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# APPLICATION OF OVERDRIVEN DETONATION OF HIGH EXPLOSIVES TO SHAPED CHARGES

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So far at the present, most shaped charges are initiated by the way from which the detonation of explosives is fulfilled in a usual Chapman-Jouguet (C-J) detonation form. This paper presents the new designs of shaped charges that utilize the overdriven detonation of high explosive for the purpose of achieving the higher jet velocity. The initial experimental tests have been performed in an attempt to exploring the features of these shaped charges. The jet velocities are measured and the penetration effects are tested by the steel blocks. A comparison of the results is made between the shaped charge in usual form and the ones demonstrated in this study.

## INTRODUCTION

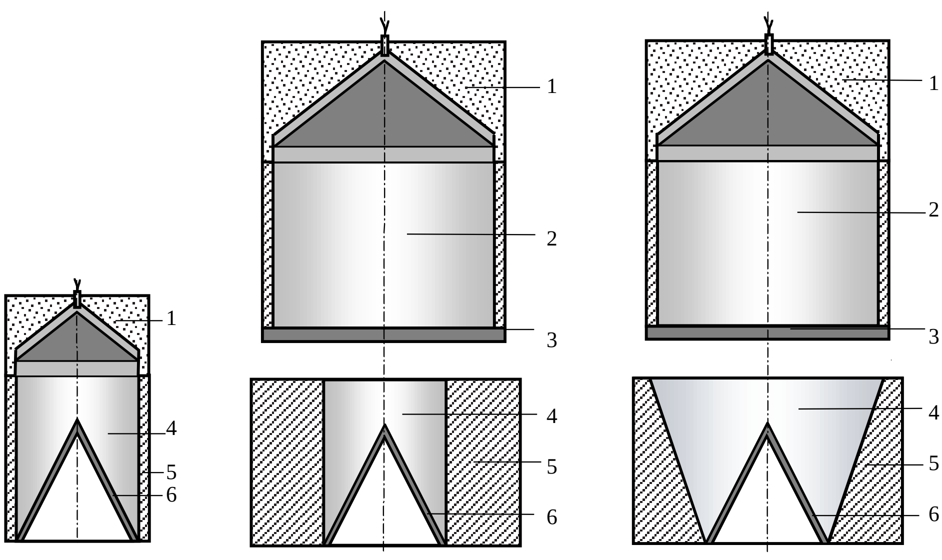
Shaped charge has long been known for achieving the extremely high velocity jets and bringing out the strong penetration effects against various targets. The development of shaped charge technique is well documented in detail by Walters [1]. A simple shaped charge can be readily fabricated. Any hollow metal cone or notch-shaped metal plate wrapped by an explosive becomes a shaped charge. However, this simple configuration of the shaped charge contains the complicated interplay of many complex phenomena including explosive detonation, shock loading on the liner, high strain, high strain rate, melting as well as the phase changes of the liner material. Generally, the jets formed in the shaped charges can reach the velocity ranging from 6 to 10 km/s. Since such high velocity can be achieved by shaped charge, there is no other way to compete with shaped charge at present so efficiently on the acquirement of high velocity object.

Recently, with the advancement of the space exploration activity, it becomes more and more important for the protection of the spacecraft from impact of various meteoroids or space debris. Several investigators [2,3] employed the jets from shaped charge to simulate the orbital space debris for the study of whipple bumper design. However, the current shaped charges, in most cases, are initiated by the way from which the detonation of explosives is fulfilled in the common Chapman-Jouguet (C-J) detonation form. As a consequence, the detonation products begin to expand from the C-J state to collapse the liner, forming the jets. Overdriven detonation [4,5], however, is a detonation process that can cause higher or much higher pressure in the products than does the C-J detonation of explosives. Taking use of the concept of overdriven detonation in shaped charges, the jet velocity may be expected to be improved because the liner is pushed by the overdriven detonation products. In order to reach a velocity as high as possible in a shaped charge, we try to design the shaped charges that use the overdriven detonation in the explosives for replacement of the conventional detonation way in shaped charges having ever been used.

