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Experimental Study of Multiple Interior Impacts

by

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ABSTRACT

In this paper, experiments involving interior impacts on soft, lead targets are described. The term "interior impact" refers to the impact of a projectile at the bottom of a pre-drilled hole in the target. It is demonstrated that impact of low-velocity projectiles into such soft targets results in plastic flow and cavities similar to those obtained in high-velocity impact of hard targets. Therefore, comparatively simple rifle-propelled projectile impacts on soft targets may yield useful information for high-speed hard target impacts.

Double impacts, with a short time interval (on the order of microseconds) between projectile arrivals were conducted. The leading projectile creates an "occlusion," which hinders the entrance of the trailing projectile. The total penetration depends on the time interval between the projectiles.

A method was developed to obtain double impacts at the same point. The method was a duplex round, a round which is made up of two separate projectiles fired from the same cartridge. With this round, a series of impact experiments was conducted. It was learned that occlusion is negligible for nearly simultaneous projectiles (less than 10 usec between impacts), and greatest with about 80 to 100 usec between impacts. The projectile velocity was measured by the use of properly placed photodiodes.

I. INTRODUCTION

Experiments involving interior impacts of single projectiles on soft, homogeneous lead targets have been conducted previously [1]. The term "interior impact" refers to the impact of a projectile at the bottom of a pre-drilled hole in the target. It was demonstrated that impact of low-velocity projectiles into such soft targets results in plastic flow and cavities similar to those obtained in high velocity impact of hard targets. Therefore, comparatively simple rifle-propelled projectile impacts on soft targets may yield useful information for high speed hard target impacts.

Reference 1 also predicted and observed an occlusive effect in the pre-drilled holes after the impact by the first projectile of the two projectile impact cases. The occlusive of the passage after the first projectile impact hindered the entry of the second projectile and resulted in reduced total penetration. The two projectile impacts were conducted separately, with at least a few minutes between impacts.

This paper describes the experimental results of a study of multiple impacts with short time (on the order of microseconds) between projectiles. The purpose of these experiments was to determine the effect of such occlusion on the subsequent projectile, as indicated by total penetration depth and cavity size and shape.

To examine the short time occlusion effect, it was necessary to develop some method to obtain dual impacts at the same point with time between impacts on the order of microseconds. The adopted method was a duplex round, a round which is made up of two separate projectiles. With this round, a series of impact experiments was conducted; it was learned that occlusion is negligible for nearly simultaneous projectiles (less than 10 μsec. between impacts), and greatest with about 80 μsec. between impacts.

II. DESCRIPTION OF DUPLEX ROUND

The duplex round (a round containing two separate projectiles) was fired from a 0.220 caliber Swift rifle. The leading projectile was a copper-jacketed lead bullet, originally a 2.91 gm (45 grain) Spitzer-type bullet, but with the base cut off, dropping the weight to 2.1 gm $\pm$ 0.09 gm. This projectile is shown in Figure 1. As loaded, it was mounted in the barrel rifling.

The trailing projectile was also made from a lead, copper-jacketed, 2.91 gm (45 grain) Spitzer. This bullet was used with the nose cut away and a hole of constant diameter drilled through the axis. This hole allowed some of the expanding gases to pass through, forcing the leading projectile away and creating the desired spacing. The hole diameters ranged from zero mm to 0.79 mm (1/32 inch). This projectile weighed 2.82 gm $\pm$ 0.08 gm, and was mounted in the shell case, with 2.33 gm (36 grains) of Du Pont type 1MR-3031 gunpowder to complete the round (see Figure 1).

The velocities of the two projectiles were found to be the same for a given shot. The average velocity, from 18 measurements available, was 1060 m/sec, with a standard deviation of 28.9 m/sec, or 2.72 percent. The time between projectiles ranged from zero μsec to 82 μsec, the latter representing a spacing of 87 mm.

Further tests showed that 1.88 gm (29 grains) of powder would drive the leading projectile alone to 1060 m/sec; 2.02 gm (31.3 grains) propelled the trailing projectile to this same speed.

