BALLISTIC RANGE DEVELOPMENT

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THESIS

BALLISTIC RANGE DEVELOPMENT

by

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June 1976

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High velocity and low velocity guns were investigated. Charge values
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necessary user information and test results.

Ballistic Range Development

by

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Submitted in partial fulfillment of the
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ABSTRACT

A ballistic range was developed for use in testing structural materials. High velocity and low velocity guns were investigated. Charge values for various projectile weights were determined and velocity consistency and reproducibility were verified. A range note-book was compiled with necessary user information and test results.

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LIST OF FIGURES

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* See List of Graphs, page 8, for graph parameters.

LIST OF GRAPHS

	Projectile Diameter Inches	Projectile Weight Grains	Powder Type	Dacron Filler
1.	.458	140	Unique	Yes
2.	.458	140	IMR 4227	Yes
3.	.458	140	IMR 4227	No
4.	.458	350	IMR 4227	Yes
5.	.458	350	IMR 4198	Yes
6.	.458	350	IMR 4198	No
7.	.458	550	IMR 3031	Yes
8.	.458	550	IMR 4064	Yes
9.	.224	$27\frac{1}{2}$	IMR 3031	No
10.	.224	$27\frac{1}{2}$	IMR 4198	No
11.	.224	45	IMR 3031	No
12.	.224	45	IMR 4064	No
13.	.224	63	IMR 4064	No
14.	.224	63	IMR 4320	No

ACKNOWLEDGEMENT

I. INTRODUCTION

The purpose of this project was to develop a ballistics facility suitable for testing a wide range of structural materials. The facility was designed for maximum versatility and developed to provide quick usage enabling the experimenter to concentrate on the material to be tested and not the mechanics of the range itself.

The reloading data offered here were gathered through extensive testing and retesting. Before using these data the experimenter should consider the variables involved and should be thoroughly familiar with Appendix B. These data will provide a good departure point to begin preparing custom-made loads for any given laboratory need. However, production changes affecting the performance of components can occur at any time, so the reloader is cautioned to approach maximum, minimum, and unlisted loads with care.

Much of what follows here is repeated in Appendix B in a somewhat different form. The purpose of Appendix B is to provide the user of the ballistic range with a short background in internal and external ballistics and to provide a quick reference for information to supplement the reloading library. Thus Appendix B supplements the Thesis proper which is concerned only with the initial experimentation.

II. EQUIPMENT

A. RETURN TO BATTERY MACHINE REST (RBMR)

The Return to Battery Machine Rest was designed by Hornady Manufacturing Company, Inc., Grand Island, Nebraska. Blueprints were obtained from them and the rest was built in the Aeronautical Engineering machine shop. (Figure one)

Two barreled actions were acquired. The first was a 45-caliber barrel from Shilen Rifles, Inc., 205 Metropark Blvd., Ennis, Texas, which was mated to a commercial magnum Mauser action by Micro-Sight Co., 242 Harbor Blvd., Belmont, California 94002. The second barreled action was a 22-caliber Savage heavy-barreled model 110.

The two barreled actions were fitted with 110-volt solenoids which enabled them to be fired remotely. Both actions are loaded singly and are equipped with safeties and removable bolts. The loading and ejection ports are located on the right side of the receiver. Both bolts have two forward locking lugs, one rear safety lug, and gas vent holes in both the bolt and receiver. The Savage action has solid bottom while the Mauser action has a magazine cut, although the magazine was made inoperable.

The barrel, action, and solenoid assembly was held in the machine rest by an eight-inch slotted aluminum block, utilizing eight cap screws to clamp the barrel in position.
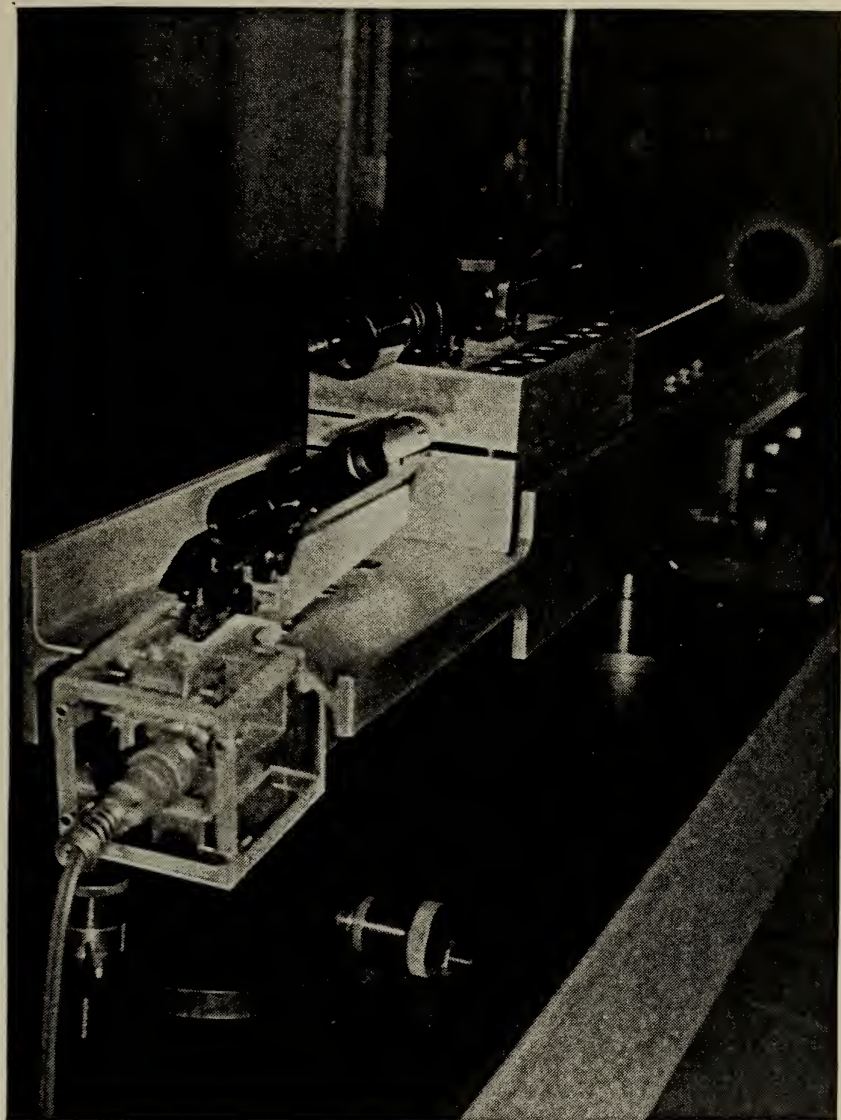
Figure One
RETURN-TO-BATTERY MACHINE REST

The aluminum block and barrel assembly was bolted to an aluminum I-beam fitted with hardened rails. The rails fit into tracks in the heavy RBMR base and the entire I-beam assembly recoils as a unit. The unit is returned to battery manually after each shot.

The RBMR base was made from three-eighth-inch steel plate and weighs approximately forty pounds. It was fitted with hardened stands for the I-beam assembly to ride on, and a provision for both vertical and horizontal adjustment was incorporated at the rear of the base. Aiming the apparatus was accomplished by means of a four-power Weaver scope mounted on top of the eight-inch aluminum block and by the adjusting screws at the rear of the base.

All steel parts of the RBMR were finished by the author in a rust-resistant blue. The finish was achieved by both heat and chemical means and has proven satisfyingly durable.

B. CHRONOGRAPH

As a permanent part of the range, an Oehler Chronograph and photoelectric screens were installed. A full description of the chronograph can be found in Appendix B. In short, the chronograph requires only push-button resetting between shots and gives a direct readout in feet per second.

C. BULLET TRAP

A most essential piece of equipment was a bullet trap designed to handle the velocities and energies anticipated. Two different bullet

traps were used.

The first was a trap left over from a previous project. A new 1.5-inch armor plate backing was installed and the trap performed adequately throughout the majority of the test firing. However, since the old trap had no provision for exhausting lead dust produced on impact of high velocity projectiles, the decision was made to produce a new bullet trap which incorporated the desired features.

The 1.5-inch armor plate backing was retained, but was manufactured in such a way as to be removable. (Figure two). The desired exhausting feature was accomplished by a small electric motor and squirrel cage blower mounted behind the trap and exhausting from its base. (Figure three). The forward portion of the trap was slotted to accept a front plate which increased the velocity of the air moving through the trap. The front plate also provided a limited blow-back protection from bullet fragments. (Figures four and five).

D. RELOADING EQUIPMENT

The reloading equipment obtained was the best quality available. The following is a pictorial listing of the major components and a basic summary of their use.

Figure Two
BULLET TRAP BACKING
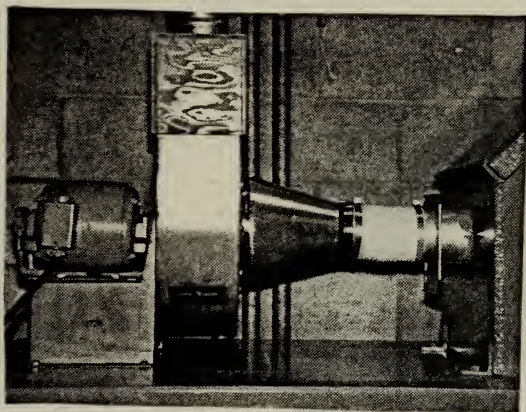
Figure Three
BULLET TRAP EXHAUST BLOWER

15
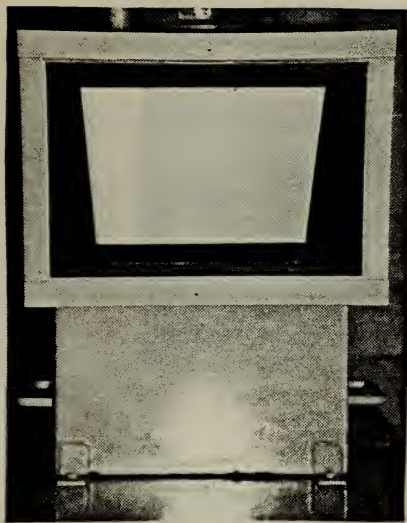
Figure Four
BULLET TRAP OPEN FACE

Figure Five
BULLET TRAP FRONT PLATE

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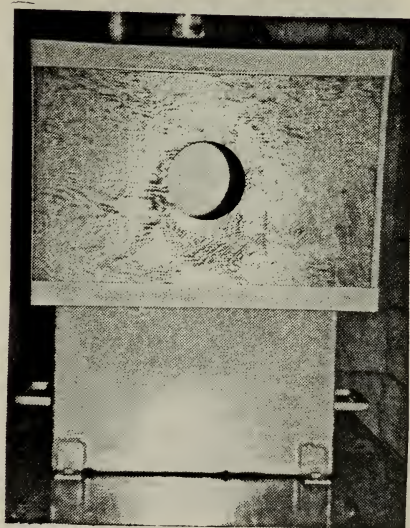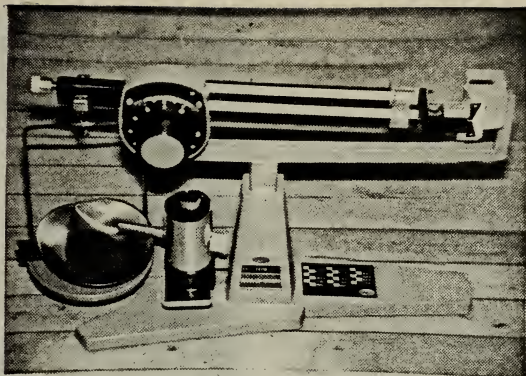
Figure Six
POWDER SCALE

Ohaus Model 304 Dial-O-Grain. This scale features a 1,110 grain capacity, hardened steel knives, polished agate bearings, magnetic damping, over size pan, die cast base, and powder trickler. The dial is engraved with increment values of from 0.1 to 10 grains.

Figure Seven.

POWDER MEASURE

RCBS Uniflow Powder Measure. This measure adjusts quickly from one charge to another without emptying the powder hopper. The powder level is visible at all times. The measure is stand-mounted and has two drop tubes to fit the .224 and .458 caliber cases.
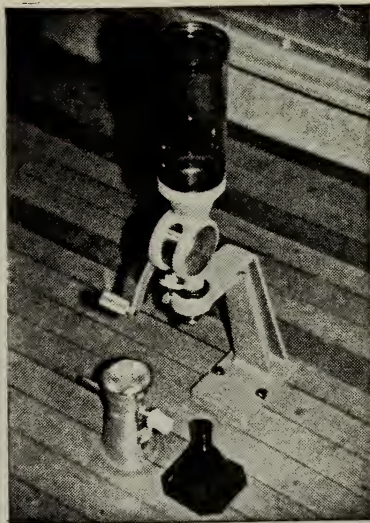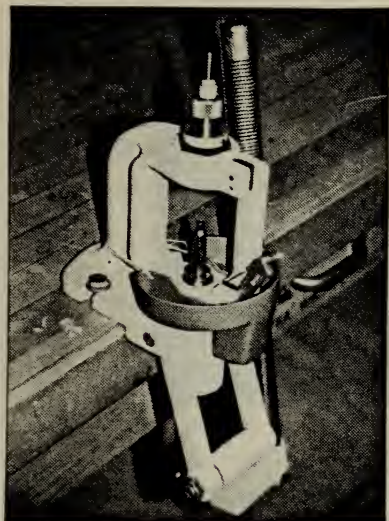
Figure Eight
RELOADING PRESS

The RCBS R. C. press with its compound leverage delivers up to 200% more leverage than most presses designed for heavy duty reloading. The block "O" frame prevents the press from springing out of alignment. It full-length resizes cartridge cases with ease and will handle any bullet making job with the appropriate swaging dies. Shell holders snap into the ram and the base is fitted with a primer catcher.

Figure Nine
PRIMER PRESS

The RCBS priming press incorporates an automatic primer feed and produces superior leverage while maintaining precise feel for repriming cases. Case priming production is increased and precision primer seating is insured.
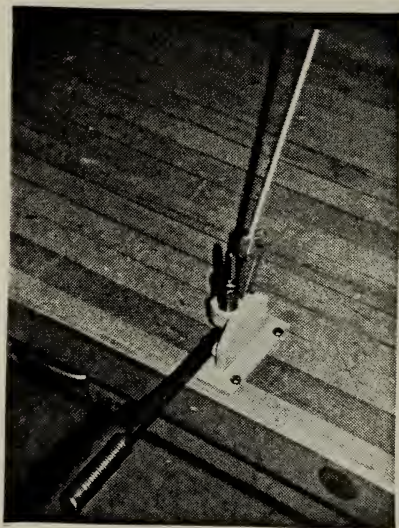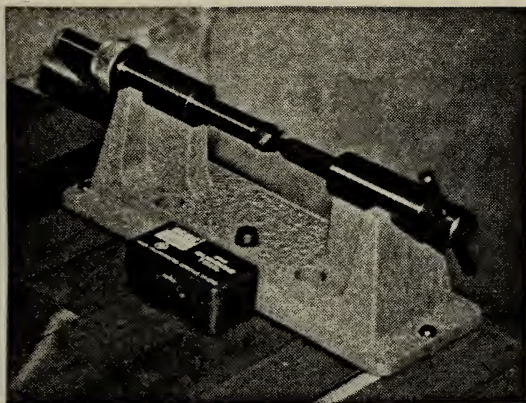
Figure Ten

CASE TRIMMER

The RCBS case trimmer insures uniform
case length. It operates as a miniature
lathe and allows precise control of case
length for use in high pressure loadings.

