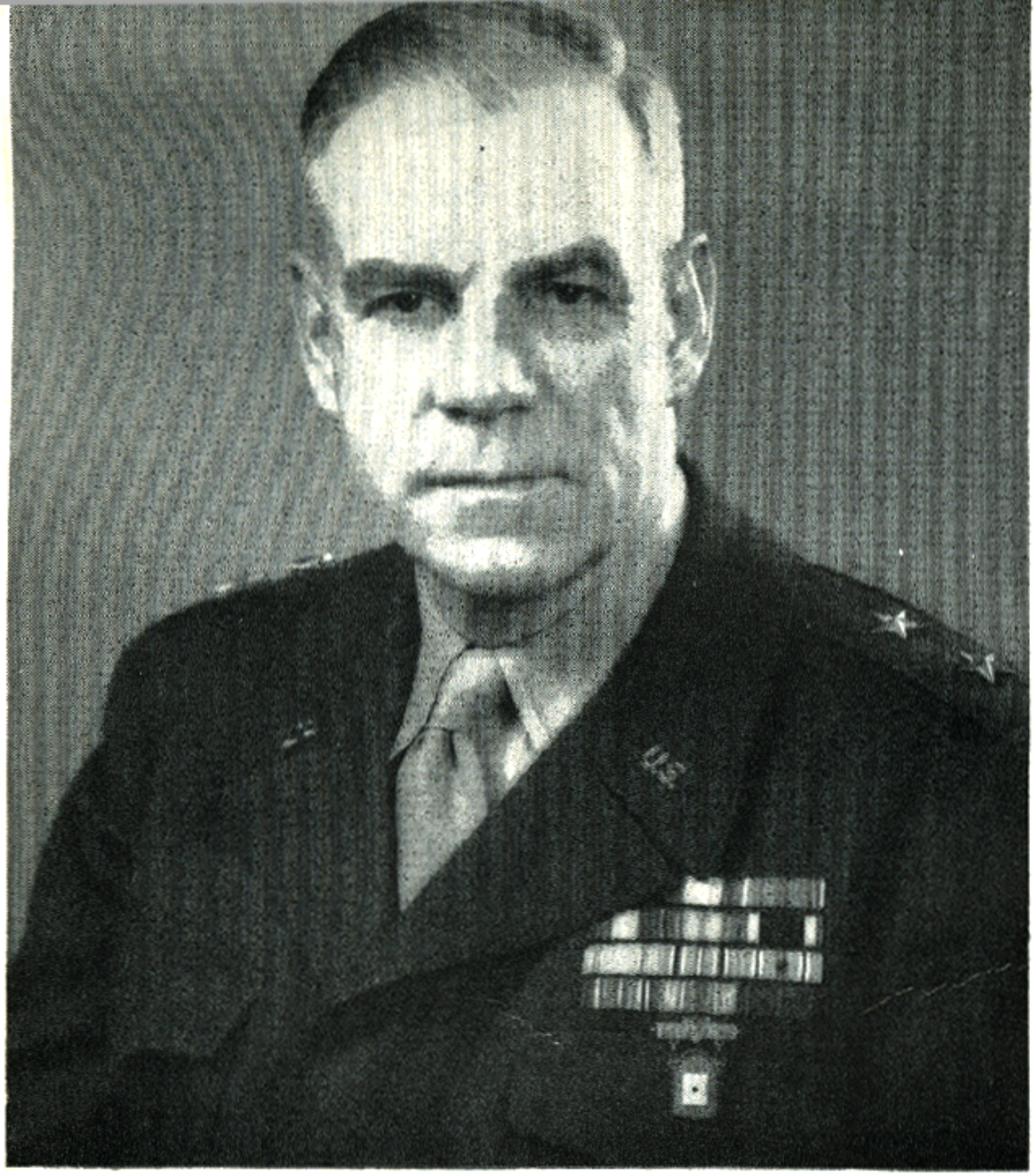
A Standard Reference Book
for Shooters, Gunsmiths,
Ballisticians, Historians,
Hunters and Collectors

By JULIAN S. HATCHER
Major General, U. S. Army, Retired

HATCHER'S NOTEBOOK



JULIAN S. HATCHER

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Editor, "The Dope Bag," Pistol Section, *Arms and the Man* and *The American Rifleman*, 1922 to 1933. Life member, United States Revolver Association.

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Distinguished Service Medal, Legion of Merit.

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WHEN in 1946, after 41 years service, I retired from the Army and became Technical Editor of *The American Rifleman*, I collected together a number of reference notes for my own use. These proved so useful to me that I thought it would be nice to have them permanently available in book form, so I arranged for their publication under the title of HATCHER'S NOTEBOOK.

As the supply on hand sold out, the book has been reprinted from time to time; now, nine years after the book's first appearance, the publisher's stock is again nearing exhaustion, and it again becomes necessary to print a fresh supply. For that reason this seems an appropriate time to add some chapters covering additional subjects which my experience as head of the National Rifleman's Technical Service has shown to be of interest to members of that association and to readers of the *Rifleman*.

Accordingly, all of the original material of HATCHER'S NOTEBOOK has now been reprinted without change as Part One, and four new chapters have been added as Part Two which will give much important information not included in the original volume. The original index is retained at the end of Part One and an index of the new material appears at the end of Part Two.

First of the new chapters covers the development and adoption of a new non-corrosive primer, a new rifle and machine gun cartridge, a new service rifle, and a new all-purpose machine gun by the Army, as well as the development and marketing of a number of new rifle cartridges by the commercial ammunition companies.

The second new chapter covers the subject of explosions and powder fires, as well as the behavior of ammunition when it is exploded, accidentally or otherwise, while it is not in a gun. The many inquiries on this subject that I received from Police and Fire Departments, state and municipal authorities, and from readers of the magazine caused me to make a large number of interesting experiments to be able to answer their questions with certainty. The information thus developed is of great value, and is so important that it should be preserved permanently in convenient form for reference.

The third new chapter covers the fascinating and little understood subject of what happens when a bullet is fired straight up. Many experimenters have fired bullets vertically upwards and tried to note their return to earth; but in most instances such bullets simply disappear into the wild blue yonder and no sign of their return is

ever detected. The reason is here explained and well documented by the results of official tests taken from Ordnance files.

The fourth chapter, on the subject of exterior ballistics, is again the result of my urgent desire to have available a handy bound reference book for which I can reach when I want to make any of a number of simple but necessary ballistic calculations arising out of such questions as—What is the ballistic coefficient of a newly designed bullet of which I have just received a sample? If the chronograph shows a certain velocity at 25 feet in front of the gun, what is the real muzzle velocity? If it loses 125 feet of its original velocity in the first 100 yards, how much will it lose in the next hundred and the next? What will be its time of flight over any given distance and how much will the bullet drop below the line of departure at various ranges? And other similar questions.

As technical Editor, I often receive requests for the name of a book on exterior ballistics that will give such information; and I am always distressed to have to reply that the books that I use for that work are out of print and unobtainable. The ballistic tables and references that I use are contained in six different books, and in this new chapter I have endeavored to include material that will enable me to throw those six books away and never miss them.

The best exterior ballistic tables for use in small arms work are those of Ingalls, published years ago by the Ordnance Department in the now out-of-print Artillery Circular M. Ingalls' highly useful Table I has been included in full, together with an abridged form of his Table II. In addition the history and principles of exterior ballistics have been stated in a simplified form, together with a comparative tabulation of the hard-to-find basic retardation functions as determined by several different experimental firings in various countries.

Mr. Walter J. Howe, editor of *The American Rifleman*, on whose great knowledge and excellent judgement I rely greatly, has been most helpful. Col. E. H. Harrison, Ordnance Corps, U.S. Army, retired, of *The American Rifleman* editorial staff, has made numerous valuable suggestions, and has pointed out several errors in my work that without his help would have gone undetected. Mr. Homer S. Powley, of Shaker Heights, Ohio, who is extremely accomplished in the field of exterior ballistics, has been of incalculable help to me in my efforts to obtain a better understanding of this subject, and has furnished me valuable material which I have included. To these three men I offer my sincere thanks for the assistance they have so generously given.

Falls Church, Virginia.
July, 1957.

JULIAN S. HATCHER,
Major General, U.S.A., Retired

ACKNOWLEDGEMENT

It is a pleasure to acknowledge my indebtedness to the many friends and associates who have so willingly answered my requests for assistance in the preparation of this work.

Charles B. Lister, Editor of *The American Rifleman*, spent much time and labor in reading the first draft of the manuscript, and made a number of extremely valuable suggestions which resulted in a complete re-arrangement and rewriting of the book. Richard Gordon McCloskey made a number of highly constructive suggestions as to form and contents which were most gratefully received and put into execution.

Invaluable technical information and assistance was freely given by a number of my friends who will be mentioned in alphabetical order as follows: Alvin H. Barr, of the National Rifle Association Technical Staff; Lt. Col. Calvin Goddard; Maj. J. C. Gray and Col. Samuel G. Green, of the Ordnance Department; my son, Lieut. Robert D. Hatcher, now on active duty in the Navy; Mr. Stanley F. Hood, Small Arms Maintenance Expert for the Ordnance Department; Col. G. B. Jarrett, of Aberdeen Proving Ground; Capt. F. J. Jervey, retired hero of the Marne fight in World War I, now Ordnance Engineer and ammunition expert; Capt. Melvin M. Johnson, U. S. M. C. R., eminent arms designer; Mr. Frank J. Kahrs, of the Remington Arms Co.; Mr. Edwin Pugsley, of the Winchester Repeating Arms Co.; Maj. J. J. Reen; Capt. Philip B. Sharpe; Col. Rene R. Studler, Chief of the Small Arms Division, Ordnance Research & Development Service; and my longtime friend and counselor, Col. Townsend Whelen.

It should be understood that the opinions given herein represent my own views, and are not necessarily the views of the Chief of Ordnance or of the War Department.

JULIAN S. HATCHER,
Major General, U.S.A., Retired.

Falls Church, Va.,
July 8, 1947.

CONTENTS

PART ONE

1. Brief History of the Springfield 1
2. Brief History of the Enfield 12
3. Brief History of the .30-'06, the .30 M1, and the .30 M2 Cartridges 19
4. Automatic Gun Mechanisms 32
5. Notes on Machine Guns and Their Development 70
6. The Military Semiautomatic Rifle 139
7. Experiments with Barrel Obstructions 180
8. The Strength of Military Rifles 198
9. Receiver Steels and Heat Treatment 212
10. Headspace 232
11. Block That Kick!—Some Observations on Recoil 253
12. The Theory of Recoil 279
13. Notes on Gunpowder 300
14. Gun Corrosion and Ammunition Developments 334
15. The Pedersen Device 361
16. Notes on Set Triggers 373
17. Random Notes on Various Subjects 381
    1. The Men Behind the Guns 381
    2. National Match Ammunition 385
    3. Caliber .30 International Match Ammunition 388
    4. Palma Match Ammunition 391
    5. National Match Pistol Ammunition 393
    6. Dimensions of Cartridges 393
    7. Accuracy Specifications 394
    8. Primers 394
    9. Nomenclature of Cartridge Defects 395
    10. Interior Ballistics 396
    11. Muzzle Velocity vs. Position of Cartridge when Loading 398
    12. Effect of Variations in Powder Temperature on Muzzle Velocity 398

13. Distribution of the Heat Energy of Powder 399
14. Velocity vs. Barrel Length 399
15. Tables of Remaining Velocities, Energies and Form Factors for Ammunition 400
16. Ballistic Data 401
17. Rule of Computing Ordinate to Trajectory 403
18. Formula for Wind Deflection 403
19. Relation Between Muzzle Velocity and Instrumental Velocity 404
20. Mil vs. Minutes 404
21. Comparison of Angles of Departure of .30 M1 Ammunition 405
22. Bullet Penetration in Various Mediums 405
23. Bullet Lubricant Formulae 408
24. Identification Codes of German Arms, Ammunition and Optical Instrument Makers 409
25. Headstamps on U. S. Service Cartridges 416
26. Army Test Procedure and Weapons Nomenclature 416
27. Methods of Measuring Chamber and Bore 419
28. Reference List of Numbers Marking Changes in Gun Design or Manufacture 421
29. Overloads in Revolvers 422
30. Target Measurements 422
31. Weights of Weapons 423
32. Weights and Measures, English and Metric 423
33. American and Foreign Caliber Equivalents 427
34. Value of $\frac{\delta 1}{\delta}$ for Temperature and Pressures 429
35. Cartridge Dimensions and Identification Tables 431

18. Record of Accidents to the U. S. Rifle M1903, 1917 to 1929 442

Index 483

PART TWO

19. Recent Developments 491
20. Bullets From the Sky 511
21. Explosions and Powder Fires 520
22. Exterior Ballistics 542

Index 627

PART ONE

I

Brief History of the Springfield U. S. Rifle, Caliber .30, Model of 1903

IN the Spanish American War of 1898, our Army was armed partly with Krag Jorgensen .30 caliber repeaters and partly with the old .45 caliber Springfield single shots, while the Navy used the Lee Straight Pull rifles in a caliber called 6 mm U.S.N., which in inches was equal to .236 caliber.

The Mauser rifles used by the Spaniards proved to be formidable weapons, and gained a reputation which caused our weapons to be regarded so critically that immediately after the war the Chief of Ordnance ordered the preparation of the pilot model of a new rifle. This gun had a 30 inch barrel and was fitted with a rod bayonet housed in the stock beneath the barrel. The mechanism was a modification of the Mauser action; it had two locking lugs at the front of the bolt instead of one at the rear as did the Krag. The rimmed cartridge was fed from 5 shot clips into a single row magazine extending below the stock.

The pilot model was forwarded to the War Department on August 25, 1900 for examination, after which it was tested at Springfield by a board which on October 2, 1900, recommended that the form of the magazine should be changed "to allow the cartridges to lie in a zig-zag manner, thus avoiding the necessity of having the magazine project below the stock" and that the rifle should use cannelured cartridges. A new model was then made which was basically the same as the M 1903 Springfield except that the barrel was 30 inches long and the rod bayonet was used. After test, this rifle was approved for experimental manufacture as the Model of 1901.

The construction of 5000 of these guns was authorized, but first the machinery had to be changed, and this took a long time, so it was not until April 7, 1902 that an appropriation of $1700 was made for the manufacture of 100 experimental rifles. (Thirty years later an order was given for the production of 80 experimental Garands at $1000 apiece.)

The 100 rifles were tested at Springfield Armory on Feb. 16, 1903, by a board which recommended that the barrel and bayonet each be shortened six inches to permit the gun to be used by the mounted services as well as by the Infantry, and thus avoid the necessity for a carbine.

On the recommendation of Brigadier General William Crozier, Chief of Ordnance, this new model was on June 19, 1903, approved as standard by the Secretary of War and designated as the U. S. Magazine Rifle, Model of 1903, Caliber .30.

On June 20, 1903, orders were given to begin immediately the manufacture of the fixtures, dies, tools gauges, etc., required for making 225 of these rifles per 8 hour day at Springfield Armory and 125 per 8 hour day at Rock Island Arsenal. The following month these instructions were changed to direct the manufacture of sufficient fixtures, etc., for making 400 rifles per 8 hour day at Springfield Armory.

These fixtures, etc., were made with such rapidity that quantity production of the rifles was begun in November, 1904, and continued without interruption until after the close of World War I.

Various changes were made from time to time in the components of the rifle and the methods of manufacture, some of the more important of which were as follows:

During the fiscal year of 1904, the first year of manufacture, 30,503 rifles were made. These had the rod bayonet and claw-hammer rear sight. During this period the cocking piece and safety lock were redesigned so that the rifle might more satisfactorily meet the requirements imposed by the Infantry Drill Regulations of that time.

During the fiscal year 1905, (starting July 1, 1904) 43,905 rifles with rod bayonets were made. On Jan. 11, 1905, work on the rod bayonet was stopped, following a letter dated Jan. 4, 1905, from President Theodore Roosevelt to the Secretary of War, which stated in part: "I must say I think the rod bayonet about as poor an invention as I ever saw. As you observed, it broke off as soon as hit with even moderate violence. It would have no moral effect and mighty little physical effect. . . . This ramrod bayonet business does not make me think we can afford to trust too much to theory . . ."

The Army was then experimenting with a trowel shaped combination bayonet and intrenching tool, but this idea was dropped, and a knife bayonet was approved on April 3, 1905 by Secretary of War Howard Taft as the Model of 1905. All rifles were altered to take this new bayonet.

In this period also, all work on the rear sight was suspended pending the outcome of trials of an improved sight, which was finally adopted. All rifles equipped with the old sight were changed so as to have the improved model.

The cartridge used with this gun was known as the Ball Cartridge, Caliber .30, Model of 1903. It had a rimless case and a 220 grain round nosed full metal jacketed bullet, with a muzzle velocity of 2300 feet per second. In the meantime, experiments had been underway with a sharp pointed bullet of lighter weight and higher velocity.

On October 15, this improved cartridge was approved by the Secretary of War, under the designation of Cartridge, Caliber .30, Model of 1906. It had the same case as the older one, except that the neck was shortened .07 inch; the bullet was of the sharp pointed or so-called spitzer type, weighing 150 grains, and having a muzzle velocity of 2700 feet per second.

This sharp pointed bullet did not extend as far forward as did the older round nosed one, and it therefore became necessary to alter the design of the bullet seat in the barrel of the rifle to fit the changed bullet contour. During the months of November and December 1906 and January and February 1907, no rifles were assembled, owing to the necessity of rechambering the barrels to fit the changed ammunition. All rifles previously made were afterward brought back to the Armory and rechambered. This was done by taking out the barrels, cutting them off at the rear end for a distance of two threads of the breech screw (two tenths of an inch), rethreading, putting back the barrels, and then reaming the chamber to the new size.

Up to the beginning of World War I, there had been manufactured at Springfield Armory a grand total of 606,924 rifles. In addition there had been manufactured nearly a third as many at Rock Island Arsenal, using tools, fixtures, gauges, etc., made at Springfield Armory and furnished to Rock Island.

The production of the M 1903 Springfield Rifle from its adoption up until the beginning of World War I was as follows:

Fiscal	Year	of	1904 (July 1, 1903 to July 1, 1904)	30,503 rifles
"	"	"	1905	43,905 "
"	"	"	1906	97,603 "
"	"	"	1907	102,116 "
"	"	"	1908	62,565 "
"	"	"	1909	25,662 "
"	"	"	1910	46,797 "
"	"	"	1911	49,697 "
"	"	"	1912	35,179 "
"	"	"	1913	38,070 "
"	"	"	1914	26,545 "
"	"	"	1915	25,977 "
"	"	"	1916	13,631 "
"	"	"	1917 to declaration of War, Apr. 6, 1917	8,674 "

Production by months during the War of 1917-1918 is given on Page 6.

On February 20, 1918, at rifle No. 800,000, a major change was made in the heat treatment of the receiver and bolt, which resulted in a rifle of far greater strength than before.

On May 11, 1918, at receiver No. 285,507, Rock Island Arsenal



adopted an improved heat treatment for carbon steel M 1903 receivers and bolts. Around August 1, 1918, at about receiver No. 319,921, that arsenal began using nickel steel for part of the production of receivers and bolts, but at the same time continued to make these parts of carbon steel also.

On April 1, 1927, at rifle No. 1,275,767, Springfield Armory changed the material in the bolt and receiver to nickel steel. The receivers in this series, while not quite as strong as the double heat treated ones which preceded them, still had ample strength, and the manufacture was simpler, as the complicated double heat treatment was avoided. In changing to the nickel steel, another advantage of the double heat treated receivers and bolts was lost, and this was the surface skin of very hard metal which gave a superb wearing surface, and made for a very smooth working action, without the "stickiness" of the relatively soft nickel steel. These nickel steel actions, are, however, highly satisfactory, everything considered. In the rare event of a failure, it occurs by a gradual stretching rather than by a sudden rupture.

Nickel steel receivers and bolts of rifles numbered in the 3,000,000 series made by the Remington Arms Co. during World War II were surface carburized, making them quite hard on the outside and thus avoiding the stickiness above mentioned.

During the years after World War I, it was the custom to make up each year several thousand rifles which were especially selected for use at the National Matches. In general these were the regular rifles, with star-gauged barrels, which simply means that the barrels were measured with a device called a star-gauge, so that any not within

---

MAKERS OF RIFLE HISTORY

"Major Hatcher, explaining to Expert Stock Maker Taylor, the details of the new .22 calibre Springfield.

"About the time that Europe blazed into war, a young officer of the United States Army was becoming known as an authority on rapid firers. As the war progressed, he turned his attention to military small arms, and having been interested in rifle and pistol shooting all his life, soon became even a more prominent human factor in the development of our army rifles than he had been in his work with machine guns.

"For the three years past, which have seen the greatest strides made in perfecting the most accurate of weapons for our riflemen, Major Julian S. Hatcher has been actively concerned with the production of super-accurate rifles at Springfield Armory. He has served with the Ordnance branch of the National Match Staffs of 1918, 1919, 1920 and 1921, has personally competed in the matches and applied his practical knowledge of the needs of the rifleman, thus gained, to the problem of producing for the National and International Matches the best possible weapons. In addition, Major Hatcher has been a member of three boards appointed to select ammunition for the National Matches, and has contributed scientific articles to the 'Encyclopedia Britannica,' 'The Saturday Evening Post,' 'The Scientific American' and "Arms and the Man.'"

From the February 1, 1922 issue of "Arms and the Man."

tolerances could be thrown out. In addition, the actions were carefully fitted for good trigger pull and the best possible functioning.

At one time the National Match rifles were made with headless cocking pieces, the idea being to get a faster firing pin action. The regular firing pin required .0057 second to travel through its six-tenths inch fall, while the headless pin required .0049 second; an advantage which was very likely more imaginary than real. It was found that the lessened inertia of these headless firing pins encouraged ruptured primers or primer blow-backs, and they were declared dangerous by the Ordnance Department and discontinued.

Several different kinds of pistol grip stock were tried on the National Match Springfields, and eventually one of these, which had undergone extensive tests by the service boards was adopted as standard in place of the old straight grip stock. This new stock was the one submitted for test under the designation of "Type C." Besides having a pistol grip, it omitted the finger grooves on the sides of the stock.

This was standardized on March 15, 1928, by Ordnance Committee Minute No. 6860, and the rifle so altered was known as the M 1903 A1. A1, of course, stands in Army nomenclature for Alteration 1.

Alteration 2 is one which is not seen by the ordinary user of the M 1903. It is a stripped barrel and action used inside a tank cannon for subcaliber practice; the only interest it has here is to let the reader know what the M 1903 A2 is, and so fill the gap in the record.

Along about the 1930's, the Ordnance Department made up a few thousand Springfield rifles with sporting stocks and Lyman No. 48 rear sights for sale to the members of the National Rifle Association. This was known as the Rifle, Caliber .30, M 1903, Style N.R.A.

Some heavy barrelled target rifles were also made up on sporting type stocks. These were known as the Rifle, Caliber .30, M 1903, Style T.

Occasionally a Springfield M 1903 will be seen that has an ejection port in the left side of the receiver, and the words Mark I on the receiver ring. This is one of the rifles that was made up for use with the Pedersen Device during the latter part of World War I.

During the early 1930's, the rifle production at Springfield Armory was confined to replacement parts for use in overhaul, plus a few National Match Rifles assembled in those years when the matches were held. By 1936, the Armory was being tooled up for the production of the Garand, and no Springfields were made that year, though a few were made after the tooling was completed.

Ordnance records show that in each of the calendar years in which these rifles were made at Springfield, receivers produced at the beginning of January had serial numbers according to the list which follows:

Year	Serial number of receiver Produced at start of Year	Year	Serial number of receiver Produced at start of Year
1907	269,451	1922	1,239,641
1908	337,862	1923	1,252,387
1909	358,085	1924	1,261,487
1910	398,276	1925	1,267,101
1911	456,376	1926	1,270,301
1912	502,046	1927	1,274,765
1913	531,521	1928	1,285,266
1914	570,561	1929	1,305,901
1915	595,601	1930	1,338,406
1916	620,121	1931	1,369,761
1917	632,826	1932	1,404,026
1918	761,758	1933	1,425,934
1919	1,055,092	1934	1,441,812
1920	1,162,501	1935	1,491,532
1921	1,211,300		

In 1936, during the tooling up for the Garand, production of the Springfield was suspended, but it was resumed in a small way in 1937. The last receiver made was in October 1939, and it had the number 1,532,878.

On November 12, 1941, the production of Springfields was again resumed at the plant of the Remington Arms Co., Ilion, N. Y., and the first rifle produced by them under this contract was 3,000,001. There are therefore no Springfields with numbers between 1,534,878, the last one made at Springfield Armory, and 3,000,001, the first one made on commercial contract during World War II.

At first, Remington made the ordinary M 1903, with some options as to the form of stock and other details. They started making receivers and bolts with the same 3½% nickel steel used in the Springfields, afterward changing to a chrome-nickel-molybdenum steel with only .20% to .40% nickel, or on the average, about one tenth as much as had been used formerly, but with the same amount of chromium, that is, .20% to .40%, plus a small percentage of molybdenum.

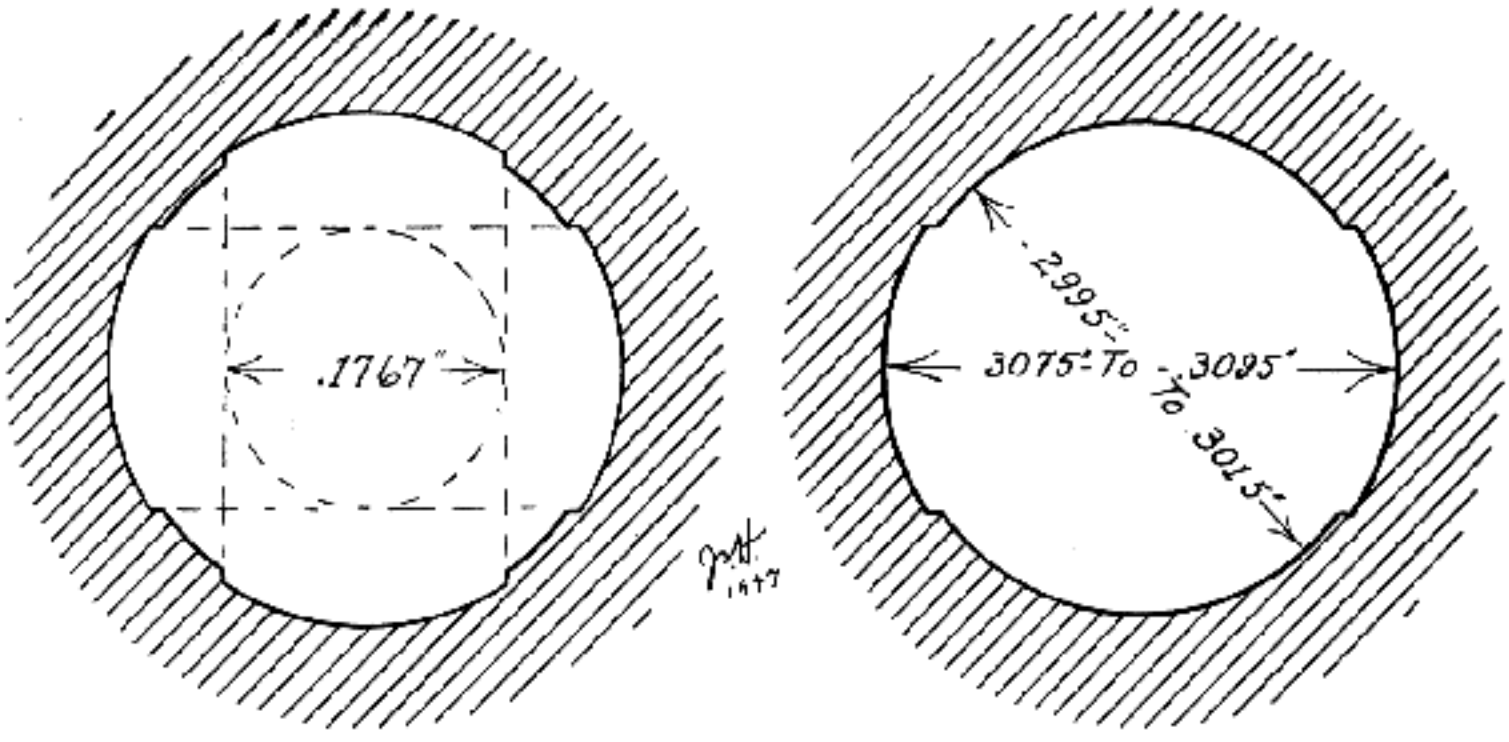
In the effort to gain increased production, this firm immediately began studies and experiments on design changes to make manufacture simpler and easier. One change was to omit two of the four grooves used in rifling the barrel. As it was found that there was little difference in the performance of the two grooved barrel and the four grooved one, this was approved. There were a number of other changes, and one which was a distinct improvement was the provision of a receiver peep sight.

On May 21, 1942, this simplified form of Springfield was approved for manufacture under the name of Rifle Caliber .30, Model of 1903 A 3.

Other changes on the A 3 model are:

Stock. Similar to that on the '03, except that the pistol grip is optional

Barrel Guard. Replaces the handguard of the '03, also covers the space formerly occupied by the rear sight.



Forms of rifling used in the M1903 Springfield rifles.

Left: standard four groove rifling used previous to 1943. The grooves are three times as wide as the lands, and the twist is one turn in ten inches, right handed. Nominal dimensions are: bore diameter, .300 inch, groove diameter .308 inch; width of grooves, .1767 inch. However, these exact dimensions are rarely encountered, as the manufacturing tolerances permit the bore to be anything from .2995 inch to .3015 inch, with grooves from .167 inch to .177 inch, and a groove diameter from .3075 to .3095 inch.

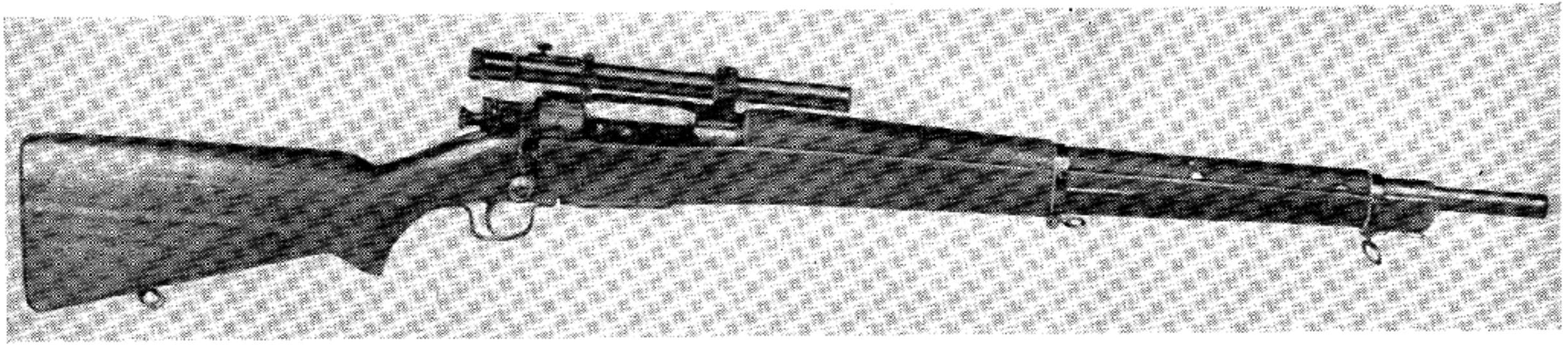
Right: two groove rifling approved in 1943 for use in the M1903 A3 rifle and for replacement barrels for the M1917 Enfield. This is simply the four groove rifling with two of the grooves omitted.

Upper Band Assembly. Is made of sheet metal stampings. The bayonet stud band, which replaces the upper band of the '03, is shorter, solid on top, and has two bayonet mounting stud bands on the bottom. The stacking swivel and its band are stampings.

Lower Band and Lower Band Swivel. These are made from sheet steel stampings.

Trigger Guard Magazine Assembly. This is the new nomenclature for the stamped, staked, and welded magazine, trigger guard and floor plate.

Front Sight Group. This is composed of a flat front sight pinned in a slot in a ring type sight base which is keyed and pinned to the barrel near the muzzle. The front sight blades are furnished in five heights from 0.477 to 0.537 inches. In targeting the rifles the proper height of blade is used to make the gun shoot as nearly as possible in agreement with the rear sight graduations.



U. S. Rifle, Caliber .30, M1903A4—**Sniper's.**

Weight (without sight)—8 pounds, 10 ounces. Sight magnification—2½ power.
Weight (with Model 330 Weaver Sight)—9 pounds, 2 ounces. Eye Relief—3 to 5 inches.
Weight (with Lyman Alaskan Sight)—9 pounds, 6 ounces.

Butt Plate Group. This is made of stampings.

Butt Swivel Group. This is made of two plates welded together with the swivel between them.

Bolt Group. While it is basically the same as that for the 1903, some parts differ in design and will not interchange with the 1903.

Follower Group. This is made from a stamping, but will interchange with the same part from the 1903.

Serial Numbers of the 1903 A 3. Before the approval of these changes the Remington Arms Co. had produced 348,085 M 1903 Springfields with serial numbers lying between the numbers 3,000,001 and 3,348,085. They continued to produce rifles, but these were now of the M 1903 A 3 type lying within blocks of serial numbers assigned to this firm. These blocks of numbers, not all of which were used, however, are as follows:

3,348,086	to	3,607,999	inclusive
3,708,000	to	4,707,999	"
4,992,001	to	5,784,000	"

Rifle Caliber .30 Model 1903 A 4. On June 14, 1943, the 1903 rifle similar to the A 3, but fitted with a telescopic sight was approved as the Rifle Caliber .30, Model of 1903 A 4. The sight used was the Weaver 330 3-power telescopic sight, slightly modified, and called by the Army the M 73 B 1. Redfield Junior Mounts were used to attach these Weaver Telescope sights to these Sniper's Rifles.

The rifle, caliber .30, M 1903 A 4, with Weaver telescopic sight and Redfield Junior Mounts was made by the Remington Arms Co., with serial numbers in the blocks given below:

3,407,088	to	3,427,087	inclusive
4,992,001	to	4,997,045	"
Z4,000,000	to	Z4,002,920	"

Springfield Made by L. C. Smith-Corona Typewriters, Inc. This firm was the only other besides Remington which produced Springfield Rifles during World War II. This plant started on the production of M 1903 A 3 rifles on Oct. 24, 1942, and actually began to turn out rifles in volume early in 1943. Blocks of numbers were assigned to this firm as follows:

3,608,000	to	3,707,999	inclusive
4,708,000	to	4,992,000	"

Production at this plant stopped February 19, 1944, with rifle No. 4,845,831, after a total of 234,580 rifles had been produced. Again it will be noted that not all the numbers were actually used, as the total produced does not agree with the difference between the serial number of the first and the last rifle. This is because of the loss of numbered receivers through rejections, experimental tests, etc.

Principal Dimensions and Weights of U. S. Magazine Rifle, Model of 1903

Barrel: Dimensions	Inches
Diameter of bore	0.30
Exterior diameter at muzzle	0.619
Exterior diameter at breech	1.14
Length of chamber and bore	23.79
Length of barrel, total	24.006
Length of travel of bullet in bore	21.697
Diameter of chamber, rear end	0.4716
Diameter of chamber, front end	0.442
Diameter of neck of chamber, rear end	0.3425
Diameter of neck of chamber, front end	0.3405
Length of body of chamber	1.793
Length of shoulder of chamber	0.16
Length of neck of chamber	0.396
Length of chamber, total	2.3716
Rifling:	
Number of grooves, 4.	
Twist, uniform, one turn in	10.00
Width of grooves	0.1767
Width of lands	0.0589
Depth of grooves	0.004
Height of front sight above axis of bore	1.05
Distance from top of front sight to rear side of leaf, leaf raised	22.1254
Stock:	
Length, with butt plate	40.166
Crook, i.e., distance from axis of bore to heel of butt	2.089
Distance from trigger to butt plate	12.74
Length of gun complete	43.212
Sight radius	22.1254
Width of single division on windage scale	0.0267

Weights	Pounds
Barrel	2.79
Barrel, with rear sight base and front sight stud	3
Butt plate	0.26
Receiver	0.98
Bolt mechanism	1
Magazine and trigger guard	0.44
Magazine mechanism, including floor plate	0.17
Bayonet	1
Stock	1.58
Hand guard	0.13
Front and rear bands, including swivels	0.25
Rear sight, not including base	0.20
Total weight of metal parts	7.30
Oiler and thong case	.19
Total weight of arm, including oiler and thong case, with bayonet	9.69
Total weight of arm, including oiler and thong case, without bayonet	8.69
Weight to compress mainspring	16 to 18
Trigger pull (measured at middle point of bow of trigger)	3 to 4½

II

Brief History of the Enfield, U.S. Rifle Caliber .30, Model of 1917

IN 1907 the British adopted the Lee-Enfield rifle that now is known as the Short Model Lee-Enfield, (S.M.L-E.), using a rimmed cartridge of .303 caliber that somewhat resembled our old Krag cartridge.

Three years later, they began the development of a new rifle to permit the use of a higher powered rimless cartridge with improved ballistics. By 1914 the new rifle and cartridge had been perfected and had undergone the official trials and was about to be adopted under the name of Rifle, Enfield, Caliber .276, Pattern of 1913.

The name Enfield came from the fact that the rifle was developed at the Royal Small Arms Factory at Enfield Lock, in Middlesex, 11 miles north of London Bridge.

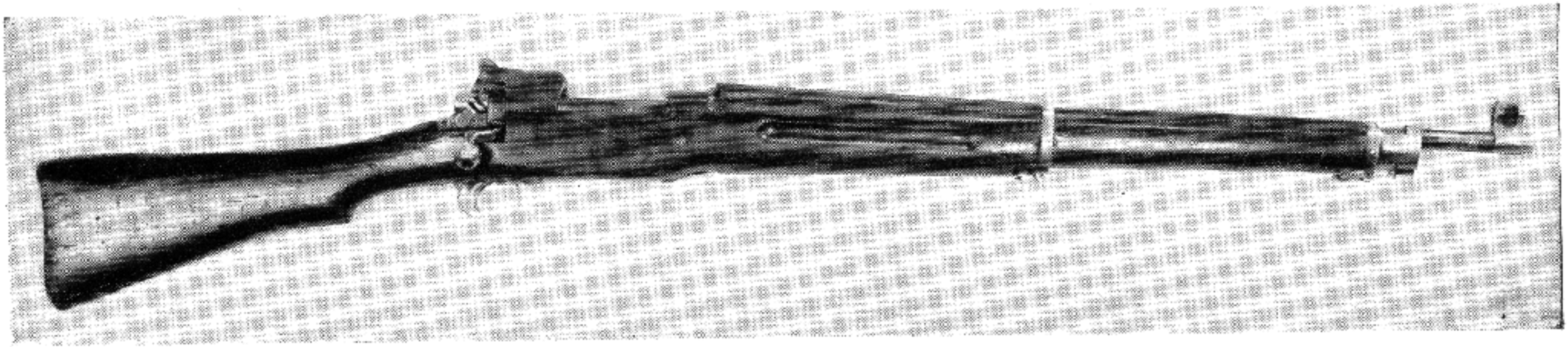
At that period Britain became involved in World War I, and time limitations prevented the intended change to a new caliber of small arms cartridge. As the need for rifles was urgent, existing plants in England which had previously made the .303 S.M.L-E. were put into high gear and production of the old model was stepped up to the maximum possible.