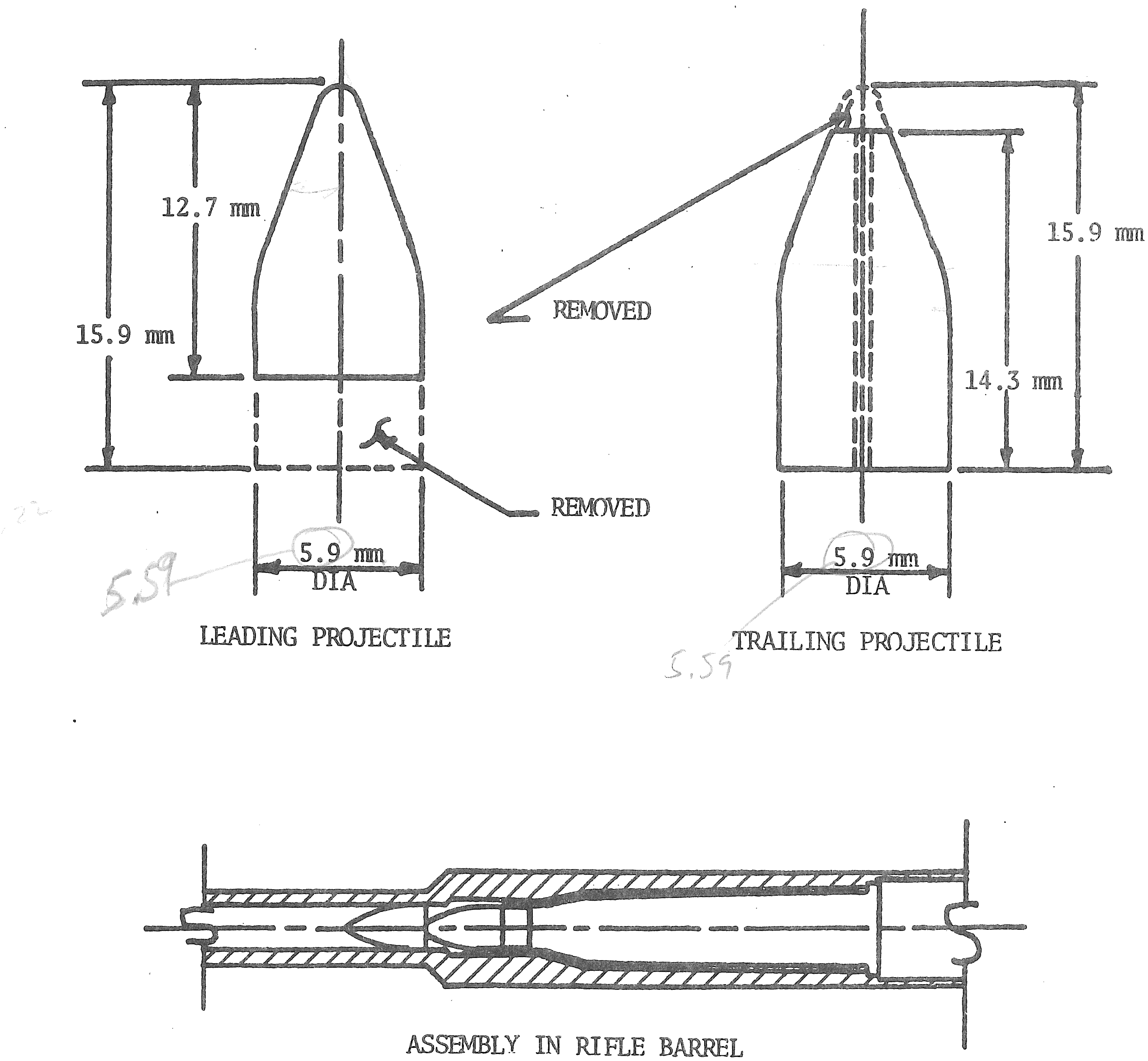


Figure 1 - Diagram of a Typical Duplex Round

III. VELOCITY MEASUREMENT EQUIPMENT FOR RIFLE RANGE

Three EG&G 100A photodiodes are mounted diametrically across from three light sources in a 64 mm diameter tube, at 152 mm intervals. This tube and a thin foil switch are placed in the projectile's path in such a way that the projectile will break the foil (no effect on the motion of the projectile) and subsequently cross the beams from each light source, as shown in Figure 2.

The diodes are attached to the input terminals of a Tektronix oscilloscope (either a 565 dual-beam scope or a 564 storage scope) equipped with a 3A74 four trace vertical amplifier, of which three traces are used, one each to read the voltages across the diodes. A 90 volt source provides bias voltage for the diodes, and a 6 volt source powers the light sources.

The foil trigger is connected to a voltage divider circuit (6 volts supplied) which is in turn attached to the trigger mechanism of the oscilloscope. As the foil is broken, the scope is triggered for a single sweep. As the projectile then crosses the light beams to the photodiodes, the corresponding trace is disturbed, indicating the time at which the projectile crosses that point (a duplex round creates two disturbances per trace). The time between disturbances is measured; since the distance is known, the velocity can be calculated. The time interval and the distance between duplex projectiles can also be calculated.

The sweep time deemed most suitable was 500 μsec. The traces consisted of dots of about 5 μsec. width in themselves. When measuring velocities on the order of 10^3 meters per second, this time error causes a velocity error of about four percent. Measurements of a given projectile between diodes 1 and 2, and between 2 and 3 always differed by less than 10 μsec, and usually did not differ at all. Since more than half of this difference may have been caused by equipment inaccuracy, deceleration was deemed negligible.

