

## Deformed Flying-Plate Influence on the Interaction between Jet and ERA

Hong-wei LIU, Yong ZHANG\* and Jun-hong LUO

Key Protective Materials' Laboratory of The Military 2110 Project, Department of Airport Engineering, Airforce Service College, Xuzhou, Jiangsu, China 221000

\*Corresponding author

**Keywords:** Deformation of flying-plate, ERA, The shaped charge jet, Disturb model.

**Abstract.** The basic physical mechanisms associated with a shaped charge jet penetrating ERA were described in many previous works. In the previous disturb model, the fly-plate was thought as rigid body with no deformation. In according to the physical phenomenal of flying-panel moving, the fly-plate in ERA is deformed. Followed the deformation model of flying-plate, dynamic model of jet disturbances caused by deformed plate of ERA has been set up. A comparison between theoretical results with the numerical simulation and experiment ones show good agreement.

### Introduction

ERA is light in weight, small in size, cheap, strong in anti-missile and so on, now is widely used in main battle tanks, self- mechanized guns and armored vehicles. Its basic structure is that the thin layer of explosive is sealed between two thin layers, when the explosive boom, it drives the thin metal layers fly along the normal direction, which will disturb the shaped charge jet and the armor piercing shell and make them useless or useless partly.

Document 1 uses the numerical simulation of the whole process that the shaped charge jet pierce the explosive vertically, it thinks that under the pressure of the explosion, the shaped charge jet flow back and interact with the later shaped charge jet, which disturbs the later shaped charge jet; document 2 set up the model of the shaped charge jet pierce the explosive vertically under the pressure of explosion; document 3 conduct lots of research on the shaped charge jet penetrate the ERA and put forward the famous scree disturbing model; the article mainly study how the deformation of flying-plate influence the shaped charge jet of the ERA. In the previous disturb model, the fly-plate was thought as rigid body with no deformation.

### Interaction between Jet and ERA “the Scree Model”

M. Maysel and others don't consider the deformation on the base of the physical mechanisms associated with a shaped charge jet penetrating ERA, according to the mass flow ratio of flying-plate and jet,  $m_p$  and  $m_j$ , they divide the interaction of flying-plate and jet into interval and continuous process; they think when the jet impacts the flying-plate, the spread velocity of the hole is high, the jet will lose the contact with the plate temporarily, but with the spread velocity of the hole gets down, it makes the jet contact the hole again, this process repeated emergences and make the periodicity and interval jet.

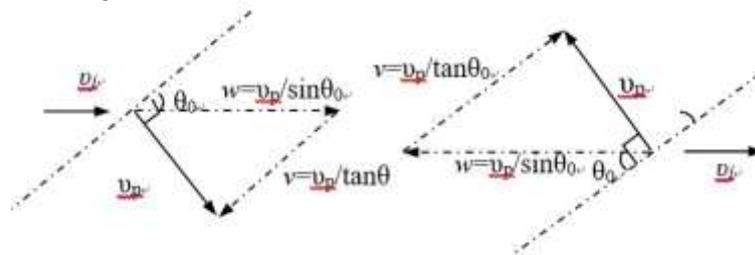


Figure 1. Velocity geometrical relationship fly plate.

But with the speed of the jet comes down, the flying-plate will slicing the jet continuously, after sliced by the flying-plate, the diameter of the jet will decrease and get a transversal speed, which

make the later motion of the jet become curve and break. Resolve the speed of flying-plate along the tangential and the jet direction, as figure 1 shows. The mass ratio is:

$$\frac{m_j}{m_p} = \frac{\pi \rho_j d_j}{4 \rho_p h} \left( \frac{v_j}{v_p} \tan \theta_0 \pm \frac{1}{\cos \theta_0} \right) \quad (1)$$

$$v = \frac{v_p}{\tan \theta_0}, \quad w = \frac{v_p}{\sin \theta_0} \quad (2)$$

Apply the theorem of conservation of momentum and get the deflection angle of velocity after interference is:

$$\tan \alpha = \pm \left[ \frac{\pi \rho_j d_j}{4 \rho_p h \cos \theta_0} \frac{v_j}{v_p} \left( \frac{v_j}{v_p} \tan \theta_0 \pm \frac{1}{\cos \theta_0} \right) \mp \tan \theta_0 \right]^{-1} \quad (3)$$