This, however, did not seem to be enough, so Britain turned to the U. S. for further supplies of small arms, and placed contracts for the establishing of three huge rifle plants.

These were the enormous plant built at Eddystone by a newly incorporated firm, the Remington Arms Company of Delaware, to have a capacity of 6000 rifles per day; the Winchester Repeating Arms Company, New Haven, Connecticut, 2000 rifles a day; and the Remington Arms Company, Ilion, N. Y., capacity, 3000 rifles per day.

The rifle to be made in these factories was the Enfield, Pattern of 1914, (the .276 Pattern '13 converted to take the .303 cartridge) which, while it did not work as well through the magazine as the rimless cartridge, was and still is a good military small arms cartridge.

These plants proved to be more or less of a disappointment to the British, for they were slow getting tooled up and into full production, and by the time a satisfactory volume was achieved, the British had overcome their rifle shortage by production in their home plants. By the early part of 1917, the British had started reducing these contracts, and before the U. S. entered the war on April 6 of that year, large lay-offs were taking place, and the remainder of the



U. S. Rifle, caliber .30, M1917.

work on these contracts was to be terminated by about June 1, June 21, and July 21, for the three plants respectively.

The rifle that was being produced for the British was of highly advanced design, making it the best military rifle used in World War I. Though it was basically a typical Mauser, it was improved in several respects, and had a bolt and receiver of high grade nickel steel that gave it a superbly strong action. The well protected peep sight, mounted on the receiver, close to the shooter's eye, with a front sight likewise protected by strong steel ears, gave a sighting combination that was far superior to that on the Springfield, and by a considerable margin the best and most practical of any seen in that war.

The bolt mechanism, like that of the S.M. L.-E., was designed to cock on the closing motion. This was to make the extraction easier in rapid fire, when the heat always tightens things up. With the Springfield, the work of cocking the firing mechanism is added to that of extracting the cartridge, with the result that unless very hard brass is used, the bolt becomes very difficult to open after a few rounds of rapid fire. This feature, considered a great advantage by the British, was in general not liked by our people who were thoroughly used to the Springfield, which cocks on the opening of the bolt.

The .303 Enfield had a set of auxiliary long range sights for musketry work at extreme ranges. These were attached to the left side of the rifle, but were omitted in our M. 1917.

When we entered World War I on April 6, 1917, we had on hand about 600,000 M 1903 Springfields, and some 140,000 Krags. Springfield Armory had a capacity of 1000 rifles per day, and Rock Island Armory could turn out 400 Springfield Rifles per day.

With the rapid mobilization of our forces, the need for rifles was urgent; our newly inducted soldiers were actually using broomsticks instead of rifles for their basic drill instruction.

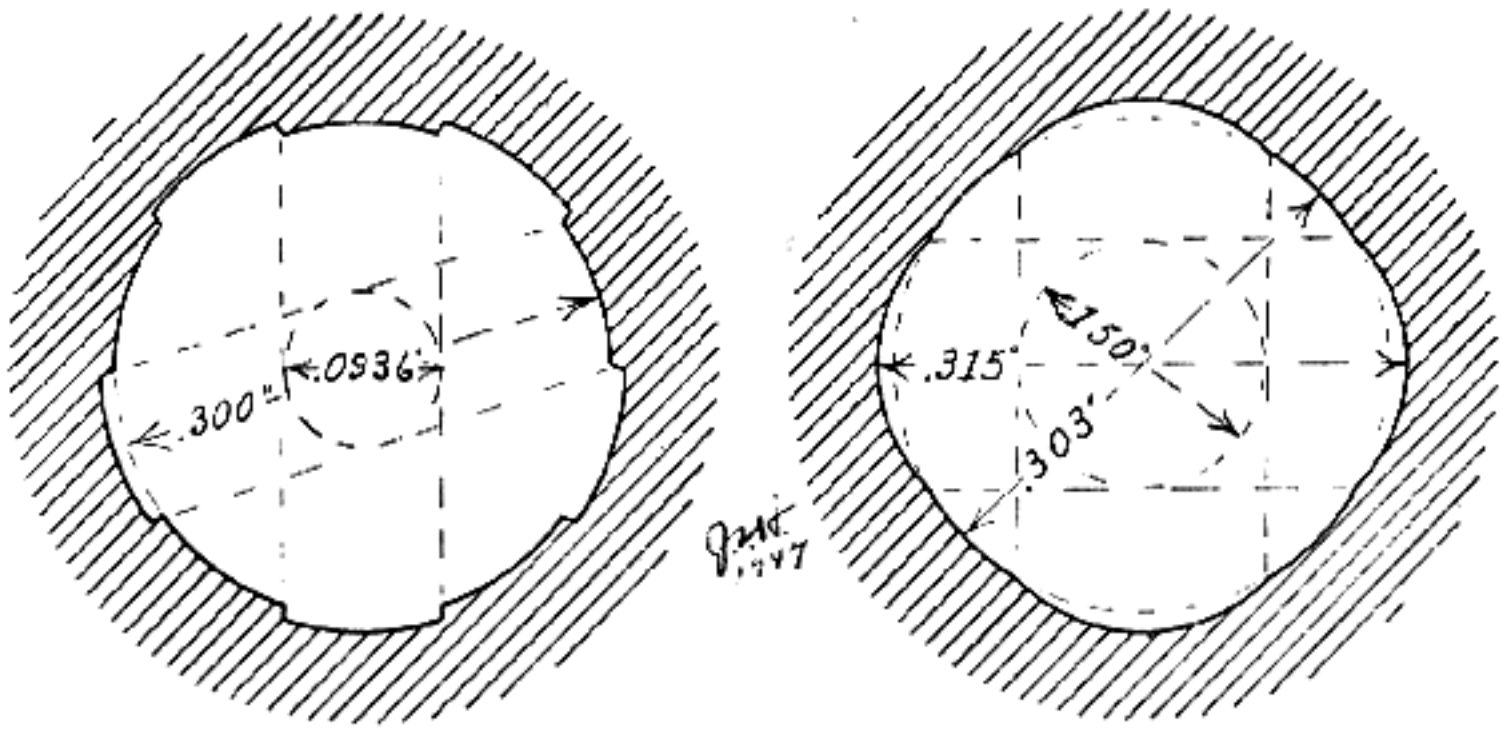
It was obvious therefore that these three great rifle plants should be gotten into production at the earliest possible moment, making rifles for our own use. To convert them to make the Springfield rifle would take months; therefore it was decided that we would use the Enfield, but that first it would be converted to use our .30-'06 cartridge.

The only really poorly designed feature on the rifle was the ejector, which had the ejector spring formed integral with it by milling a slot in one side and letting the thin part thus separated act as the spring. This often breaks in service, but fortunately the ejector with its spring is cheap and easy to replace.

For this rifle the British used the Enfield type of rifling, with wide lands and deep grooves, which had been adopted as a result of years of research to obtain a form of rifling that would best resist the severe erosion and barrel wear of the hot nitro-glycerine powder used

in the British service. This had a left hand twist, with five lands and five grooves of equal width, the grooves being .0058 inch deep in a bore of .303 inch diameter.

We retained the Enfield form of rifling, but changed the bore and groove dimensions to suit our own bullet diameter of .3086 inch. To accomplish this we changed the bore from .303 inch to .300, and made the grooves .005 inch deep instead of .0058 as in the .303.



Left: Form of rifling used in the M1917 Enfields. There are five lands and five grooves, and lands and grooves are of equal width. Nominal dimensions call for a bore of .300 inch, the same as for the Springfield. Grooves are .005 inch deep, and have a twist of one turn in ten inches, left handed. During World War II, many 1917 Enfields were rebarrelled with two grooved barrels, with right hand twist, the same as used in the M1903 A3 as to form and dimensions of rifling and direction of twist.

Right: Rifling of the "Metford" type, as used in the Model 99 (1939) 7.7mm Japanese rifle. Grooves are .006 deep in the center, and have a twist of 1 turn in 9.5 inches, right handed. Other Japanese rifles and pistols use a similar form of rifling. This Metford rifling was developed in England, and was used in the Lee-Metford Rifle, but was superseded by the Enfield form of rifling to permit longer barrel life.

This gave a somewhat tighter barrel than was used on the Springfield, as will be seen when it is remembered that in the M 1903 the grooves are three times as wide as the lands, while in the 1917 the lands and grooves are equal.

In the M 1903 Springfield the bore diameter is .300 inch, but only one fourth of it is left this size. The other three fourths has the groove diameter of .308 inch, so that the average diameter is .306 inch.

In the 1917 the bore is likewise .300 inch, but this comprises one half of the entire inside surface, instead of only one fourth as in the Springfield. The other half consists of grooves, and as they are .005 deep, the equivalent groove diameter is .310 inch though as each groove is opposite to a land there is no actual place where the groove diameter can be measured directly. With half the bore having a diameter of .300 inch and half having a diameter of .310 inch, the average would be .305 inch as against .306 inch for the '03 Springfield.

While this is, as shown above, somewhat tighter than the rifling we had been using on the M 1903, it was adopted because after careful tests it seemed to give the best results for that form of rifling with the diameter of bullet we were already using.

This has been gone into at some length because we so often see in print the erroneous statement that the 1917 has a bore that is too loose for our bullet, because we "used the British dimensions" when we took over the manufacture of the Enfield.

The statement that this is not so is from first hand knowledge, because during a large part of the First World War, I was Chief of the Machine Gun and Small Arms Section, Engineering Division, Ordnance, or in other words, Chief of Engineering and Design for Small Arms for the Army, and had personal contact with this matter at the time these rifles were being made.

It is interesting to note in this connection, that many tests made during the years since then have shown that the 1917 barrels will always outwear the '03 Springfield barrels. At this writing, March, 1947, there is serious consideration being given to adopting some such form of rifling as that on the Enfield for all future small arms manufacture.

At the present time, not all 1917 Enfield Rifles have barrels of the type described above, for some were rebarreled with 4 groove barrels having a right hand twist, of which the Hi-Standard Manufacturing Co., of New Haven, Conn., made 61,250, and some were rebarreled with 2 groove barrels, of which Johnson Automatics, Inc., of Providence, R. I., made 81,571. Recent Ordnance tests show that the accuracy of all these barrels is comparable, but that the 2 groove barrels give slightly lower pressures with high powered hunting loads. The difference is not, however, great enough to give these two-groove barrels much advantage over the four groove type.

During the First World War the three plants mentioned above turned out a total of 2,202,429 Model 1917 Enfields, at a cost of approximately $26 each.

Principal Dimensions and Weights of United States Rifle, Cal. .30, Model 1917

Dimensions	Inches
Barrel:	
Diameter of bore	0.30
Exterior diameter at muzzle	0.60
Exterior diameter at breech	1.32
Length of chamber and bore (from face of bolt to muzzle)	26.
Diameter of chamber, rear end	0.4716
Diameter of chamber, front end	0.442
Diameter of neck of chamber, rear end	0.3425
Diameter of neck of chamber, front end	0.3405
Length of body of chamber	1.785
Length of shoulder of chamber	0.16
Length of neck of chamber	0.396
Length of chamber, total	2.341
Rifling:	
Number of grooves, 5.	
Twist, uniform, left hand, one turn in	10.
Width of grooves	0.0936
Width of lands	0.0936
Depth of grooves	0.005
Height of front sight above axis of bore (mean)	1.06
Distance from top of front sight to rear side of leaf, leaf raised	31.76
Stock:	
Length, with butt plate	42.62
Crook, i.e., distance from axis of bore to heel of butt	2.12
Distance from trigger to butt plate	13.5
Length of gun complete	46.3
Sight radius	31.76
Sight radius (battle sight)	31.69

Weights

Bayonet	1 lb. 2 oz.
Oiler and thong case	3 oz.
Total weight of arm with oiler and thong case and bayonet	10 lbs. 5 oz.
Total weight of arm with thong case without bayonet	9 lbs. 3 oz.
Weight to compress mainspring	16 to 18 lbs.
Trigger pull (measured at middle of bow of trigger)	4½ to 6½ lbs.

RIFLE PRODUCTION TO NOV. 9, 1918

Months	Eddystone	Winchester	Ilion	Springfield Armory	Rock Island Arsenal	Total
Before August, 1917	.....	.....	.....	14,986	1,680	16,666
Aug. 1, 1917 to Dec. 31, 1917	174,160	102,363	26,364	89,479	22,330	414,696
1918						
January	81,846	39,200	32,453	23,890	7,680	185,069
February	98,345	32,660	39,852	6,910	2,460	180,227
March	68,404	42,200	49,538	120	420	160,682
April	87,508	43,600	36,377	2,631	.....	170,116
May	84,929	41,628	54,477	3,420	550	185,004
June	104,110	34,249	52,995	6,140	619	198,113
July	135,080	35,700	60,413	14,841	2,038	248,072
August	106,595	20,030	65,144	27,020	1,597	220,386
September	110,058	31,550	58,027	29,770	3,813	233,218
October	100,214	33,700	53,563	35,920	3,256	226,653
Nov. 1-9, 1918	30,659	9,100	16,338	10,500	808	67,405
Total	1,181,908	465,980	545,541	265,627	47,251	2,506,307

Note: Eddystone, Winchester, and Ilion plants turned out the Enfield, while the Springfield Armory and the Rock Island Arsenal produced the Springfield. The months marked by a drop in the production at Springfield and at Rock Island were months in which the components manufactured were not assembled but were used for spare parts.

III

A Brief History of the .30-'06, the .30 M1 and the .30 M2 Cartridges

WHEN the M 1903 rifle was first adopted, the cartridge designed to go with it had a rimless case, which, except for very minor changes, is the same as that we have now. The bullet was of round nosed shape, weighing 220 grains, with a muzzle velocity of 2300 feet per second.

In 1906 we adopted a lighter bullet weighing 150 grains, having a sharp or "spitzer" point, and with a muzzle velocity of 2700 feet per second. This bullet had a cupro-nickel jacket, and a core composed of 1 part tin to 39 parts of lead. The maximum range was given in the handbooks as 4700 yards.

For use in long range matches, the commercial companies furnished a cartridge with a 180 grain bullet, having better wind bucking qualities, and longer range.

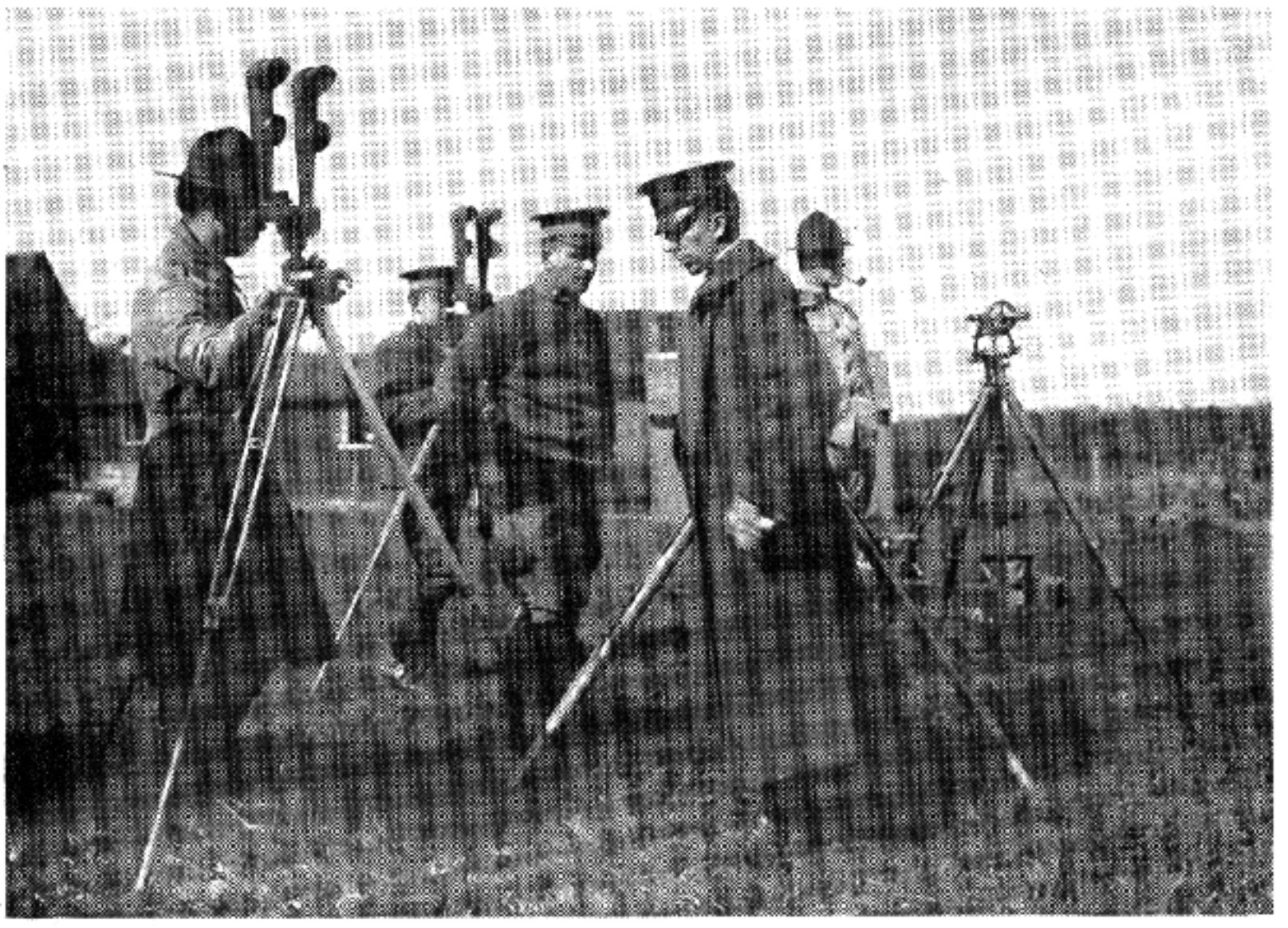
In 1911 to 1913, when I was a licutenant of Artillery stationed in Florida, I did a lot of shooting, and onc of the things I tried was to see how far I could shoot a Springfield rifle along the beach. To my disappointment, I just never could seem to get it to shoot as far as the book said it would.

As Chief of the Machine Gun and Small Arms Section, Engineering Division, Ordnance, during World War I, I decided to solve this mystery, so I got one of my Mexican Border Machine Gun School assistants, with whom I had often collaborated in similar experiments, and set him to check the range tables. This was the late Lt. Col. Glenn P. Wilhelm, and the work was started at Borden Brook Reservoir, near Springfield Armory, and later was continued at Miami, then at Daytona Beach. The late noted firearms writer, Capt. Edward C. Crossman was one of Col. Wilhelm's assistants in this work, as was my brother, Major James L. Hatcher, 65th Artillery, who was firing his 9.2 inch howitzers on the fortress of Metz the day of the Armistice and returned to this country immediately afterward. The troops he was to take back to France were cancelled in view of the Armistice, and while waiting for another assignment he worked on this project with Col. Wilhelm. This started him on a long and brilliant career in the Ordnance Department as a small arms expert.

Col. Wilhelm and his crew soon found, as I had suspected from my Florida experience, that the .30-'06 bullet would not go anywhere nearly as far as the book said it would. The maximum range

was found to be 3300 to 3400 yards at an angle of about 29 degrees, and the same up to about 45 degrees, after which the range began to shorten.

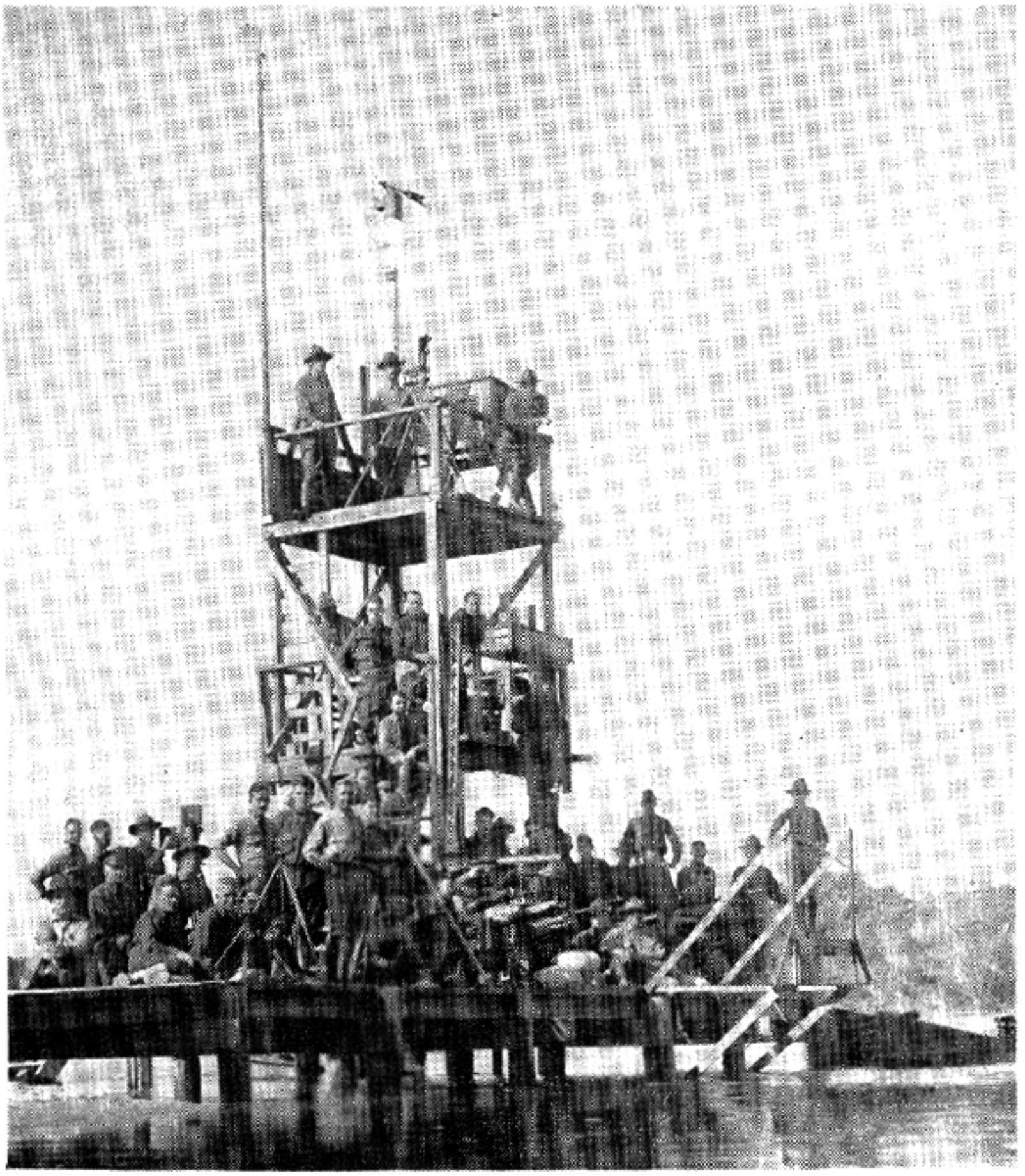
When the reason for this discrepancy was investigated, it was found that the original tables of fire had been made at Springfield Armory as a result of test firings at Longmeadow, along the Connecticut River not far from the Armory. Up to 1200 yards, the results were quite accurate; beyond this range, the target became harder and harder to hit, and had to be made larger and larger. Then, even with the largest practicable targets, some bullets would be on and some off, and the center of impact had to be more or less estimated. When the range went beyond 1800 yards, it became impossible to get results, and the figures on out to extreme range were then calculated according to the best information available in those days, which, however, was not good enough. The figures for the extreme range were about 38% too big.



Beginnings of the investigation to check the small arms range tables, Borden Brook Reservoir, Mass., 1918. Center, Lt. Col. Glenn P. Wilhelm. Right, nearest the camera, Lt. Col. Wallace L. Clay.

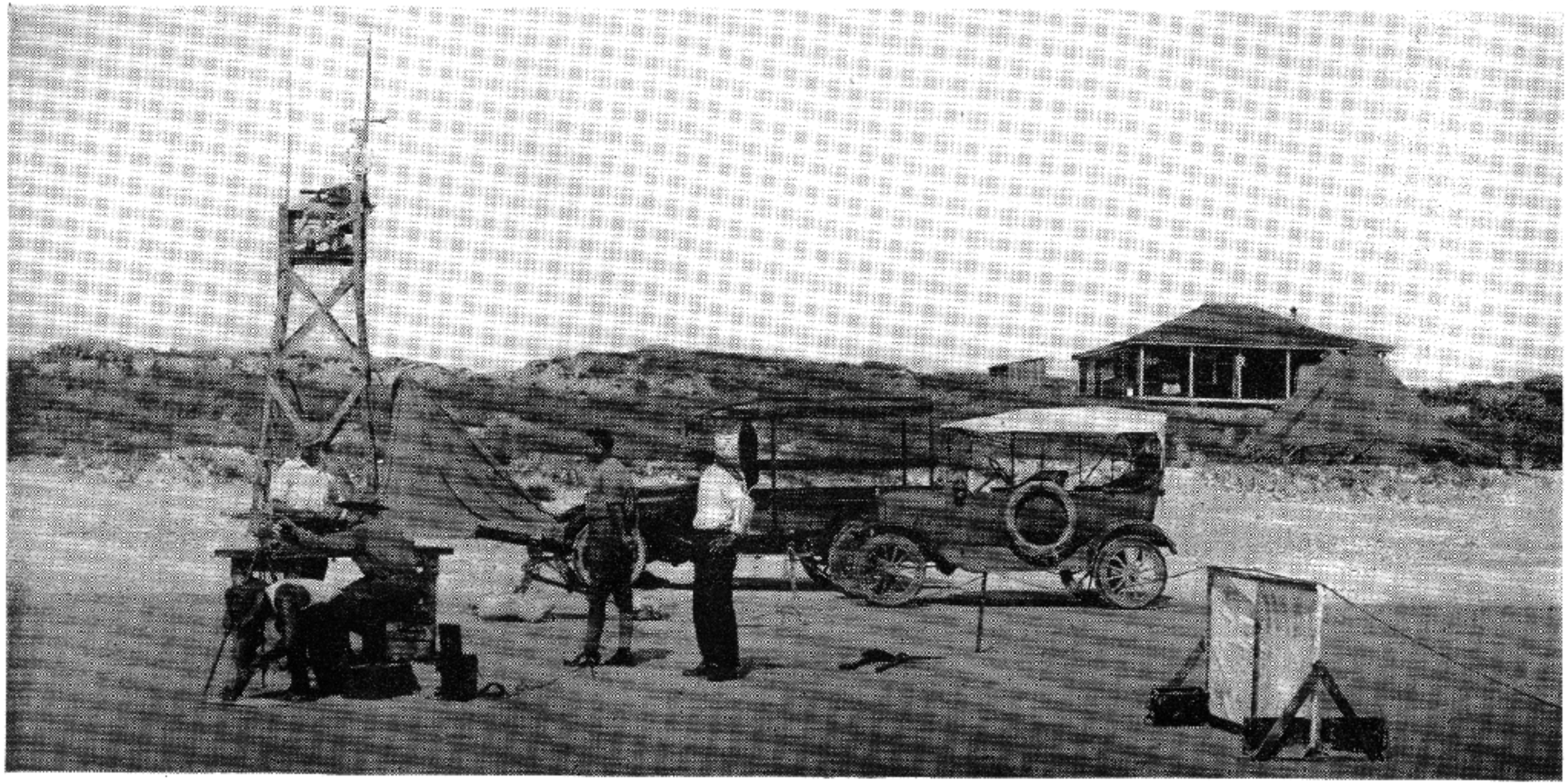
When this long range firing program was initialed, I felt certain that sooner or later our forces in France would demand greater range in the Small Arms cartridges, as the Heavy Machine Gun was being much used at that period and extreme range was an important characteristic. I had been head of the Machine Gun Schools, first

on the Mexican Border, then at Sandy Hook and later at Springfield, and had just written a book, with Wilhelm and Malony on Machine Guns, their tactics, fire control, etc., and felt that when the users of these guns in France found that their bullets were inferior in striking power at long ranges to some others, trouble would start. So to be ready with some kind of solution, I ordered 100,000 rounds of 180 grain match ammunition, and made range firings with that also.



Col. Wilhelm's Ballistic Station at Miami in 1918. Officer in center of top platform under range clock is Major (now Colonel) James L. Hatcher, brother of the author.

Our Army had practically no machine guns when the war started, so we armed our first troops in France with British Vickers guns and with the French Hotchkiss. The Vickers used the .303 Mark VII



Col. Wilhelm's Ballistic Station, Daytona, Fla., 1919. Firing the .30 Caliber rifle with Swiss boat tailed bullets for maximum range.

cartridge, having a 174 grain flat based bullet, and the French Hotchkiss used the "Balle D," a solid bronze boat tailed bullet weighing about 198 grains.

Very soon the users of these guns found that these bullets had an extreme range nearly 50% greater than did our .30-'06. When the Vickers and Hotchkiss guns gave way to the new Brownings, and the troops found that they could no longer lay down barrages at the same long ranges as before, cablegrams came back hot and heavy demanding that something be done about it. Fortunately we were already well along toward finding out what our ammunition would really do and what it wouldn't, and the reasons for the condition. An officer from my office who was in France on temporary duty told them about the 180 grain Match bullets we were trying, and immediately a demand was cabled back for some of this to try, and it was sent. We were then told that a longer range for our small arms cartridges was necessary and work was started on developing such a cartridge. Not long afterward the Armistice of November 11, 1918 put and end to the work for the time.

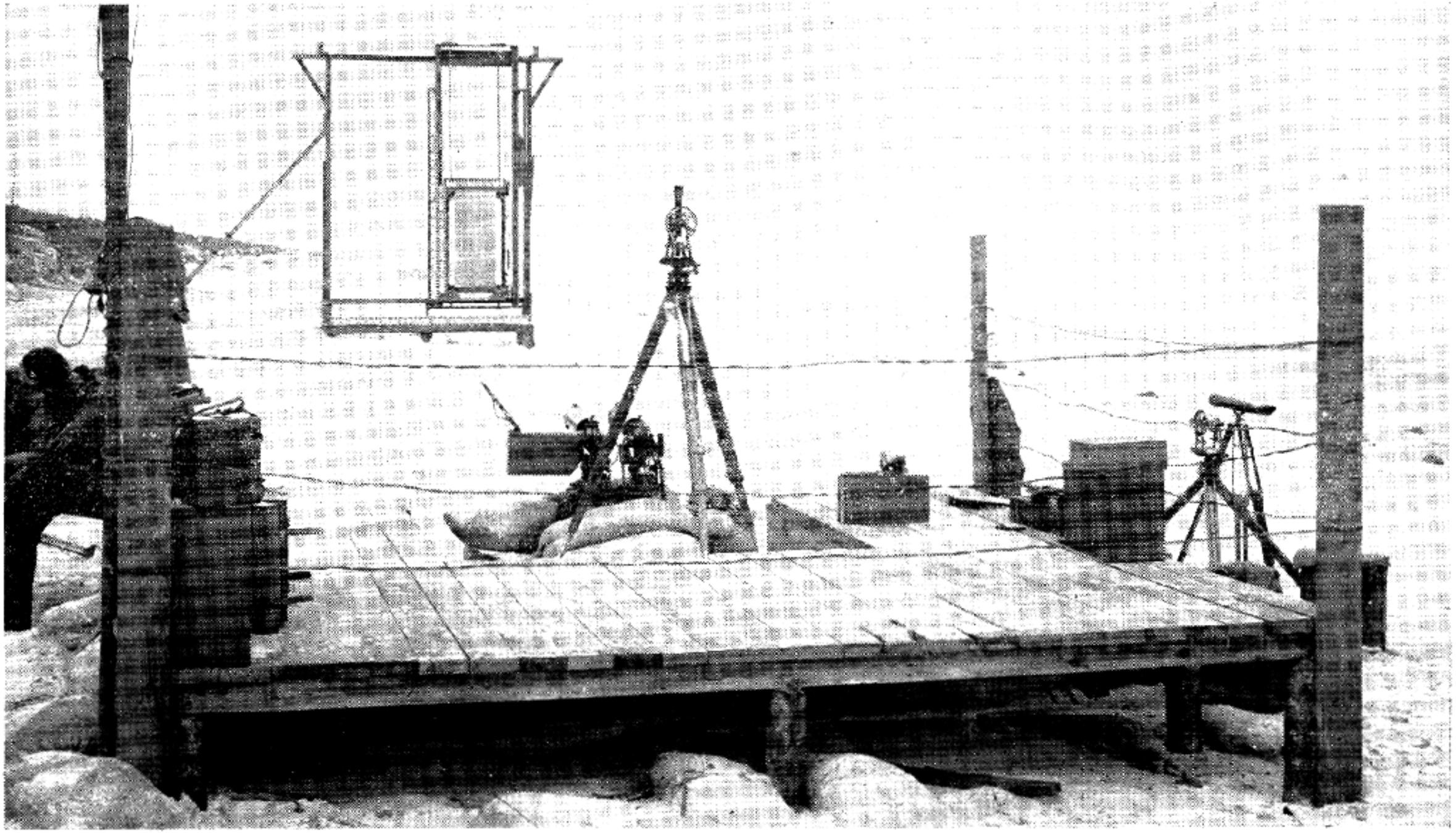
In France, the Fiske Board, with Col. Earl McFarland, Maj. Lee O. Wright, and Lt. Col. J. S. Hatcher as Ordnance Members, visited each Division, Corps, and Army headquarters and interviewed the Commanding General as to the actual charactertistics that should be embodied in the new cartridge. It was determined that the same ammunition should be provided for both rifle and machine gun, and that it should have the longest possible range and the flattest possible trajectory that would still permit it to be used in the rifle.

After the end of the War, the development of this new ammunition proceeded, with much advice from the Infantry Board and the Cavalry Board, and with some of the experimental types being tried out at the National Matches at Camp Perry each year.

In connection with these tests we had our attention directed by Col. Lucian B. Moody to the Swiss Service Ammunition, which had a 174 grain boat tailed bullet of the same diameter, as our own service bullet, that is, .308 inch. Very early in the game Col. W. L. Clay, Commanding Officer of Frankford Arsenal conducted a series of firings with this ammunition that showed it to be immensely superior to ours at long ranges. Conveniently enough, these Swiss bullets could be loaded into our own cases and fired in our guns.

Col. Townsend Whelen succeeded Col. Clay in command of Frankford Arsenal, and made up a series of bullets with boat tails from 2 degrees on up to 12 degrees taper. These were fired at Aberdeen Proving Ground, and it turned out that the 9 degree bullet gave the best performance.

Meantime, in 1923, I succeeded Col. Whelen in charge of the Frankford Small Arms Ammunition Plant, and in 1925 the type E 9 degree boat tailed bullet was adopted as standard for both rifles



The Ballistic Station at Daytona, Fla., 1919. Arrangement for obtaining the actual angle of departure by firing through a screen and measuring the height of the bullet hole above that of the bore.

and machine guns, and the ammunition was called the .30 caliber M 1. The bullet had a gilding metal jacket, and a new and improved ogive, of 7 calibers radius, giving it a slightly better form factor than the very similar looking ogive on the 1906 bullet. The muzzle velocity was 2700 feet per second, and the extreme range was 5900 yards, as against 3400 for the 1906.

To get 2700 feet per second muzzle velocity with this heavy bullet and still keep within a desirable pressure range was found to be so difficult that many lots of powder were eliminated; as a result, Col. Clay, Chief of the Small Arms Division, pushed through a reduction of the velocity to 2640 f. s. at the muzzle or 2595 at 78 feet. This reduced the extreme range to about 5500 yards.

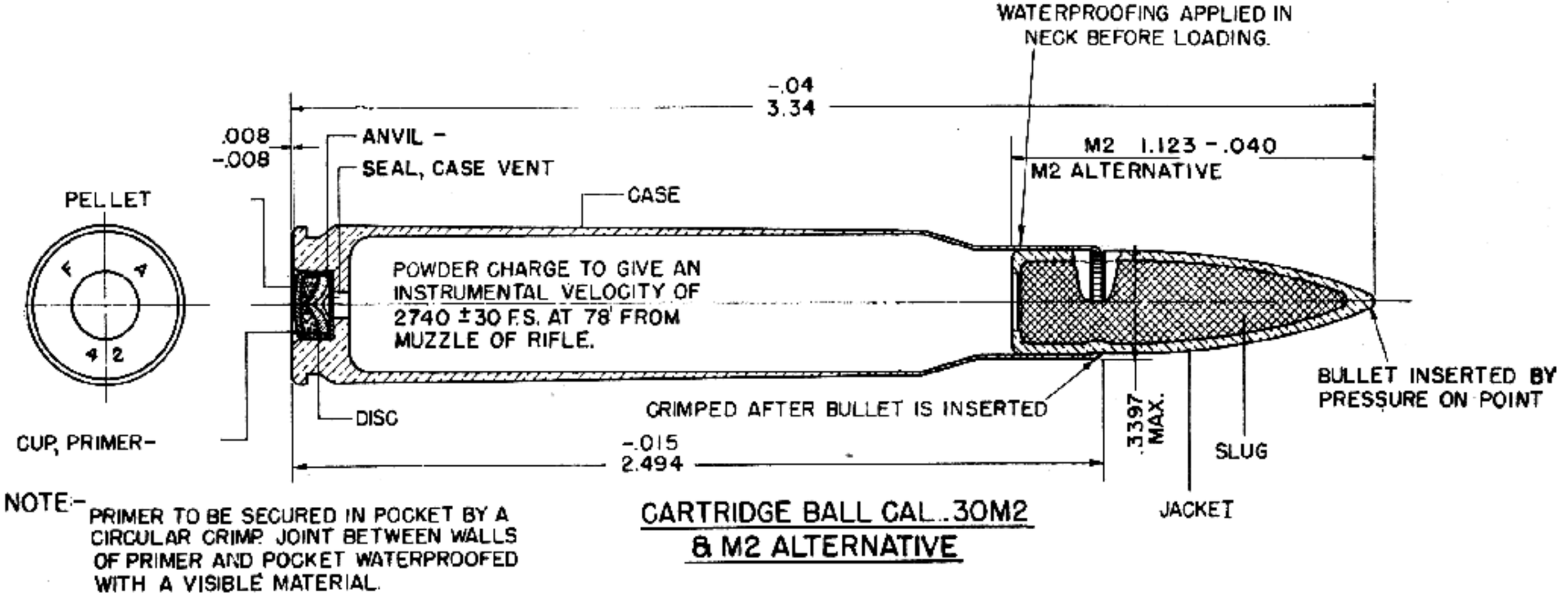
The old .30-'06 bullet had been made with a core of 29 parts lead to 1 part tin; this was found to be too soft for the boat tailed bullet, which, in the early samples at least, seemed to require a very hard core, so the metal used was 1 part antimony to 7 parts lead. The .30-'06 bullet had a cupro-nickel jacket; the M1 had one of gilding metal, hence there was no difficulty in distinguishing between them by appearance. The bullet on the '06 looked silvery, the M1 looked like gold.