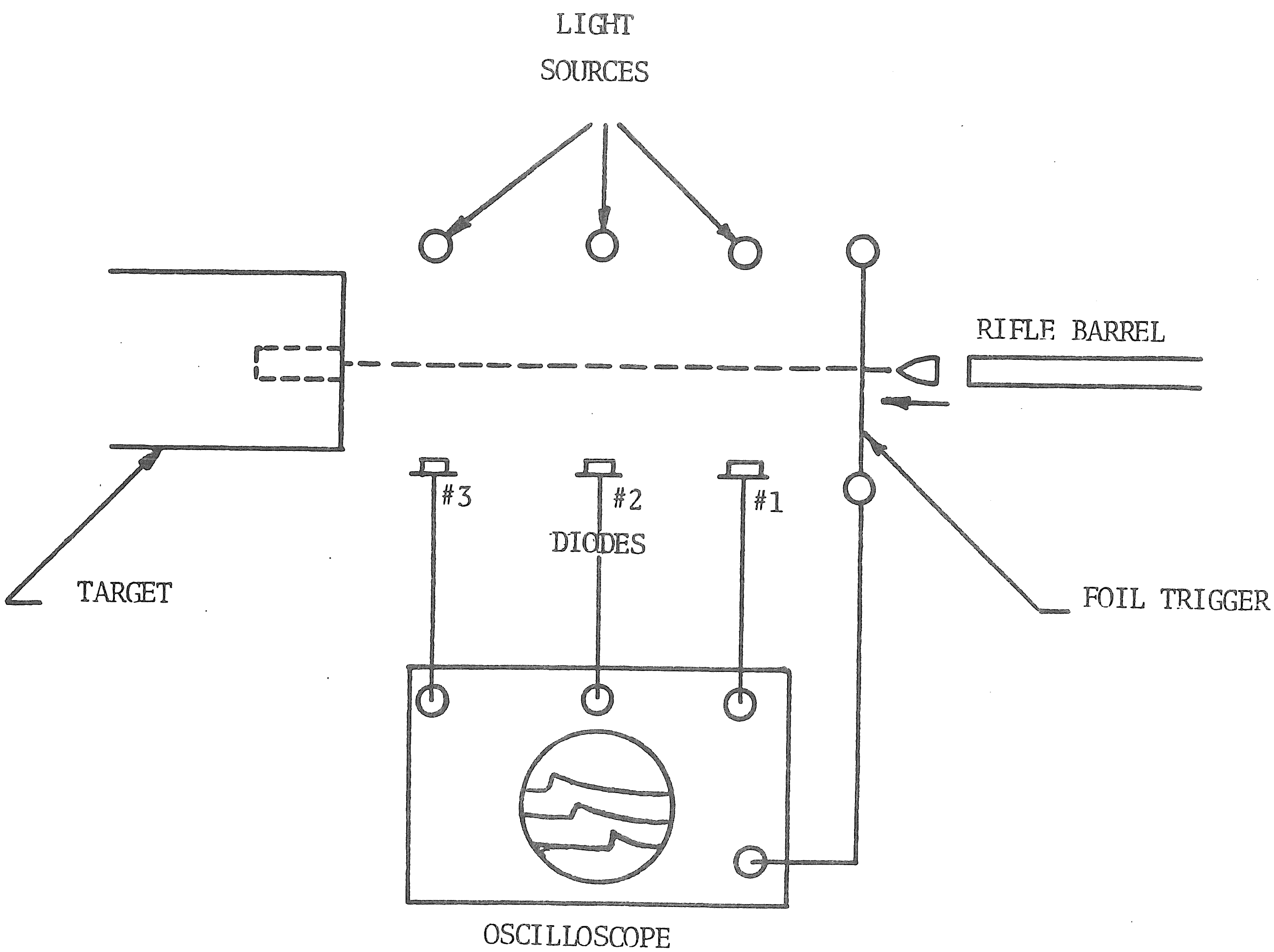


Figure 2 - Schematic Representation of Velocity Measurement System for Rifle Range

IV. FLIGHT CHARACTERISTICS OF DUPLEX ROUNDS

The photodiode system permits the determination of projectile velocities and spacing for the duplex rounds. It does not, however, give information on projectile flight characteristics. Severe tumbling or other anomalous behavior would possibly make test reproducibility difficult. Therefore, a microflash system - model 549, EG&G, Electronic Products Division was incorporated into the experiment. This system is a short duration strobe light triggered by a microphone pick up. A still camera with open lens records the image of the projectile in flight.

Multiple tests were conducted on the duplex round configurations. Four of the resulting photographs are reproduced in Figure 3. The flight characteristics of the majority of tests were good. Some anomalous behavior did materialize as shown in Figure 4. In (a) and (b), slight tumbling can be seen. In (c) a separation of the jacket from the trailing projectile has occurred and in (d) the jacket has fragmented. The observed degree of tumbling was felt not to be a problem for this very short range. However, all targets of the duplex round study were examined for indication of impact by jacket debris on the front surface and scoring in the pre-drilled hole.

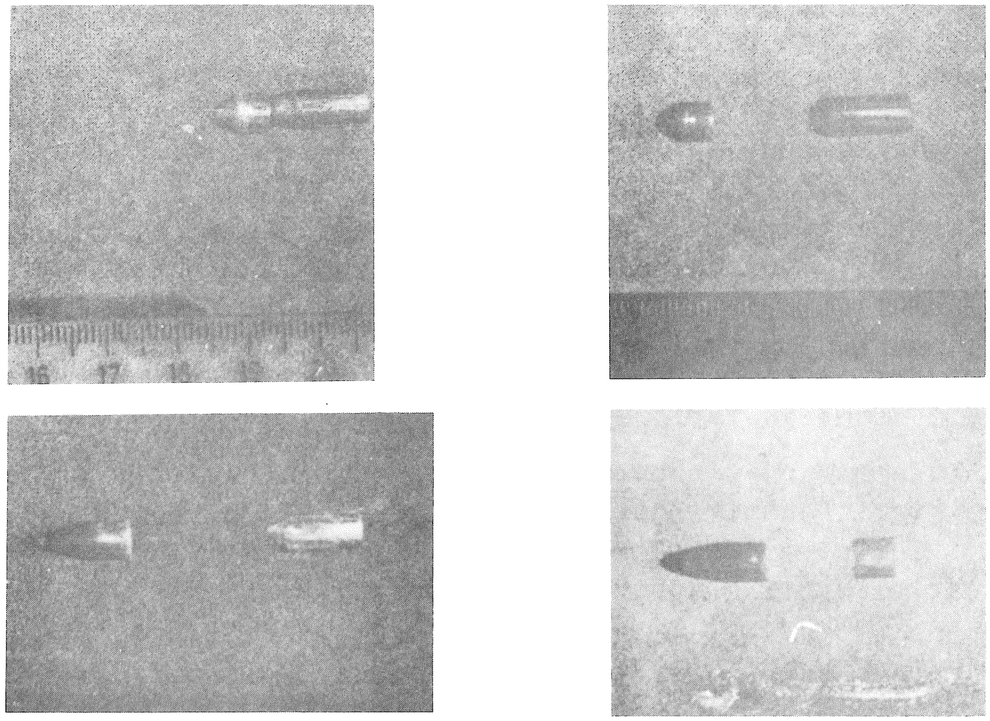
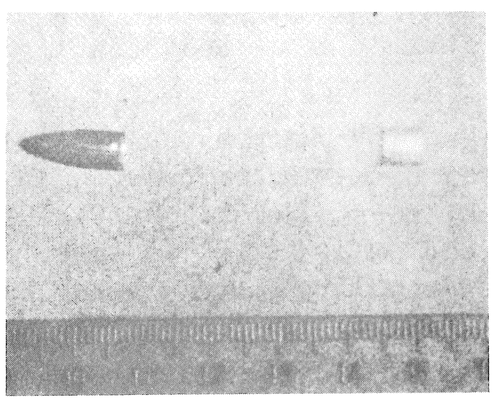
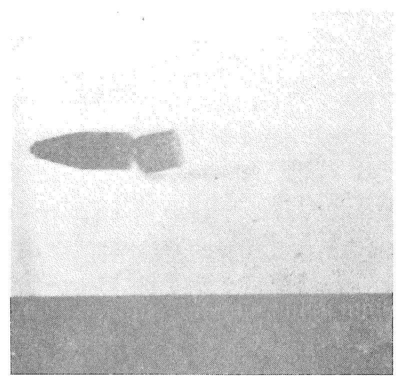