Figure Eleven

CASE TUMBLER

The Thumbler case tumbler
reduces the work required
for reloading by cleaning
and polishing cases while
the reloader is busy with
other tasks. It facilitates
case inspection and insures
an oil-free case, necessary
in high pressure loads.
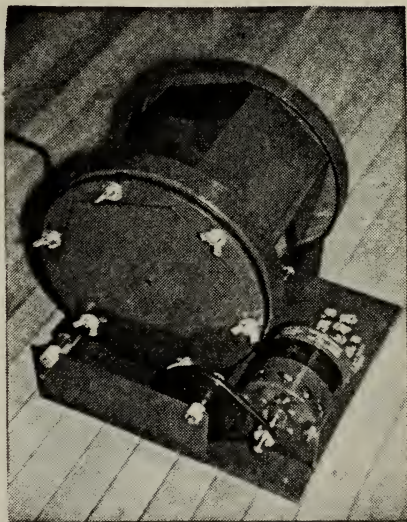
.Figure 12

LEAD POT AND CORE MOULDS

The Lee lead pot and Corbin core moulds
are used to produce lead cores necessary
for swaging 45 and 22 caliber bullets.
The lead pot has a bottom pour capability
which decreases the amount of lead fluxing
necessary. The Corbin core moulds produce
four precision cores at a time and are fully
adjustable for core weight.

Figure 13

SWAGING PRESS

The Herter's swaging press
and dies were altered spe-
cifically to produce 140, 350,
and 550 grain cylindrical
projectiles for the 45 caliber
gun. Production is slow on
the illustrated press, but
adequate for the anticipated
volume needed.

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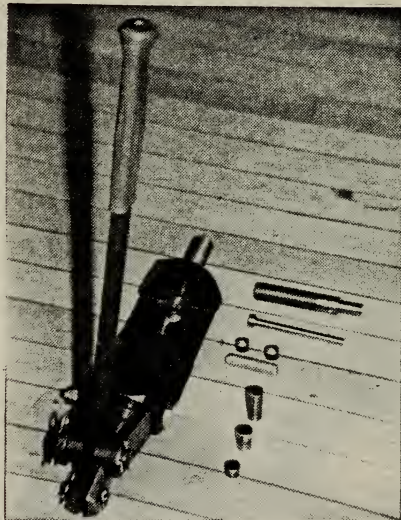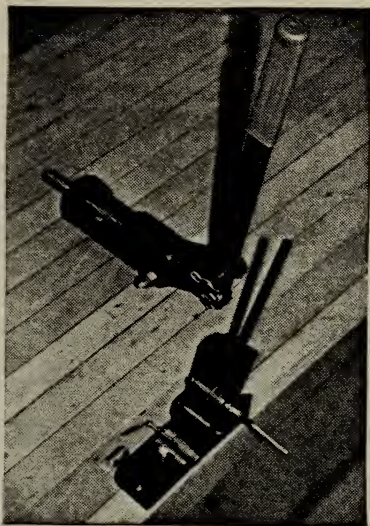
Figure 14
CANNELURE TOOL

The Corbin cannelure tool (illustrated with the Herter's bullet swaging press) is used to cannelure gas checks onto lead cores while making 45 caliber cylindrical projectiles. The cannelure process insures that the gas check and lead core will stay together upon firing.

Figure 15
OVERVIEW

Reloading equipment as arranged on reloading bench.
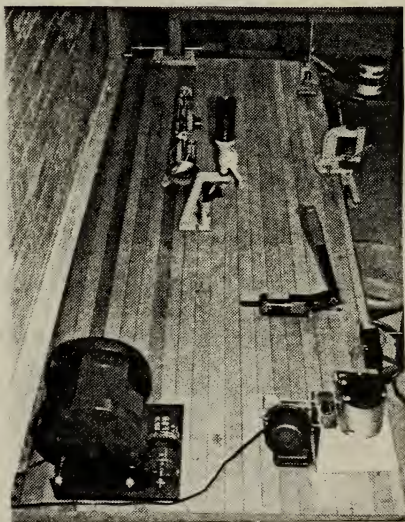
E. BULLET SELECTION

The selection of projectiles for this project was straight-forward.
The full range of capability of each caliber was to be investigated, so
the lightest possible bullet, heaviest possible bullet, and an inter-
mediate weight bullet were chosen.

In the 45-caliber barrel the lightest bullet was 140 grains. That
was the lightest weight possible because the length of the projectile
was less than the bore diameter. A lighter bullet could possibly turn
in the bore, become lodged and constitute an obstruction for the next
round. The heaviest 45-caliber bullet was dictated by equipment
limitations. The longest possible bullet in the cylindrical configura-
tion weighed 550 grains. The intermediate weight chosen was 350
grains. A 350 grain bullet falls in the middle of the range of weights
of sporting bullets for the .458 bore diameter. (Figure 16).

The form of the .458 diameter projectiles was chosen for several
reasons. In the cylindrical shape a gilding metal gas check can be
inverted over the nose of the bullet, thus protecting the test sample
from the effects of a mushrooming soft lead nose. Since the 45-caliber
barrel is used primarily for low velocity experimentation, the protected
nose would seem to remove one more variable. It should be noted,
however, that with an exposed lead nose the nose shape can be changed
simply by changing the nose punch in the final step in the bullet making
operation.
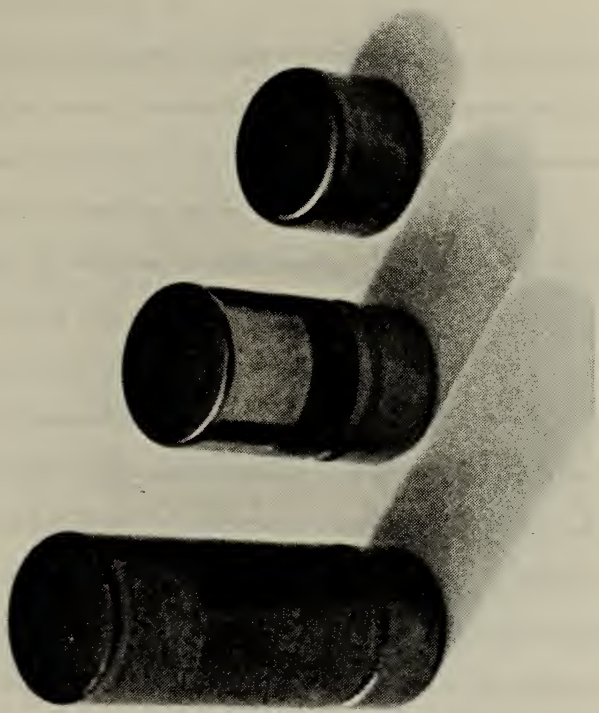
Figure 16

45-CALIBER BULLETS

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Another reason the cylindrical shape was chosen was because that shape gives the shortest overall length for any given weight. While that is mildly detrimental with the lightest bullet, it permits the heavier projectiles to be stabilized at low velocities with the given barrel twist [Ref. 4].

Finally, the cylindrical shape allows a harder alloy to be used in the swaging process. Generally, a commercially pure lead is used when swaging bullets because the harder alloys require excessive force to form the desired shape. If an alloy is first cast in a cylindrical shape, it requires minimal sizing. The use of harder alloys allows the use of scrap lead which is generally too hard for normal swaging operations [Ref. 10].

In the 22-caliber barrel the lightest possible bullet was 27.5 grains. The lower weight limit was dictated by equipment limitations. The production of a lighter projectile was impractical because the gas check used and the conical nose shape -- when filled completely -- weighed 27.5 grains. Additionally, at the high velocity anticipated, the 27.5 grain bullet is extremely overstabilized (overstabilized in that it is spinning faster than is required to stabilize that length projectile) due to the rate of rifling twist. With a lighter bullet the overstabilized condition would have been even more pronounced. The heaviest 22-caliber bullet was 63 grains and the medium weight bullet chosen was 45 grains. (Figure 17).
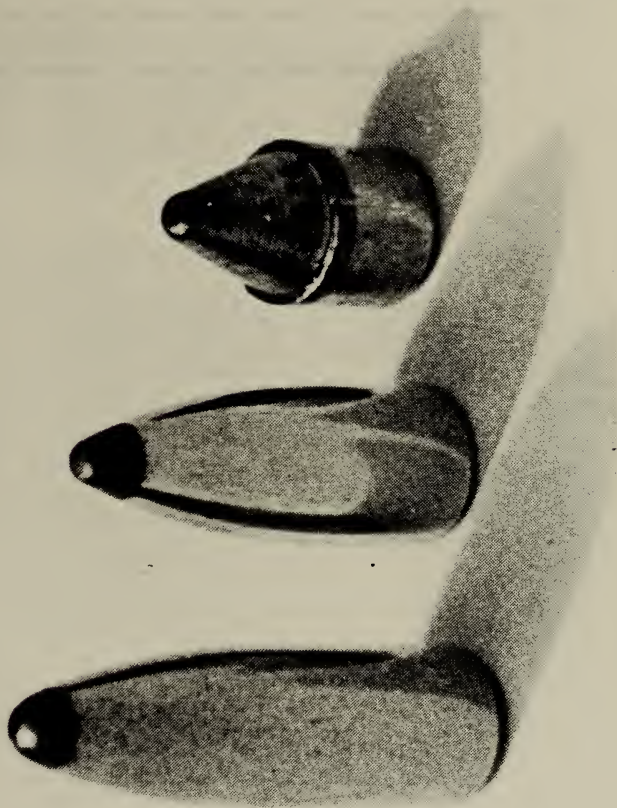
Figure 17
22-CALIBER BULLETS

The form of the 22-caliber bullets was chosen because they were the easiest to produce and were compatible with the high velocity application. The two heavier weights were commercially produced and the light weight spire point was the most efficient design for the weight desired and the velocities anticipated.

III. PROCEDURE

A graphical system was chosen to represent the data gathered. Rather than firing five or ten rounds with a given powder charge, averaging the string, and publishing the average as a single load, the following method was adopted.

After powders were chosen as being appropriate for a case and bullet weight (generally the choice was made based on previous experience with the powder), they were loaded in increments of one grain (or five grains) from an intermediate point up to the point where high pressure was indicated or where the case was completely filled with powder. The load was then reduced from the intermediate starting point by one grain (or five grain) increments to the point where a satisfactorily low velocity was obtained, the case failed to seal the chamber, detonation was experienced, or the velocity spread for a given charge was excessive. (The five-grain increment was chosen over the one-grain increment where pressures were not critical, and in an effort to conserve components.)

After the loads were fired, the velocities were plotted and a polynomial least squares curve fit of order three was used to fit a curve to the plotted data. (Note: The polynomial least squares curve fit of degree three worked very well. While higher degrees in some

cases fit the data slightly better, the increased accuracy was not significant.) The completed graph could then be read for any desired intermediate powder charge or velocity.

Great care was taken to list only loads that were safe and reliable in the two test barrels. Erratic loads in both the high and low pressure ranges were omitted in the curve fit graphs.

The following factors contributed to the uniformity of the test results:

1. Brass was either new or once fired.

2. Cases were of the same manufacture and lot number.

3. Cases were trimmed to the minimum length.

4. Flash holes were checked for uniformity.

5. All projectile weights were within 0.1 grain of their listed weights.

6. Powder charges were weighted (not thrown from a measure).

7. Primers were of the same manufacture and lot number.

8. A "warmer" shot was fired before each new string.

9. The barrel was cleaned prior to each new string.

10. A uniform period of time was allowed between strings of three shots for barrel cooling.

IV. DISCUSSION OF RESULTS

The results as illustrated in graphs one through fourteen are self-explanatory. However, several observations should be made.

In general a middle range of charge weights was apparent where the shot-to-shot consistency was very high. Toward both the high and low ends of the data the scatter became much more pronounced. The increased velocity dispersion from shot to shot with a single powder weight became a warning that the outer bounds of the powder's design pressure range had been exceeded. Loads beyond the design pressure range generally exhibited other signs of deficiency in addition to velocity spread.

Special note should be taken of graphs two, three, five, and six. In the loads plotted in graphs three and six no dacron filler was used. The results were obviously extremely inconsistent and the dacron filler was used in all other 45-caliber loads. The position of the powder charge in the case at the time of ignition was obviously extremely important. The dacron filler served to hold the powder charge uniformly close to the primer. It was concluded that in a large capacity case light charges of powder distributed throughout the case causes incomplete ignition in most cases, and in a few cases detonation. A comparison of graph two with graph three, where all

other factors were equal, will illustrate the point. No dacron filler was used in the 22-caliber case because the loading density was high and the bottle-necked case displayed a lesser tendency toward partial ignition [Ref. 11].

Several case failures were experienced while testing the 140-grain 45-caliber bullet. (Figure 18) With the faster burning powder (unique) in the heavier charge weights, the shock of ignition and the sharp pressure rise were sufficient to expand the base of the bullet against the case and cause a stretched case neck or complete separation. That type of failure constituted an upper bound for loads with Unique powder and the exposed lead base bullet. Apparently the slower burning powder (IMR 4227) had a slower pressure rise and consequently did not deform the base of the bullet to as great a degree.

The 27½ grain bullet tested in the 22-caliber barrel was disappointing. The bullet was easily damaged in loading and the shot-to-shot consistency was not as good as the 45-grain or 63-grain bullets. Well over 5000 feet per second was expected but never achieved due to the projectile breaking up around 4,900 feet per second. The area of exposed lead was large, the projectile was highly over stabilized, and these, combined with any minor damage in loading, resulted in poor accuracy at best and a necessitated chronograph screen replacement at worst.

Since the data obtained in these tests are to be used by others, duplicability is very important. In general, velocities can be
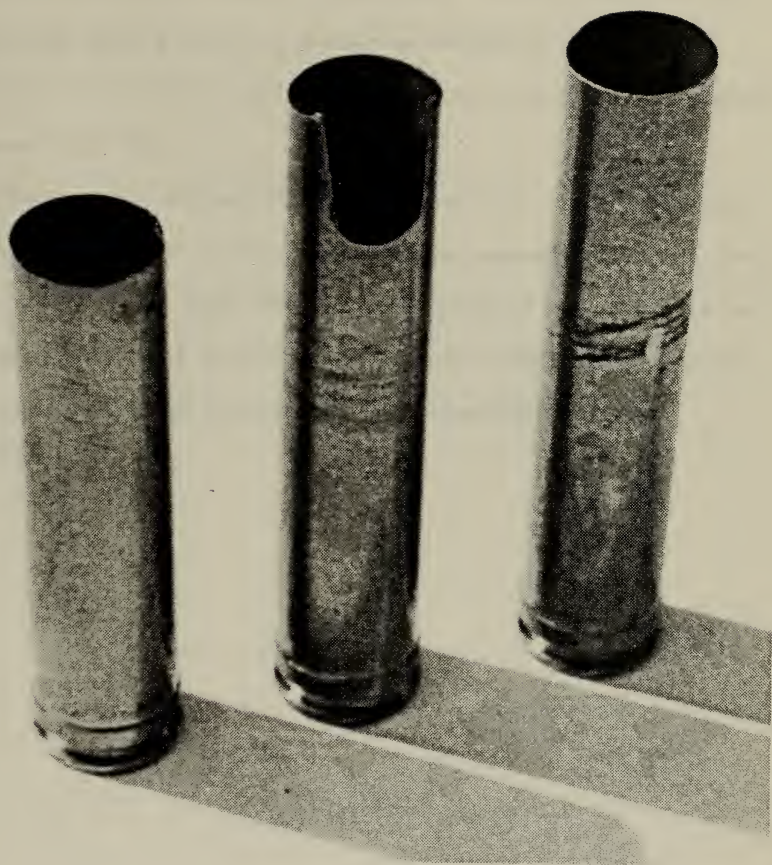
Figure 18
45-CALIBER CASE FAILURES

predicted through the load range to an average 3.5 per cent. Toward the center of the load range the error expected in prediction is less than 1.5 per cent.

