

## MODELING IN SHAPED CHARGE DESIGN

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The efficient development of scientific programs dealing with studies of reliability of the body lining of a spacecraft, as well as the quality of the results being obtained, depends to a great extent on the operational parameters of the shaped charges, their killing characteristics in particular, which are used to form jet particles. An integral parameter for assessment of the efficiency of the shaped charge is the length of the shaped jet.

It is known that the characteristics of the shaped jet, and its length in particular, depend on the geometry of the shaped charge. The influence of this factor will be analyzed shortly.<sup>1</sup> The solution of the task is satisfied within the hypothesis of the radial-flat scheme of the hydrodynamic model of Orlenko-Stanukovitch (See Figure 1). In the Cartesian co-ordinate system  $zOy$  the following equations of the generating line of the surfaces of the basic details of the shaped charge with height  $H$  are determined:  $y_1 = F(z)$ ,  $y_2 = \Phi(z)$ ,  $y_3 = \varphi(z)$ , and  $y_4 = f(z)$ . They describe the external and internal surface of the body, and the external and internal surface of the lining of the shaped charge, respectively. The following constraints are imposed on the functions just listed -- they are continuous and have continuous first derivatives. Furthermore, the following conditions are always fulfilled:

$$\xi \geq F(z) \geq \Phi(z) \geq \varphi(z) \geq f(z); \quad H \geq 0; y \geq 0. \quad (1)$$

The front of the detonation wave is flat and perpendicular to the polar axis of the shaped charge in its movement into the weight of the charge from left to right. There are no constraints on the permissible boundary deformations of the jet material.

Let us assume that the collapse velocity of the lining  $W_0(z)$  does not depend on time and it is a function only of the  $z$  coordinate.<sup>2</sup>  $W_0(z)$  is related to the launch velocity of the shaped jet  $W_1(z)$  in the cross-section that is examined by means of the kinematics relation:<sup>3</sup>

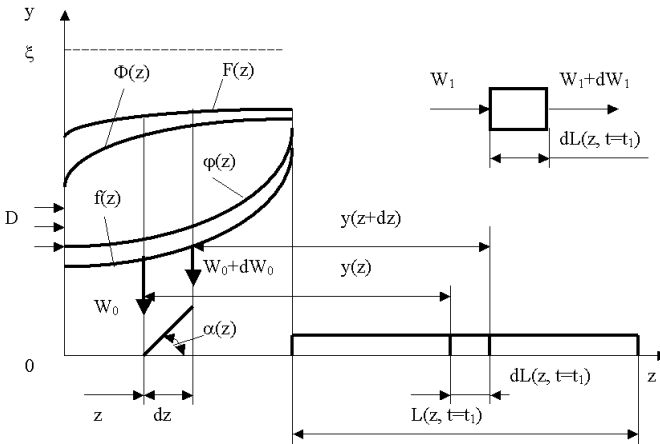


Figure 1: Radial-flat scheme of Orlenko-Staniukovitch for deformation and collapse of the lining of the shaped charge and formation of the jet.

$$W_0(z) = W_1(z) \cdot \operatorname{tg} \frac{\alpha(z)}{2} = \frac{k_i \cdot D}{2} \cdot \sqrt{\beta(z) \cdot [2 + \beta(z)]^{-1}},$$

where:

$k_i$  is coefficient which gives the reading of redistribution of the impulse of the explosion according to the height

of the shaped lining;

$D$  is a velocity of detonation of the explosive;

$\beta(z)$  is an explosive load coefficient;

$\alpha(z)$  is an angle of collapse of the lining.