Figure 3 - Flight Characteristics of Duplex Rounds

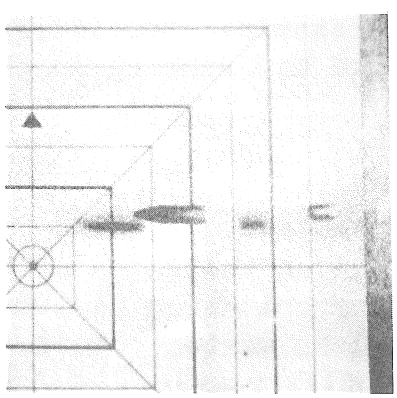
(a)



(b)



(c)



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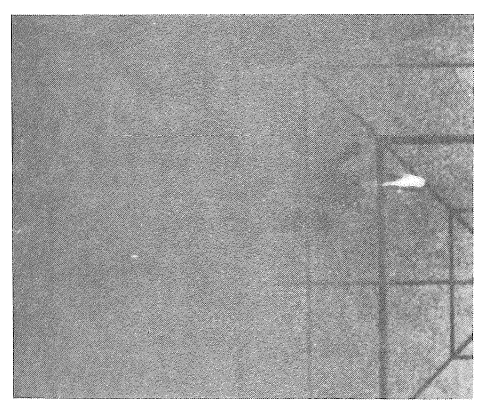

Figure 4 - Examples of Anomalous Flight Behavior

V. INTERIOR IMPACT FROM DUPLEX ROUND

Impacts were made with the duplex round into a homogeneous lead block target having a 90 mm by 90 mm target surface, and ranging from 90 mm to 120 mm deep. This target may be considered as semi-infinite for the present case, because no permanent deformation was observed on the outside surfaces. A 25.4 mm deep, 7.94 mm (5/16 inch) diameter hole was drilled into the target. The projectiles from the duplex round entered this hole sequentially and impacted at the bottom of the hole. These tests were run to study occlusion of the entrance after the impact of the leading projectile and total penetration depth due to both projectiles.

Figures 5 to 10 and 12 are photographs of lead target blocks, cut open after impact. The specimen in Figure 5 was subjected to a single projectile impact. The projectile mass was 2.2 gm, and had an impact velocity of 1060 m/sec; these values are the same as those of the leading projectile of subsequent duplex shots. Thus the cavity in Figure 5 may be used for comparison with subsequent cavities due to multiple impacts. Note that the cavity is approximately spherical, and the penetration (measured from the bottom of the pre-drilled hole to the bottom of the cavity) is 25 mm.

Figures 6 to 10 show cavities caused by duplex round impacts, with increasing spacing between projectiles. The cavity in Figure 6 resulted from projectiles with no spacing in between, equivalent to a single, long projectile. As expected, the cavity is elongated in shape, with a penetration (measured from the bottom of the pre-drilled hole) of 37 mm. This indicates that the trailing projectile probably entered without hindrance; there was no time for the entrance to close up after the impact from the leading projectile.

Figure 7 is a cavity resulting from a duplex round impact with an estimated time between impacts of 10 μsec, which corresponds to a spacing between projectiles of approximately 11 mm. The cavity is beginning to separate into three distinct chambers. The center chamber is the chamber created by the leading projectile, as evidenced by comparing to Figure 5. After the impact of the leading projectile, the "passage" is partially closed due to the plastic flow of the target material. The trailing projectile first impacts at this narrowed neck, "consuming" part of its mass and kinetic energy. This impact creates a front chamber in the target. The remainder of the trailing projectile reaches the bottom of center chamber and creates a third chamber in the back. In this figure, the front chamber is quite small, indicating very little occlusion. The back chamber is almost full-size. Penetration is approximately 42 mm.

