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FINAL REPORT

FC

13 September 1956

DEVELOPMENT OF TWO "SALVO" ANTI-PERSONNEL WEAPONS

Contract No. DA-23-072-ORD-959
Ordnance Project No. TS1-2

M.R.I. Project No. 710-E-65

Frankford Arsenal
Pitman-Dunn Laboratories
Philadelphia 37, Pennsylvania

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MIDWEST RESEARCH INSTITUTE

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M I D W E S T   R E S E A R C H   I N S T I T U T E

ENGINEERING DIVISION

FINAL REPORT

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Prepared for

Frankford Arsenal
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FOREWORD

This report contains a compilation of the research and development work which Midwest Research Institute performed on two "salvo" anti-personnel weapons under Army Ordnance Contract No. DA-23-072-ORD-959. The activities covered by this contract are a continuation of salvo weapon studies conducted for the Office of the Chief of Ordnance under previous contracts. Technical supervision of the program has been the responsibility of Frankford Arsenal.

The immediate contract covered the development of two salvo anti-personnel weapons and their associated ammunition. One of these weapons is a 22 caliber "squirt" gun, firing a number of spin-stabilized projectiles at high rates of fire. The other weapon is a shotgun type, firing a number of fin-stabilized projectiles in a cluster from a single cartridge.

During the course of the contract, covering the period 14 December 1955 to 13 August 1956, seven monthly progress reports were issued. Additional details of the program's developments are contained in these previously issued reports. This final report contains a summary of the activities performed throughout the program and is divided into three sections: (1) the 22 caliber squirt gun section; (2) the dart gun section; and (3) the probability of hit section.

ABSTRACT

During the period of the contract, research and development were conducted on two salvo weapon systems. One of the salvo weapons was a 22 caliber, employing squirt gun principles in a shoulder-fired rifle. This weapon fires a number of spin-stabilized projectiles, from a single cartridge, at high rates of fire. The other salvo weapon was a shotgun type firing clusters of fin-stabilized projectiles. Both of the weapons were intended for anti-personnel use, and were: (1) to be effective against personnel at ranges up to 300 yd. and (2) to provide a higher probability of incapacitation than conventional, single-projectile weapons.

Experimental work with the 22 caliber squirt gun was directed toward improvement of the ballistic cycle and design of a complete cartridge and prototype weapon. The cartridge evolved has an average projectile velocity of 2,550 fps at 50,000 psi chamber pressure, and an average firing rate of 80,000 projectiles per minute. The average pattern, at 100 yd. has a horizontal standard deviation of 1.98 mils and a vertical standard deviation of 1.15 mils. The prototype weapon is a bolt-action, box-magazine rifle of conventional design.

Experimental work with the miltiple-projectile dart weapon was directed toward the development of finished cartridges that could be fired in standard, cylinder-bore, 12-gauge shotguns. Seven different types of darts were included in the test firing, and at least two of the resulting round types exhibited satisfactory patterns. Rounds loaded with 10 darts per cluster of 14-grain darts had an average pattern mean radius of 5.74 mils. Rounds loaded with 19 darts per cluster of 9-grain darts had an average pattern mean radius of 7.77 mils. Rounds represented by these average figures are completely closed and sealed cartridges.

I. 22 CALIBER SQUIRT GUN

A. Introduction

The objectives for this phase of the contract were the development of a cartridge to fire a number of 22 caliber, spin-stabilized projectiles at high rates of fire, as well as the design and manufacture of a prototype rifle for the cartridge. The weapon system was to employ the basic ballistic cycle originally developed for the 20 mm squirt gun. Requirements specified for the weapon system were: (1) to be shoulder-fired; (2) to contain a minimum of two projectiles per cartridge; (3) to have a minimum firing rate of 10,000 projectiles per minute; (4) to have a muzzle velocity of approximately 4,000 fps; (5) to produce a pattern at 300 yd. no greater than a 40 in. diameter circle; and (6) to fire projectiles weighing approximately 50 grains each.

Major emphasis has been placed on the development of a complete cartridge based on the 20 mm M21A1 case. Developmental work carried out under previous contracts for similar studies had utilized a modified 60 caliber case for the cartridge; however, the weight and bulk of a prototype weapon for the 60 caliber case were excessive. The choice of the 20 mm M21A1 case was dictated by the desire to duplicate, as nearly as possible, the chamber volume of the modified 60 caliber case; thereby avoiding the problems associated with designing a completely new system.

The cartridge developed for the 22 caliber squirt gun does not meet all the requirements set forth at the beginning of the study, but does represent the best attainable within the time available under this contract. Results of the developmental work and prototype weapon design, as well as conclusions and recommendations, are set forth in the subsequent sections of this report.

B. Test Weapon and Test Procedure

The test weapon used throughout the contract period for development of the 22 caliber squirt gun is shown in Fig. 1. The breech block is a universal, mechanical firing head, widely employed for pressure gun work by various agencies. The chamber section is separate from the barrel to allow greater flexibility in the test weapon. The barrel proper is a commercial heavy-walled 22 caliber barrel with the rifling pitched one turn in 14 in. The chamber and the barrel are tapped for piezo gauge holders to allow recording of the pressure-time histories during the interior ballistic cycle.

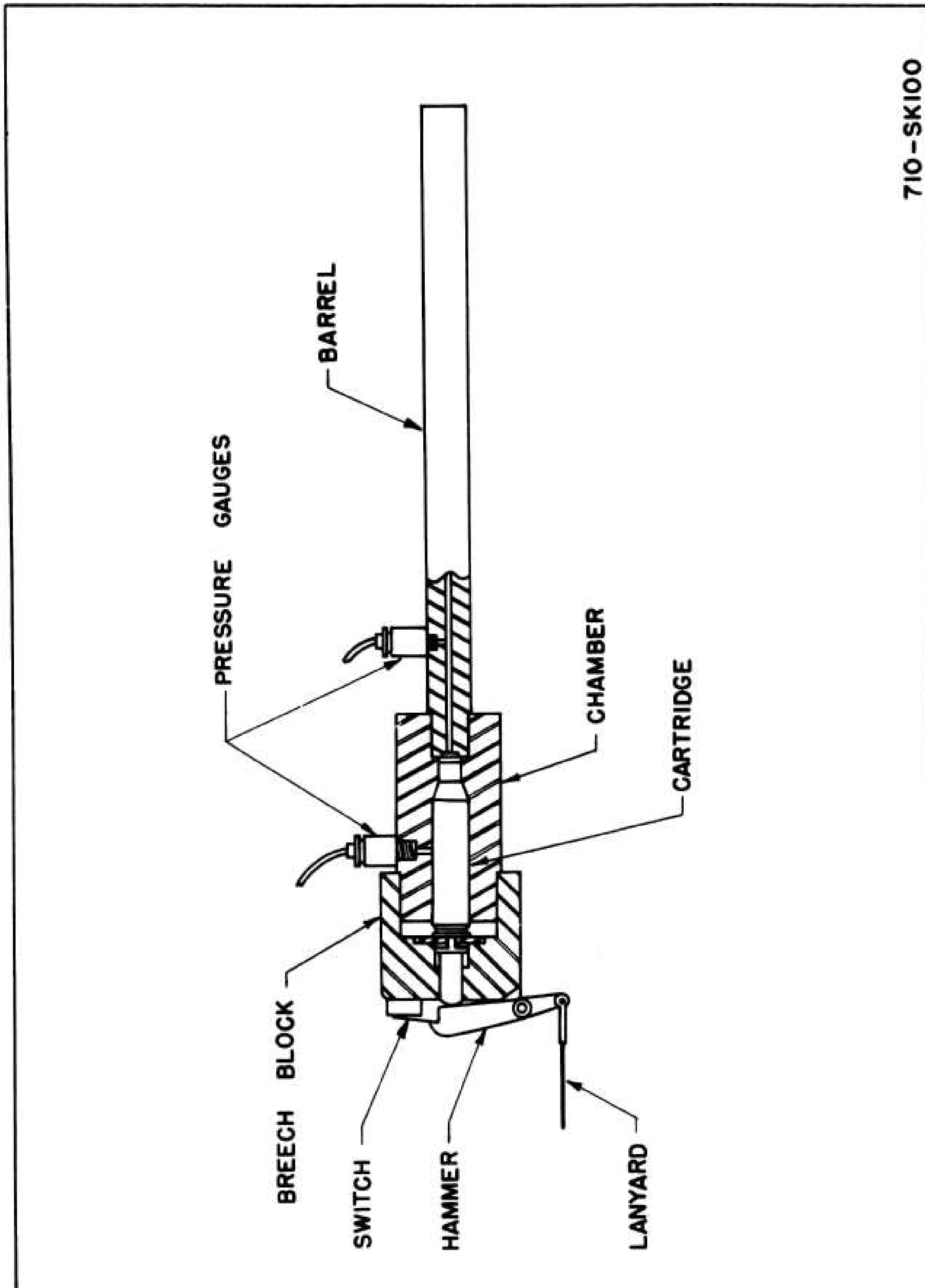

Fig. 1 - Schematic Diagram of 22 Caliber Test Squirt Gun

A "make" switch was mounted on the rear face of the breech block in such a position as to complete the instrument triggering circuit simultaneously with the striking of the firing pin.

The test weapon was clamped to a rigid mount for all firing tests. Firing was accomplished from a remote point by the use of a long rope lanyard attached to the rear crank on the test weapon.

Individual projectile velocity was measured by recording the output signal of two Lumiline screens on a drum camera coincident with a reference timing mark produced by a precision frequency standard generator. The distance between screens, divided by the time for a projectile to pass the screens, will give an average velocity for the interval with sufficient accuracy to satisfy the requirements of this program.

Target pattern data were obtained by placing a cardboard target 295 ft. from the muzzle of the test weapon. When desired, the patterns were analyzed by mathematical procedures for standard deviation in horizontal and vertical directions, and standard deviation of salvo centers of impact.

C. Cartridge Development

The basic design of the 22 caliber squirt gun cartridge, shown in Fig. 2, remained the same throughout the contract period. Minor variations were incorporated into this basic design in an attempt to increase over-all performance, reduce firing rate and control pattern spread.

The major difficulties encountered in cartridge development were control of the firing rate (time between ejection of succeeding projectiles) and control of individual projectile velocity. All firing tests were conducted at pressure levels comparable to the maximum allowable for the system. Attempts to conduct investigations at reduced pressure levels for safety of operation were unsuccessful. A propellent charge that would operate succussfully at one pressure level would not perform in a predictable manner when the pressure level was increased.

Index hole size for the final cartridge design is 0.035 in. diameter, and gas port size is 0.125 in. diameter. This combination results in an average firing rate between 66,000 and 86,000 bullets per minute. Several different index hole sizes and combinations of sizes were tested, in an effort to control the time between ejections of individual projectiles. Variations of the basic pattern did not produce satisfactory results. In all cases the average firing rate was increased, and in most cases there was in-flight interference between projectiles.

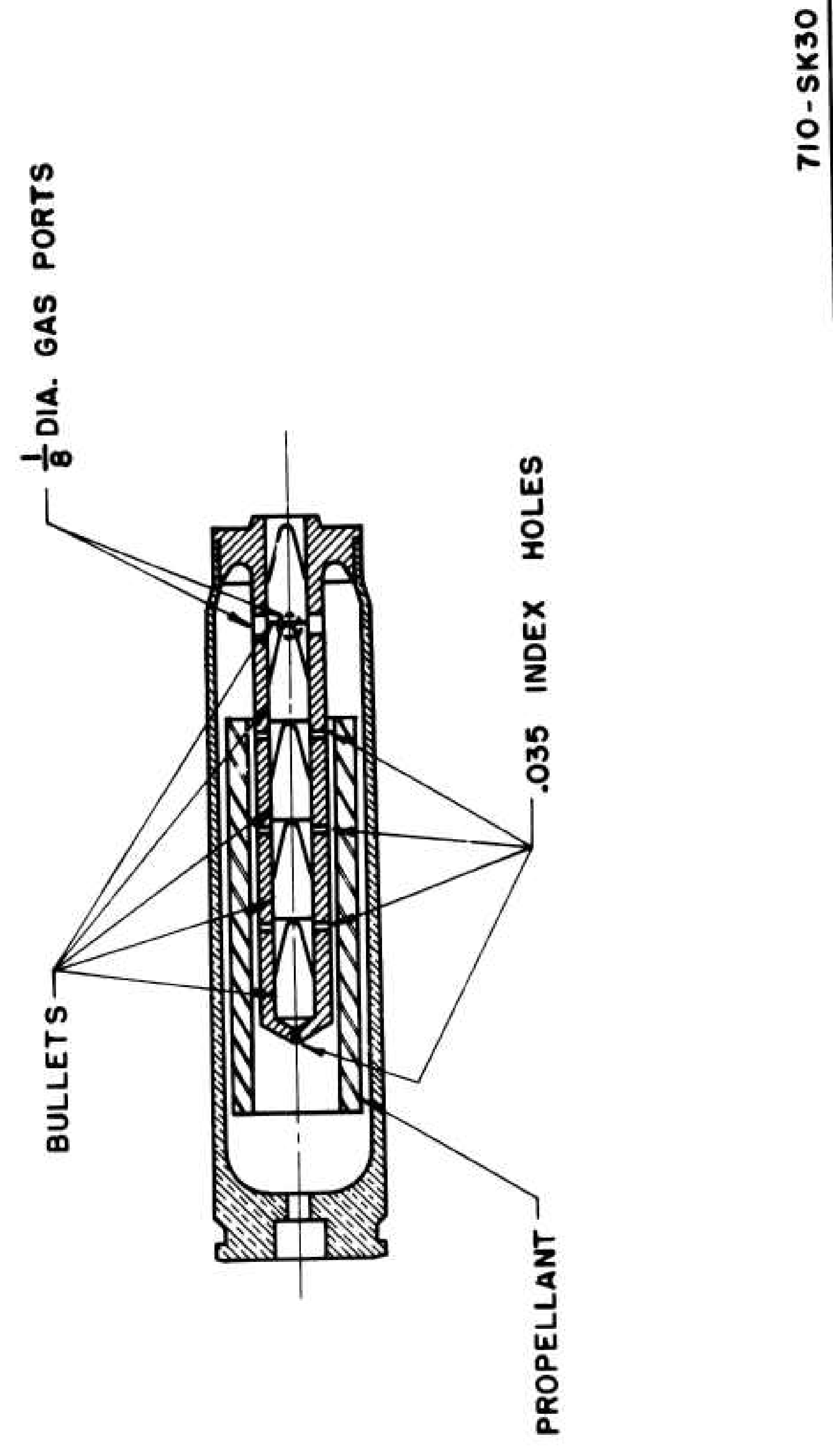

Fig. 2 - Schematic of 22 Caliber Squirt Gun Round

The final cartridge design is as follows:

Case	20 mm M21A1
Primer	Percussion
Magazine	In-line, steel 0.035 index holes (4) 0.125 gas ports (4)
Projectiles	Solid brass 39 grains each
Ignition propellant	7.50 grams PC 202, 0.0135 web
Stick propellant	11.35 grams HES 5193.6B single-perforated Cylindrical 0.75 x 0.56 x 2.35

Average performance of this cartridge should be as follows:

Maximum chamber pressure	50,000 psi
Average projectile velocity	2,550 fps
Average firing rate	80,000 bullets/minute
Pattern horizontal standard deviation	1.98 mils
Pattern vertical standard deviation	1.15 mils

The performance of this cartridge does not meet the desired average projectile velocity of 4,000 fps specified at the beginning of the study, but it does represent the best average velocity obtainable within the limit of 50,000 psi maximum chamber pressure. Evaluation of the pattern's adequacy must await further investigation into the determination of the probability of hit for salvo weapons.

D. Ballistics

The major effort during this phase of the project was directed toward improvement of the ballistic cycle of the 22 caliber squirt gun. Basically the objectives were to attain as high an average muzzle velocity as possible, consistent with reasonable pressure levels and firing rates. In order to achieve the desired objectives several characteristics of the system must be balanced properly as well as simultaneously.

The basic ballistic cycle of the squirt gun is more complex than an ordinary single projectile system. The operation of the squirt gun cycle may be described as follows: (1) the propellant is lighted by the primer and begins to build up pressure in the chamber; (2) the first projectile moves down the barrel toward the muzzle; (3) at some time, the pressure acting on the first projectile falls off enough so that the second projectile is pushed past the gas ports by pressure in the magazine, thus cutting off the supply of propellent gases behind the first projectile; and (4) the chamber pressure rises and the second projectile moves down the barrel. This process is repeated until all the projectiles are ejected. It may be seen from Fig. 3 that the second, third, fourth and fifth projectiles must move against the residual pressure in the barrel and thus cannot attain as high a velocity as the first projectile.

An ideal system would allow the gases behind one projectile to be evacuated from the barrel before the next projectile started down the barrel. Since this is not possible, the next alternative is to regulate the indexing of succeeding projectiles in some manner such that the opposing pressure acting on any projectile will be as low as possible. The method used to regulate indexing in the 22 caliber squirt gun depends upon proper sizing of the gas ports and index holes in the magazine, and upon tailoring the propellent charge to achieve a desirable rate of pressure rise, a desirable maximum chamber pressure and a suitable duration of maximum pressure. This has been accomplished by establishing the index hole size at 0.035 diameter, the gas port size at 0.125 diameter, and adjusting the propellent charge to achieve the desired interior ballistic cycle. The propellent charge evolved for the final cartridge design has the following characteristics: average rate of pressure rise 42,000,000 psi per sec.; maximum chamber pressure 50,000 psi; average duration of maximum pressure 1.0 millisec. The final cartridge design will have an average firing rate of 80,000 bullets per min. with an average projectile velocity of 2,550 fps.

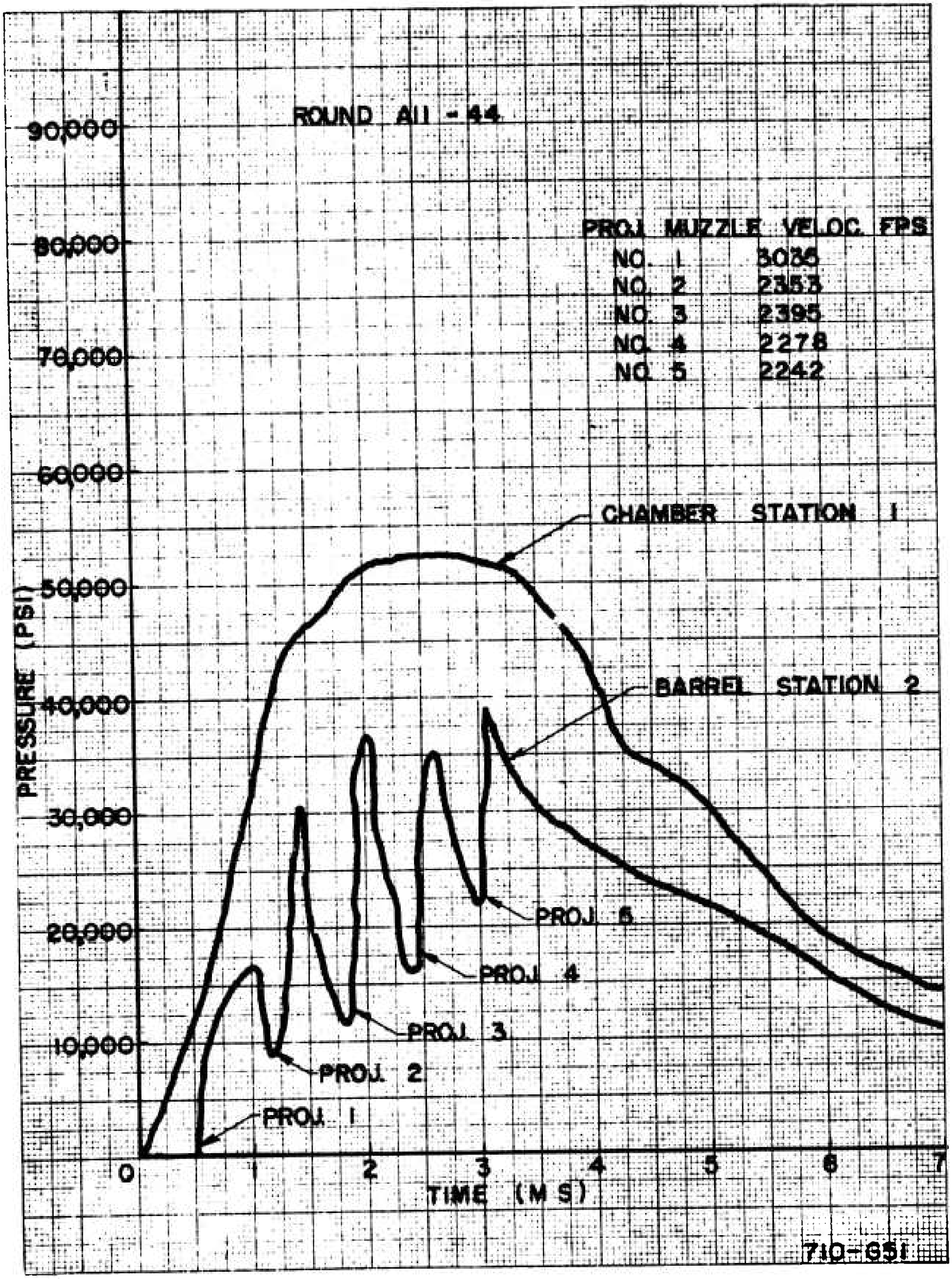

Fig. 3 - Graph of Pressure-Time Characteristic and Velocity of Round A11-44

E. Magazine Design

The magazine design for the 22 caliber squirt gun cartridge is shown in Fig. 4. The basic function of the magazine is to hold the projectiles in the cartridge and feed them into the barrel during the ballistic cycle. A secondary function is to seal the mouth of the cartridge case against gas leakage.

The gas port size and index hole size were established by experiments conducted during the course of a previous contract. The basic gas port size (0.125 diameter) and index hole size (0.035 diameter) were varied several times during the course of this contract, both separately and in combination, without any improvement of the ballistic cycle being accomplished. Changing index hole size and/or gas port size to either larger or smaller diameters always resulted in increased firing rate. In a majority of the tests, this increased firing rate was accompanied by in-flight interference between projectiles with consequent incomplete patterns and one or more "wild" projectiles.

The secondary function of the magazine, that of sealing the mouth of the cartridge case against gas leakage, was satisfactory for all rounds where the pressure in the chamber was above 40,000 psi. At lower chamber pressures, sealing was incomplete and leakage resulted. Since the cartridge is designed to operate at 50,000 psi chamber pressure, leakage should present no problem.

F. Propellants

A variety of propellants were employed in charge development studies conducted during the course of this contract. The ballistic requirements of the squirt gun system are such that the charge must be made up of two components, if conventional propellants are to be employed. The length of time required for a squirt gun ballistic cycle dictates the need for a thick-web propellant with little or no regressivity during burning. Thick-web propellants have low surface area per unit weight, and are more difficult to ignite than thin-web, high-surface-area propellants. The required combination then, is one where a small portion of the charge will be easily ignited and will rapidly evolve a large quantity of gases. These gases will, in turn, ignite the rest of the charge (composed of thick-web propellant) which will sustain the mass discharge rate of the charge to burnout.

With these conditions in mind, plus the desire to use single-base propellants entirely, if possible, the initial series of test cartridges were loaded with multi-perforation cannon propellants ignited by IMR 4895 rifle propellant.