All the initial firing was done in the jet test cell at ambient temperatures of around 50 degrees Fahrenheit. The controlled environment the range now enjoys is 70 degrees Fahrenheit. Therefore a correction factor for the change in temperature increases the prediction accuracy [Ref. 12].

The accuracy obtained with all loads, with the exception of those with the 27 ½ grain 22-caliber projectile, was exceptional. Time after time, strings of ten shots with a velocity spread of a thousand feet per second or more were fired into less than .375 inches center to center. Shot placement to any desired point was exceedingly easy and consistent.

V. CONCLUSIONS AND RECOMMENDATIONS

The ballistic range as developed comprises a facility suitable for testing any of the broad range of materials. The inherent accuracy displayed during the testing makes possible the use of small samples and the confident use of other equipment in the immediate impact area.

Where possible, the loads near the center of the range of loads listed should be used for best velocity uniformity. Velocity predictability in that area was extremely good.

A velocity correction of 50 feet per second should be added to the listed data to correct for the controlled environment temperature. The 50 feet per second correction is not exact but, in every case tried, yielded a better correlation to the velocity obtained than using the original data.

One-half grain of dacron filler should be used with all 45-caliber loads. The resulting increased uniformity is marked and the resulting decrease in powder capacity in the high density loads is insignificant. Gas checks for the 45-caliber loads should be crimped carefully to the body of the projectile to keep them from becoming detached in flight. With the heavy bullets and heavy loadings in 45-caliber, the recoil sets the RBMR at its stops. Heavier loads than listed are possible, but should be approached with caution and used only sparingly.

If loads are desired other than those listed, a good rule of thumb to use with the IMR series powders is that a 10 per cent increase in powder weight yields a 10 per cent increase in velocity and a 20 per cent increase in pressure. That rule was used during the test firing and found to be reasonably accurate.

When using high energy or high velocity loads, the point of impact on the bullet trap should be moved periodically to prevent deep penetration of the armor backing. A series of twenty 22-caliber high velocity rounds will, at the end of the string, produce a significant scattering of fragments back out of the bullet trap, if the point of impact is not changed.

As the barrels are used (particularly the 22-caliber) their characteristics may change. For example, the high velocity 22 will gradually erode its throat due to the high pressures and temperatures involved. After a throat is eroded, bullet jump from cartridge to bore increases and pressures and velocities decrease. Therefore in an eroded barrel more powder is required to reach the same velocity obtainable with a smaller charge in a new rifle.

Finally, all firing should be done with more than one person present. Safety cannot be overemphasized.

APPENDIX A

Figure A-1

Velocity vs. Powder Weight
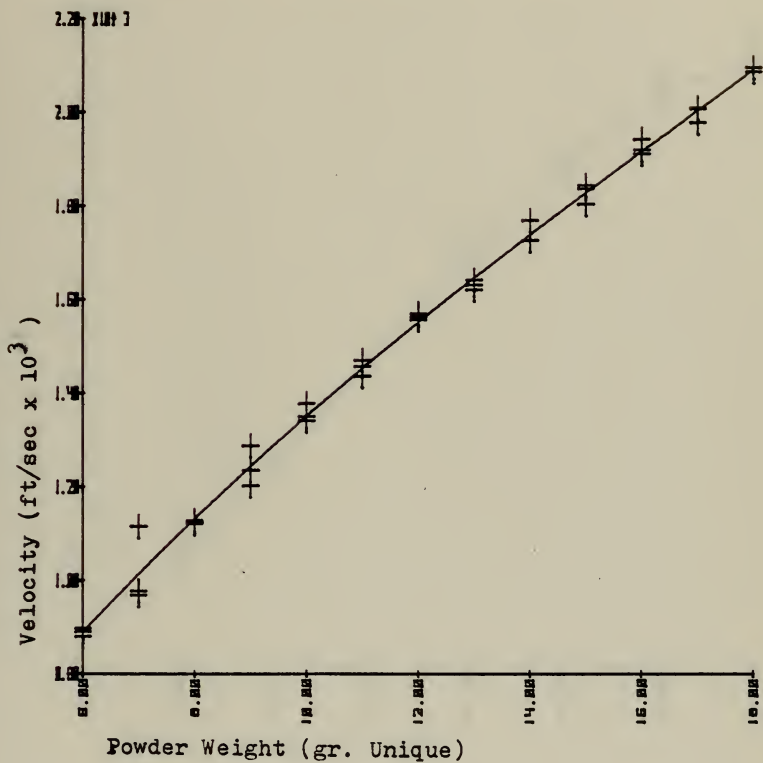
Graph 1

.458 dia.
140 gr. Button
Unique powder
Rem. 9½m primer
Rem. cases (458 Win. Mag.)
½ gr. Dacron filler

Figure A-2

Velocity vs. Powder Weight
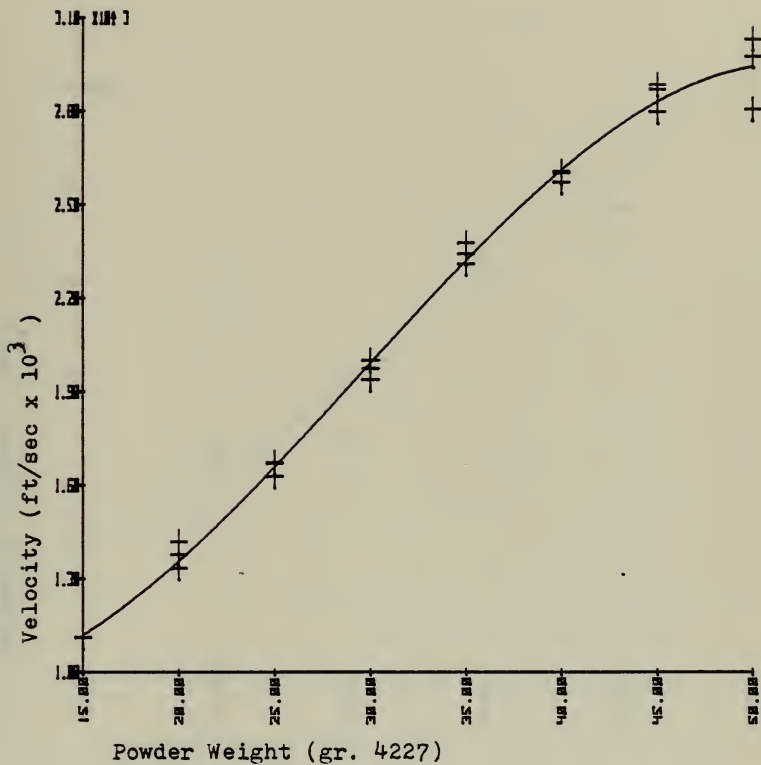
Graph 2

.458 dia.
140 gr. Button
IMR 4227 powder
Rem. 9½m primer
Rem. cases (.458 Win. Mag.)
½ gr. Dacron filler

Figure A-3

Velocity vs. Powder Weight
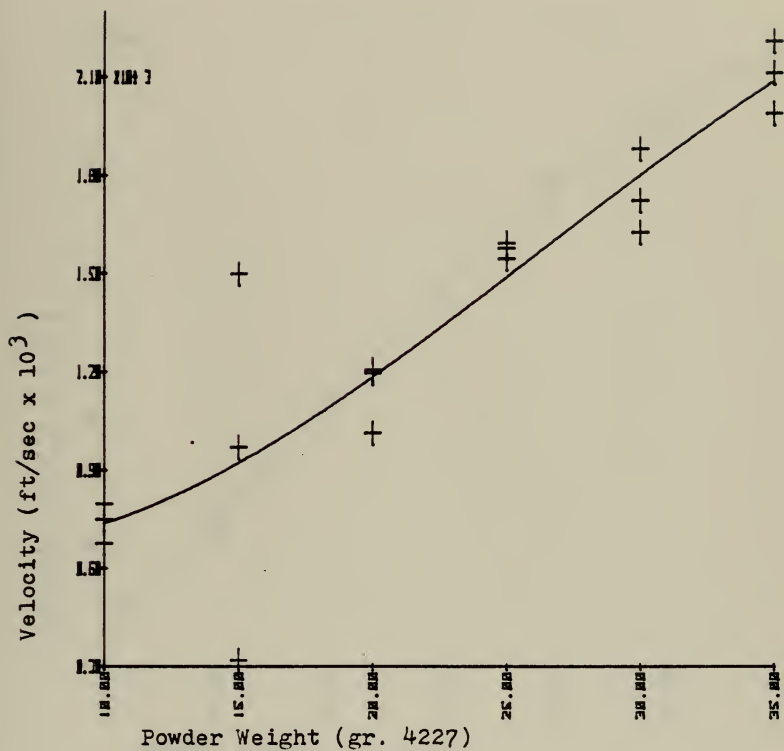
Graph 3

.458 dia.
140 gr. Button
IMR 4227 powder
Rem. 9½m primer
Rem. cases (.458 Win. Mag.)
No filler

Figure A-4

Velocity vs. Powder Weight
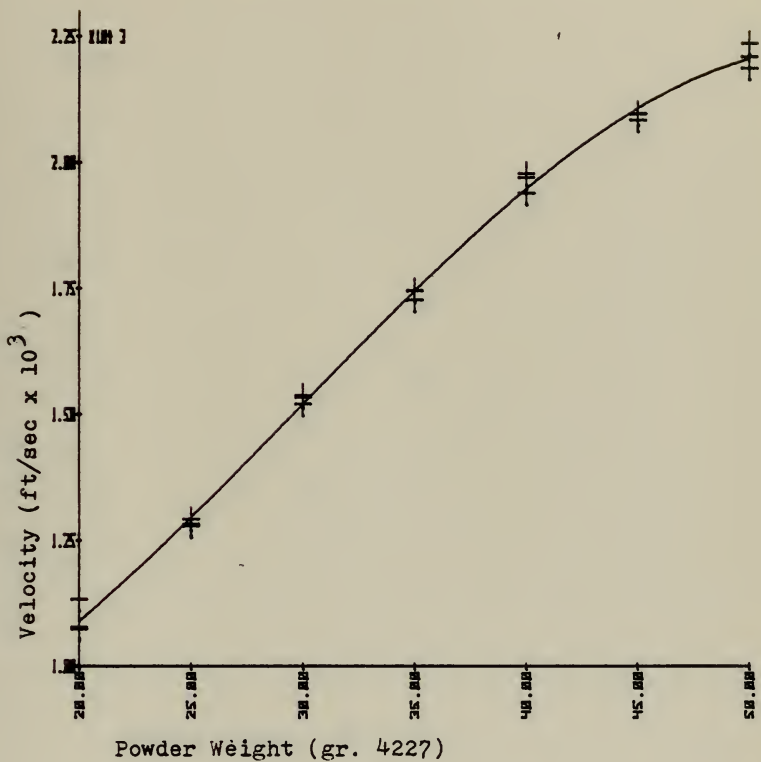
Graph 4

.458 dia.
350 gr. W. C.
IMR 4227 powder
Rem. 9½m primer
Rem. cases (.458 Win. Mag.)
½ gr. Dacron filler

Figure A-5

Velocity vs. Powder Weight
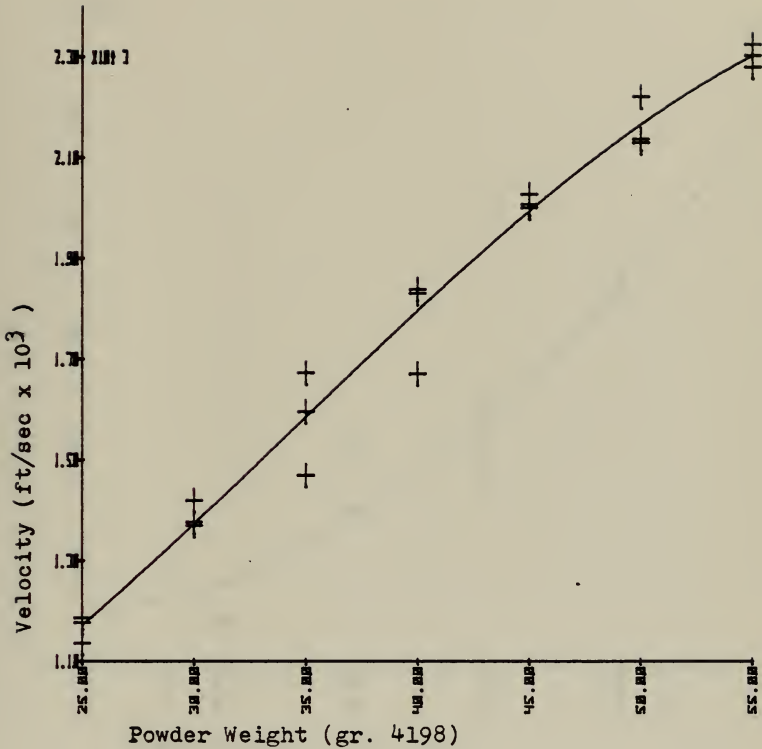
Graph 5

.458 dia.
350 gr. W. C.
IMR 4198 powder
Rem. 9½m primer
Rem. cases (.458 Win. Mag.)
½ gr. Dacron filler

Figure A-6

Velocity vs. Powder Weight

Powder Weight (gr. 4198)

	.458 dia.
	350 gr. W. C.
Graph 6	IMR 4198 powder
	Rem. 9½m primer
	Rem. cases (.458 Win. Mag.)
	No filler

Figure A-7

Velocity vs. Powder Weight
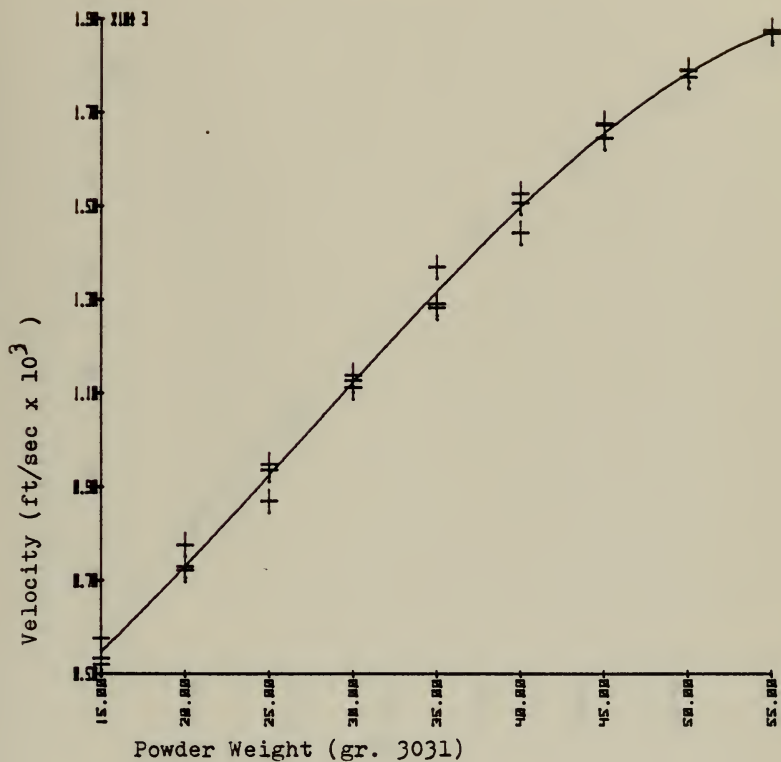
Graph 7

.458 dia.
550 gr. W. C.
IMR 3031 powder
Rem. 9½m primer
Rem. cases (.458 Win. Mag.)
½ gr. Dacron filler