In Figure 8, a duplex impact with an estimated time of 35 μsec between impacts (37 mm) is shown. The front chamber is larger than that of Figure 7, indicating greater occlusion effect from the leading projectile, and the back chamber is smaller. Penetration is reduced to 35 mm.

This trend is continued in Figure 9. Time is about 82 μsec between impacts (87 mm). The front chamber is larger than previous ones (greater occlusion effect), and the back chamber is smaller. The penetration is 29 mm.

Figure 10 shows a "duplex round" with several minutes between projectiles (actually two separate shots of appropriate masses and velocities). The cavity in this test does not follow the established pattern, but rather has a small front chamber and a large back chamber, with penetration of 43 mm.

In view of this reversed trend, one additional identical experiment was conducted; the results indicate that the behavior in Figure 10 is repeatable. The results in Figures 5, 7, and 8, were also duplicated by the execution of one additional test each. Repeatability was assumed to exist for Figures 6 and 9. The conclusion drawn was that maximum occlusion does not occur with infinite spacing, but rather at some intermediate point. Subsequent attempts were made to determine this point using duplex rounds with spacing larger than 82 μsec; the tests were not successful.

The results of this series of tests are summarized in Fig. 11 as a curve of a total penetration versus time between impacts. Note that among the five tests the total penetration is minimum at 82 μsec, which is 31% less than the maximum penetration at 10 μsec. It could not be ascertained whether the total penetration has reached an absolute minimum at 82 μsec if additional test results with longer than 82 μsec between impacts were available. It is also interesting to note that maximum penetration does not occur with two projectiles in contact with each other (zero time in between), but rather during the 10 μsec case. From this, it may be speculated that a continuous rod may not necessarily produce the deepest penetration; a properly spaced series of projectiles may be most effective.

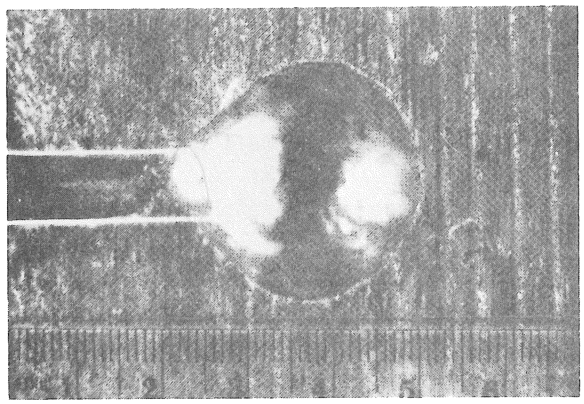

Figure 5 - An Impact Cavity from the Leading Prljectile Only. Projectile Mass = 2.2 gm. Penetration Depth = 25 mm from the Bottom of the Pre-Drilled Hole. Velocity = 1060 m/sec ± 40 m/sec (Standard for Figures 4 through 9). White Overlay shows Original Dimensions of the Pre-Drilled Hole.

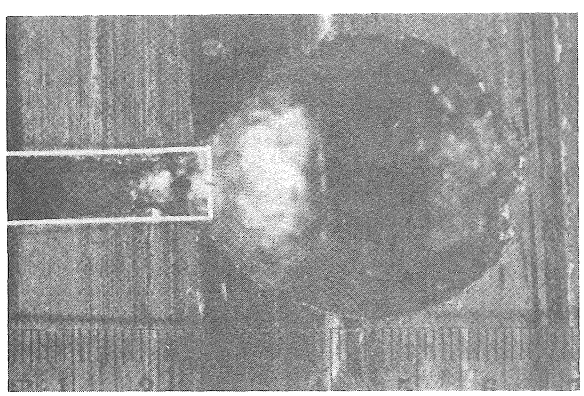

Figure 6 - A Cavity Due to Impact by a Duplex Round with Zero μsec Between Impacts. Leading Projectile Mass = 2.1 gm. Trailing Projectile Mass = 2.8 gm. Penetration Depth = 37 mm. Note Elongated Cavity Shape Compared to Figure 4.

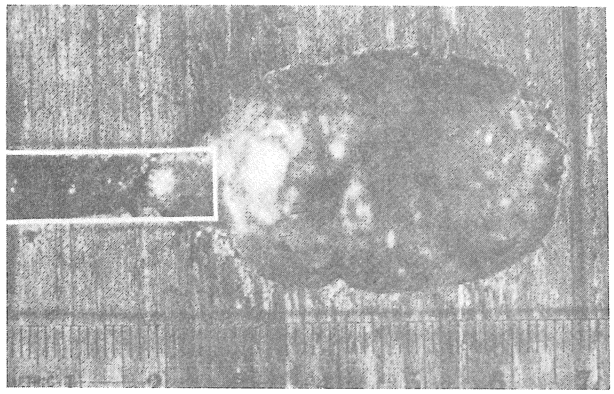

Figure 7 - A Cavity Due to Impact by a Duplex Round with 10 μsec Between Impacts (11 mm Spacing). Projectile Masses are the same as in Figure 5 (Standard for Figures 5 through 9). Hole Diameter in the Trailing Projectile is 0.33 mm. Penetration = 42 mm. Note Three Chambers Beginning to Form.

