Slip Motion of a Projectile Striking a Water Surface, I

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Abstract

A survey of the photographs taken with both a 35 mm camera and an 8 mm cine camera, reveals that there are two kinds of slip motion. (1) After striking the water surface, the projectile slides along the water surface sending up a spray, and after a while it falls down. (2) After striking the water surface, the trajectory of the projectile in the air seems to be extended into the water. And an instant later the course in the water curves upwards, and the projectile reaches the surface but it does not fly off the water. So, the projectile moves along just beneath the surface for some time and then falls down.

In the former case, the major axis of the projectile does not coincide with the tangent of trajectory of the projectile but is horizontal or close to the horizontal. And in the latter case, the major axis of the projectile coincides with the tangent of the trajectory. So, this case is considered to be the critical case of the ricochet.

1. Introduction

The studies of ricochet motion of a bullet, a sphere and a harpoon were carried out by Isobe[1], by Ramsauer[2] and by Hirata[3] respectively. And the force of impact of a projectile striking a water surface at a right angle[4] or an arbitrary angle[5] has been reported. The motion of a projectile with head-cone or a harpoon was also investigated by the author[6], [7] [8].

The projectile ricochets if its incident angle is smaller than the critical incident angle. The ricochet motion was analyzed[7] introducing the following non-dimensional coefficients: coefficient of retardation $e_x = 1-(v_2 \cos \alpha_2 / v_1 \cos \alpha_1)$, coefficient of ricochet $e_y = v_2 \sin \alpha_2 / v_1 \sin \alpha_1$, and coefficient of slip $e_s = s_2/d$ (Fig. 1). The critical incident angle between ricochet and swimming for any projectiles obtained from the experiment is considered to be the critical angle coresponding to the critical conditions $e_x = 0$, $e_y = 1$. Therefore, if these conditions are satisfied, it is expected that the motion which resembles the slip of a projectile striking the smooth wall will appear.

In the present paper the author's intention is to make clear the slip motion which will appear at the critical incident angle between ricochet and swimming.

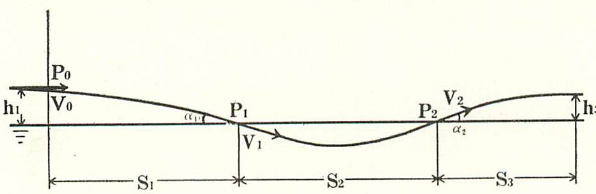

Fig. 1. Symbols used in e_x, e_y and e_s.

2. Experiment and Result

1) To investigate the slip on the water surface, four types of projectiles, each apex angle of which measures 180°, 90°, 60° or 30°, are projected horizontally with the velocity of 4.6 ~ 4.9 m/sec on the water surface. The dimensions of the projectile are as follows—diameter: 15 mm, full length: about 62 mm, weight: about 28 g, tail: 4 plates.

The course of the projectile is intermittently illuminated with an intensely bright multi-stroboscope newly devised for this experiment and then the projectile in motion, in the air and in the water, is photographed simultaneously with both a 35 mm camera and an 8 mm cine camera.

2) A survey of the photographs reveals that there are two kinds of slip motion. One of them is the following: after striking the water surface, the projectile slides along the water surface sending up a spray. Then it falls down as shown in Fig. 2. Another is the following: after striking the water surface, the trajcctory of the projectile in the air seems to be extended into the water. And an instant later the course in the water curves upwards, and the projectile reaches the surface but it does not fly off the water. So, the projectile in the water moves along just beneath the surface for some time and then falls down (Fig. 3).

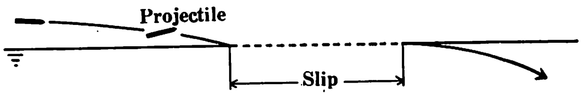

Fig. 2. Slip motion : the major axis of a prjectile does not coincide with the tangent of the trajectory.

Fig. 3. Slip motion: the major axis of a projectile coincides with the tangent of the trajectory.

In the former case, the major axis of the projectile that slides well like an aquaplane, does not coincide with the tangent of trajectory of the projectile but is horizontal or is close to the horizontal. This motion is similar to the gliding of a seaplane.

And in the latter case, the major axis of the projectile coincides with the tangent of the trajectory. So, this case is considered to be the critical case of the ricochet.

Therefore, the author summarizes the data obtained from the photographs in which the major axis of the projectile coincides with the trajectory, and reports in the present paper the results for the projectile with an apex of 60°.