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Figure A-8

Velocity vs. Powder Weight
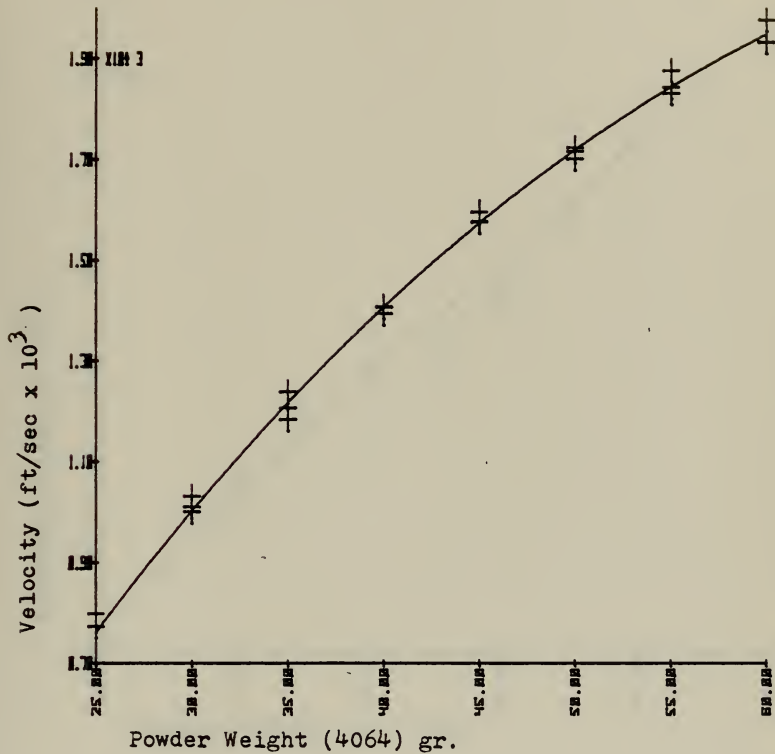
Graph 8

.458 dia.
550 gr. W. C.
IMR 4064 powder
Rem. 9½m primer
Rem. cases (.458 Win. Mag.)
½ gr. Dacron filler

Figure A-9

Velocity vs. Powder Weight
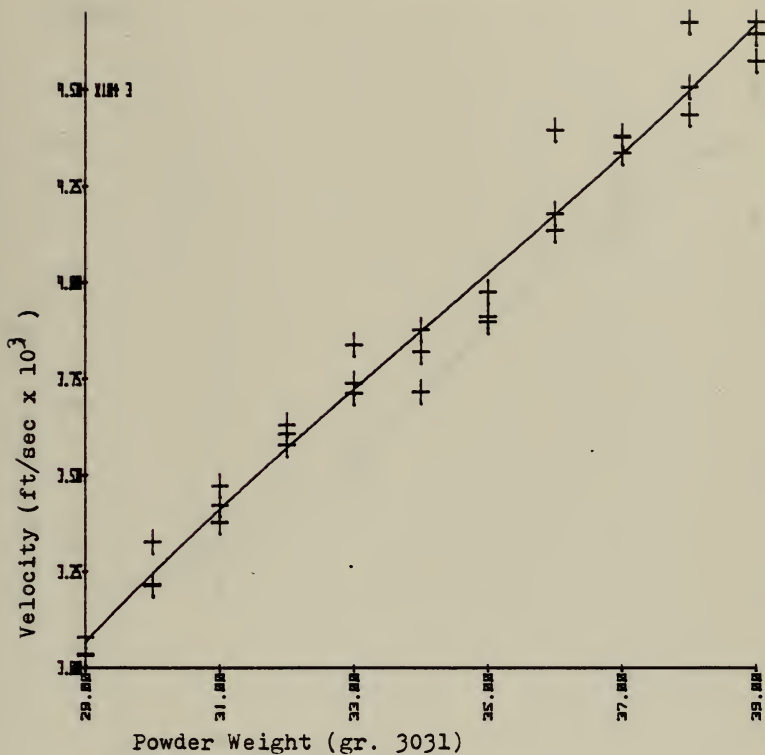
Graph 9

.224 dia.
27½ gr. Spire point
IMR 3031 powder
Rem. 9½m primer
Win. cases (22-250 Rem.)
No filler

Figure A-10

Velocity vs. Powder Weight
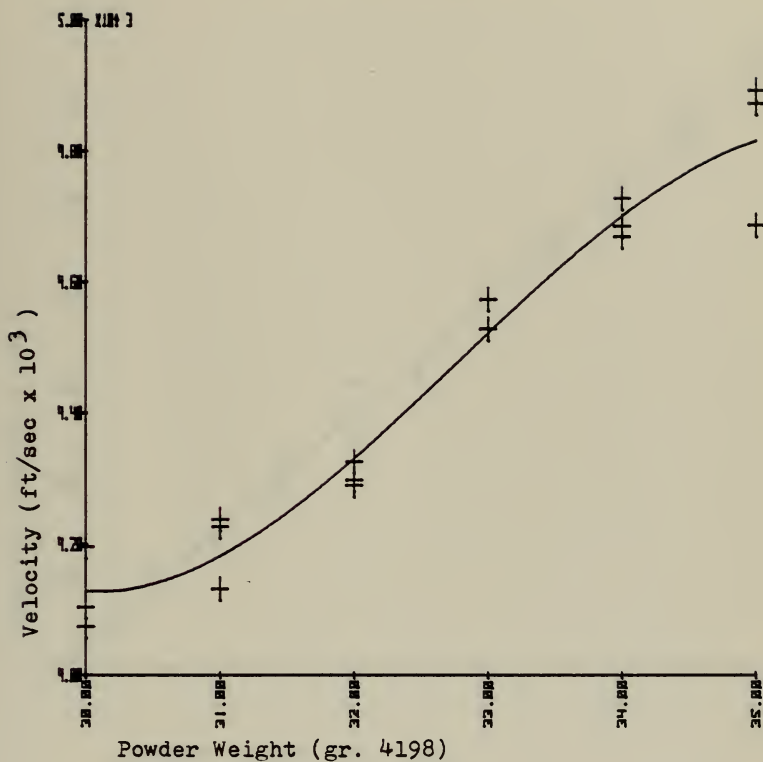
Graph 10

.224 Dia.
27½ gr. Spire point
IMR 4198 powder
Rem. 9½m primer
Win. cases (22-250 Rem.)
No filler

Figure A-11

Velocity vs. Powder Weight
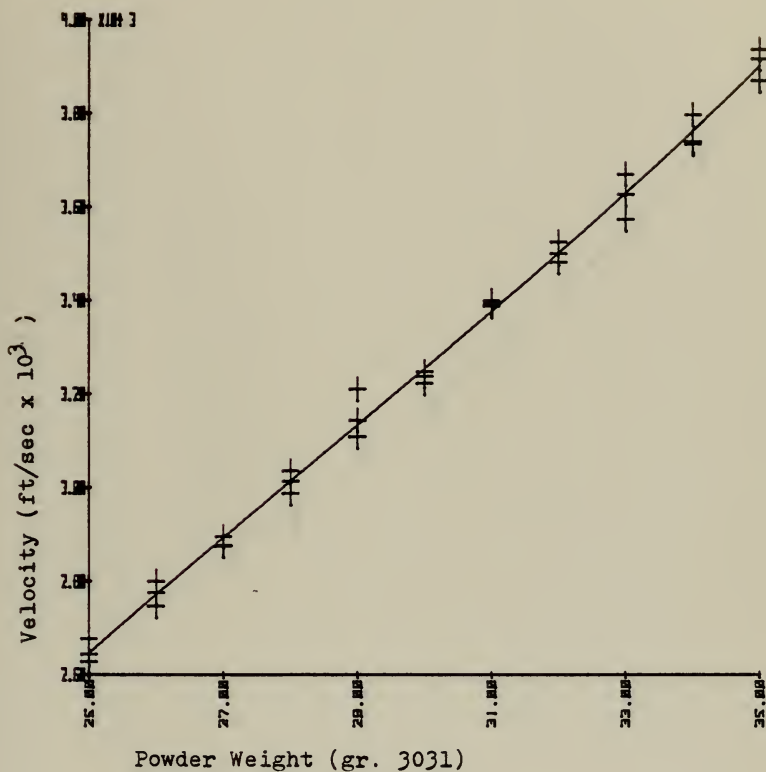
Graph 11

.224 dia.
45 gr. Pointed Soft Point
IMR 3031 powder
Rem. 9½m primer
Win. cases (22-250 Rem.)
No filler

Figure A-12

Velocity vs. Powder Weight

Velocity (ft/sec x 10²)

Powder Weight (gr. 4064)
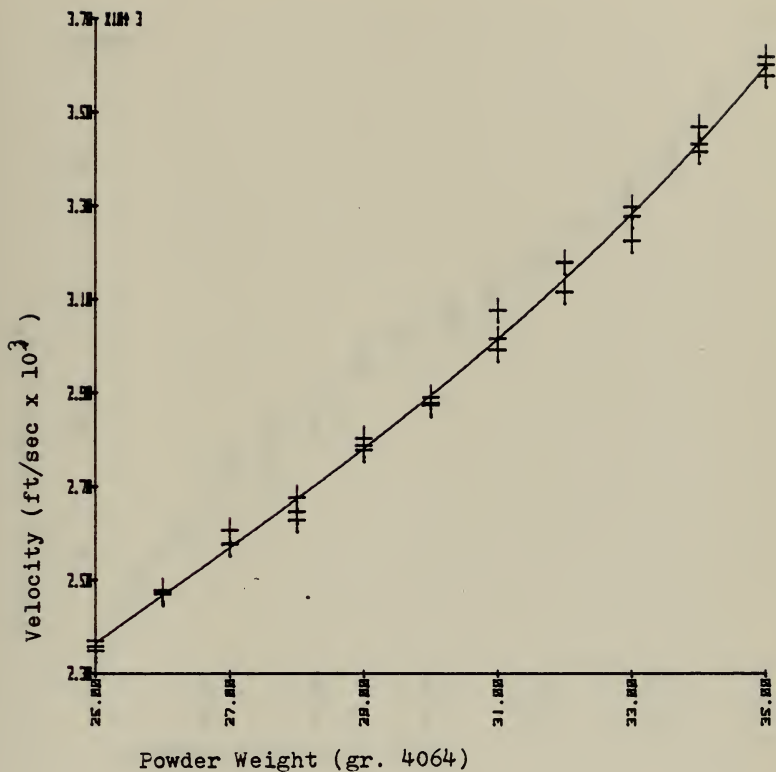
Graph 12

.224 dia.
45 gr. Pointed Soft Point
IMR 4064 powder
Rem. 9½m primer
Win. cases (22-250 Rem.)
No filler

Figure A-13

Velocity vs. Powder Weight
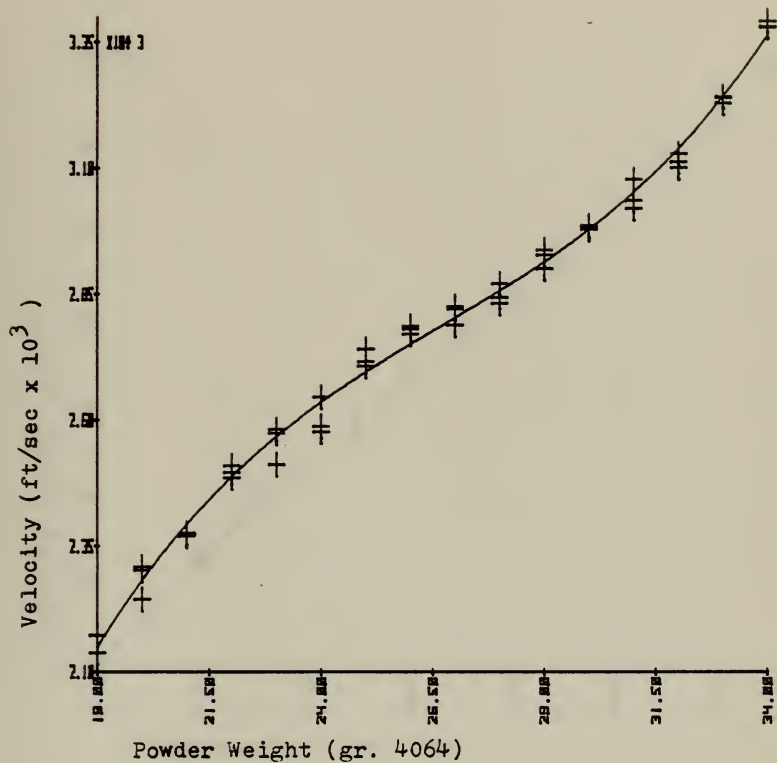
Graph 13

.224 dia.
63 gr. Pointed Soft Point
IMR 4064 powder
Rem. 9½m primer
Win. cases (22-250 Rem.)
No filler

Figure A-14

Velocity vs. Powder Weight
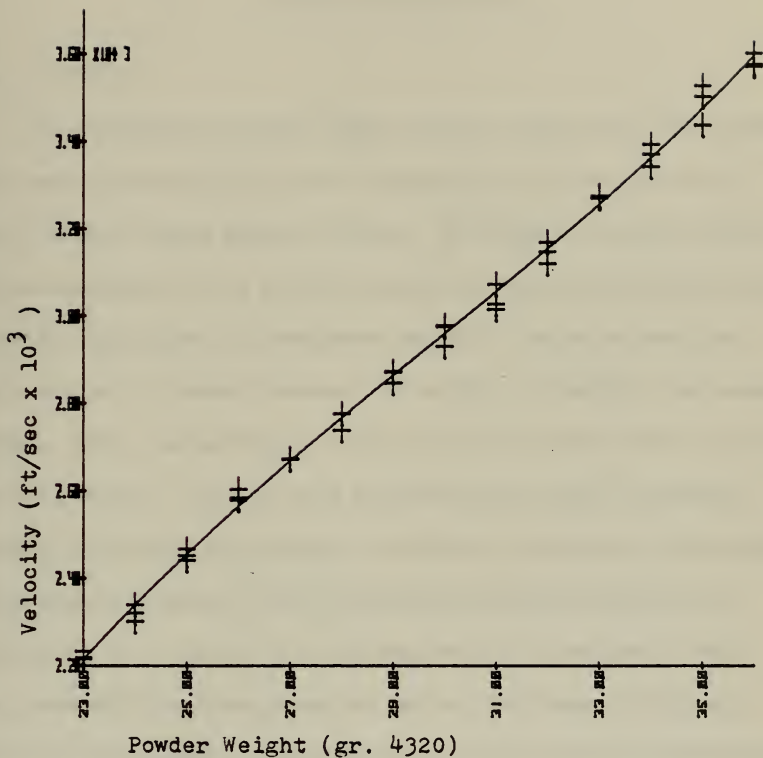
Graph 14

.224 dia.
63 gr. Pointed Soft Point
IMR 4320 powder
Rem. 9½m primer
Win. cases (22-250 Rem.)
No filler

APPENDIX B

I. RANGE DESCRIPTION

A. PURPOSE

The composite materials impact research laboratory was designed
as a multi-purpose tool for use in determining material reactions
under widely varying impact loadings. An example of its use would be
the determination of the relative importance of momentum and kinetic
energy in the failure of a composite sample. The range itself was
built with an eye toward maximum versatility, variability, and expand-
ability. Hence the equipment selected was of the most direct and robust
nature available. Cost of every component was critical so outside
purchase, although unavoidable, was held to a minimum, and maximum
utilization was made of Naval Postgraduate School manufacturing
facilities. By long lead-time planning the item of equipment which
was potentially the most expensive, namely the Return-to-Battery
Machine Rest (RBMR), was produced in the Aeronautical Engineering
Shop.