At this time we had on hand about two billion of the war-time .30-'06 cartridges, and as ammunition is perishable, the policy was to use up the oldest ammunition first, keeping the newer for war reserve. Thus the shooters on Army, National Guard and Civilian rifle ranges had to use the old war time stuff, while wishing for the happy day to come when they could get some of the good new ammunition to use.

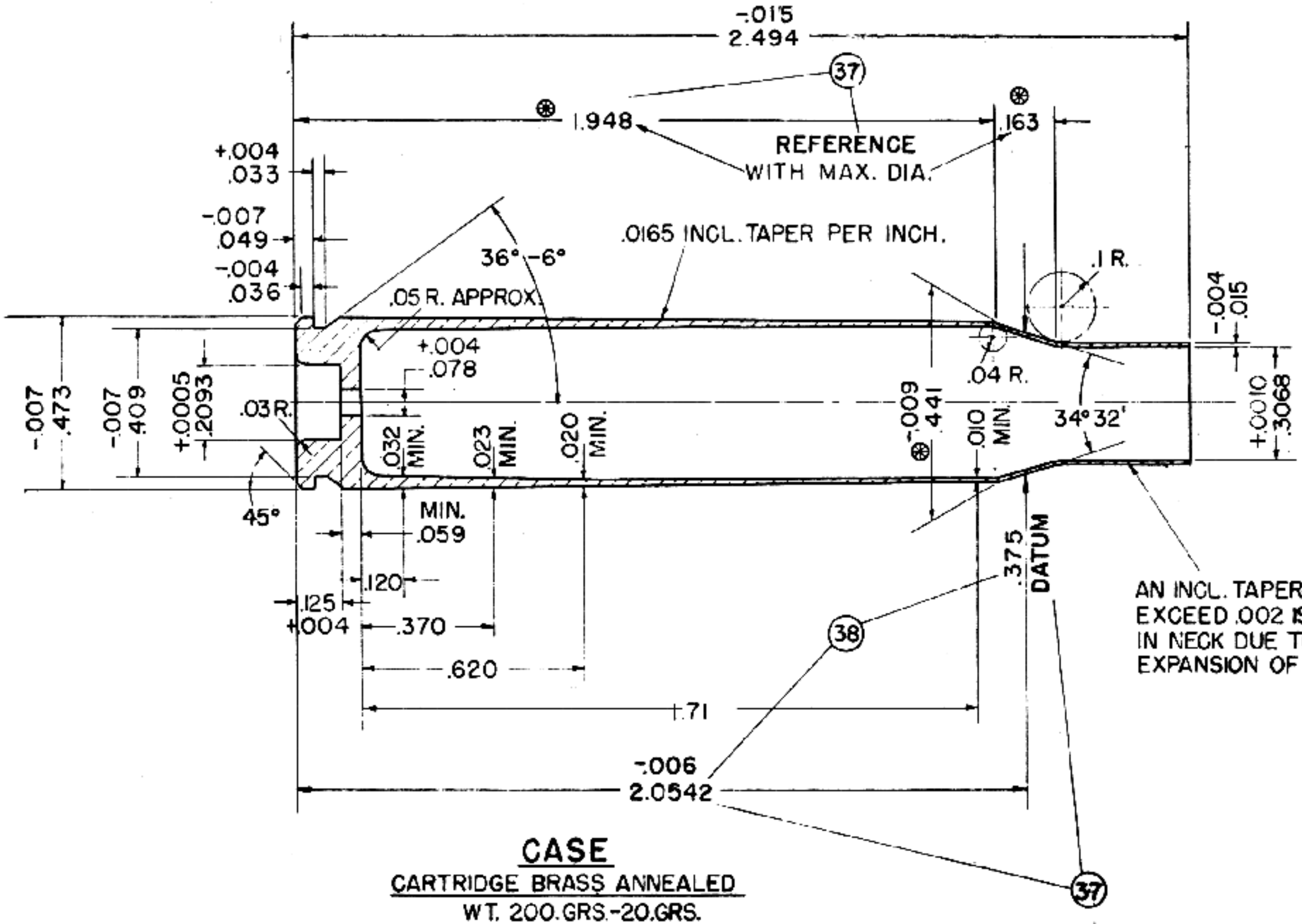
Finally about 1936 that wished-for day arrived, and with it trouble of an unexpected sort. The new ammunition had so much longer range and carrying power that it began to shoot beyond the previous danger zones of the existing ranges. The National Guard Bureau then requested the War Department to make up some ammunition like the old 1906, to use on the restricted ranges, and the order was given to make up 10,000,000 rounds of it.

This short range ammunition was made as much like the 1906 as possible. It had a 150 grain flat base bullet, but the jacket was of course made of gilding metal instead of the old cupro-nickel. It was, however, colored to look like the 1906 by the use of a stannic stain, so it could be de distinguished from the M 1. The ogive was of the same shape as the M 1, and differed a bit from the shape of the 1906, but the difference was so slight as to be imperceptible.

Some of this ammunition reached the Service Boards, which by now had lost all of the old World War I machine gunners who so keenly felt the inadequacy of our ammunition in 1918. Our soldiers liked the lessened recoil of the new ammunition. More rounds could be carried for the same weight, etc., so the suggestion was made and carried through that it should be substituted for the M 1. In 1940 this ammu-



Cartridge, Ball, cal. .30 M2 (Gilded) and M2 alternative (Steel Socketed).



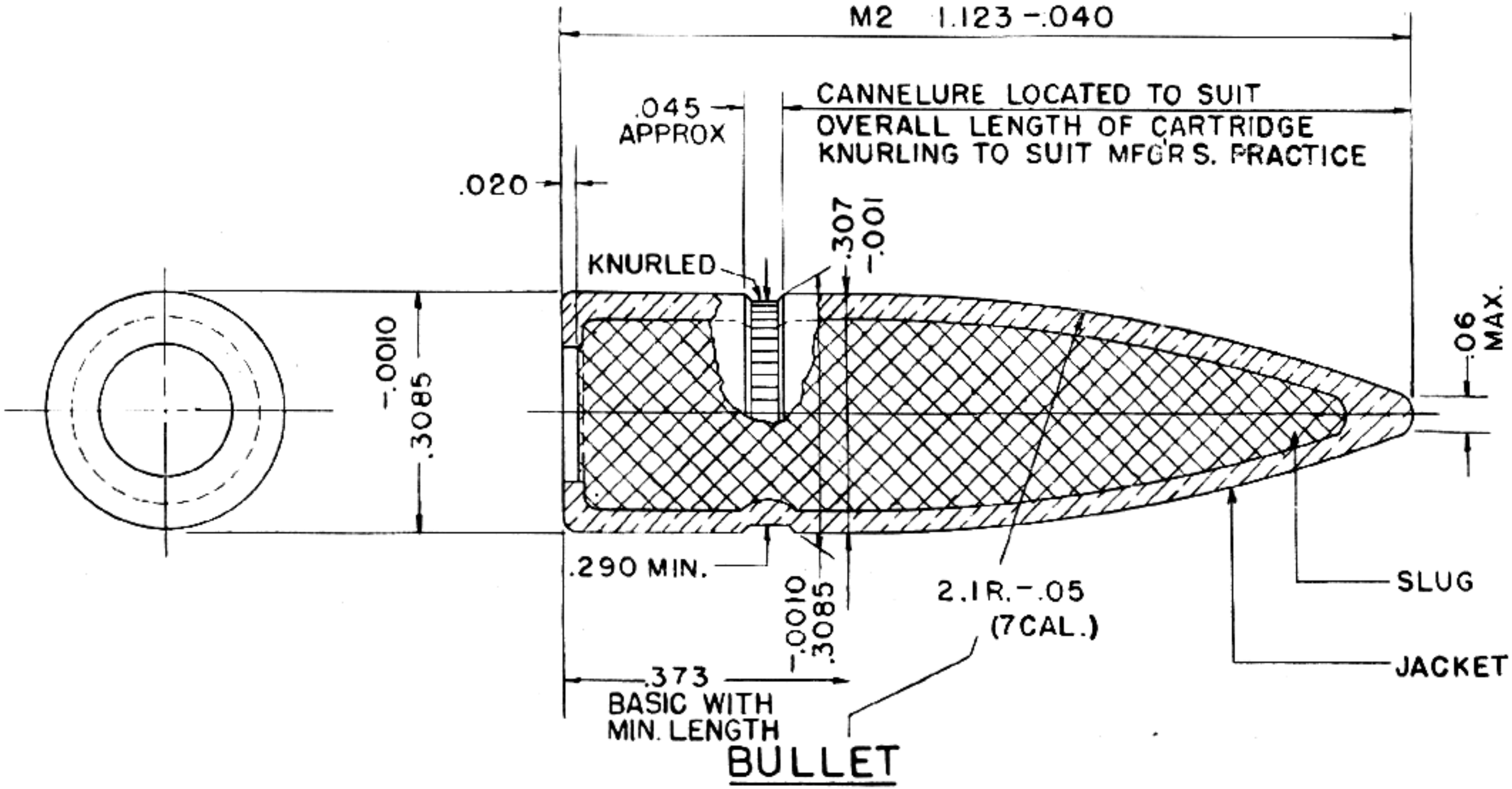
CASE

CARTRIDGE BRASS ANNEALED

WT. 200. GRS.-20. GRS.

⊛ DIMENSIONS GIVEN AT INTERSECTION OF LINES

Case for caliber .30 Service Cartridge.



Bullet, Ball, caliber .30 M2.

nition with some slight further changes, was standardized as Cartridge, Ball, Caliber .30 M 2.

By the time this ammunition was standardized, tin and antimony were getting scarce, and it was found that it was satisfactory to make the bullet core of lead without the addition of any alloying material. As the lead used is secondary lead, that is, reclaimed from batteries, etc., it will have some hardening material in it, but not much. This results in a slightly increased bullet weight of 152 grains instead of 150. The muzzle velocity was also boosted from 2700 f. s. to 2805 f. s.

While we were going backward, the Germans were going to the opposite extreme. During the first World War, their standard infantry bullet weighed 154 grains, and was a flat based type, with a cone shaped depression in the base.

For machine gun use during that war, they developed a boat tailed bullet weighing 196 grains. This was adopted by them as standard and was the one used in the recent war.

In our own Army, the tendency is definitely to use armor piercing ammunition for everything, and to do away with plain ball. The Armor Piercing Ammunition that we use now is nearly identical with that developed immediately after World War I by Col. Clay, known as the M 1922. Our present type is known as Cartridge, Armor Piercing, Caliber .30, M 2. A black tip on the bullet indicates that it is armor piercing. The bullet weight is 168.5 grains.

Characteristics of the Various Types

Type	Bullet weight grains.	Muzzle Velocity foot seconds.	Instrumental velocity @ 53 Ft.	Instrumental velocity @ 78 Ft.	Muzzle Energy Ft. lbs.
Cal. .30-'06	150	2700	2655	2640	2429 Ft. lb.
Cal. .30 M 1	174.5*	2647	2620	2600	2675 Ft. lb.
Cal. .30 M 2	152*	2805	2755	2740	2656 Ft. lb.
Cal. .30 A.P. M 2	168.5*	2775	2730	2715	2780 Ft. lb.

*Maximum weight minimum 3 grains less.

Tables of Fire

Range, yards.	Cal. .30-'06 Angle of Departure, Minutes.
100	2.6
200	5.2
300	8.3
400	11.7
500	15.8
600	20.7
700	26.33
800	32.4
900	39.8
1000	48.3

Cartridge, Ball, Caliber .30, M1

Range Yards	Angle of elev. minutes	Time of flight seconds	Maximum ordinate feet	Angle of fall minutes
100	2.7	0.12	...	2.7
200	5.4	0.25	0.3	6.1
300	8.4	0.39	0.6	10.1
400	11.8	0.54	1.17	14.9
500	15.9	0.70	2.01	20.25
600	20.25	0.88	3.09	27.3
700	25.31	1.07	4.56	35.8
800	30.7	1.27	6.45	46.2
900	36.8	1.50	9.00	95.9
1000	43.5	1.75	12.3	74.3

Cartridge, Ball, Cal. .30, M2

Range Yards	Angle of elev. minutes	Time of flight seconds	Maximum ordinate feet	Angle of fall minutes
100	2.4	0.12	...	3.4
200	5.1	0.25	0.3	6.8
300	8.1	0.38	0.6	10.1
400	11.5	0.53	1.2	13.5
500	15.5	0.70	1.8	20.3
600	20.3	0.89	3.0	30.4
700	26.0	1.11	5.1	40.5
800	32.4	1.35	7.2	57.4
900	40.2	1.62	10.8	74.3
1000	49.3	1.91	15.3	94.5

Cartridge, Ball Caliber .30 Armor Piercing M2

Range Yards	Angle of elev. minutes	Time of flight seconds	Maximum ordinate feet	Angle of fall minutes
200	5.1	0.24	0.3	5.7
400	11.5	0.52	1.2	14.5
600	19.6	0.87	3.0	29.7
800	30.7	1.30	6.9	54.0
1000	46.2	1.82	13.5	90.1

Table of Fire for the .22 Caliber Long Rifle Cartridge

Range, yards	Velocity, f. s.	Energy, ft. lbs.	Time of flight sec.	Drop at target, inches	Mid range ordinate inches	Angle of departure, minutes
0	1,100	102				
25	1,070	95	0.068	0.89	0.24	3.5
50	1,020	89	0.140	3.17	0.98	7.6
75	980	84	0.214	8.06	2.28	11.7
100	950	79	0.292	14.82	4.08	15.8
125	920	75	0.372	24.73	6.78	20.5
150	890	71	0.455	36.64	10.02	24.9
175	860	67	0.541	50.80	14.20	29.6
200	840	64	0.630	72.93	19.10	34.3
225	810	61	0.720	93.04	28.30	39.7
250	790	58	0.812	118.21	31.87	44.7
275	770	55	0.911	147.20	39.87	50.8
300	750	52	1.005	177.12	48.69	55.7

Table of Fire for the Cartridge, Ball, Cal. .45 M1911

Range, Yards	Time of Flight Seconds	Drop, Inches	Deflection due to drift, inches (To the Left)
10	0.037	0.3	0.1
20	0.75	1.1	0.2
30	0.113	2.4	0.3
40	0.151	4.4	0.4
60	0.229	9.9	0.8
80	0.308	18.0	1.3
100	0.388	28.0	2.0

IV

Automatic Gun Mechanisms

AN automatic firearm is one which fires, throws out the empty cartridge, and reloads itself when the trigger is pulled. Strictly *automatic* firearms will also keep on firing as long as the trigger is held down; but the term automatic pistol, or automatic shotgun, etc., is often used to designate what is more properly called a *semiautomatic* or *self-loading* gun, which is one that unloads and reloads itself but which fires only one shot for each pull of the trigger. Thus on the Government automatic pistols the trigger must be released and pulled again for each shot fired.

The first automatic firearm was the Maxim machine gun. Machine guns were known for many years before the advent of the Maxim gun in 1884 but these older machine guns were hand-operated. In other words, they were worked with a crank like a sausage grinder, the cartridges being fed into a hopper, or feed-way, by one hand while the other one turned the crank. In 1880 Sir Hiram Maxim constructed a mechanism in which the barrel of the gun was allowed to kick back for about three-quarters of an inch when the shot was fired, and this backward motion was utilized to unlock the breech, eject the empty cartridge and feed a new one in. Maxim's gun was, therefore, what is known as a *recoil-operated* gun.

It was not very long after this that John M. Browning, a gunsmith of Ogden, Utah, conceived the idea of making an automatic gun that would operate like a little gas engine. He bored a hole in the barrel of the gun about a foot from the muzzle and fitted this hole with a piston on the end of a swinging lever. When the gun was fired, the bullet first passed this little hole in the barrel, then the gas under very high pressure struck on the piston resting in this hole and drove it downward with great force. This piston was on the end of a lever which was swung downward and to the rear by the force of the gas, operating a connecting rod which worked the breech mechanism. This gun was said to be *gas-operated*. The invention of the Colt gun by Browning in 1889, was almost immediately followed by the invention by Baron Von Odkolek, in Austria, of a gun in which the gas acted on a piston moving straight to the rear in a tube under the barrel. This gun, also gas-operated, was subsequently developed into the Hotchkiss. More about these inventions will be found in a later chapter.

As soon as the first successful machine gun was produced, this very fact turned the attention of inventors to the subject of automatic



Browning designed Colt Machine Gun.

firearms and almost immediately there were a large number of inventions produced along this line. Many of the early efforts turned to pistols and some successful ones such as the Mauser, Luger, and Colt, were soon produced. All these guns worked on the recoil-operated principle.

During the half century that has elapsed since the automatic machine guns first demonstrated their success, there have been hundreds of attempts to make machine guns, semi-automatic rifles and automatic pistols, and the patent offices and war departments of the world have been inundated by a constant flood of inventions of this general category. It is really amazing to see the different ingenious devices that were thought of in an effort to produce a successful semiautomatic shoulder rifle. Most models of such guns were either recoil-operated or gas-operated, but there have been dozens of models based on novel principles, such as operation by the movement of the primer in the cartridge case; inertia-operated shoulder guns in which a sliding weight remains relatively stationary while the gun recoils; guns with movable butt plate resting on the shoulder of the firer and operating through a system of rods to unlock the gun when the kick pushed the butt plate against the firer's shoulder; guns in which the breech was held stationary and the barrel allowed to move forward; and many others, the principal ones of which will be described in detail later.

Much of the mechanism of the machine gun is involved in the locking and unlocking of the breech block. A high-powered rifle cartridge generates a pressure of 50,000 pounds to the square inch when the gun is fired, and this pressure, acting on the head of the cartridge case, tends to force the breech block to the rear. Accordingly, when high pressure cartridges are used, the breech block must be securely locked to the rear end of the barrel in order to hold the cartridge in the chamber of the gun during the explosion. However, the force of the explosion of a cartridge is gone in a very small fraction of a second. The high pressure of 50,000 pounds to the square inch lasts less than one-thousandth of a second and then drops rapidly off to zero.

If we had a fairly heavy breech block, it would not move enough to do any harm during the very short time the pressure lasts. If the weight of the breech block could be chosen correctly, it would be possible to make a breech mechanism in which no locking device would be necessary. The pressure on the cartridge case would be just sufficient to give the heavy breech block enough movement so that the breech would open after the cartridge is fired, and if the proper spring were put behind the breech block it would close again, pushing a new cartridge in at the same time.

Blow-back Mechanisms

Actually this type of breech mechanism, called the *straight blow-back* system, is perfectly practical for low-powered cartridges, and such mechanisms are used on almost all pocket automatic pistols and on caliber .22 pistols and rifles. The breech block is simply held against the head of the cartridge by a spring, and when the gun is fired, the powder pressure blows the bullet out through the muzzle with very great rapidity, and at the same time pushes the breech block back with just the right speed to extract the fired case after the powder pressure has fallen to zero. If the breech block is made too light, it will open too quickly, and if it opens while pressure is still in the cartridge case, the cartridge case will be ruptured and gas will escape to the rear.

Calculations and experiments have shown that for the caliber .30 cartridge, such as is used in the Springfield rifle, the breech block would have to weigh in the neighborhood of twenty-seven pounds to operate satisfactorily on the blow-back principle. As the Springfield rifle itself weighs only nine pounds, the use of this kind of breech mechanism is obviously impracticable for a semiautomatic shoulder rifle using the Springfield cartridge, where the weight must be kept down to the lowest possible figure. Moreover, such a breech block is entirely too heavy for even a machine gun using the full powered Army rifle cartridge.

However, straight blow-back guns powerful enough for hunting have been produced but these guns are considerably less powerful than the Army rifle. The most powerful hunting rifle built on the blow-back principle is the Winchester self-loading rifle which was made in .32, .35, .351 and .401 calibers, with a straight cartridge shaped somewhat like a large pistol cartridge.

Even though the mechanisms of the blow-back type do not seem to be suited for military machine guns or semiautomatic rifles, the straight blow-back principle was applied to the Springfield rifle in the production of the Pedersen device, described elsewhere in this volume. This remarkable weapon was an automatic bolt for the Springfield rifle, enabling the rifle to be converted in a few seconds into a semiautomatic gun capable of firing forty shots with one reloading and having detachable magazines so that after the forty shots were fired new magazines containing forty more cartridges could be attached almost instantly.

The application of the blow-back principle to the military rifle in this case was made possible by the fact that instead of using the full powered military cartridge, the device used a caliber .30 pistol cartridge of very much the same size and dimensions as the cartridge for the caliber .32 automatic pocket pistol but considerably more powerful. The device was in reality nothing more or less than an automatic

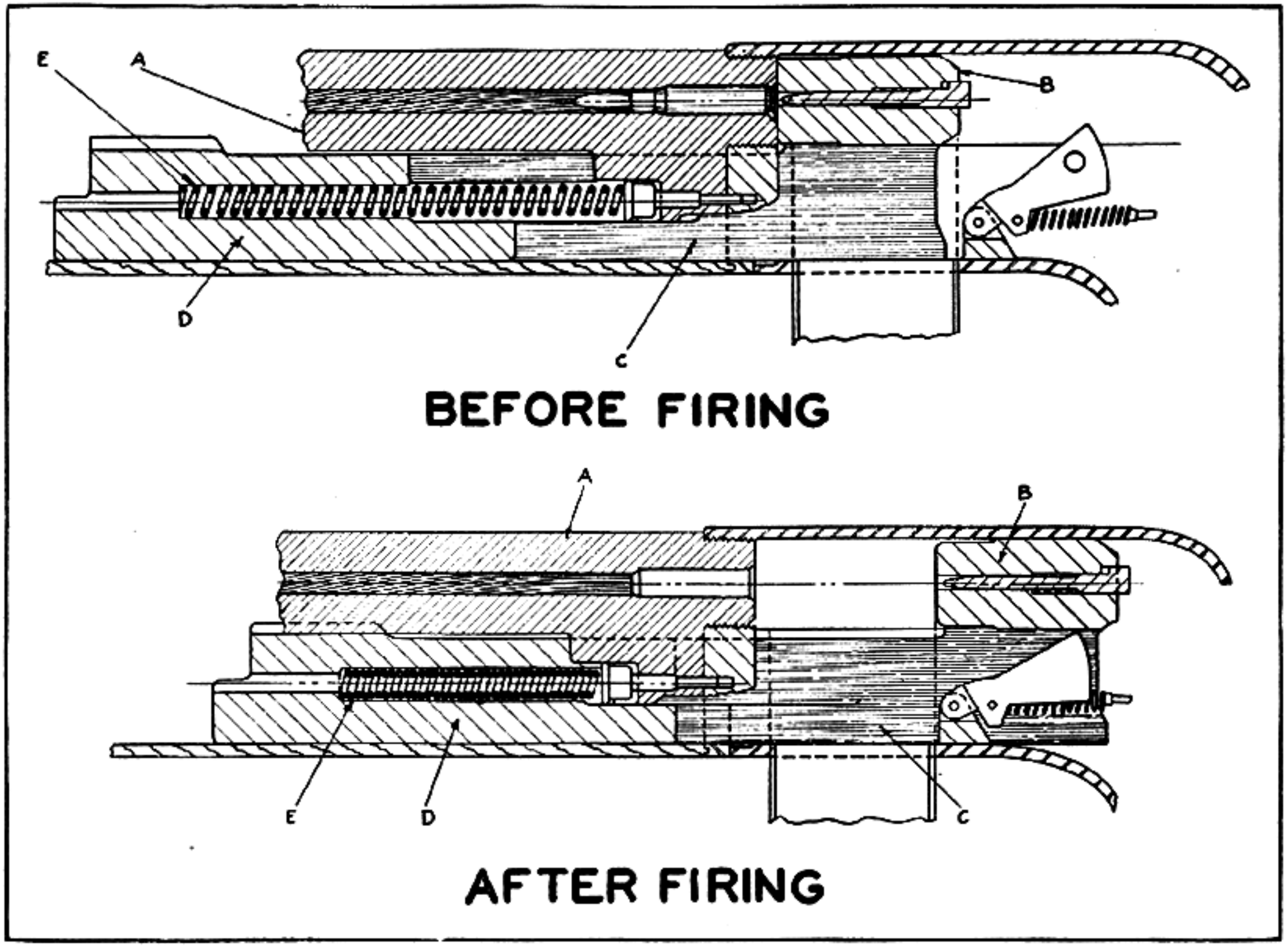


Fig. 1. Diagram of straight blow-back breech closure principle as used in the Winchester self-loading rifle.

pistol specially shaped so that it could be attached in the breech of the rifle in place of the regular bolt. The additional power of the cartridge was taken care of by a weight attached to the breech block of the device.

Fig. 1 is a diagram showing the principle of the Winchester self-loading rifle, the most powerful blow-back gun. In order to handle the powerful cartridge used in this rifle, the breech block must have a considerable amount of weight, which is provided by attaching to it a large bar of iron which lies inside the hollow wooden forearm under the barrel. The weight of this large piece of metal lying inside the forearm of the gun, gives a rather curious balance to these self-loading rifles, but aside from this they are very satisfactory guns.

Referring to Fig. 1, *B* is the breech block proper, but *B*, *C*, and *D* are all one piece of metal, as the sliding weight, *D*, lying inside the hollow wooden forearm of the gun is connected to the breech block, *B*, by the slotted section, *C*, which straddles the magazine well and the hammer. When the gun is fired the breech block slides to the rear, ejecting the empty cartridge case and at the same time compressing the return spring *E*. This return spring then forces the breech block forward again, feeding in a new cartridge from the magazine. The rearward motion of the breech block also serves to force the hammer down into the cocked position. The straight blow-back guns are the simplest of all automatic firearms as regards mechanism.

Submachine Guns

Submachine guns are called machine pistols by the Germans. They are weapons larger than a pistol and smaller than a rifle, intended to be fired from the shoulder or with two hands from the hip. They use high powered pistol cartridges, and can usually be fired either full or semi-automatically.

These weapons were much used during World War II, and there are numerous types in existence. They have one thing in common, and that is the fact they are built on the straight blow-back principle, with no locking mechanism for the breech, an exception being the early model Thompson which had a retarding wedge. This however was removed in later models.

It requires little or no ingenuity or engineering ability to build a submachine gun, and the existing models exhibit so few design features of interest that not much space will be given to them in this work.

There is just one outlet for really fine engineering in the field of submachine guns, and that is in simplifying the manufacturing processes as was done by Col. Studler in the U. S. M3 type.

"Blow-Forward" Mechanisms

We have seen above that some method must be provided to hold the breech block against the barrel when the gun is fired, because otherwise the pressure of the powder gas pushing back on the cartridge case would drive the breech block back away from the barrel and let the cartridge out while the explosion was going on. With the blow-back gun the breech block is allowed to move in this manner, but is made heavy enough so that the movement does not occur too quickly.

Instead of allowing the breech block to move back, it would be quite possible to attach the stock and all the frame-work of the gun firmly to the breech block and then allow the barrel to move forward when the gun is fired.

In 1917 an inventor appeared at Springfield Armory with a machine gun made to fire the Krag army cartridge, having the framework of the gun solidly fixed and the barrel loosely mounted so that it could move forward against the action of a spring when the gun was fired. This gun operated, but it was necessary to grease the cartridge case to prevent the front part of the case, expanded by the pressure, from sticking to the barrel as it moved forward.

While nothing came of this effort, it should be noted that several automatic pistols, notably the Schwarzlose and a model by Von Mannlicher have been constructed on this principle.

Retarded Blow-back Mechanism

We have mentioned above that with light cartridges giving low pressure it is quite possible to use what is known as the straight blow-back breech mechanism, which depends entirely on the weight of the breech block to keep it from opening too quickly. We also stated that with the full power army cartridge the breech block would have to weigh about twenty-seven pounds to prevent it from opening too soon if we depended on weight alone.

There are other things that we can depend on besides weight to retard a blow-back action. In a straight blow-back the cartridge merely pushes the breech block directly to the rear so that the full thrust is exerted in the direction of the motion. Instead of using extra weight to slow up the action, we can slow it up by arranging so that the thrust is working at a mechanical disadvantage; in other words, so that it takes more push to produce the same amount of motion or the same push to produce less motion.

If we arrange the breech block like the piston of a gas engine so that it is attached to a crank and connecting rod, it is quite obvious that if the crank and connecting rod are exactly on dead center the breech block will be prevented from moving, and all the force will be transmitted to the crank shaft. If the gun were

made like this it would never operate at all. However, if it is made so that the crank, instead of being on dead center, is just slightly to one side or the other of it, then most of the thrust of the breech block will be transmitted to the crank shaft, or in this case, the pin supporting the connecting rod; but there will be a certain component of it that will tend to drive the crank pin around in a circle just as the explosion does in the cylinder of an automobile. If the crank is almost exactly on dead center when the explosion starts, so little of the force in the breech block is directly applicable at once to moving the crank away from dead center that the motion is retarded sufficiently to enable the explosion to be largely completed before the breech block moves away far. The further away the crank goes from dead center, however, the more power the breech block has to accelerate the motion.

The Schwarzlose machine gun is made on this principle of the retarded blow-back, with the crank and connecting rod attached to the breech block as described above. In addition, the breech block is made fairly heavy and there is a very strong spring behind it. All these elements combine together to retard the motion enough so that full powered military cartridges can be handled successfully, though the breech is not actually locked to the barrel.

The diagram of the Schwarzlose machine gun (Fig. 2) shows how the crank and connecting rod work.

There is one queer thing, however, that is common to almost all blow-back and retarded blow-back guns, and that is that there is a tendency to rupture the cartridges unless they are lubricated. This is because the moment the explosion occurs the thin front end of the cartridge case swells up from the internal pressure and tightly grips the walls of the chamber. Cartridge cases are made with a strong solid brass head and a thick wall near the rear end, but the wall tapers in thickness until the front end is quite thin so that it will expand under pressure of the explosion and seal the chamber against the escape of gas to the rear. When the gun is fired the thin front section expands as intended and tightly grips the walls of the chamber, while the thick rear portion does not expand enough to produce serious friction. The same pressure that operates to expand the walls of the case laterally, also pushes back with the force of fifty thousand pounds to the square inch on the head of the cartridge, and the whole cartridge being made of elastic brass stretches to the rear and, in effect, gives the breech block a sharp blow which starts it backward. The front end of the cartridge being tightly held by the friction against the walls of the chamber, and the rear end being free to move back in this manner under the internal pressure, either one of two things will happen. In the first case, the breech block and the head of the cartridge may continue to move back, tearing the cartridge in two and leaving the front end tightly stuck in the chamber;

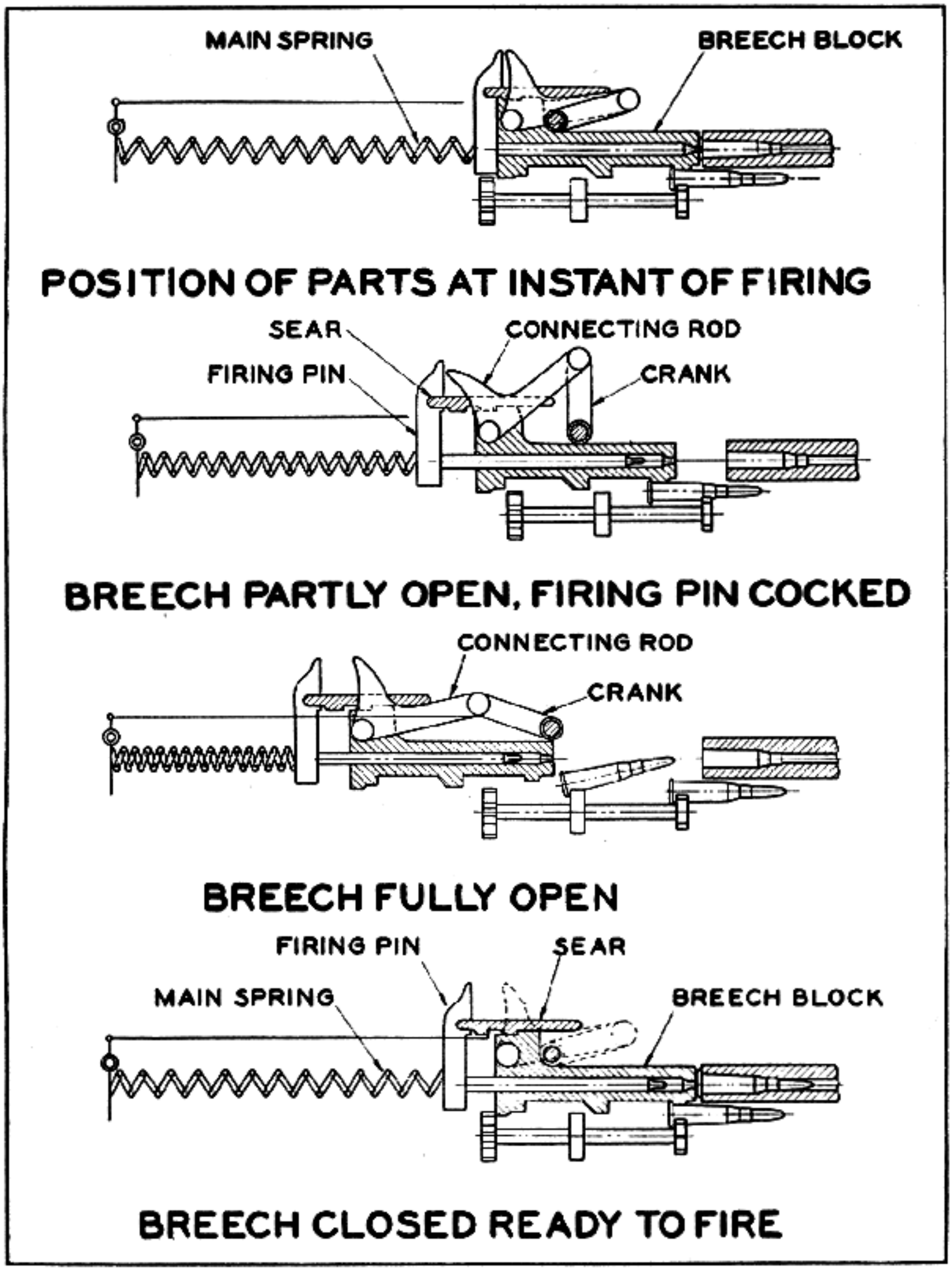


Figure 2. Diagram of the retarded blow-back closure principle as used in the Schwarzlose machine gun.

or, if the breech block is sufficiently retarded so that it does not allow a very violent backward motion, the result may simply be that the breech block moves back a short distance and the jerk of the extractor on the cartridge case stops it, and the gun will not operate.

However, this difficulty can be overcome entirely by lubricating the cartridges in some way. In the Schwarzlose machine gun there is a little pump installed in the mechanism which squirts a single drop of oil into the chamber each time the breech block goes back. In the Thompson Auto-Rifle there are oil-soaked pads in the magazine which contains the cartridge. In the Pedersen semiautomatic rifle the lubrication is taken care of by coating the cartridge with a light film of wax.

Pedersen Semiautomatic Rifle

About the year 1927 Mr. J. D. Pedersen perfected a semiautomatic rifle on the retarded blow-back principle, which rifle gave an especially satisfactory account of itself in trials. It also has a crank and connecting rod as does the Schwarzlose gun, but the mechanical arrangement is somewhat different. The operation of the Pedersen rifle is shown in Fig. 3. *A* is the breech block which is held against the head of the cartridge by the blocks *B* and *G* which are in line with each other and which transmit the thrust of the breech block to the heavy pin, *D*, which goes through the receiver. These three parts, *A*, *B* and *G*, form a toggle joint, and *C*, the point of contact between *B* and *G*, is just slightly above the line of thrust between the head of the cartridge case and the pin, *D*. Thus when there is a very heavy pressure on the front end of the breech block, *A*, there is tendency for the toggle joint to "break" and the piece, *B*–*G*, to move upward as shown in the cut marked "After Firing." If the point of contact at *C* were directly on the line of thrust, the toggle joint would remain locked and the breech would not open, but as this point, *C*, is just above the line of thrust the breech does fly open as soon as the pressure comes on the head of the bolt, but this opening is retarded because the two pieces, *B*–*G*, roll on each other in starting to open in such a manner that the contact point, *C*, continues for some little time to remain near the line of thrust. The shape of the rolling surface is worked out very skillfully in order to insure this result. As the breech opens the spring, *F*, is compressed and as soon as the motion is completed this spring causes the breech to close again.

However, like the Thompson gun, this mechanism starts to open while the high pressure is still on, and therefore it was necessary to lubricate the cartridges. Instead of lubricating them with oil, each cartridge was coated with a very thin film of hard wax which had a very high melting point, so that the cartridges would not pick up dirt when dropped as they would if oily or greasy.