The results for 180°-, 90°-, and 30°-projectiles will be reported in the next paper.

3) The photograph (Experiment No. 02–35, incident angle 7.3°, incident velocity 4.6 m/sec) taken with a 35 mm camera does not obviously show that the projectile ricochets (Fig. 4), but the consecutive photographs (Fig. 5) taken with an 8 mm cine camera show the projectile in ricochet motion. The coefficients obtained from the consecutive photographs of the projectile are $e_x=0.6$, $e_y=0.9$.

Now, by definition of ricochet coefficient, the case $e_x=0$ seems intuitively to be the boundary between ricochet and swimming. Unexpectedly enough, according to the experiment[8] $e_y=1$ seems to be the boundary between the two motions. The photograph (Experiment No. 02–35) is suitable to observe the transition stage from ricochet to swimming.

4) Next, in the photograph (Experiment No. 03–27, incident angle 8.0°, incident velocity 4.8 m/sec) we can see the slip of the projectile under the water surface (Fig. 6). The projectile projected from a spring gun strikes a water surface, and sends up a spray at the water surface, its path being continued for a while as if its path in the air is extended into the water. Then, the projectile is wholly submerged in the water and at this stage, the air mass follows, especially in the wake of the projectile. As the projectile moves on, the air mass is divided into small bubbles, but its greater bulk

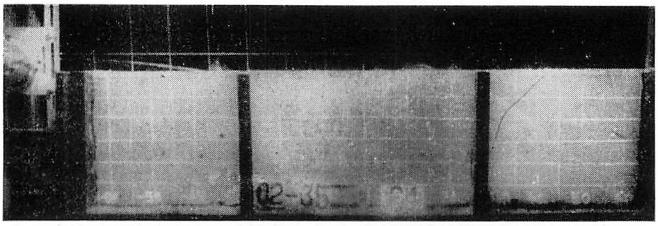

Fig. 4–1. Ricochet motion of a projectile
(Experiment No. 02–35).

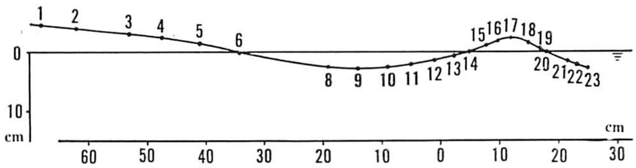

Fig. 4–2. Path of the projectile in the air and in the water
(Expeirment No. 02–35).

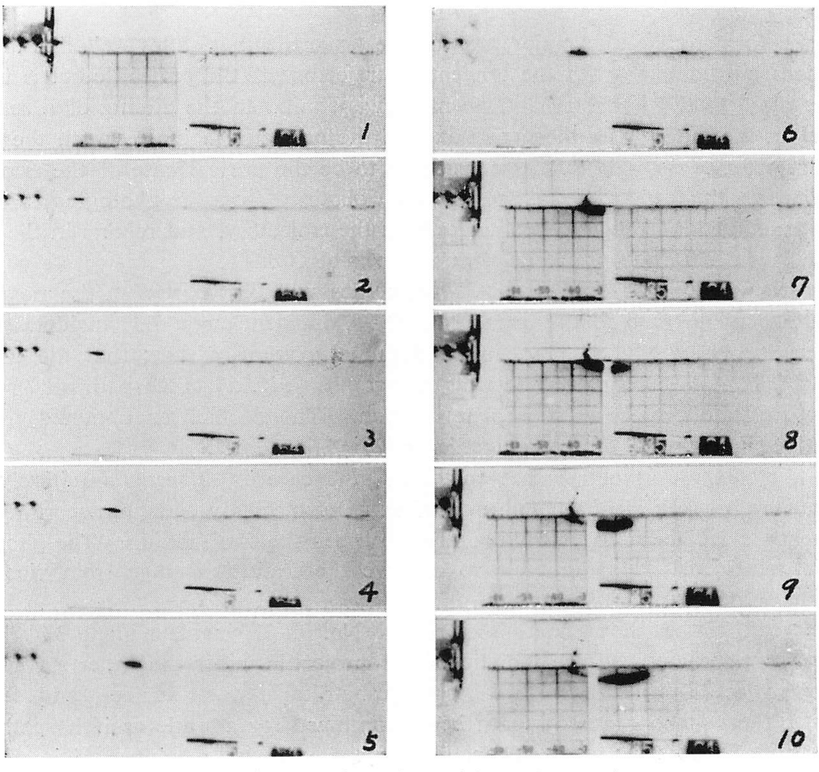

Fig. 5–1～10. Photographs taken with an 8 mm cine camera
(Experiment No. 02–35).