# EXPERIMENTAL PROCEDURES

## Design of shaped charges

Figure 1 shows three types of configurations of shaped charges used in the experiments corresponding to the situations of normal and overdriven detonations. All forms of shaped charges shown here are of conical geometry. Figure 1(a) is the regular type of shape charge employed by many practitioners who involved with the researches of shaped




(a) RC (b) ORC (c) OCC

Figure 1: Several types of shaped charges used in this study. (1-Explosive lens, 2-Explosive, 3-Flyer plate, 4-Explosive in charge, 5-Casing, 6-Liner.)

charges. The other two types, as shown in Figs. 1(b) and 1(c) are the newly designed shaped charge devices attempt to applying the overdriven detonation of high explosive. For simplicity of later description on these devices, some signification is made here. The regular type shaped charge is signified by 'RC', meaning the regular conical shaped charge. Meanwhile, the other two devices are indicated by 'ORC' and 'OCC', respectively, for shaped charges with the right-circular casing and inversely-conical casing. The 'RC' charge is directly initiated by a plane-wave generator, while, the 'ORC' and 'OCC' charges are initiated by a flyer plate accelerated by an additional explosive cylinder. The flyer is expected to cause the overdriven detonation in the explosive contained in charges. The detailed characterization on those three types of shaped charges is expressed in Table 1. The conditions for the acceleration of flyer plate used in' ORC' and 'OCC' types of shaped charge are presented in Table 2. Further, Table 3 illustrates the Chapman-Jouguet detonation properties of the explosive used in all shaped charges.

Table 1: The conditions related to liners, casings and exploisves used in three types of shaped charges

| Charge type | Liner | Casing | Explosive |
|---|---|---|---|
| RC | Shape: hollow cone<br>Material: copper<br>Dimensions:<br>20 mm outer diameter<br>20 mm height<br>1 mm thickness | Shape: right circular hollow cylinder<br>Material: SS 400 steel<br>Dimensions: 50 mm outer diameter,<br>20 mm inner diameter,<br>30 mm height | PBX (HMX 78% by weight) |
| ORC | Shape: Hollow cone<br>Material: copper<br>Dimensions:<br>20 mm outer diameter<br>20 mm height<br>1 mm thickness | Shape: right circular hollow cylinder<br>Material: SS 400 steel<br>Dimensions: 50 mm outer diameter,<br>20 mm inner diameter,<br>30 mm height | PBX (HMX 78% by weight) |
| OCC | Shape: Hollow cone<br>Material: copper<br>Dimensions:<br>20 mm outer diameter<br>20 mm height<br>1 mm thickness | Shape: right-circular cylinder with an inverse conical hollow<br>Material: SS 400 steel<br>Dimensions: 50 mm outer diameter<br>20 mm small inner diameter<br>42 mm great inner diameter<br>30 mm height | PBX (HMX 78% by weight) |

Table 2: Data of flyer acceleration in "ORC" and "OCC" charges

| Flyer | Explosive | Casing |
|---|---|---|
| copper : 45 mm diameter<br>2 mm thickness | PBX (HMX 78% by weight) | SS 400 steel, cylindrical<br>45 mm outer diameter, 41 mm inner diameter, 2 mm thickness |

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Table 3: Chapman-jouguet detonation properties of 78% explosive

| Density (g/cm$^3$) | Detonation velocity (km/s) | Detonation pressure (GPa) |
|---|---|---|
| 1.584 | 7.337 | 20.64 |