In the formula:  $\rho_p$ 、 $\rho_j$  is the speed of the density of plate and jet;  $v_j$  is the speed of the micro jet;  $d_j$  is diameter of the local jet;  $h$  is the thickness of plate;  $\theta_0$  is the angle between the plate and the jet. The transverse velocity  $v'_{jx}$  of residual jet after the ERA is:

$$v'_{jx} = \left[ \frac{\pi \rho_j d_j}{4 \rho_p h \cos \theta_0} \frac{1}{v_p} \left( \frac{v_j}{v_p} \tan \theta_0 \pm \frac{1}{\cos \theta_0} \right) + \frac{\tan \theta_0}{v_j} \right]^{-1} \quad (4)$$

### The Disturb Model in the Consideration of the Deformation of the Flying-Plate

The “scree model” takes no consideration of the influence of the deformation of plate, but in fact, in the process of motion, the plate will deform. Because of the angle of the deformed plate, the angle between jet and micro element of plate gets larger. And make disturb of the plate decreases. Resolving the speed of micro element along the tangential direction and the axial of the jet, since the direction of the speed of the plate is parallel to the initial normal direction, so the geometrical relationship of the speed of acting point of the jet and the plate is shown in figure 3 and 4.

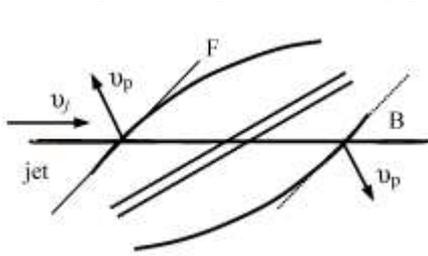


Figure 2. Geometrical relationship of deformed plate.

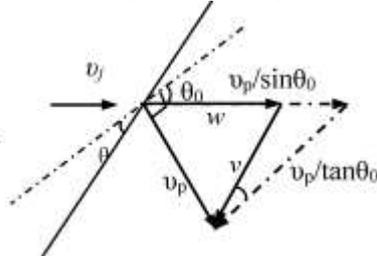


Figure 3. Velocity geometrical relationship B plate.

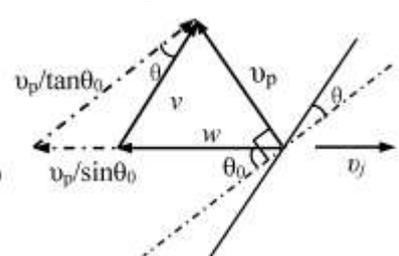


Figure 4. Velocity geometrical relationship F plate.

Supposing the initial angle between plate and jet is  $\theta_0$ , the deformation angle of plate is  $\theta$ , so the angle between the jet and the deformed plate is  $\theta_0 + \theta$ . The dotted line is the geometrical relationship of the resolution of velocity without consideration of the deformation of plate, the active line is the geometrical relationship of the resolution of velocity with consideration of the deformation of plate. Supposing the velocity component along the tangential direction and axial direction after the deformation of plate is  $v$ 、 $w$ , from the former geometrical relationship we can get:

$$v = \frac{v_p \cos \theta_0}{\sin(\theta_0 + \theta)}, \quad w = \frac{v_p \cos \theta}{\sin(\theta_0 + \theta)} \quad (5)$$

