THE PERFORMANCE OF SMALL ARMS AMMUNITION WHEN FIRED INTO WATER

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ABSTRACT: Standard small arms ammunition was tested by firing into water from air. The test results show this ammunition to be relatively ineffective in water, having a lethal slant range of 1.5 feet. By proper design of the projectile, staying within the restrictions for standard ammunition, the lethal slant range can be increased to about 8 feet.

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REFERENCES

1. "Wound Ballistics," U. S. Army Medical Service Washington, Office of the Surgeon General, 1962
2. "Hydroballistics Design Handbook," NAVORD Rpt 3533, Mar 1955
3. "Model Tests and Scaling," H. G. Snay, NOLTR 63-257, 1 Dec 1964
4. "Antiswimmer Explosive Weapon Survey," J. O. Mobley, NOLTR 67-196, 20 Dec 1967

INTRODUCTION

The hydrodynamic forces experienced by a missile as it breaks the air-water interface are proportional to the square of the impact velocity. As the missile proceeds through the new medium, its stability and acceleration are greatly influenced by the water impact force and an induced angular acceleration (whip). In the case of high-velocity water entry the problems associated with water impact and whip are obviously compounded.

Consider now the particular high-speed water-entry problem of a bullet-like projectile. In this case it is desirable to have the missile enter not only at high speeds, but also at oblique angles. To be a lethal underwater projectile it must continue along a predictable trajectory and deliver a fixed minimum of energy to the target. This problem was brought to the attention of the Naval Ordnance Laboratory by the Vietnam Laboratory Assistance Program. Small arms fire is used in an attempt to protect bridges or water-bound installations from swimmer placed or water borne explosive charges. The floating charges may be surface or subsurface. Sentries are instructed to fire on all suspicious objects in the hope of discouraging enemy swimmers or destroying floating charges. Previous experience with bullets fired into water caused the effectiveness of such tactics to be questioned. A standard ogival bullet is spin-stabilized for its air flight and is unstable in water. The instability of the bullet for water flight is increased by the water-entry forces. A tumbling projectile has the double disadvantages of rapidly decreasing energy and an unpredictable trajectory.

The purposes of this study were: (1) provide an experimental evaluation of the effectiveness of small arms when fired from air into water; (2) design, if possible, a bullet that would be more effective than the standard round without causing any changes in the weapons themselves.

ANALYSIS AND EXPERIMENTAL DESIGN

The small arms rounds studied were the 7.62mm NATO round fired by the M-60 machinegun and the 5.56mm round fired by the M-16 rifle. The muzzle velocity for both of these weapons is about 3000 feet per second. At 100 yards the velocity is still well over 2500 feet per second. At these velocities in water a cavity is generated which envelopes the missile except at the nose.

The pressure drag force on the body far exceeds all other forces. Thus, for a simplified analysis the buoyant and gravity forces are neglected. The equation of motion is simply

$$\text{drag} = -m \frac{dv}{dt}$$

since the drag is opposed to the direction of motion, or

$$\frac{dv}{dt} = -\alpha v^2$$

where

$$\alpha = \rho \frac{C_D A}{2m}$$

This can be rewritten as

$$\frac{dt}{ds} \frac{dv}{dt} = -\alpha v$$

and

$$\int_{v_o}^{v} \frac{dv}{v} = -\alpha \int_{o}^{s} ds$$

so that taking the water surface at $s = 0$ and the entry velocity as v_o,

$$v = v_o e^{-\alpha s}$$

or

$$s = \frac{1}{\alpha} \ln \left(v_o/v\right)$$

Reference 1 implies that a minimum bullet velocity of about 300 feet per second is required to inflict a lethal wound in the human body. On this basis, using a muzzle velocity of 3000 feet per second, the effective distance of water travel s is

$$s = 2.3/\alpha$$

The bullet weights are fixed at 55 grains for the 5.56mm round and 145 grains for the 7.62mm round. It is advantageous to keep any new bullet design close to these weights to avoid any changes in powder loads and therefore air flight ballistics. The distance traveled through water over which the bullet can be considered effective is dependent upon its C_DA product. Experience with water-entry shapes has demonstrated that a nose flat with a minimum diameter of one-half the actual body diameter could give good high-speed water-flight characteristics. The pressure drag coefficient for a disc is 0.8. Using this size the maximum effective range for the two bullets can be calculated as approximately 15 feet for the 7.62mm round and 11 feet for the 5.56mm round. Note that these are the maximums expected for effective underwater flight presuming the bullet remains stable.

The ogive bullets would have a lower drag coefficient but again past experience tells us that during oblique water entry they are subject to high transverse forces which cause them to be unstable. A flat nosed projectile should offer better entry characteristics. In addition, the flat nose provides a more stable cavity running vehicle. Unfortunately, the small length-to-diameter ratio of a bullet is not good for a cavity running vehicle. With a larger L/D, angular motion induced at entry can be compensated for by the afterbody bouncing off the wall of the cavity. Reference 2 suggested an entry shape that would give little or no induced angular acceleration at entry.

As noted in the initial request for assistance, the first part of the test series was devoted to the determination of lethality and underwater penetration of light metal containers for standard ammunition. This phase also included a survey of the pressure pulses generated at water entry in an effort to establish what effects these could have in the event of a near miss. The second and third test phases were to improve underwater penetration of a bullet by changing its shape considering optimum water-entry characteristics within the constraints imposed by the launching weapon.

All tests were run in the Pilot Hydroballistics Facility at the Naval Ordnance Laboratory. A photograph and artist's concept of the tank are shown in Figure 1. Launcher stands were built which allowed angle variations from vertical to near zero degrees. These were mounted on top of the tank as shown in Figure 2. Firing was done remotely by means of a solenoid connected to the gun trigger. In general, rounds were individually fired. The firing pulse was fed into a Fastax high-speed motion picture camera so the bullet trajectory could be recorded from water entry onward. LC 10 pressure transducers were located at various points in the water to record pressures associated with the shot. A schematic of a typical test setup is shown in Figure 2. An M-14 rifle was borrowed from the Aberdeen Proving Ground and used instead of an M-60 machinegun because of handling ease. The M-14 fires the same 7.62mm NATO round. An M-16 rifle was available for testing the smaller 5.56mm round. A 30-06, 1903 A3 rifle was used for the bulk of the new shape testing. General physical constants for the corresponding military ammunition of each of these rifles is given in Table 1.

Table 1
Physical Constants for Ammunition

Rifle	Round	Muzzle velocity (ft/sec)	Weight (grains)	Dia. (in.)	Length (in.)	Barrel twist (in./turn)
M-16	ball	3250	55	.223	0.75	12
(5.56mm)	tracer		55	.223	0.88	
M-14	ball	2950	145	.308	1.12	12
(7.62mm)	armor piercing		135	.308	1.21	
03A3	ball	2750	150	.308	1.104	10
(30 cal)	armor piercing		160	.308	1.365	

A photograph of the bullets showing comparative sizes is shown in Figure 3.

