdot \cdot\left[6(R_S-R_I)^2 - 15R_S(R_S-R_I) + 10R_S^2\right] + \frac{1}{10}\frac{1}{(R_S-R_I)^2}\cdot \cdot\frac{(R_0-R_S)^3}{\left(R_0^3-R_I^3\right)}\left[6(R_0-R_S)^2 + 15(R_0-R_S) + 10R_S^2\right]\right\}^{-1/2} \tag{2.23}$$

The simple gas-dynamic assumptions made in the Gurney model do not apply for certain circumstances, and then Gurney analysis either should not be applied or should be applied with corrections to account for the deviations [5].

3. MILITARY APPLICATIONS OF MODELS

3.1. Introduction

The equations, considered in section 2, are widely used in design of military items. For example, the equations developed for cylindrical geometries are used in design of shaped charges. In this section we'll give some interesting equations for design warheads and fuzes for which starting points in developments were the equations given in section 2.

3.2. Warheads design

Naturally fragmenting warheads are classified as uncontrolled fragmentation devices. The idea behind the natural fragmentation warhead is to break the case into a number of fragment masses giving a bias toward a particular mass. The four-step natural fragmentation break-up process is shown in figure 3.1.

The modified equation (2.8) that accounts for warhead length, L, is expressed as:

$$v_m = \sqrt{2E}\sqrt{\frac{m_e/m_m}{\left(1+\dfrac{m_e}{2m_m}\right)\left(1+\dfrac{D_e}{2L}\right)}}, \tag{3.1}$$

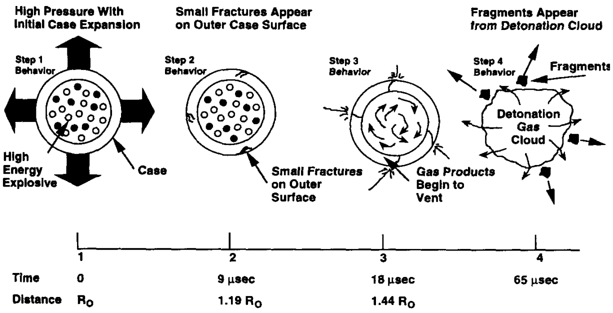

Figure 3.1 Expansion process of natural fragmentation warhead.

Here D_e is the explosive's diameter. This equation accounts for explosive gas venting based on warhead length. If we know the desired peak velocity of fragments from consideration of warhead effectiveness the ratio m_e/m_m is given by:

$$\frac{m_e}{m_m} = \frac{1+\dfrac{D_e}{2L}}{\left(\dfrac{\sqrt{2E}}{v_m}\right)^2 - \dfrac{1}{2}\left(1+\dfrac{D_e}{2L}\right)}, \tag{3.2}$$

Based on initial warhead geometry, $D_0=2R_0$ and $D_I=2R_I$, the internal diameter of warhead case, D_I, is:

$$D_I^2 = \frac{\rho_m\left(1+\dfrac{D_e}{2L}\right)D_0^2}{\rho_e\left(\dfrac{\sqrt{2E}}{v_m}\right)^2 + \left(1+\dfrac{D_e}{2L}\right)\left(\rho_m - \dfrac{\rho_e}{2}\right)}. \tag{3.3}$$

Here ρ_m and ρ_e are metal and explosive density, respectively. The ratio of the outside case radius to the inside case radius is expressed as:

$$\frac{R_I}{R_0} = \sqrt{\frac{(1+R_e/L)\rho_m/\rho_e}{\left(\dfrac{\sqrt{2E}}{v_m}\right)^2 + \left(1+\dfrac{R_0}{L}\right)\left(\dfrac{\rho_m}{\rho_e}-\dfrac{1}{2}\right)}}. \tag{3.4}$$

Premade fragment warhead design logic offers the warhead designer the best method of selecting the exact fragment weight and size to be used in a warhead. Premade fragmentation warheads require an inner liner. The inner case is usually made of aluminium, which sometimes acts as a structure to carry dynamic missile loads. Aluminium is light, to maximise initial fragment launch velocity, but strong enough to contain explosive gases for a short period of time. A warhead with premade fragments with an uncontrolled fragmentation case is shown in figure 3.2. This type of warhead would generate a combined-effects warhead that would accelerate large mass fragments at heavy components with small, light fragments that would kill thin components.