Take the deformation of plate in to consideration, the mass flow of jet and plate is:

$$\frac{m_j}{m_p} = \frac{\pi \rho_j d_j}{4 \rho_p h} \left( \frac{v_j}{v_p} \frac{\sin(\theta_0 + \theta)}{\cos \theta_0} \pm \frac{\cos \theta}{\cos \theta_0} \right) \quad (6)$$

From formula (3) we can see that when the initial angle between plate and jet is  $\theta_0$ , which has little difference comparing with the angle of the plate  $\theta$ , so the deformation of plate will influence the speed of the plate is obvious, and then influence the result of the disturb jet. The deflection angle of the jet after disturb is:

$$\tan \alpha = \pm \left[ \frac{\rho_j d_j}{4 \rho_p h \cos \theta_0} \frac{v_j}{v_p} \left( \frac{v_j}{v_p} \tan \theta_0 \pm \frac{1}{\cos \theta_0} \right) \mp \tan \theta_0 \right]^{-1} \quad (7)$$

In the formula:  $\rho_p$ ,  $\rho_j$  is the density of plate and jet;  $v_j$  is the speed of the micro jet;  $d_j$  is diameter of the local jet;  $h$  is the thickness of plate;  $\theta_0$  is the angle between the plate and the jet. The transverse velocity  $v_{jx}$  of residual jet is:

$$v_{jx} = \left[ \frac{\rho_j d_j}{4 \rho_p h \cos \theta_0} \frac{1}{v_p} \left( \frac{v_j \sin(\theta_0 + \theta)}{\cos \theta_0} \pm \frac{\cos \theta}{\cos \theta_0} \right) + \frac{\tan \theta_0}{v_p} \right]^{-1} \quad (8)$$

## Results and Analysis

### Calculation Model and the Material Parameter

In order to analyze the transverse deflection velocity after ERA, we conduct numerical simulation of the acting process of the jet and ERA. Using LS-DYNA multi material ALE algorithm to do the numerical simulation of the formation, stretching and penetration of the jet.

Calculation model loading diameter is 56mm, height of post cap is 31mm, medicine shaped cover is red copper, the mouth diameter is 54mm, the cover thickness is 1mm, height of burst is 80mm. when calculating, the medicine shaped cover and target boss both use *Johnson-Cook* model and GRUNEISEN state equation to describe, the model can describe the strength consistent with material strain, strain rate and temperature, the main parameter of medicine shaped cover and target boss can be seen in Table 1.

Table 1. Parameter of material.

parameter	$\rho/\text{gcm}^{-3}$	$E/\text{GPa}$	$\mu$	$A/\text{MPa}$	$B/\text{MPa}$	$C$	$n$	$m$
liner	8.96	124	0.34	100	300	0.025	0.31	1.09
target	7.8	210	0.22	792	180	0.016	0.12	1

Main charge uses JWL state equation, material characteristic parameter, its value is in Table 2.

Table 2. Parameter of explosive

parameter	$\rho/\text{gcm}^{-3}$	$A_{JWL}/\text{MPa}$	$B_{JWL}/\text{MPa}$	$R_1$	$R_2$	$\omega$	$D/\text{ms}^{-1}$
explosive	1.72	$3.74 \times 10^5$	3300	4.5	0.95	0.3	8930

Sandwich charge is military B explosive, it uses elastic and plastic model and ignition growth of reaction in he to describe, the material parameter is in figure 3. The physical meaning of parameter in the figure is as followed:  $I$  is hot spot quantity parameter to control ignite;  $G_1$  and  $G_2$  is early reaction growth and reaction speed under high pressure after controlling ignite, which is related to contact state of explosive particles;  $a$  is critical compression degree, which is used to limit the ignite, when the compression degree is less than  $a$ , the explosive doesn't fired;  $b$ ,  $c$  is the related parameter of the largest position of reaction speed;  $d$ ,  $g$  is related parameter of the shape of hot spot;  $y$  and  $z$  is related parameter of non-laminar flow of burning reaction, its value is normally is 0.8~2.0,  $\lambda_{igmax}$ ,  $\lambda_{G1max}$  is the maximum of reaction of ignite and burning;  $\lambda_{G2min}$  is the minimum of the reaction,  $\rho_0$  is the density of explosive,  $P_{CJ}$  is the C-J explosive pressure;  $D$  is the speed of explosion.