TEST RESULTS

Typical test data are shown in Figures 4 and 5. Figure 4 is the photographic record of an M-14 ball round fired at vertical entry. The bullet is seen to turn broadside to the direction of motion shortly after entry and is soon broken up as evidenced by the two major pieces. The two small markers represent a distance of 6 inches. This motion is due to its instability in water and is typical of conventional bullets. At oblique entry angles the motion is similar down to angles of 15 degrees. Below this angle the bullets broached or came back out of the water. The reduced data of Figure 4 are reproduced as a velocity versus distance (depth) curve in Figure 5. As a result of its instability, the bullet has a lethal depth of penetration at 90 degrees of about 18 inches. This is considered a conservative conclusion because at this distance the bullet would impact its target broadside rather than nose-on. Penetration of a target under these conditions would be degraded. A closer study of Figure 4 will show a bubble-like cavity forming at the point where the bullet tumbled which grows and decays in time very similar to the motion of a bubble generated by an underwater explosion. Three cycles of the oscillation have been clearly recorded (Fig. 8a). Apparently the bullet, by tumbling, has dissipated most of its energy at that point, causing the explosive-like bubble. An equivalent mass of TNT required to generate a bubble of the same size can be calculated from an equation given in reference 3 as

$$A_{max} = J\left(\frac{w}{z}\right)^{1/3} = \text{max bubble radius (ft)}$$

$$z = \text{absolute hydrostatic pressure (ft)}$$

$$J = \text{constant for TNT} = 12.6\ ft^{4/3}/lb^{1/3}$$

Analysis of the bubble size from the films of tests on both the M-16 and the M-14 bullets indicates equivalent masses of approximately 2 and 4 grams, respectively, of TNT would generate a similar bubble under water. However, as can be calculated from reference 3, the lethality of the bubble generated pressure pulse is approximately 6 inches. Figure 6(a) shows a double flash strobe picture of an M-16 bullet just after entry and just after it turns and fails. The bubble is seen in its initial stages of growth. In Figure 6(b) a similar event is shown. The large accelerations acting on these projectiles are apparent. Pieces of the ball round, recovered after firing from the M-14 and M-16, are compared to whole bullets in Figure 7. A pressure record from a typical bubble oscillation is shown in Figure 8 along with a time stretched record for a typical impact pressure. This impact record was recorded for an M-16 ball round entering the water at 45 degrees. The closest gage was 1.5 feet deep in the water and a slant distance of 1.64 feet away from the entry point. The next two gages were both at the same depth but at respective slant ranges of 3.5 feet and 4.92 feet. The impact traces are typical for the bullets tested at 90 degrees and 45 degrees. That is, the pressure records have the same shape and about the same pulse width, approximately 150 microseconds. Differences occur in amplitudes. For example, the peak pressure for the number one gage shown in Figure 8 is about 145 psi whereas the same gage located at the same depth but at a slant range of 2.12 feet recorded a peak pressure of about 300 psi during impact of the heavier M-14 ball round. This information is offered not as a refined study of impact pressures but simply to give an idea of the magnitude of the pressures associated with the bullet entry in water. Reference 4 indicates that for a pressure wave to be lethal to humans, 130 psi-milliseconds must be delivered in 2.1 milliseconds. On this basis, we conclude that any pressure associated with the water flight history of these bullets has a much smaller lethal range than the bullet itself. In general, the impact pressure will have no effect on a swimmer.

In addition to numerous tests at various angles of entry with the ball ammunition, an attempt was made to establish the ability of the M-16 to penetrate a 0.042-inch thick aluminum plate. It was found that the plate could not be penetrated below a depth of 1 foot; at 10 inches, penetration was marginal. These metal penetration tests were made at an entry angle of 90 degrees in an effort to establish the damage that might be done to lightly clad explosive charges floating on or near the water's surface. Again the conclusion is that the conventional bullets had very limited effectiveness due to the inability to penetrate stably into water.

In summary of the tests on standard ball ammunition it is concluded that the ammunition tested has an effective underwater slant range of 18 inches against personnel. This figure represents a maximum for the M-14 rifle. The M-16 effective slant range is closer to 12 inches. These ranges are considered conservative because of the unpredictable trajectory after entry.

An attempt was made to improve the entry characteristics of the ball and armor-piercing rounds by filing flat noses on the bullets. This was ineffective due to material failure, i.e., mushrooming of the end of the bullet. The next step was to launch an equivalent weight aluminum projectile with a one-half diameter nose flat. This was a cylinder 3 inches long, 0.298 inches in diameter with a truncated cone nose. These "bullets" had an average velocity of 800 feet per second after traveling 5 feet through water thus showing a greatly improved performance. The length however is too great to be used as standard ammunition. A trial and error procedure with different combinations of materials and nose shapes produced a bullet of more standard dimensions but with a lesser performance than the 3-inch long aluminum projectile. It also was realized that a bullet of that length could not be spin-stabilized by the standard rifling. A solid copper bullet with a truncated cone nose was found to be very effective at 90-degree entry. This bullet was 1.2 inches long, .308 inch in diameter with a nose flat of .18 inch and a weight of 170 grains. The average velocity after 5 feet in water was 600 feet per second. However, the copper yielded at impact, see Figure 9a, and due to this, or whip at oblique entry, an instability caused these bullets to tumble after traveling about 6 feet through water. To avoid the impact deformation, a bullet, as shown in Figure 9b, was tested. This consisted of a steel cylinder .18 inch in diameter enclosed for about two-thirds of its length in a copper cup .308 inch in diameter. The overall length was 1.2 inches and the weight about 170 grains. At the time, the test plan was to use the 03A3 as a development launcher. When design was finalized, the bullets could then be tested in the newer M-14 and scaled down for tests in the M-16. The performance of the same bullet when fired from the M-14 however was not consistent with that of the 03A3. For example, the steel, copper-clad bullet described above, when fired from the 03A3, traveled a straight trajectory and still had a velocity of 350 feet per second after 9 feet of water flight with an entry angle of 30 degrees. The same bullet when fired from the M-14 at the same angle consistently tumbled after about 6 feet of water flight. The only difference in the two weapons is about 200 feet per second out of about 2800 in muzzle velocity and about 300 revolutions per second out of 3000 in spin rate. The reasons for the inconsistent bullet performance were not investigated. At this time tests with the 03A3 were dropped and the M-14 was used as the prime launcher. After trying various sizes of the steel, copper-clad bullets which consistently tumbled at about 6 feet, it was decided that some entry induced instability was degrading performance. A truncated cone of Mallory metal was attached to a cylindrical afterbody of aluminum. The nose flat was .21 inch. Here the object was to move the center of gravity much farther forward. This bullet performed very well, did not tumble, and had a velocity of 300 feet per second after 8 feet of water flight. However, the bullet was decided to be impractical due to cost of manufacture. The next bullet tried was the low or zero whip shape described in reference 2. This bullet was copper with an aluminum pin inserted in the aft section to lighten the bullet and move the center of gravity forward, see Figure 9b. The performance was good, 300 feet per second at about 7.5 feet, and consistent when scaled down to the M-16. Oblique entry was attempted down to 3 degrees where about 50 percent of the rounds did not broach or ricochet. At 5 degrees all rounds entered the water and maintained a straight trajectory. Air flight tests of this round indicated sufficient stability in air. As a final test to check the feeding for semiautomatic or automatic fire, two of the new rounds were loaded behind one standard armor piercing round into an M-14 clip. The gun was aimed at a light metal can 3 feet below the water surface. The gun angle of 51 degrees gave a slant distance in water of 3.7 feet. Films of the test are shown in Figure 10. Note that the AP round does not even get to the target. Figure 11 shows the pierced can. No feeding problems were detected in this test. A comparison of the effectiveness of the new round with the standard round is given in Figure 12 and a sketch of the round is shown in Figure 13.

