

Experimental Investigation on Flattened Head Harpoon An Attempt for Restraining Ricochet

BY

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1. Introduction

It is well known that the harpoon with the usual pointed head ricochets when it strikes the water surface aslant, jumping over the body of whale even when the point of incidence falls within a few feet from the aim. The present writer also witnessed in several occasions such wasteful missings of aims in the course of an experimental test of electrocution of whales, carried out by the whaling boat, Taiheimaru No. 1 in the vicinity of Hokkaido between the period of August to October, 1949, under the auspices of the Committee for the Improvement of Equipments of Whaling Vessels. It was considered very desirable to improve the harpoon so as to prevent such ricochet and to hit the whale even if the harpoon passed some distance through the water. A brief account of the experimental investigations made in connection with this problem will be reported in the following lines.

2. Mechanism of ricochet and its counter-measure

The phenomenon of ricochet is not characteristic one of harpoon, but also holds for any high speed rigid body impinging obliquely against the surface when its angle of incidence is smaller than some critical value which is determined by both the shape and the impacting velocity of the body. E. de Jonqui re¹⁾ showed that when a spherical body, initially immersed in water, was shot in the direction parallel to the free surface, its path turned upwards gradually and at last emerged out of the surface. As for the pressure distribution in front of the sphere, the point of maximum pressure was slightly shifted to the side opposite to the free surface, thus exerting some driving force towards the free surface. C. Ramsauer²⁾ also studied the path of a sphere shot into the water with small incident angle. It followed

1) E. de Jonqui re, C. R. 97 (1883), 1278.

2) C. Ramsauer, Ann. d. Phys. 84 (1927), 721.

nearly a circularly curved path in water and the angle of emergence was nearly equal to that of incidence. T. Isobe³⁾ determined the critical angle of incidence for occurrence of ricochet for ordinary pointed bullet. In this case, the axis of bullet, after the immersion into water, started rapid rotation in the direction such that the pointed side turned upwards, thus at the first stage, the bullet received the lifting force of greater magnitude than the case of sphere, resulting to some complicated path in water. As an example of such a case, a moment photograph of bullet moving in water taken by the present writer is shown in Fig. 1., in which the region of great pressure along the front surface of the bullet revealed by the change of index of refraction of water will be noticeable.



Fig. 1. Moment photograph of 6.6 mm bullet moving in water.

These investigations indicate clearly that the ricochet is not the phenomenon occurring only at the surface but is closely associated with the behaviour of the body in water. When the shape of the body is oblong, if we want to prevent its ricochet and to extend the path straight forwards into the water as far as possible, it is necessary to keep its longer axis always in the direction parallel to that of motion.

The rudder action of a flat plate moving in fluid should be noticed as the most effective measure for this purpose. Namely, the most stable orientation of the flat plane moving in water is attained when the normal to the surface coincides with the direction of motion. Various reports have already been published concerning the bullet with flattened head for the purpose of hitting the object under

3) T. Isobe, Journ. Ordn. Soc. Japan 36 (1942), 237.

water⁴⁾. Now in the case of harpoon, however, with such a long stem trailing heavy rope, it is questionable in what extent the flattening the head is effective in comparison with the case of bullet. Great difficulties will be expected to solve the problem only from the side of the mathematical calculations. In Fig. 2, a schematic diagram of expected formation of cavitation in water due to the head of harpoon.

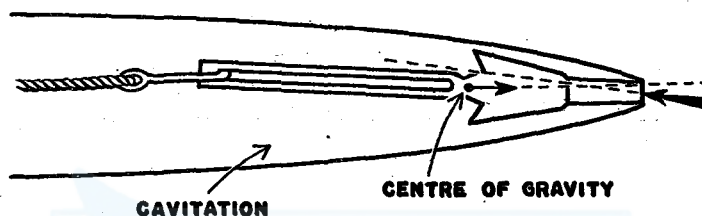


Fig. 2. Harpoon moving in water. In case of slight inclination of the axis of harpoon, the force acting at the flattened head surves the restoring effect.

So, in the course of the test work of Taiheimaru No. 1 mentioned above, following preliminary experiment was made in the harbour of Kusiro, Hokkaido, in September, 1949.

3. Experiment on flattened head harpoon

The tip of the ordinary grenade of harpoon was cutted off and the inner cavity was filled closely with hard wood making a flattened head. Two kinds of such grenades were prepared, the diameters of the flattened areas being 93 mm and 73 mm respectively. The ordinary harpoons equipped with these grenades were shot at the distance of about 50 m from the gun. An usual pointed grenade was also tried for the comparison. Three small boxes were floated along the line of shooting at the distances of 25 ken (45.5 m), 30 ken (54.5 m) and 35 ken (63.6 m) respectively as the markings of distances for naked eye observation. A straw-mat ($2 \times 2 \text{ m}^2$) was suspended vertically under the second box for the indication of the path in water. The results are shown in Fig. 3, which contains also the results obtained at the later experiments.