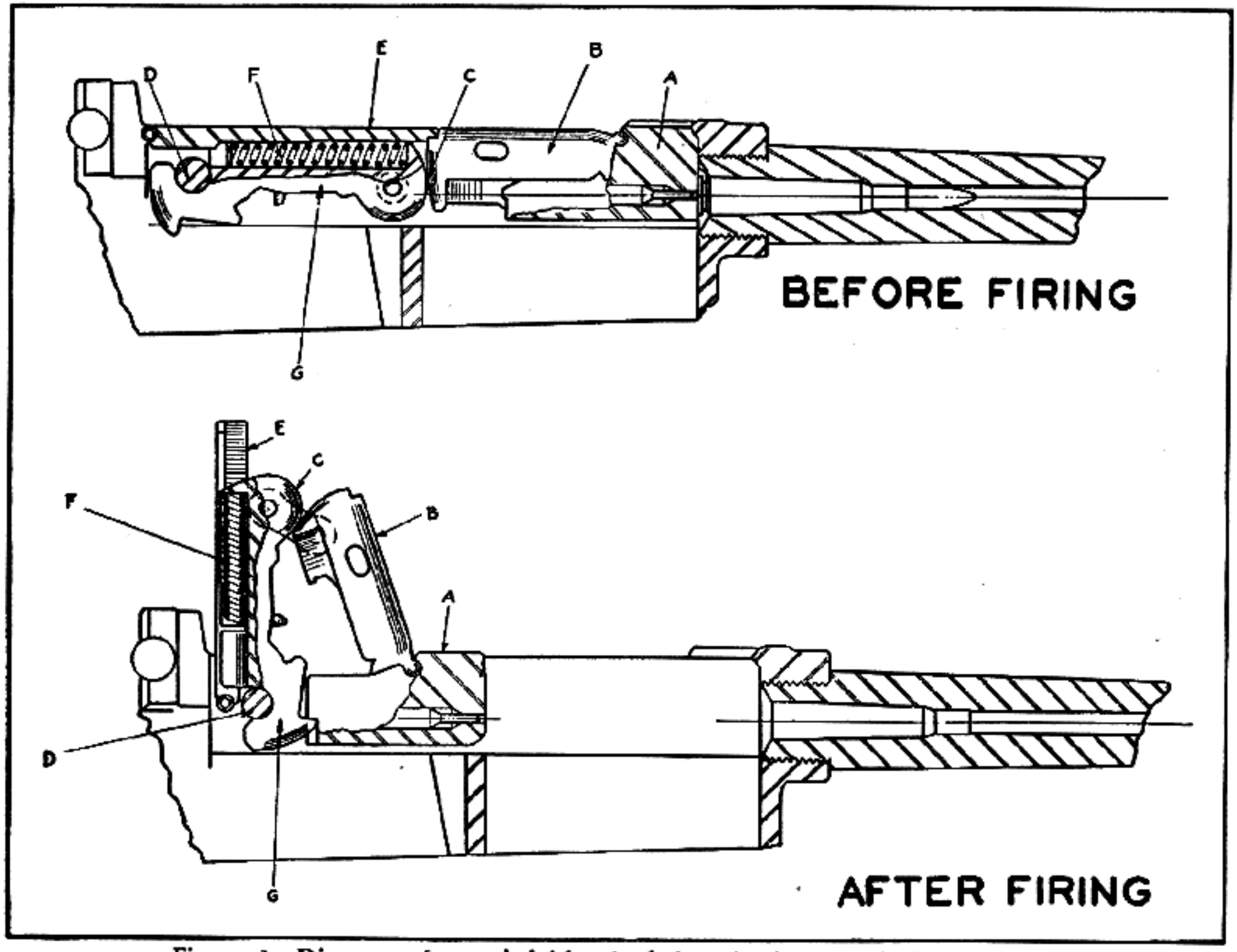
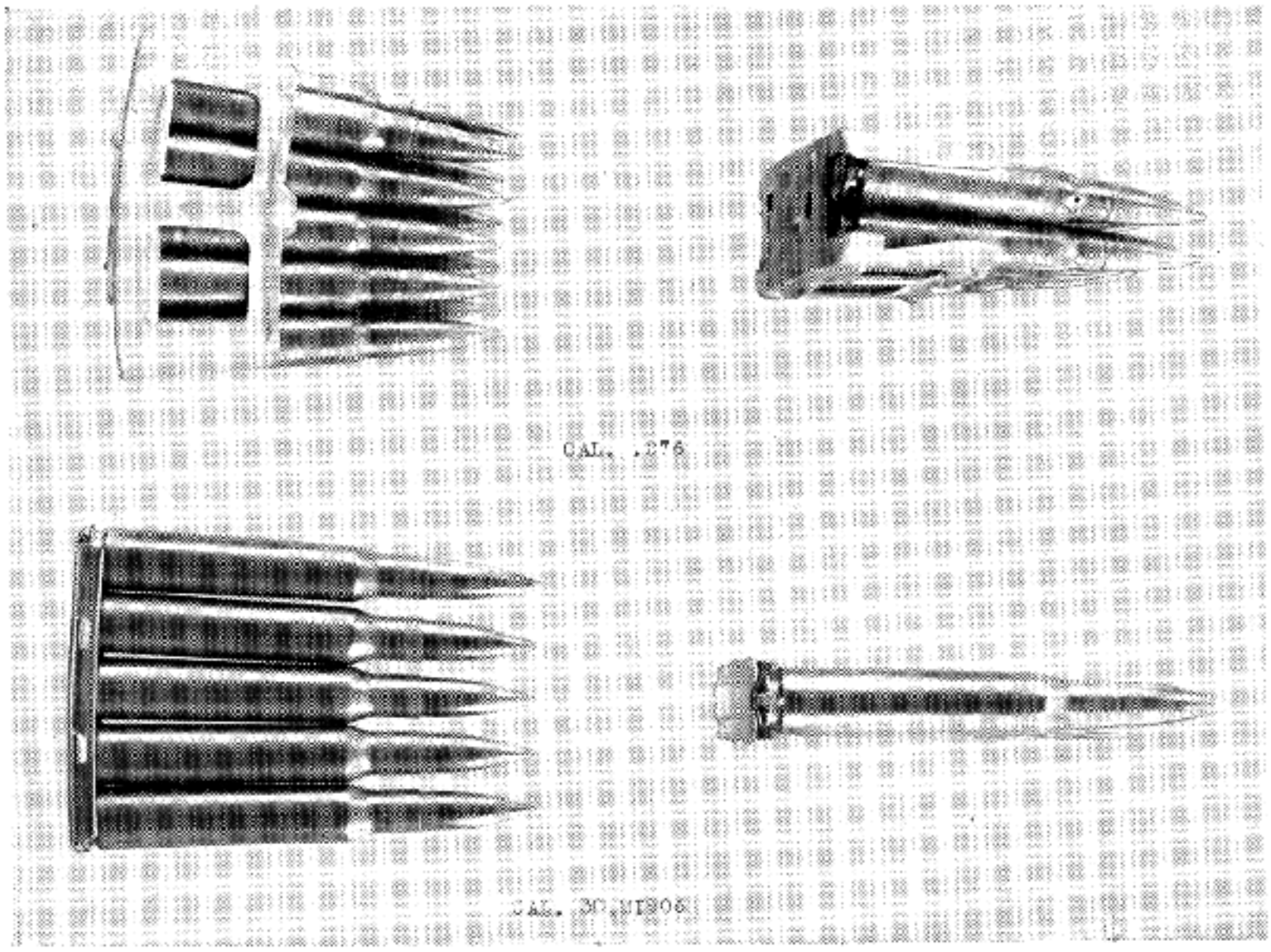


Figure 3. Diagram of retarded blow-back breech closure principle as used in the Pedersen semiautomatic rifle.

There was a good deal of talk about the disadvantage of "lubrication" in this gun; but after all, it seems that this disadvantage is more fancied than real, as the cartridges are not greasy or oily. Moreover, it has been found that corrosion is one of the greatest causes of season cracking in brass cartridge shells, and if this wax prevents the cartridge brass from corroding it may be quite possible that it would eliminate deterioration of cartridges from season cracking.



Pedersen .276 cartridges in his ten shot "en block" clip designed by him for his semiautomatic rifle. U. S. cal. .30 clip for comparison

Up to that time, all the semi-automatic rifles submitted for test had been required to be of .30 caliber, adapted to use the service cartridge. Mr. Pedersen presented very convincing arguments to the effect that the .30 caliber cartridge was more powerful than was required for the shoulder rifle, and that to reduce the caliber to the ballistically ideal 7 mm or .276 would result in a number of advantages, to wit; saving in weight; saving in material, reduction of heating in rapid fire; ability of the soldier to have a larger number of cartridges available; etc.

The Army made an extended study of this question, including a series of firings at live animals with .256, .276, and .30 caliber bullets. It was found that the .256 was apparently the worst killer, on account of the fact that the bullet had less diameter, hence less

gyrostatic stability, and would yaw badly upon impact, and make very lethal woulds. The .276 was found to be about as effective, and as it had certain advantages over the .256, its adoption was decided on for the new semi-automatic rifle that it was hoped would soon be adopted.

The cartridge selected had been designed by Mr. Pedersen with features making it especially suitable for automatic firearms, such as an increased taper for easy extraction. The ammunition was first made with a solid bronze bullet weighing 125 grains; later with a 126 grain jacketed boat tail bullet. The bullet diameter was .2845. The charge was about 30 grains of duPont IMR No. 25. At one time a small lot of this ammunition was made with flat base bullets.

The Pedersen gun was made with what is called the block clip. This is an arrangement whereby a packet of ten cartridges is shoved bodily into the magazine, clip and all. After firing ten shots, the clip automatically jumps out of the rifle and the bolt stays open, ready for the next clip to be inserted.

After the Pedersen rifle, using the special .276 caliber cartridge designed by Mr. Pedersen, had successfully passed the severe Army tests, it seemed on the point of adoption by our armed forces; but a high command decision was made not to change the caliber of the service cartridge, and the final action to adopt this gun was never taken.

Blish Principle

Some experiments by Commander Blish, U. S. Navy, retired, led him to believe that inclined surfaces which would slide on each other under light pressure would not slide when the pressure was heavier. He is said to have been started on this investigation through observing that when heavy naval guns were fired with full charges the breech remained locked, whereas when they were fired with light charges the breech had a tendency to unscrew by itself. Accordingly he took out U. S. Patent No. 1,131,319, dated March 9, 1915, covering the application of this principle to firearms and describing his findings in detail with elaborate diagrams.

Utilizing this theory, the Thompson Autorifle is constructed so that the breech block is locked to the barrel by a steep thread. The pitch of this thread is made just steep enough so that the gun will not unlock too quickly under the full pressure of the explosion. The supposition is that while the full pressure is on the breech block, adhesion of the threads on the breech block to the threads in the receiver will prevent any motion, but as soon as the pressure drops slightly this adhesion will no longer operate and the threads will then unscrew, allowing the breech block to open.

A diagram of this breech closure is shown in Fig. 4. The breech block, *B*, has steep threads, *D*, engaging the receiver, *C*. When the

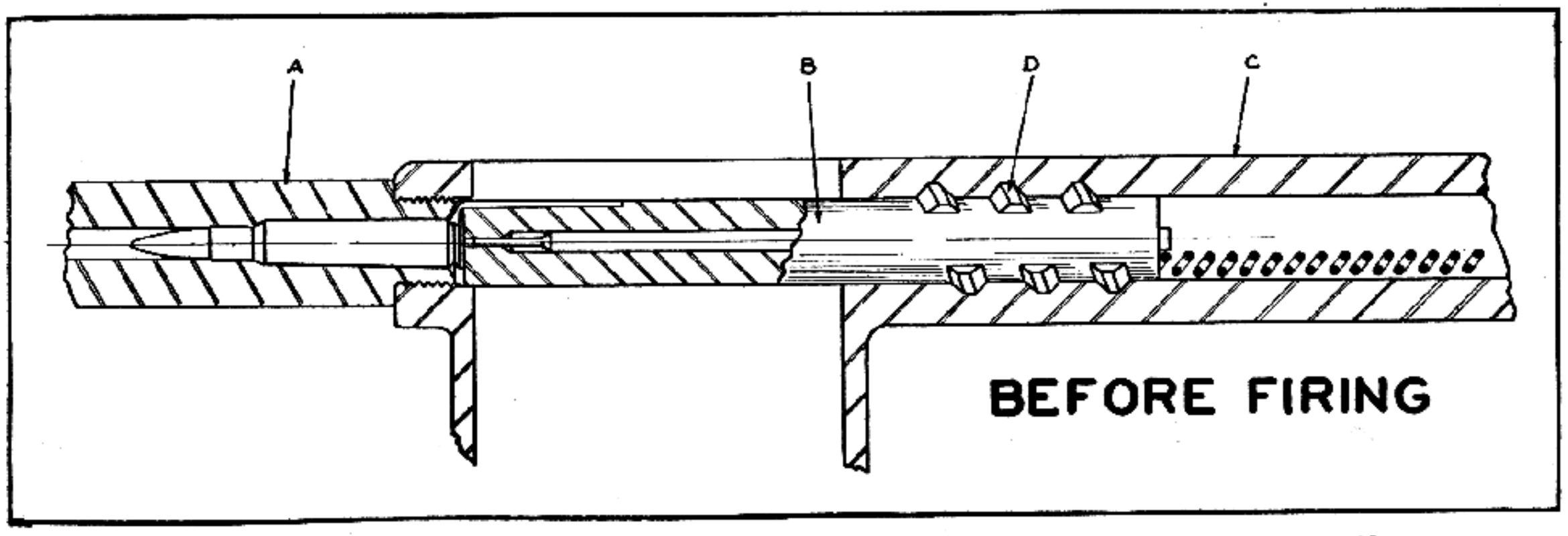


Figure 4. Diagram of the Blish type breech closure principle as used in the Thompson Autorifle.

Both of these will be described in turn, and as the simplest example of the short-recoil type of action we will take the Service automatic pistol shown in Fig. 5.

Colt Automatic Pistol

In this mechanism the barrel and breech are locked together, and when the gun is fired the recoil drives them both back at one time. However, it takes only about one-quarter of an inch of motion to unlock the breech block from the barrel and as soon as this one-quarter inch has been completed, the barrel strikes sharply against a stop and remains in position while the breech block continues on back through the momentum imparted to it by the one-quarter inch kick, coupled with a residual pressure that may remain in the case.

The action in detail is as follows: (Refer to Fig. 5)

Referring to the diagram marked "Before Firing," it will be observed that the barrel, *A*, is locked to the slide, *B* (which is in one piece with the breech block), by the locking shoulder, *C*, formed on top of the barrel and fitting into the recesses, *D*, in the slide. When the gun is fired the recoil pushes the slide and breech block, *B*, to the rear and as the slide is locked to the barrel, the barrel is also carried to the rear. However, the barrel is pivoted to the frame of the pistol by means of the link, *E*, and as the barrel continues its rearward motion, the top end of this link first moves backward in the arc of a circle and then downward around the lower pin as an axis. This motion swings the back end of the barrel downward, and disengages the locking shoulders in the slide, which continues to the rear, leaving the barrel in position with its bottom lug against the stop shoulder in the frame. This rearward motion of the slide throws out the empty cartridge and at the same time compresses the return spring, *F*, which immediately returns the slide to its forward position, at the same time feeding a new cartridge into the chamber from the magazine in the handle (not shown in the drawing). As the slide completes its forward motion, it strikes against the rear end of the barrel and as the barrel goes forward it swings upward through the action of the link, causing the locking shoulders, *C*, to engage in the recesses, *D*, in the slide.

Maxim and Browning Machine Guns

These two guns are also examples of the short-recoil type of mechanism, but in a much more refined form. As described above for the Colt pistol, the barrel goes back about one-quarter of an inch carrying the breech block with it and stops with a bang against the solid shoulder and lets the breech block go on to the rear by its own momentum. This will work with a low-powered cartridge like that used in the pistol, but even so the shock to the action of

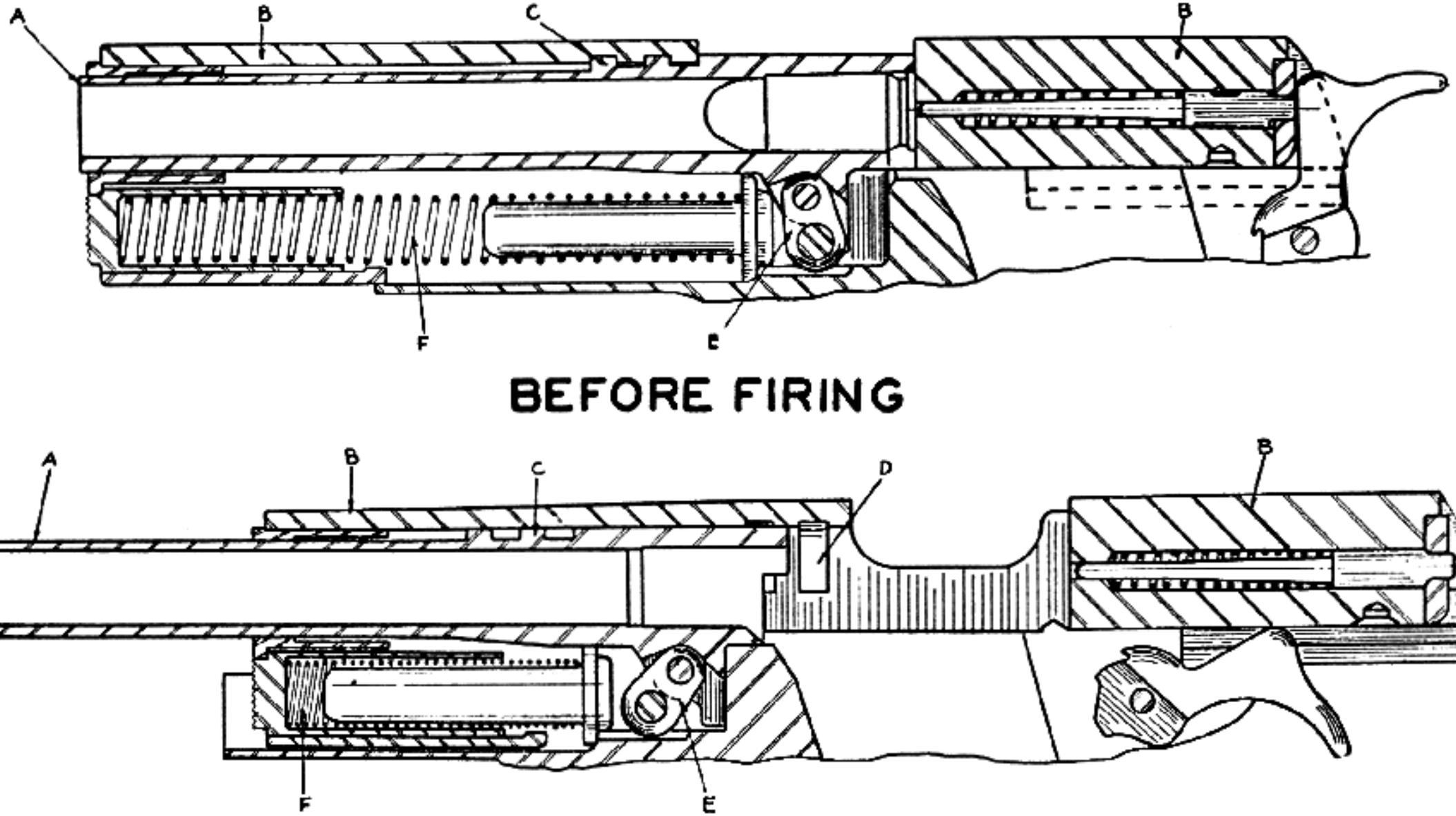
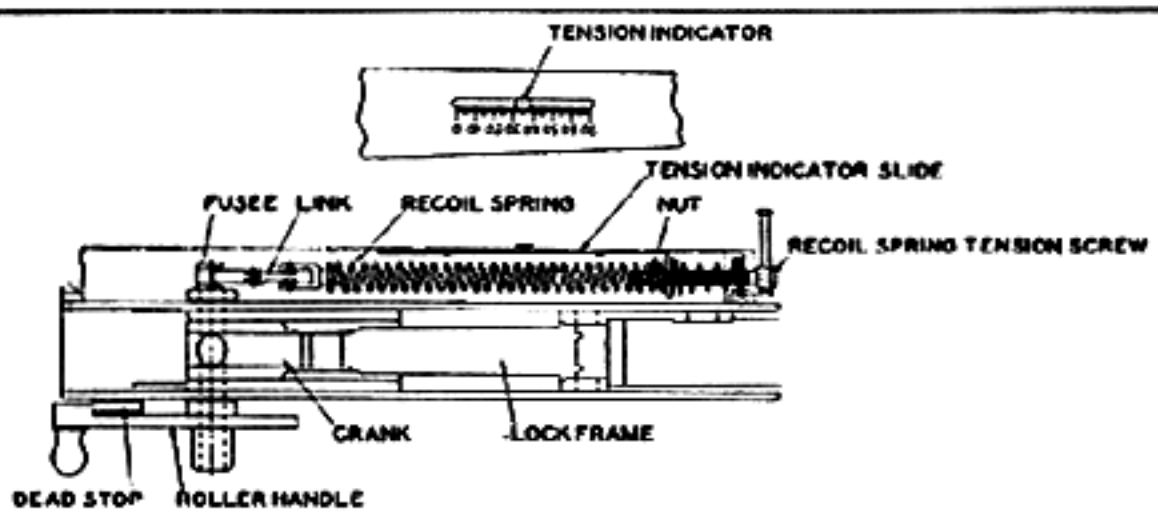
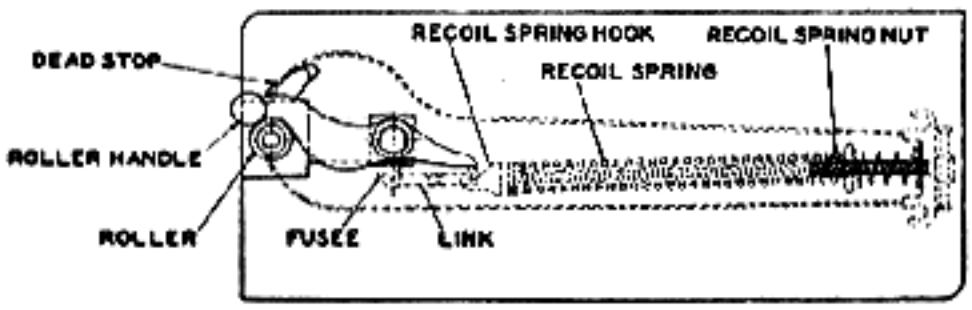


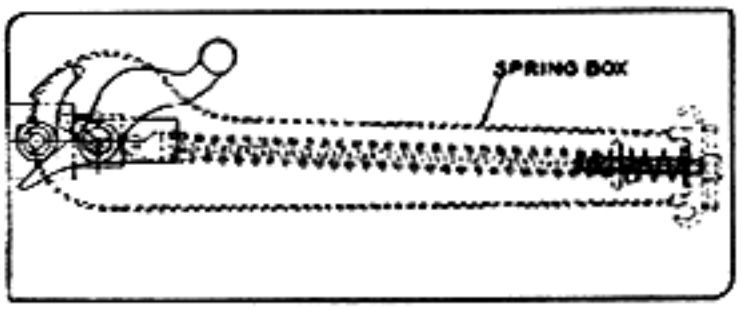
Figure 5. Diagram of the short-recoil type breech closure principle as used in the Colt automatic pistol.



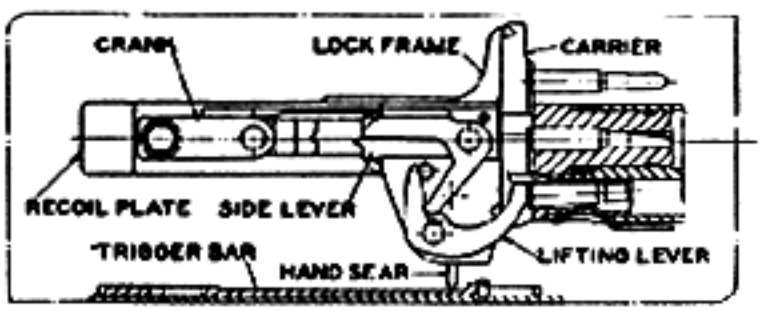
TOP VIEW SHOWING RELATION OF
ROLLER HANDLE AND RECOIL SPRING



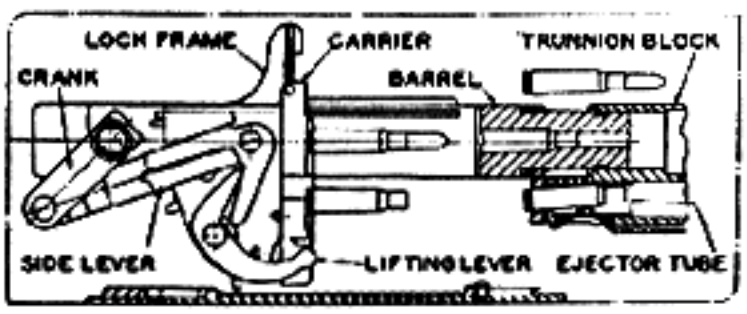
FIRING POSITION
RIGHT SIDE OF RECEIVER SHOWING ACTION OF ROLLER HANDLE



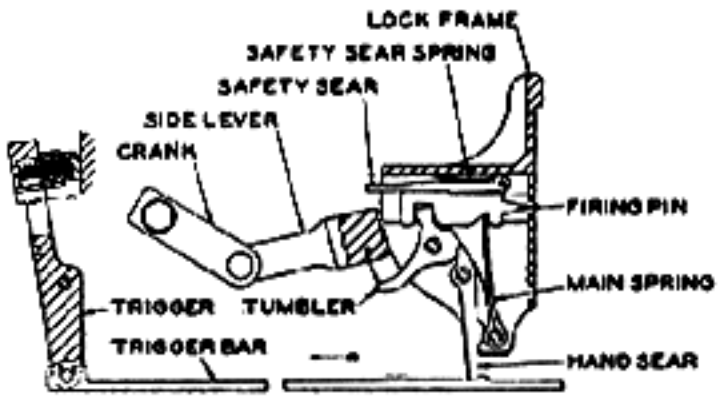
END OF RECOIL



FIRING POSITION



END OF RECOIL



CROSS SECTION THRU LOCK
SHOWING FIRING MECHANISM

Figure 6. Diagram of the short-recoil type breech closure principle as used in the Maxim machine gun.

the gun is severe, and with a high powered cartridge it is necessary to resort to some device by which the barrel is gradually brought to a stop through transferring its energy to the breech block and then allowing it to be gradually absorbed through a fairly long travel of the breech block against the return spring.

In the Maxim machine gun (Fig. 6) the locking of the breech is accomplished by having the breech block (called in this gun the "lock") attached to the barrel extension (called in this gun the "recoil plates") through the medium of a crank and connecting rod

(called in this gun the "slide lever") as was discussed under the subject of retarded blow-back guns. However, in the Maxim gun the crank is on dead center when the explosion comes, so that the lock cannot move back in relation to the barrel, and the thrust of the cartridge on the lock is transmitted through the side lever and crank to the crank axle and thence to the recoil plates through which the crank axle passes. Hence the barrel, lock and recoil plates all move back together as a unit, under the force of the recoil.

On the right-hand end of the crank axle is a handle with a convex shaped bottom, and this handle rests on a roller attached to the side of the gun. As the barrel, lock and recoil plates move back together, this handle, which is on the axis of the crank, also moves back, while the roller is fixed in position on the side of the gun. An examination of the figure will readily show that this backward motion of the roller handle against the roller causes it to rotate so that the back end of the handle moves upward. This rotation of the crank axle by means of the roller handle throws the crank and connecting lever off dead center and draws the lock away from the barrel. In other words, as soon as the roller encounters the cam on the roller handle, the action of the cam is to slow down the barrel and transfer its motion into an accelerated rearward motion of the breech block. However, as the rotation of the roller handle continues, the tail of the roller handle strikes on the roller and by the action of these two surfaces on each other the rotation of the roller handle is checked and the recoil plates are pushed forward, shoving the barrel to battery.

On the left-hand side of the gun there is a strong spring attached to the extension on the end of the crank axle. This recoil spring tends to do two things; first, to keep the barrel pulled into battery and resist any rearward motion, and second, to keep the roller handle rotated so that the lock is in the closed position. As soon, therefore, as the barrel has been returned to battery by the reaction of the tail of the roller handle against the roller, assisted by the pull of the recoil spring, a further pull of the spring rotates the handle back into the original position, and closes the breech of the gun, putting the lock back in the firing position. This action can be very easily understood from the diagrams.

However, the drawing does not show the method of feeding the cartridges into the gun. They are supplied in a fabric belt and there is a feed crank operated by the recoil of the barrel which advances a fresh cartridge into position each time the barrel moves to the rear.

The Browning gun accomplishes the same thing in a somewhat different manner. In this gun the barrel moves to the rear about five-eighths of an inch. There is a frame screwed onto the back end of the barrel. This frame is called the barrel extension, and the heavy breech bolt is locked to this frame through the medium of a

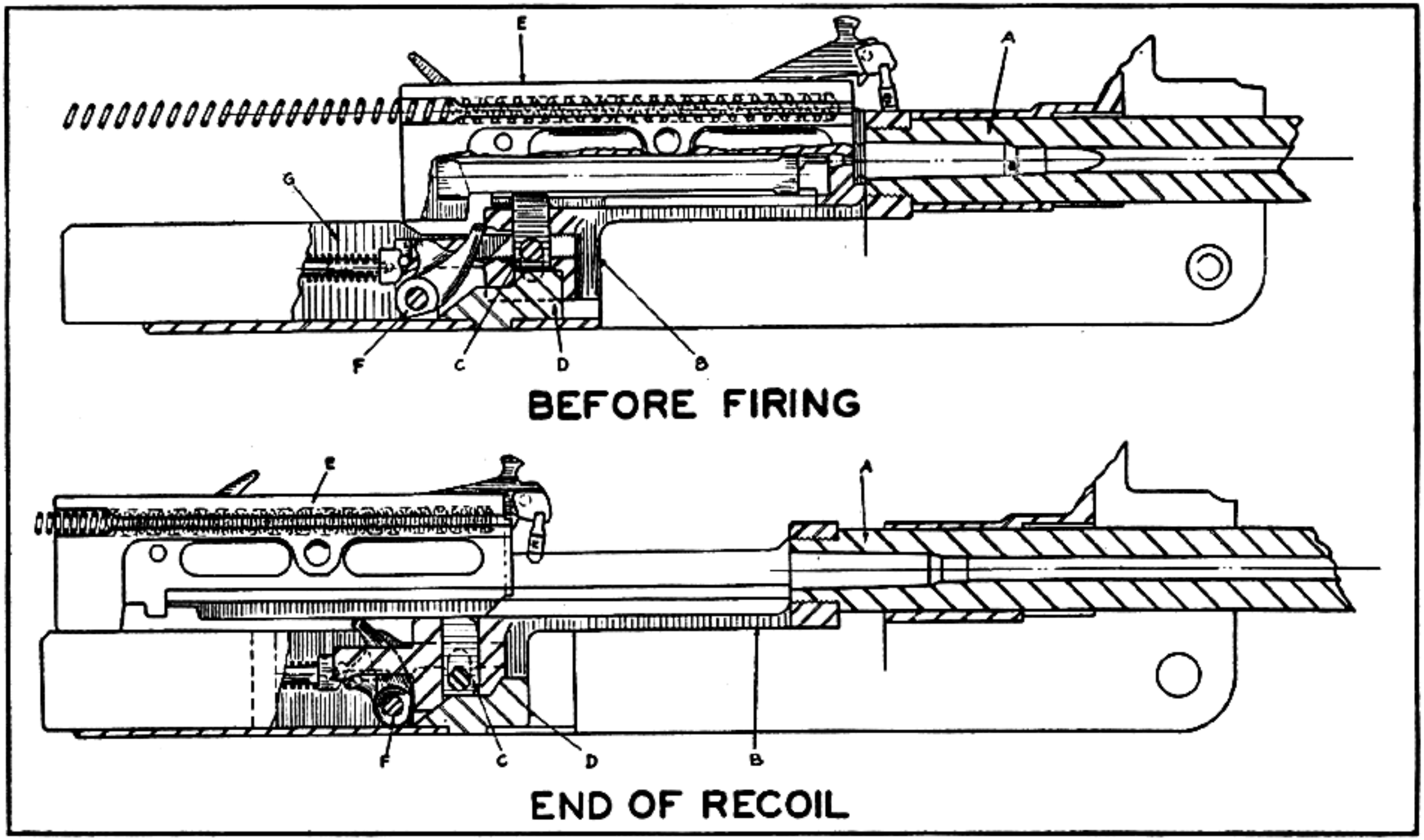


Figure 7. Diagram of short recoil type breech closure principle as used in the Browning machine gun.

gun is fired the breech block unscrews from the pressure and opens against the action of the return spring which immediately shuts the breech block again and causes it to rotate into the locked position when the threads engage each other. The locking of the breech block is assisted by the action of a knob on the end of the bolt handle which adds a sort of flywheel effect to the motion of the bolt and thus assists in locking it securely.

There is no doubt that this mechanism can be made to operate as described, provided the cartridges are lubricated, but there has been some dispute among engineers as to whether or not the Blish principle really exists. Some of them claim that this is merely a retarded blow-back breech mechanism and that as soon as the pressure comes on the end of the bolt it starts to unscrew; but on account of the fact that the angle of the thread is so slow it takes a great deal of pressure to unscrew it, and for this reason the bullet is gone before the bolt has unscrewed enough to do any damage. That this type of mechanism actually opens while there is still considerable pressure in the cartridge case is evident from the fact that the gun does not operate satisfactorily unless the cartridges are lubricated.

Thompson Sub-Machine Gun

The Thompson sub-machine gun, utilized to fire pistol cartridges at a rapid rate from magazines holding 20, 30, 50 or 100 cartridges, was also constructed on the Blish theory, but instead of having a screwed breech block with a steep thread as does the Thompson Auto-rifle, it simply has the breech resting against a vertical sliding wedge held in its upper position by spring pressure. When the breech block is pushed backward a sloping surface on the rear end of the breech block resting on a similar surface of the wedge, cams the wedge downward as the breech block moves to the rear. This downward motion of the sliding wedge is supposed to retard the breech block in its rearward motion and thus assist in reliable functioning. Owing to the low pressure involved in the pistol cartridge, it is not necessary to lubricate the case.

Recoil Operated Guns

It has already been mentioned that the first machine gun, the Maxim, was recoil-operated, and that the barrel moved back about three-quarters of an inch. A gun in which the barrel moves only a short distance and the breech block moves through the rest of its travel from the momentum imparted to it by this motion of the barrel, is called a "short-recoil" gun.

There is another kind in which the barrel moves all the way to the rear along with the breech block and then leaves the breech block back in the rearward position while the barrel goes forward. This is called the "long-recoil" type.

vertical sliding bolt, called the breech lock, which is actuated by a cam on the bottom of the gun. Thus when the barrel and barrel extension are in the forward position, the bolt is locked securely to the barrel extension. However, when the barrel recoils about one-half inch the breech lock cam is drawn down out of engagement with the bolt and the bolt is entirely free from the barrel and barrel extension. As the barrel continues its backward motion it strikes against the convex side of a curved lever, the point of which rests against the breech block. The continued motion of the barrel to the rear swings this lever backward in such a manner as to separate the breech block from the barrel; in other words, to slow up the barrel and speed up the breech block, throwing it forcibly from the barrel and at the same time extracting the cartridge case. Of course the breech block already had a rearward motion imparted to it while the barrel was recoiling, but this motion is increased or accelerated by the action of the curved lever which is accordingly called an accelerator.

The mechanism of this gun, which is shown in Fig. 7, will now be described in detail. The barrel, *A*, is screwed into the barrel extension, *B*, which extends to the rear for several inches and carries in a slot in its rear end the vertical sliding breech lock, *C*. In the closed position the breech lock cam, *D*, in the bottom of the gun, holds the breech lock up so that its top end engages in a slot in the bolt, *E*, and locks it to the barrel extension.

When the gun is fired, the barrel, *A*, recoils about five-eighths of an inch carrying with it the barrel extension, *B*, the breech lock, *C*, and the breech bolt, *E*, all locked together. However, as the parts move to the rear the breech lock moves off the high surface on the breech lock cam and a transverse pin through the breech lock strikes a slanting surface on the lock frame, *G*, which forces the breech lock down out of engagement with the breech block.

Just under the breech bolt there is an accelerator, *F*, pivoted on a horizontal axis. As the barrel extension, *B*, moves to the rear it swings this accelerator backward and the point of the accelerator catches in a notch in the bolt and throws the bolt forcibly to the rear, compressing the return spring which immediately returns the bolt to its forward position.

While the bolt is in the rearward position, the barrel extension and lock frame are fastened together by the accelerator in such a position that the barrel cannot move forward. However, when the bolt goes forward far enough to strike the accelerator, it disengages the barrel extension from the lock frame and allows the barrel and barrel extension to move forward with the bolt as it completes its motion. The forward motion of the barrel extension carries along with it the breech lock which rides up the sloped surface of the breech lock cam and again locks the bolt to the extension ready for firing.

The backward motion of the bolt extracts the empty cartridge

case and the forward motion feeds a new one in. The top of the bolt has a cam slot in it which actuates the lever which feeds the belt of cartridges in, the width of one cartridge each time the bolt moves to the rear.

Long-Recoil Type

The long-recoil type of automatic mechanism, in which the barrel and breech bolt, locked together, recoil for several inches, and then the breech bolt is held back while the barrel goes forward, is used for the Remington auto-loading rifle, the Remington, Winchester and Browning automatic shotguns, and the Chauchat machine rifle.

In a typical gun of this type there are two return springs, one to return the barrel and a separate one to return the breech block. The breech block being locked to the barrel when the cartridge is fired, the pressure on the head of the breech block drives it three or four inches to the rear until it is arrested by striking a stop provided for this purpose. The barrel being locked to the breech block, also goes to the rear and this rearward motion compresses both the breech block return spring and the barrel return spring. When the breech block has reached the limit of its rearward motion, it is caught and held in that position by a latch. The barrel return spring then pushes the barrel forward and the lock on the breech block is so constructed that when the breech block is held and the barrel is pulled forward, the bolt will unlock itself from the barrel and allow the barrel to go forward. As the barrel goes forward, the empty cartridge, held to the breech block by the extractor, is ejected. As the barrel reaches its forward position, it strikes a lever which drops the latch and allows the breech block to come forward, feeding in a new cartridge.

Remington Auto-Loading Rifle

The action of this type of breech closure can be followed in detail by reference to Fig. 8 showing the Remington auto-loading rifle. The barrel, *A*, is supported in a barrel jacket, *B*, and is held forward by the coil spring, *I*, surrounding the barrel. The breech block, *E*, has a turning bolt head, *D*, arranged to be rotated by the action of two pins, *F*, working in cam slots cut in the sides of the bolt head, *D*.

This bolt head is arranged to lock in the barrel extension, *D*, by the action of the pins, *F*, in the cam slots, turning the bolt head. There is a separate return spring, *G*, for holding the breech block in the forward position.