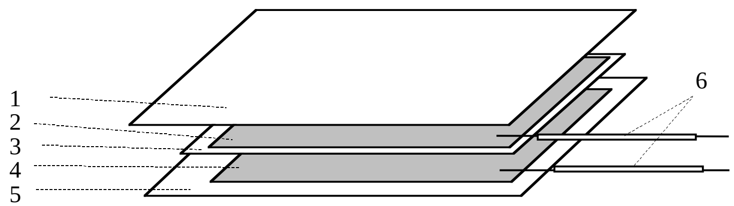


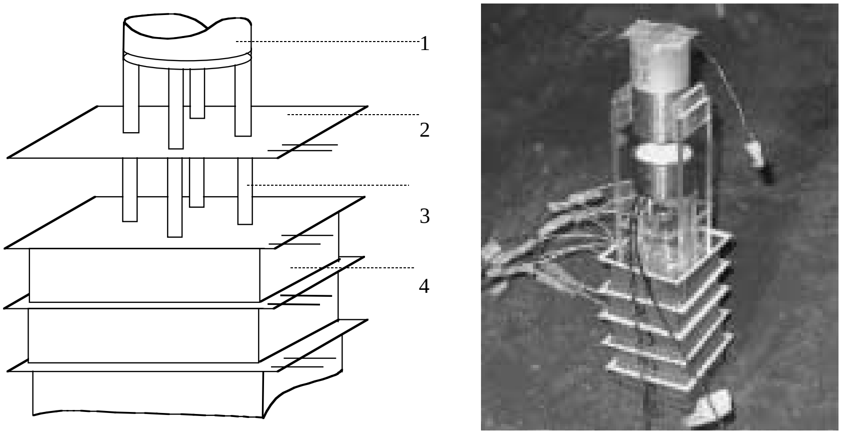

Figure 2: Illustration of the structure of pin-probe measurement of jetvelocity. (1,5-OHP sheet, 2,4-Aluminium foil, 3-Paper, 6-Electrical foot line).

## Measurement of jet velocity

The velocities of jets from three types of shaped charges are measured by using the pin-probes as shown in Fig. 2. The probe is of a sandwich structure, consisting of two very thin pieces of aluminum foil (2 microns or so) separated by a piece of paper as well as two plastic sheets (such one in use for over-head projector) protective coverings. The foot-lines for the circuit start from the two foils, respectively. All the feet are connected with an oscilloscope for monitoring the signal transmission. When jet impacts on the probe, the electrical conductivity becomes possible and then the signal is recorded as the time instance of arrival of the jets at the corresponding position. For two known locations, the average velocity of jets between them can be determined by dividing their distance over the time difference of arrivals at them.

## Test on jet penetration

The penetration capability of the jets from those shaped charges is tested by a stack of steel blocks with the dimensions of 70 mm by 70 mm by 25 mm. So, the penetration depth and the size of the holes can be measured after the recovery from the experiments. Figure 3 exhibits the combined arrangement for the measurement of jet velocity and the penetration capability simultaneously in one experimental firing. The distance for the initial jet velocity measurement is parted as 30 mm away. Also the average jet velocity between a steel block can be estimated based on this arrangement. The right-hand side of Fig. 3 shows the photograph of an experimental assembly before firing.




(a) (b)

Figure 3: Arrangements for jet velocity measument and penetration test. (a) Schematic Illustration (1. Shaped charge, 2. Pin-probe, 3. Suppot truss, 4. Steel block), (b) Photograph of experimental assembly before firing.

## RESULTS AND DISCUSSION

The experimental results from the conducted experiments are summarized in Table 4. First, let's look into the detonation velocities of explosives in the respective charges. The detonation velocity was measured through the optical fiber method. For 'RC' charge, the measured detonation velocity is 7.692 km/s, deviating from 7.337 km/s of the C-J detonation velocity of the PBX explosive. In the 'ORC' charges, the measured velocities have