B. EQUIPMENT

The RBMR was considered absolutely necessary due to the ex-
treme accuracy required while firing between expensive equipment

located in the impact area. Accuracy over a wide range of velocities, energies, and momenta could not be compromised. The most readily available and widely known plans for the required RBMR were those produced by Hornady Manufacturing Company, Box 1848, Grand Island, Nebraska 68801. The blueprints were obtained and once material procurement was completed manufacture commenced. That manufacture required extensive machine work and the cost to contract such work would be high. If such equipment is desired and time is a driving factor, or machine shop or heat treatment facilities are not available, there are a number of adequate commercial machines. (One maker of machine rests is B. L. Broadway, Route 1, Box 281, Alpine, California 92001.)

The chosen design incorporated a return-to-battery feature. That system is generally accepted as the most reliably accurate and is used throughout the sporting arms and ammunition industry for testing bullet quality. The gun itself is mounted on a free-recoiling carriage which rides on hardened rails. The carriage is manually returned to its initial position after each firing. That repositioning is very accurate from firing to firing, and the vibrational pattern of the entire unit is consistent from shot to shot [Ref. 11]. (Figure B-1).

Two pieces of equipment which are only slightly less important to the basic range are the chronograph and the bullet stop. The chronograph used was the Oehler Research Model 31 Chronotach with
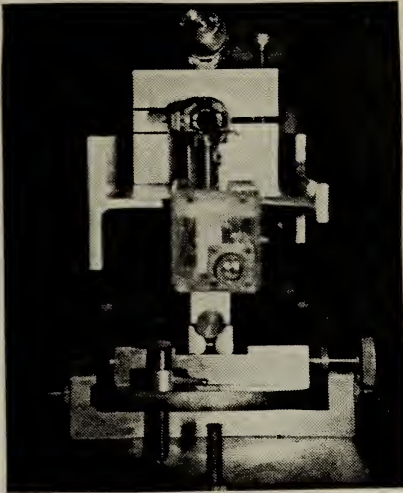
B-1.a Breech View
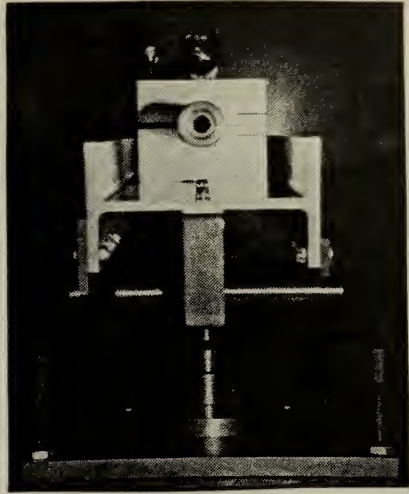
B-1.b Muzzle View

Figure B-1

RBMR THREE-VIEW
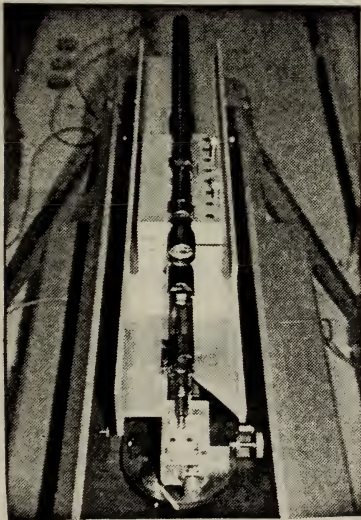
B-1.c Top View

Model 51 Ballistic Screens. (Figures B-2 and B-3). The Model 31 was chosen because it gives a direct velocity readout without reference to tables or any computation. The unit wiring can be easily changed internally via "push-on" connectors to compensate for different screen spacings of five, ten, or twenty feet. That variability in screen spacing adds to the chronograph's versatility when used in cramped laboratory conditions. The Model 51 Ballistic Screens were chosen because of their ruggedness, placement versatility, and extreme velocity range. They will detect projectiles of 0.17 caliber and larger at velocities from 200 feet per second to well over 5,000 feet per second. The screens will operate under any conditions of ambient light from darkness to direct sunlight.

The bullet trap used initially was wholly unsophisticated and barely adequate. It was a home-made affair with a one and one-quarter inch armor plate backing, left over from a previous project. The replacement bullet trap incorporated a vent system and much heavier construction. Provision was made on the trap system table to incorporate the mounting of various forms of load frames for future needs. (Figures B-4 and B-5).

C. PHYSICAL LAYOUT

The layout of the range was straight-forward and is versatile in the extreme. The dimensional relationships between the various items of equipment were determined by the desired range use, the projectile

Figure B-2
CHRONOGRAPH

Figure B-3
CHRONOGRAPH SCREENS
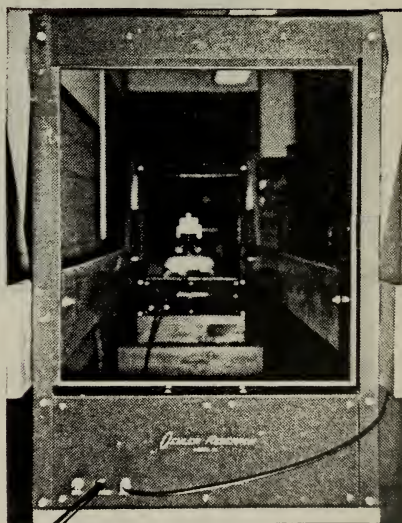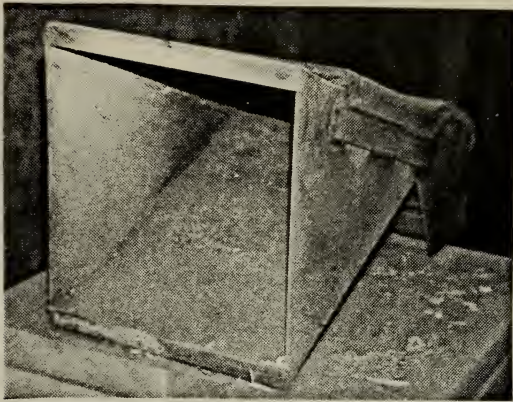
Figure B-4
OLD BULLET TRAP
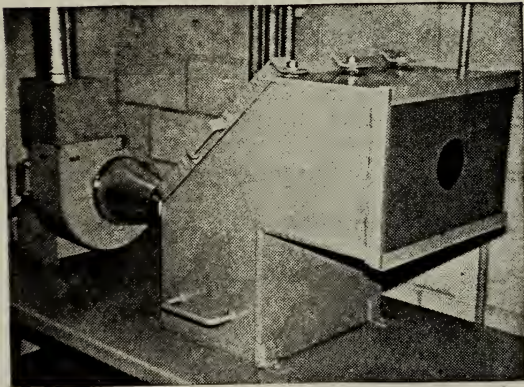
Figure B-5
NEW BULLET TRAP

limitations, and the space available. The minimum basic range width, disregarding photographic, photoelastic or other specialized equipment, is six feet. That dimension gives adequate working as well as equipment room. The minimum length can be as short as fifteen feet. As indicated, the screen spacing is critical but can be varied to as short as five feet. The muzzle-to-screen distance is not critical with the use of a blast shield. In general, the range is portable to a limited extent, takes a minimum of space, and requires only conventional 120-volt AC power. (Figure B-6).

II. BALLISTICS

A. EXTERNAL BALLISTICS

The following summary of external ballistics history is given for background purposes only. In the present application the understanding of practical internal ballistics is much more important. However, historically the desired external results have dictated what was attempted either knowingly or unknowingly internally. For the most part, that is exactly the current situation. One has a desired trajectory, accuracy level, energy or momentum level, or some other externally measurable property of the projectile and tries to achieve his goal through changing the internal ballistics.

The study of ballistics has existed as a technical art for thousands of years. The word "ballistics" is of Greek origin and can be traced
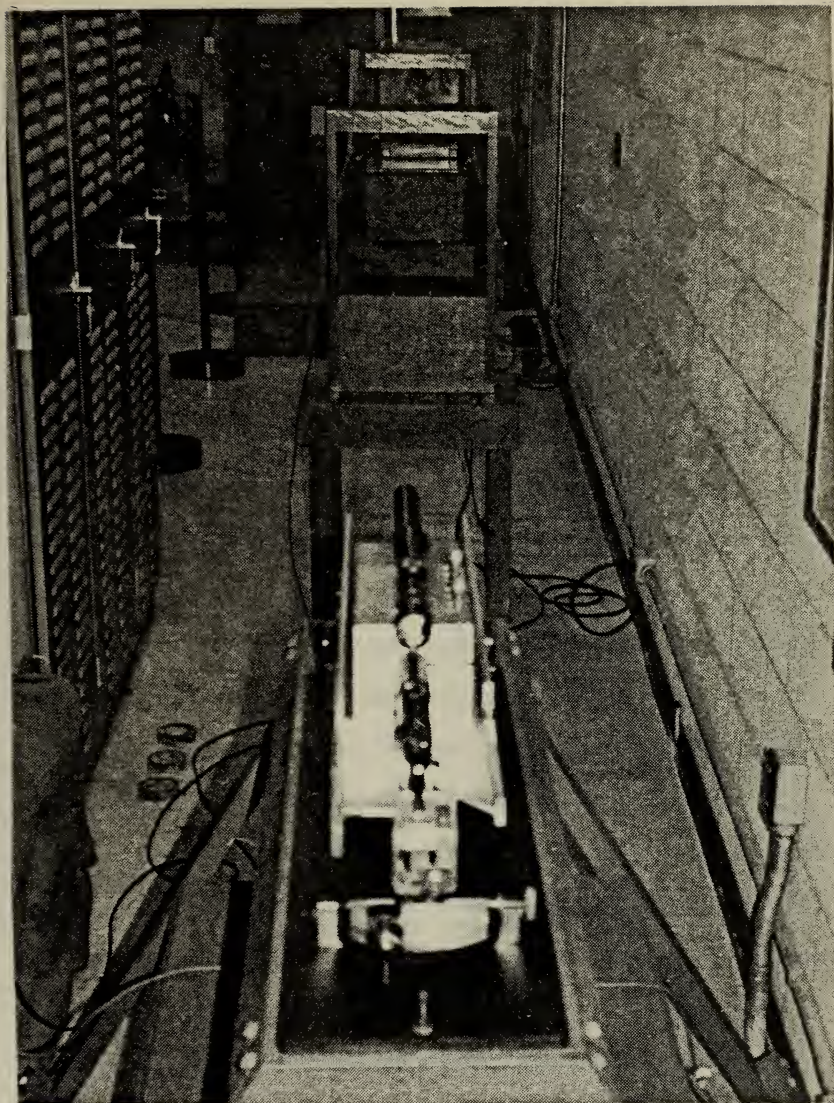
Figure B-6
DOWN RANGE

to writings on the design of throwing machines or ballistae. Research on ballistae was important as early as 300 B.C., and throwing machines and specialized projectiles date to man's earliest use of tools.

The development of ballistics as an orderly science probably dates from the time that firearms were introduced into warfare in western Europe. Early in the fifteenth century many of the most energetic investigators turned to, or were commissioned to, the study of the new war machines. That investigation has continued undiminished through the centuries. The best qualified people were commissioned to work on the problems of designing better guns for all purposes and computing accurately the flight and effect of the projectiles. The most highly respected names in science and mathematics have been associated with the development of ballistics, including Leonard Euler, Isaac Newton, Francis Bacon, and Leonardo da Vinci, among others. It should be noted that money spent on the study of ballistics directly spurred the development of mathematics, mechanics, dynamics, and aerodynamics. There has never been greater motivation in the sciences than the desire to obtain the upper hand in conquest or defense [Ref. 8].

The trajectory of an airborne projectile is determined by basically three factors: its initial velocity, the force of gravity and the aerodynamic forces acting on the projectile. When firearms were

first introduced in Europe, nothing was known about the relevant aerodynamic factors and very little about gravity. Curiously, almost 200 years later, the shape of the path of a bullet was still unknown. It was initially guessed that a projectile proceeded along the bore axis until it had zero forward velocity and then fell straight to the ground. Cannons and mortars were soon developed and it could be seen that the trajectories were not straight. Since it was obviously wrong to assume the shot proceeded straight along the bore axis, the theory was modified to include a straight line to the highest point of flight and another straight line from that point to the point of impact. (The straight line approximation has apparently been useful since the beginning of human endeavor!)

Finally in 1537 the Italian scientist Tartaglia wrote a book on ballistics in which he stated that the trajectory of a bullet was a continuous curve. The exact form of that curve was still unknown, but he was nevertheless commissioned to determine the angle of elevation of the bore that would achieve maximum range. He directed extensive firing tests and found 45 degrees to be close to the maximum range elevation. He also noted that the trajectory was indeed a continuous curve.

Almost exactly 100 years later (1636) Galileo published the results of experiments designed to investigate the forces acting upon the projectile. He used those results to explain why the path of the

bullet was curved, and he published the first analytical description of trajectories. His analytical approach was unproven, largely because there was no method to measure the muzzle velocity, which was a critical piece of data needed for the calculation. It is perhaps just as well since Galileo's computations omitted the aerodynamics of the projectile. He neglected the drag for two reasons: first because he thought its effects were small when compared with the effects of gravity, and because he simply had no way to measure it.

Slightly more than another 100 years passed before a way to measure velocity was devised. In 1740 Benjamin Robins invented the ballistic pendulum in England. Robins worked extensively with 12 gauge (75-caliber) musket balls. His experiments were conducted at various ranges and from his data he calculated velocity, drop, and the approximate drag on the projectile. He concluded that the aerodynamic drag at 1400 to 1700 feet per second on the round musket balls was almost 85 times the force of gravity. He was widely disbelieved, but from his time on aerodynamic forces on bullets were considered most significant.