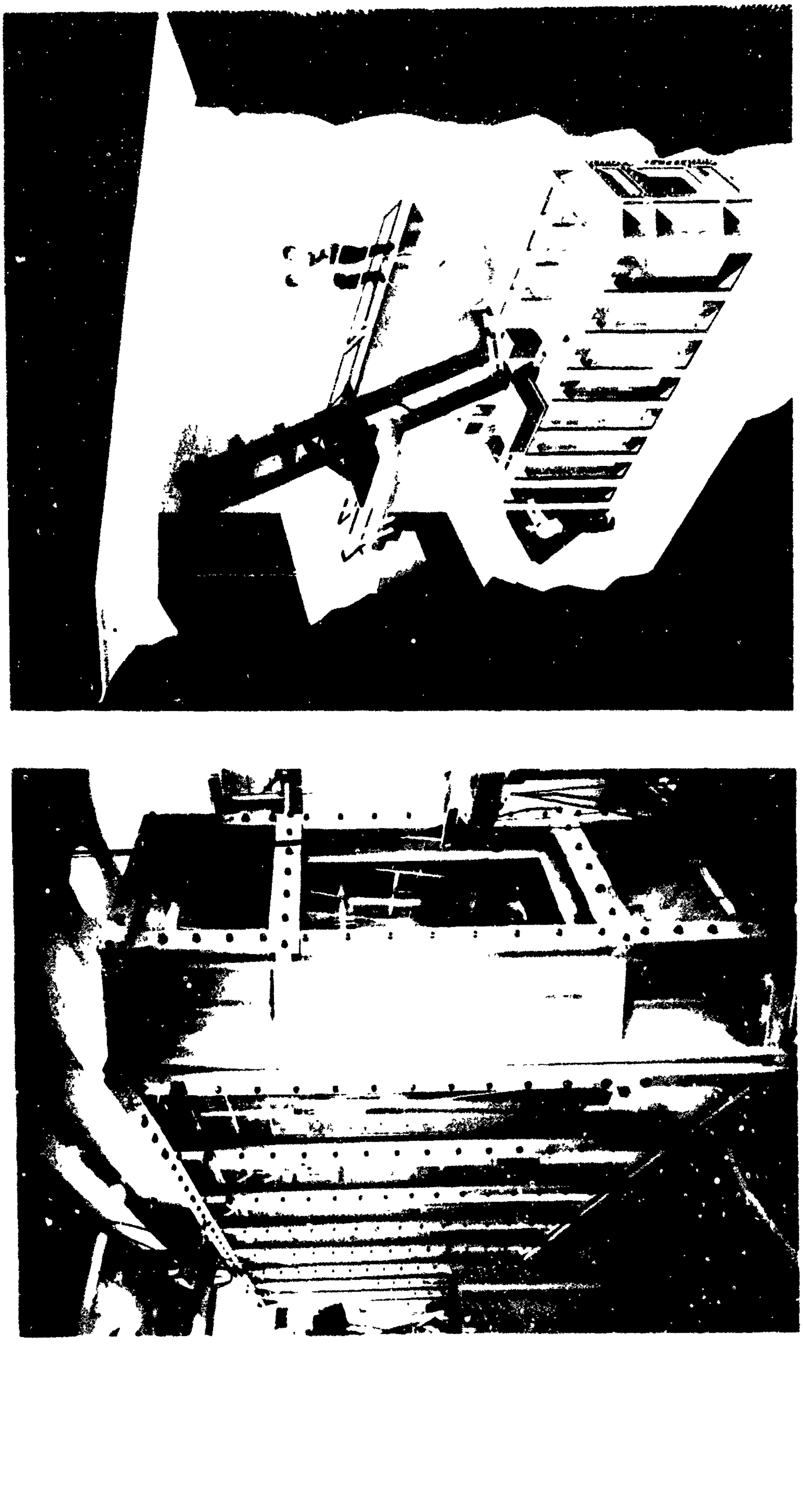
SUMMARY OF CONCLUSIONS

Conclusions based on these tests are summarized as follows:

1. Conventional small arms ammunition, ball and AP, have little underwater effectiveness against personnel or light gage metal containers. Effective range is not much more than 1 foot in water.

2. The underwater effectiveness of small arms can be improved greatly by proper design of the projectile keeping within the following restrictions; the bullet should (a) have approximately the same dimensions and weight as a standard ball round, (b) be fired from the M-14 or M-16 without changes being made to the weapon, (c) not change the normal firing rate of the weapon, (d) be launched from the standard cartridge with the standard powder load, (e) be stable in air flight, (f) be relatively inexpensive to produce in quantity. Within these constraints, a round was designed with an effective range of 7.5 feet in water.

3. As an expedient solution to the problem presented, this solution is considered acceptable. As a general underwater projectile, the range is still limited. The range can probably be extended by considering a different system; for example, one that utilizes longer dart-shaped missiles. This is certainly an area that needs more study.



