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# REBOUNDING OF A SHAPED-CHARGE JET

**E. V. Proskuryakov,[1] M. V. Sorokin,[1] and V. M. Fomin[2]**

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*The phenomenon of rebounding of a shaped-charge jet from the armour surface with small angles between the jet axis and the target surface is considered. Rebounding angles as a function of jet velocity are obtained in experiments for a copper shaped-charge jet. An engineering calculation technique is developed. The results calculated with the use of this technique are in reasonable agreement with experimental data.*

**Key words:** *shaped charge, shaped-charge jet, rebounding, dynamic strength, shock wave.*

Experiments performed in late 1950s showed that small angles between a shaped-charge jet (SCJ) and a target on the armour surface may be responsible for SCJ rebounding. The SCJ rebounding phenomenon can be hardly explained within the framework of the hydrodynamic theory of cumulation based on the model of an incompressible fluid, because there is always an SCJ stagnation point on the target surface in which the pressure multiply exceeds the dynamic strength of the armour. The target becomes deformed at this point, and the SCJ can penetrate into the target.

Let us consider a metal SCJ as a planar jet of a compressible fluid impacting with a supersonic velocity $V_0$ onto a flat target at an angle $\varphi$ (Fig. 1). We assume that the angle $\varphi$ is small and the SCJ material changes the direction of its motion in an oblique shock wave (SW). Meanwhile, the pressure in the SW is lower than the dynamic strength of the target and the target is not deformed.

We use $V_0$, $\rho_0$, $V$, and $\rho$ to denote the SCJ velocity and density ahead of the SW and behind the latter, $V_{0n}$, $V_{0t}$, $V_n$, and $V_t$ are the normal and tangential components of SCJ velocity ahead of the SW and behind it, $P$ is the pressure behind the SW front, $\theta$ is the angle between the direction of the SCJ velocity vector and the SW surface, and $\beta$ is the angle between the SW surface and the target surface.

The following relations are used to solve the problem:

— equation of continuity on the SW

$$\rho_0 V_{0n} = \rho V_n; \tag{1}$$

— equation of continuity of velocities along the SW front

$$V_{0t} = V_t; \tag{2}$$

— law of conservation of momentum on the SW front

$$V_{0n}\rho_0(V_{0n} - V_n) = P; \tag{3}$$

— relations for the shock adiabat of the SCJ material

$$P = P(\mu), \qquad \mu = \rho/\rho_0 - 1. \tag{4}$$

Using Eqs. (1)–(4), we present $V_{0n}$ and $V_n$ as functions of $P$ and $\rho$:

$$V_{0n} = \sqrt{\frac{P(\mu+1)}{\rho_0\mu}}, \qquad V_n = \sqrt{\frac{P}{\rho_0\mu(\mu+1)}}. \tag{5}$$

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[1] Novosibirsk Higher Military Institute, Novosibirsk 630117; saper67@mail.ru. [2] Khristianovich Institute of Theoretical and Applied Mechanics, Siberian Division, Russian Academy of Sciences, Novosibirsk 630090. Translated from Prikladnaya Mekhanika i Tekhnicheskaya Fizika, Vol. 48, No. 5, pp. 17–20, September–October, 2007. Original article submitted November 15, 2006; revision submitted May 11, 2007.

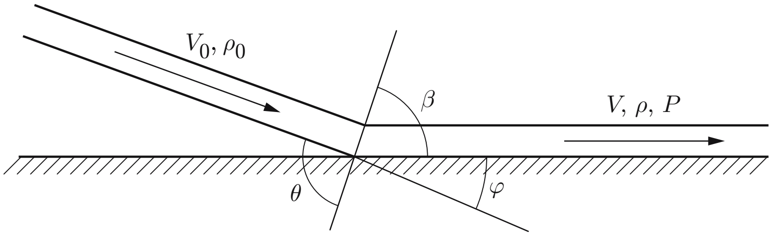

Fig. 1. Turning of a planar jet in an oblique shock wave.

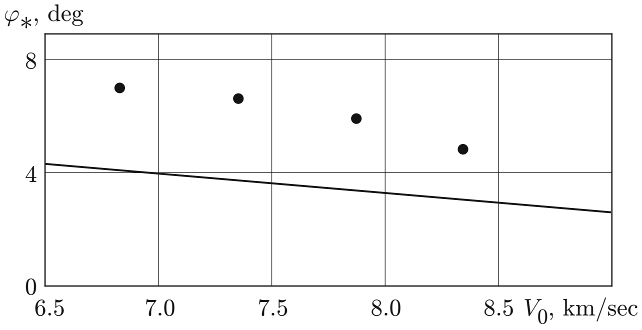

Fig. 2. Rebounding angle $\varphi_*$ as a function of SCJ velocity: the curve and points are the calculated and experimental data, respectively.