In this case the peak fragment velocity is given by expression:

$$\left(\frac{v_{fm}}{\sqrt{2E}\eta}\right)^2 = \frac{\pi L r_e^2 \rho_e (1+r_e/L)^{-1}}{\pi L\left(2(r_0-t)\rho_f t + \dfrac{r_e^2\rho_e}{2}\right) + \dfrac{\pi L \rho_l\left(r_l^2-r_e^2\right)}{B^2 t_l^{\frac{5}{3}} D_e^{\frac{2}{3}}\left(1+\dfrac{t_l}{D_e}\right)^2}} \tag{3.5}$$

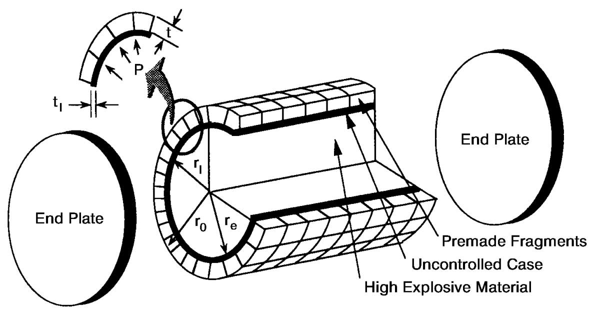

Figure 3.2. Premade fragments on uncontrolled fragmentation case

Here η is the explosive efficiency, and B is constant. This equation is used for optimisation of premade fragment and liner thickness for given fragment velocity, warhead weight and volume.

KE-rod warhead technology offers designers a new type of warhead that can attack and destroy ballistic missiles. This warhead deploys high-density massive rods at tactical ballistic missiles (TBM) that can penetrate thick or hardened payloads. This concept is becoming more popular but differs significantly compared to conventional blast fragmentation warheads. In this concept we analise centre core and jelly roll concepts.

The centre core KE-rod warhead configuration is used during isotropic missile/target encounters. The warhead device contains a centre explosive core surrounded by rods arranged circumferentially, as shown in figure 3.3.

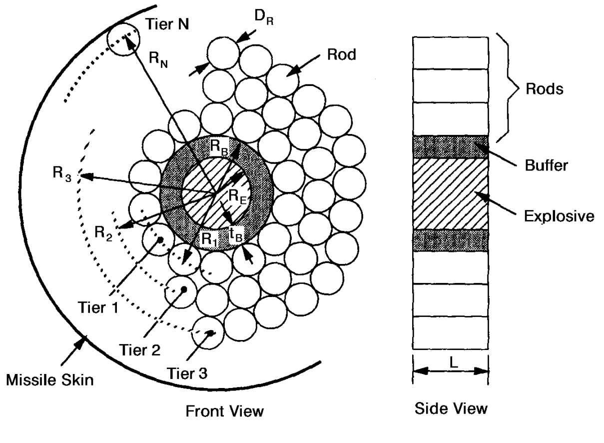

Figure 3.3. Geometric description of centre core warhead

Starting from the equation (3.1), we get the following equation for the explosive radius R_e:

$$R_e^3\left[\frac{\pi}{2}\delta\rho_e\right]+R_e^2\left[\pi\rho_e L(\delta-1)+\frac{\pi^2 D_R\rho_R N\delta}{2}\right]+$$
$$+R_e\left[\pi^2\frac{D_R^2}{4}\rho_R N\delta\left(\frac{2L}{D_R}+N\right)\right]+\delta\pi^2\frac{D_R^2}{4}L\rho_R N^2=0 \tag{3.6}$$

Here δ is $\delta=(v_{mR}/\sqrt{2E})^2$. This equation is used to estimate rod velocity v_{mR} as function of explosive radius R_e, rod diameter D_R, number of rod tiers N, and rod length L.