A PHOTOGRAPH

B. ARTIST'S CONCEPT

FIG. 1 HYDROBALLISTICS PILOT TANK

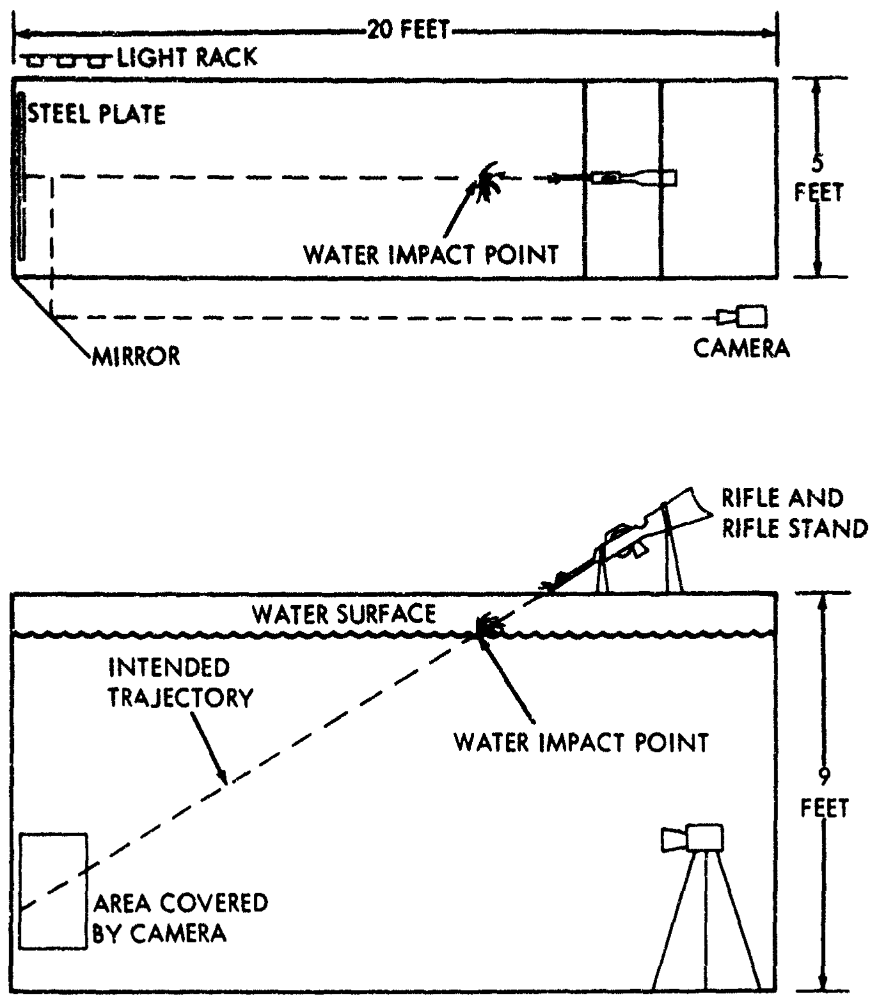


FIG. 2 SCHEMATIC OF A TYPICAL TEST SETUP

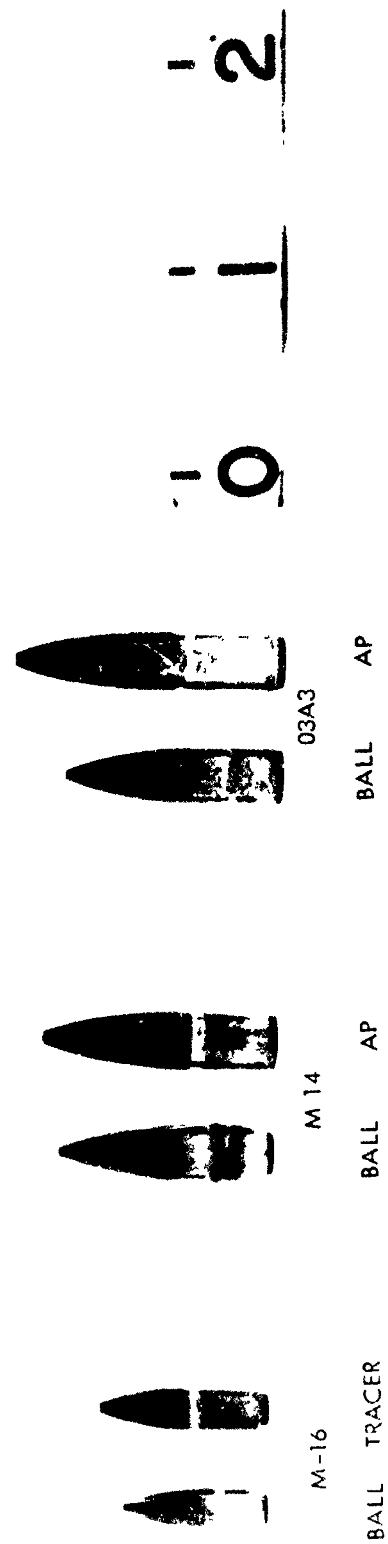


FIG. 3 MILITARY BULLETS

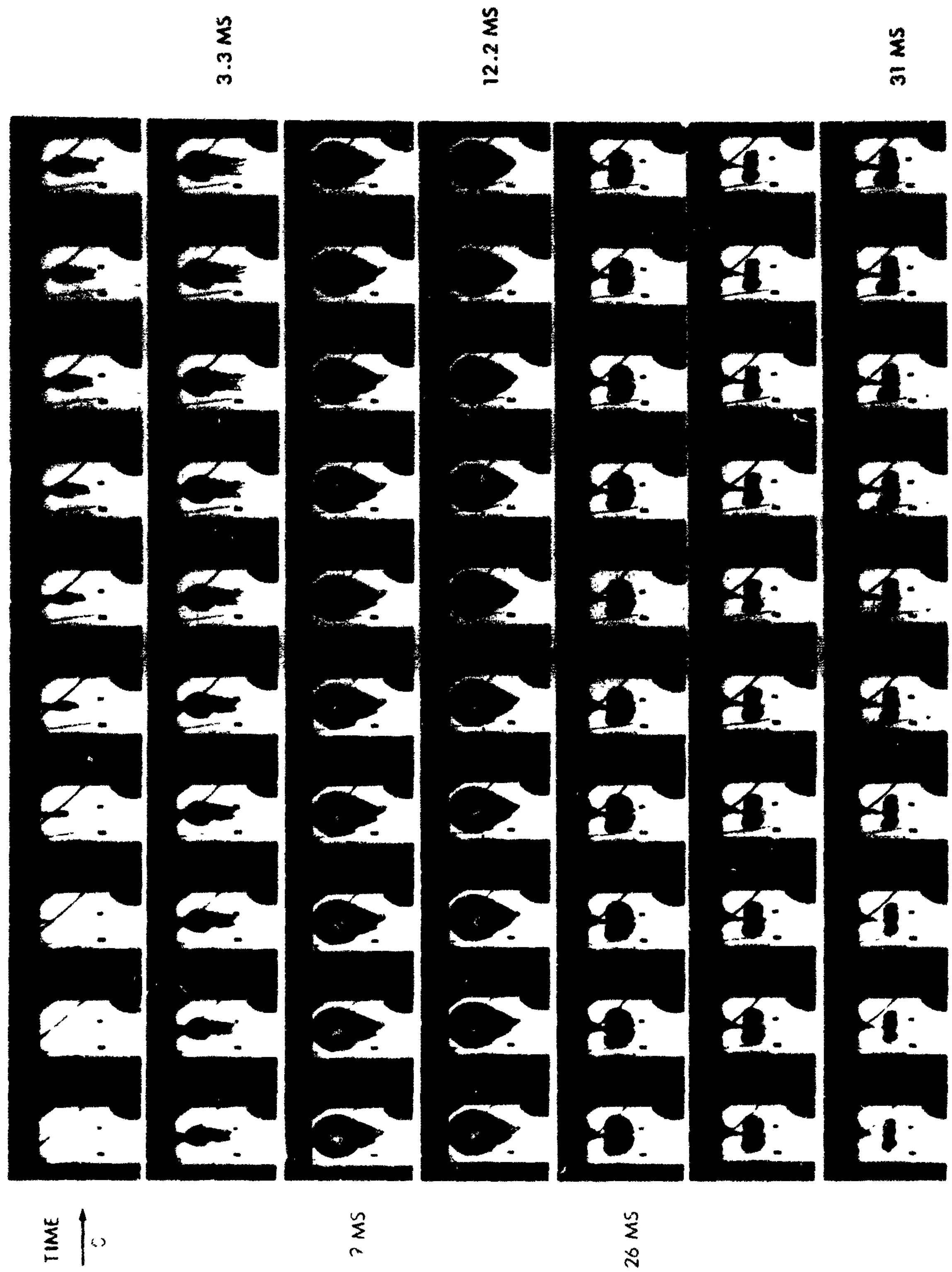


FIG. 4 M 14 BALL ROUND 90° ENTRY

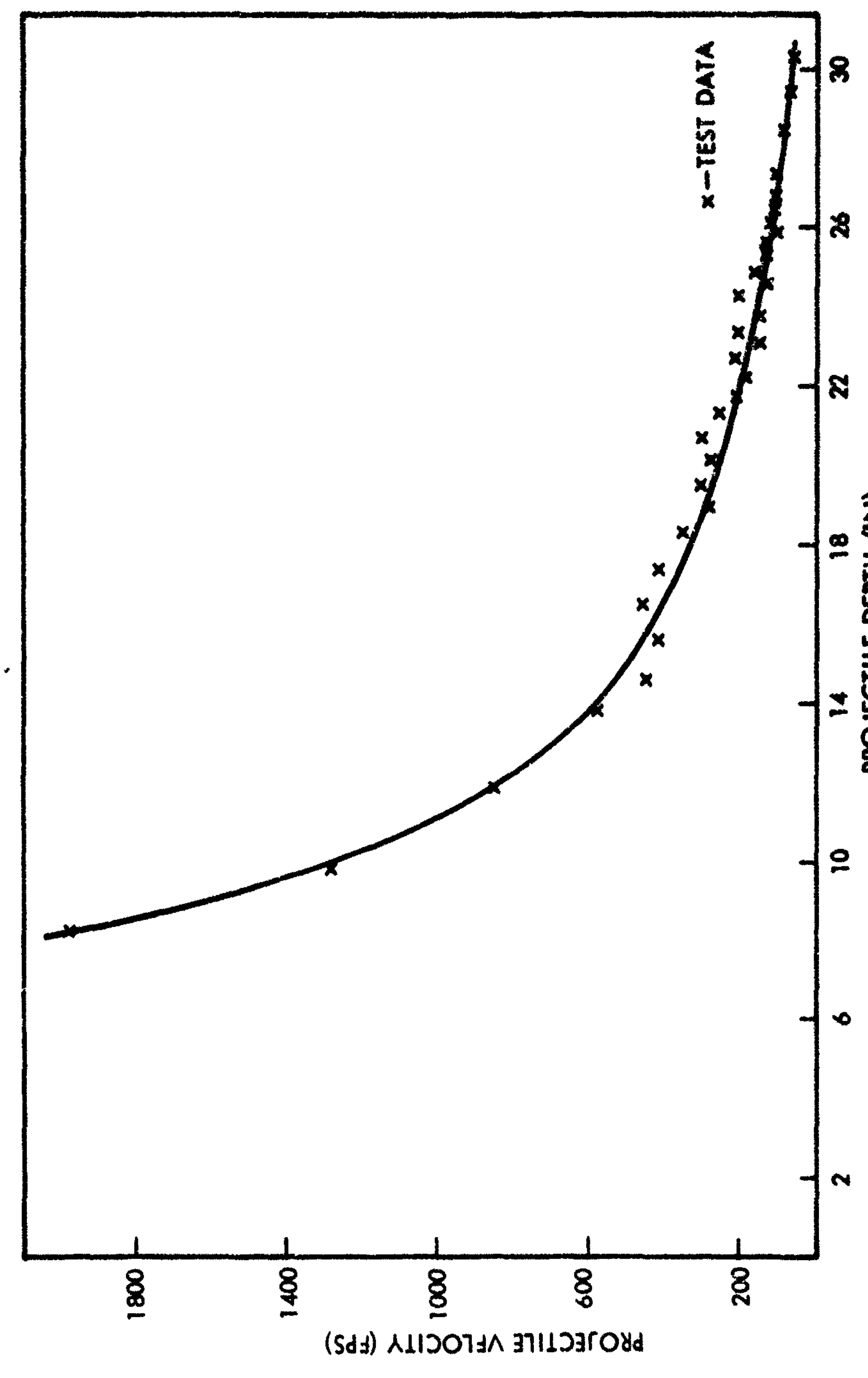