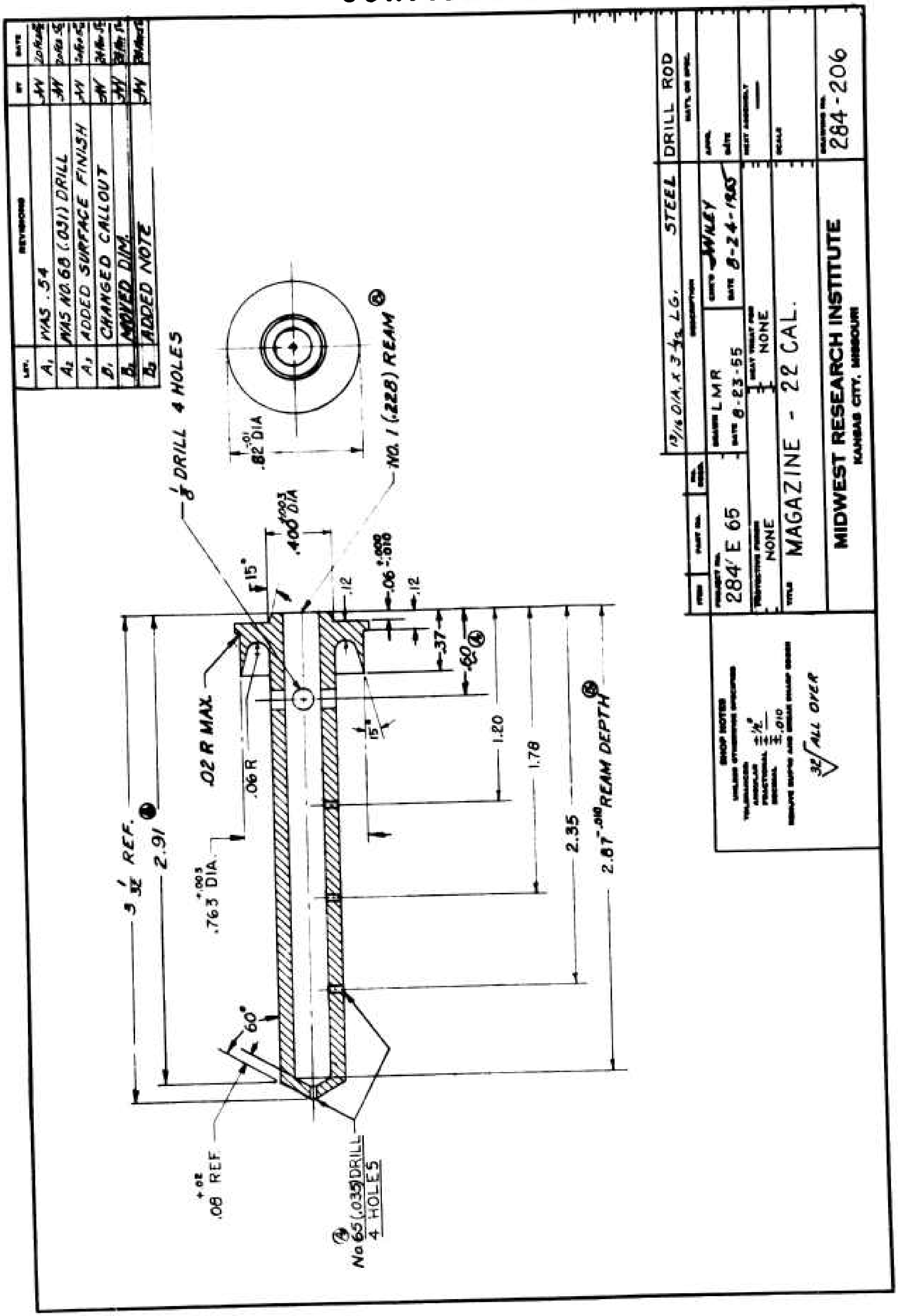

Fig. 4 - 22 Caliber Squirt Gun Magazine

The most satisfactory charge utilizing granular propellants was composed of 12 gm. of IND 33038 and 3 gm. of IMR 4895. Peak chamber pressue for this load was 48,750 psi, and average projectile velocity was 2,500 fps. The load did not produce consistent results; however, frequently the projectiles would index too rapidly, causing in-flight collision with resultant "blown" patterns. The inconsistency is attributable, in part, to variation in ignition of the main propellent charge. The variation in ignition then leads to variations in the rate of pressure rise and consequent irregular indexing of the projectiles.

Concurrent with the test firing of single-base, granular propellent charges, test firing of cartridges loaded with double-base, stick propellants was initiated. Following the determination of the maximum performance obtainable with available granular propellants, all test rounds were made up of double-base, stick propellants ignited by small-grain, granular propellants. Since the stick propellants available required machining before use, the possible variations in surface area and web thickness were almost unlimited. Additional flexibility of charge design was afforded by the variety of ignition propellants available. By proper choice of the type and weight of ignition propellant, and by adjustment of the stick-propellant surface area and web thickness, the pressure-time characteristic of the charge could be fitted to the interior ballistic requirements of the system.

Initial test work employed HES 5193.5 as the stick propellant and IMR 4895 as the ignition propellant for the majority of the rounds fired. Two rounds were fired with HES 5190.5 as the stick propellant, and three rounds were fired with HES 5130.3C as the stick propellant. Both HES 5130.3C and 5190.5 are slower burning propellants than HES 5193.5. Ignition was erratic for all five of the rounds, with the result that the pressure-time characteristics were entirely unsatisfactory.

Eight rounds were fired with PAE 16888 as the stick propellant. Results were satisfactory although the maximum pressure level (59,750 psi) was higher than the desired 50,000 psi. Tests with this propellant were discontinued because of short supply. The propellant is an experimental lot reworked to stick form from its original sheet form. Obtaining an additional supply would not have been possible within the time limits of the contract.

The propellant incorporated into the final cartridge design was received late in April 1956. This propellant, HES 5193.6B, was a new lot made to the same specifications as a previous lot that had been depleted. The composition of HES 5193.6B is essentially the same as the HES 5193.5 originally used for test firing.

Test firing eventually concentrated upon determining the type and quantity of ignition propellant required, and the initial surface area and web thickness for the stick propellant. Five different ignition propellants were used in the test firing. All of these were single-base, M10 composition, single-perforation propellants for small arms. The most suitable ignition propellant tested was PC 202 with an average web thickness of 0.0135 in. The finalized cartridge was loaded with 7.40 gm. of PC 202 for ignition propellant, and a stick of HES 5193.6B with 9.95 sq. in. surface area and 0.105 web thickness. Total charge weight for the finalized cartridge is 20.10 gm. and loading density is 0.65.

G. Prototype Weapon

The prototype weapon designed for use with the 22 caliber squirt gun cartridge is a bolt-action magazine rifle, similar in design to ordinary Mauser type rifles. The prototype squirt gun rifle is considerably larger through the receiver and chamber section than any ordinary rifle, primarily because of the size of the 20 mm cartridge case employed for the squirt gun cartridge.

The rifle is designed for a maximum chamber pressure of 50,000 psi. By application of the gun design code, the actual value used in calculations for design pressure was 77,500 psi. The gun design code accounts for the permissible maximum individual pressure and for the normal increase in pressure caused by high temperature of the round.

The chamber, receiver and bolt of the rifle are made of alloy steel heat-treated to a minimum yield strength of 165,000 psi. Other parts of the rifle are made of various steels treated in such a manner as to develop the required characteristics for each part. The stock is made of laminated walnut for maximum strength.

Although the rifle has been designed for shoulder firing, it is bulky and heavy because of the large receiver. Any size reduction possible in the ultimate cartridge design, would result in a more compact weapon competitive with present infantry hand weapons for portability and ease of employment.

H. Conclusions

The following conclusions may be made relative to the 22 caliber squirt gun.

1. A shoulder-fired salvo weapon system employing squirt gun principles can be fabricated in 22 caliber.

2. The weight of the system will be considerably greater than present infantry shoulder weapons.

3. An average projectile velocity of 2,550 fps appears to be the maximum attainable within reasonable pressure limits for conventional propellants. Greater velocities may be obtained at the expense of higher pressures and a consequent increase in rifle weight.

4. The 22 caliber squirt gun will produce a satisfactory pattern at the target. Complete evaluation of the effectiveness of the pattern must await the development of a proper expression for salvo hit probability.

5. Barrel erosion is a problem with the 22 caliber squirt gun because of the long ballistic cycle. Hard chrome plating of the bore reduces erosion considerably.

I. Recommendations

The following recommendations are made for consideration in the future development of the 22 caliber squirt gun.

1. Determine effectiveness of the weapon system as compared to existing small arms infantry weapons.

2. Investigate the possibility of reducing the over-all size of the cartridge by employing special propellants.

3. Apply the squirt gun principle to a 25 caliber weapon, and compare results with existing infantry weapons.

4. Investigate the effect of reducing the number of projectiles from five to four or three on the over-all effectiveness of the system.

5. Investigate the possibility of applying the small caliber squirt gun cartridge to weapons other than the shoulder-fired infantry type.

II. MULTIPLE-PROJECTILE DART WEAPON

A. Introduction

This phase of the contract was concerned with the development of a shotgun type of salvo weapon to fire clusters of fin-stabilized projectiles simultaneously from a single cartridge. The weapon system is to be shoulder-fired, and is to be effective against personnel at ranges up to 300 yd. The weapon system should provide a higher probability of incapacitation than is afforded by conventional infantry weapons, when employed for tactical situations within its range of capabilities.

Work with the dart weapon under this contract was concentrated upon the development of satisfactory finished rounds. Two preceding contracts also included studies of the design of the darts, analysis of the aerodynamic interference between darts in a cluster and studies of the probability of hit for salvo type weapons. Studies of the lethal capabilities of the darts have been conducted by The Army Chemical Center, Edgewood, Maryland.

Firing tests conducted during this program were designed to measure the performance of various cartridge configurations and their individual components. Seven different types of darts were fired during the tests, and variations of individual components resulted in 53 individual round types. Some of this wide variation in round types is attributable to the scarcity of darts at various times during the program. The number of darts contained in a particular round was varied from 10 to 37 depending on the size of the darts and the geometry of loading. All firing has been done from 12-gauge, cylinder-bore shotguns. Most of the rounds were fired from a standard 12-gauge, Model 12, Winchester shotgun. When pressure-time histories were required, a heavy-wall test weapon was used.

A general description of a multiple-dart cartridge is as follows. The shell itself is an ordinary paper shot shell, identical with those used in commercial shotgun cartridges. Into this shell the propellant is loaded, followed by over-powder and cushioning wads properly compressed onto the propellant. The dart-sabot package is inserted into the shell and pressed firmly into place. A thin, frangible closure disk is placed on top of the sabot, the remaining length of shell is roll-crimped onto the closure disk, and the end of the cartridge is sealed by paraffin coating against moisture penetration. Each dart type and loading geometry requires a sabot tailored to the cluster which insures proper restraint and support of the darts during launching.

B. Test Facilities and Procedure

All test firing was conducted on an enclosed range operated by Midwest Research Institute and located at Sunflower Ordnance Works, DeSoto, Kansas. The range facility provides a maximum of 185 ft. from the muzzle of the test weapon to the face of the bunker. Test equipment and instrumentation employed for this program included the following items:

1. Counter chronographs for velocity measurement.

2. Dual beam oscilloscopes equipped with drum cameras for recording veolcity and pressure records.

3. Copper crusher gauges and piezoelectric crystal gauges for pressure measurement.

4. Lumiline screens, aluminum foil contact screens, and printed circuit contact screens for velocity measurement and shadowgraph photography.

5. Kraft paper targets (6 ft. by 6 ft.) for impact patterns.

6. Heavy-walled pressure gun for propellant tests and pressure measurement.

7. Winchester Model 12, 12-gauge shotgun mounted in a rigid mount for pattern testing.

Figure 5 is a photograph of the heavy-walled test weapon on a rigid mount as set up for firing tests. The Model 12 shotgun is fitted with a 4 X telescope to facilitate aiming.

Velocity measurements were made at 15 ft. from the muzzle for nearly all of the experimental rounds. Spark shadowgraphs of the clusters in flight were made whenever the performance of sabots, closure disks or clusters was being investigated. Target patterns were taken for all rounds and analyzed to provide a comparative measure of performance of the round designs. Charge development rounds were fired in the heavy-walled pressure gun. Pressure-time records were obtained with piezoelectric pressure gauges and drum cameras.

The dart-sabot package was simulated in form and weight by a plastic and steel slug. Otherwise, the rounds were loaded in the same manner as experimental dart rounds in order that the actual conditions of launching would be simulated as closely as possible.

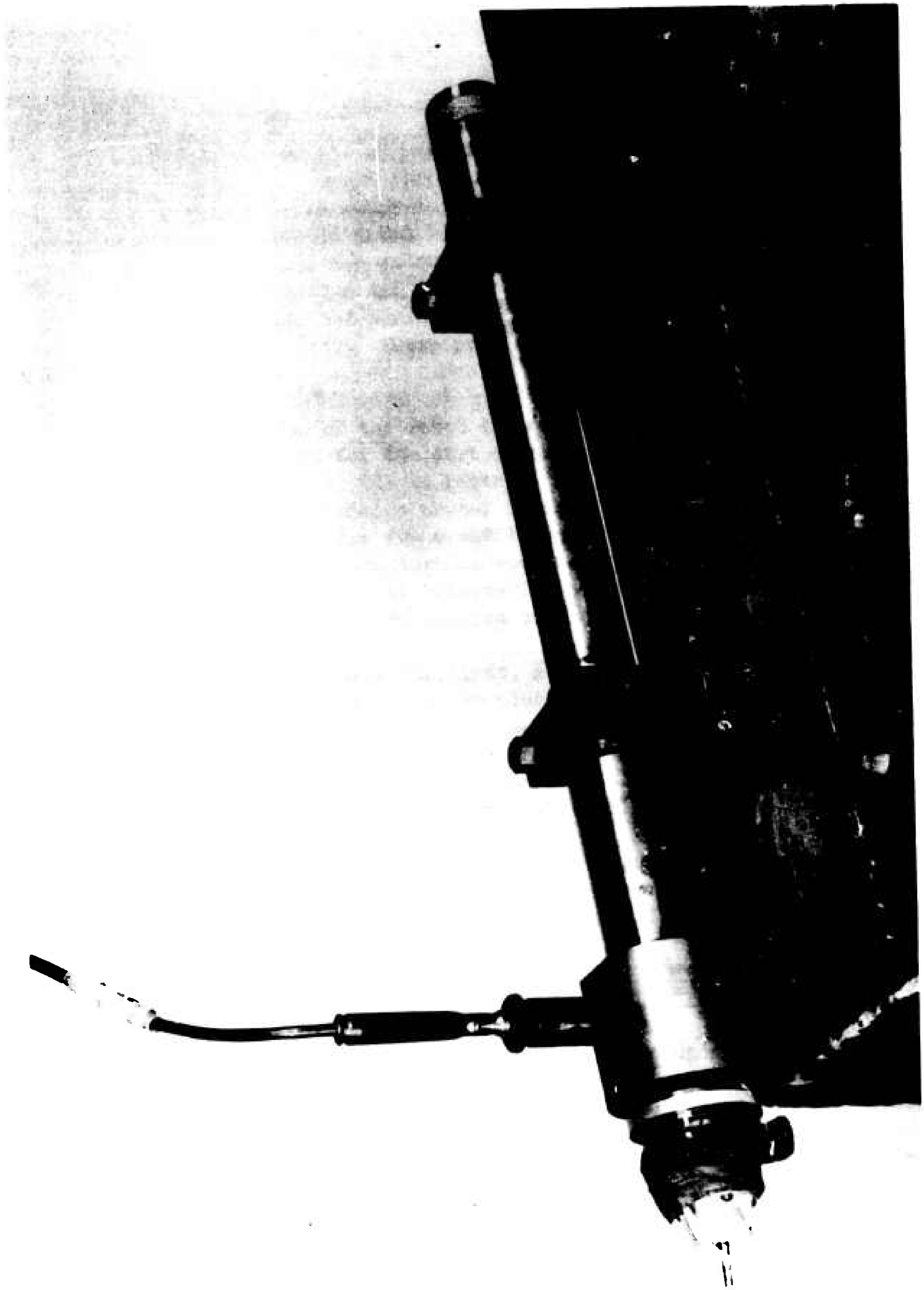

Fig. 5 - Heavy-Walled Test Shotgun as Set Up for Firing Tests

C. Experimental Dart Cartridge Tests

During the period of this contract, 226 experimental multi-dart cartridges were fired. Seven different types of darts were loaded into the experimental rounds. The basic objective of the firing tests was to develop the best possible finished round loaded with dart (fin-stabilized) projectiles. Several problems are encountered in attaining the objective. Among them are: (1) sabot design and performance, (2) dart design and performance, (3) closure disk design and performance, (4) geometry of the dart cluster, and (5) launching velocity. These problems are discussed individually in the subsequent paragraphs.