When the gun is fired, the parts recoil into the extreme rearward position, as shown in the figure marked "End of Recoil." At this point the breech block is locked in its rearward position by the latch, *H*, and the barrel then starts forward under the impulse of the barrel return spring, *I*. As the barrel moves forward it draws with it the bolt head, *D*, but this forward motion of the bolt head causes the pins, *F*,

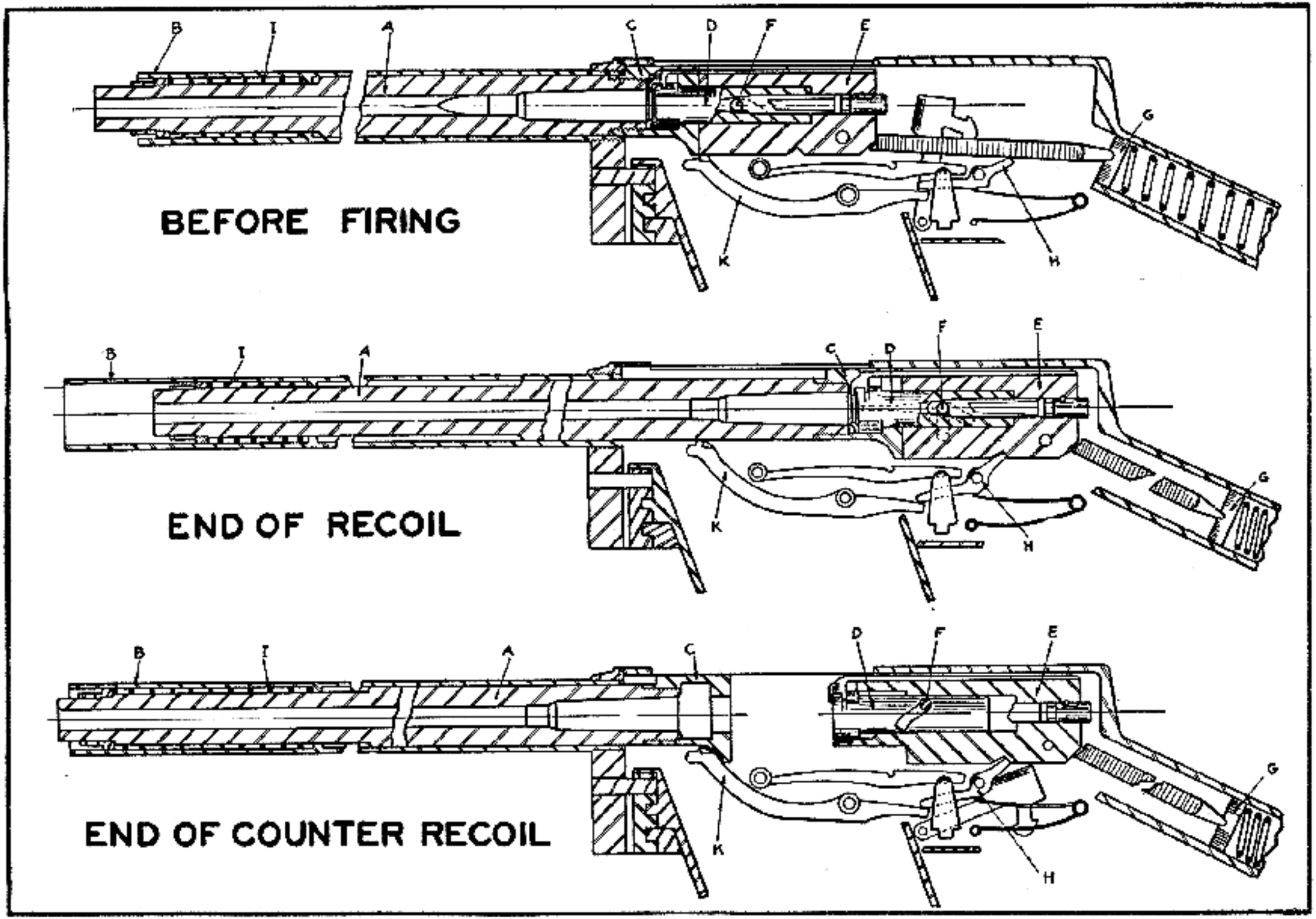


Figure 8. Diagram of the long-recoil type breech closure principle as used in the Remington autoloading rifle.

to act in the cam slots so as to turn the bolt head and release it entirely from the barrel. As the barrel continues forward it leaves the empty cartridge case held by the extractor and when the barrel is entirely off the cartridge case a spring ejector in the bolt head kicks the cartridge out of the gun. At this moment the parts have reached the position marked "End of Counter-recoil" and the curved surface on the bottom of the barrel at the rear end strikes against the lever, *K*, which in turn disengages the latch, *H*, allowing the breech block to be pushed forward again by the spring, *G*. As the breech block goes forward it feeds a new cartridge into the barrel from the magazine (not shown). As the bolt approaches its forward position, the bolt head, *D*, enters the recess, *C*, in the barrel and then a further motion of the bolt causes the pins, *F*, to act on the cam slots in the bolt head in such manner as to turn the bolt head and lock it to the barrel so that the gun is again ready for firing.

Gas-Operated Type

While the original machine gun was built on the recoil-operated principle and while nearly all automatic pistols are made on that principle, the gas-operated system has also been a great favorite, especially with inventors of semiautomatic shoulder rifles, as it does away with the necessity for mounting the barrel so that it can slide, which is a great complication in making a rifle.

One of the earliest successful machine guns, the Colt, invented by Mr. Browning in 1889, was gas-operated. The Hotchkiss gun, invented about the same time, was also gas-operated, and both of these guns have been used extensively ever since. During World War I the Colt gun was modified somewhat by the Marlin Arms Corporation, of New Haven, though the breech mechanism remained the same in principle, as did the construction of most of the parts.

A light form of the Hotchkiss, known as the Benet-Mercié, was adopted as the standard of the U. S. Army in 1909 and remained standard until 1916. This also was a gas-operated gun.

Then at the beginning of the World War, Mr. Browning submitted a model of what he called a light machine gun built on the gas-operated principle. This gun, afterward known as the Browning Automatic Rifle, was adopted and many thousands of them were used during the World Wars I and II. While it is called an automatic rifle, the reader should clearly distinguish between this type of automatic rifle which is really a light machine gun, and the semiautomatic rifle which is a self-loading shoulder rifle to take the place of the Springfield. Bear in mind that the "automatic rifle" and the "machine rifle" are really light machine guns.

While the recoil-operated principle as embodied in the Maxim, Vickers and Browning guns was more widely used than any other, the gas-operated type as exemplified in the Colt, the Hotchkiss and

the Marlin machine guns and the Browning, Bren and other automatic rifles, have been a close second in popularity.

As mentioned above, the gas-operated system has been the favorite for semiautomatic shoulder rifles, but while a great many guns have been produced which operate on this principle, none of them prior to the Garand attained any lasting popularity or wide use. Among the more prominent early ones may be mentioned the Mondragon, adopted by the Mexican Government in 1911 but never very extensively used; the "Standard" automatic shoulder rifle manufactured about 1915 as a sporting rifle, and the St. Etienne semiautomatic shoulder rifle used to a limited extent by the French during the first World War.

In the conventional gas-operated system there is a hole drilled in the barrel, and some of the gas of the explosion passes through this hole and acts on a piston driving it to the rear with sufficient force to unlock and open the breech. One of the great troubles with rifles of this kind has been the fact that it is difficult to control this gas under extremely high pressure so as to prevent it from operating too quickly. In the Army tests of the 1930's an inventor named White submitted a gas-operated shoulder rifle in which the front end of the gas piston is hollow and the gas port is bored not only through the barrel and through the gas cylinder, but through the walls of this hollow piston so that as soon as the piston starts to move the gas port is cut off after the manner of the slide valve in a steam engine. Thus gas can go into the hollow piston only before it starts its motion; as soon as it begins to move the gas supply is shut off and the gas which is already in the piston is supposed to act by expansion, therefore producing a less violent action than would otherwise occur. So reasons the inventor. However, other designers state that inasmuch as the gas pressure in the barrel lasts only about a thousandth of a second, it makes no difference whether this cut-off action is used or not.

Another inventor who attempted to get away from the brusque action of the gas is Mr. Hudson, who invented a machine gun in which he used the gas to compress a spring which then operates the mechanism.

In order to give the reader an opportunity to study the mechanical action of the gas-operated breech closure in detail, three different examples of this type of mechanism will be illustrated with drawings and descriptions. The guns chosen for illustrations are the modified Colt, known as the Marlin, the Browning automatic rifle and the Garand semiautomatic rifle.

Marlin Machine Gun

The mechanism of the Marlin machine gun, shown in Fig 9, operates as follows: The barrel, *A*, has a gas port, *D*, drilled in it

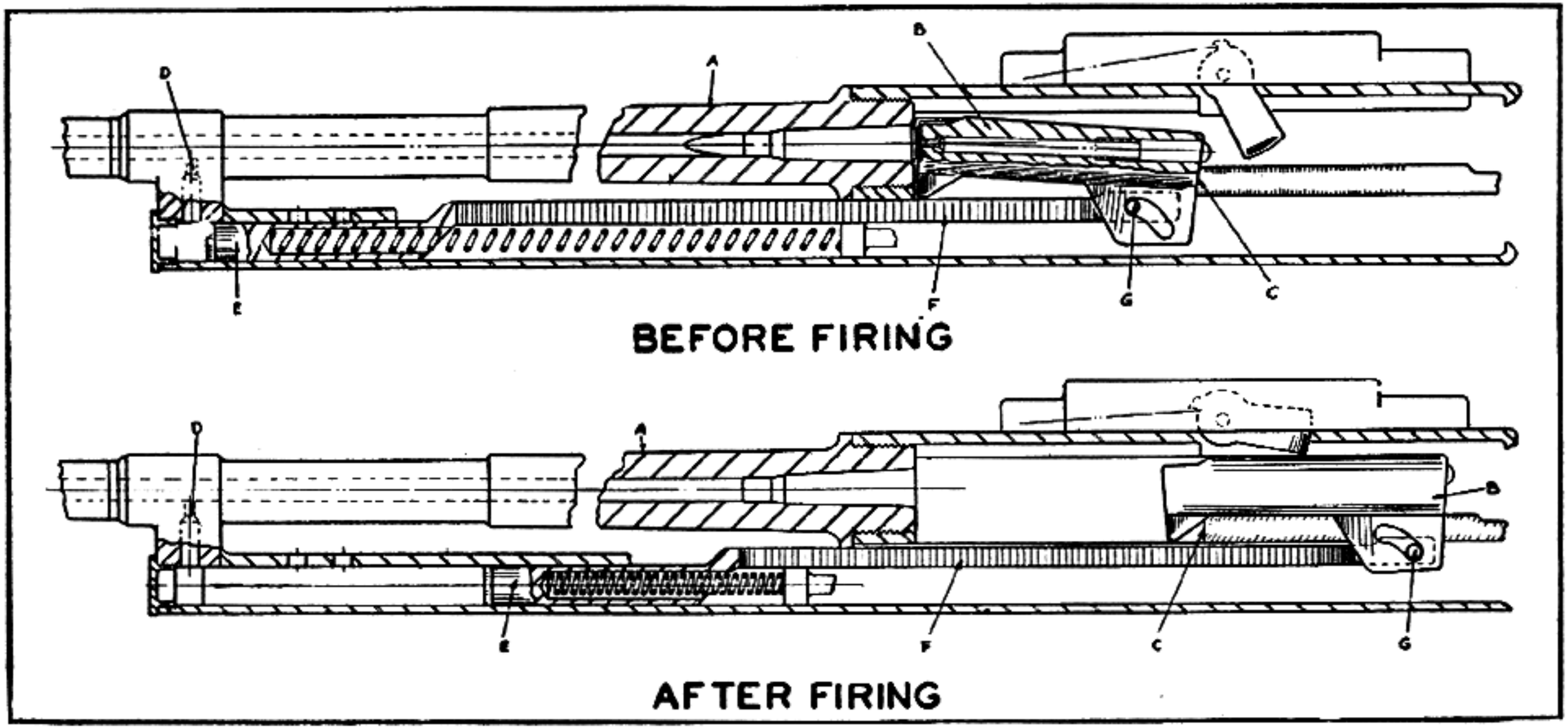


Figure 9. Diagram of the gas-operated type breech closure principle as used in the Marlin machine gun.

at some distance from the muzzle. This gas port communicates with a gas cylinder lying under the barrel containing a piston held in its forward position by a spring. This piston is attached to the bolt, *B*, through a connecting rod, *F*, which is fastened to a pin, *G*, riding in a cam slot in a wing on the bottom of the bolt. When the piston is forward the bolt is forward and the rear end of the bolt is drawn down by the action of the pin, *G*, in the cam slot, until the back surface of the bolt rests against the locking shoulder, *C*, cut in the receiver. When the gun is fired the cartridge is held firmly in place by the bolt, which is locked in position against the shoulder, *C*. After the bullet passes the gas port, *D*, near the muzzle of the barrel, some of the gas rushes into the gas cylinder and impinges on the head of the piston, *D*, driving it violently to the rear, together with its connecting rod, *F*, and the pin, *G*, which is in the slot in the bolt. As the pin, *G*, goes to the rear, the first action is to press on the top of the cam slot and raise the bolt up out of engagement with the shoulder, *C*, after which the bolt is carried to the rear as shown in the cut marked "After Firing." This rearward motion of the bolt ejects the empty cartridge. The compressed return spring immediately causes the piston to move forward, carrying the bolt with it, until the shoulder, *C*, is reached, when the action of the pin, *G*, in the cam slot again locks the bolt down behind this shoulder and the gun is ready for firing once more.

Browning Automatic Rifle

The operation of the Browning automatic rifle is shown in Fig. 10. In this gun the barrel, *A*, has a gas port, *B*, and there is a piston, *C*, lying in the gas cylinder under the barrel. This piston connects with the bolt, *G*, by means of the connecting rod, *D*. However, instead of being connected to the bolt by means of a pin in a cam slot, the connection in this case is by means of a linkage consisting of the bolt link, *E*, and the bolt lock, *F*. In the firing position the bolt lock, *F*, presses against the shoulder, *H*, in the top of the receiver and this holds the bolt firmly in position against the head of the cartridge. When the gas impinges on the end of the piston, *C*, and drives it to the rear, the bolt link, *E*, draws the bolt lock down out of engagement with the shoulder, *H*, and then draws the bolt to the rear, as shown in the cut, "After Firing."

Garand Semiautomatic Rifle

The principle of the Garand rifle is shown in Fig. 11, which illustrates the gas take-off used in the first examples of this gun. These early Garands, instead of having a conventional gas port drilled in the barrel, had a muzzle cap, *B*, screwed on to the end. After the bullet had left the rifled portion of the barrel, some gas went down

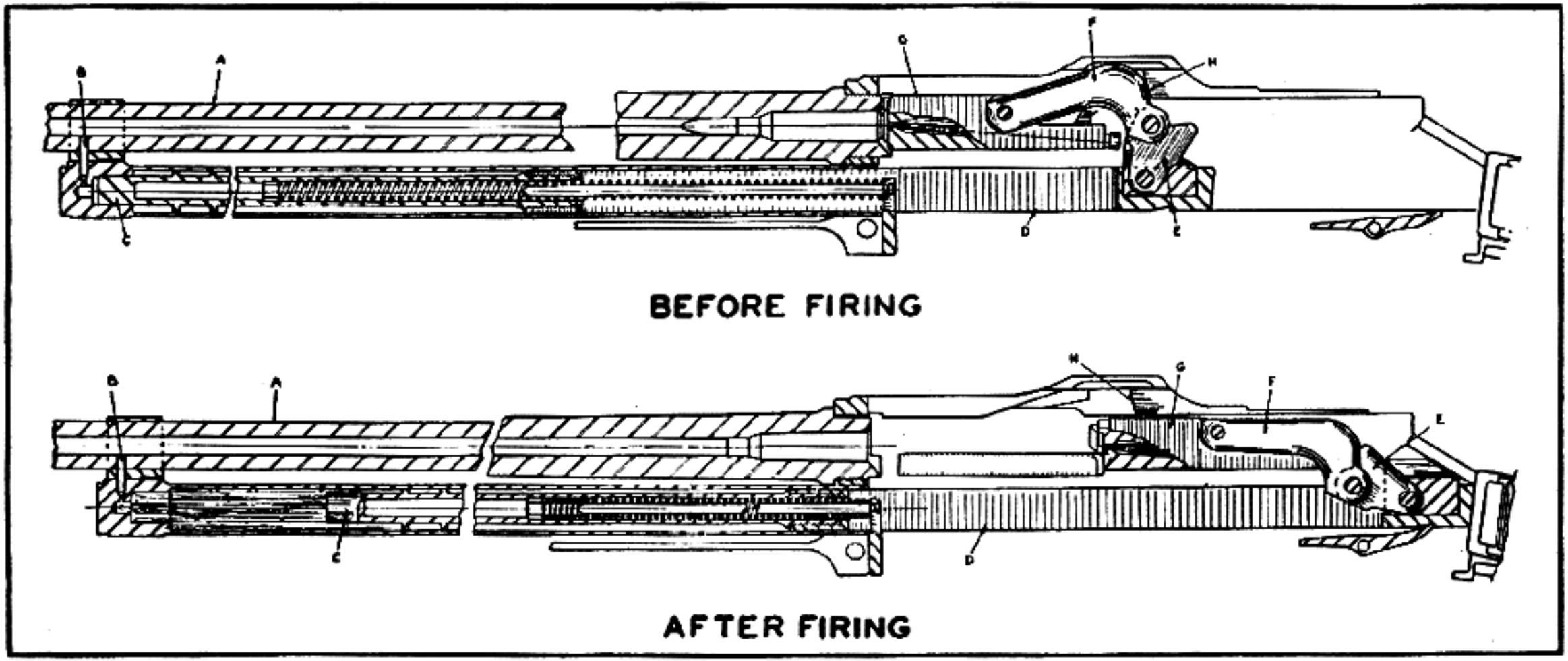


Figure 10. Diagram of gas-operated type breech closure principle as used in the Browning automatic rifle.

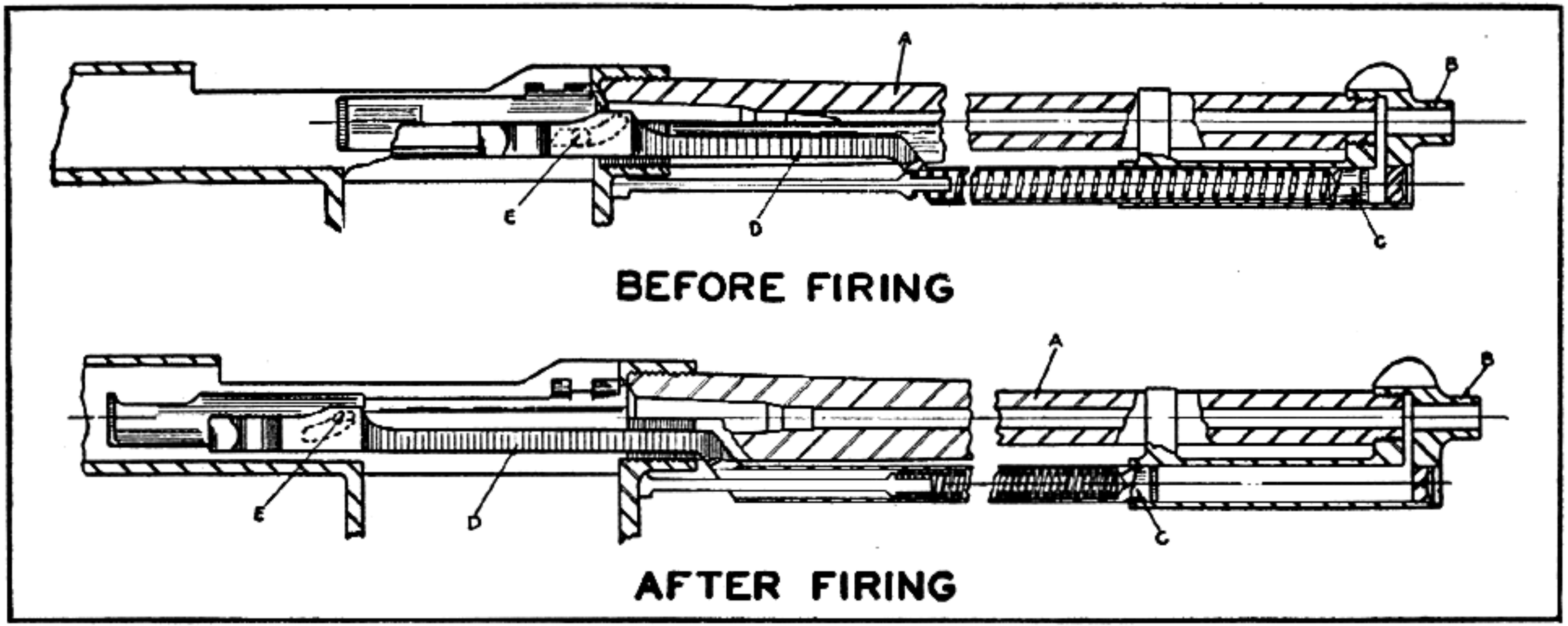


Figure 11. Diagram of gas-operated type breech closure principle as used in the Garand semiautomatic rifle.

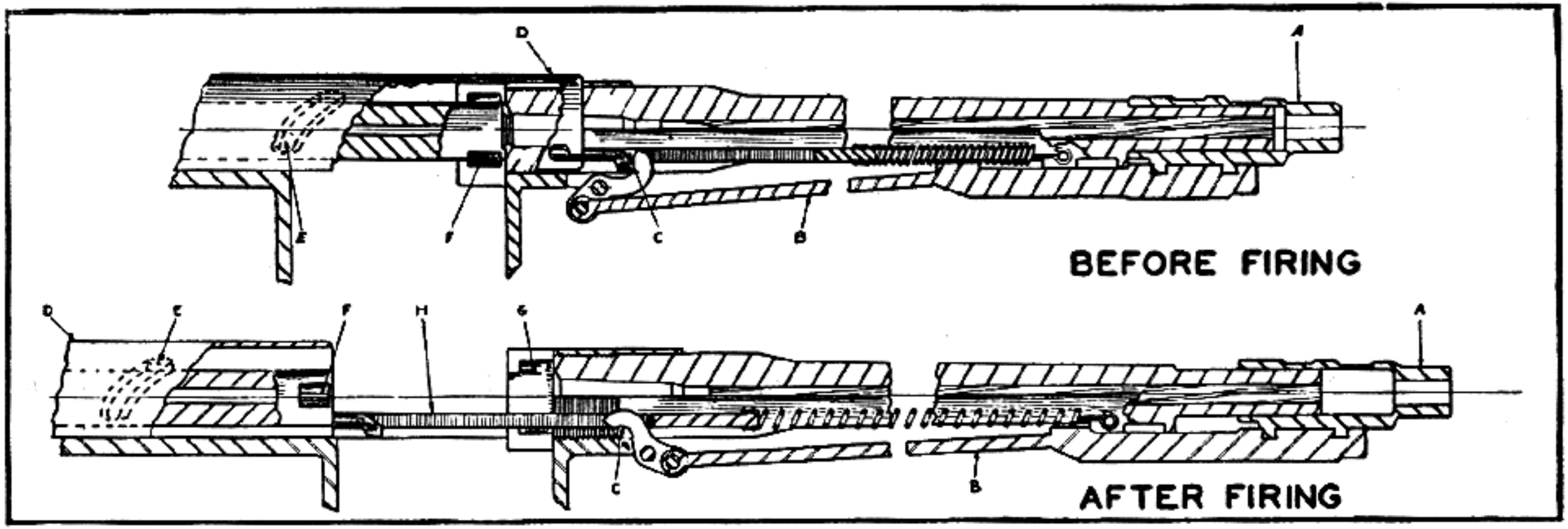


Figure 12. Diagram of the operating principle as used in the Bang semiautomatic rifle.

between this muzzle cap and the end of the barrel, to strike on the piston, *C*, driving it to the rear, together with the operating rod, *D*, which works the bolt through a cam slot and a lug, *E*.

The bolt is of the ordinary rotating type, locked to the receiver by locking lugs engaging in suitable recesses. As the piston goes back, the cam slot, working on the lug, *E*, first rotates the bolt, then carries it to the rear.

As soon as the rearward motion is completed, the return spring pushes the operating rod forward, closing the bolt and rotating it into the locked position.

This muzzle cap arrangement was soon abandoned in favor of a convential gas port drilled near the muzzle. Otherwise the principle of the gun remains the same.

Bang Principle

In 1911 Soren H. Bang, of the Danish Recoil Rifle Syndicate, presented a semiautomatic shoulder rifle to the United States Government for test, and this rifle functioned exceptionally well. The principle on which it operated is shown in Fig. 12.

The barrel had a sliding cap, *A*, fitting over the muzzle. When the bullet passed out, some of the gas acting in the space between this cap and the end of the barrel, pulled the cap forward as shown in the figure marked "After Firing." The cap, *A*, was fastened to a connecting rod, *B*, which operated a lever, *C*. This lever in turn acted against a sliding breech cover, *D*, having in it a cam-cut acting with a lug, *E*, on the bolt. In the position of rest, the bolt is locked to the barrel by the locking lugs, *F*, in the locking recess, *G*. When the gun is fired, the gas escaping from the muzzle pulls the muzzle piece, *A*, forward, thus causing the lever, *C*, to throw the sliding breech cover, *D*, quickly to the rear. As this cover goes to the rear, the cam slot acting on the lug, *E*, turns the bolt so as to unlock it and then carries the bolt to the rear along with the breech cover. There is a return spring under the barrel which is connected to the breech cover through a rod, *H*. As soon as the rearward motion is arrested, the spring pulls the breech cover forward again and when the forward motion of the bolt is completed the cam slot in the cover acting on the lug, *E*, again locks the bolt to the rear end of the barrel.

Primer Actuated Type

Among the many novel ideas for operating a semiautomatic rifle, is the scheme for allowing the primer to move enough in the cartridge case to unlock the breech mechanism. If the head of the cartridge were supported around the edge only, leaving the primer free, the primer would move back under the pressure of the gas when the gun is fired, and if it were allowed enough freedom it

would be blown entirely out of the cartridge case. However, it is possible to control this motion and allow the primer to move back just a few hundredths of an inch, utilizing this short but powerful motion to impart energy enough to the moving actuator to cause it to unlock the breech.

Garand's Invention

In the first World War, John C. Garand, a machine designer living in New York, began working on the design of a light machine gun to be operated by the set-back of the primer in its pocket. The primer was to be allowed to move back slightly, and in so doing, it was to transmit this motion through the firing pin to an actuator which would open the breech and extract the empty cartridge, after which the gun would be reloaded by the action of a spring which had been compressed during the first motion. The United States Bureau of Standards at Washington being anxious to aid the war effort, employed Mr. Garand and provided him with facilities to work on the invention.

When the gun was examined by the Ordnance Department in 1919, it was seen to be exceptionally well designed, and was considered to have such promise that Mr. Garand was hired and sent to Springfield Armory, where he has remained as an Ordnance Engineer ever since.

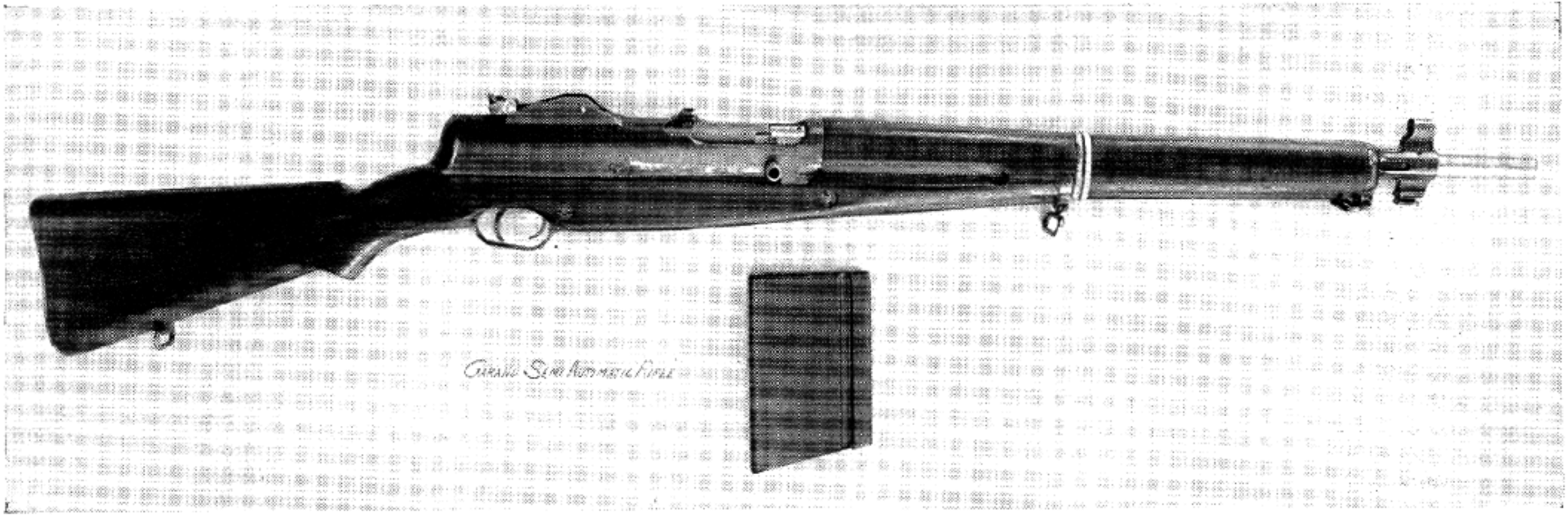
Early models of Mr. Garand's gun worked well in tests, but just about the time he had his second and much improved model nearly perfected and ready for adoption, the type of powder was changed from the old fast burning pyro to the progressive burning Improved Military Rifle power, in which the first rise in pressure was not nearly so rapid.

Mr. Garand was much disappointed when his mechanism, which up to now had done so well, failed to function reliably with the new type of powder. He thereupon dropped the primer actuated system and switched over to the gas operated type of gun for his future work along this line which eventually resulted in the production of the present U. S. Rifle Cal. .30 M 1.

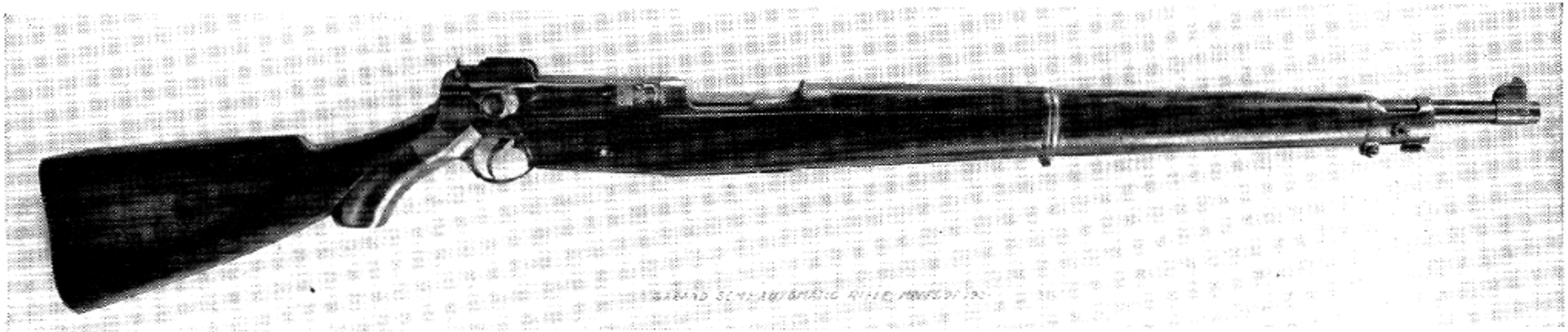
In spite of the fact that this rifle is not now being used, a description of the mechanism is included here because the novelty of this principle makes it interesting to any student of firearms.

Referring to Fig. 13, *A* is the barrel screwed onto the receiver, *B*. *C* is the breech block containing inside of it a moving actuator, *G*, arranged to have motion imparted to it by a slight motion of the firing pin, *F*. When the gun is fired the firing pin moves back about three-hundredths of an inch. This motion is very quick and imparts a considerable blow to the actuator, *G*, which travels rapidly to the rear.

The bolt up to this time has been locked to the receiver, by the locking block, *D*, bearing on the shoulder, *E*. As the actuator goes



Garand's first semiautomatic rifle, a primer actuated model built at Springfield in 1920. It used the service .30 caliber cartridge.



Garand's second primer actuated .30 caliber model, produced at Springfield Armory in 1921. It did not use a turning bolt, as did the first model. The bolt, which moves back and forth in a straight line, was locked by a piece of steel hinged at its rear end, and fitted to be lifted or depressed by the motion of an actuator inside the breech block. When the gun was fired, the primer was allowed to move back .035 inch, and this motion, transmitted through the firing pin to the actuator, operated the gun.

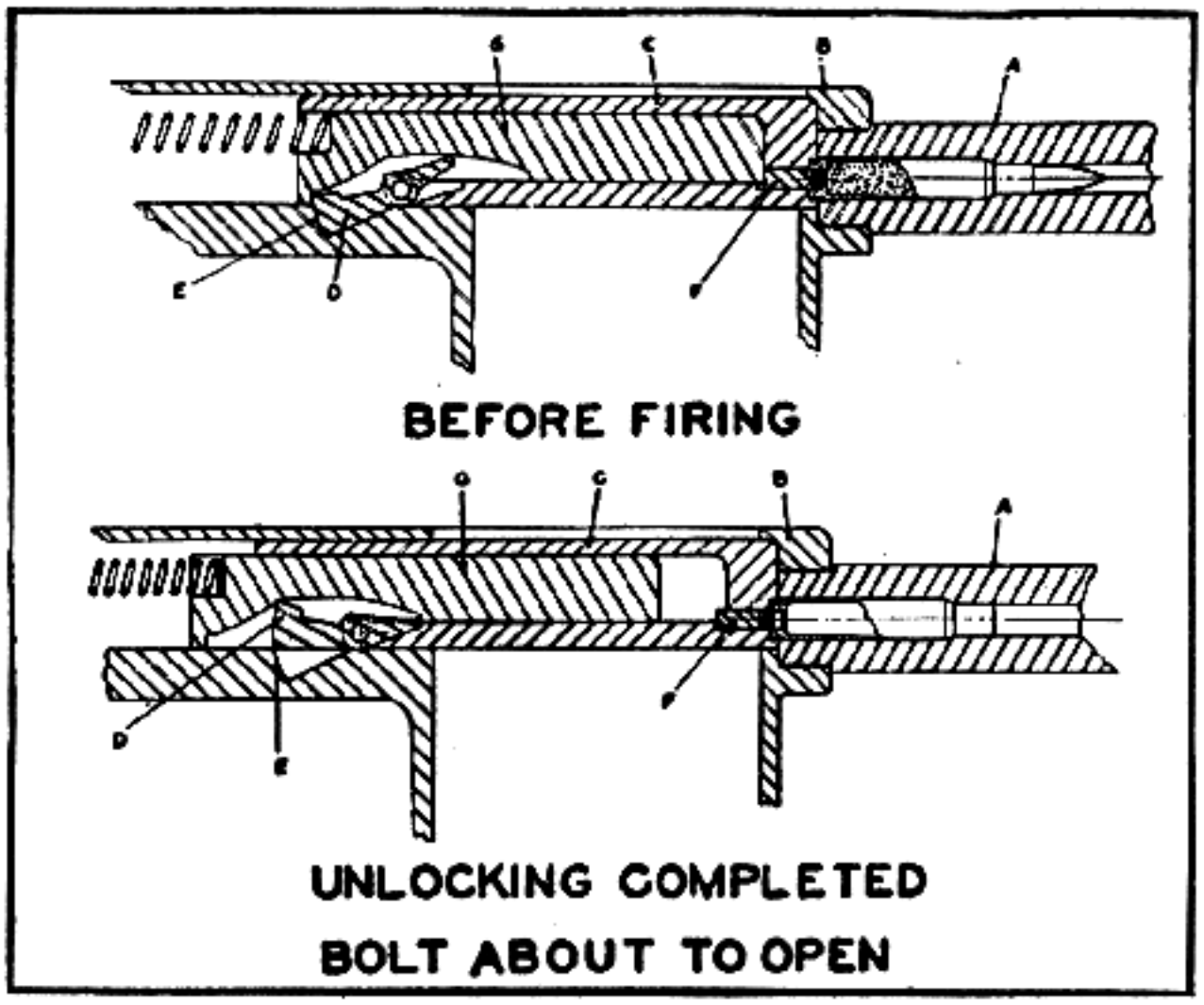


Figure 13. Diagram of primer-actuated type breech closure principle used in an early experimental Garand semiautomatic rifle.

to the rear the cam surface lifts this locking block out of engagement with the receiver and the bolt then moves to the rear with the actuator against the action of the return spring, which causes the parts to move forward again as soon as the rearward motion is completed.

Caliber .22 Machine Gun

While most of the principal methods of operating machine guns and semiautomatic rifles have been described above, one can never be sure when an inventor will come in with something entirely new and different. For example some time ago a desire was expressed by the Army for some means of shooting caliber .22 cartridges in a machine gun. It was desired to do this for two reasons; first, because it was thought that by using the very cheap and inexpensive caliber .22 cartridges for machine gun practice in time of peace, a great deal of training could be obtained without expending the expensive full powered cartridges and, consequently, much money would be saved; and in addition, it was desired to find some safe method of allowing troops to obtain antiaircraft practice with machine guns, which in most military posts cannot be accomplished with full powered cartridges because the great power and range of the Army cartridge makes it dangerous to fire at high elevation.

At first glance it seemed very difficult to construct a machine gun that would work with the low powered caliber .22 cartridge, but a young mechanic, David M. Williams, of Godwin, North Carolina, appeared in the Ordnance Office and offered, not to make a special

machine gun for .22's, but to take a heavy Browning gun and operate its massive mechanism with the .22 cartridge. This feat appeared so absolutely impossible that the arms experts had not even given it any consideration, but when this young inventor outlined his proposed method of doing the job he was given the order to proceed. In six weeks he modified a Browning machine gun so that it operated in a normal manner with the caliber .22 cartridges with never a malfunction. The Browning gun is a recoil-operated gun and the caliber .22 cartridge does not have a fraction of the recoil power to operate this gun, but Mr. Williams accomplished his job by making the chamber of the gun in a separate piece from the barrel, somewhat in the same way as the cylinder of the revolver is separate from the barrel. The separate chamber, however, instead of being outside the barrel is in the form of a hollow piston fitting into the rear end of the barrel. When the gun is fired the gas of the explosion gets into the space between the face of the chamber and the rear end of the barrel, and the pressure of the gas is sufficient to force the separate chamber backward with more than enough recoil to operate almost any mechanism.