FIG. 5 VELOCITY VS DISTANCE M 14 BALL ROUND 90° ENTRY

A. FIRST FLASH: BULLET IS 4.25 INCHES DEEP
SECOND FLASH: DEEPEST PIECE IS 11.5 INCHES

B. FIRST FLASH: BULLET IS 6.75 INCHES DEEP
SECOND FLASH: DEEPEST PIECE IS 11.5 INCHES

FIG. 6 DOUBLE STROBE EXPOSURES OF TWO DIFFERENT M 16 BALL ROUNDS

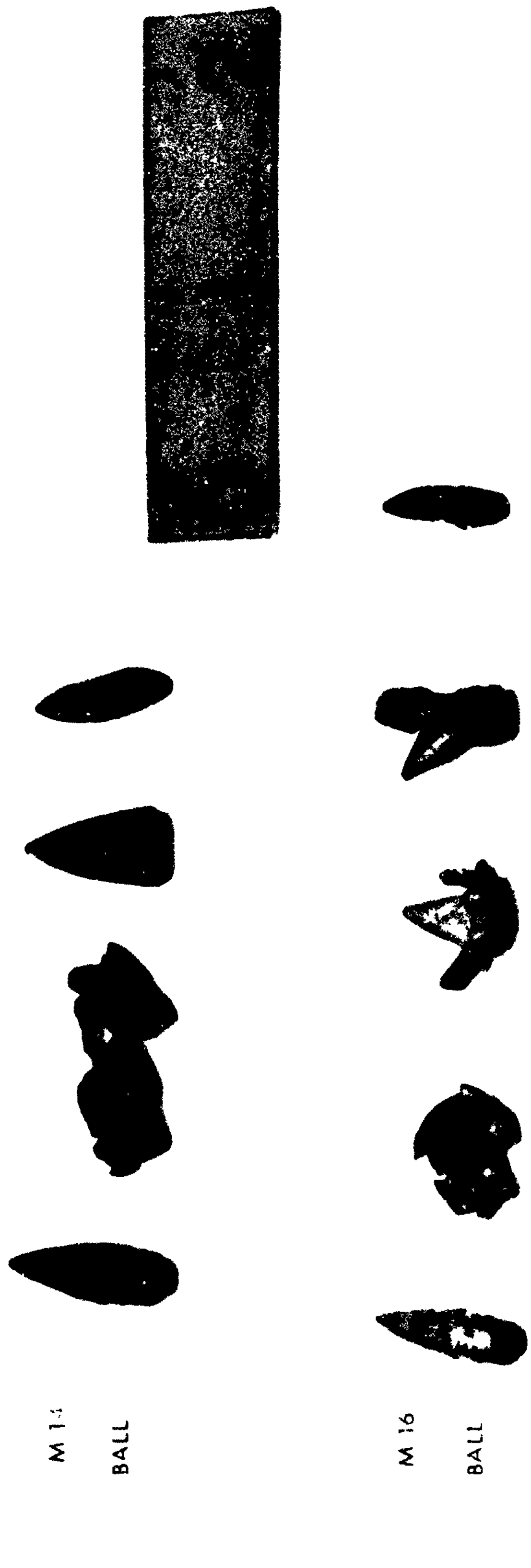
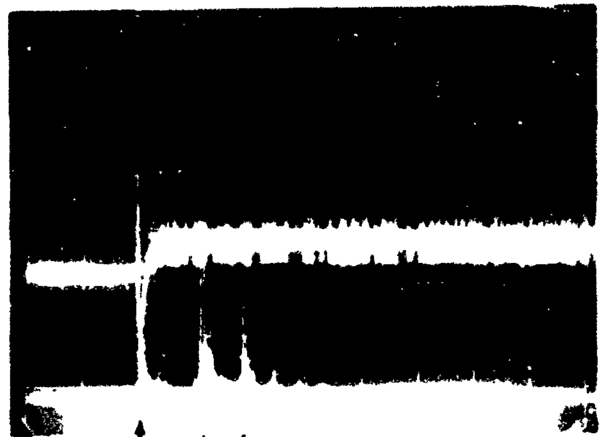