Drag was investigated extensively from the mid-1700's to the late 1800's, but theoretical investigations never did arrive at the point where the drag could be computed without experimental measurements. Drag is, of course, a complicated function of projectile shape, size, velocity and surface condition of the projectile, as well as ambient

air density and temperature. The experimental determination of drag became possible with the advent of the chronograph as developed in England and Germany in the late 1800's [Ref. 8].

During this same time period the development of firearms advanced rapidly, and the range, dependability, and accuracy of artillery and shoulder arms improved considerably. The development and application of the rifled bore, elongated bullets, percussion ignition, breech loading systems, metallic cartridges, interior ballistic theory, and smokeless powder all came about in a single century. The listed advances and others only increased the need for a good understanding of exterior ballistics. Accurate long range fire from both small arms and artillery depended on that development.

To simplify the theoretical drag computations the concept of the "standard bullet" was developed about 1850. Projectiles had evolved to the most used shape of cylindrical body, conical leading surface, and flat base. A certain size and shape was adopted as "standard" and all other sizes and shapes of bullets were related to the standard' by a constant factor. This was the birth of the ballistic coefficient. The ballistic coefficient was defined as the deceleration of the standard bullet divided by the deceleration of the actual bullet. The relationship was strictly true only if the actual bullet was a scale model of the standard bullet. Considering the difficulty of drag measurements the process was considered accurate enough to allow fairly accurate

ballistic computations for the actual bullet. In addition to the use of the ballistic coefficient, about 1580 the Italian ballistician Siacci discovered a way to simplify the required calculus calculation for the determination of trajectories. He showed that the trajectory of the actual bullet could be computed from the trajectory of the standard bullet (in the case of horizontal fire) by using the ballistic coefficient. The resulting computation required simple algebra and was much faster. Siacci's method was such a simplification that it is widely used in ballistics even today [Ref. 4].

From Siacci's contribution through the first World War every country adopted a different standard projectile and in each case the standard trajectory was computed for comparative use. Among the more significant tests were those by Krupp of Germany (1881) and by the Gavre Commission in France (1873 - 1898). The Gavre Commission work was most comprehensive and included firing tests up to 6,000 feet per second, as well as a comprehensive study of the data available from tests conducted by other countries. Unfortunately, since the tests and study spanned such a long period of time, varying atmospheric conditions introduced significant errors. Shortly after the commission's work, standard atmospheric conditions for the reporting of drag data were adopted and generally used.

The Krupp test data were used most extensively as the basis for ballistics tables for small arms, especially sporting and target

ammunition. The standard Krupp bullet had a flat base, was three calibers long, and had a two caliber ogive nose. Shortly after the Krupp tests a Russian Army Colonel named Mayevski determined a mathematical model for the standard drag deceleration for the Krupp bullet. Colonel James M. Ingalls, U. S. Army, used the Mayevski analytical model, the Krupp standard bullet and computed a complete set of ballistic data for that design. His results were published as the "Ingalls' Tables," and they were used for years as the departure point for computing the ballistics of most bullets for sporting use.

In 1947 the Ballistics Laboratories of Aberdeen Proving Grounds conducted an extensive series of firing tests using sporting bullets exclusively. Subsequently they published four standard drag models based on four types of bullets. The four types were: lead-nose hollow point, boattail, sharp-pointed full patch, and "all others." It turned out, interestingly enough, that the "all others" category was almost identical to the earlier Krupp model. In any case, the Aberdeen tests are the most comprehensive to date, and standard drag deceleration for current sporting (and many military) rounds are found by using their results. There is no doubt that there are more precise analytical computer methods now available to obtain the desired drag decelerations. However, the Aberdeen results are adequate, well-known, and relatively inexpensive to use [Ref. 6].

It should be noted that the same factors which tend to increase drag on a projectile in the atmosphere also tend to increase the drag on the projectile in any other medium. The effects of a change of medium on rates of energy transfer should be obvious. In any medium the methods for computing the drag would be similar to those mentioned above.

B. INTERIOR BALLISTICS

External ballistics depend to a great extent on what happens to the projectile while it is in the bore, since it is there that it achieves the velocity that plays such an important role in its external ballistics. Thus to achieve the desired external effects, the internal processes must be controlled. It is in this area that expertise is truly needed to effectively produce the desired results on the range. Once again a reference to history and an explanation of terminology is imperative.

The most important factor is pressure. In this work the word pressure means explicitly chamber pressure. It is that pressure which accelerates the chosen projectile down the bore and consequently imparts upon it its initial (or muzzle) velocity. Reloading techniques for the RBMR are designed to efficiently harness that pressure. Pressure must be held within the limits of safety, and in order to keep it within those safe bounds a practical knowledge of chamber pressure effects is necessary.

Almost everyone has a general idea of what happens when a cartridge is fired in the chamber of a firearm. When the primer is ignited, by percussion or electrically, it explodes. The charge of powder is started burning by the primer flash. As the powder burns, it produces a great quantity of hot expanding gases which in turn produce a building pressure in all directions. That increased pressure and temperature aids the burning of the remainder of the charge and pressures continue to build. The pressure of the burning charge pushes against the case head driving the cartridge case against the breech face, and it expands the case walls against the chamber walls to produce a gastight seal. As the pressure builds it drives the projectile with increasing velocity down the barrel. Of vital concern to the reloader is how high the pressure builds, how safely it can be contained, and that it produces the desired effects on the projectile.

For many years chamber pressure was measured in terms of "thousands of pounds per square inch" or simply "psi." For example, the 30-06 was said to have a working pressure of 47,000 psi. This implied that both 30-06 cases and firearms designed for that round could, under normal operating circumstances, safely control pressures up to that 47,000 psi rating [Ref. 4].

Since the means for measuring that pressure was the "crusher method," the actual results were more relative than absolute. However, the industry well understood the implications and the psi

designation worked well. Unfortunately, those outside the industry interpreted the psi rating literally as a specific measurement in pounds per square inch, which it was not. To eliminate confusion, or at least to offset any possible liability, the industry quickly turned to expressing chamber pressure in terms of "lead units of pressure (LUP)" and "copper units of pressure (CUP)." To understand the terminology and to explain more about the ever-important pressure, a look at how chamber pressure is usually measured is appropriate.

First, a pressure gun is a piece of laboratory equipment which bears little resemblance to any sporting or accuracy arm. It consists of quickly interchangeable chambered barrels and a massive and solidly mounted receiver. On the top of the receiver is a heavy yoke which holds the crusher assembly. Threaded into the yoke is the crusher anvil. A lead or copper plug (crusher) of known dimensions is placed between the crusher anvil and a piston. That piston fits into a right-angle hole that leads directly to the chamber. Upon firing, the chamber pressure that drives the bullet also acts upon the piston. The pressure drives the piston against the anvil. (Lead crushers are used in testing most metallic cartridges.) The length change of the crusher is meas-ured and that measurement is compared to "Tarage Table" values supplied by the crusher manufacturer. The "Tarage Table" in effect allows one to transform the length change of the crusher into a rela-tive value of force or CUP value [Ref. 9].

Published pressures are averages of a number of rounds fired under exacting laboratory conditions, with explicit procedures and using the pressure measuring technique described above. Cartridge cases, primers, and powder are each from a single manufacturer and have the same lot number. Temperature is closely controlled, and loading is slow and meticulous. Note that even with the great care exercised, published pressure figures are averages. Obviously some shots showed a higher individual pressure than the recorded average. No standard deviation or variance is given, so published pressures should be considered as only the roughest guidelines. Personal experience will guide the pressure analysis of individual rounds [Ref. 7].

Pressure for a given load using a metallic cartridge varies considerably with the specific dimensions of the individual firearm. The chamber, groove, bore, throat, case, bullet, and head-space dimensions all have a significant bearing on the pressure generated. Primer brand and composition, case capacity variance, bullet shape, bullet diameter and hardness, and case-neck tension also play a major role in determining the level of working pressure. Therefore, it is apparent that working up an efficient load is something more than just pouring a given amount of powder into a cartridge case and setting it off.

When more powder is added to the case there is generally a corresponding increase in pressure. Also, when used in equal amounts and under like conditions, fast-burning powders produce higher

pressures than do slow-burning powders. However, under certain conditions, a desired velocity level is not achieved when using the amount of powder that was previously determined should produce that velocity. On the other hand a load that would be expected to produce safe pressure levels can show signs of excess pressure.

Considering powder characteristics alone, there are several considerations that can help in early load development. Often knowledge of these considerations can accelerate that development, increase the understanding of observed phenomena, and aid in the choice of load and powder. First, it should be clearly understood that modern smokeless powders are chemically complicated, and are so because of a manufacturer's desire to provide a product best suited to a given application. The pressure versus time relationship of a given propellant varies drastically with a small change in burning conditions (i.e. larger bullet, smaller case or chamber, etc.). In addition a small increase in the amount of powder can boost pressures unexpectedly because the design pressure range for the powder has been exceeded. That is to say that every propellant has a design pressure range wherein it is most efficient. Operate below that range and erratic performance will result. Operate above that range and a radical increase in pressures could be experienced that could damage equipment.

To complicate matters further, using powder volumes much less than case capacity can cause interesting and unexpected results.

Detonation can be experienced, usually when using reduced loads with slow burning powders. Detonation is not adequately explained in any current loading publication, but it is probably caused in straight-walled cases by an erratic, unstable, and large area flame front. Upon initial primer ignition the powder can be driven forward distributing itself throughout the large capacity case. Since it is dispersed thinly the flame front can expand in all directions surrounding the grains, and thus reach a much larger powder surface area than would be expected. The burning rate is therefore multiplied tremendously and extremely high pressures can result -- often to the extent of causing material failure in the breech area. The same result can come from using a fast burning powder in a large capacity case, but the frequency of occurrence seems to be less. Reduced loads are often mandatory in the laboratory situation so steps are taken to keep the powder in close contact to the primer during ignition. That is usually done by using about one-half grain dacron filler on top of the powder charge.

Detonation in large capacity bottle-neck cases may also be caused by light charges of slow burning powder combined with a low intensity primer. In that case the powder charge is driven forward and effectively forms an obstruction in the case neck and shoulder area [Ref. 3].

To aid in load development much should be known about pressure signs. Pressure signs are indications of pressure that can be readily observed on the cartridge case after firing. Since the laboratory lacks

pressure testing equipment, the operator must rely on these visual indications of the level of pressure. The standard reloading manuals do not give explicit guidance for the low velocity, heavy projectile loads or the light projectile, high velocity loads, so extreme care must be exercised to insure safety, as well as to obtain the required results.

The first place to look after a round has been fired is at the primer. If a primer has a definite flattened appearance when compared to a like but unfired primer, the chamber pressure levels are significant. If there is flowing of the primer evident around the edges of the primer pocket, or if the firing pin indentation has a cratered appearance, pressures are too high for continuous application of that load. Also, if a primer is punctured or loose in its pocket, it indicates that the load producing such a situation should not be used again. It should be apparent that for these indications to be consistent, the same brand and kind of primers should always be used. Soft or thin primers will flatten more than hard or thick primers, and every manufacturer has different specifications for his manufacturing process.

The primer pocket can expand to the point of loosening the primer, if pressures are high enough. As the load pressure increases, the head of the case is subjected to increasing stresses. The increased stresses can cause immediate failure in the primer area, or they can cause accelerated fatigue in that area, which then results in

failure. In any case, if loose primers are a problem, the load should be reduced and the loader should revert to the use of new brass until the problem is pinned down. Also note that if pressure is high enough, the stress on the cartridge head can cause the brass in the head and rim area to "flow," taking on the shape of bolt irregularities, extractor cuts, and dimming the head stamp.

Head expansion can be a more exacting indicator of pressure when all other signs are normal. The sides of a cartridge case are designed to expand upon firing to seal the chamber. That expansion prevents high temperature and high pressure gases from wrecking the action. When the sides of a case are smudged with dark powder residue, it is an indication that the pressure is very low and the sealing action is not taking place. On the other hand, excess case expansion is a sure sign of high pressure. A rule of thumb is that case head expansion (measured just ahead of the belt) of greater than .0015 inches indicates excessively high pressure. In the case of the 45 caliber barrel the case head, after firing a mild load, measures .5085 inches. Therefore, a measurement of .5100 inches or over would indicate high pressure. These signs will almost always be accompanied by other signs as described in the paragraph about primer pressure signs. If any of the above signs are experienced to any excessive degree, the headspace of the RBMR should be checked by a competent gunsmith prior to any other firing.

In general there are a few rules that should always be followed when working up loads for any firearm. The first is that the starting point for the load should be a combination of components that is known, beyond any doubt, to be safe. If upon case inspection (necessary after every firing) there are signs of excess pressure, the load should be reduced at least ten per cent. All powder charges should be weighed on a powder scale. Charge increase should be in gradual increments; one-half grain at a time for charges over 25 grains, one-tenth grain at a time for charges under 25 grains. At least five rounds should be fired at each new powder weight to form a basis for measuring consistency and establishing safety. In working up a load only new or once fired cases should be used. All case sizing lubricant should be removed from the cases prior to firing and the chamber should be clean and dry. (Excess lubricant can cause excessive thrust on the bolt face.) Never mix brands of primers, cases, or lots of powder. If a brand is changed or a new powder lot started, a load must be checked again as the pressure will have undoubtedly changed.

III. COMPONENTS

A. POWDER

There are definite hazards to handling and storing smokeless powder. Smokeless powders are highly flammable substances and should be treated as such, but the handling and storage of powder

becomes risky only to the careless. Since carelessness has no place in any form of research, this should not constitute a problem. The problem arises from the research itself. The thirst for achievement in a given project and the desire for an expedient result can lead the uninitiated into situations he is not qualified to handle. To reiterate, the burning characteristics of smokeless powders are complex in nature and, depending on the application, can change drastically. The chemical composition, grain shape and size, density or porosity of the composition, and special coatings tend to control the burning rate. But it must be kept constantly in mind that the degree of confinement, head of ignition, temperature of combustion, chamber pressure, loading density, projectile friction, chamber dimensions, and a host of other factors affect greatly the actual burning rate. (Figures B-7 and B-8). This point cannot be overemphasized [Refs. 1 and 2].