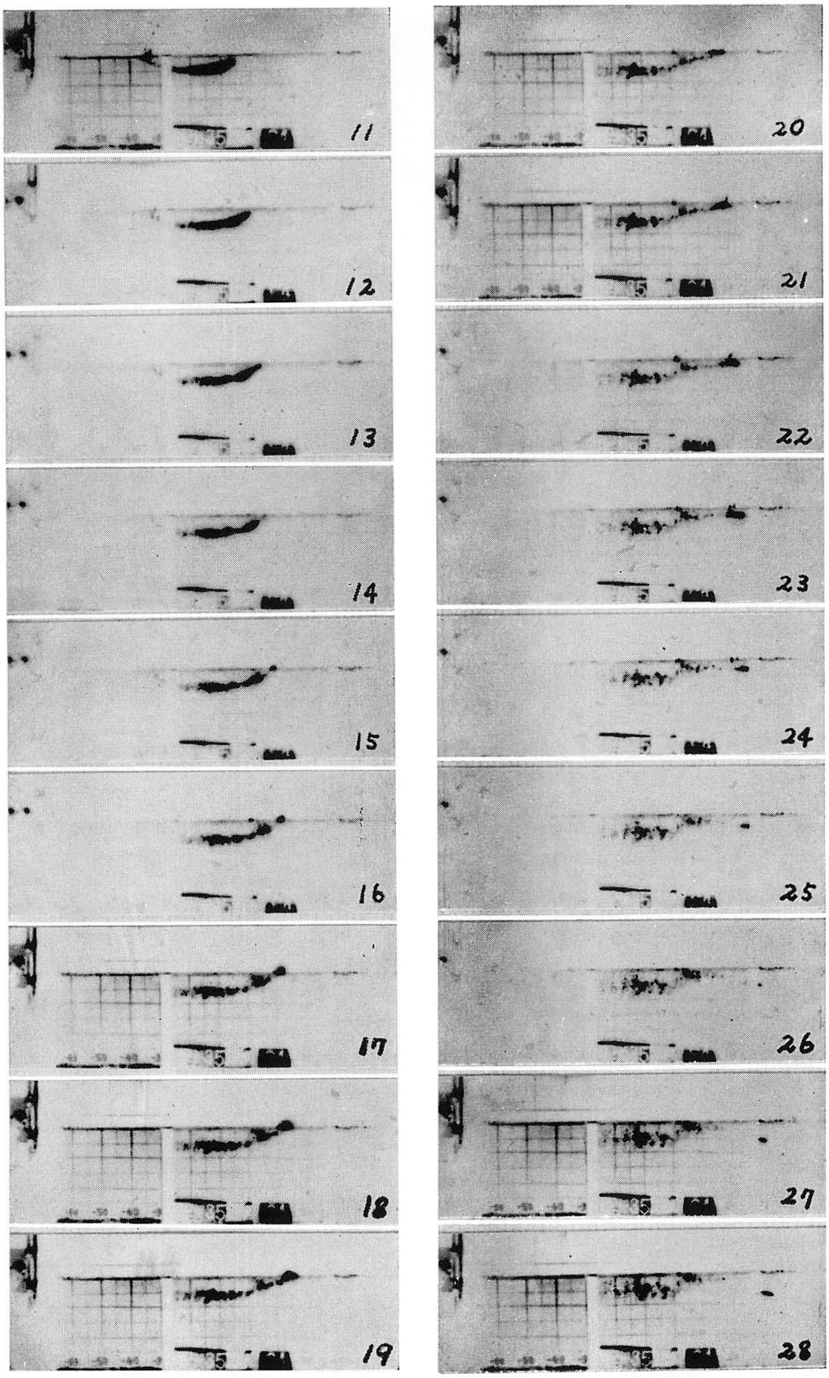

Fig. 5-11～28. Photographs taken with an 8 mm cine camera (Experiment No. 02-35).

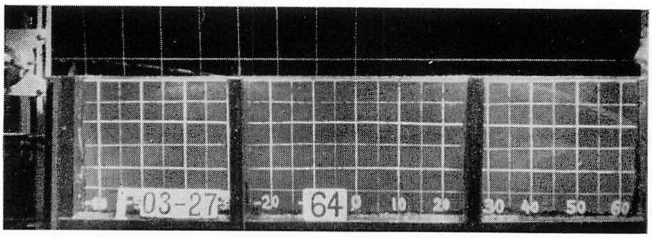

Fig. 6. Slip motion of a projectile (Experiment No. 03-27).