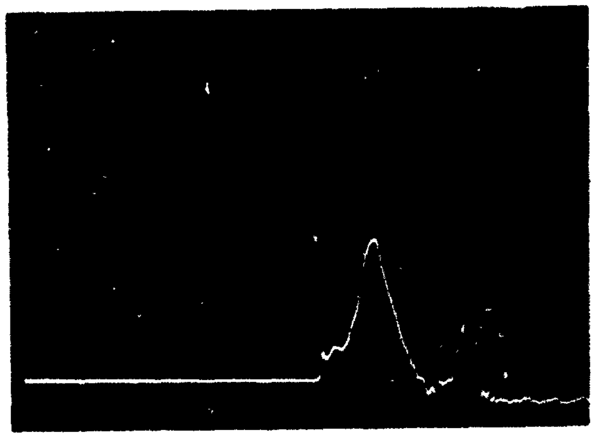


FIG. 7 RECOVERED PIECES AND UNFIRED ROUNDS



IMPACT FIRST AND SECOND BUBBLE CLOSURES

A. M 16 ROUND 90° ENTRY



GAGE IS 1.5 FEET DEEP AND
1.64 FEET FROM IMPACT POINT

UPPER TRACE GAGE IS 2 FEET DEEP
AND 3.5 FEET FROM IMPACT POINT.
LOWER TRACE GAGE IS 2 FEET DEEP
AND 4.92 FEET FROM IMPACT POINT.