The jelly roll KE-warhead ejects its rods about the missile axis and is only used during isotropic missile/target engagements. The jelly roll configuration consists of explosive, buffer, and rods arranged in alternating circular layers as illustrated in figure 3.4.

The rod ejection velocity is expressed as a function of inner rod radius r_i, where each rod velocity is computed based on inner rod geometric location:

$$V(r)=\sqrt{2E}\,\frac{r_i}{R}\sqrt{\frac{m_e/m_m}{\frac{1}{2}(1+m_e/m_m)}}\ , \tag{3.7}$$

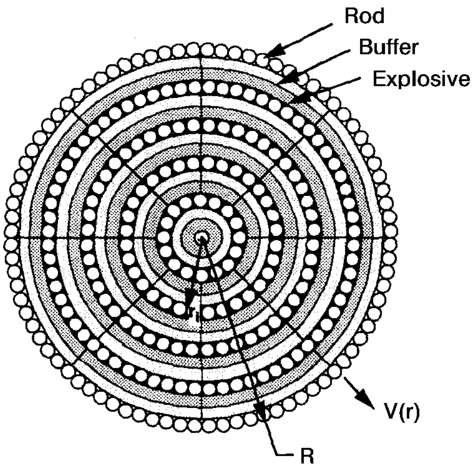

Figure 3.4. Jelly roll geometric configuration
This equation computes the same rod launch velocity on each row given a constant explosive thickness.

Gimbaled warheads offer warhead designers unique and novel warhead options for use against TBM targets. A gimbaled warhead is shown in figure 3.5.

This warhead is designed to fire fragments through the front end of the warhead instead of out the sides of the warhead as in most conventional devices. Metal confinement is used via the cylindrical case with a metal tamper inserted on the aft end. The tamper thickness controls the peak fragment velocity.

The peak velocity of fragments and tamper can be computed using following equations:

$$v_{fm}=\sqrt{2E}\left[\frac{1}{3}\frac{1+(\frac{a}{b})^3}{1+\frac{a}{b}}-\frac{m_n}{m_m}\frac{m_m}{m_e}(\frac{a}{b})^2+\frac{m_m}{m_e}\right]^{-\frac{1}{2}}, \tag{3.8}$$

$$v_{tn}=v_{fm}\ a/b\ , \tag{3.9}$$

where $a/b=[(m_e/m_m)+2]/[(m_e/m_m)+2(m_n/m_m)]$.

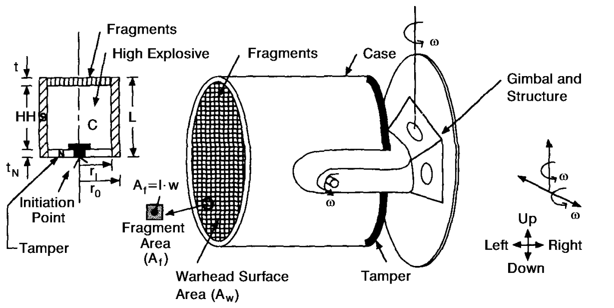

Figure 3.5. Description of a gimbaled warhead

3.3. Fuzes

In fuzes detonation is often transferred from a detonating element (called the donor) to a second explosive charge (called the acceptor) by use of the donor charge to drive a flying plate which impacts the acceptor charge and shock initiates it. This concept is applied in low-energy flyer plate detonators as shown in figure 3.6, which use a 3.5 A firing current to initiate a mixture of TiH/ClO_4 which detonates a small charge of HNAB explosive. This projects an aluminium flyer plate over a 10 mm range at up to 1.3 km/s to impact another two pellets of HNAB pressed to different densities, giving reliable full-order detonation output.