Smokeless powders should be stored in a cool dry place away from spark producing equipment, excess heat, open flame, and should not be stored with flammable liquids, flammable gases, or other highly combustible materials. No smoking should be allowed in, or around an area where powder is used or stored. The only container that should be used to store powder is the original factory cannister. Those powder cans meet standards set by the U. S. Department of Transportation. Powders should not be mixed, transferred to other containers, relabeled, or kept in quantities exceeding twenty pounds

Figure B-7

CANISTER GRADE, SMOKELESS PROPELLANTS GENERALLY
AVAILABLE IN THE U. S. -- FROM FASTEST TO SLOWEST *

1.	HERCULES BULLSEYE	25.	DU PONT IMR 4227
2.	OLIN 230	26.	OLIN 680
3.	NORMA 1010	27.	NORMA 200
4.	HODGDON TOPMARK	28.	DU PONT IMR 4198
5.	HERCULES RED DOT	29.	DU PONT 3031
6.	DU PONT HI-SKOR 700X	30.	NORMA 201
7.	HERCULES GREEN DOT	31.	OLIN 748
8.	DU PONT SR 4756	32.	HODGDON H335
9.	HERCULES UNIQUE	33.	HODGDON BLC2
10.	DU PONT SR 7625	34.	DU PONT IMR 4895
11.	AL5	35.	HODGDON H 4895
12.	HODGDON HS5	36.	NORMA 203
13.	AL7	37.	DU PONT IMR 4064
14.	HODGDON HS6	38.	DU PONT IMR 4320
15.	OLIN 540	39.	HODGDON H380
16.	HERCULES HERCO	40.	OLIN 760
17.	HERCULES BLUE DOT	41.	HODGDON 414
18.	AL8	42.	DU PONT IMR 4350
19.	NORMA 1020	43.	NORMA 204
20.	OLIN 630	44.	DU PONT IMR 4831
21.	HERCULES 2400	45.	HODGDON H450
22.	HODGDON H110	46.	HODGDON H-4831
23.	OLIN 296	47.	NORMA 205
24.	DU PONT SR 4759	48.	HODGDON H 870

* [Ref. 12]

Figure B-8

VARIATION OF MUZZLE VELOCITY

WITH POWDER TEMPERATURE *

Temperature Degrees Fahrenheit

40	50	60	70	80	90
2668	2682	2700	2722	2750	2784
2767	2782	2800	2823	2851	2887
2866	2881	2900	2924	2953	2990
2965	2981	3000	3025	3055	3092
3064	3080	3100	3125	3157	3196
3163	3179	3200	3226	3258	3299
3261	3279	3300	3327	3360	3402
3360	3378	3400	3428	3462	3505
3459	3477	3500	3529	3564	3608
3558	3577.	3600	3629	3666	3711
3657	3676	3700	3730	3768	3814
3756	3775	3800	3831	3870	3918
3854	3875	3900	3932	3971	4021
3953	3974	4000	4033	4073	4124
4052	4073	4100	4133	4173	4227
4151	4173	4200	4234	4277	4330

*[Ref. 12]

unless special precautions are taken. Smokeless powder is not an explosive, but pressures can build dangerously if the powder burns in a highly confined area. Therefore, bulk powder should be stored in a relatively weak or well ventilated cabinet. Lastly, several containers are safer than one large one, and good housekeeping is imperative.

B.   THE CARTRIDGE CASE

The history of cartridge cases and their design is an extensive one. Cartridged ammunition began its development in the 1850's. Development was steady but slow until about the turn of the century, and the expansion of the American frontier and the expanse of the British Empire spurred development more than any other factors. The first cartridge cases that effectively sealed the chamber were wrapped copper cases. Primer design went hand in hand with case design to the form seen today. Today cartridges are of five basic rim designs (rimmed, semi-rimmed, rimless, belted, and rebated), three basic body forms (straight, straight-taper, and bottle-neck), and utilize two basic types of primers (Boxer and Berdan). Cartridge brass is generally 70% copper and 30% zinc with a sophisticated heat treatment. Modern cartridge cases are strong, durable, and efficient and should last twenty reloadings or more with common care and normal loads. They do require constant inspection and consideration of the pressures they are subjected to. After the safety of a load

has been established, cases should be re-examined before <u>each</u> re-loading, checking for fatigue signs that mark the end of the case life. Cases are checked again after resizing to insure the absence of fatigue cracks and that the case has not lengthened beyond the tolerance allowed by the chamber dimensions. If a new primer enters a case too easily or seats loosely, the case should be discarded. Thorough case inspection requires an orderly procedure repeated as a matter of course with each case. A cartridge case can be examined best by holding it in a good light and turning it slowly while looking for minute cracks (usually longitudinal) in the neck area. The sides should be inspected for pin hole burns and close attention should be paid to the primer pocket and flash hole. Irregularities in the primer area should cause case rejection. Primer pockets should be cleaned where necessary. General cleanliness is important, especially the absence of any lubricant or oils, but dull cases are fully as good as bright ones. The modern cartridge case gives exceptional performance with reasonable inspection and care in reloading.

C.   PRIMERS

The development of primer design and priming compounds closely followed firearms development. Early match locks used a glowing chord to ignite finely granulated powder which in turn ignited the main powder charge. Flint locks achieved ignition by the striking of flint and steel. With the development of highly explosive priming compounds

came percussion firearms, shortly followed by the primed cartridge. The primed cartridge evolved quickly to the use of only two basic primer designs: the Boxer and Berdan. Berdan primers found their greatest use in Europe (particularly England) and differed from the Boxer design mainly in that the anvil was a part of the cartridge case. Boxer primers are used almost exclusively in the United States and are gradually replacing Berdan primers throughout the world. In the Boxer primer the anvil is a part of the primer and not the case. Interestingly, the Boxer primer was initially developed in England and the Berdan primer in the United States. The Boxer primer has as its primary advantage ease of reloading and simplified case design.

The Boxer primer is simple in design. It consists of a metal cup containing a primer compound covered by a foil or paper disk and has the anvil positioned over the disk. The firing pin crushes the primer compound between the primer base and the anvil causing detonation. Although the basic design is simple, the actual construction is com- plicated by the requirements of different types of ammunition. The cups of pistol primers are made of thinner material than are rifle primers due not only to the great differences in working pressures, but also because of the strength of the respective mechanical ignition systems. (The hammer fall on a hand gun is much lighter than the striker fall on a rifle.) In addition, the ignition characteristics of the priming compound must be chemically engineered to be compatible

with the desired use. Large case capacities require a hotter and longer burning primer mixture than do smaller capacity cases. Therefore, primer choice for a given application is very important. In general the primers available are in two sizes and two strengths for both rifle and hand gun. The small primer in each case is .175 inches in diameter and the large primer is .210 inches in diameter. Generally the pistol designation indicates a thinner cup and shorter flame duration. Thw two strengths of primers available are referred to as "standard" and "magnum." The magnum primers are used where large case capacities and/or difficult to ignite powders are used [Ref. 5]. (Figure B-9)

Handling primers is safe if a few rules are observed. Primers are explosives, not propellants, so they should be respected as such. They should never be left around a working area where there is a chance of heavy objects being placed on them, or where they are subject to high temperature or sharp blows. They should be stored in their shipping containers away from all other flammables. A primer's burning characteristics are affected by changes in moisture content of the priming compound. Since they are designed for standard conditions they should not be stored with drying agents, or in an area of unusually high humidity. Oil will deactivate a primer if present in minute amounts. Hence spray lubricants should not be used when primers are exposed in the working area, nor should it be used on

U.S. BOXER PRIMER CHART

	Large Rifle	Large Rifle Magnum	Small Rifle	Small Rifle Magnum	Large Pistol	Large Pistol Magnum	Small Pistol	Small Pistol Magnum
REMINGTON & PETERS	9	9 M	6 7		2		1 5	
WINCHESTER & WESTERN	120-8	7M-111F	116-6	1 M-108	111-7		108-1	
FEDERAL	210	215	200		150		100	
ALCAN	Large Rifle Max-fire	Large Rifle Magnum	Small Rifle Max-fire		Large Pistol Max-fire		Small Pistol Max-fire	
CCI	200	250M	400	450M	300	350M	500	500M

Figure B-9

PRIMER CHART

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loaded rounds as a misfire could result. Case lubricant in very small

amounts in the primer pocket or on the primer, as a result of handling,

can produce the same results. Cleanliness during the priming opera-

tion is a necessity.

D. BULLETS

The shape and internal design of projectiles has changed steadily

from the ballistae and its rocks to the boosted designs of today. The

development of the understanding of shape factors on external perform-

ance was outlined in the section on external ballistics. The intent here

is to present a review of currently available projectiles designed for

sporting use. An understanding of the intended use of the available

projectiles gives insight into the construction of the bullet, which in

turn has a bearing on projectile selection for a given laboratory use.

In general bullet use can be divided into two basic use categories:

target and hunting. The target use can be further divided into long

range and short range sub-categories. The short range bullets are

generally lighter in weight and have form factors significantly less

efficient than long range bullets. Long range bullets are usually

close to the heaviest practical weight for the given caliber and rifling

twist, and are usually boattailed with long tapering noses. In every

case with match grade bullets, materials and processes are used

which give the maximum possible uniformity. Little consideration

is given to what happens to the design after impact.

Hunting bullets on the other hand are usually subdivided into three categories: big game, varmint, and small game or fur. For small game the desired results are minimal tissue destruction so the bullet is of extremely heavy design -- often without any exposed lead or hollow point. (This discussion relates only to high velocity centerfire rifle bullets.) The heavy construction and closed-point design minimizes bullet upset on impact, and so slows down the energy transfer. On varmints the results desired are explosive. Varmints are hunted at extreme ranges and often in fields containing livestock, or close to populated farm areas. Therefore, expansion for rapid and sure energy transfer is desired, as is a fragmentable bullet to eliminate the hazard of ricochet. Bullets for this purpose are very lightly constructed -- often to the extent of being velocity limited -- and have lead-nose or open-point designs. The key word when considering big game bullets is controlled expansion. The rate of energy transfer is extremely important so the bullets for this purpose are made to hold together, but expand on impact. The rate of expansion is engineered to produce the desired energy transfer rate [Ref. 5]. Bullets may be manufactured by the individual experimenter to eliminate variables or to produce desired effects in the impact area. However, consideration should be given to using commercially available designs. Custom bullet design leads to its own experimentation and the limited production process is expensive due to the equipment required and is especially time consuming.

IV. RELOADING POINTS

A. INTRODUCTION

A comprehensive practical procedure for most loading situations can be found in the range library compiled during the initial experimentation. That library is available at all times. Procedures in the various references differ somewhat, as do the load data. However, a thorough familiarity with the sources above will enable the reloader to recognize problem areas he will encounter and plan around those difficulties. The more time one spends with the reloading manuals the less time will be required on the range.

A common question inexperienced reloaders have is, "How common are material failures, and what causes them?" Common causes of chamber, bolt, or barrel material failure while using factory ammunition are: obstructions in the barrel; opening the bolt too soon after a misfire, which instead of a misfire may be a hang-fire; extracting a loaded cartridge and leaving the bullet in the barrel, then loading another cartridge behind it. Also, it is possible to get overloaded factory ammunition, although it is usually not overloaded to the extent which will cause a blowup.

There are a great number of blowups caused by improper handloading. The majority of handloaders use powder measures, and powder measures are not infallible, although they are excellent

mechanically. Quite often a powder measure will hold up part of a charge thus creating a reduced charge, then this partial charge which is held in the measure will be dropped into the case along with the next full charge, thus creating an overloaded cartridge. This trouble does not occur often with small capacity cartridges, but can occur frequently with large capacity cartridges which are being loaded with a relatively fast powder. When such cartridges are charged with powder, it is well to look into each cartridge case after the powder has been put in, to observe whether the powder charge is near the proper level.

Another common source of accidents is getting powders mixed. Material failures have occurred because a faster burning powder was accidentally substituted for slow burning powder. For example, if cartridges are to be loaded with a full charge of IMR 4064 powder, and 3031 is used in the same amount, the machine rest will be severely damaged.

Cartridges with short necks (like the 22-250) must be checked carefully after the bullets have been seated. If a case with thin brass is sized in the normal sizing die, it is possible that the neck will not be tight enough to hold the bullet firmly. That bullet is then susceptible to being pushed back into the case when the round is chambered. If the cartridge is then fired, pressures will generally be dangerously high.

Another source of extremely high pressures and consequent damage is the use of reduced charges of slowburning powder in overbore capacity cartridges. This phenomenon is mentioned elsewhere in this work, and will not be reviewed here. In any case, it is seldom experienced if recommended loads are used exclusively.

B. THE USE AND ADJUSTMENT OF LOADING DIES

Few handloaders understand what a full length sizing die is supposed to accomplish. The reloading manuals deal with this very critical piece of equipment in a cursory manner. A better background is needed.

All die manufacturers work to certain tolerances and all rifle manufacturers, including custom gunsmiths, also have standard working tolerances. When a full length sizing die with maximum tolerance is mated to rifle with a minimum chamber, results may not be satisfactory; and results can be just as unsatisfactory when a minimum sizing die is mated to a maximum chamber. To allow for these tolerances the reloader must understand the use and adjustment of his dies.

A practice common among inexperienced handloaders is simply to screw the full length sizing die down against the shell holder in the press, on the assumption that the shell holder is standard, the sizing die is standard, and the chamber is standard. As a rule, conditions are seldom standard.

One successful method of die adjustment is to set the full length sizing die down against the shell holder, then back off one-half turn. Then run a fired case all the way into the die. Remove the case and observe exactly where the sizing action stops. This will be indicated by a visible ring on the neck of the case. Usually, if the die is backed off one-half turn, this visible ring will be slightly above the shoulder of the case. The die can then be turned in slightly and the operation repeated, again observing where the sizing action stops. The die should be adjusted so that it just touches, but does not push back the shoulder of the case. The lock ring on the die can then be secured.

The purpose of a full length sizing die is to reduce an expanded fired cartridge to a dimension suitable for reuse. The ideal die will size the fired case just enough so that it will enter the chamber freely. This should amount to only one or two thousandths of an inch in the head area and shoulder, with perhaps three or four thousandths reduction in the neck diameter. Proper die adjustment can go a long way to reduce case fatigue and erratic or dangerous pressures, and it will promote shot-to-shot consistency.

V. RANGE SPECIFICS

A. GUN DESCRIPTION

The gun used on the range is one of return-to-battery design much as is used in the bullet manufacturing industry for testing

bullet accuracy. It is fired electrically from a remote position and returned to battery manually.

All data were gathered using two barrelled actions. (Figure B-10) The two barrelled actions are both compatible with the return-to-battery machine rest. They are interchangeable in the rest in about five minutes.

The entire assembly with the forty-five caliber barrel installed weighs eighty-eight pounds. The carriage assembly, which weighs approximately forty pounds, moves aft on recoil and must be manually returned to battery prior to firing another round. If it is not returned to battery prior to each shot, the point of impact of the projectile will vary as much as four inches vertically.

The carriage is equipped with stops to limit both its forward as well as its aft movement. The stops are particularly robust and require no maintenance.