The complete collapse of the lining is performed for a period of time  $t = H/D$ . The elementary fraction of the lining with a coordinate  $z$  and a length  $dz$  occupies a spatial position which is limited by the coordinates  $y(z)$  and  $y(z+dz)$ , and taking into account the geometry of the charge and the kinematics of the elementary fraction of the lining, we obtain:

$$dL = \left\{ \left( \frac{W_0}{tg \frac{\alpha}{2}} \right)' \left[ \frac{H-z}{D} + \frac{f(H)}{W_0(H)} - \frac{f}{W_0} \right] + \frac{W_0}{tg \frac{\alpha}{2}} \left[ -\frac{1}{D} - \frac{f'W_0 - fW_0'}{W_0^2} \right] \right\} dz. \quad (2)$$

For  $tg \frac{\alpha}{2}$  we have the following quadratic equation:<sup>4</sup>

$$Atg^2 \frac{\alpha}{2} + 2tg \frac{\alpha}{2} - A = 0.$$

And according to the physics of the process, the solution is the root

$$tg \frac{\alpha}{2} = \frac{-1 + \sqrt{1 + A^2}}{A},$$

where

$$A = f' - \frac{f\beta'}{\beta(2+\beta)} + \frac{1}{2} \sqrt{\frac{\beta}{2+\beta}}.$$

If we integrate (2) from 0 to  $H$  we shall obtain the complete length of the shaped jet at the moment of completion of its formation:

$$L = \int_0^H \left\{ \frac{A}{\sqrt{1+A^2}-1} \left[ \frac{\beta'}{\sqrt{\beta(2+\beta)^3}} \left( B_H - \frac{1}{2}z \right) - f' - \frac{1}{2} \sqrt{\frac{\beta}{2+\beta}} \right] - \frac{A'}{\sqrt{1+A^2}(\sqrt{1+A^2}-1)} \left[ \sqrt{\frac{\beta}{2+\beta}} \left( B_H - \frac{1}{2} \right) - f \right] \right\} dz, \quad (3)$$

where  $B_H$  is a known function of the load coefficient at  $z=H$ :

$$B_H = \frac{H}{2} + f_H \sqrt{\frac{2 + \beta_H}{\beta_H}}.$$

Expression (3) is an initial expression that can be used to determine the extremum of the functional:

$$I = \int_0^H \bar{L}[z, \zeta(z), \zeta'(z)] dz,$$

where:

$\bar{L}$  is a specified function;

$0$  and  $H$  are specified boundaries of integration;

$\zeta = \zeta(z)$  is a variable function of the geometry of the charge (e.g. external or internal surface of the body, the charge or the lining).

The function  $\zeta = \zeta(z)$  that is sought, is a solution of the boundary task with boundary values for a conventional Euler-LaGrange differential equation of the type:

$$\bar{L}'_{\zeta} - \bar{L}''_{z\zeta'} - \bar{L}''_{\zeta\zeta'} \frac{d\zeta}{dz} - \bar{L}''_{\zeta\zeta'} \frac{d^2\zeta}{dz^2} = 0 \quad (4)$$

and specified boundary conditions:

$$\zeta(0) = \zeta_0; \quad \zeta(H) = \zeta_H. \quad (5)$$

For real designs with a cylindrical body and a shaped lining with a constant thickness an additional integral condition can be used that provides optimum conditions for formation of the shaped jet<sup>5</sup> where the variable function is the profile of the lining:

$$\int_0^H G(z, f, f') = \int_0^H \left\{ \frac{1}{2} \frac{\beta'}{\sqrt{\beta(2+\beta)^3}} + f'' - \frac{(f'\beta' + f\beta'')(2+\beta)\beta - 2f\beta'^2(1+\beta)}{\beta^2(2+\beta)^2} \right\} dz = K \quad (6)$$

Here,  $K$  is a specified parameter. According to some authors<sup>6</sup> values for lining made of steel, aluminum and copper are equal to  $K_{St}=0,231$ ;  $K_{Al}=0,268$ ;  $K_{Cu}=0,364$ , respectively.

As a result we obtain a task with a conditional integral extremum that is equal to the task of an unconditional extremum of the expression:

$$\int_0^H \bar{L}(z, f, f') dz + \lambda \int_0^H G(z, f, f') dz = \int_0^H (\bar{L} + \lambda G) dz, \tag{7}$$

where  $\lambda$  is an unknown constant multiplier of LaGrange.<sup>7</sup>

The task is reduced to the determination of the solution of the Euler equation for the modified function:

$$\begin{aligned} \bar{L}^*(z, f, f') &= \bar{L}(z, f, f') + \lambda G(z, f, f') = \\ &= \left[ \frac{\beta'}{\sqrt{\beta(2+\beta)^3}} \left( B_H - \frac{1}{2}z \right) - f' - \frac{1}{2} \sqrt{\frac{\beta}{2+\beta}} \right] \frac{K}{\sqrt{1+K^2-1}} + \\ &+ \lambda \left[ \frac{1}{2} \frac{\beta'}{\sqrt{\beta(2+\beta)^3}} + f'' - \frac{(f'\beta' + f\beta'')(2+\beta)\beta - 2f\beta'^2(1+\beta)}{\beta^2(2+\beta)^2} \right]. \end{aligned} \tag{8}$$