The functions of the sabot in a multi-dart cartridge are: (1) to provide adequate support for the dart cluster so that the darts are not damaged by setback forces; (2) to restrain the darts during barrel travel so that the dart cluster maintains proper orientation; (3) to contain the dart cluster in its original form for a sufficient length of time, after ejection from the muzzle, allowing the dart cluster to travel beyond the region of muzzle blast effect; and (4) to release the cluster for free flight without imparting undesirable yawing tendencies to the cluster.

To accomplish these functions, a cluster geometry is decided upon and the sabot is designed to hold the cluster in place. Means must be provided to remove the sabot after emergence from the barrel. This may be done by designing the sabot to upset from the cluster by reason of aerodynamic forces, or it may be done by providing an initial thrust to the sabot in the form of an internal spring. Sponge rubber rings and sectioned rubber O-rings have been used as the internal springs. The best sabot performance has been realized by incorporating the separate rubber rings into the package design as internal springs. Sabots were made that would separate from the cluster without internal springs but their over-all performance was unsatisfactory.

A typical sabot design is shown in Fig. 6. The base is machined concave to support the dart cluster in a conical form. The tapered wall at the fin end of the dart cluster supports the fin section of the darts. Constraint of the darts at the nose end is provided by the internal spring of rubber. The sabot sides extend slightly beyond the end of the dart cluster to support the closure disk, thus avoiding any initial disturbance of the cluster by fracturing the closure disk. The crimp on the mouth of the shell is forced out by the sabot sides as the sabot is accelerated into the barrel. The sabot is fitted closely to the inside diameter of the barrel so that a minimum of initial disturbance of the cluster will take place.

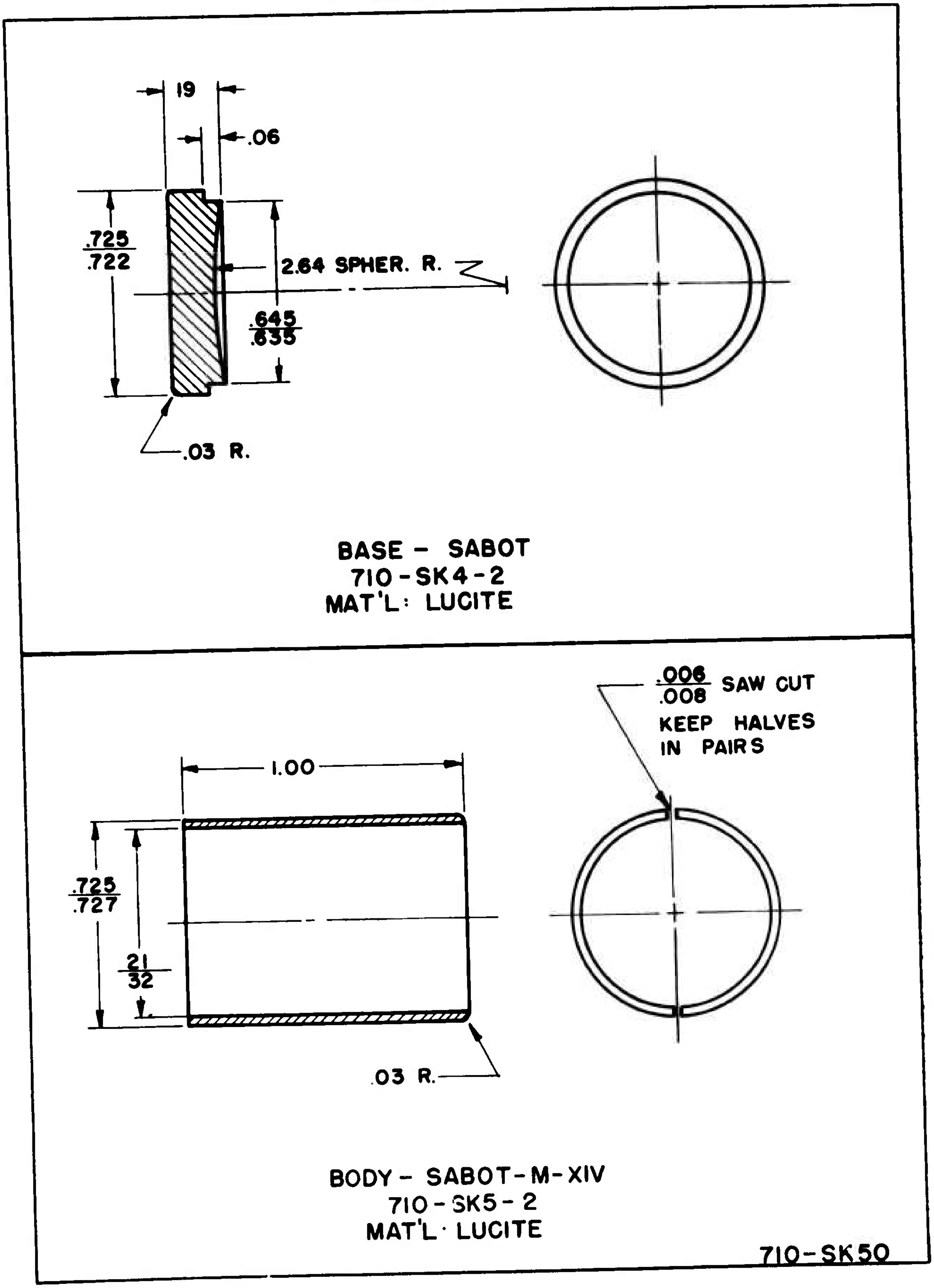

Fig. 6 - Sabot Parts for Round Type 8(II-E2)

The problems that must be met in the design of a dart (fin-stabilized projectile) for the salvo weapon are many and varied. The choice of values for many of the factors affecting the design are, of necessity, arbitrary. The design selected for experimental use by MRI was based upon the desire for maximum stability commensurate with the limits imposed by fitting the maximum number of projectiles within the bore of the weapon. This dart was expected to equal previous designs in terminal performance; however, such was not the case as subsequent tests proved. It should be noted, nevertheless, that design criteria for maximum terminal effectiveness did not exist at the time the dart was originally designed.

Three basic designs of darts are represented in the seven types utilized during this program. The MRI designed dart is shown in Fig. 7, and the three-finned Armour design dart is shown in Fig. 8. Performance data for these three types of darts are contained in subsequent sections of this report.

The basic functions of the closure disk are: (1) to seal the cartridge against moisture; (2) to protect the dart cluster during handling; and (3) to fracture under the action of the sabot, presenting as little disturbance as possible to the passage of the cluster. The requirements are diametrically opposed so that some point of compromise must be reached where satisfactory performance results. The results of tests of the various materials used for closure disks are contained in another section of this report.

The geometry of the dart cluster has an important bearing on the performance of a multi-dart cartridge. Certain configurations are stable and easily handled while others are sensitive to restraint and handling. Thus, the three-finned Armour dart stacks readily into a hexagonal pattern, which is easily retained in position, provided the bases are flat and square with the dart center line. The Aircraft Armaments dart with its offset, four-finned design, stacks into a neat, square package (see Fig. 9), and cannot be made to assume any other configuration. The MRI design, with four symmetrical fins, does not assume any stable pattern even though the points may be forced into either square or hexagonal patterns. Consequently, darts with four symmetrical fins must be restrained more rigidly in the sabot before launching occurs.

Launching velocity also affects the over-all performance of a multi-dart cartridge. The higher the muzzle velocity, the shorter the time of flight for a cluster. As a consequence, disturbing influences are acting for a shorter time and their total effect will be smaller. Also, the shock wave originating at the nose of each projectile will be of a smaller angle, and the time of influence (interference) with adjacent darts will be shorter,