B. M 16 BALL ROUND 45° ENTRY

FIG. 8 PRESSURE RECORDS

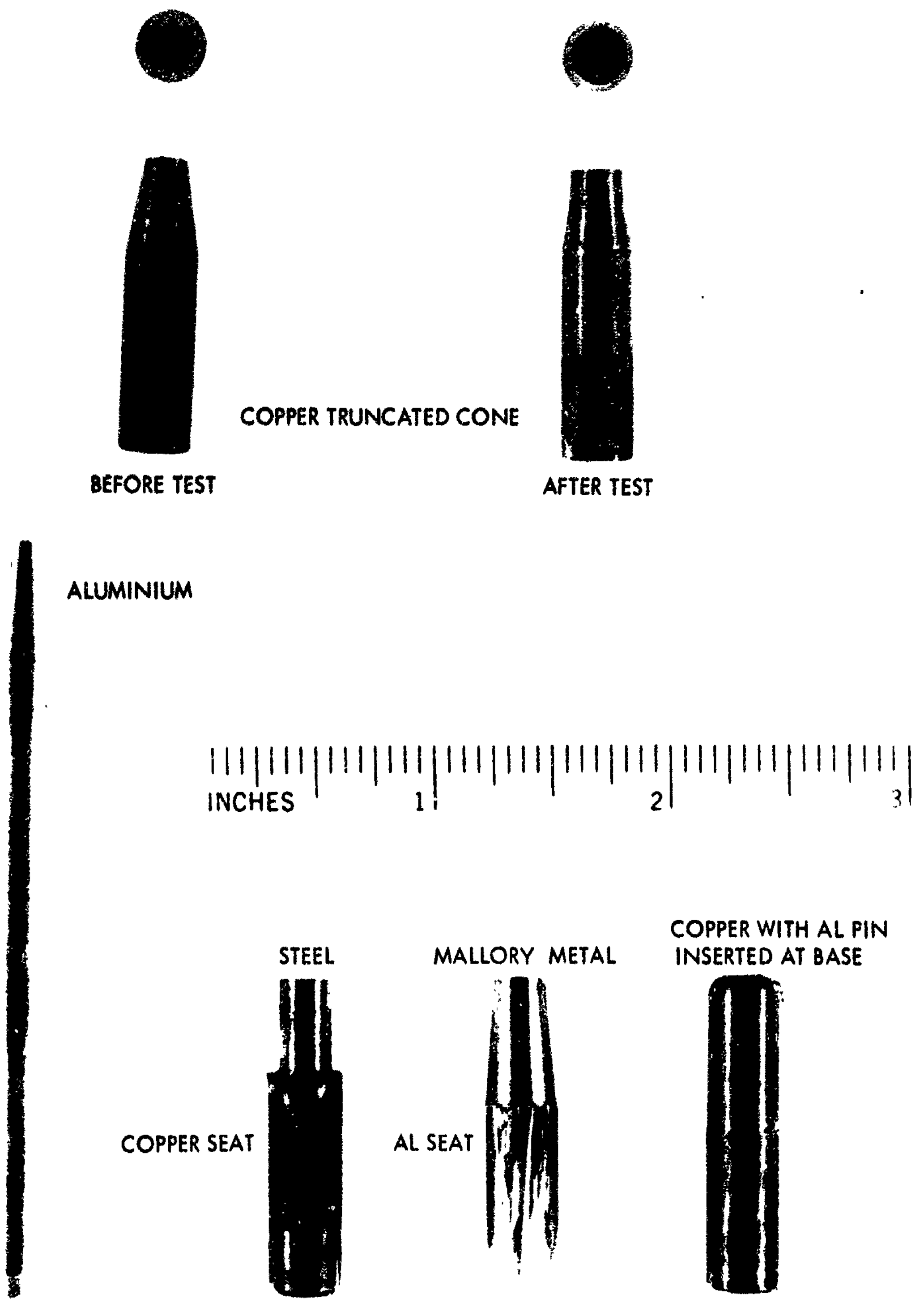


FIG. 9 TEST PROJECTILES

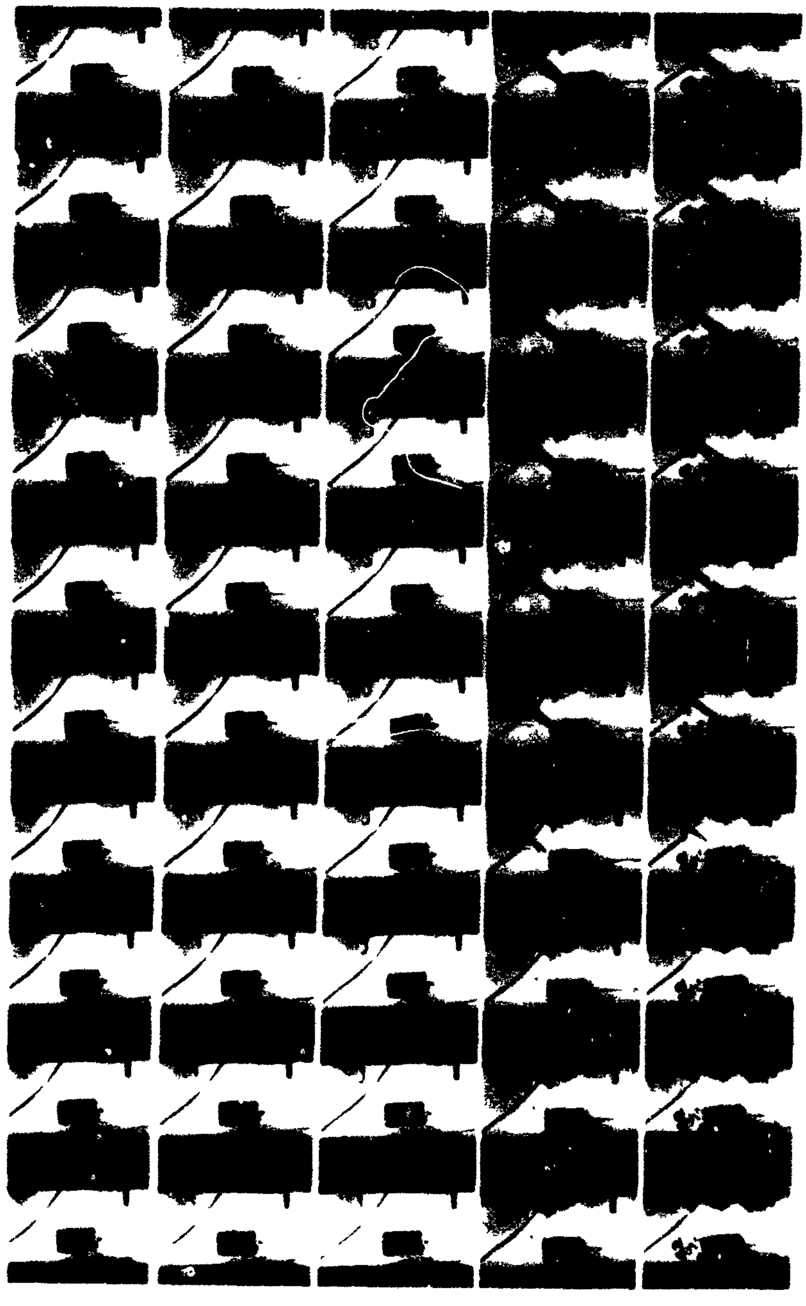
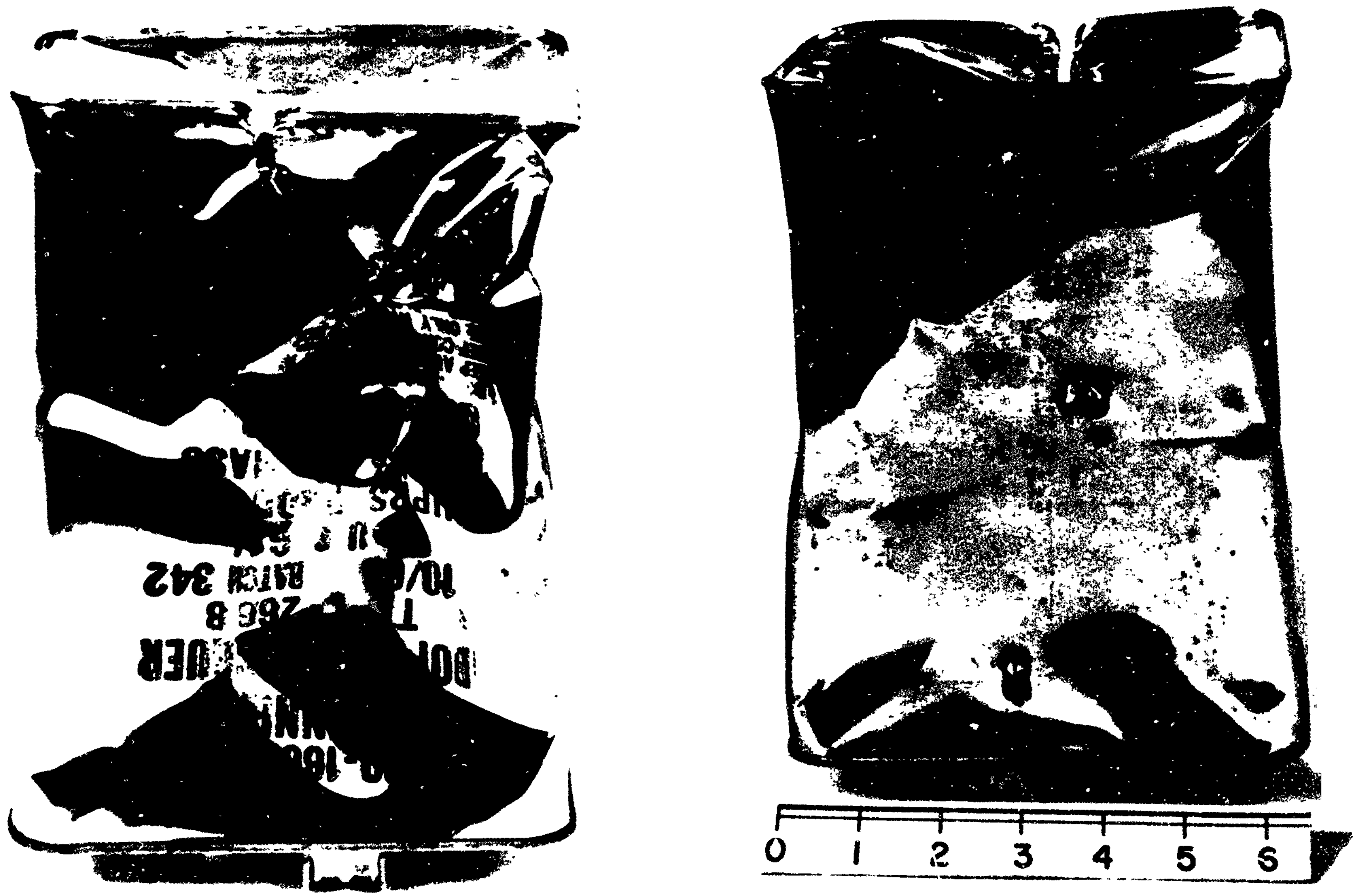