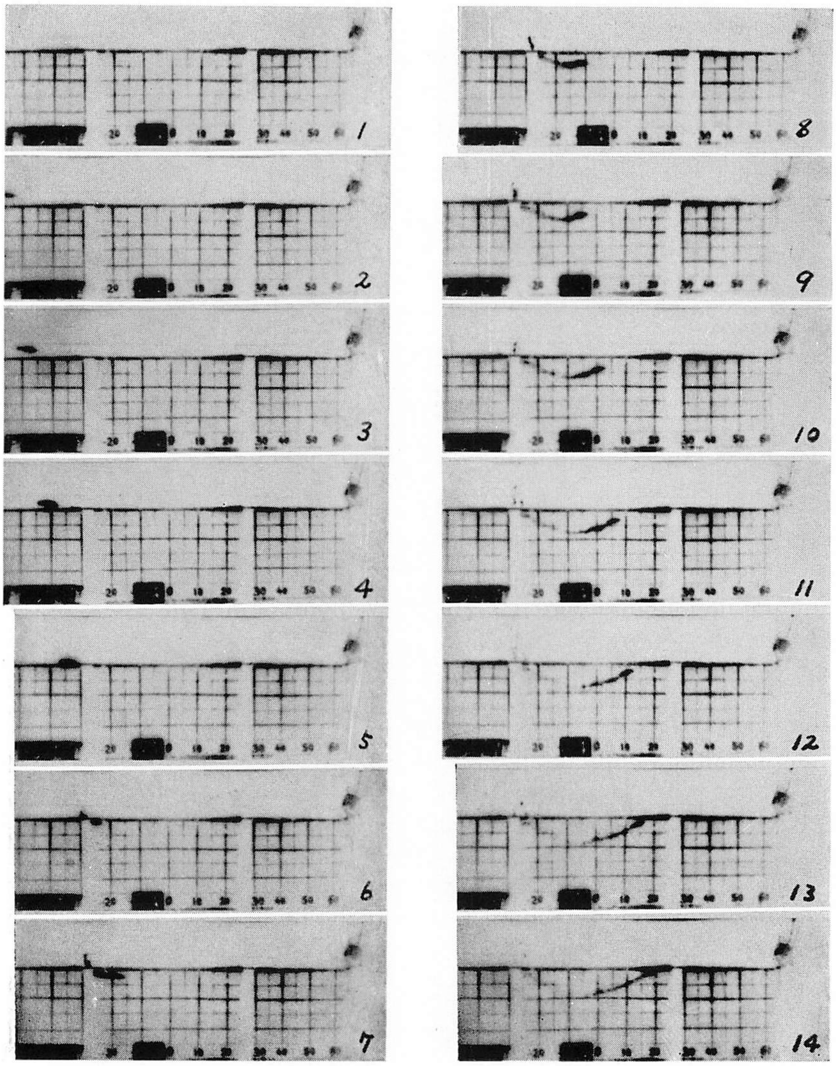

Fig. 7-1～14 Photographs taken with an 8mm cine camera (Experiment No. 03-27).