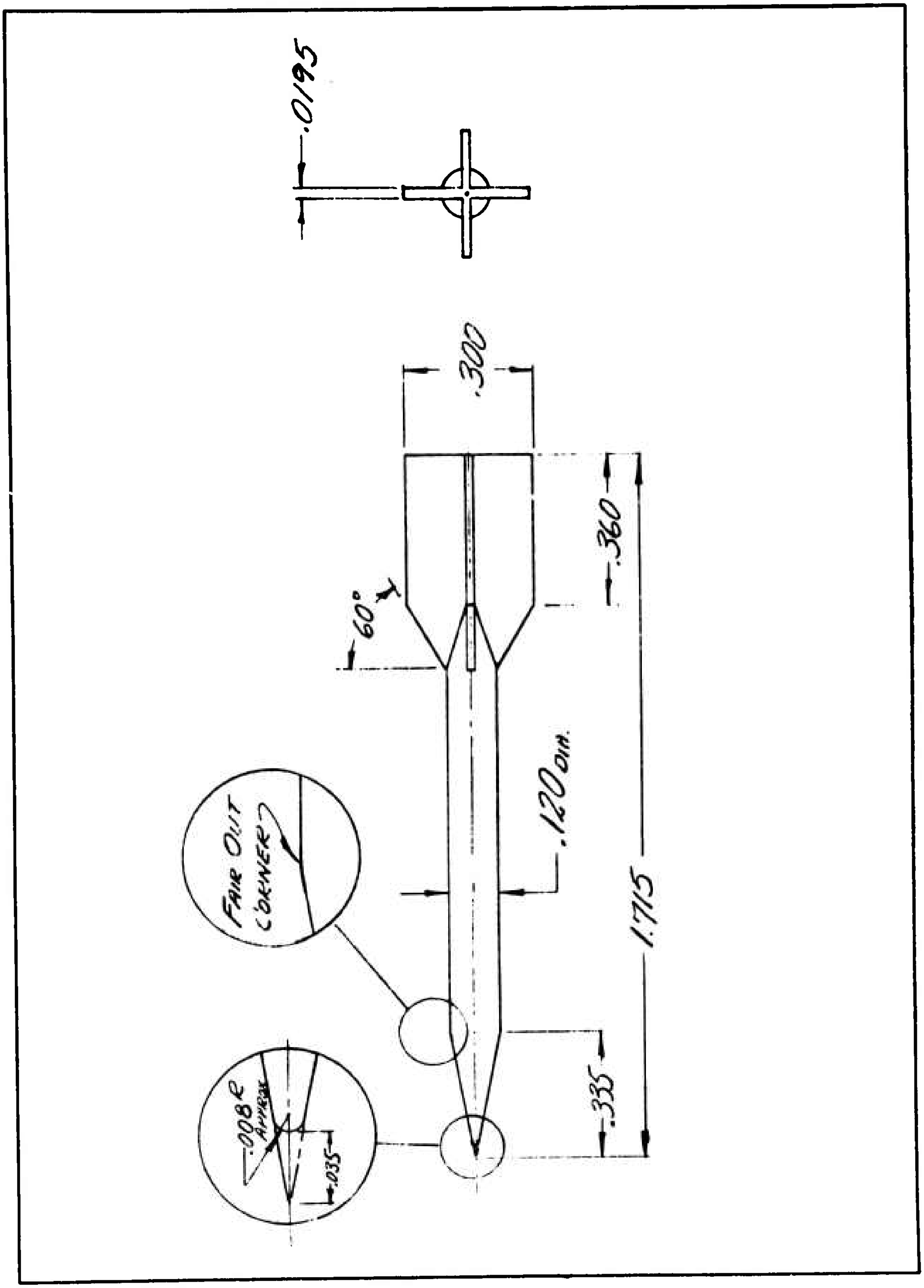

Fig. 7 - MRI Design Type II Dart

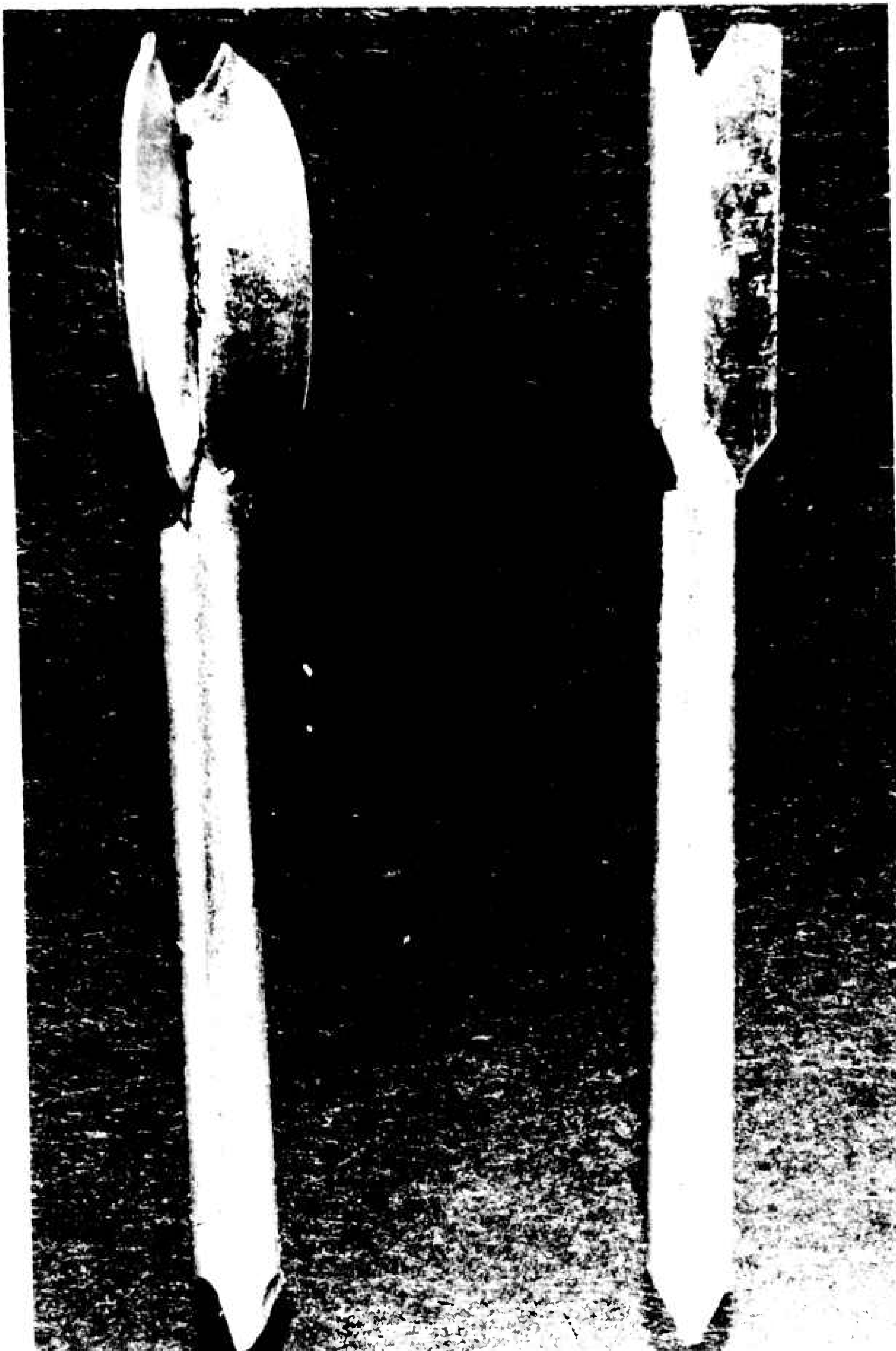

Fig. 8 - Armour Design Dart as Received and as Modified

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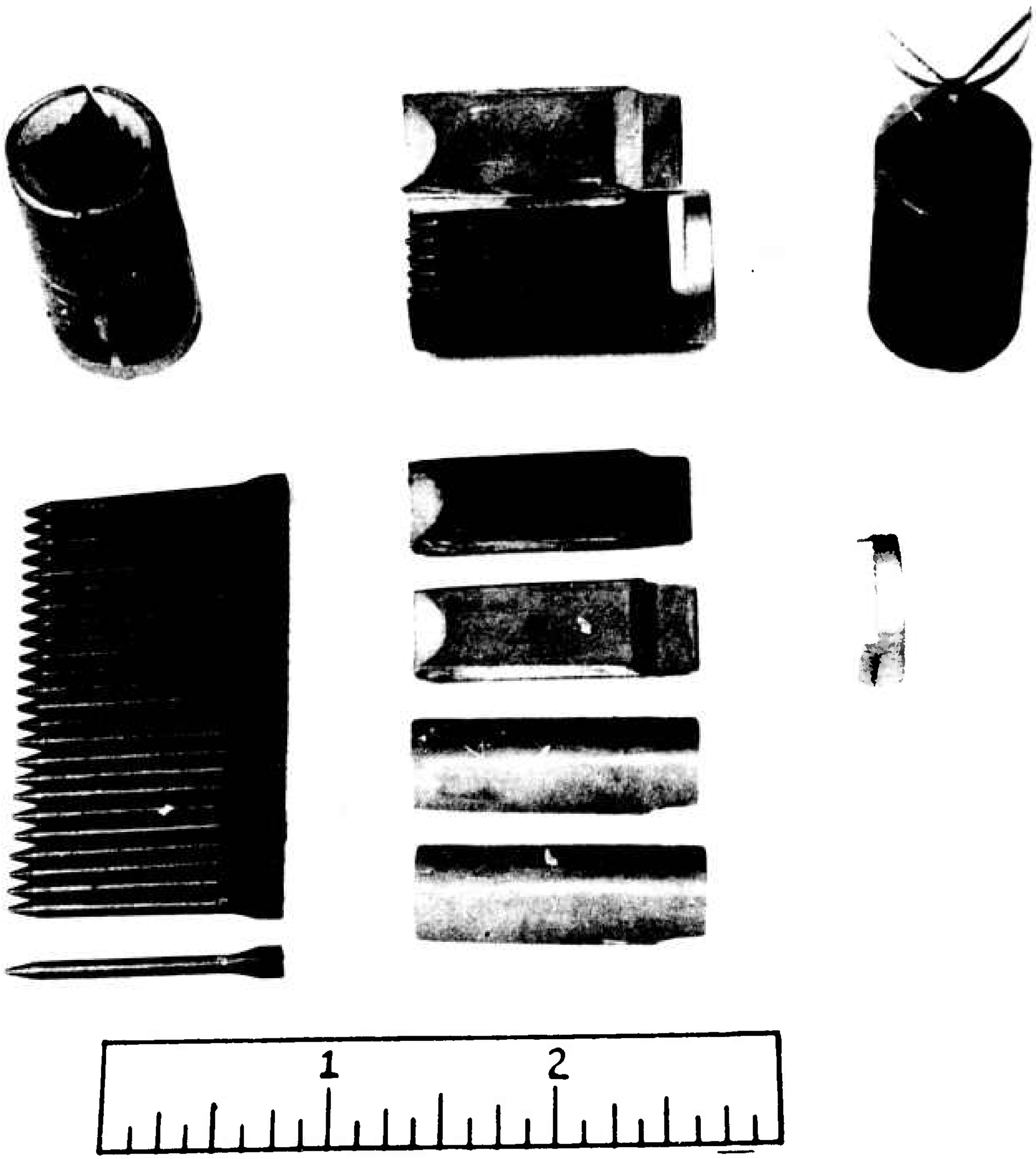

Fig. 9 - Components of Four Dart-Sabot Assemblies for Round Type 3(AA)

leading naturally to a tighter cluster in flight. Launching velocity should not be so high that the darts are damaged, however, or the purpose will be defeated. Likewise, launching velocity should not be so high as to produce excessive recoil of the weapon.

A brief discussion of the experimental rounds fired with each of the seven types of darts follows. A tabulation of round types with comparative performance figures for each type, is contained in Table I, page 28.

1. Type II-D1 darts: The darts designated Type II-D1 are cast phosphor-bronze, four-finned, 17-grain darts made by Frankford Arsenal. These darts follow the geometrical design established by MRI for experimental firing. The general design specifies a 14 caliber length, 2-1/2 caliber fin span, 3 caliber fin chord, 30° included angle conical nose, and 60° sweepback on the fin leading edge. The II-D type was 0.097 diameter resulting in 1.358 length and 0.243 fin span. When this design is cast in phosphor-bronze, the average dart weight is 17 grains. The maximum number of these darts that may be loaded into a 12-gauge shot shell is 14. The majority of the experimental rounds contained clusters of 10 or 12 darts.

A total of 52 experimental rounds containing Type II-D1 darts were fired during the course of the program. The 52 rounds were divided into 23 different round types. Differences between round types were often minor changes made to check sabot performance, wad performance, closure disk performance or any other of the many variations that might have been introduced.

The best series fired with this type of dart (where the number of shots was sufficient to provide a reasonable sample) was round Type 23(II-D1). Average pattern mean radius was 8.41 mils at a range of 185 ft. Excluding Round A10-80, which exhibited a "blown" pattern, the remaining four rounds had an average pattern mean radius of 5.86 mils at a range of 185 ft. It is felt that this is a satisfactory level of performance for this dart.

Considerable difficulty was encountered with experimental firing of these darts because of their inadequate strength. Frequently, recovered darts would exhibit damage caused by set-back forces. The rounds from which the damaged darts were fired invariably exhibited patterns with a large pattern mean radius. Not all of the widespread patterns were the result of dart damage but the frequency of occurrence was too great to be a chance element of failure.

Over-all average pattern mean radius for the 52 rounds fired was 9.68 mils. The range of pattern mean radius was from 4.45 mils to 18.62 mils, with 58 per cent exhibiting less than average pattern mean radius.

2. Type II-D2 darts: The darts designated as Type II-D2 are cast phosphor-bronze, four-finned, 14-grain darts made by altering the Type II-D1 darts. These darts were shortened to an over-all length of 11 calibers, otherwise they were the same as the Type II-D1 darts. The alteration was made to allow a greater thickness of cushioning wads to be loaded into the cartridge without increasing the over-all length of the complete cartridge.

Only seven rounds were fired with this type of dart because of the short supply of projectiles. Performance was considered satisfactory with the pattern mean radius of all rounds averaging 5.74 mils. The short darts exhibited a greater tendency to yaw than the Type II-D1 darts, but the patterns did not display any adverse effects attributable to the instability. The Type II-D2 darts may be loaded into a standard 2-3/4 in. shot shell with 1/2 in. of cushioning wads whereas the Type II-D1 darts require a "Magnum" shot shell of 3 in. length to accommodate a 3/8 in. cushioning wad. It is felt, therefore, that the Type II-D2 dart is superior to the Type II-D1 dart because it is more easily adapted to existing weapons without extensive alteration.

3. "Armour" three-finned darts: The darts designated as "Armour" for purposes of identification are made to specifications set up by Armour Research Foundation for a different application. The darts, as received, have the trailing edge of the fins cut at an angle. This does not provide a sufficient base for accelerating the cluster so that the darts fired in the experimental rounds were altered to a flat base configuration.

A total of 12 experimental rounds comprised of three round types containing the Armour darts were fired during the program. The small size of the darts (7-grain weight) permitted 37 darts to be loaded into each cluster.

Performance of the Armour darts was not considered satisfactory. Average pattern mean radius was 16.67 mils with a best pattern of 13.75 mils mean radius and a worst pattern of 23.29 mils mean radius. These darts are not considered satisfactory for salvo weapon use in spite of the fact that large numbers may be loaded into a single cartridge. The wide cluster dispersion exhibited by experimental rounds tends to offset any advantage inherent to a large number of projectiles per round.

4. Type II-E1 darts: The darts designated as Type II-E1 are 9-grain, cast phosphor-bronze, four-finned darts made by Frankford Arsenal according to MRI design specifications. This dart type is the smallest of the MRI series II design. The maximum number of Type II-E1 darts that may be loaded into a cluster is 19. Twenty-five experimental rounds containing the Type II-E1 darts were fired during the program. Performance of the

experimental rounds was disappointing. Average pattern mean radius was 15.54 mils with a best pattern of 10.16 mils mean radius and a worst pattern of 19.52 mils mean radius.

The lot of Type II-E1 darts supplied for this program appeared to be much softer than previous lots resulting in a considerable number of the darts being damaged by set-back forces during launching. The inevitable result of such damage is large patterns and inconsistent performance.