FIG. 10 PERFORMANCE OF STANDARD AND NEW ROUNDS



A. BULLET ENTRANCE HOLES

B. BULLET EXIT HOLES

FIG. 11 TARGET AFTER TEST

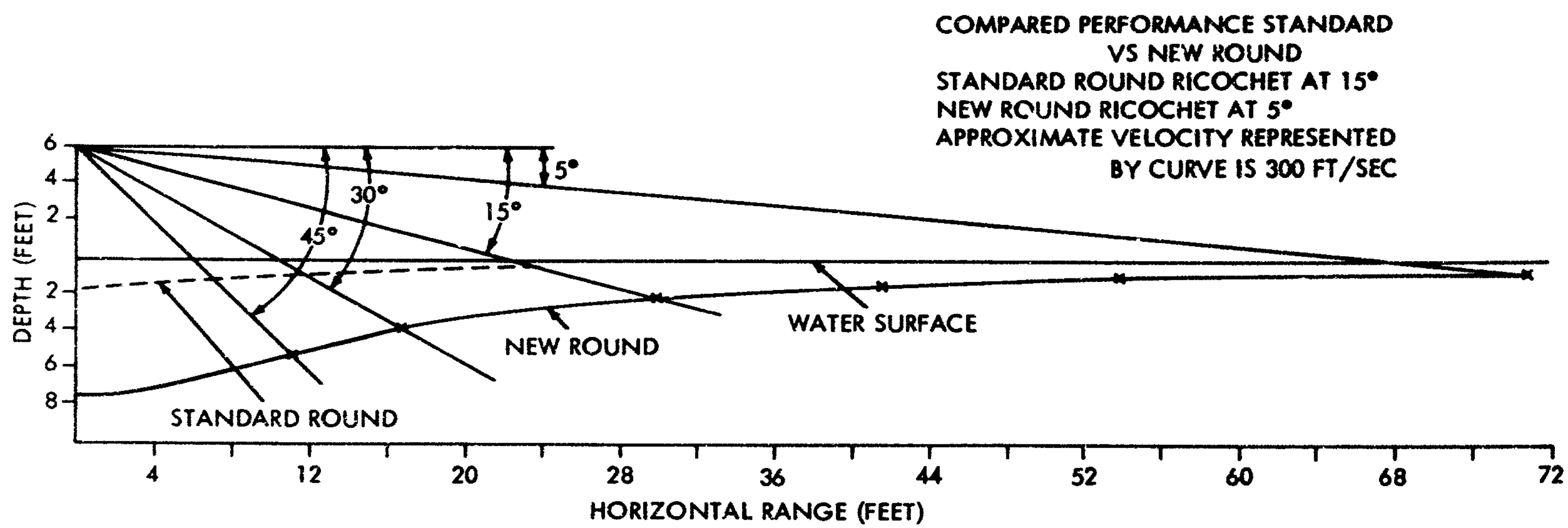


FIG. 12 COMPARISON OF STANDARD AND NEW ROUNDS

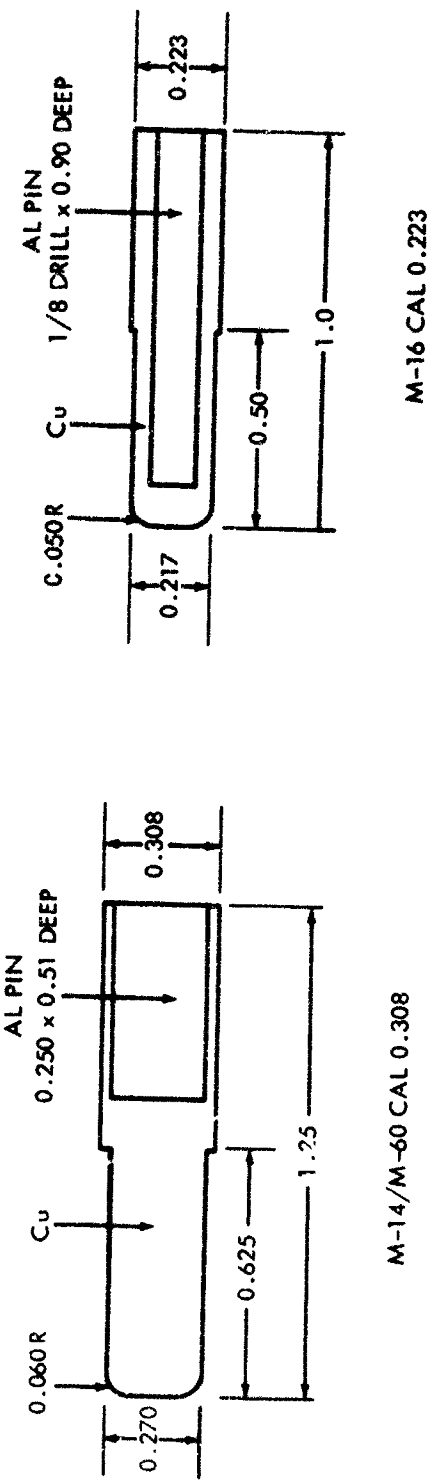


FIG. 13 NEW ROUND SKETCH