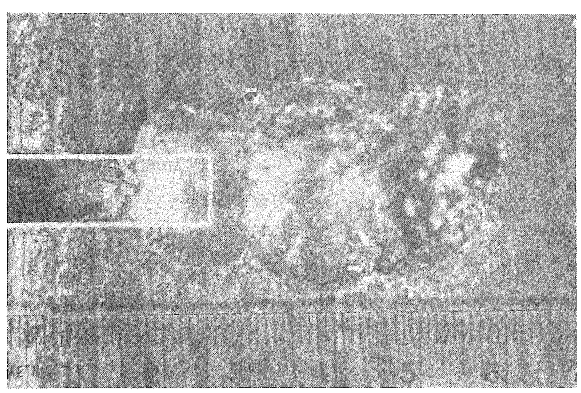

Figure 8 - A Cavity Due to Impact by a Duplex Round with 35 μsec Between Impacts (37 mm). Penetration = 35 mm. Hole Diameter in the Trailing Projectile is 0.51 mm. Note Enlargement of Front Chamber and Shrinkage of Back Chamber.

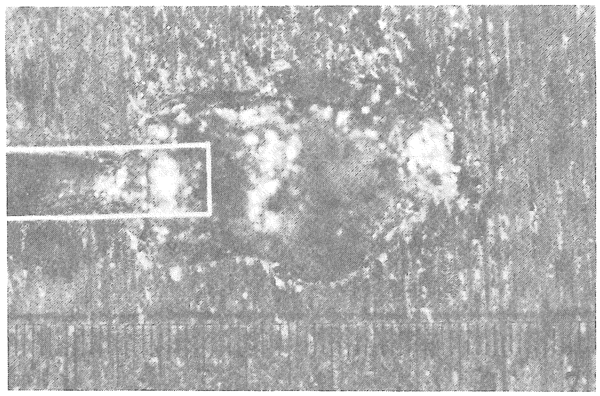

Figure 9 - A Cavity Due to Impact by a Duplex Round with 82 μsec (87 mm) Between Impacts. Penetration = 29 mm, Minimum Among all Multiple Impacts. Hole Diameter in the Trailing Projectile is 0.79 mm. The Front Chamber Continues to Grow; Back Chamber is Smaller.

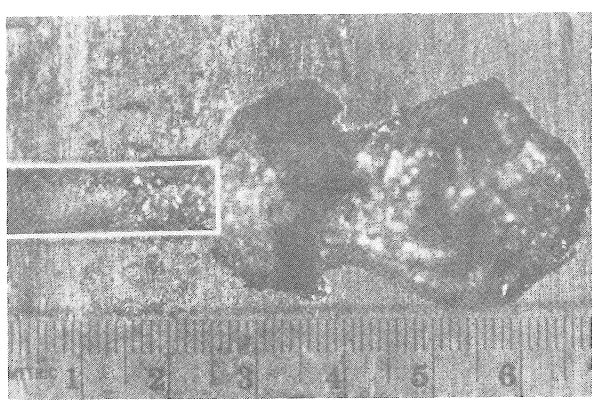

Figure 10 - A Cavity Due to Multiple Impacts with Several Minutes Separation. Penetration = 43 mm. The Front Chamber is Quite Small; Back Chamber is Large.