5. Type FL-17 darts: The darts designated as Type FL-17 were made for International Harvester Company for a different application. They are made of steel and average 8 grains in weight. These darts were supplied to MRI for test purposes when no other darts were available. The darts, as supplied, were not particularly uniform nor did they have flat bases on the fins. The fin bases were machined flat before firing, and the nose profile was changed from a four-sided pyramidal shape to a conical shape.

Twenty rounds loaded with clusters of FL-17 darts were fired during the program. Performance of the rounds, while not outstanding, was better than had been expected. Average pattern mean radius was 10.55 mils with a best pattern of 7.64 mils mean radius and a worst pattern of 18.08 mils mean radius. It is reasonable to expect that a more symmetrical and uniform dart of this type could produce even better patterns.

6. Aircraft Armaments darts: Aircraft Armaments darts were supplied through Frankford Arsenal by Aircraft Armaments, Inc. It is a forged, heat-treated steel dart of unique design. The four fins are offset from directly opposed positions, and are canted slightly along their length to induce slow rotation in flight. The offset fins allow body-to-body stacking of the darts to produce a square cluster. The Aircraft Armaments darts weigh 12.5 grains each and are approximately 1.25 in. long.

Sixteen experimental rounds, loaded with clusters of 25 AA darts per cluster, were fired during the program. Average pattern mean radius was 14.76 mils with a best pattern of 8.88 mils mean radius and a worst pattern of 21.08 mils mean radius. It is our belief that the AA darts are marginally stable, and that this level of performance is the best to be expected for the launching conditions which exist in this type of cartridge.

7. Type II-E2 darts: The darts designated as Type II-E2 for identification purposes are forged-steel, four-finned, 8-grain darts produced for American Machine and Foundry Company. The basic configuration is the same as the MRI Type II-E1, with slight differences introduced by the manufacturing methods employed.

A total of 94 experimental rounds, containing clusters loaded with 19 darts per cluster, were fired during this program. Average mean pattern radius for all the rounds was 9.82 mils with a best pattern of 5.11 mils mean radius and a worst pattern of 19.10 mils mean radius. The best round design loaded with II-E2 darts was Type 8(II-E2). Eliminating one "blown" pattern from a series of eight rounds, the remaining seven rounds had an average pattern mean radius of 7.77 mils. It is felt that this group is representative of the results that can be obtained with the Type II-E2 darts.

TABLE I

COMPARATIVE SUMMARY OF MULTI-DART CARTRIDGE TESTS

Round Type	Round No.	No. Darts	Velocity at 15 Ft.	Total Hits	Hits at < 10 Mils MPI	MR Mils	No. Hits for Radius from Cluster MPI: 5 Mils	10 Mils	15 Mils	20 Mils	C - Crimped, UC - Uncrimped
3(II-D1)	A10-1	12	1,660	12	7	10.50	0	7	10	12	C
	-2	12	1,600	9	3	13.32	0	3	6	9	C
	-3	12	1,660	12	10	6.44	5	10	12	12	C
4(II-D1)	-4	12	1,670	12	10	6.46	4	10	12	12	C
	-5	12	1,680	12	10	7.75	4	10	11	12	C
	-6	12	1.620	12	11	7.12	4	11	11	12	C
	-7	12	1,700	12	6	10.77	1	6	9	12	C
	-8	12	1,685	12	8	10.84	1	8	9	11	C
5(II-D1)	-9	12	-	12	11	6.83	5	11	11	12	UC
6(II-D1)	-10	12	1,460	8	2	15.31	0	2	4	6	C
	-11	12	1,500	1	-	-	-	-	-	-	C
	-12	12	1,580	12	7	8.92	3	7	10	12	C
7(II-D1)	-13	12	1,710	12	10	6.11	5	10	12	12	C
	-14	12	1,635	12	6	12.16	2	6	9	11	C
	-15	12	1,640	12	9	7.94	3	9	11	12	C
8(II-D1)	-16	12	1,630	12	10	5.83	6	10	12	-	UC
9(II-D1)	-17	11	1,560	10	3	13.71	2	3	7	8	C
10(II-D1)	-18	11	1,520	11	11	6.37	2	11	11	11	C
	-19	11	1,560	6	1	13.58	0	1	5	5	C
11(II-D1)	-20	11	1,540	10	7	8.39	2	7	9	10	C
12(II-D1)	-21	11	1,540	11	3	15.26	0	3	6	8	UC
	-22	11	1,590	11	3	10.68	1	3	10	11	UC
13(II-D1)	-23	11	1,580	10	3	12.18	1	3	8	9	C
14(II-D1)	-24	11	1,610	11	11	6.08	5	11	11	11	UC
15(II-D1)	-25	11	1,605	11	4	12.72	2	4	6	10	C
	-26	11	1,615	11	1	17.99	0	1	3	6	C
16(II-D1)	-27	11	1,595	11	9	6.80	4	9	11	11	UC
17(II-D1)	-28	12	1,480	12	10	8.10	3	10	11	12	UC
18(II-D1)	-29	12	1,630	9	3	15.30	2	3	5	6	C
19(II-D1)	-30	12	1,670	9	7	10.83	3	7	7	7	C
20(II-D1)	-31	10	1,677	10	8	8.13	3	8	9	9	C
	-32	10	1,692	10	4	17.00	0	4	5	6	C
	-33	10	1,658	10	9	6.56	5	9	9	10	C
	-34	10	1,572	10	9	4.56	7	9	10	10	C
	-43	10	1,623	6	1	11.50	1	1	4	6	C
	-44	10	1,642	10	7	8.14	2	7	9	10	C
21(II-D1)	-35	10	1,672	9	8	6.15	4	8	9	9	C
	-36	10	1,585	10	7	7.54	3	7	10	10	C

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TABLE I (Continued)

Round Type	Round No.	No. Darts	Velocity at 15 Ft.	Total Hits	Hits at < 10 Mils MPI	MR Mils	No. Hits for Radius from Cluster MPI 5 Mils	10 Mils	15 Mils	20 Mils	C - Crimped UC - Uncrimped
22(II-D1)	A10-45	10	1,626	10	7	8.80	2	7	9	10	UC
	-46	10	1,580	10	9	6.60	3	9	10	10	UC
23(II-D1)	-57	10	1,642	10	9	6.33	4	9	10	10	C
	-58	10	1,712	10	9	6.29	2	9	9	10	C
	-59	10	1,724	10	9	5.99	5	9	10	10	C
	-80	10	1,621	8	1	18.62	0	1	2	6	C
	-81	10	1,704	10	10	4.83	4	10	10	10	C
24(II-D1)	-60	14	1,626	14	10	8.71	3	10	12	14	C
	-61	14	1,587	14	2	15.43	0	2	8	11	C
25(II-D1)	-82	10	1,721	10	7	8.10	4	7	9	9	C
	-83	10	1,667	10	9	4.45	8	9	10	10	C
	-84	10	1,695	10	8	6.68	3	6	10	10	C
	-85	10	1,639	9	1	18.12	0	1	3	7	C
	-86	10	1,681	9	4	11.02	2	4	6	9	C
1(II-D2)	-62	10	1,779	10	10	4.66	5	10	10	10	C
	-63	10	1,669	10	10	3.81	9	10	10	10	C
	-87	10	1,730	10	10	5.49	5	10	10	10	C
	-88	10	1,675	10	9	6.02	5	9	10	10	C
	-89	10	1,767	10	9	6.46	5	9	9	10	C
2(II-D2)	-64	10	1,770	10	8	6.37	4	8	10	10	C
	-65	10	1,650	10	9	7.39	4	9	10	10	C
1(Armour)	-117	37	1,580	29	2	19.61	2	2	8	18	C
	-118	37	1,650	33	11	13.75	4	11	22	27	C
	-119	37	1,493	21	6	16.59	2	6	9	10	C
	-120	37	1,656	24	7	15.95	2	7	12	17	C
2(Armour)	-135	37	1,655	14	1	23.29	0	1	2	6	C
	-136	37	1,550	15	1	16.56	0	1	8	12	C
	-137	37	1,433	26	6	17.08	0	6	13	17	C
	-138	37	1,779	22	7	16.87	3	7	11	13	C
3(Armour)	-158	37	1,821	26	8	14.63	2	8	16	20	C
	-159	37	1,786	29	11	15.70	3	11	14	20	C
	-160	37	1,667	26	3	15.83	3	3	13	20	C
	-161	37	1,645	31	12	14.16	3	12	16	25	C
4(II-E1)	-176	17	1,637	15	0	20.17	0	0	4	9	C
	-177	17	1,600	10	4	12.01	1	4	7	10	C
	-178	17	1,563	12	3	15.64	1	3	7	9	C
	-179	17	1,529	9	2	16.88	0	2	4	4	C
	-180	17	1,144	9	4	13.20	0	4	5	8	C
	-181	17	1,550	12	5	11.13	1	5	7	12	C
	-182	17	1,623	15	6	13.44	1	6	8	13	C
	-183	17	1,580	15	3	18.77	1	3	5	10	C
6(II-E1)	-172	19	1,499	15	4	16.82	0	4	8	9	C
	-173	19	1,629	15	3	17.41	2	3	6	10	C

TABLE I (Continued)

Round Type	Round No.	No. Darts	Velocity at 15 Ft.	Total Hits	Hits at < 10 Mils MPI	MR Mils	No. Hits for Radius from Cluster MPI 5 Mils	10 Mils	15 Mils	20 Mils	C - Crimped UC - Uncrimped
7(II-E1)	A10-174	19	1,642	19	10	10.16	1	10	16	19	C
	-175	19	1,567	11	3	19.42	0	3	5	5	C
8(II-E1)	-189	17	1,712	11	2	14.66	1	2	7	9	C
	-190	17	1,479	11	4	13.24	2	4	7	9	C
	-191	17	1,730	14	1	19.18	1	1	5	10	C
	-192	17	1,832	10	0	19.33	0	0	3	6	C
	-193	17	1,808	16	4	14.70	3	4	8	12	C
	-194	17	1,815	15	10	11.93	5	10	11	11	C
	-195	17	1,812	14	4	13.87	1	4	9	12	C
	-196	17	1,825	10	2	17.27	0	2	3	8	C
	-207	17	1,653	16	2	18.52	1	2	5	8	C
	-208	17	1,724	14	2	19.52	0	2	4	8	C
	-209	17	1,721	16	7	12.46	2	7	10	13	C
	-210	17	1,724	15	2	15.24	2	2	7	11	C
	-211	17	1,715	14	5	13.48	1	5	11	12	C
1(FL-17)	-197	19	1,818	18	11	8.83	6	11	17	17	C
	-198	19	1,773	18	1	18.08	0	1	7	11	C
	-199	19	1,792	19	15	7.93	4	15	17	19	C
	-200	19	1,866	19	10	10.98	2	10	16	18	C
	-201	19	1,786	14	5	13.45	2	5	10	10	C
	-202	19	1,815	19	9	11.45	2	9	14	16	C
	203	19	1,822	19	12	9.00	4	12	17	18	C
	-204	19	1,815	19	11	10.50	2	11	15	18	C
	-205	19	1,876	19	10	9.06	4	10	18	18	C
	-206	19	1,840	16	3	17.76	1	3	7	10	C
2(FL-17)	-212	19	1,689	19	14	8.60	4	14	17	18	C
	-213	19	1,712	18	9	10.61	2	9	15	17	C
	-214	19	1,754	18	12	10.00	4	12	13	17	C
	-215	19	1,767	19	9	12.02	3	9	18	19	C
	-216	19	1,748	19	14	7.64	5	14	18	19	C
	-217	19	1,783	19	10	10.55	2	10	15	17	C
	-218	19	1,835	19	7	8.82	3	7	18	19	C
	-219	19	1,792	18	11	9.78	3	11	14	16	C
	-220	19	1,845	19	15	7.75	4	15	18	19	C
	-221	19	1,852	18	13	8.13	4	13	18	18	C
1(AA)	-166	25	1,631	21	2	16.39	1	2	9	13	C
	-167	25	1,661	19	10	11.52	3	10	14	17	C
	-168	25	1,656	14	2	21.08	0	2	3	6	C
2(AA)	-169	25	1,706	23	15	8.88	4	15	22	23	C
	-170	25	1,704	20	7	13.86	1	7	12	16	C
	-171	25	1,761	21	14	9.44	6	14	18	19	C
3(AA)	-184	25	-	20	5	15.35	0	5	12	15	C
	-185	25	-	18	4	18.88	2	4	7	10	C

TABLE I (Continued)