Table 3. Parameter of elastic and plastic model and ignition growth of reaction.

$P_0/\text{GPa}$	$\rho/\text{gcm}^{-3}$	$I/\mu\text{s}^{-1}$	$G_1/\mu\text{sGPa}^{-1}$	$a$	$c$	$y$	$\lambda_{G2\text{min}}$
27	1.72	$4.4 \times 10^{11}$	310	0	0.667	1.0	0
$\lambda_{\text{igmax}}$	$\lambda_{G1\text{max}}$	$D/\text{cm}\mu\text{s}^{-1}$	$G_2/\mu\text{sGPa}^{-1}$	$b$	$d$	$z$	$g$
0.3	0.5	6930	$4.0 \times 10^4$	0.667	0.111	2.0	1.0

## Result and Analysis

In order to validate the result of the numerical simulation, we conduct the experiment of jet penetrate the ERA, we put the penetrator and ERA vertically, mainly to test the deformation of the ERA plate and the flying speed, although the numerical simulation is oblique penetration, but the angle of inclination do little influence to the motion law and the process of deformation of ERA plate. The experiment uses the 56mm standard penetrator, it can be seen in figure 5, in the figure, the deformation of the plate got by numerical simulation is consistent with that got from X-photos. From the experiment, we know the limit speed of the plate is 933 m/s. the limit speed got from the numerical simulation is 996 m/s, which is slightly bigger than the one got from the experiment, it indicates that the numerical simulation is right.

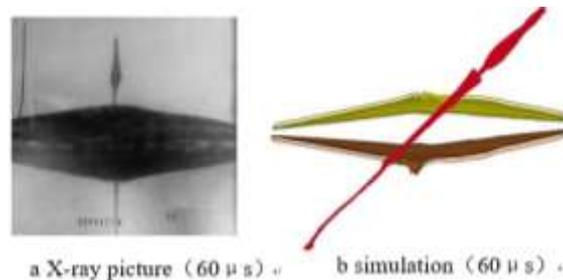


Figure 5. Physical image of jet with plate.

## Conclusion

By analyzing the physical interaction of the jet and plate, on the base of considering the deformation of plate, we build up the ERA disturb the jet model in consideration of deformation of plate by using the elastic collision theory of plasticity, and get the calculation formula of lateral velocity of interfering residual jet, the calculated result is consistent with the numerical simulation and experimental result.

## References

- [1] Philip Pincosy, Peter Poulsen. Jet propagation through energetic materials 20# International Symposium on Ballistic, 2002.
- [2] M. Mayselless, Y. Erlich, Y. Falcovitz, G. Rosenberg. Interaction of shaped-charge jet with reactive armour. 8# International Symposium on Ballistic, Orlando Florida USA, 1984.
- [3] M. Mayselless, E. Marmor, N. Gov etc., interaction of a shaped charge jet with reactive or passive cassettes, 14# International Symposium on Ballistic, 439~448, Quebec Canada, September
- [4] L.S. Nicholson, M.C. Rogers, R.J. Cos, G. Merrit, the use of analytical shaped charge jet and target response mode to predict the efficiency of jet disruption by single and multiple explosive armour targets, 9# International Symposium on Ballistic.
- [5] M. Mayselless. Jet plate interaction: the precursor. 18# International Symposium on Ballistic, San Antonio TX, 1019~1026, 1999.
- [6] Dr. Thomas Szendrei, link between axial penetration and radial crater expansion in hypervelocity impact, 17# International Symposium on Ballistic, 25~32, South Africa, March 1998.