The Colt Service Model Ace .22 Caliber Pistol

This is another well known adaptation of the Williams Floating Chamber. It is a replica of the Army .45 Pistol, M. 1911 A1, only it is made to shoot the ordinary .22 long rifle cartridge. Through the action of the floating chamber, the .22 caliber cartridge is given enough power to function the slide with enough energy to give a very good imitation of the recoil experienced with actual .45 caliber cartridges.

The utility of this gun is to give practice in handling the service sidearm, including rapid fire practice, without the expense of using the full powered loads. The action of this gun will be readily understood from the accompanying illustrations.

The Short Stroke Piston Principle

In 1940 the Winchester Repeating Arms Co. submitted for test a 9½ pound Cal. 30 semiautomatic rifle operating on the short stroke piston principle, patented by Mr. David M. Williams.

The gas is taken off near the breech, where the pressure is very high. The piston is completely housed in the cylinder, and is permitted to move through a stroke of only about a tenth of an inch. At the rear of its stroke, it acts as a valve, and prevents the gas from escaping from the gas cylinder except by going back into the barrel through the port by which it entered the gas cylinder.

The operating slide rests against the projecting end of the piston, which, under the impact of the gas, strikes the operating slide a sharp blow. Even the short piston stroke imparts to the operating

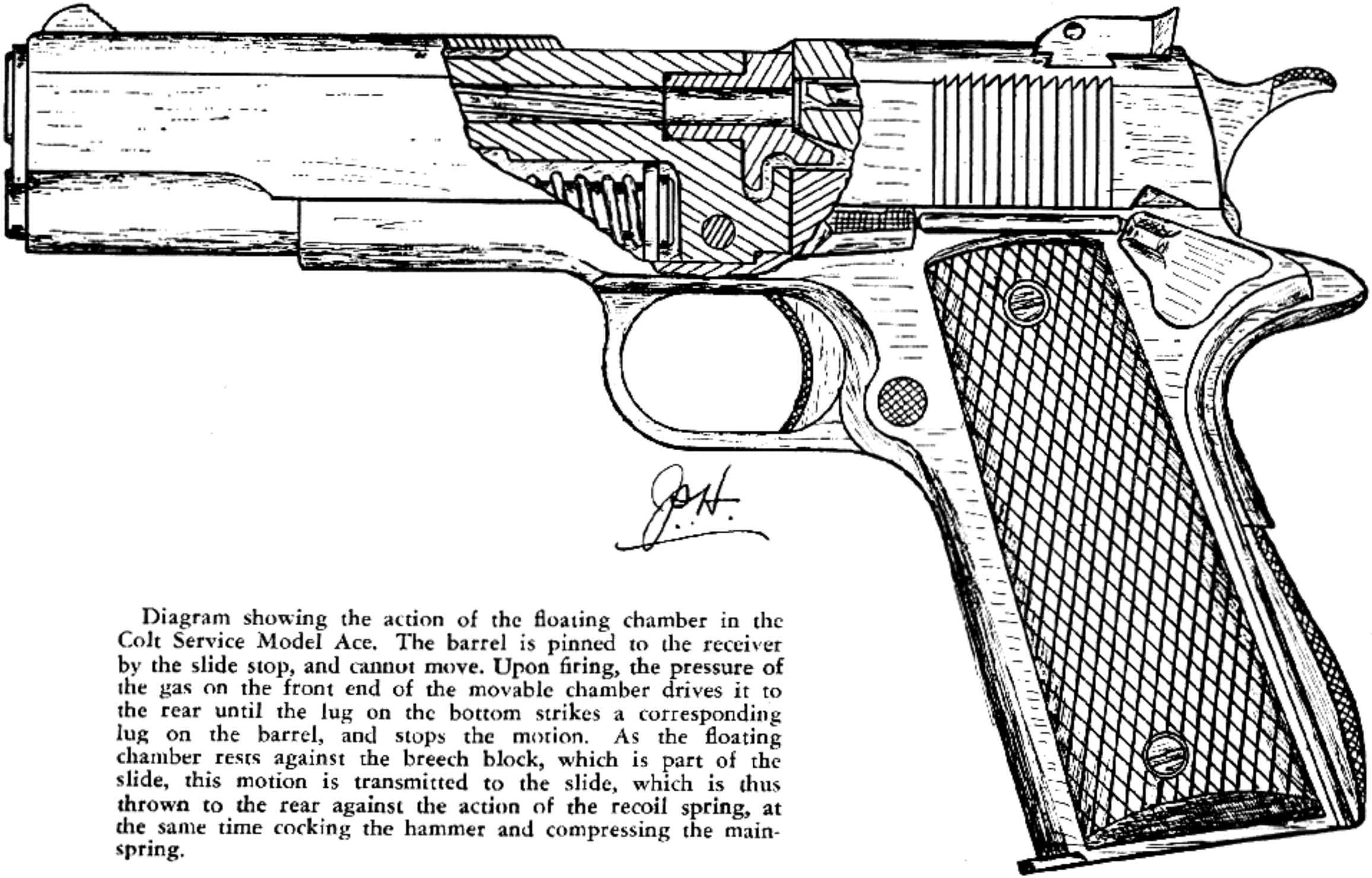
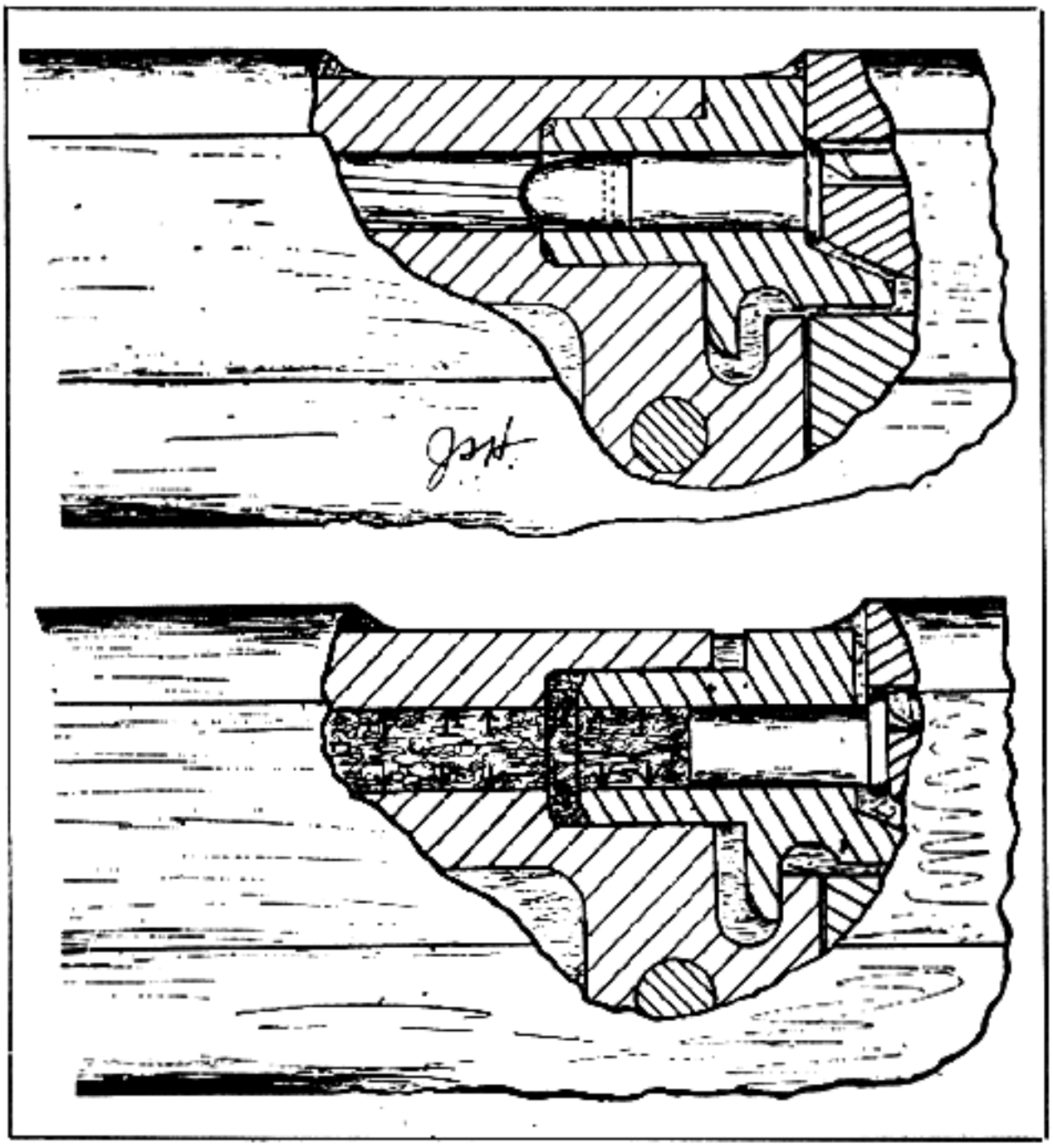


Diagram showing the action of the floating chamber in the Colt Service Model Ace. The barrel is pinned to the receiver by the slide stop, and cannot move. Upon firing, the pressure of the gas on the front end of the movable chamber drives it to the rear until the lug on the bottom strikes a corresponding lug on the barrel, and stops the motion. As the floating chamber rests against the breech block, which is part of the slide, this motion is transmitted to the slide, which is thus thrown to the rear against the action of the recoil spring, at the same time cocking the hammer and compressing the main-spring.

slide sufficient energy to cause it to carry through and operate the mechanism.

It is something like the action of a croquet ball held under the



Action of the floating chamber in the Colt Service Model Ace.
Upper: Position of the parts at the instant of firing. The floating chamber with the cartridge, is held forward by the slide under pressure of the recoil spring. The barrel is held fast to the receiver and cannot move.
Lower: The gun has just been fired, and gas pressure (indicated by arrows) acts on the inside surface of the cartridge head and on the front face of the chamber to drive the chamber, cartridge case and slide to the rear. When the floating chamber has moved a short distance to the position shown, its motion is arrested by a lip on the bottom, which strikes a corresponding lip on the barrel. The momentum which the slide has acquired carries it on to the rear.

foot and struck a sharp blow with a mallet while another ball rests freely against the far side. The second ball will be driven swiftly away by the elastic impact.

This same principle was used in the Winchester Carbine which was adopted by the Army in 1941 as the U. S. Carbine Caliber .30, M 1.

This system has the great advantage of doing away with the long operating rod; moreover, the power of the gas impact on the piston is so great that there is little or no danger of having the piston stick from fouling or other cause. The gas impact slaps the piston to the rear 1/10 of an inch; then the operating slide, driven forward by the return spring, slaps it back again.

V

Notes on Machine Guns and Their Development

GUNS which are capable of delivering continuous fire as long as the trigger is held and while the ammunition supply holds out are in the main called machine guns, though there is another nomenclature used in our army for the very light fully automatic guns capable of being fired from the shoulder, which are called "automatic rifles," as distinguished from the semi-automatics which require a separate pull of the trigger for each shot.

The mechanical principles used to operate these automatic weapons will be described in the following chapter. Here we propose to set down a very brief history of the development of the machine gun, together with some information on the various types which have been or still are standard weapons of our army, as well as some information on the principal foreign types.

Machine guns as a class are not a very new invention, for some type of gun capable of firing more than one shot at a time has been the goal of inventors ever since the beginning of firearms history, and many inventions of this class were tried out in the days of muzzle loaders, and perhaps even before that, for it is said that there was a cross-bow used at the Battle of Hastings in 1066 A. D. which was capable of firing ten arrows at one time.

From the earliest days of firearms until the present time, the effort to increase the volume of fire obtainable from a single weapon has been continuous, and this has resulted in the production of an innumerable host of contrivances, most of which were merely curios but a few of which were useful.

In the era of the muzzle loader, the machine guns of that time usually took the form of a row of musket barrels mounted side by side in a frame like the pipes of an organ, and arranged so that they could be fired one at a time or all together. These contrivances were called "organ guns." In general they were not much of a success. In the first place they were heavy and clumsy to handle, but this was not their greatest disadvantage. That was the fact that after all the barrels had been fired in rapid succession, thus gaining quite a volume of fire for a short time, this period of usefulness was immediately followed by the long interval of inaction necessary to reload separately each of the muzzle-loading barrels.

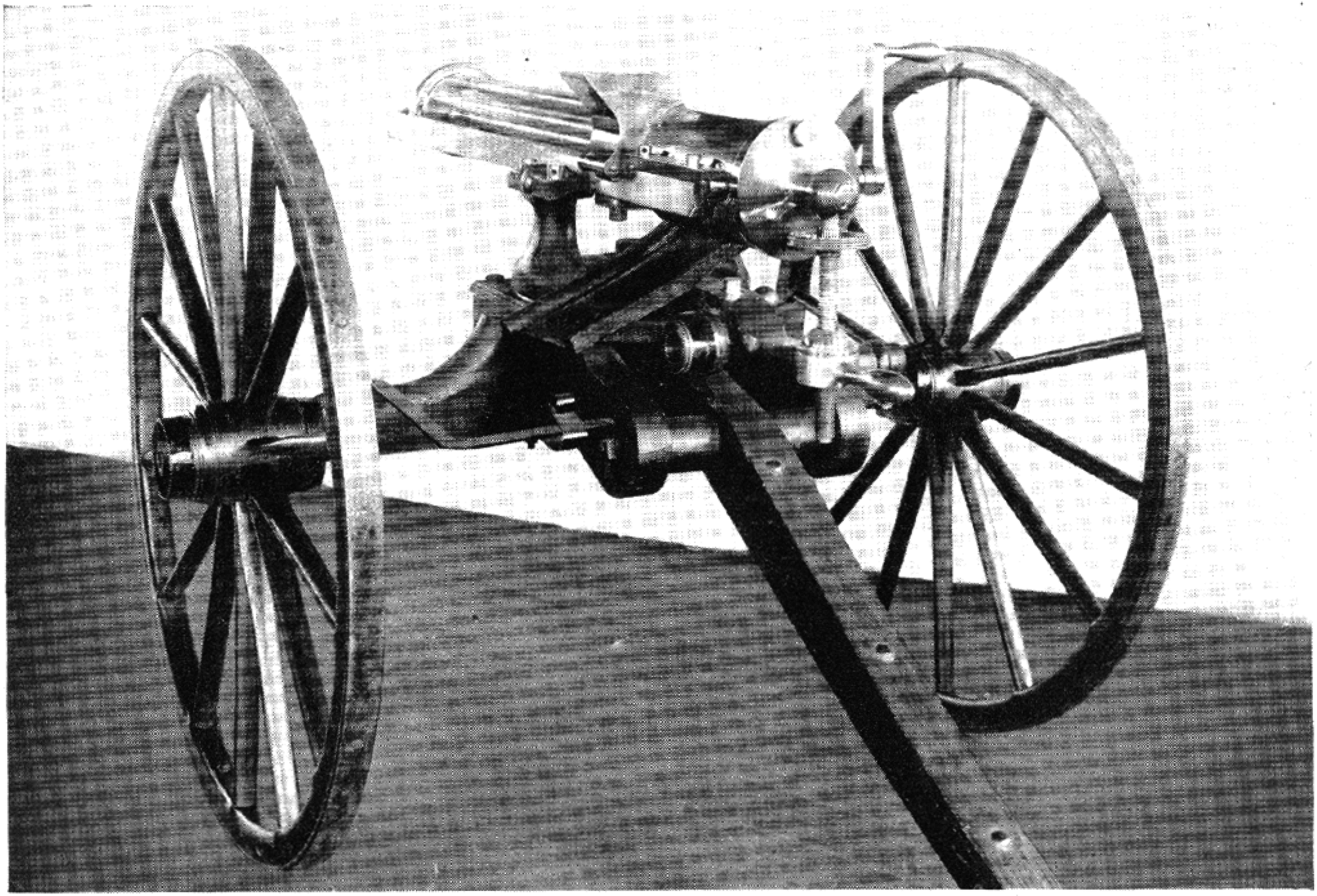
A much improved gun of this general type, called the "Requa battery," was used in the late stages of the American Civil War.

The gun had a sliding breechblock which could be operated by a lever, and when the breechblock was opened the gun could be charged with special cartridges which were held in a long strip, behind which the breechblock was closed by the lever handle. Each cartridge had in the back end a hole which communicated with a vent in the breechblock. The vents were all connected together by a hole extending through the entire length of the breechblock and arranged to be filled with fine powder. In the middle of the breechblock was a regular percussion lock with a hammer, and a nipple for a cap. When this cap was fired the flame spread from the center toward each end of the breechblock, and the cartridges were ignited successively. The reloading could be done with reasonable rapidity as all that was necessary was to replace the strip of cartridges, place some powder in the communicating channels, cock the hammer, and place a new cap on the nipple.

Another old Civil War machine gun embodied the principle of the revolver. This gun used cap and ball ammunition which was loaded in steel containers, which served the double purpose of cartridges and explosion chambers, as the containers did not enter the barrel of the gun at all but during the explosion were held close behind the barrel but in line with it, like the chambers of a revolver. To prepare the gun for action, a number of the containers were loaded with powder and ball and each was primed by placing a percussion cap on the nipple. The loaded containers were then placed in a hopper on top of the gun, and upon turning the crank the charges were fed down into grooves on the edge of a revolving cylinder which carried them past the breech end of the barrel, where they were successively fired, each empty container being rolled out on the far side of the breech as a fresh one was being fed up. This gun had only one barrel, which was consequently subject to overheating and excessive fouling from the residue of the black powder which was used in those days.

The Gatling Gun

The first really practical and successful machine gun was invented on November 4, 1862, by Dr. Richard J. Gatling. The Gatling gun was somewhat similar to the revolver gun described above, in that it used the same general type of steel cartridges which were fed from a hopper into grooves in a cylinder which was revolved by a crank on one side of the gun. At one point in the travel the charge was held firmly against the back end of the barrel by a cam mechanism, and fired as in the early revolver gun; but the Gatling gun differed importantly from the other gun in that instead of having only one barrel, it had six, one for each of the grooves in the feeding cylinder at the breech. These six barrels revolved with the cylinder so that each cartridge, after once entering the mechanism, remained



The Gatling gun

in line with its respective barrel until it was fired and finally ejected from the gun. In this way each barrel was fired only once for each revolution, and the heating and fouling effects were greatly reduced. An additional advantage was the fact that hangfires were rendered comparatively harmless, as the cartridge was always in line with the barrel.

As this invention occurred during a war, the promoters found an easy way to demonstrate it by bringing the gun out on a battlefield, and firing at an actual enemy.

As soon as the self-contained metallic cartridges were invented, great improvements in the Gatling mechanism were made and the number of barrels was increased, usually to ten.

The Gatling gun was adopted by many nations and enjoyed a long period of popularity. It was really a most effective weapon and had some very good features. In our own service it was the standard machine gun as lately as during the Spanish-American War. In the Santiago campaign both automatic machine guns and the Gatlings were used side by side, and the Gatlings seemed to be the more effective at that time.

The Mitrailleuse

During the Civil War many experimental guns were tried, but as this was before the days of metallic cartridges, none were very successful and all were considered freaks or experiments, as indeed they were. As the Gatling came out near the end of the war, it passed practically unnoticed. After the war it gradually became popular, but before it reached this popularity the Franco-Prussian War occurred, and the French invented a machine gun called the "mitrailleuse," which created a great sensation at that time.

The word "mitrailleuse" comes from the French word *mitraille*, meaning small cannon balls or grape shot. The French now call all machine guns by this name, and they also call a machine gunner a *mitrailleur* (or grape shooter). The name originated, however, with the weapon which Napoleon III used against the Prussians in 1870. This consisted of 25 rifle barrels fastened together into a parallel bundle and encased so as to resemble a field gun. The breech of the gun could be opened to allow a block containing 25 cartridges to be inserted. Each of the holes in the block registered with one of the barrels. After the breech was closed, a turn of the handle released the 25 firing pins, one after the other, thus firing a volley of 25 shots, which could be made slow or fast according to the speed of the firing handle. The gun was capable of firing about 125 shots a minute.

The advent of brass cartridge cases had removed many difficulties attending the invention of machine guns, and the mitrailleuse was really a formidable weapon. This gun was adopted a year or two before the Franco-Prussian War, and its construction and operation

were kept a deep secret. Though efforts were made to keep the actual details of the guns secret, their existence was widely heralded, and the French were told that they had a weapon which would make them invincible, and would render victory easy and sure.

The fame of this invention and the secrecy surrounding its actual use proved its undoing. The Prussians heard of the wonderful new gun, and from what they knew of the Gatling and other machine guns they were sure that they had a formidable antagonist. Therefore they set about with characteristic energy and strategy to compass its downfall, in which they were most successful. They realized that the French were well supplied with these weapons, and that what few machine guns they themselves could obtain would not be sufficient to counteract it. Accordingly, for the purpose of producing a moral effect, they scorned the Gatling and such other machine guns as they could have obtained, and fostered a contempt for all weapons of this class. At the same time, they carefully instructed the artillery to concentrate on the mitrailleuses whenever they appeared, and to insure their destruction at all costs.

In addition to this handicap, the mitrailleuses went into the war practically unknown to the army that was to use them. They were kept about as much a secret from the army as from the public, and the result was that the personnel was unfamiliar with the mechanism, and that no proper tactics had been worked out. When the guns were finally brought into action they were used as artillery, and not as infantry weapons, and the usual result was that they were quickly destroyed by the German artillery. In one or two instances they were used with effect, but in general they were a failure. The German strategic fiction that machine guns were useless soon came to be believed not only by the Germans themselves but by everyone else, and the adoption of machine guns by all nations was delayed for years by the fiasco of the mitrailleuse, the machine gun field for some years following being largely filled by the Gatling gun.

It will be observed by the reader that up to this time all the guns described were hand-operated guns, or guns in which the muscular power of the operator was used by means of a crank or lever to do the loading or unloading. For example, in the Gatling, one man put the cartridges into the gun while another man turned the crank continuously as long as he wanted the gun to shoot.

The Maxim Gun

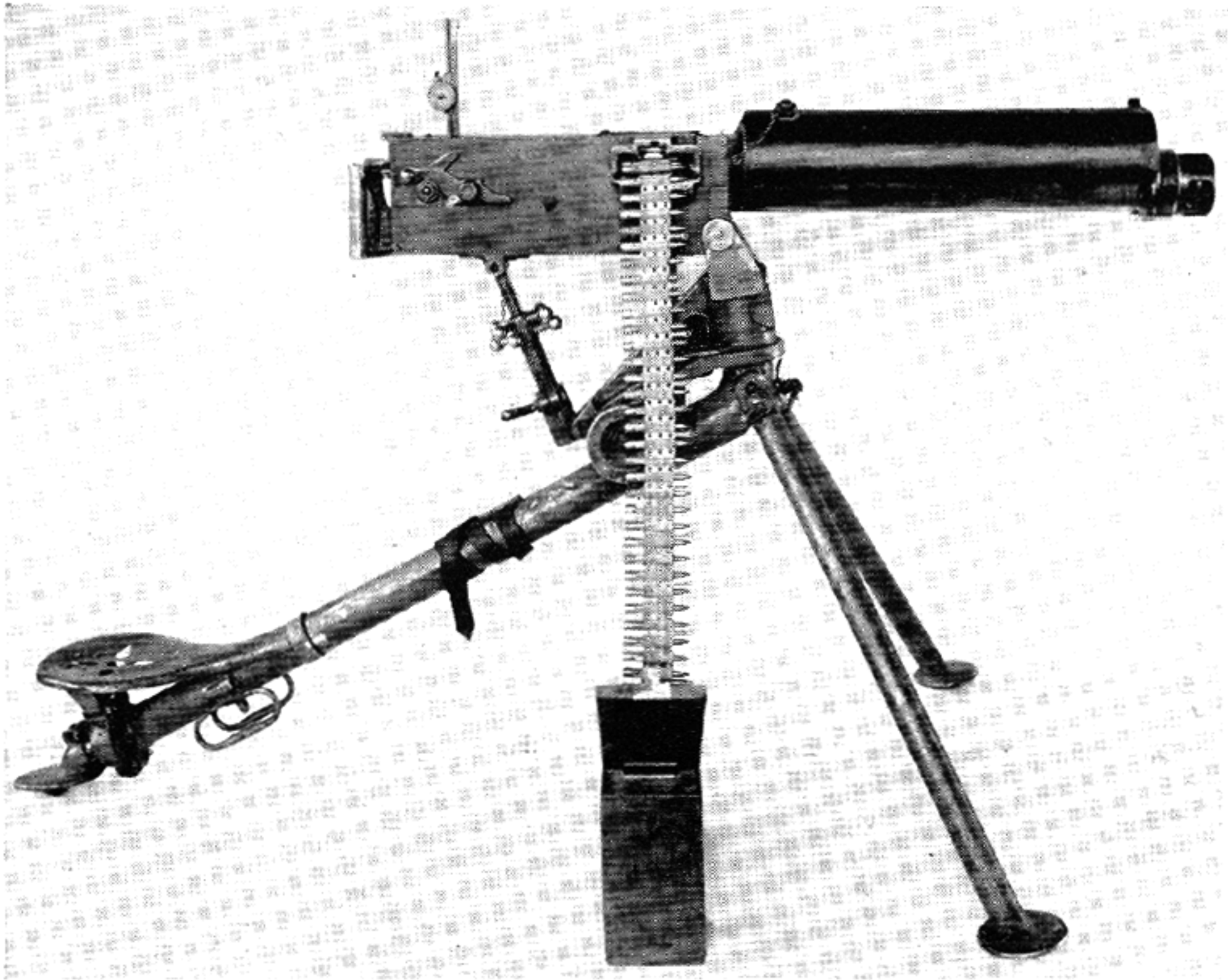
It was inevitable that sooner or later some inventor would discover a way to make the gun fully automatic, that is, to utilize part of the force of the explosion for throwing out the empty shell, operating the mechanism of the gun, and putting in a new shell. This was accomplished in 1884 by Sir Hiram Stevens Maxim, who produced the first successful automatic gun; and today in nearly its original



A machine gun of 50 years ago. A very early model of the Maxim at the end of a 20,000 round endurance test at Springfield Armory. Firing was into a sand pile in the room in front of the gun. The cartridges are the rimmed type of .30 caliber used in the then new Krag Model of 1892. It is interesting to note that there is very little difference between this early machine gun and some that were used in World War II.



A group of World War I officers witnessing a demonstration of the Vickers machine gun, Model of 1916. Photo taken in May, 1917.



Maxim machine gun model of 1904. This heavy type machine gun was in use by our Army from the time of its adoption up until the beginning of World War I.

form it remains one of the leading machine guns of the world, though it is now known principally by the name of Vickers, from the firm which made it for so many years. This firm was first known as Vickers Sons & Maxim, but is now Vickers, Limited.

Maxim was an American, traveling in Europe at the time of this invention. In a letter to the editor of the *London Star*, in 1915, he gives the following account of how it happened that his inventive efforts were turned to the field of firearms:

"In 1881 I visited the Electrical Exhibition in Paris, and was made a Chevalier of the Legion of Honor on account of some electrical and chemical work I had done; and about a year later I was in Vienna where I met an American whom I had known in the States. He said: 'Hang your chemistry and electricity! If you wish to make a pile of money, invent something that will enable these Europeans to cut each other's throats with greater facility.'

"This made me think of the time when I was about 14 years of age and was making drawings for my father of a handworked machine gun. I also thought of the powerful kick I got the first time I fired a United States military rifle. On my return to Paris I made a very highly finished drawing of an automatic rifle. Happening to meet a Scotchman in Paris whom I had known in the States, I showed him my drawings. He invited me to come to London. I did so; and shortly after I started an experimental shop at 57d, Hatton Garden."

The Maxim gun, described on page 247, has a very simple and reliable action, and for many, many years has given extremely satisfactory functioning wherever it was properly used.

As long as the firing mechanism is held down this gun will continue to reload and fire automatically at a rate of about 450 rounds per minute until the belt of 250 cartridges is exhausted, when a new belt must be fed in and the gun loaded with the motion of the crank on the side, after which it is ready to fire again.

The gun is ordinarily fired from a tripod which enables it to be controlled for both elevation and direction. Owing to the intense heat of firing so many cartridges in rapid succession, the gun would become red hot in a very short time unless some special means of cooling were adopted. For this reason there is a water jacket surrounding the barrel, which holds 7½ pints of water. The water in the jacket begins to boil after 600 rounds, and then evaporates at the rate of 1½ pints for each thousand rounds.

The Vickers gun weighs 38 pounds, including the water in the jacket, and the tripod weighs 35 pounds.

In 1904 the heavy Maxim gun was adopted as standard for the United States Army, to be superseded in 1909 by the Benet-Mercié, which will be described later. In 1916 the Vickers gun, which was a lighter edition of the same type of mechanism as the Maxim, was

adopted as the Army standard, and many Vickers guns were used during World War I.

The Colt Machine Gun

The invention of the Maxim machine gun was followed by the design of a gun by John Browing, of Ogden, Utah, which afterward became known as the Colt. Mr. Browning produced the first model of this gun in 1889.

In this connection, the following letter will be of interest as establishing the date when Mr. Browning made this invention.

Hartford, Conn.,
Dec. 20, 1917.

Capt. J. S. Hatcher,
Springfield Armory,
Springfield, Mass.

Sir:

In regard to our recent conversation, would say that the application for the first machine gun patent granted to my father was filed Jan. 6, 1890.

This arm was, more properly speaking, of the machine rifle class, weighing less than 12 pounds, and meant to be fired from the shoulder.

The mechanism was operated by means of a lever, or "flapper," which was pivoted near the forward end of the barrel; this lever being actuated by the gases at the muzzle. The gun took the .44 Winchester black powder cartridge, and fired at the rate of about 16 shots per second. A model of this gun was made early in the year 1889.

As far as I can learn, this was the first effort of my father's in the machine gun line, his time previous to this being taken up in designing the Winchester repeating and single shot firearms which are still on the market.

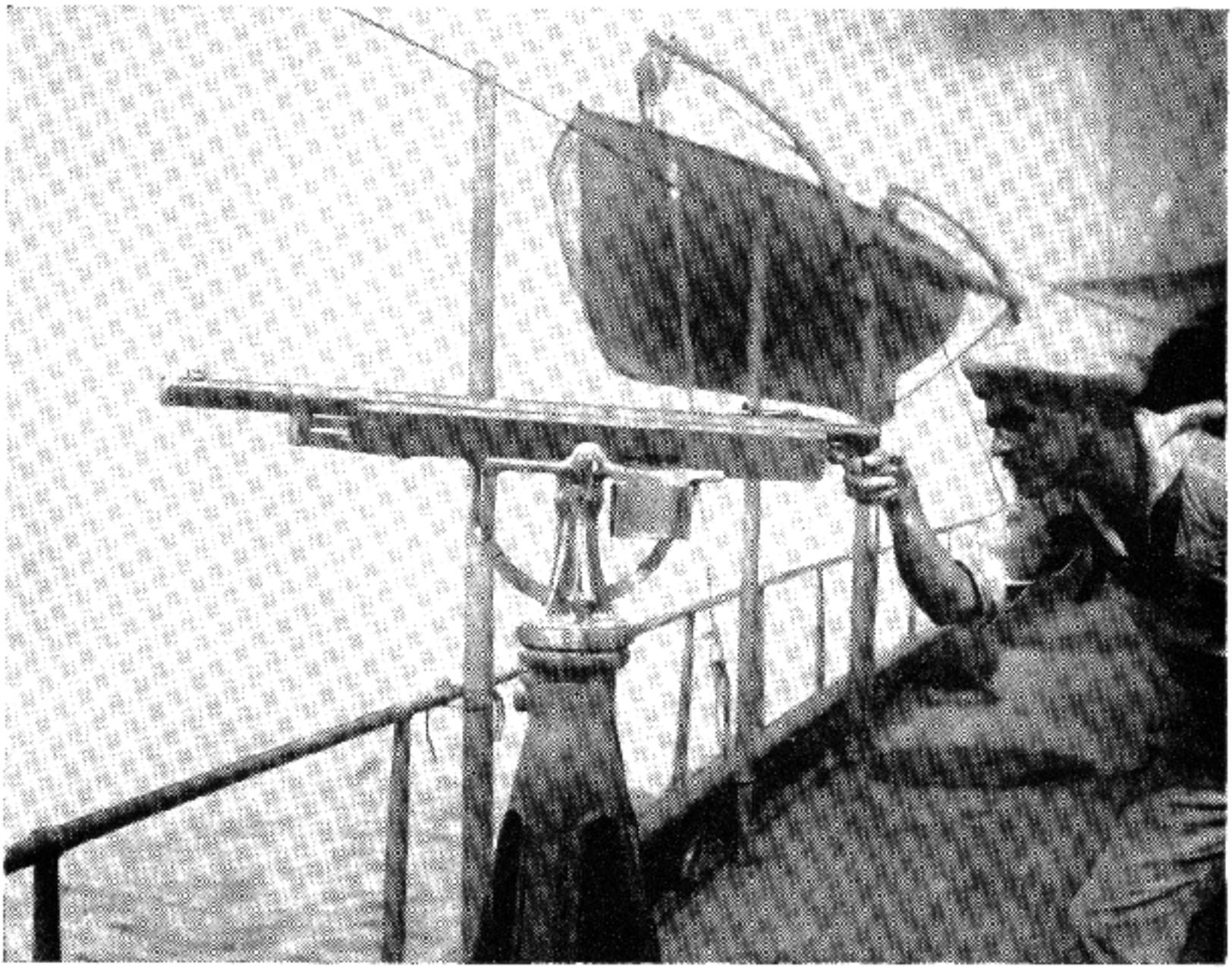
Thanking you for your courtesy extended to me at Springfield Armory, I am,

Respectfully,
V. A. Browning

About 1892, Mr. Browning brought an improved version of this invention to the Colt factory at Hartford, where it was perfected and put into production as the Colt Machine Gun, Model of 1895. This gun was adopted by the Navy, and then by the Army, and was used in the Spanish American war of 1898, along with a number of the old hand operated Gatlings.

This gun did not have a water jacket for cooling, as did the Maxim. Instead, it had the barrel made as heavy as practical, to enable a number of shots to be fired before the barrel would become too hot

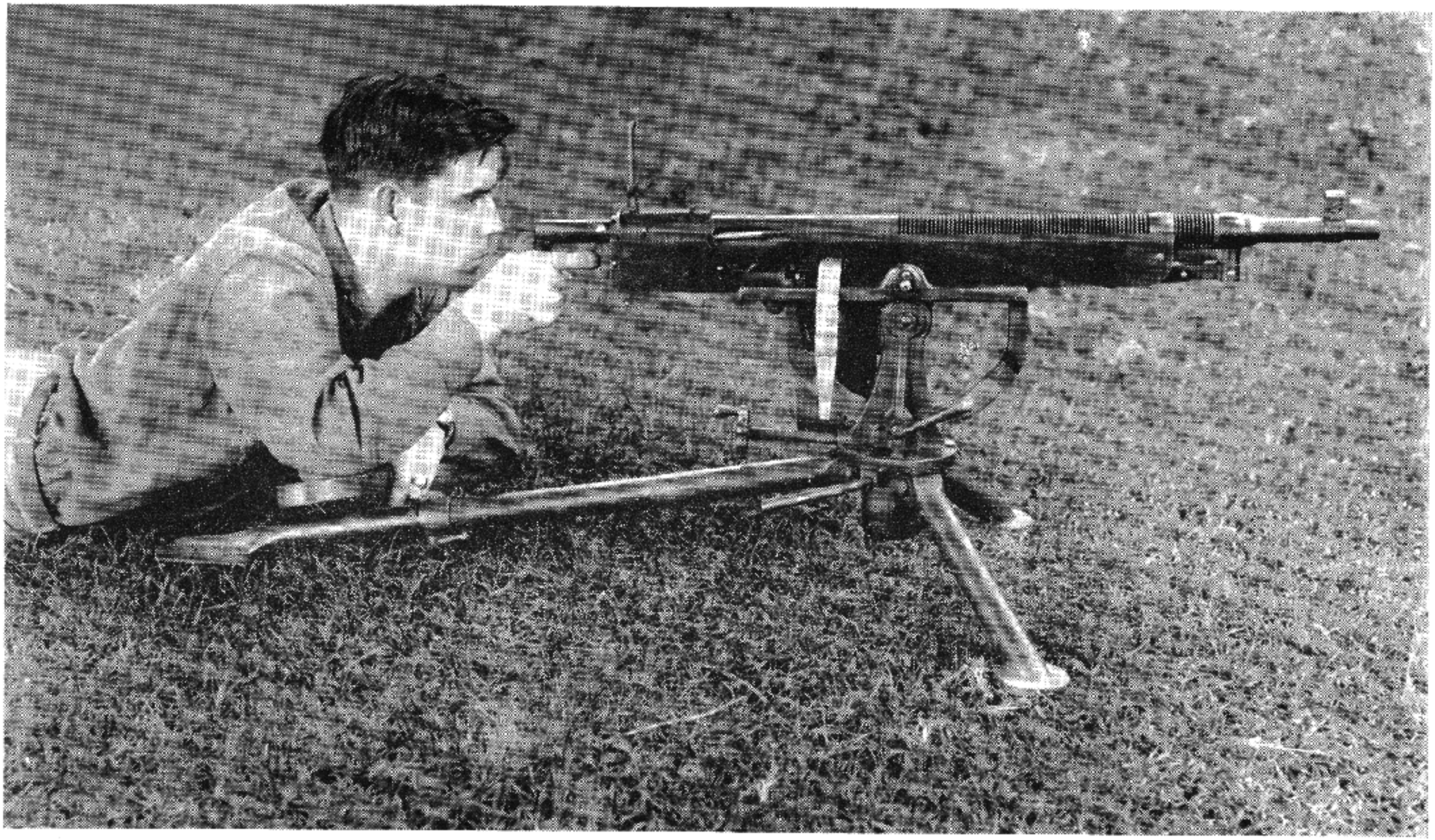
for operation. One disadvantage of this gun was that when the finger was removed from the trigger, the breech remained closed on a live cartridge. If a long burst of shots had been fired, the barrel would be so hot that the round thus left in the hot chamber would go off from the heat in a short time. The remedy was for the gunner to unload the gun at each interruption of fire.



One of the original Browning designed Model 1895 Colt machine guns in use during the Spanish American War of 1898 on board the U.S.S. Aileen.

The weight of the Colt gun was about 35 pounds, and it used a tripod weighing some 56 pounds. Like the Maxim and the Vickers, it was fed from belts holding 250 rounds. However, these belts were much simpler and cheaper to make than the ones used by Maxim type guns.