Round Type	Round No.	No. Darts	Velocity at 15 Ft.	Total Hits	Hits at < 10 Mils MPI	MR Mils	No. Hits for Radius from Cluster MPI 5 Mils	10 Mils	15 Mils	20 Mils	C - Crimped UC - Uncrimped
3(AA)	A10-186	25	-	23	6	15.69	2	6	10	16	C
	-187	25	-	19	4	19.05	1	4	8	11	C
	-188	25	-	16	2	18.58	0	2	6	9	C
4(AA)	-222	25	1,727	22	8	8.59	1	8	11	14	C
	-223	25	1,727	23	5	16.63	2	5	11	16	C
	-224	25	1,709	23	11	14.20	2	11	14	18	C
	-225	25	1,739	23	4	17.78	0	4	8	15	C
	-226	25	1,736	23	13	10.30	5	13	18	19	C
7(II-E2)	-37	19	1,613	19	8	12.84	1	8	13	16	C
	-38	19	1,675	19	8	10.58	5	8	15	18	C
	-39	19	1,678	19	12	9.39	7	12	16	17	C
	-40	19	1,639	19	14	7.42	8	14	17	19	C
	-47	19	1,709	18	10	11.01	3	10	14	16	C
	-48	19	1,721	19	10	11.34	2	10	15	16	C
8(II-E2)	-41	19	1,642	19	15	6.58	6	15	19	19	C
	-42	19	1,639	18	16	6.59	8	16	17	18	C
	-49	19	1,745	19	18	5.13	10	18	19	19	C
	-50	19	1,669	18	4	13.27	3	4	12	15	C
	-51	19	1,838	19	13	8.46	4	13	16	19	C
	-52	19	1,822	19	15	7.32	8	15	18	19	C
	-53	19	1,758	19	15	7.31	7	15	18	19	C
	-54	19	1,862	19	12	8.95	6	12	16	19	C
	-55	19	1,908	19	13	9.28	7	13	14	18	C
	-56	19	1,883	19	14	7.95	4	14	17	19	C
	-104	19	1,642	17	10	9.67	3	10	14	16	C
	-105	19	1,712	19	15	7.56	6	15	18	19	C
	-106	19	1,686	19	10	10.55	3	10	14	18	C
	-121	19	1,832	19	16	5.98	6	16	19	19	C
	-122	19	1,818	19	15	7.15	6	15	17	19	C
	-154	19	1,930	19	11	8.86	5	11	18	19	C
	-155	19	1,934	19	12	8.86	7	12	17	18	C
	-156	19	2,004	16	9	10.55	5	9	13	14	C
	-157	19	-	18	6	14.17	3	6	10	14	C
9(II-E2)	-66	19	1,684	18	12	9.67	3	12	16	16	C
	-67	19	1,684	18	3	14.74	1	3	10	15	C
	-68	19	1,618	19	13	8.39	4	13	18	19	C
	-69	19	1,570	19	6	13.07	3	6	12	16	C
	-70	19	1,656	19	11	9.02	4	11	18	19	C
	-71	19	1,742	16	5	12.50	2	5	10	16	C
	-93	19	1,745	18	9	11.00	1	9	16	17	C
	-94	19	1,639	19	10	10.76	2	10	14	19	C
	-95	19	1,724	19	14	7.60	5	14	18	19	C
10(II-E2)	-72	19	1,751	19	14	8.18	7	14	16	18	C

TABLE I (Continued)

Round Type	Round No.	No. Darts	Velocity at 15 Ft.	Total Hits	Hits at < 10 Mils MPI	MR Mils	No. Hits for Radius from Cluster MPI 5 Mils	10 Mils	15 Mils	20 Mils	C - Crimped UC - Uncrimped
10(II-E2)	A10-73	19	1,751	18	15	6.91	7	15	17	18	C
	-78	19	1,536	18	6	12.48	1	6	11	18	C
	-79	19	1,610	19	11	10.27	2	11	17	19	C
11(II-E2)	-74	19	1,754	19	18	5.11	11	18	19	19	C
	-75	19	1,786	19	17	7.17	6	17	18	18	C
	-99	19	1,613	17	10	11.57	5	10	11	12	C
	-100	19	1,761	19	14	8.69	7	14	16	17	C
	-101	19	1,795	19	14	8.77	5	14	17	17	C
	-107	19	1,658	19	15	7.52	5	15	17	18	C
	-108	19	1,727	18	14	7.47	7	14	16	17	C
	-109	19	1,618	19	6	14.53	1	6	8	15	C
	-110	19	1,727	19	9	11.85	3	9	13	16	C
	-123	19	1,724	15	6	12.68	1	6	10	12	C
	-124	19	1,776	19	14	7.28	9	14	18	18	C
	-125	19	1,764	19	15	8.50	6	15	17	17	C
	-126	19	1,730	18	10	11.02	4	10	14	15	C
12(II-E2)	-76	19	1,767	18	8	11.12	1	8	14	16	C
	-77	19	1,808	19	11	9.92	4	11	14	18	C
13(II-E2)	-96	19	1,692	18	8	11.92	4	8	12	16	C
	-97	19	1,742	17	5	14.87	0	5	7	14	C
	-98	19	1,757	17	10	10.08	6	10	13	15	C
14(II-E2)	-90	19	1,715	19	9	11.60	1	9	15	18	C
	-91	19	1,724	19	11	11.64	4	11	13	15	C
	-92	19	1,727	19	12	7.09	8	12	18	19	C
15(II-E2)	-102	19	1,634	19	10	10.87	3	10	14	16	C
	-103	19	1,754	19	8	11.95	1	8	16	17	C
16(II-E2)	-111	19	1,582	13	1	19.10	0	1	3	7	C
	-112	19	1,637	19	7	11.77	5	7	13	17	C
	-113	19	1,764	17	5	17.23	2	5	9	11	C
	-114	19	1,742	19	17	5.61	10	17	19	19	C
	-127	19	1,754	18	10	14.10	2	10	13	17	C
	-128	19	1,770	19	14	8.12	6	14	16	19	C
	-129	19	1,709	18	15	6.39	6	15	17	17	C
	-130	19	1,754	19	9	12.24	3	9	13	18	C
	-141	19	-	19	8	10.28	4	8	16	18	C
	-142	19	-	19	11	10.22	4	11	14	18	C
	-143	19	-	19	11	11.05	2	11	16	18	C
17(II-E2)	-115	19	1,692	18	15	6.17	8	15	18	18	C
18(II-E2)	-116	19	1,675	19	17	5.96	9	17	19	19	C
19(II-E2)	-131	19	1,767	19	14	7.69	6	14	18	19	C
	-132	19	1,733	13	5	11.17	3	5	9	13	C
	-133	19	1,808	19	10	9.20	4	10	18	19	C
	-134	19	1,739	19	10	10.06	6	10	15	18	C

TABLE I (Concluded)

Round Type	Round No.	No. Darts	Velocity at 15 Ft.	Total Hits	Hits at < 10 Mils MPI	MR Mils	No. Hits for Radius from Cluster MPI: 5 Mils	10 Mils	15 Mils	20 Mils	C - Crimped UC - Uncrimped
19(II-E2)	A10-139	19	1,802	19	14	7.69	4	14	18	19	C
	-140	19	-	13	5	11.17	1	5	8	12	C
20(II-E2)	-144	19	1,852	19	14	8.08	4	14	18	19	C
	-145	19	1,686	19	17	7.50	5	17	18	19	C
	-148	19	1,838	19	15	7.12	5	15	19	19	C
	-149	19	1,848	19	14	8.02	5	14	18	19	C
	-162	19	1,808	19	8	11.55	1	8	13	18	C
	-163	19	1,855	19	12	9.05	3	12	17	18	C
	-164	19	1,805	19	14	11.15	4	14	14	17	C
	-165	19	1,825	19	14	8.02	7	14	18	18	C
21(II-E2)	-146	19	1,859	19	7	11.22	1	7	15	18	C
	-147	19	1,866	18	8	11.70	0	8	12	16	C
	-150	19	1,802	18	9	9.98	4	9	15	17	C
	-151	19	1,727	18	11	8.81	3	11	15	17	C
	-152	19	1,748	18	14	7.47	5	14	17	17	C
	-153	19	1,712	16	6	13.36	1	6	10	13	C

8. General comparisons: The target size selected at the beginning of the salvo weapons investigations was a circle of 5.4 sq. ft. area. The radius of the specified target circle at 100 yd. will be 4.37 mils. As an arbitrary measure of the performance of a dart round, the number of darts within a circle of 10 mils radius from the cluster center of impact was selected. Table II contains a listing of the rounds previously discussed, using the arbitrary 10 mil circle comparison.

TABLE II

Dart Type	Round Type	Darts per Round (Avg.)	Darts in 10 Mil Circle (Avg.)	Per Cent of Total Darts
II-D1	All Types	11	6.75	61
II-D1	23(II-D1)	10	7.60	69
II-D2	1(II-D2) and 2(II-D2)	10	9.29	93
Armour	All Types	37	6.25	16
II-E1	All Types	17	3.68	22
FL-17	1(FL-17) and 2(FL-17)	19	10.00	53
AA	All Types	25	6.38	26
II-E2	All Types	19	11.12	59
II-E2	8(II-E2)	19	13.00	68

A comparison of rounds on this arbitrary basis shows that the Type II-E2 rounds had a greater number of darts within the 10-mil radius than any other type. The heavier Type II-D2 dart (14-grain as compared to the 8-grain Type II-E2) shows respectable performance on this basis, with the possibility of being a much better dart from the standpoint of terminal effectiveness. This sort of comparison emphasizes the need for a method of comparing performance where all the factors affecting total performance are properly considered.

D. Charge Development

A brief program of charge development was initiated near the end of the project in an attempt to find a propellant that would accelerate the dart clusters to higher velocities (2,000 - 2,100 fps) without damaging the darts. Hercules Red Dot propellant has been employed for the majority of the experimental rounds. This propellant was quite satisfactory at lower velocity levels (1,550 - 1,700 fps), but it develops too high a chamber pressure when the charge is increased to attain the higher velocities. Accordingly, a number of other propellants were tried in an effort to find a more satisfactory propellant for high velocities. The propellants employed in the tests were:

Hercules Red Dot	Alcan AL-5
Hercules Unique	Alcan AL-7
Hercules Herco	Alcan AL-8
DuPont PB	Western Ball X463.1

A composite graph of velocity versus charge weight is shown in Fig. 10. No graph of pressure versus charge weight is shown because the pressure-time history varied so widely from one round to another that no decent correlation existed. Figure 11 is a pressure versus time graph of a typical charge development round, loaded with Red Dot and, for comparison purposes, a standard shot shell. The charge development round, loaded with a rigid slug to simulate the size and weight of a sabot-dart package, exhibits an extremely fast pressure rise to a high peak pressure, followed by a fast pressure drop and then a leveling off to muzzle exit pressure. The standard shot shell does not exhibit this characteristic at all. No explanation has been found for the curious behavior of the slug-loaded rounds. Two possible causes exist: (1) the rigidity of the slug simulating the dart-sabot package may impose greater resistance to motion, by action of the propellent gases, before the crimp is moved aside and the slug is accelerated down the barrel; (2) the short wad column necessary in the dart round may not compress enough to provide a proper volume change in the shell, the result being to raise the burning rate of the propellant, and thereby increase the rate of pressure rise and the peak pressure.

The charge development work was not extensive enough to establish any propellant as a satisfactory substitute for Red Dot in the shotgun weapon. A propellant midway in granulation between Hercules Red Dot and Hercules Herco might prove to be adequate.

E. Over-Powder Wads

The function of the over-powder wad in a shot shell is to seal the gases behind the shot column and impart uniform thrust to the filler (cushioning) wads.