The function  $f = f(z)$  that was sought is a solution of the boundary task with two (one) no-move values for a conventional differential equation of Euler-LaGrange:

$$\bar{L}^*_{f'} - \bar{L}^*_{f''} - \bar{L}^*_{ff'} f' - \bar{L}^*_{f'f'} f'' = 0 \tag{9}$$

and specified boundary conditions:

$$f(0)=f_0; \quad f(H)=f_H. \tag{10}$$

The two integration constants and the LaGrange multiplier are determined by the three conditions -- two boundary and one additional condition.

The solution of the task is a set of straight lines that are parallel to the straight-line profile of the body (a cylinder or a cone) and depend on the specified boundary conditions. Figure 2 illustrates the solutions.

The solutions have a physical meaning. In all solution cases the angle of collapse and the load coefficient along the shaped charge are constants. The angle of collapse is minimum and is formed as a result of the delay of the front of the detonation wave that, in turn, provides the high launching velocity of the jet and its maximum length.

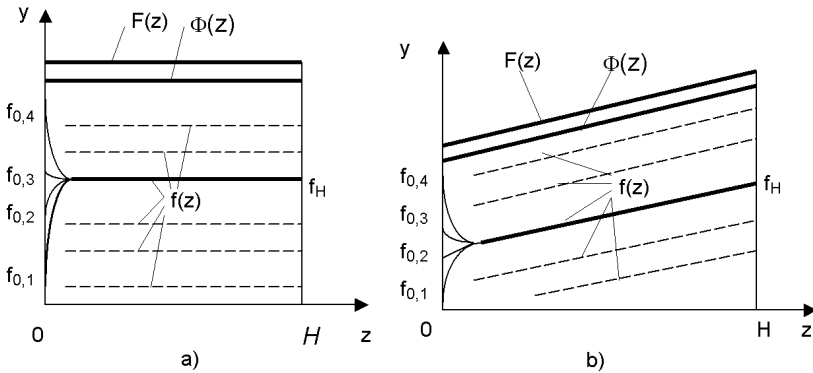


Figure 2: Solutions in case of: a) cylindrical body profile; b) conical body profile.

## Notes

- <sup>1</sup> Kirril Stanukovitch, *Explosion Physics* (Moscow: Science, 1975), 703.
- <sup>2</sup> Hristo Hristov, *Justification of a Possibility of Effect Heightening of the Jet Members for a Cartridge Ammunition by No-gradient Jet Forming*, Ph.D. Thesis (Tula, Russia: Tula State University, 1993). -- 146 pp.
- <sup>3</sup> Stanukovitch, *Explosion Physics*, 605.

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- <sup>4</sup> Victor L. Baranov, Hristo I. Hristov, Milcho S. Patechkov, "A Variation Problem with a Conditional Extremum by Explosion Clapping of the Metallic Layers," *Technical Ideas* 1-2 (Bulgarian Academy of Sciences, Sofia, 2000): 141-146.
  - <sup>5</sup> Nikolay Zlatin, "About Maximum Velocities of a Close Set Condensed Jet Spray," *Mathematics and Mechanics Problems* (Novosibirsk, Russia: Nauka, 1983).
  - <sup>6</sup> Sergey Godunov, "About Influencing Viscosity of a Material on Process of Formation of Sprays at Impingement of Metallic Laminas," *Physics of Burning and Explosion* 1 (Novosibirsk, Russia, 1975): 3-18.
  - <sup>7</sup> Lev E. Elsgolz, *Differential equations and variations calculation* (Moscow: Nauka, 1969). -- 424 pp.

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