The flattened head harpoon with the diameter of 93 mm proceeded

4) T. F. Framantle, "The Book of the Rifle", (1901) 304. Scientific American, 68 (1918), 125.

T. Isobe made a detailed experiment on 6.6 mm bullet with flattened head in 1943, though not published officially, of which the writer was told by his kind personal communication.

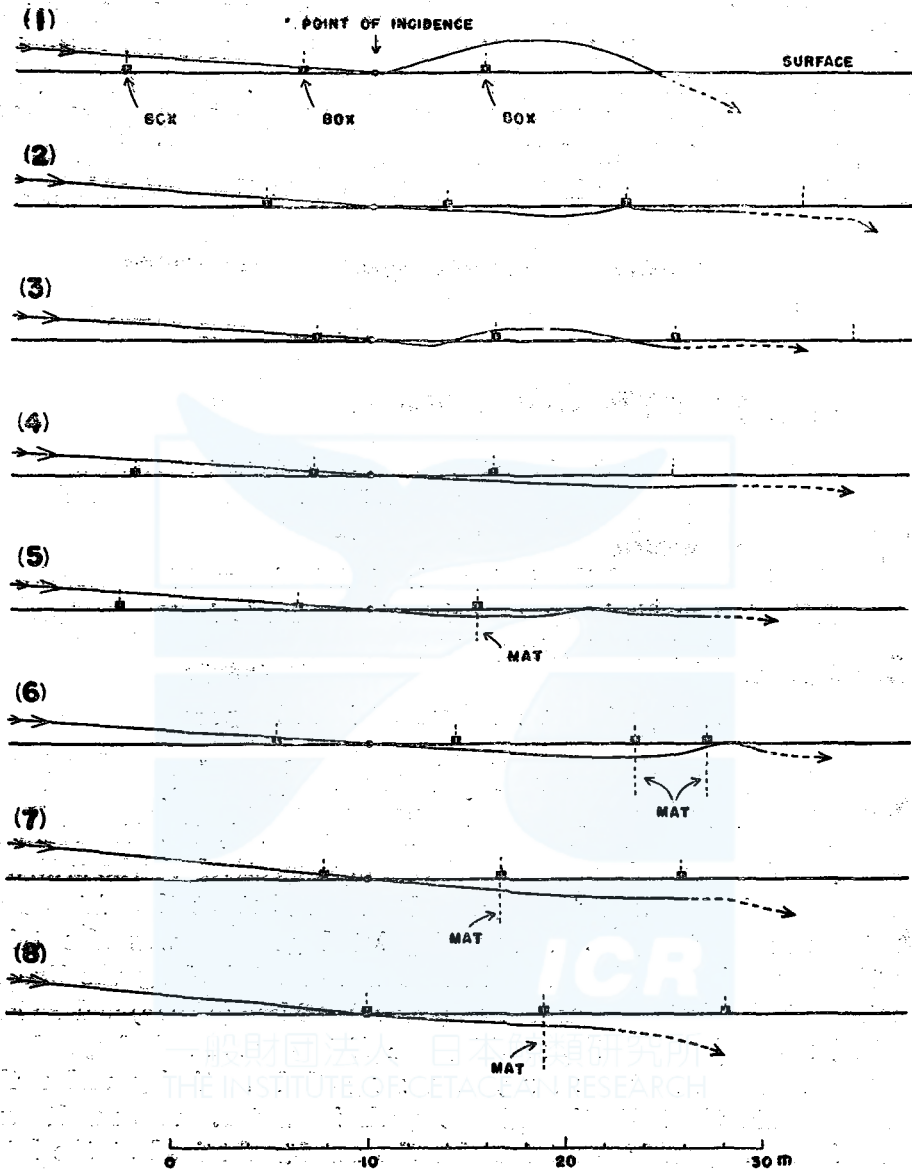


Fig. 3. Behaviour of harpoon striking the water surface.

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| 1) Pointed. | 2) Plain, 93 mm. | 3) Plain, 73 mm. |
| 4) Plain, 93 mm. | 5) Plain, 93 mm. | 6) Disc, 101 mm. |
| 7) Disc, 101 mm. | 8) Disc, 126 mm. | |

in water trailing a straight streak of cavitation as long as 20 m in one case (Fig. 3 (4)), while in the other case (Fig. 3, (2), (5)), the harpoon

exposed a part of its head out of the surface only a moment after diving into water as long as 14 m from the point of incidence and again continued its way into water. In the case of 73 mm in diameter, the duration of the first diving into water was much reduced as shown in Fig. 3, (3).