The point of impact may be changed by windage and by vertical adjusting screws located beneath the aft glide rail. The adjusting screws have lock rings and these should be checked periodically as they can be shaken loose when using heavy loads. If more adjustment is needed, there are three foot-screws located on the base plate which will give a gross adjustment.
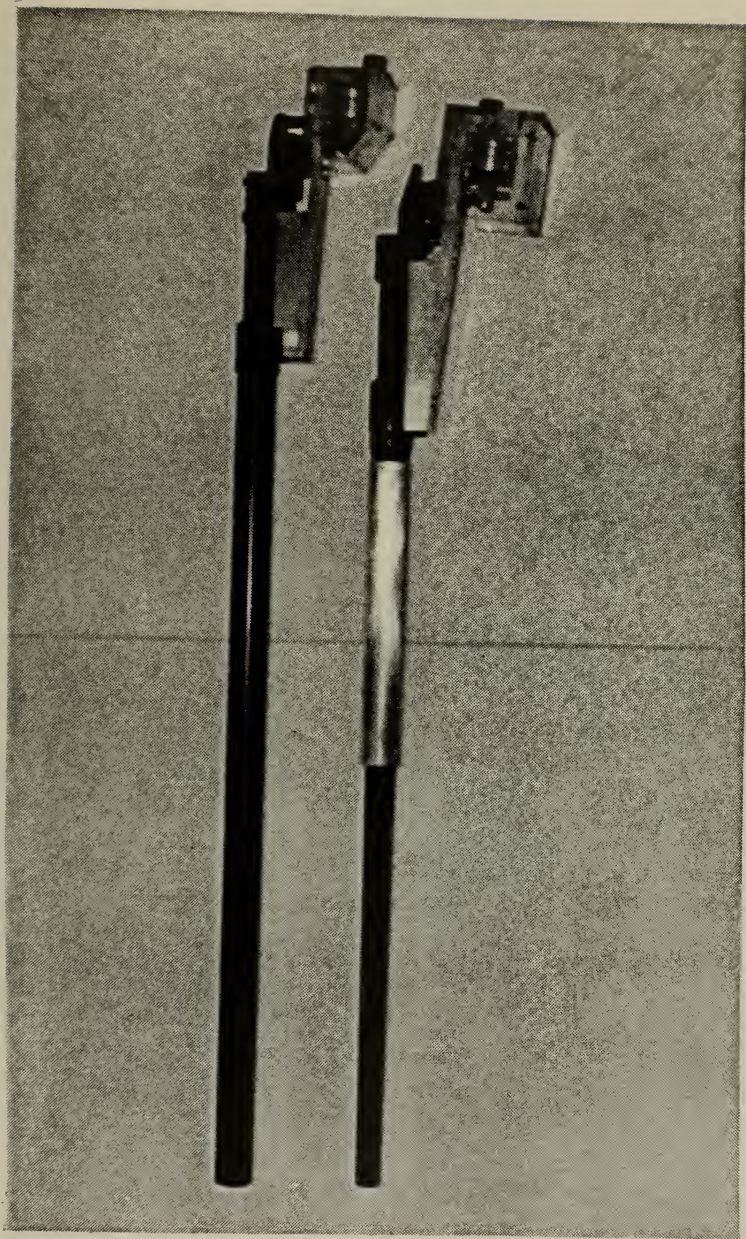
Figure B-10
BARRELED ACTIONS

PREFIRING CHECKLIST

1. Aft hatch - Pinned
2. Bullet trap blower - on
3. Specimen - as required
4. "Stop" Chronograph Screen - on
5. Warning Light - on
6. "Start" Chronograph Screen - on
7. Chronograph - on
8. Down Range - check
9. Barreled Action - secure
10. Bolt - Install

FIRING CHECKLIST

1. Safety Glasses - on
2. Sound Attenuates - on
3. Down Range - check
4. Gun Carriage - return to battery
5. Gun - load
6. Chronograph - reset
7. Down Range - check
8. Gun - fire

POSTFIRING CHECKLIST

1. Velocity - record
2. Spent Round - eject
3. Spent Round - inspect
4. Gun carriage - return to battery
5. If proceeding down range - remove bolt

SECURE CHECKLIST

1. Bolt - remove and return to locked area
2. Plexiglas Cover - replace
3. Chronograph - off
4. "Start" Chronograph Screen - off
5. Warning Light - off
6. "Stop" Chronograph Screen - off
7. Bullet Trap Blower - off
8. Aft Hatch - remove pin.

Figure B-11

CHECK LISTS

GLOSSARY*

annealing: In handloading, the heating of brass after work-hardening to prevent it from becoming too brittle. Only the neck should be annealed and great care should be taken not to overheat and thus soften the head and rear portion of the case.

anvil: In the priming system, a fixed metallic point against which the priming mixture is crushed and thereby detonated by the action of the firing pin.

ball: Early term for "bullet." Still used in military nomenclature.

ball powder: Copyrighted trade-name for a double base smokeless propellant powder developed by Olin Industries. Either spherical or flattened spherical shape.

ballistic coefficient: Ratio of the sectional density of a bullet to its coefficient of form. Represents the projectile's ability to over-come the resistance of the air in flight.

bearing surface: That portion of a bullet's surface that touches the bore in moving through the barrel.

bell: To open the mouth of a case slightly in order to seat a bullet more easily.

belted (case): Cartridge cases with raised band or belt at the base ahead of extractor groove. Belt acts as case reinforcement and to headspace cartridge.

Berdan: Type of primer with no integral anvil. Anvil is formed in
    bottom of primer pocket. Common in Europe. Named after Col.
    Hiram Berdan, the inventory, an American.

boattail: Name given to a bullet type with tapered base. Also "taper
    heel."

body of a case: That section of a cartridge case between the head
    and the shoulder. The part of the case that contains the powder.

bolt thrust: The actual force on the face of the bolt of a rifle caused
    by the pressure of burning powder gases.

bore: The inside of the barrel of a gun of any kind and, in rifled
    arms, the diameter of the barrel before the rifling is cut.

Boxer: The standard American type of primer, named after the
    inventor of this type of primer, Col. Boxer, of the British
    Army.

brass: A term often applied to empty cartridge cases. An alloy
    of copper and zinc of which cartridge cases are usually made.

brisance: That quality, in an explosive, of brusqueness, or shat-
    tering power. The brisant an explosive is, the more rapidly
    it detonates and the greater its relative power of demolition.

bullet: The missile only. Becomes a projectile when in flight.
    Not to be applied to the "cartridge."

burning rate: A relative term. The rapidity with which a given
    powder burns in comparison with other powders.

caliber: Approximate bore or groove diameter expressed (in English) in decimals of an inch, otherwise in the metric system. Frequently compounded to indicate powder charge; to show date of adoption; to show case length, or to show proprietor or designer e.g. .30/40, .30/06, 8x57mm, .375 Holland & Holland, or .257 Roberts. In strict military usage a "fifty-caliber" barrel may be of any diameter so long as the length is fifty times the bore diameter; however, a "caliber.50" barrel is one with a groove diameter of approximately .509" -- or roughtly .50".

cannelure: Circumferential groove(s) around a bullet or cartridge case. Used for identification, to hold lubricant, or to crimp case into.

cap: See "primer".

cartridge: A complete unit of ammunition assembled. i.e.: Case, propellant, powder, primer, and bullet. Usually applied only to rifle and pistol ammunition, but occasionally to shotshells.

case: The paper, metal, or plastic container which holds all the other components of a round of ammunition. Sometimes called "hull" or "shell".

cast bullet: Bullets for rifle or pistol cast from lead or lead alloy.

center fire (cf): Refers to centrally located primer in base of metallic cartridges. Most center fire cartridges are reloadable.

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chamber: That part of the bore, at the breech, formed to accept
and support the cartridge.

chamfer: To ream a taper on the inside of a case mouth -- facilitates
bullet seating.

charge: The amount of propellant powder measured into the case in
loading. Also refers to amount of shot measured into shotshell.

chronograph: An instrument used to measure the velocity of a
projectile.

compressed charge: A charge of powder which the bullet compresses
on being seated in the case.

components: Those parts which go into the making of a cartridge.

crimp: The bending inward of the mouth of the case, in order to
grip the bullet, or to close the mouth of a shotshell case.

die: In handloading, a tool to form or reform cases, bullets, or to
seat bullets.

double base powder: Smokeless powder made with nitroglycerine
and nitrocellulse base.

duplex load: Use of two different powders in loading the same cart-
ridge. There is little or no advantage in duplex loading and
results are unpredictably dangerous.

energy: The amount of work capable of being done by a projectile
at a given range, expressed in foot-pounds.

extruded primer: A primer that on firing has had the metal of the primer cup forced back into the firing pin hole in the face of the bolt.

flash hole: The hole leading from the primer pocket into the body of the cartridge case.

freebore: The distance, if any, which a bullet travels upon firing before it contacts the rear portion of the rifling.

gas check: A copper or brass cup used to prevent hot powder gases from deforming the base of lead bullets.

gilding metal: A copper-zinc alloy used for bullet jackets. Usually from 5% to 10% zinc, balance copper.

grain: In weight measure 7000 grains equal one pound; 437.5 grains equal one ounce. May also be used in referring to a particle, or kernel, of powder. However, "35 grains of powder" always refers to 35 of the weight-unit grains, never to 35 individual kernels of powder.

grooves: Spiral cuts or impressions in the bore of a firearm which cause a bullet to spin as it moves through the barrel.

hangfire: Ignition in a cartridge which is delayed beyond the normal time after the firing pin has struck the primer.

heel: The edge of the base of the bullet.

hollow point (hp): Bullet design feature; an axial hole at point of bullet.

headspace: The distance from that surface of the barrel or chamber
that positions the cartridge and prevents its further forward
movement into the chamber, to the face of the bolt or breech block,
when the latter is fully back against its supporting surface. This
is the most important dimension governing the safety of the
shooter. In handloading, the combination of cartridge case and
gun must be considered when talking of headspace. To the hand-
loader, a useful way to think of the headspace would be this:
The linear endplay of a cartridge in the chamber, with the bolt
closed. To a handloader, no gun need have excessive headspace,
since he can adjust the cartridge case to fit the chamber, even
though the chamber may have excessive headspace when meas-
ured by SAAMI standards.

ignition: The setting on fire of the propellant powder charge by the
primer.

IMR: Abbreviation for "Improved Military Rifle," a type of powder
developed by DuPont, which has a deterrent coating on the surface
of each kernel of powder for control of burning rate. It produced
higher velocities with lower pressures than smokeless powders
formerly used.

jacket: The cover or skin of a bullet; usually made of gilding
metal in this country. Gilding metal-clad steel or mild steel
are also used.

keyhole: An elliptical or elongated imprint of a bullet on a target, which shows that the bullet was not traveling point-on at the time of impact.

lands: The spiral raised portion of a bore remaining after the grooves have been cut or formed.

leading: Lead deposited in the bore from shooting lead bullets.

loading density: Ratio of the volume of powder charge to the volume of the case.

magnum: A load, or cartridge, having greater power. A magnum case is usually longer. For example, the .44 Magnum is approximately 1/10th inch longer than the .44 Special. Or it may be a caliber with exceptionally large powder capacity in relation to the bore diameter, for example, the .264 Winchester Magnum.

metal fouling: Bullet jacket material deposited in bore. Not common since adoption of gilding metal for jackets.

misfire: Complete failure of a cartridge to fire after the primer is struck by the firing pin.

muzzle: The front end of a barrel. The point at which a projectile leaves the barrel.

muzzle blast: The blast of the hot powder gases from the muzzle of the gun with the attendant flash and noise.

neck: That portion of a cartridge case which grips the bullet. In a bottle-necked case, that portion of the case in front of the shoulder.

neck size: To resize part or all of the neck only.

ogive: The radius of the curve of the nose of a bullet, usually expressed in calibers.

overbore capacity: A common, unscientific, term referring to a cartridge case that has too much volume for its bore diameter. Every case is over bore capacity with some powder. Generally used when a case has a volume so large, in relation to the bore diameter, that only the very slow burning powders will give optimum performance.

pierced primer: A primer that has been punctured, caused by a defective firing pin, and/or weak firing pin spring.

powder: The propellant material used in most firearms. Divided into two basic types: "Smokeless" powder and "Black powder," or "Gunpowder." It is produced in a wide variety of types, forms and brand-names intended for specific applications. It varies chiefly according to burning speed. The fast-burning types are used for light bullets in short barrels at low velocities: Slower-burning powders are used in longer barrels and in greater quantities to drive the bullet at higher velocities. Most powder contains a major percentage of nitrocellulose, with small traces of other compounds intended to control burning rate or prevent deterioration; such powder is called "Single-Base;" Smokeless powders containing a percentage of nitroglycerine are called

"Double-Base, " and powders containing substantial amounts of
other organic nitrates are called "Multi-Base. "

pressure: The pressure exerted by a burning charge of powder in
the chamber of a gun. Expressed normally as the peak pressure in
pounds per square inch (psi), or copper units pressure (cup).

primer: Also called "cap, " deriving from "percussion cap" which is
the priming form used with some muzzle loading arms. In a center-
fire cartridge, the small metal cup, containing a detonating mixture
which is used to ignite the propellant powder. The primer is seated
in the primer pocket in the base of the cartridge case. The standard
American type of primer, the "Boxer, " also contains an anvil.
Electrically fired primers are used in some military weapons and
in some experimental European sporting arms. In a rimfire cart-
ridge the priming mixture is contained within the rim of the case.

primer pocket: The cavity in the base of a cartridge case made to
receive and support the primer.

progressive: Characteristic of a powder which burns relatively slowly,
compared to black powder, producing a relatively slow pressure
build-up.

rifling: Parallel spiral grooves cut or impressed into the bore of
rifles and pistols in order to make the bullets spin, insuring
steady, point on, flight to the target.

rim: The projecting edge at the base of most cartridge cases, upon
which the extractor pulls. In England this is called the "Flange."

round: A military term meaning one complete cartridge.

seating depth: In a loaded round, the depth to which the base of the
bullet is seated below the case mouth.

sectional density: A bullet's weight, in pounds, divided by the square
of its diameter, in inches.

shank: The cylindrical section of a bullet.

shoulder: The sloping or rounded part of a bottlenecked cartridge
case. Joins the neck to the body.

single base powder: Smokeless powder made from a nitrocellulose base.

sizing: Also known as resizing. Reducing the cartridge case, which
has been expanded by firing, to about the original dimensions, by
forcing it into a sizing die. Bullets are also sized or reduced in
diameter by forcing through a die.

soft point (sp): Bullet design feature. Where a portion of the lead alloy
core is exposed at the point or nose of a jacketed bullet.

spitzer: Bullet design feature. A bullet with a pointed nose.

swage: To form by forcing into or through a die.

throat: That area of the bore immediately ahead of the chamber; tapers
to the point where the rifling starts. Also "Leade."

twist: The angle of the rifling in relation to the axis of the bore.
Usually measured by length of barrel required to make one
complete turn.

wadcutter: A cylindrical, sharp shouldered bullet, designed to cut a

clean round hole in a paper target.

web: That part of a cartridge case between the bottom of the primer

pocket and the interior of the case. The web is pierced by the

flash hole.

work-harden: Repeated Stresses of handloading cause brass to become

hard and brittle, resulting in cracks.

* [Ref. 13]

LIST OF REFERENCES

1. Ackley, Parker O., *Handbook for Shooters and Reloaders*, 6th ed., Vol. I, Plaza Publishing, 1971.

2. Ackley, Parker O., *Handbook for Shooters and Reloaders*, 4th ed., Vol. II, Plaza Publishing, 1974.

3. Ackley, Parker O., *Pocket Manual for Shooters and Reloaders*, 8th ed., Plaza Publishing, 1974.

4. Hatcher, Julian S., *Hatcher's Notebook*, 3rd ed., The Stackpole Company, 1962.

5. Hatcher, Julian S., and others, *NRA Firearms and Ammunition Fact Book*, 4th ed., 1975.

6. Hayden, Robert, and others, *Sierra Bullets Reloading Manual*, 1974.

7. Hornady Manufacturing Company, Inc., *Hornady Handbook of Cartridge Reloading*, Vol. II, 1973.

8. Greener, W. W., *The Gun and Its Development*, 9th ed., Bonanza Books, 1910.

9. Lyman Handbook Staff, *Lyman Reloading Handbook*, 45th ed., 1970.

10. Lyman Technical Staff, *Lyman Cast Bullet Handbook*, 1973.

11. Page, Warren, *The Accurate Rifle*, Winchester Press, 1973.

12. Speer, Inc., *Reloading Manual Number Nine*, 1974.

13. Speer, Inc., *Speer Manual for Reloading Ammunition*, No. 8, 1970.

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