Three types of over-powder wads were used during this program: flat cardboard disks 1/8 in. thick, cardboard cup wads, and plastic cup wads made from Remington plastic H-wads. The best over-all performance was obtained with the plastic cup wads. Experimental rounds loaded identically, except for the over-powder wads, consistently exhibited higher velocity with

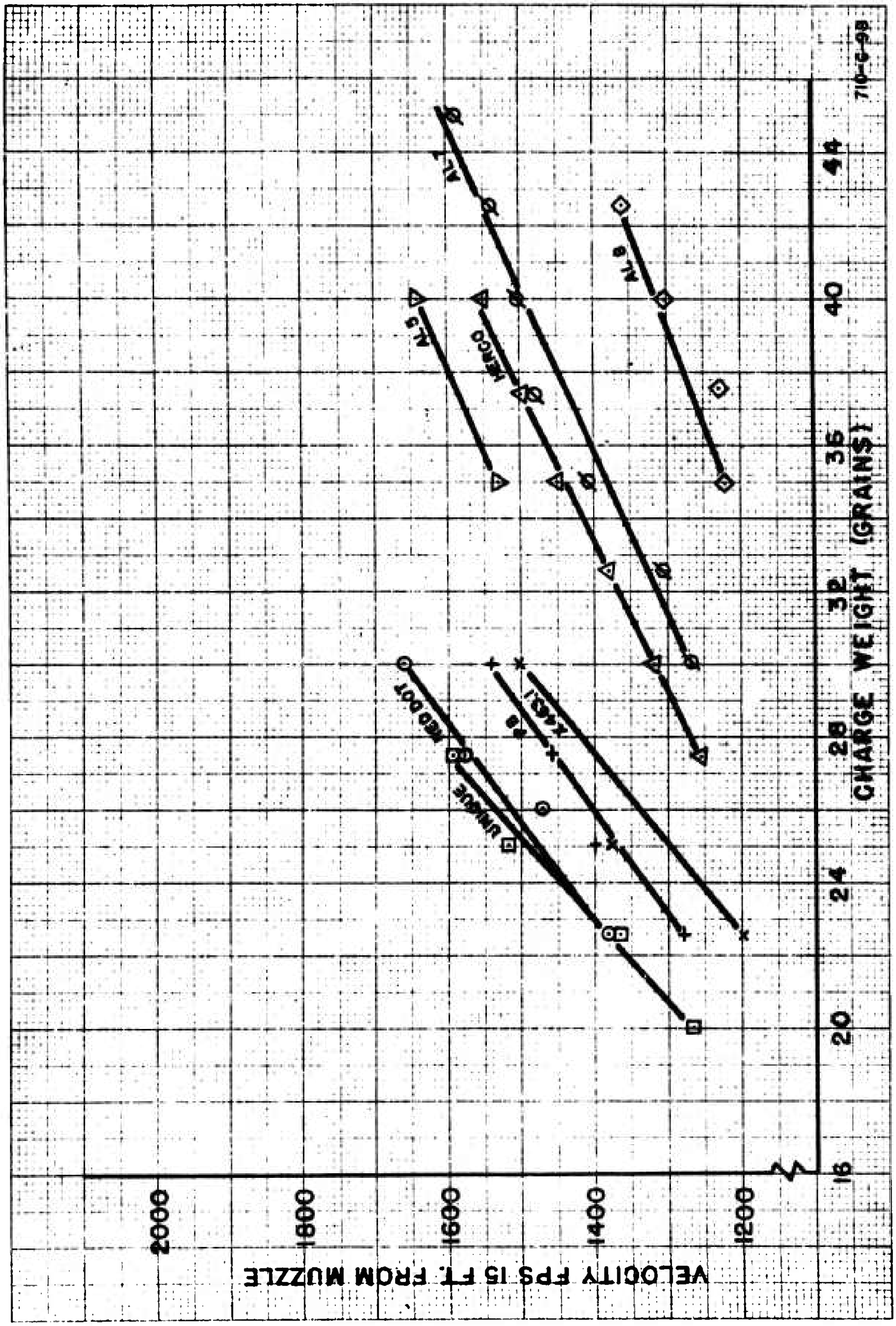

Fig. 10 - Velocity versus Charge Weight for Shotgun Propellants

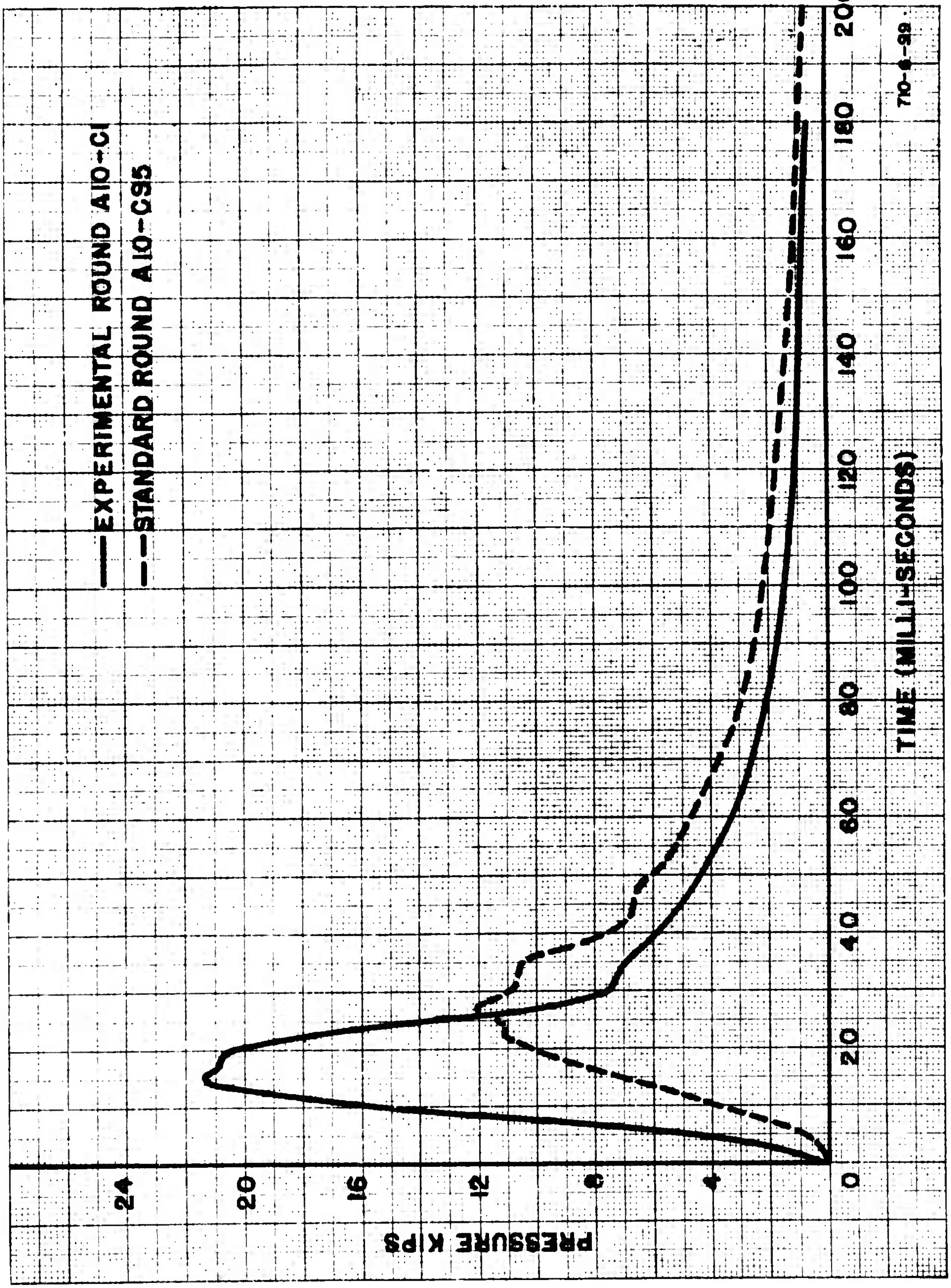

Fig. 11 - Pressure-Time Curves for Charge Development Rounds

the cup wad loads. Both the cardboard and the plastic cup wads exhibited this behavior. The velocity difference was approximately 50 fps at 1,700 fps velocity level.

Some concern was felt about the ability of the plastic cup wad to withstand the high temperature encountered in the chamber. Recovered plastic cup wads showed a slight charring at the edges, but no general charring or breakdown of the wad. One additional feature favoring the plastic cup wad is its ease of loading. The cardboard cup wad performs as well as the plastic cup wad ballistically but is much more difficult to load into the shell.

F. Closure Disks

The basic function of the closure disk is to seal the cartridge against the entrance of moisture and dirt. This may be accomplished in a variety of ways; however, when the cluster is ejected from the shell the closure disk must break up so that it will not interfere with the free passage of the dart cluster. In addition, the pieces should not interfere with the orderly flight of the dart cluster after the cluster is separated from the sabot. A number of different materials were used during the program to accomplish this task. Among these materials were: (1) Lucite disk 0.020 in. thick; (2) commercial disintegrating top wads; (3) Bakelite disks 0.050 in. thick; (4) cast Durock retaining ring and closure disk assemblies; and (5) paper reinforced Bakelite disks 0.020 in. thick.

The most satisfactory closure disk was the paper reinforced Bakelite disk 0.020 in. thick. This closure disk had sufficient strength to withstand crimping pressures, yet was brittle enough to break up satisfactorily under impact loading by the accelerating dart-sabot package.

G. Conclusions

The following conclusions may be drawn with regard to the multiple-projectile dart weapon.

1. Finished multiple-dart cartridges can be produced that are capable of patterns with 5 to 6 mils pattern mean radius.

2. Tables illustrating probability of hit and probability of kill will be required before the over-all effectiveness of multiple-dart cartridges can be properly evaluated and compared with existing infantry hand weapons.

3. Darts should be made of steel to withstand the accelerating forces imposed by muzzle velocities in excess of 1,700 fps.

4. Propellants employed during this program will not be satisfactory at muzzle velocities in the 2,000 fps range.

H. Recommendations

The following recommendations are made for future development of the multiple-dart salvo weapon.

1. Construct tables of probability of hit and kill for salvo weapons.

2. Obtain lethality data for multiple simultaneous hits with various darts.

3. Design a dart that most nearly satisfies all the requirements of the system. Analysis of the system should consider weapon geometry, flight characteristics, terminal effectiveness and tactical employment in determining system requirements.

4. Increase muzzle velocity of the cluster, thereby increasing terminal velocity and terminal effectiveness.

5. Investigate three-fin and offset four-fin dart designs to improve stability of the loaded cluster.

III. PROBABILITY OF HIT

A. Introduction

The concept of the salvo type weapon was evolved as one method of increasing the effectiveness of the individual soldier in battle. For many years the idea has persisted that two methods of improving battle effectiveness existed; one being to provide the individual soldier with enough training to develop a high degree of skill with his individual weapon. The other approach is to provide the individual soldier with a weapon that would allow a greater number of shots to be fired in a unit of time; thus increasing the coverage in an area, with a resulting increase in the number of casualties suffered by the enemy. Neither of these methods employs a logical, mathematical approach to analyze the problem in its true perspective.

B. Discussion

The first method employed to increase the effectiveness of the individual soldier, that of developing the required skill by diligent training, presupposes an ability not necessarily inherent in a soldier chosen at random. The supposition is, that given sufficient practice any person may achieve a high degree of proficiency with a rifle. This condition is not necessarily true, and generally will not be true. The first method also is refuted when emergencies arise that require the development of a large number of soldiers within a short period of time. Even if we concede that a random group of soldiers may be superior marksmen, the stress of battle conditions in all probability will influence their performance, reducing their over-all effectiveness to a level more nearly equal to an average random group.

The second method, which advocates a more "prolific" weapon, discounts the marksmanship of the individual, and assumes that the best over-all effectiveness will be realized if the "firepower", or the ability to fire a number of projectiles within a given time, is increased for the individual soldier. Granted, that a larger number of shots striking a given area per unit of time will probably result in a larger number of casualties, the method still does not provide any greater probability of hit for each shot fired.

Neither of the two methods provides a complete solution for the basic problem; namely, to provide the individual soldier with a greater probability of hit for each round fired.

A given system (over-all tactical situation) may usually be described in terms of several individual factors. If these factors may be separated, or reduced to groups of interrelated factors, limits may be established for the errors inherent in the individual factors or groups of factors. By a proper combination of the inherent errors, the probability of success or failure of the over-all system may be established. Specifying a particular tactical situation, wherein a particular weapon is to be employed, establishes a system that may be examined mathematically for its probability of success.

A mathematical model was presented for the specified system, in regard to the tactical employment of a salvo weapon, in the Final Report issued by Midwest Research Institute under Ordnance Contract No. DAI-23-072-507-ORD-(F)-2. Unfortunately, the model as finally expressed was incorrect; the error was discovered too late for correction of the report.

The fallacy of the model lies in the erroneous assumption that the errors describing the probable location of the cluster center of impact, with respect to the target, are independent of the errors describing the probable locations of the individual impacts within the cluster. From such an assumption, a condition may be inferred wherein the cluster center of impact will be at, or beyond, the edge of the target, while all the points of impact are still further removed from the target. Obviously this is impossible since, by definition, the cluster's center of impact is described as the arithmetical average of the locations of the individual points of impact, about some arbitrary reference point. The center of impact, therefore, is dependent on the individual points of impact, and the errors describing the behavior of the cluster center of impact must be dependent on the errors describing the behavior of the individual points of impact within the cluster. The mathematical model for the probability of hit for salvo weapons has been reconstructed with this dependence accounted for. The mathematical model is very complex and, thus far, has not yielded to any of the various methods of solution that have been tried. The problem is still under study and the solution, or a reasonably good approximation to the solution, may yet be found.

C. Conclusions

The following conclusions may be made regarding the probability of hit for salvo weapons.

1. The solution and evaluation of the correct expression for probability of hit must be completed before the true effectiveness of salvo weapons may be determined.

2. Comparisons of salvo weapon effectiveness with conventional weapon effectiveness cannot be made, at present, without the danger of a favorable, or unfavorable, bias being introduced.

IV. CONTRIBUTING PERSONNEL

The following personnel contributed materially to the conduct of this contract: For Frankford Arsenal - Mr. Sidney Ross and Mr. Charles Dickey, technical supervision of the program; Mr. Steve Kucson, technical direction of the program and procurement of supplies; for Midwest Research Institute - Mr. David Bendersky, technical and administrative supervision of the program; Mr. J. A. Wiley, conduct of the test program for the 22 caliber squirt gun, design of the prototype weapon, and direct supervision of the contract; Mr. D. R. Wilson, conduct of the test program for the dart weapon and data reduction of dart weapon test results; Mr. A. D. St. John, analysis of the probability of hit for salvo weapons.

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