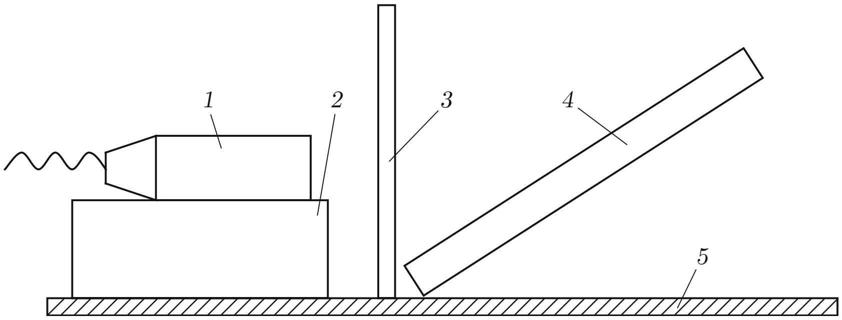

Fig. 3. Schematic of the experiment: 1) shaped charge; 2) foam-plastic support; 3) shield; 4) plate made of armour steel; 5) foundation.

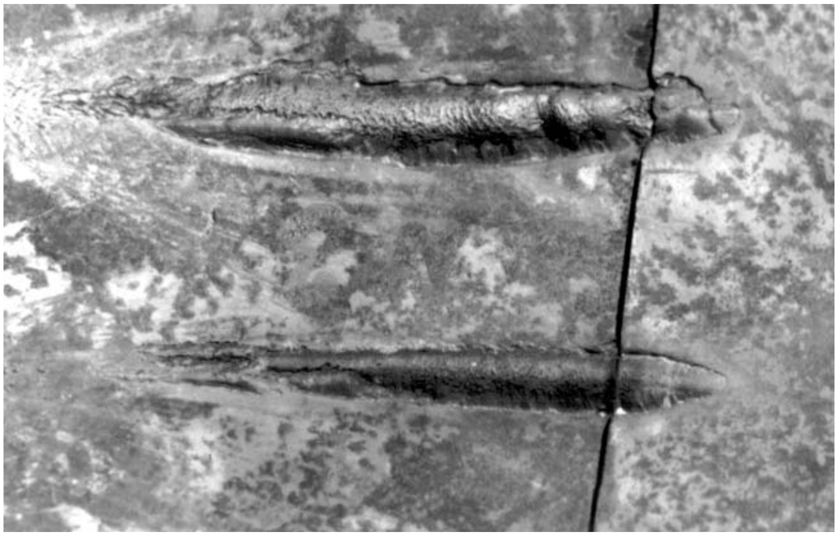

Fig. 4. Imprints of the shaped-charge jet after its rebounding from an armour target.

Figure 1 suggests that the following relations are valid:

$$\varphi = \theta - \beta, \quad \tan\theta = V_{0n}/V_{0t}, \quad \tan\beta = V_n/V_t, \quad V = \sqrt{V_t^2 + V_n^2}, \quad V_0 = \sqrt{V_{0t}^2 + V_{0n}^2}. \tag{6}$$

By transforming, with allowance for Eqs. (5) and (6), the relations

$$\tan(\theta - \beta) = (\tan\theta - \tan\beta)/(1 + \tan\theta\tan\beta),$$

we obtain the equation of the shock polar [1, 2]

$$\tan^2\varphi = \frac{P(\rho_0 V_0^2 \mu/(\mu+1) - P)}{(\rho_0 V_0^2 - P)^2}, \qquad P = P(\mu).$$

Let $\rho_0$ and $V_0$ be constants and $\mu$ be an independent parameter. As the parameter $\mu$ increases, the angle $\varphi$ becomes greater, and the pressure $P$ behind the SW front also increases. At a certain value of $P$ depending on the dynamic strength of the target, the latter becomes deformed, and the SCJ penetrates through the target. The critical value of pressure was used as a fitting parameter and was assumed to be 20 GPa in calculations for a medium-strength armour. We calculated the rebounding angle $\varphi_*$ at which target deformation started. Figure 2 shows the results calculated for a copper SCJ. The rebounding angle $\varphi_*$ is seen to decrease with increasing SCJ velocity.

The experiment on studying the SCJ rebounding phenomenon is schematically illustrated in Fig. 3. To prevent the influence of the common foundation on the charge liner collapse, the charge was mounted onto a plastic-foam support. The target was a plate made of armour steel of medium strength; the plate thickness was 30 mm. The angle between the charge axis and the target surface was within 8°. The velocity of the initial part of the SCJ was measured by means of flush radiography. In some experiments, a metallic shield was mounted ahead of the charge. This shield absorbed part of the SCJ, and the target, consequently, was impacted by more low-velocity parts of the SCJ. The results of interaction of the target and the SCJ in the rebounding mode is shown in Fig. 4. The experimental values of the rebounding angle $\varphi_*$ are plotted in Fig. 2 as functions of SCJ velocity. The angle between the shaped-charge centerline and the target surface $\varphi$ was changed with a step equal to 1°. SCJ penetration into the target was observed for $\varphi - \varphi_* \geqslant 1°$.

Thus, the angles of rebounding of a copper shaped-charge jet from the armour surface have been obtained in experiments in the present study. An engineering technique for estimating the SCJ rebounding angle has been developed.

## REFERENCES

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