When World War I broke out in 1914, the Russians placed a large order for Colt guns with the Marlin-Rockwell Co., of New Haven, and when we entered that war in 1917, we purchased some 2500 of these Colt guns from Marlin. These were used during the early part of that war for training, then became obsolete as far as our army was concerned. No Colt guns of that type have been made since 1917. However, this gun, in a modified form known as the Marlin, saw very extensive service in both aircraft and tanks in 1918.



Colt machine gun, invented by Bowning in 1889. The gas passing through a port about six inches behind the muzzle impinged on a lever pivoted under the gun, swing it downward and backward to actuate the mechanism. The present author is shown firing one of these guns in 1917, when they were being made for the Russians by Marlin-Rockwell.

The Marlin Machine Gun

When we entered the first world war we were desperately in need of machine guns of any kind, but especially of a type that could be mounted on the aircraft of that day and synchronized so as to fire through the propellers without hitting them. The engineers of the Marlin Rockwell Co. therefore decided to attempt a conversion of the Colt gun to one that would be suitable for this purpose. The action is described on page 56.

The swinging lever under this gun, while it had the advantage of giving great smoothness of operation and exceptional reliability to the action, had the very obvious disadvantage of being quite in the way. Marlin therefore did away with this lever, and substituted a straight line piston. This became a very difficult feat of engineering indeed. The piston, instead of giving a slow and accelerating backward thrust through a connecting rod, was slapped back at maximum speed right at the beginning of its stroke, with the result that as often as not, it simply tore the heads off the cartridges instead of extracting them. One thing that was done to modify this action was to add a sizeable weight to the piston, which slowed up the initial rearward motion.

Another difficulty was that the final closing motion, which with the swinging lever, acting through a connecting rod, had been slow but powerful, now became a simple and terrific slam, which drove the cartridges in so fast that they were resized enough to make them too short for the chamber, and thus give the effect of excess headspace. To counteract this effect, the chamber was made 11 thousandths of an inch shorter than standard.

The work of making this redesign was done principally by Mr. A. W. Swebilius, who accomplished a most difficult task in a few weeks, and produced a gun that was used throughout the war as the principal synchronized gun of the U. S. air force, and was also used in tanks.

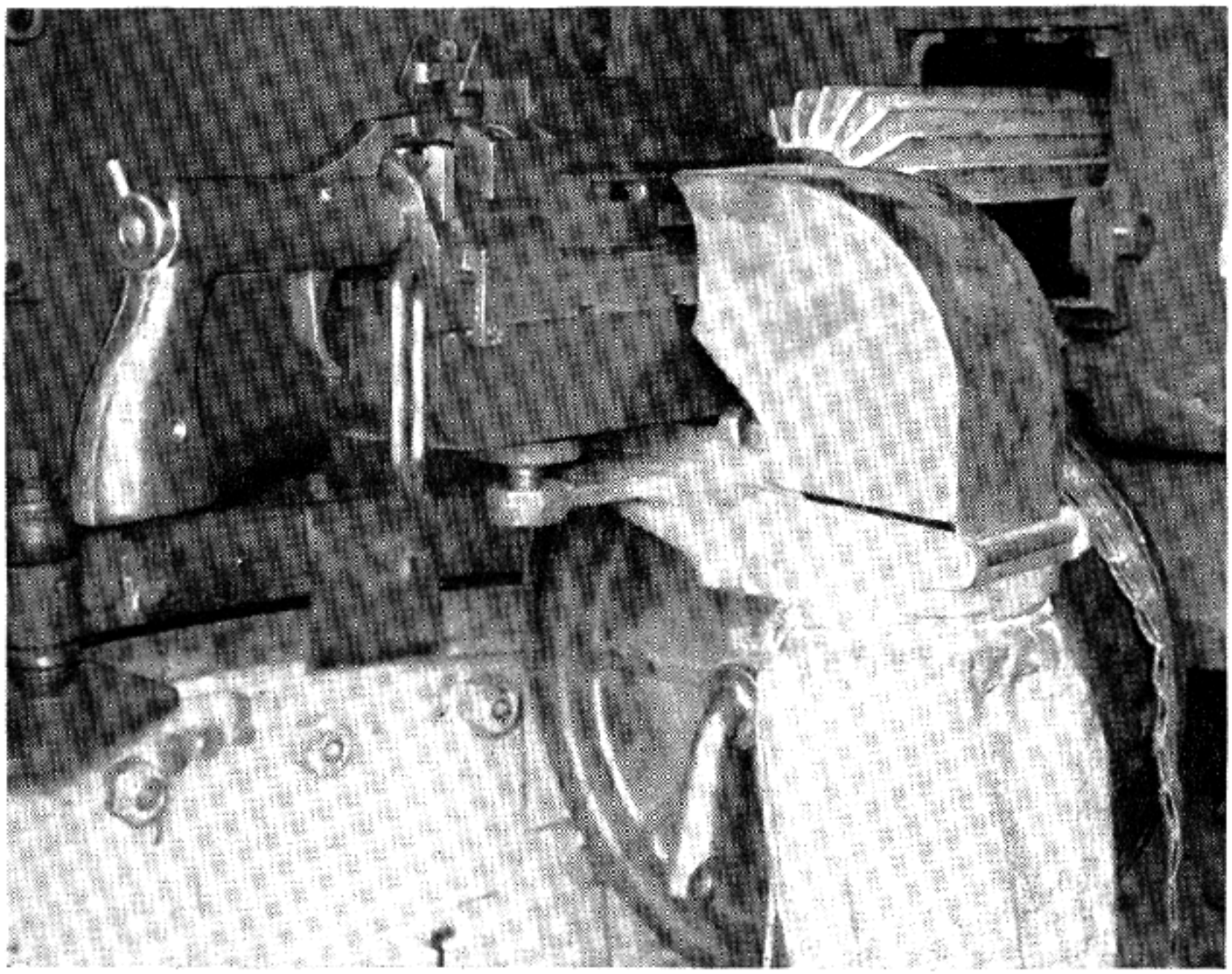
The Marlin Gun was discontinued at the end of World War I, and with its disappearance the old Browning Colt Machine Gun made its final bow.

The Hotchkiss Machine Gun

It was about the time that Mr. Browning was doing his first work on the Colt Machine Gun that an Austrian Army Officer, Baron Von Odkolek, also invented a gas operated gun. There was this difference, however; instead of using a swinging lever, he employed a simple reciprocating piston, and overcame his extraction difficulties, etc., by making the parts heavy and massive.

The heating problem was attacked by the use of very heavy barrels which would heat up slowly; moreover, the barrels were made so

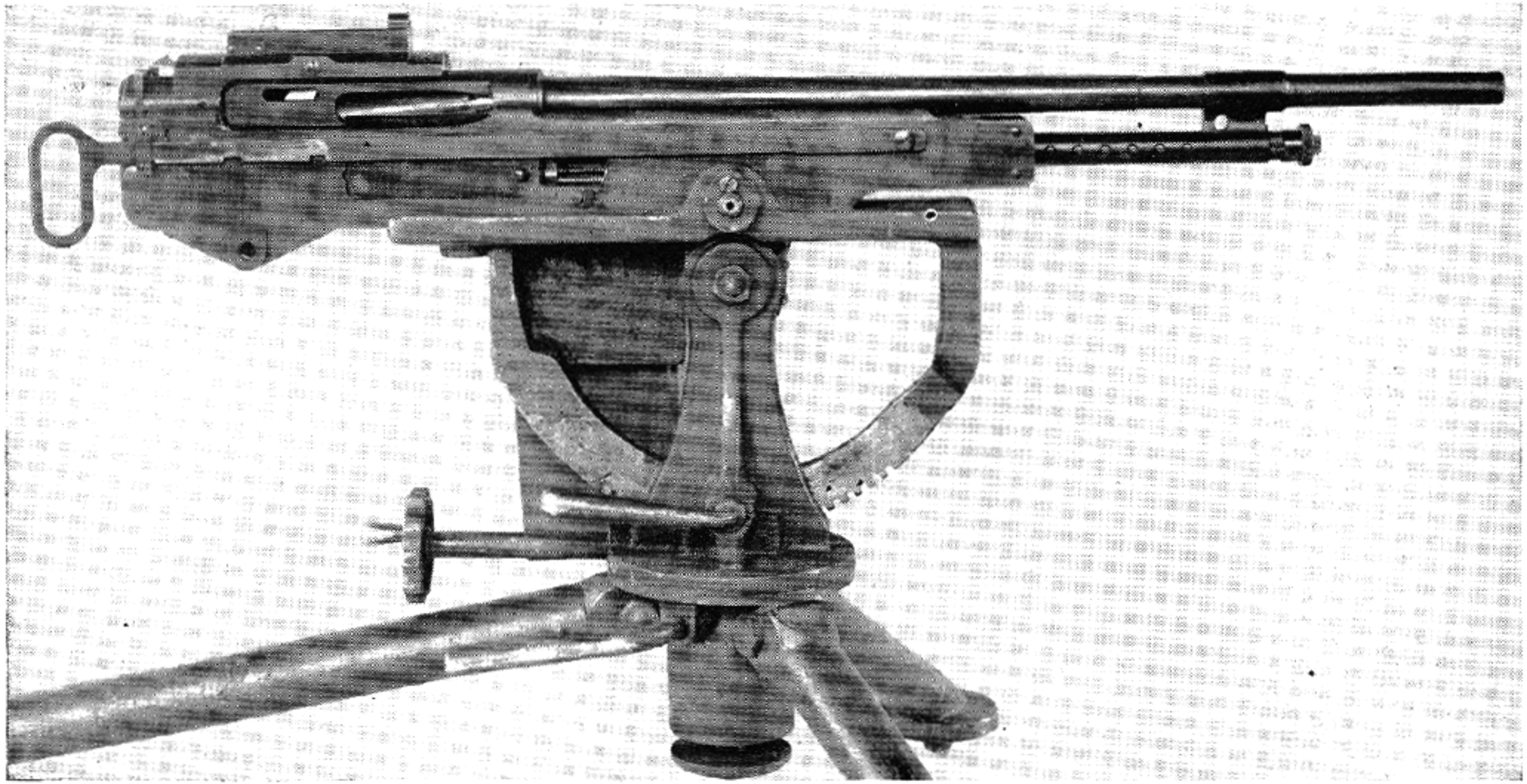
that they could be changed in an instant, even while hot. The danger of "cooking off" a cartridge in the hot barrel was overcome by so arranging the mechanism that when the trigger was released, the breech remained open, with no cartridge in the chamber.



Marlin tank machine gun of World War I shown mounted in a tank of that period. This was the Marlin aircraft gun fitted with a hand trigger and an aluminum radiator on the barrel.

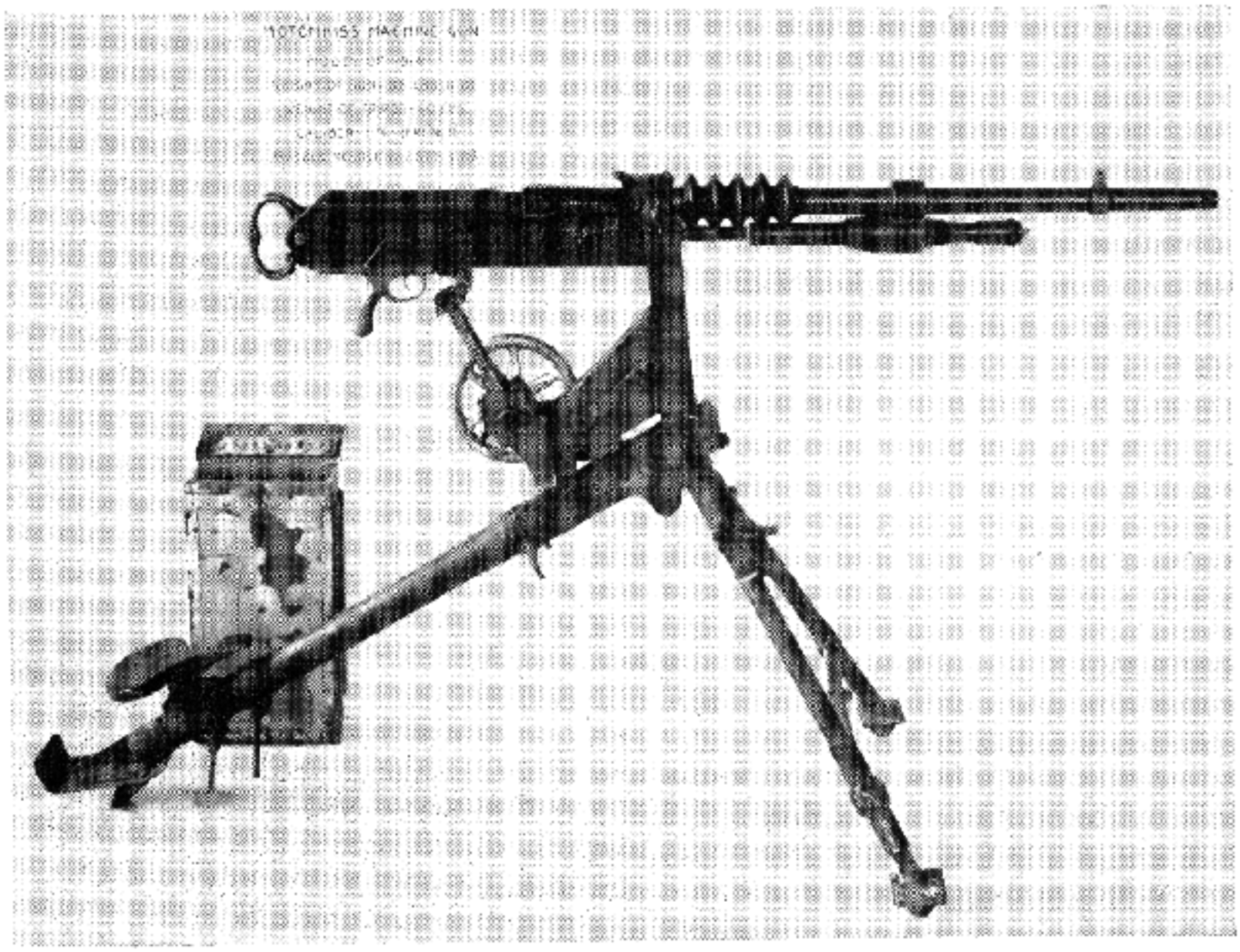
Instead of feeding the cartridges from belts, as do the Maxim, Colt and Browning Guns, the Hotchkiss feeds them from steel or brass strips holding 30 cartridges each. The cartridges are held in place by spring fingers from which they are stripped by the breech block as it goes forward. When the gun is operated, these strips can be fed in one after the other without interrupting the firing.

The gun gets its name from the fact that the Odkolek invention was perfected and put into manufacture by Mr. Ben B. Hotchkiss, an American living in Paris. The Hotchkiss Company founded by him became one of the major factors among the armament makers of the world. The gun was adopted by the French Army in 1905, and has been used by them ever since. Hotchkiss machine guns of one model or another became the standard armament of many nations, and have been noted for their ruggedness and reliability.



The Marlin aircraft machine gun of World War I. This was developed from the old Browning designed Colt machine gun by Mr. A. W. Swebilius of the Marlin Rockwell Co. The gun was used as a fixed aircraft machine gun synchronized to fire through the propellers. It is shown on the tripod merely for convenience in photographing.

During World War I, when we had almost no machine guns of our own, our early divisions in France were armed with the French Hotchkiss, Model of 1914, using the 8mm Lebel cartridge, and these guns gave a splendid account of themselves in action and were very popular with our troops. During World War II, the Standard Japanese heavy machine gun was a Hotchkiss called the Model 92 (1932). Model 92 refers to the year 2592 since the founding of the Japanese



The Hotchkiss machine gun; an old reliable performer of World War I, used by many of our divisions in France in 1918.

Empire, which occurred 1660 years before the beginning of the Christian Era; hence their year 2592 is our 1932. For a fuller explanation of the rather complicated system of model chronology used by the Japanese, see the note in Random Notes.

The Schwarzlose Machine Gun

A heavy machine gun which was prominent before and during World War I, and was even used to a considerable extent in the late war, was the Schwarzlose, Model 1907/1912, designed by the Austrian, Andrea Schwarzlose. It has a retarded blow-back mechanism which has already been described under "Mechanical Principles." It was adopted by Austria and several other countries, and was used very extensively during the war of 1914-1918. During that period the Italians captured a number of these guns from the Austrians,



Schwarzlose Machine Gun, M 1907/1912. This was the standard heavy machine gun of Austria-Hungary before and during World War I. It was also used by several other European nations. During World War II Italy used large numbers of these guns that they had captured from the Austrians during the previous World War.



Dutch Indies short-barreled Madsen captured by the Japanese.

and these were used to some extent during World War II, and hence have again come into public notice.

The Madsen Machine Gun

About 1903 there appeared on the scene a machine gun which was very much lighter and more portable than any full automatic gun had been before that time, and which was really the first of the Machine Rifle class that became so popular during World War I.



Madsen Machine Gun. The photo was taken at Springfield Armory about 1908, at the time of the tests which resulted in the adoption of the Benet-Mercié Automatic Machine Rifle, Model of 1909.

This was the 21 pound recoil operated, air cooled, magazine fed Madsen gun, invented by Captain Madsen of the Danish Army.

The Madsen was tested in this county about 1909, but was passed over in favor of the Light Hotchkiss, tested at the same time, and adopted as the Automatic Machine Rifle Cal. .30, Model of 1909.

In spite of the fact that this gun was not successful in the U. S. Army trials, it was adopted and used with great success by several nations, including Denmark and Holland. It was used to some extent in Germany, and after World War I, it was for a time seriously considered by Great Britain as a successor to the Lewis, but finally gave way to the Bren, which was adopted instead.

The Benet-Mercié Gun

Our first standard machine gun of the automatic type, as compared to the hand operated type like the Gatling, was the Colt Automatic Machine Gun, Model of 1895. Note the word "Automatic" in the name. That was put in to distinguish this new type of gun from the simple "machine guns" like the Nordenfelt or the Gatling, which did not supply their own power.

Our second standard machine gun was the Maxim Automatic Machine Gun, Model of 1904. Both these were heavy guns, mounted on tripods. Our next standard machine gun was of an entirely different type, which today would be known as a light machine gun, but in those days was called a Machine Rifle. It was the light Hotchkiss, designed by Benet, son of an American Chief of Ordnance who had gone to Paris and become an engineer with Hotchkiss, in collaboration with another Hotchkiss engineer named Mercié. This gun was adopted by our Army in 1909 after extended trials, and was called the Automatic Machine Rifle, Caliber .30, Model of 1909.

Now if at that time we had known the least thing about the tactical role of machine guns, we would have realized that we ought to have had two kinds in the Army at the same time; the heavy type for one kind of action, and the light type, for a totally different use. We didn't, however, realize this or anything else much about these matters, so we adopted this light gun as THE machine gun of the Army. In those days every regiment had a machine gun platoon, made up by detailing men from regular companies for temporary duty in the machine gun platoon. This platoon had four guns. It wasn't a regular authorized company, but just a scraped together aggregation of the men who could best be spared from other places. Many times the temptation to get rid of unwanted problem children was solved by company commanders by sending them to the machine gun platoon. A pretty sorry outfit it was, as a rule.

When we had gone through all these trials and had finally settled on the gun we wanted, and had adopted it, we gave the Hotchkiss Company an order for twenty-nine of these guns. I repeat, *twenty-nine only* of these guns at a time when nations like Germany were buying thousands of machine guns. The reason was that the funds allowed the army in those days would pay for twenty-nine guns and no more, so we got twenty-nine.

Then we put the gun into manufacture at both the Colt's Patent Fire Arms Manufacturing Co., and at Springfield Armory, and in the next few years, we made a total of 670 of these Benet-Mercié guns. That many, divided between two factories was not enough for either of them to learn and overcome the usual production and heat treating difficulties.



The Automatic Machine Rifle, Caliber .30, Model of 1909, which was the standard light machine gun of our Army at the beginning of World War I. This light Hotchkiss gun, known also as the Benet-Mercié, from the names of two Hotchkiss Company engineers who developed it, was superseded by the Browning Automatic Rifle.

This Benet-Mercié gun remained standard from 1909 until 1916, when the Vickers was adopted as a result of another set of tests and trials.

The Lewis Machine Gun.

Beginning in 1912, and at intervals thereafter the Army tested a machine gun invented by Col. I. N. Lewis, Coast Artillery, U. S. Army. This gun resembled the Hotchkiss in that it was gas operated, and employed a straight piston which was driven to the rear by a jet of gas from a port drilled in the barrel. The cartridge feed was from flat pan shaped magazines holding 47 shots each, or later, in the aircraft type, 97 shots. This was placed on top of the receiver, and was fed around and around like a cog wheel as the firing progressed.

The barrel of the gun was surrounded by an aluminum radiator, outside of which was a sheet steel casing something like a section of stove-pipe. This casing was open at the rear end, and at the front it extended past the muzzle of the gun so that the blast of gas from each shot had a tendency to create a draft of air through the steel casing over the aluminum radiator around the barrel, thus keeping the barrel reasonably cool as firing progressed.

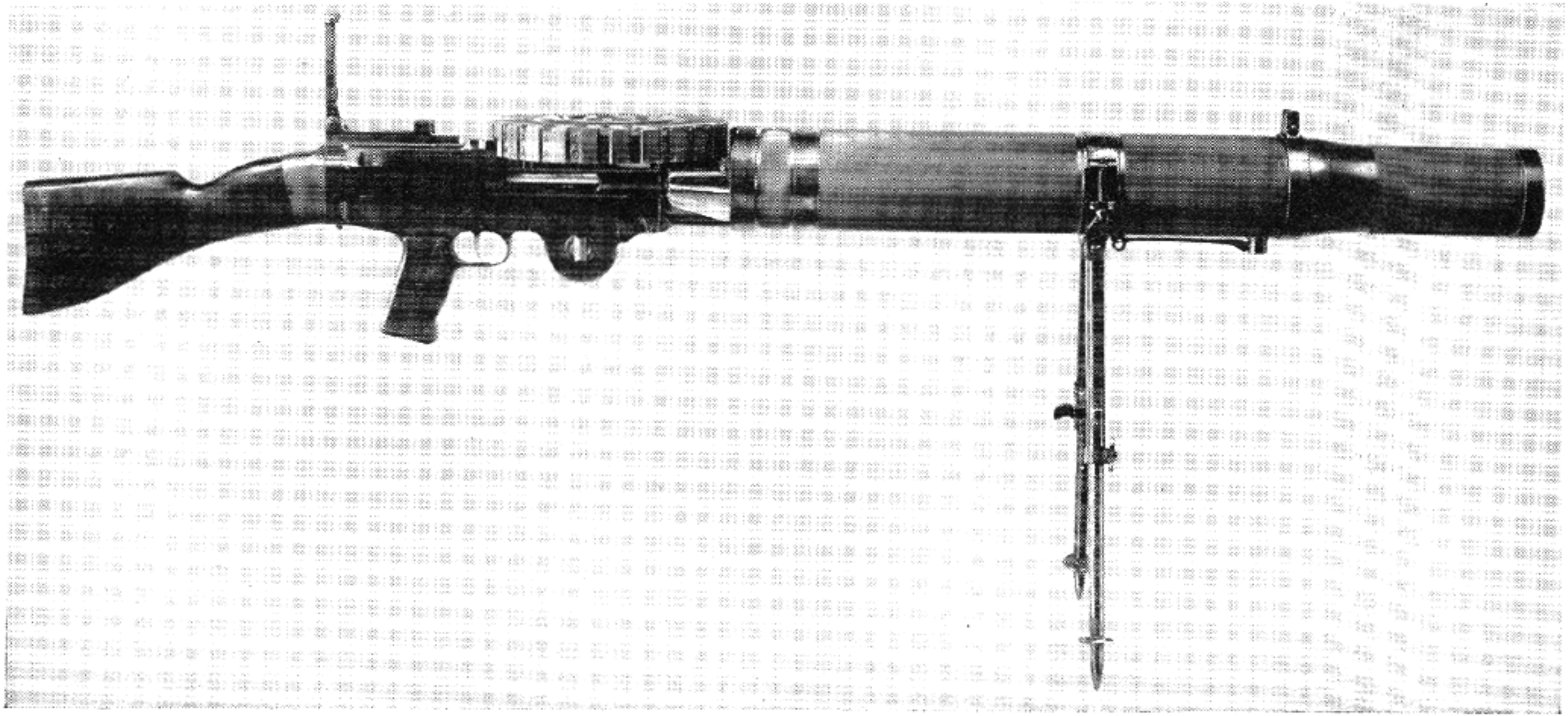
In the first several tests of the Lewis gun, it failed to handle our powerful .30-'06 cartridge successfully, and while further development was under way, the world War I broke out in Europe. Lewis submitted his gun to the British, and with the relatively low powered .303 cartridge it made a much better performance than it did with our heavy high-pressure ammunition.

In England this gun was made by the Birmingham Small Arms Co., as the Model of 1915, and it was used with great effect by the British from that year until the end of World War I.

In this country a high pressure publicity campaign was started to force our Army to adopt this gun. Repeated tests, however, did not produce a Lewis gun that would satisfactorily shoot our ammunition.

In April, 1916, the Army held a formal test to select a new machine gun as a standard to replace the Benet-Mercié. The Lewis gun, made in this country for the British by the Savage Arms Company, was naturally a strong contender in these tests, and the proponents of this gun made the most of the reputation which this gun had made for itself in the British Service, and accused the U. S. Army of the worst kind of reactionary stupidity for allowing an American invention to go unappreciated at home, only to be adopted abroad. The fact that the gun had repeatedly failed in tests with our ammunition was of course not mentioned, or was even denied.

In these April tests of 1916, a Lewis gun was submitted for the U. S. ammunition which finally put up a creditable performance and showed great promise of being capable of further development to handle our ammunition with complete satisfaction. In the test, this



Lewis Machine Gun, Model of 1917. This was the ground type Lewis gun which the Army and Navy purchased at the beginning of World War I. The Army bought 2500, and the Navy and Marines 9270. After this initial purchase the entire production of the factory was devoted to the Lewis Aircraft machine gun, of which the Army bought some 47,000.

new Lewis gun jammed 206 times, had 35 parts broken, and had 15 other parts which bent or got out of shape so that they had to be replaced. This was during the firing of the 20,000 shots which comprised the endurance test given machine guns in the usual Army trials.

In this test there was also the Vickers gun, which had no parts broken, and none that had to be replaced, and suffered only 23 jams as against 206 for the Lewis. Naturally this Vickers won the test over the Lewis, and was adopted as the Automatic Machine Gun, Caliber .30, Model of 1916.

In this same month of April, 1916, there occurred an incident that touched off a renewed and redoubled campaign of villification of the Ordnance Department and of the Army. The town of Columbus, in New Mexico, was raided by a bandit named Pancho Villa, and in this raid some civilians and soldiers were killed. It happened that this town was garrisoned by a cavalry troop and a machine gun platoon, and there were four Benet-Mercié guns available. The raid was in a way a miniature Pearl Harbor as far as the surprise element was concerned; there did not seem to be any reason to anticipate any such occurrence, and the little garrison was caught completely off guard.

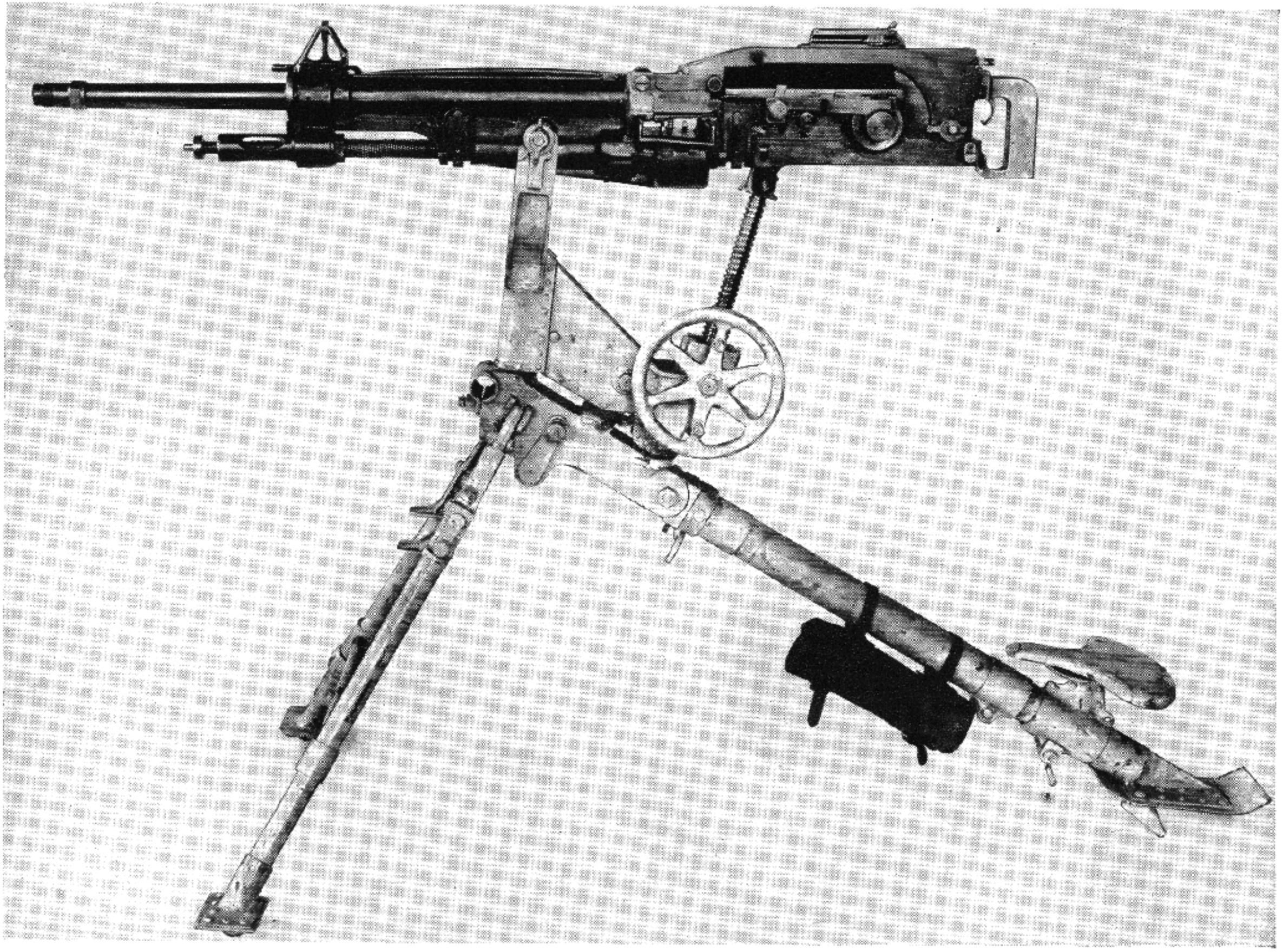
The members of the machine gun platoon, routed from their beds in the middle of the night, hauled out their guns in the dark, hunted for the ammunition, and in some way got the guns to shooting.

The following is quoted from an article that I wrote for the Saturday Evening Post in the issue of Nov. 10, 1917 "The night was dark, and naturally some trouble was experienced with the guns. Occasional jams occurred; but in each case the trouble was overcome and the guns continued in the fight. At least two of the four guns were always in action. These guns were not always firing, though, as they frequently had to stop for lack of a suitable target.

To fire machine guns in the dark streets of a town without a well-defined target is to risk killing friend as well as foe.

There were many highly excited people present, however, and to these it no doubt seemed that all the guns should be firing, regardless of whether an enemy was in sight or not. Thus it happened that a report was started that the machine guns at Columbus had jammed, and the impression was created that they had not figured in the fight. This impression was false, for the machine guns were a decisive factor in saving the town; and in spite of occasional jams, they fired nearly 20,000 rounds of ammunition in the fight."

After this incident, General Pershing was sent on an expedition for the capture of Villa, and the Regular Army and the National Guard were mobilized along the Mexican Border. The old orphan machine gun platoon was done away with, and each regiment was given a machine gun company with four guns. The machine gun company thus had its own tables of organization, with officers, non-coms, etc.,



and the system of making the machine gun outfit a catch-all for undesirables came to an end.

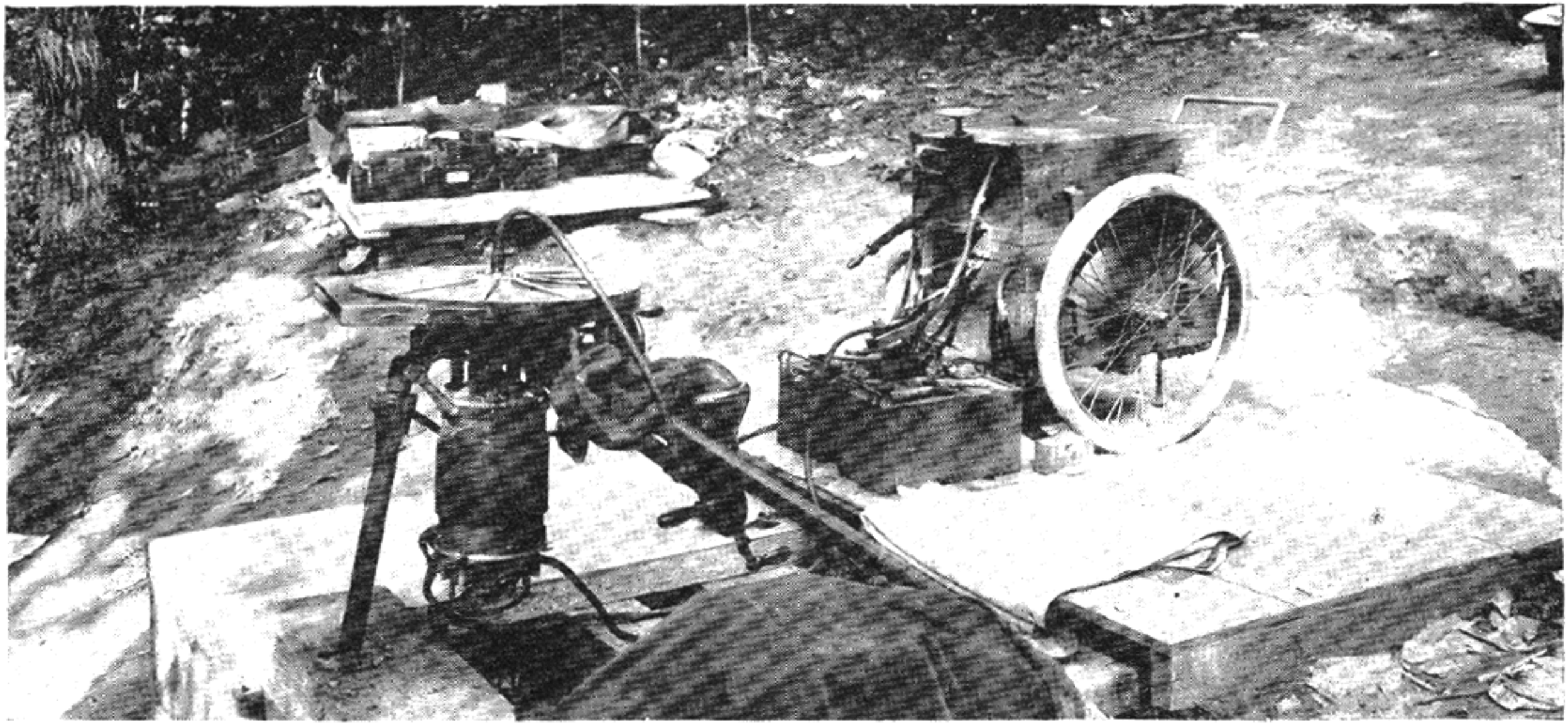
The Ordnance Department, lacking enough guns to arm the newly organized companies for all the border regiments made an emergency purchase of 350 Lewis Machine Guns from the Savage Arms Co. These were for the .303 British ammunition, as the gun for our own high powered ammunition had not yet been perfected and put into production. We of course had to buy ammunition as well as guns, and Ford trucks were also bought to act as machine gun cars. Up to this time all machine guns had been packed on mules, so this was quite an innovation for that day.

The Ordnance Department, of course, had nothing to do with the training of soldiers in how to use the guns. The guns and ammunition were furnished by the Ordnance, together with handbooks on how to operate the guns, but the actual training of the combat troops was not an Ordnance function. This was done by the School of Musketry at Fort Sill. Unfortunately, there was never enough of an ammunition allowance to permit that organization to indulge in sufficient function firing to give the gunners familiarity with the mechanical operation of their weapons. The result was just the same as a flying school would have in training pilots without any gasoline. Much attention was given to the tactics, and to the theory of how to use the guns, but no one actually knew how to keep them firing.

General Crozier, the Chief of Ordnance, was a powerful and determined man, and he decided forthwith that the gunners should have training that would eliminate the talk of machine guns that jam, and that if the people who should give this training were not doing it, he would do it himself, whether they liked it or not. He therefore gave me instructions to accompany this shipment of 350 Lewis .303 Machine guns, and to go to each organization which was armed with this gun and teach them how to use the guns, and thus prevent the guns from getting an undeservedly bad name. It is rather ironical that the first gun whose reputation he thus undertook to guard was the Lewis, whose backers were already carrying on a publicity campaign to the effect that this gun was the only one that wouldn't jam.

After a lot of fine instruction and many spectacular demonstrations from the Lewis people on the virtues of their gun, I went from regiment to regiment along the border, giving intensive instruction in just how to get the best performance, and how to avoid trouble.

French St. Etienne machine gun of World War I. It is a gas operated air cooled machine gun, using the 30-shot Hotchkiss feed strips. It has several novel features such as the front sight with a compensating mechanism to change the sight elevation as the gun barrel heats up. The gas piston is blown forward instead of backward as is usual in guns of this kind.



The Moore centrifugal machine gun, set up for test at the U. S. Bureau of Standards at the time of World War I.

The grooved rotor was driven at high speed by a powerful electric motor. Steel ball bearings were fed into the center of rotor through the flexible pipe, and were delivered at a speed of about 1200 f.s. through the slot at left. The accuracy was extremely poor, but the inventor insisted that the gun would be useful in the trench warfare on the Western Front of 1918. The gun was not used.

In doing this I expended large quantities of ammunition, as I believed that the only way to learn how to shoot a gun is to shoot it. On this job I was accompanied by Col. John J. Dooley, of the National Guard, State of Maine, retired, who was employed as an expert by Savage Arms Co.

I had received intensive indoctrination on the Lewis, and everyone I saw praised it and condemned all the others, so that knowing nothing about the other guns, I was inclined to believe the propaganda that I had been reading about how bad the other guns were in comparison.