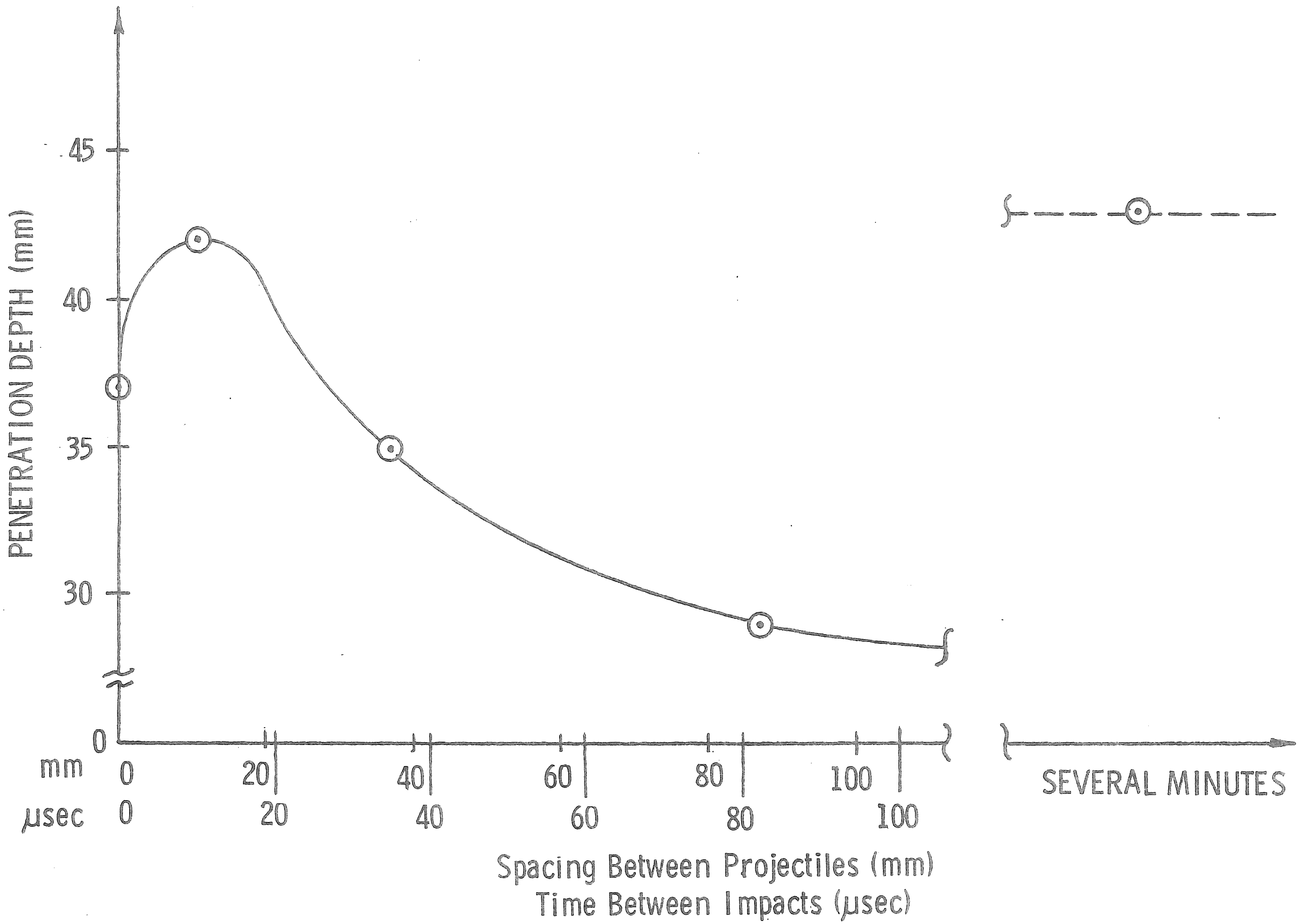

Figure 11 - Penetration Depth Versus Time Between Impacts.

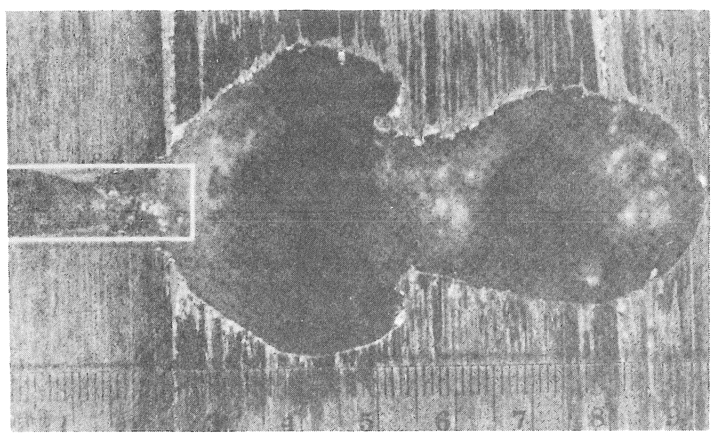

Figure 12 - A Cavity Due to Multiple Impacts with Several Minutes Between Impacts. Leading Projectile Mass = 6.47 gm. Trailing Projectile Mass = 2.91 gm. Front Chamber is Almost Non-Existent. Penetration = 67 mm.

Four additonal sets of duplex rounds were manufactured with varying mass ratio of trailing projectile to leading projectile (T:L). Each set consisted of four individual tests with varying time tetween impacts. Table I summarizes the duplex round geometry for each set. Table II summarizes the test matrix and results. The earlier data set [2] is included. Cavity configuration is given as depth of each of three possible chambers ($d_1:d_2:d_3$), where 1, 2, and 3 refer to outermost, center and innermost chambers.

Table I

Duplex Round Geometries

Projectile Mass (gm)		Mass Ratio (T:L)
T	3.4	2.43:1
L	1.4	
* T	2.8	1.34:1
L	2.1	
T	2.1	0.75:1
L	2.8	
T	1.5	0.535:1
L	2.8	
T	1.5	0.429:1
L	3.5	

* Original test configuration [2]

The results of these tests support the earlier conclusions. Total penetration depths are lowest for duplex rounds when times between impacts are in the 30-100 μsec range. This is consistent for all mass ratios tested. Only the third test in the last set (0.429:1) is in variance. The original test data (1.34:1) and the reversed configuration (0.75:1) indicate maximum penetration occurs for very short intervals between projectiles, 10 and 23 μsec.

respectively. Additionally, cavity volume is consistently seen to be significantly reduced as the interval between impacts increases. The volume of the pre-drilled hole has been subtracted out. The configuration is the familar [2] three-chambered cavity. The dimensions are noted in Table II.

It seems reasonable to conclude that the interval between impacts significantly influences penetration, cavity shape and volume. The material flow process which results in occlusion behind the first projectile is thought to be the mechanism.

Table II

Duplex Round Parametric Study

Total Projectile Mass (gm)	Mass Ratio (T:L)	Time Between Impacts (μsec)	Penetration Depth (mm)	Total Cavity Length (mm)	Cavity Configuration ($d_1:d_2:d_3$)	Cavity Volume (mℓ)
4.8	2.43:1	0	37.5	43.0	nearly spherical	22.5
4.8	2.43:1	30	33.0	43.0	19:22:2	14.2
4.8	2.43:1	45	28.6	42.8	21:11:11	12.3
4.8	**2.36:1	100	31.0	41.2	14:12:15	8.5
* 4.9	1.34:1	0	37	40	nearly spherical	
4.9	1.34:1	10	42	43	15:25:1	
4.9	1:34:1	35	35	45	14:18:13	not measured
4.9	1.34:1	82	29	40	15:12:13	
4.9	1.34:1	several minutes	43	44	12:10:22	
4.9	0.75:1	0	39.5	44.1	nearly spherical	23.4
4.9	0.75:1	23	42.0	50.0	12:25:13	21.4
4.9	0.75:1	40	36.0	50.0	17:16:17	17.2
4.8	**0.715:1	103	34.0	48.0	17:21:10	14.6
4.3	0.535:1	0	38.0	47.0	8:34:5	23.2
4.3	0.535:1	20	34.5	45.5	13:27:5	16.7
4.3	0.535:1	40	34.5	50.2	16:23:11	18.9
4.2	**0.50:1	75	31.0	46.5	16:23:8	14.2
5.0	0.429:1	0	37.0	43.5	nearly spherical	23.6
5.0	0.429:1	30	35.5	44.5	10:25:9	20.1
5.0	0.429:1	40	39.5	52.0	12:30:10	19.4
4.9	**0.40:1	65	34.5	48.0	14:29:5	17.5

* Original Test [2]
** Trailing projectile mass was not compensated for a larger hole diameter.