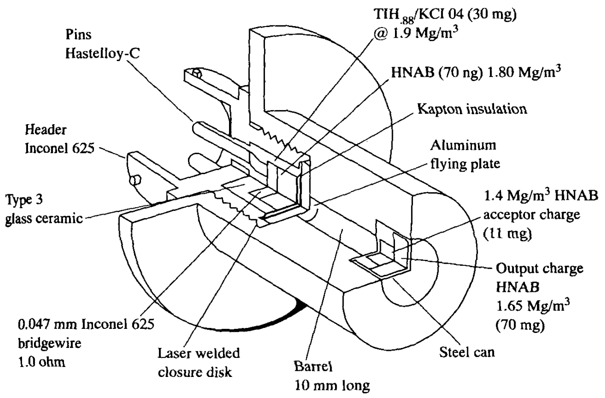

Figure 3.6. Low-energy flying plate detonator

In this and other applications involving detonation by flyer plate impact, it is typically desired that a minimal amount of donor charge be required and that efficient use be made of the flyer plate. These conditions lead to the use of thin flyer plates, which can be driven to high velocities by small donor charges. The response of explosives to the impact of thin flyer plates resulted in the shock-initiation criterion in the form $P^2\tau$. Here P is the shock pressure driven into the explosive, and τ is the shock duration. The criterion in this form is useful for engineering design purposes. To evaluate initiation criterion as a function of design parameters, we'll consider the donor-acceptor-flyer configuration sketched in figure 3.7.

Using sandwich formula, the expression for $P^2\tau$ becomes:

$$P^2\tau = \frac{4E\rho_f l_f z_a Z}{(Z+1)^2}\left(\frac{\rho_f l_f}{\rho_d l_d}+\frac{1}{3}\right)^{-1}, \qquad (3.10)$$

Here subscripts a, d, and f refer to acceptor, donor, and flyer, respectively. Also, in the equation (3.10) $z = \rho U$, where U is the shock velocity, and $Z=z_a/z_f$. The previous equation is used for optimisation of detonators from different design aspects.

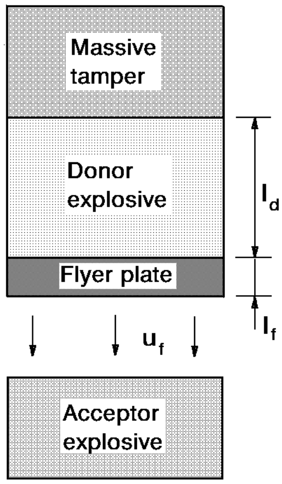

Figure 3.7. Detonation transfer configuration

4. CONCLUSIONS

On the basis of previous considerations, we can draw the following conclusions:

Explosive propulsion has the significant role both in civil and in military applications.

Different geometrical configurations, which find their applications in practice, are studied mainly through determination of terminal velocity of liners achieved during explosion.

Use of formulae, for studied geometrical configurations, in design of selected military items is presented. These formulae are the basic ones for design and optimisation of conventional warheads, anti-tactical ballistic missiles warheads, fuzes, etc.

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ВОЈНЕ ПРИМЕНЕ ЕКСПЛОЗИВНЕ ПРОПУЛЗИЈЕ

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Експлозивна пропулзија има значајну улогу у цивилним и војним применама. У овом раду различите геометријске конфигурације, које имају примену у пракси, проучаване су углавном кроз одређивање крајње брзине облога које се постижу за време експлозије. Дата је употреба формула, за разматране геометријске конфигурације, у пројектовању изабраних војних производа. Ове формуле су базне за пројектовање и оптимизацију конвенционалних бојевих глава, бојевих глава анти-тактичких балистичких пројектила, упаљача, итд.