Consulting on these results, the pointed head of electric harpoon which had been used at that time was decided to be replaced by the flattened one. On board of *Taiheimaru* No. 1, however, any suitable technical facility was not available, so a thick circular disc of steel was bolted on the tip of the harpoon as a temporary measure (Fig. 4). Three discs of different diameters, 89 mm, 101 mm, 114 mm, were prepared, thickness being the same, 19 mm.



Fig. 4. Electric harpoon equipped with a circular disc, 101 mm.

4. Thrusting power of flattened head into blubber

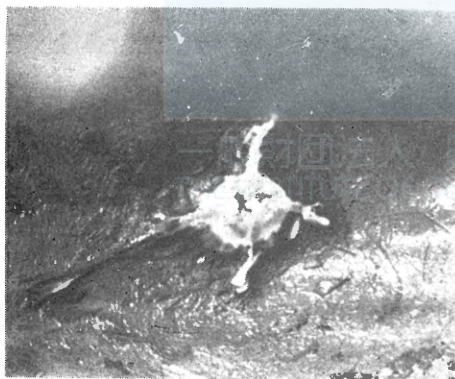
It was feared originally that the resistance of flattened head should be so great that the harpoon could not penetrate the blubber. But, at the first practical application of this electric harpoon equipped with 101 mm disc for a Sei whale (13.25 m) at the distance of 50 m, the harpoon hit the back of the whale after passing through the water as long as 2 m, and this harpoon was found by dissection lodging in the meat, 1.5 m deep from the point of intrusion. In the second case, when we met a Sperm whale (13.45 m) the same harpoon was used which struck aslant the blubber and lodged in the meat 2 m beneath the surface. It was also revealed that at the point of intrusion of harpoon the surface of blubber was scooped out in the form of a conical groove gradually increasing its depth as long as 80 cm. The angle of incidence of the harpoon to the surface was estimated from

the dimensions of this groove as only 5° , thus it was ascertained that the flattened head was also very efficient for restraining the slipping at the surface of blubber.



Fig. 5. The instant of shooting a Blue whale by the flattened head harpoon, which is seen making its way into water trailing a white streak of cavitation.

In many examples obtained later, involving the cases of explosive harpoons, the thrusting power of flattened head, 101 mm in diameter, proved satisfactory (Fig. 6), except when the distance was greater than about 70 m, especially in the cases of Sperm whales.



a



b

Fig. 6. Marks of intrusions of harpoon into blubber.

a) Flattened head, 101 mm, Sperm whale. b) Pointed head, Sperm whale.

The relations between the penetrating depth into blubber (x), the diameter of head plane (d), the mass of harpoon (m) and its striking velocity (v) were obtained by the model experiment with the whale-marking darts⁵⁾ and the following expression proved applicable approximately,

$$x = \frac{Km}{\alpha d^2 + A^2} v^2,$$

where, K and α being both a constant respectively, determined by the physical properties of blubber, A , an effective diameter of the maximum sectional area of harpoon containing hooks. This relation can also be derived theoretically with some plausible assumptions, that the decrement of momentum of harpoon, after its intrusion into blubber, is equal to the sum of the momentum newly given to the mass which is pushed away according to the progress of harpoon and the work done against the resistance due to the flattened head, while this resistance is supposed to be nearly the same to the one obtained when the harpoon is pushed in statically.

If we want to get much deeper penetration of harpoon into blubber at a given shooting distance, or by a given striking velocity, the

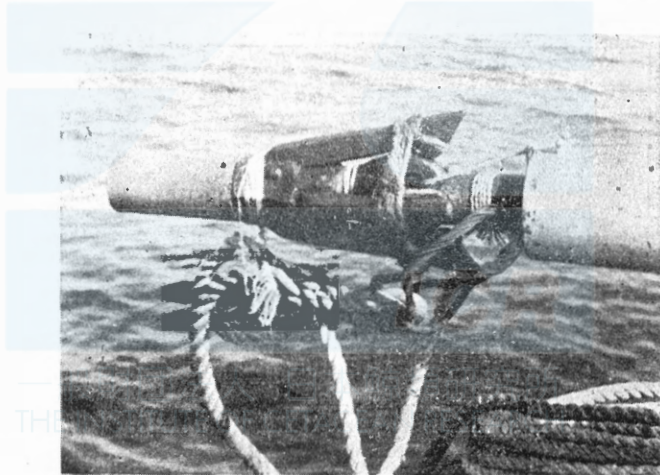


Fig. 7. Flattened head grenade, 90 mm.