VI. CAVITY FORMATION BY LEADING AND TRAILING PROJECTILES

Figure 5 shows the cavity formed by a single projectile with a mass of 2.2 gm. This was compared to the cavities of the duplex round study. It was tentatively concluded that the leading projectile forms the center cavity and the trailing projectile forms the inner and outermost chambers. An experimental procedure was developed to prove or disprove this conclusion.

Several schemes were considered to accomplish this "coding" of the cavity formation. From a study of different target materials, tin was known to flow reasonably well at the pressures encountered in these impacts. A tin projectile was manufactured by melting the lead from a standard copper jacketed projectile and refilling with molten tin. A duplex round configuration was set up with leading tin and trailing lead projectiles and fired into a standard lead target. The target was carefully sectioned by cutting to expose the cavity surface. Without disclosure of the anticipated results, the specimen was given to Drexel Materials Department personnel for study. A scanning electron microscope, SEM, microprobe survey was conducted to disclose the material types present on the cavity surface. Figure 13 shows the specimen and indicates the survey areas. The elements present are listed in Table III. Copper was also present as discrete lumps but the probe was directed away from them.

Table III

Microprobe Survey of Cavity Surface

Region	Elements Detected
3F	Pb, Sn, Aℓ, Fe
3B	Pb, Sn, Aℓ, Fe
4	Pb, Sn, Aℓ, Fe
5	Pb, Aℓ, Fe
6	Pb, Aℓ, Fe
7	Pb, Aℓ, Fe
8	Pb, Sn, Aℓ, Fe

It is seen in Figure 13 that the forward chamber is not well developed while the center and back chambers are distinct. From Figure 13 and Table III, it is seen that tin is not present on the back chamber surface, areas 5,6, and 7, but can be found on the center chamber surface, area 3b and 4, and in the region of the occlusive behind the leading projectile, area 8. This data supports the original conclusion [2] that the center chamber is formed by the leading projectile and the back chamber by the trailing projectile. The traces of iron and aluminum are contaminants in the recycled lead targets.

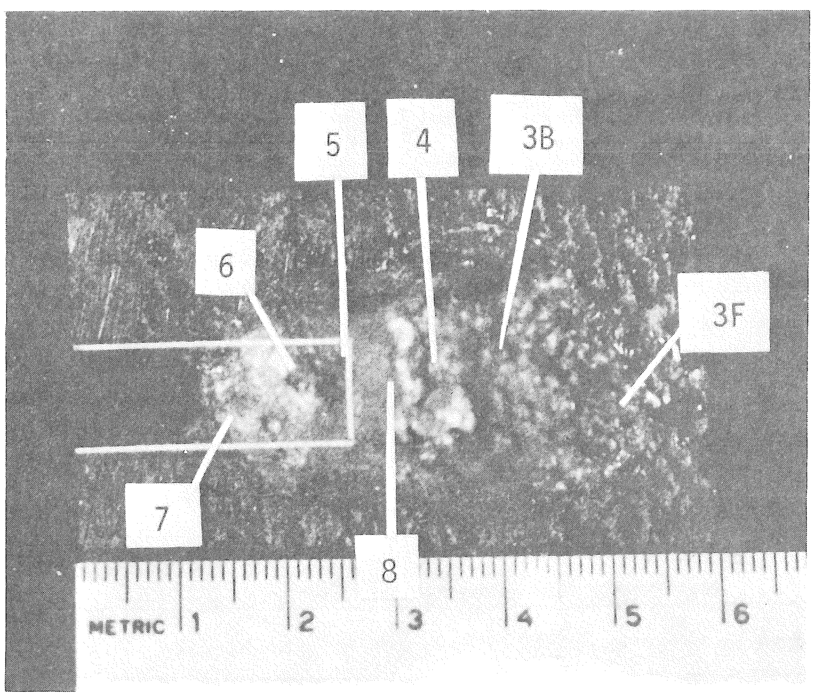

Figure 13 - Target Cavity Surveyed by Scanning Electron Microscope Microprobe

VII. CONCLUDING REMARKS

1. The impact of low-velocity projectiles into soft targets results in plastic flow and cavities similar to those obtained in high-velocity impact of hard targets. Rifle-propelled projectile impacts on soft targets may yield useful information for high-speed hard target impacts.

2. The duplex round developed here is satisfactory for creating multiple impacts with short time interval (order of microseconds) between impacts. The projectiles exhibit acceptable flight characteristics for interior impact into pre-drilled holes in the targets.

3. The leading projectile creates an occlusion which hinders the entrance of the trailing projectile and reduces total penetration. The effect of the occlusion is negligible for nearly simultaneous projectiles (less than 10 μsec between impacts) and greatest with about 80 to 100 μsec between impacts.

4. Additional information concerning temperature measurement, targets of different materials and cavity volume versus projectile energy for single projectile interior impact can be found in reference 3.

VIII. REFERENCES

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