Table 4: Summary of experimental results

| Exp. No. | Charge types | Detonation velocity in charge (km/s) | Jet velocity (km/s) | | | | Penetration depth (mm) | Standoff distance (mm) |
|---|---|---|---|---|---|---|---|---|
| | | | Initial | Between steel block (mm) | | | | |
| | | | | 0-25 | 25-50 | 50-70 | | |
| 1 | RC | | 7.075 | 2.643 | 2.100 | | 86.7 | |
| 2 | ORC | | 6.610 | 2.800 | 2.111 | | 99.1 | 5 |
| 3 | OCC | 9.375 | 9.460 | 3.113 | 2.945 | | 68.1 | 5 |
| 4 | RC | 7.692 | 5.958 | 2.830 | 2.104 | | 86.9 | |
| 5 | ORC | 6.849 | 7.059 | 2.959 | 2.343 | | 101.0 | 5 |
| 6 | ORC | 7.203 | 6.849 | 3.193 | 2.242 | 1.846 | 107.5 | 10 |
| 7 | ORC | 8.052 | 6.749 | 2.969 | 2.178 | | 99.5 | 20 |
| 8 | OCC | 9.927 | 7.853 | 2.700 | 2.366 | | 75.5 | 20 |

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a great deviation among each other, averaged value being 7.368 km/s. However, in the two 'OCC' charges, the detonation velocities both are over 9.0 km/s, far greater than the C-J detonation velocity of the explosive used. The correctness of these values should be further examined.

On the jet velocities from these experiments, the initial velocity of jets in 'RC' charges are varied from about 6.0 to 7.0 km/s, while, in 'ORC' charges, they are from 6.75 km/s to 7.0 km/s, and in 'OCC' charges, the initial velocities of jets is ranging from 7.85 km/s to 9.46 km/s. Totally speaking, the jet velocity is increased in the 'ORC' and 'OCC' charges. After the jets penetrated the first steel block, the jet velocity is almost decreased to half or less value. The later decrease in jet velocity is relatively not so great.

On the depths of the penetrated holes, the deepest is given by one 'ORC' charge in which the jets reached the fifth steel block, making a depth of hole of 107.5 mm. The situation is also clearly revealed in Fig. 5 by the photographic illustration. The second follows the 'RC' charge that penetrated to about 87.0 mm. The worst is the 'OCC' charge, only 75.5 mm maximum depth being accomplished. Although the initial jet velocity was high, the penetration, however, is of so bad effect. Once again, it demonstrates that the jet have been dispersed or particulated during its flying movement. It is naturally deduced that due to the jet dispersion or particulation, the overall or effective mass of jets is decreased so that the penetration capability is hence weakened.

Figure 4 shows the photographs of the configuration of the penetrated steel blocks in No. 4 experiment that used the 'RC' shaped charge. Fig. 4(a) gives the appearances of the top surfaces of the steel blocks that face the jet's incoming motion and Fig. 4(b) shows the bottom surfaces of steel blocks. It demonstrates that the fourth block was not penetrated completely. Similarly, Figs. 5 and 6 present the photographs of the configuration of the penetrated steel blocks in No. 6 and No. 8 experiments by 'ORC' and 'OCC' shaped charges correspondingly. In all experiments, the first block is subject to a big hole at the top surface, then, from the second block, the sizes of holes greatly decreases and the blocks are of the slow variation in hole diameter. At the same time, the hole in the first block exhibits some regularly circular shape on the situations of 'RC' and 'ORC' shaped charges, however, in the 'OCC' shaped charges, the holes are relatively shallow and, moreover, the brink of the hole displays an irregular configuration. The occurrence of this phenomenon, to large extent, is due to jet dispersion at the later phase of motion.

The sizes of penetrated holes are tabulated in Table 5. The values shown here are averaged by diameters of two perpendicular directions. Since the hole is not regularly circular, the data are only given by approximation. The hole on the top surface of the first block falls into 8 to 13 mm range. The average size can be said to approach 10 mm, nearly the half of the diameters of the liners.

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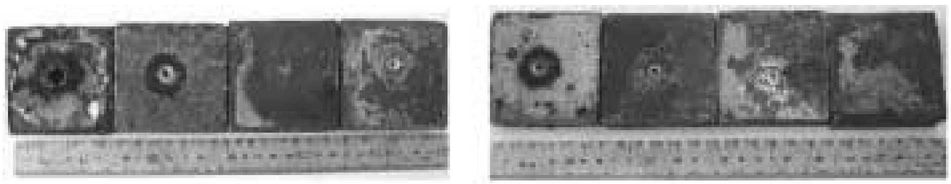
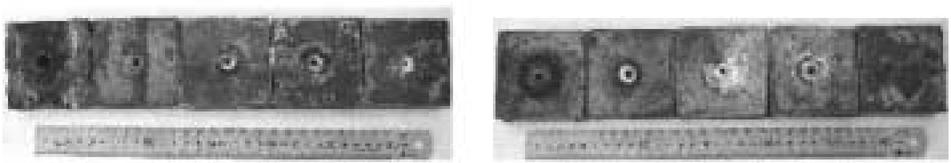