diameter of the flattened head should be decreased suitably as derived from the above equation, though the efficiency of restraining ricochet will lessen inevitably. Thus, as for the size of flattened head, 80~90

5) S. Nishimoto, M. Hirata, Report of the Committee for Improvement of Equipment of Whaling Vessels, Feb. 24, 1950.

mm in diameter seemed suitable under usual conditions, and such grenades of explosive harpoon have been tried in practice by some of the gunners with good results in the neighbouring waters of Japan as well as in Antarctic ocean since the winter of 1949 (Fig. 7).

5. Supplementary experiment

An additional experiment was carried out in August, 1951, with the gun placed on the coast of Ayukawa concerning various modified types of grenades such as shown in Fig. 8.

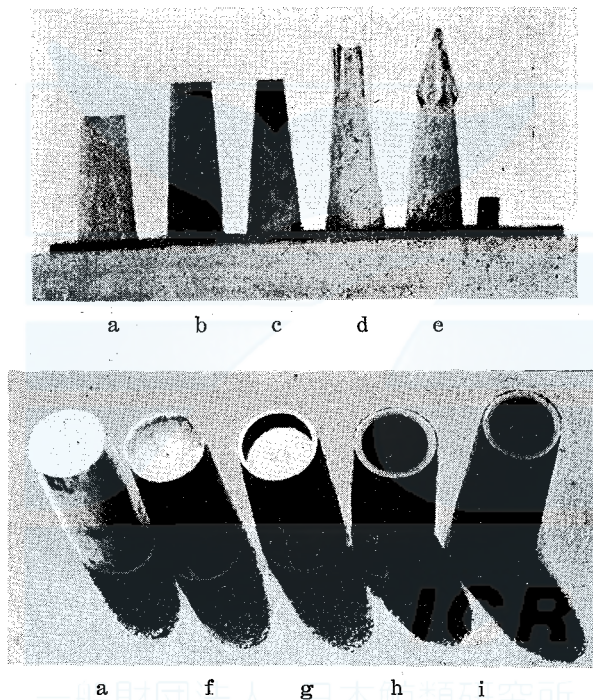


Fig. 8. Various types of grenade.

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| a) Plain, 90 mm. | e) Pointed. |
| b) Plain, 80 mm. | f) Concave, 90 mm. |
| c) Plain, 50 mm. | g) Tray, 90 mm. |
| d) Concave, 40 mm with claws
along the periphery. | h) Pipe, 90 mm. |
| | i) Pipe, 80 mm. |

Three sheets of straw-mat were suspended vertically in water fixed by wooden frame, separating 2 m with each other, for the purpose of determining the path of harpoon in water. At the same time, high speed cinematographies were taken with the rate of 130 frames

per second. The velocity of harpoon at the instant of incidence into water was about 75 m per sec., while the angle of incidence being 8° . Some of the results are depicted in Fig. 9.

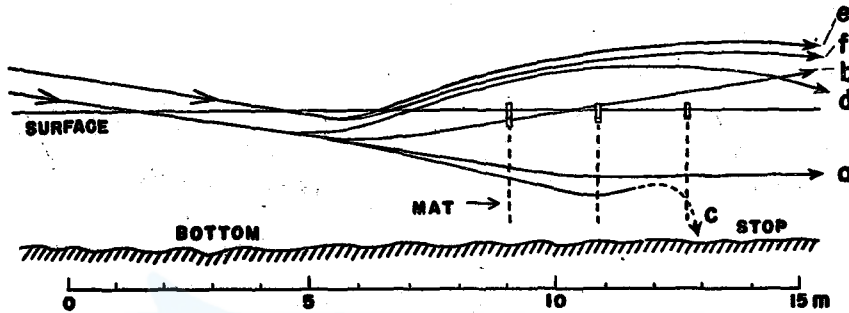


Fig. 9. Paths of harpoons with various types of head.

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| a) Plain, 90 mm. | e) Concave, 40 mm, with claws along the periphery. |
| b) Plain, 80 mm. | f) Plain, 50 mm. |
| c) Concave, 90 mm. | |
| d) Pipe, 80 mm. | |

It is revealed that the efficiencies of restraining ricochet of the head with concave surface as well as with thin walled pipe, which are originally planned for the purpose of prevention of slipping at the surface of blubber, are inferior to that of flat surface with the same diameter, while their velocities in water drop more quickly.