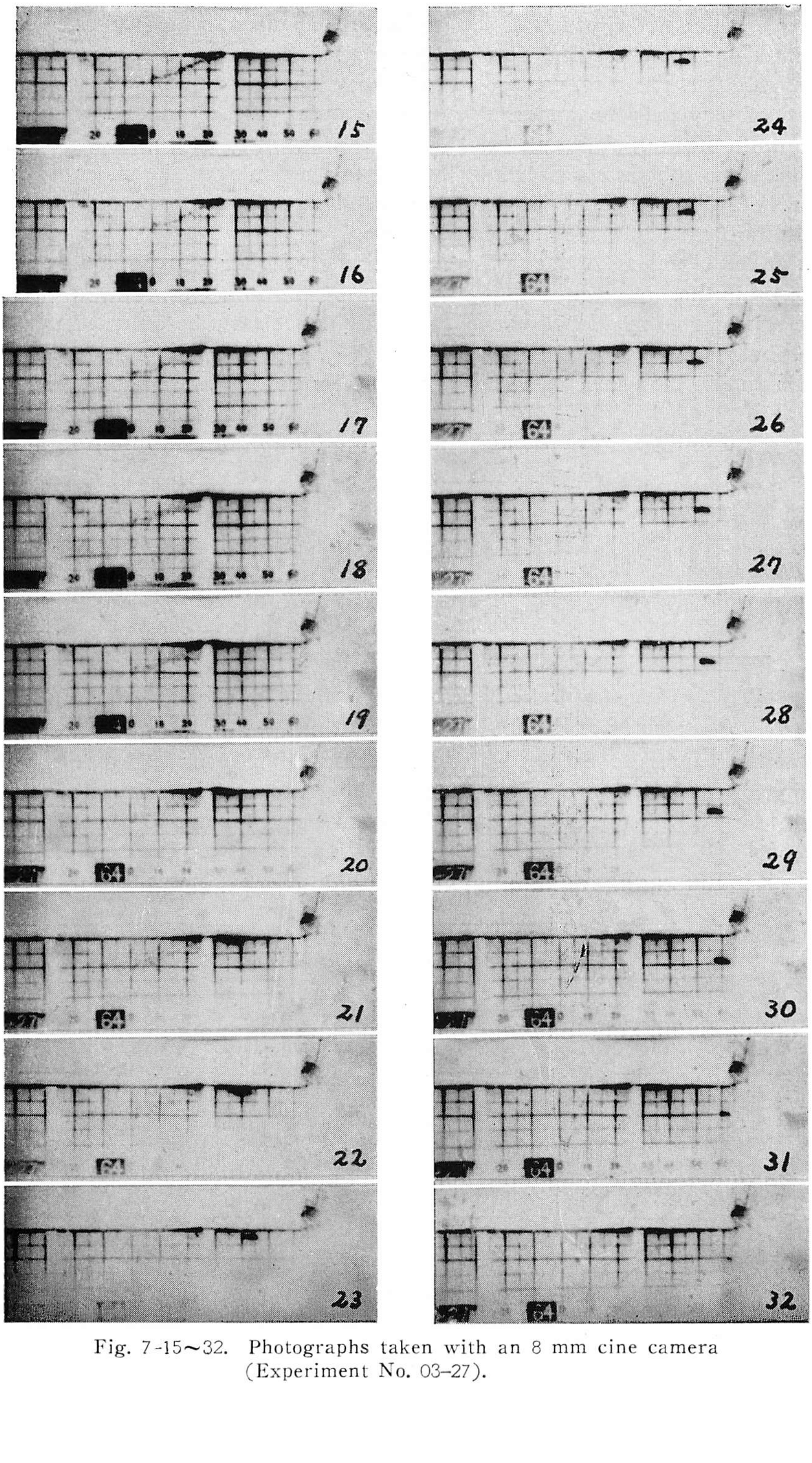

Fig. 7-15〜32. Photographs taken with an 8 mm cine camera
(Experiment No. 03–27).

remains undivided.

After a while, the direction of the projectile is changed to the horizontal and then upwards. The projectile, then, reaches the water surface, but it does not fly off the water into the air. And so, the projectile rushes along just beneath the water surface, with part of its head-cone appearing above the water surface and ruffling the water. The projectile, finally, directs its head downwards and then falls to the bottom. Although the some bubbles ascend vertically from the beginning of the under-water course until the falling-down course, the projectile is still accompanied with the great bulk of air at the beginning of the falling-down course.

But at the beginning of the falling-down course, the air mass is rapidly seperated from the projectile.

The slip motion mentioned above can easily and clearly be observed in the consecutive photographs of an 8 mm cine camera (Fig. 7). The position of the projectile in the air and in the water, its velocity and accelaration of it are shown in Fig. 8.

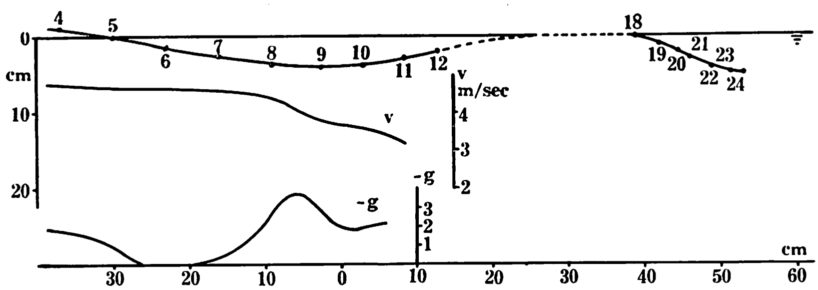

Fig. 8. Path of a projectile in the air and in the water, its velocity and acceleration.

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