(a) Top faces (b) Bottom faces

Figure 4: Photographs of penetrated steel blocks in No. 4 experiment.



(a) Top faces (b) Bottom faces

Figure 5: Photographs of penetrated steel blocks in No. 6 experiment.

(a) Top faces (b) Bottom faces

Figure 6: Photographs of penetrated steel blocks in No. 8 experiment.

Table 5: The sizes of holes in the pentrated steel blocks

| Exp. No. | Charge types | Sizes of holes in average diameter (mm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Block 1 | | Block 2 | | Block 3 | | Block 4 | | Block 5 | |
| | | T* | B | T | B | T | B | T | B | T | B |
| 1 | RC | 9.8 | 4.8 | 4.8 | 4.4 | 4.0 | 2.9 | 2.8 | 2.8 | | |
| 2 | ORC | 13.4 | 6.0 | 5.8 | 4.8 | 4.3 | 4.7 | 4.0 | | | |
| 3 | OCC | 11.2 | 6.3 | 5.4 | 5.0 | | | | | | |
| 4 | RC | 9.5 | 4.0 | 4.0 | 3.4 | 3.6 | 3.0 | 3.0 | 1.0 | | |
| 5 | ORC | 8.2 | 6.3 | 5.3 | 4.5 | 4.5 | 4.4 | | 2.5 | 2.0 | |
| 6 | ORC | 10.1 | 6.4 | 5.1 | 4.4 | 3.5 | 4.4 | 4.4 | 4.8 | 3.5 | |
| 7 | ORC | 10.3 | 5.6 | 4.8 | 4.1 | 4.0 | 3.4 | 3.5 | | | |
| 8 | OCC | 8.1 | 5.1 | 5.2 | 4.3 | 4.4 | 3.6 | | | | |

* T-Top surface, B-Bottom surface

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## CONCLUSIONS

Novel designs of shaped charges that utilize the overdriven detonation of high explosive were proposed and the experimental tests have been performed in order to make an understanding toward their characteristics. Although the experimental results demonstrate some encouraging aspects on these new designs of shaped charges, the thorough investigation should be carried out in the later work so as to give the convincible verification on the superiority of these designs. Furthermore, the numerical analysis toward this problem is under construction.

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## REFERENCES

1. W. P. Walters, "Fundamentals of Shaped Charges," in *High Velocity Impact Dynamics* (ed., J. A. Zukas), Wiley-Interscience, NY, 1990.
2. M. Katayama, A. Takeba, S. Toda and S. Kibe, "Analysis of Jet Formation and Penetration by Conical Shaped Charge with the Inhibitor," *J. Impact Engrg.*, 23, 443–454, 1999.
3. E. A. Taylor, "Simulation of Hollow Shaped Charge Jet Impacts onto Aluminum Whipple Bumpers at 11 km/s," *Proceedings of 2000 Hypervelocity Impact Symposium*, 2000.
4. Z. Liu, S. Nagano and S. Itoh, "Overdriven Detonation Phenomenon in High Explosive," in *Shock Compression of Condensed Matter-1999* (eds., M. D. Furnish, L. C. Chhabildas and R. S. Hixson), AIP Press, NY, 227–231, 2000.
5. J. N. Fritz, R. S. Hixson, M. S. Shaw, C. E. Morris and R. G. McQueen, "Overdriven-Detonation and Sound-Speed Measurements in PBX-9501 and the 'Thermodynamic' Chapman-Jouguet Pressure," *J. Appl. Phys.*, 80, 6129–6141, 1996.