After all the 350 Lewis guns had been distributed, I was directed to set up a school and teach all machine gunners on the border, no matter what gun they had, how to use their guns. At Harlingen, Texas, near the mouth of the Rio Grande, there was a newly established Ordnance Depot commanded by Captain Everett S. Hughes, now Major General, Chief of Ordnance. Here I set up a school for instruction in the Colt, the Maxim, the Benet, and the Lewis.

I soon found, much to my surprise and chagrin, that every one of the other three was a far better and more reliable gun than the Lewis I had been praising so highly. The Lewis had some parts that broke and others that bent easily, and after a few hundred miles of being carried around in those Ford trucks, the gun was loose at the joints, the magazine rims were deformed so that they would skip shots, and the feed fingers that guided the cartridges in to the feedway would bend and cause jams; etc., etc. In short, it was just about impossible to keep these guns in firing condition. The other three were strong, rugged, well tempered, and would stay in shape indefinitely if not abused.

In the school everyone in the company, from Captain to cooks, had to learn how to keep the guns going under every kind of adverse condition. The course lasted two weeks; during the first part, the reason for every part and how it worked was explained, also what troubles could happen. Then everyone had days and days of actual firing. First the gun would be fired in good condition; afterward, a bad part would be put it, and the firer would be given ammunition, and when the gun misbehaved, he was given all the time he wanted to find out the trouble and fix it. It was amazing what a difference that two weeks would make in a company.

Typical is the case of a captain who wrote to the Chief of Ordnance telling him that his Benet-Mercié guns were utterly worthless, and asking to have them exchanged for the new Lewis gun. When he came in for his course, I told him that he could have his guns exchanged for any of the other three kinds, but that first he would have to take the two weeks course with all four kinds.

He was dissatisfied with this; wanted to change immediately. Said he had been using his guns four years, and had never been able to

get more than two shots out of any gun without a jam. I said that we would make the exchange, but first I wanted him to fire each of his four guns 300 shots just to see how they worked. That really gave him a laugh. He assured me that no one could get any of his guns to shoot more than two shots.

His guns were placed on a table, and he was told to have his men gather around and pay close attention as we were going to explain the function of each piece. My assistants and I then took the guns to pieces, and explained just how each piece worked, but at the same time casually pointed out some defects. We would say, for example, "Now the firing pin must have a good rounded point, so that it will indent the primer properly without puncturing it. This firing pin has no point at all. Naturally the gun would not fire in that condition, so let's put in this new firing pin. On this other gun the actuator is badly bent—see, right here. That will keep the breech block from closing and of course the gun will not fire, let's replace that bent part with a new one." By the time the guns had been put together again, the bad parts had been replaced. Also, the Captain was doing a bit of thinking, no doubt.

We then had his own gunners load the gun, but two of them started to put the feed strips in wrong. There is a little trick to loading, if it is done wrong, the gun will fire just two shots and then jam. This is all explained in the instructions, but nobody had read them, it seems. So his gunners fired three hundred shots each, with no jams or trouble of any kind. The Captain said that he just wouldn't have believed it; he said he saw that there was a lot to learn about this business.

After he had completed his two weeks he was asked which of the three other makes of gun he wanted in exchange for his. He said "No one is going to get those guns away from me; they are the best guns in the world, and I'm going to sit right down and write to the Chief of Ordnance and tell him so." And he did: I saw the letter afterward in Washington.

During the nine months that this school ran, it trained one company a week; it was a two weeks course, but there were two companies present all the time, one taking the first week, of mechanical instruction, the other taking the second week, of actual firing. The men that were trained in this border school and one that I later ran at Sandy Hook for all the young regular Ordnance officers and at Springfield Armory for reserve officers and emergency officers became the key machine gun men in the entire Army during World War I.

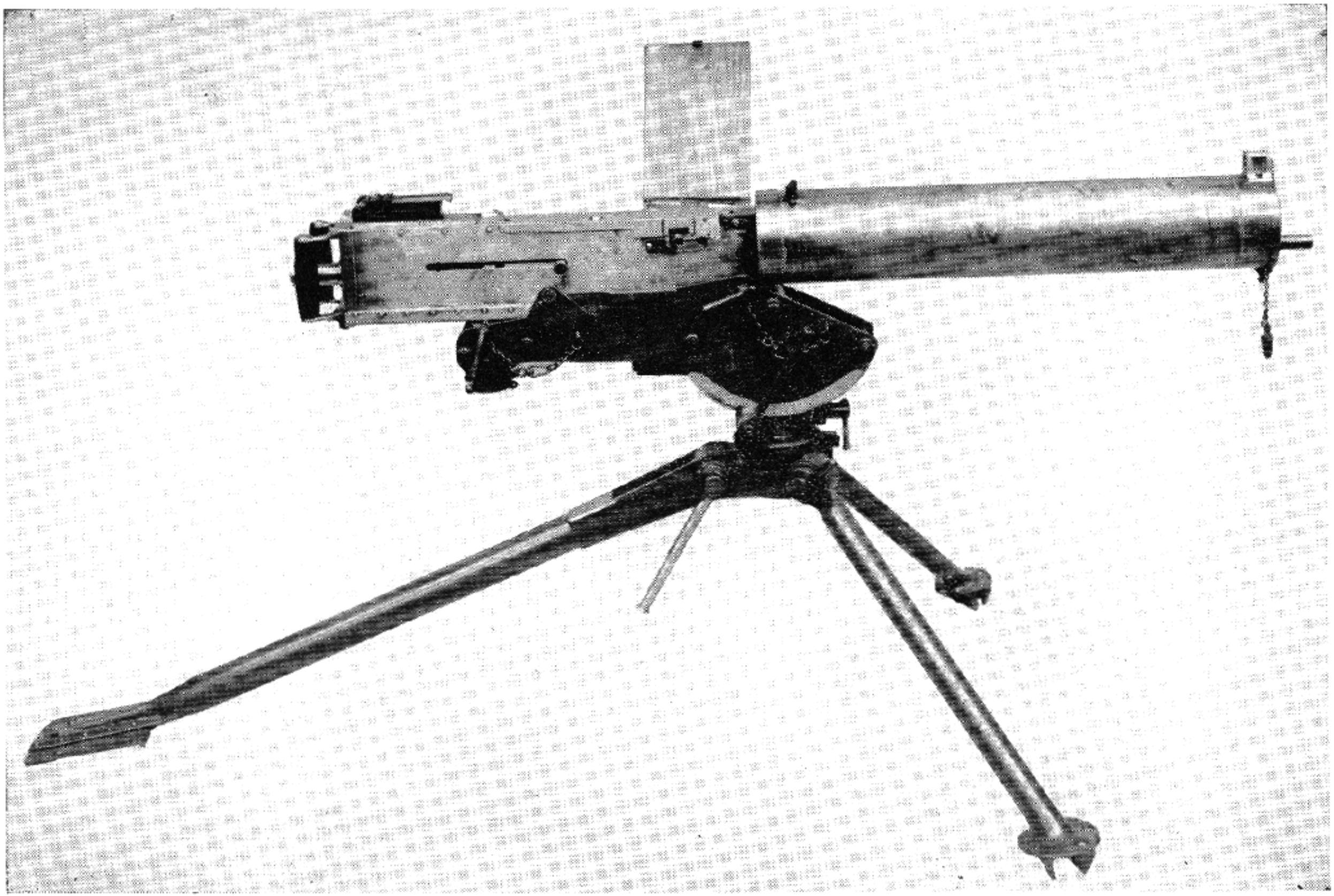
This school kept going until the first of April, 1917, when war with Germany seemed imminent, and I received a telegram ordering handle our ammunition with complete satisfaction. In the test, this



The Berthier machine rifle submitted for test in 1917. It passed an excellent test, but was not adopted, as the Browning was then being put into production. The officer firing the gun is the present author.

my notes there is an old Ordnance Office memo sheet on which I have written; "War Declared; on hand 670 Benet, 282 Maxim, 143 Colt, 353 Lewis." Believe it or not, those figures represent all the machine guns this great nation owned when we went to war with Germany in 1917. None of the new Vickers had yet been delivered.

A little further down on that memo is the entry; "April 12; 1300 Lewis Guns Ordered." It seems that while all this border instruction



Early model of the Browning .50 caliber machine gun, made by Colt in 1924.



The Browning .30 caliber water cooled machine gun.

had been going on, the Savage Arms Company had been perfecting the Lewis for our ammunition, and we ordered these 1300 without a formal trial. We really needed guns by then.

In May 1917, the War Department held a machine gun test before a board composed of Army officers, Navy officers, and civilians, called the United States Machine Gun Board. At this test the Lewis gave a good account of itself, and more were ordered by the Army to a total of 2500. The Navy and Marines got 9270. The Army then adopted a stripped and lightened version of the Lewis as the standard flexibly mounted gun for aircraft use, and purchased 47,000 of them. This Lewis Aircraft gun did not have the barrel jacket or the aluminum radiator.

The Browning Machine Gun

A gun which gave a sensational performance before this United States Machine Gun Board was a heavy water cooled gun submitted

by Mr. John Browning, of Ogden, Utah. It was built on the recoil principle, with a very much simplified action. As it was much easier to manufacture than the then standard Vickers, none of which had yet been delivered, it was decided to concentrate on the simpler and more easily made Browning. The Colt Co. which was already getting into production on the Vickers, produced 9327 of the water cooled type, and 7502 of the aircraft model during the war, while Westinghouse and Remington produced 71,019 heavy Browning machine guns during World War I.

Like the Vickers, the Heavy Browning is water cooled and belt fed, but the belt is of much simpler and cheaper construction. In fact, it is exactly the same as Browning used on his Colt Machine Gun Model of 1895. The weight of the Heavy Browning is 36½ pounds with water in the jacket, and the tripod weighs 48 pounds. The rate of fire is about 550 shots per minute.

The Browning machine gun with water jacket removed and with the barrel made heavier and shorter was used for arming tanks, and was also adapted to ground use on a tripod as a light machine gun. Stripped of its water jacket it was used during World War I as a synchronized aircraft gun for fixed mounting on the aircraft of that day, firing through the propellers. Much improved and lightened after the war, and fitted with right and left hand feed, it became the standard .30 caliber aircraft machine gun.

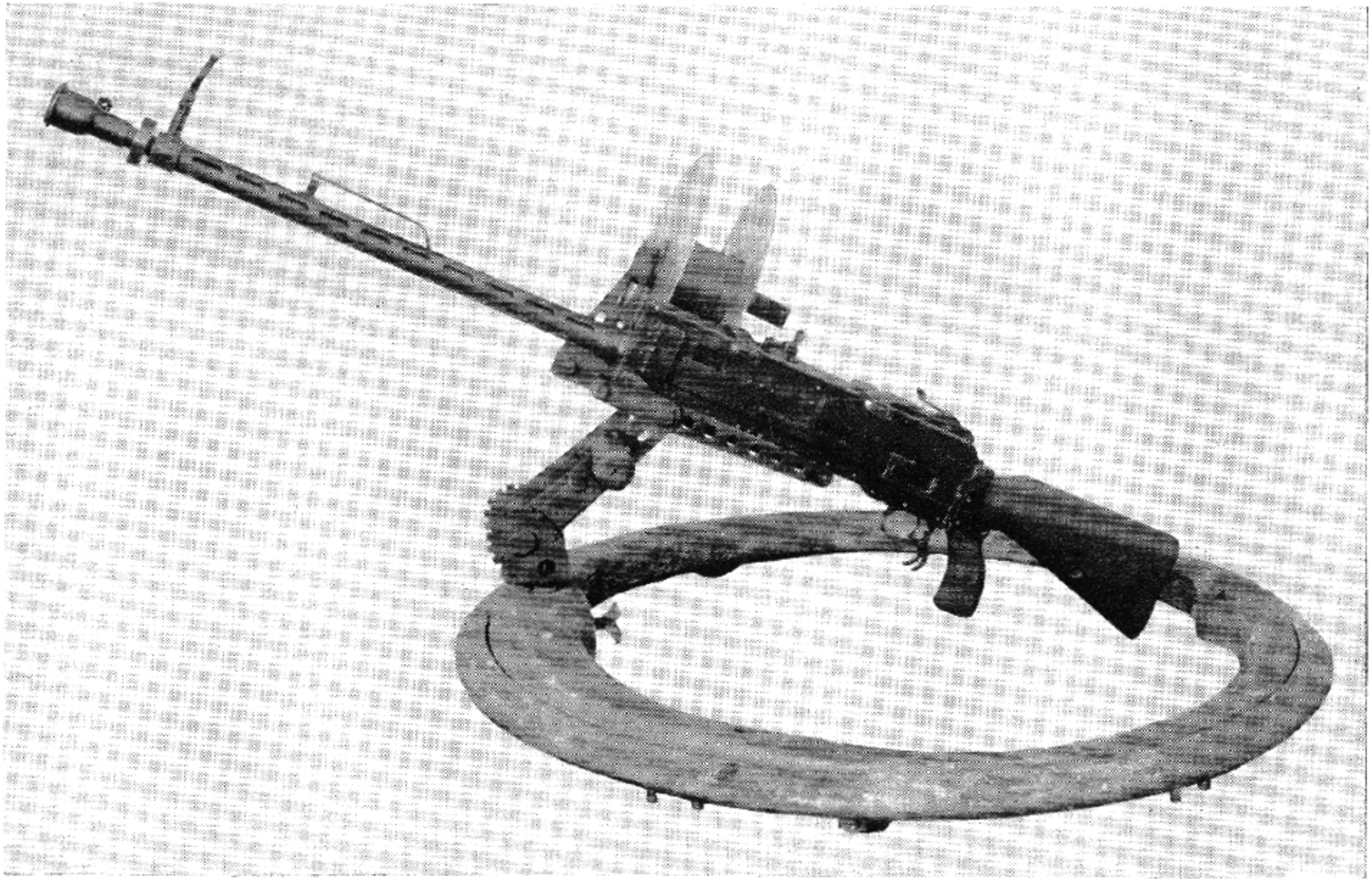
A similar series of Browning guns was made up in .50 caliber. These are used for both aircraft and ground use, and have been widely copied all over the world, and were used not only by the U. S., but by many other nations during World War II.

Light Machine Guns

During the early part of the first World War, the Germans were armed only with the heavy Maxim machine gun, and had no light machine gun to compare with the British Lewis. These lighter guns could readily be carried forward with advancing troops, and after the men had attained an advanced position, they could lie flat with these guns, and produce bands of fire to stop a counter attack.

The Germans soon felt the need for such a gun, and produced a lightened version of the Maxim gun, known as the '08/15. This was simply a Maxim with a smaller water jacket, and mounted on a bipod support so that it could be used in the prone position, the same as the Lewis could. Feeding was from 100 round belts carried in small boxes arranged to attach to the side of the gun. This was a most effective weapon, and produced many casualties among our forces.

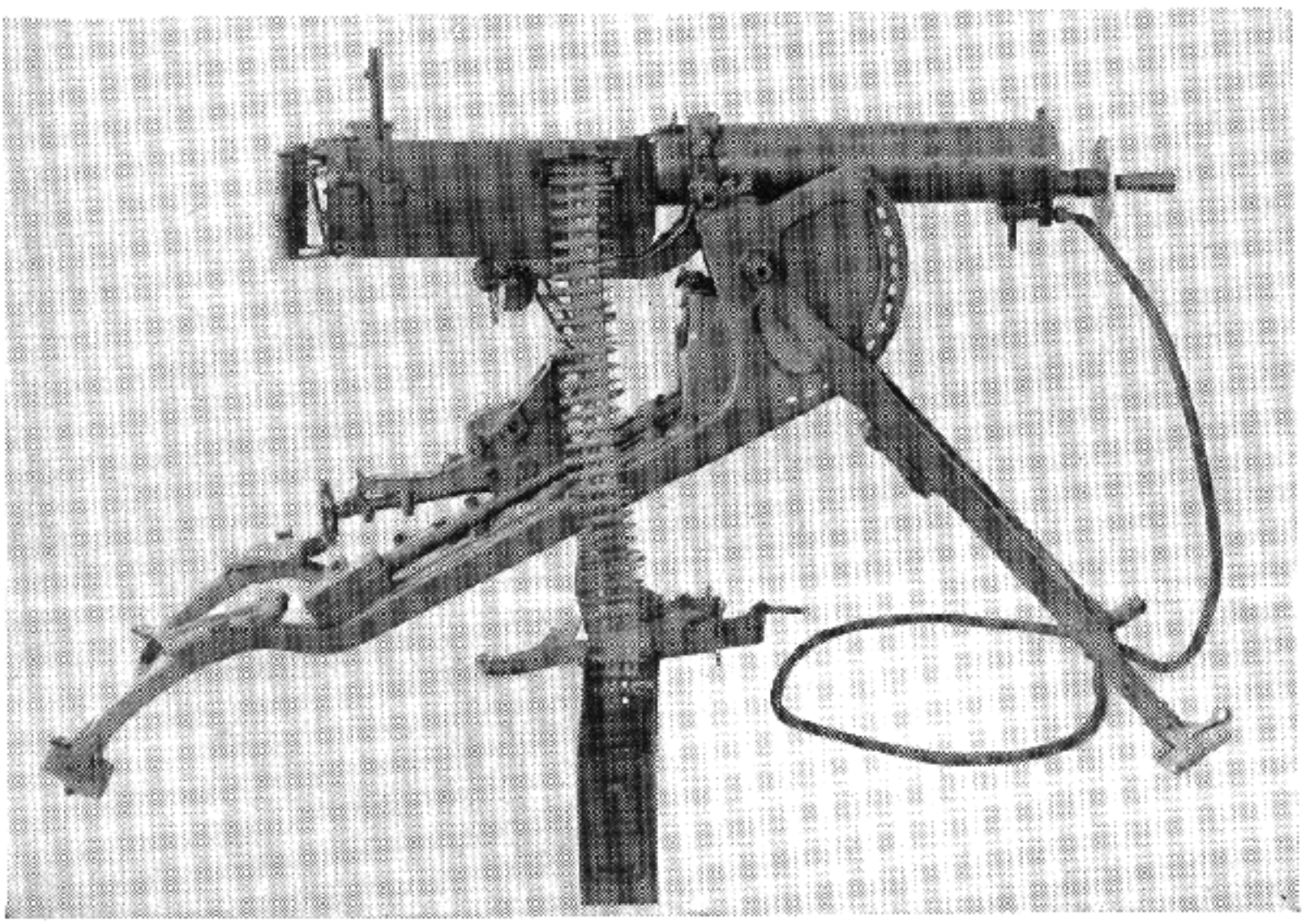
Toward the end of that war the Germans produced another light type of Maxim, called the '08/18, which was the same as the other, except that the water jacket was omitted entirely, and a perforated barrel supporting tube was substituted for it. Naturally the ability



German Parabellum aircraft machine gun. This weapon, designed by Karl Heinemann, bears the following lettering on the left side, "S. M. Gew. Mod. Parabellum 1913. Berlin." It was used as a flexible machine gun in German World War I aircraft.

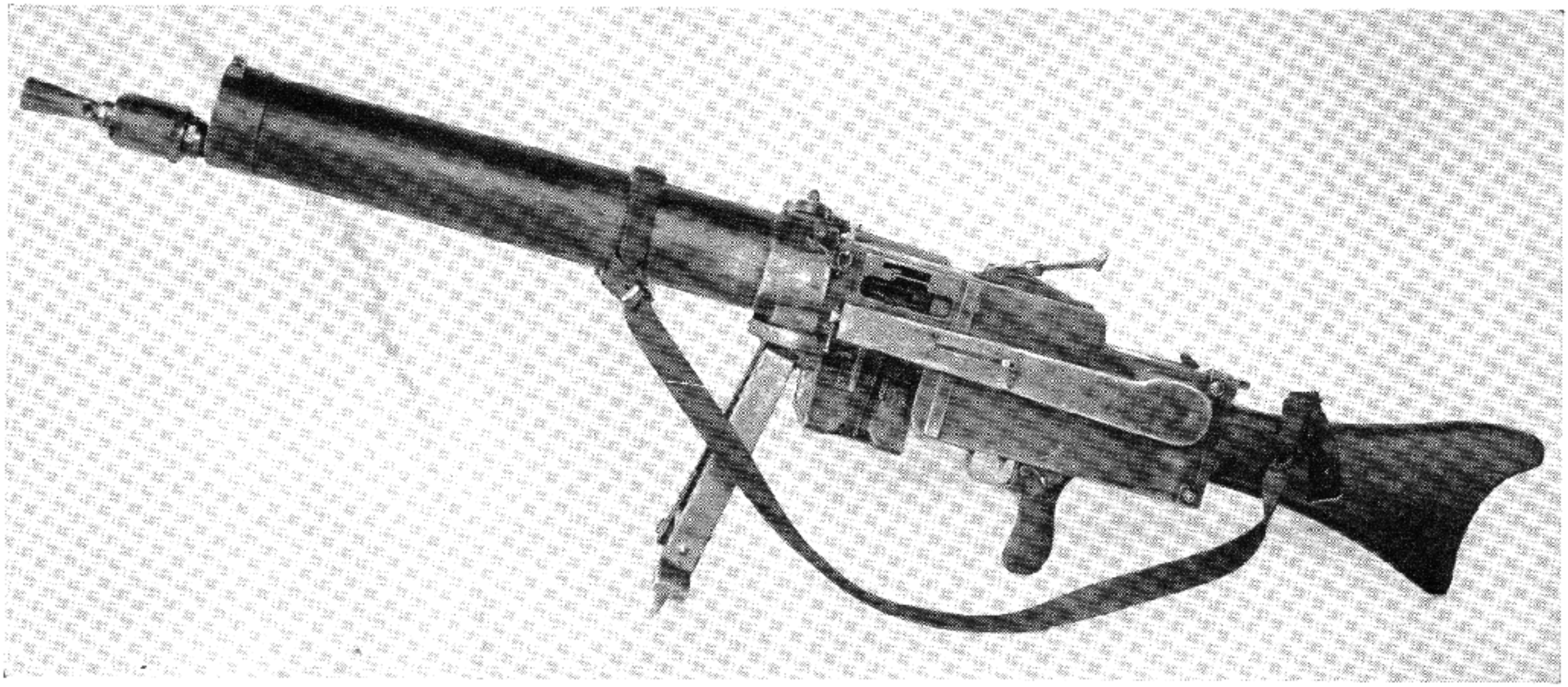
to produce sustained fire was less, as the barrel would heat up after about a hundred rounds so that it was too hot to shoot.

This use of light guns by the British and Germans caused a need for such a gun to be acutely felt by the French, and the result was the development of a new gun called the "Chauchat," weighing only about 25 pounds. With this gun a new type of machine gun firing became much talked of, and that was the so-called "walking fire." The gunner was supposed to carry the gun forward with him during

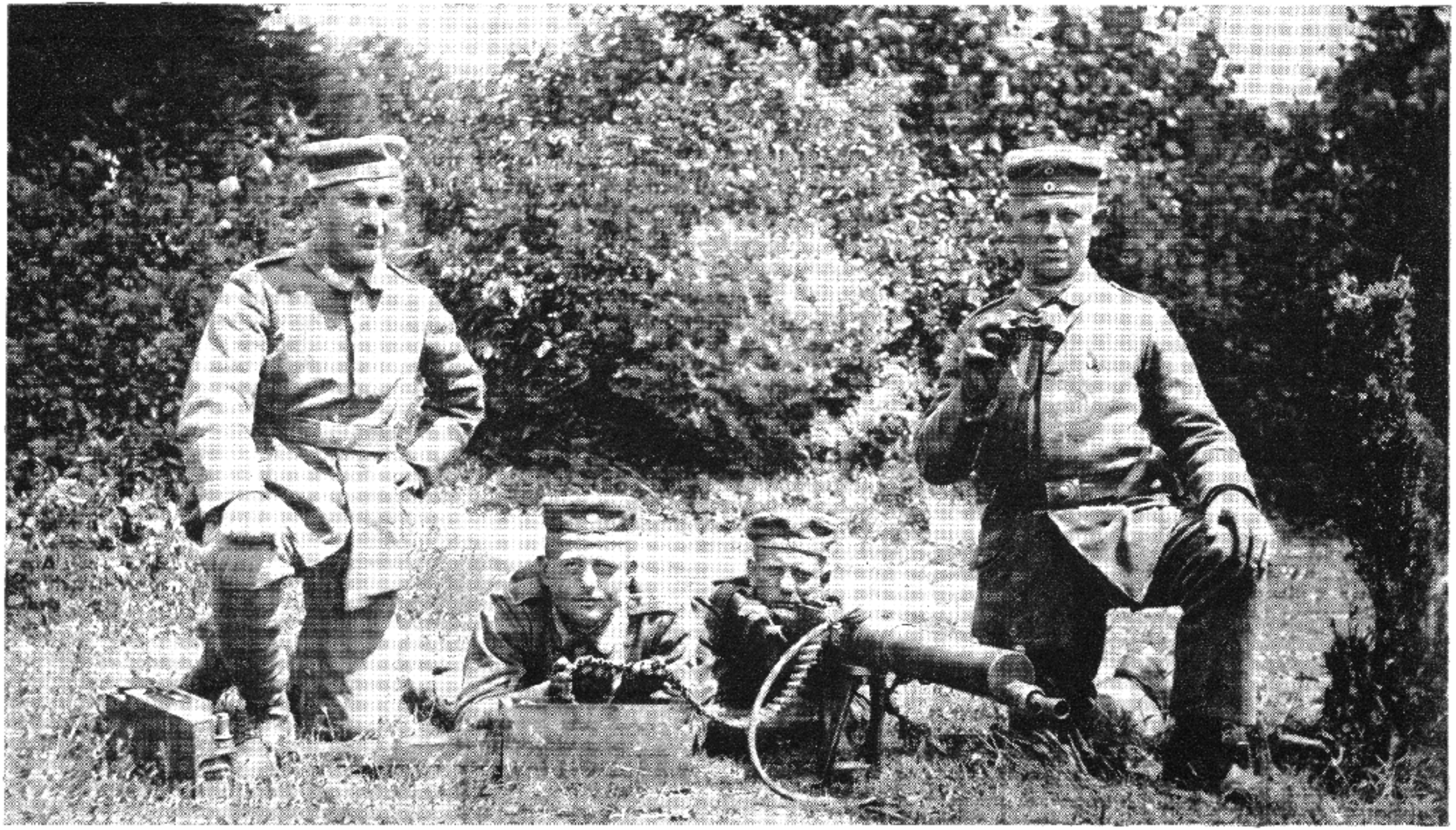


German Maxim machine gun, Model of 1908. It was the standard heavy machine gun of the German Army in World War I, and was used as a reserve and home defense weapon in World War II.

his advance, point it in the direction of the enemy, and fire it from the hip. The Chauchat was a machine rifle with a bipod, and was of the "Long-recoil" type mechanism. The barrel and all of the breech mechanism recoiled several inches to the rear inside the barrel casing. These heavy parts moving backward and forward weighed almost as much as the rest of the gun, and the result was a violent, jerky motion of the gun when firing. The mechanism was crude, but it was simple, and for this latter reason the guns could be made in almost any fairly well equipped machine shop. Many thousands of them were used, not only by the French but by the American Army as well, those used by the Americans being chambered for our own cartridge. This gun was much disliked as a crude makeshift, and was discarded as soon as possible after the war.



German Maxim '08/15 Light Machine Gun. This was the standard Light Machine Gun of the German Army in the first World War, and did enormous execution. It was continued in use as a standard gun by the Germans up to about 1936, and was used to a considerable extent as a substitute in World War II.



A German machine gun crew of World War I. This picture was found on the soldier at the right when he was captured in 1918.



The French Chauchat machine rifle as used by the American Army in 1918. The gun shown was made for use with the 8 mm Lebel cartridge. The semi-circular magazine held 30 shots.



The Hotchkiss machine rifle submitted for test in 1917. It had in the mechanism a clockwork device like that in an electric toaster, to keep it from firing too fast. "Walking fire," shooting the gun from the hip, as shown, while advancing across the "No Man's Land" of the 1918 trench warfare was a favorite way of using the automatic weapons of that day.

The British incorrectly call this gun the "Chauchard."

The instruction pamphlets in French that accompanied the 8mm Chauchat guns that we used in 1918 spelled it "Chauchat". Col. Calvin Goddard, of the Historical section, Army War College, traced the word back to its origin from the name of Chauchat. The French call it Model 1915 C.S.R.G., from Chauchat, Suterre, Ribey Rolle and Gladiator, who developed this gun.

The Browning Automatic Rifle

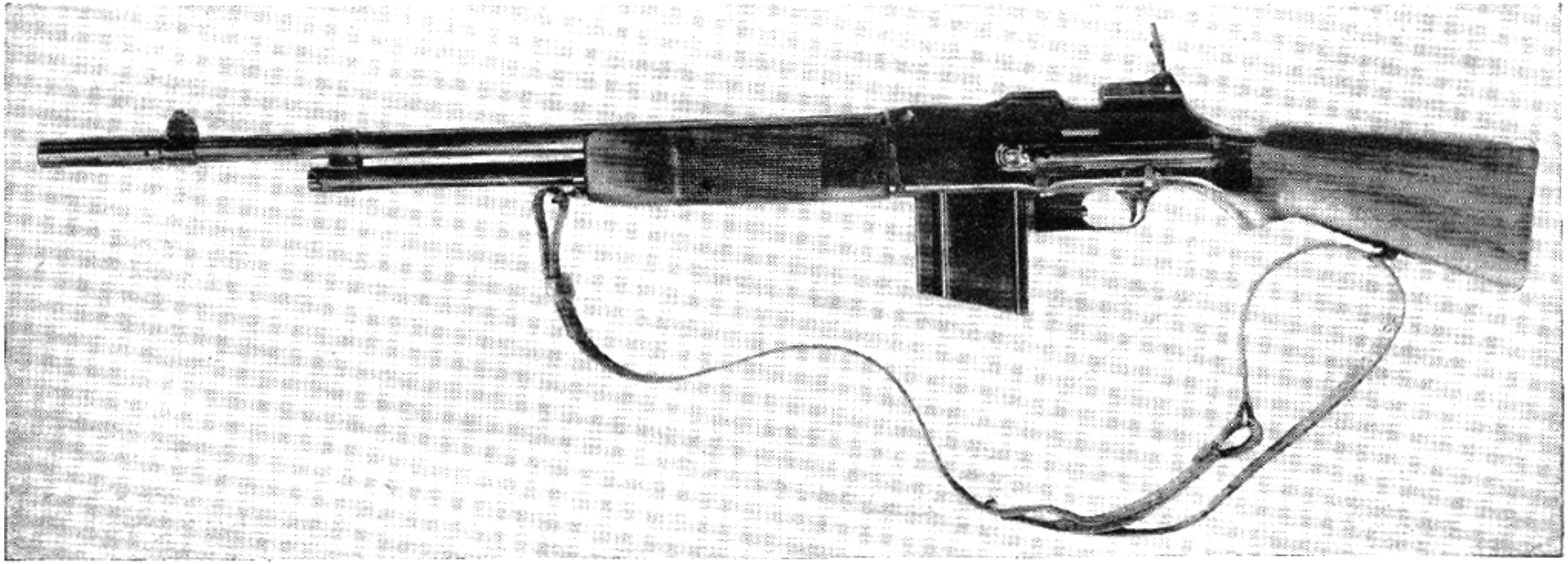
Another gun that Mr. Browning submitted to the United States Machine Gun Board in May, 1917 was the Browning Automatic Rifle. This gun was so different in characteristics from the conventional Machine Gun or Machine Rifle of the day that it created a sensation when it was submitted to the Board. I was present, and well remember the excitement it produced.

It was the first weapon light enough to be fired from the shoulder and at the same time sufficiently heavy and rugged to permit fairly long bursts of full automatic fire. It was a 15 pound gun made on the lines of a large shoulder rifle. It was gas operated, and was fed from detachable box magazines holding 20 shots each. It could be arranged to deliver either full automatic fire or single shots at will, by changing the position of a lever on the side of the gun. It was well adapted for the marching fire in vogue during the trench warfare of those days, as well as for full automatic fire from the prone position, using any rest that might be available for the muzzle of the gun. The action is described on page 58.

This gun can be fired full automatic from the shoulder, but it requires practice to do this without losing control of the gun. When this is attempted by someone who does not know the trick, the rapid succession of recoils, coming at the rate of 450 a minute, will quickly throw the firer off his balance, and he will usually allow the muzzle to swing around to the right, or up into the air, or both. A serious tragedy was narrowly avoided at an early demonstration of this gun when an inexperienced person tried to fire it this way, and the muzzle swept rapidly toward the group of persons standing at the firer's side. It is really the surprise effect more than anything else that is responsible, for if the firer will just lean heavily into the rifle as he starts firing, this motion can be controlled.

This gun passed a magnificent test before the board, and was immediately adopted, and 85,277 of them were produced during the year and a half that elapsed before the end of that war. This gun, officially called the "Browning Automatic Rifle, Model of 1918," but more commonly known as the BAR, was the standard weapon of its type in our Army during World War II. The Germans called BAR's captured from Poland the Maschinengewehr 28(p), and those captured from Belgium the 127(b).

During the years since its adoption there have been several changes or modifications to this gun. The Browning Automatic Rifle, Cal. .30, M 1918 A1, which is limited standard at this writing, has a gas cylinder with spiked feet attached to the gas cylinder tube just forward of the forearm, and a hinged butt plate extension designed to rest on top the shoulder of the firer. The gas cylinder has been changed to have a larger diameter, and to incorporate a relief valve in the head. The forearm is shorter, and is cut away from the barrel.



The Browning Automatic Rifle, Model of 1918.



Browning machine rifle made by Fabrique Nationale, at Herstal, Liege, Belgium.

The M 1918 A2 has the forearm cut away even more, with a metal shield incorporated to protect the recoil spring from the heat. A bipod with skid type shoes is assembled to the flash hider and a stock rest is fitted into a recess in the buttstock. This model also has a device for slowing the rate of fire when desired. It also has a hinged butt plate extension, which is shorter than that on the A1. The rear sight has been changed to include click adjustments for both elevation and windage.

The Browning Machine Rifle, M 1922 has a bipod and a heavy flanged barrel. This modification of the B A R which was used for a time as a light machine gun has been superseded for this use by the Browning Machine Gun, M 1919 A4, and is now obsolete.

Those nations which do not use the B A R all use some other gun of similar characteristics. Examples of other guns on the same general principle or at least of similar dimensions and designed for the same tactical use are the British Bren, the French Chatellerault, the Japanese Year 99 Model, (M 1939), the Mexican Mendoza, and others.

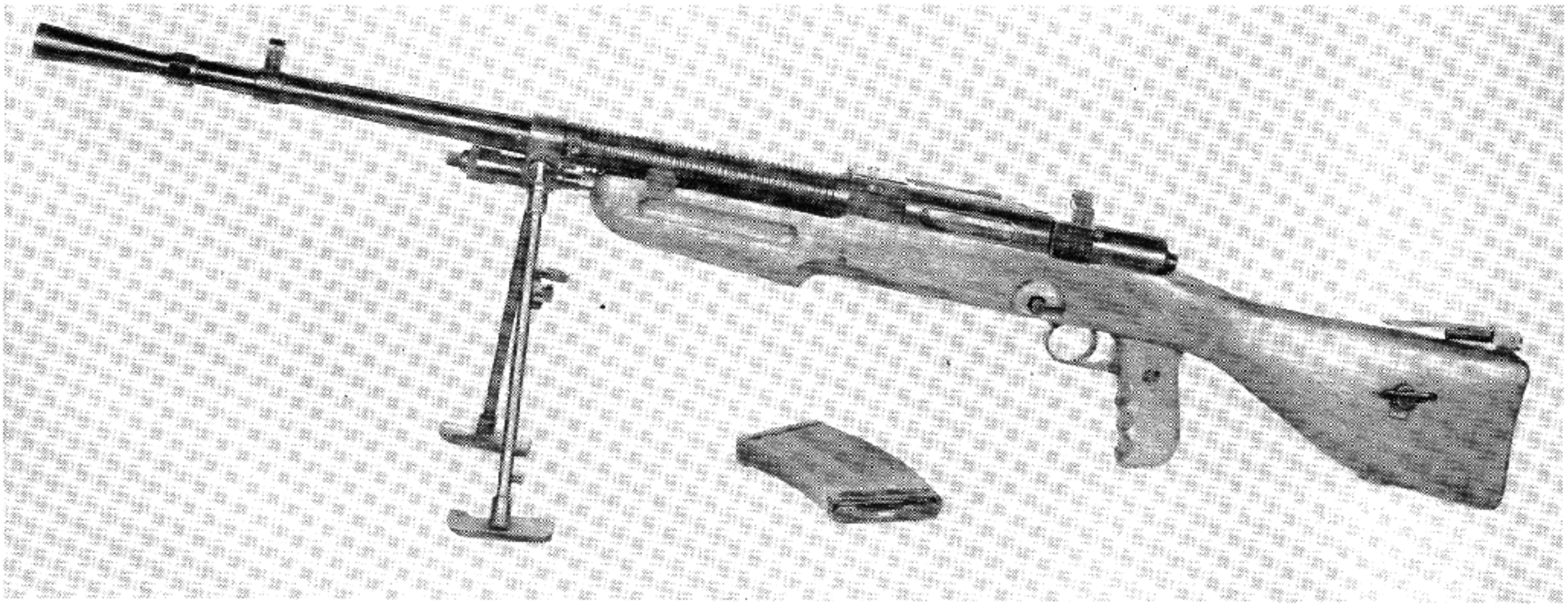
General Observations on Machine Guns

It will be seen from what has been written above that machine guns can be divided roughly into two classes, water cooled and air cooled.

In the water cooled guns, whenever the trigger is released during firing, the mechanism stops with a live cartridge in the chamber. Most air cooled guns are made so that trigger is released, the gun stops with the breech open and the chamber empty. When the trigger is again pulled, it releases the mechanism, which closes, pushing in a fresh cartridge at the same time, and fires as it locks. The Hotchkiss Machine Gun, the Lewis, the Benet-Mercié, the Browning Automatic Rifle, and most other similar guns are made in this way. The reason for this is obvious. With an air-cooled gun the barrel gets very hot, and if a live cartridge were left in the barrel when the firing was interrupted it might explode in a few seconds from the heat.

At a lecture at Sandy Hook in the early part of 1917, after I had just previously been conducting a series of machine gun schools along the Mexican border, the fact was mentioned that the barrel of a gun would get red hot when fired extensively without stopping. An official who was present said that it was impossible to fire a gun that much without a jam. Accordingly a demonstration was arranged for a class of students who were studying machine guns, and I personally fired a Benet-Mercié machine rifle 1,000 shots without stopping. After 700 shots the barrel was red hot, and at the end of the thousand shots the barrel was a bright cherry red, and part of the receiver had begun to glow. The official who had started the argument was dancing up and down, shouting: "I see it but I don't believe it."

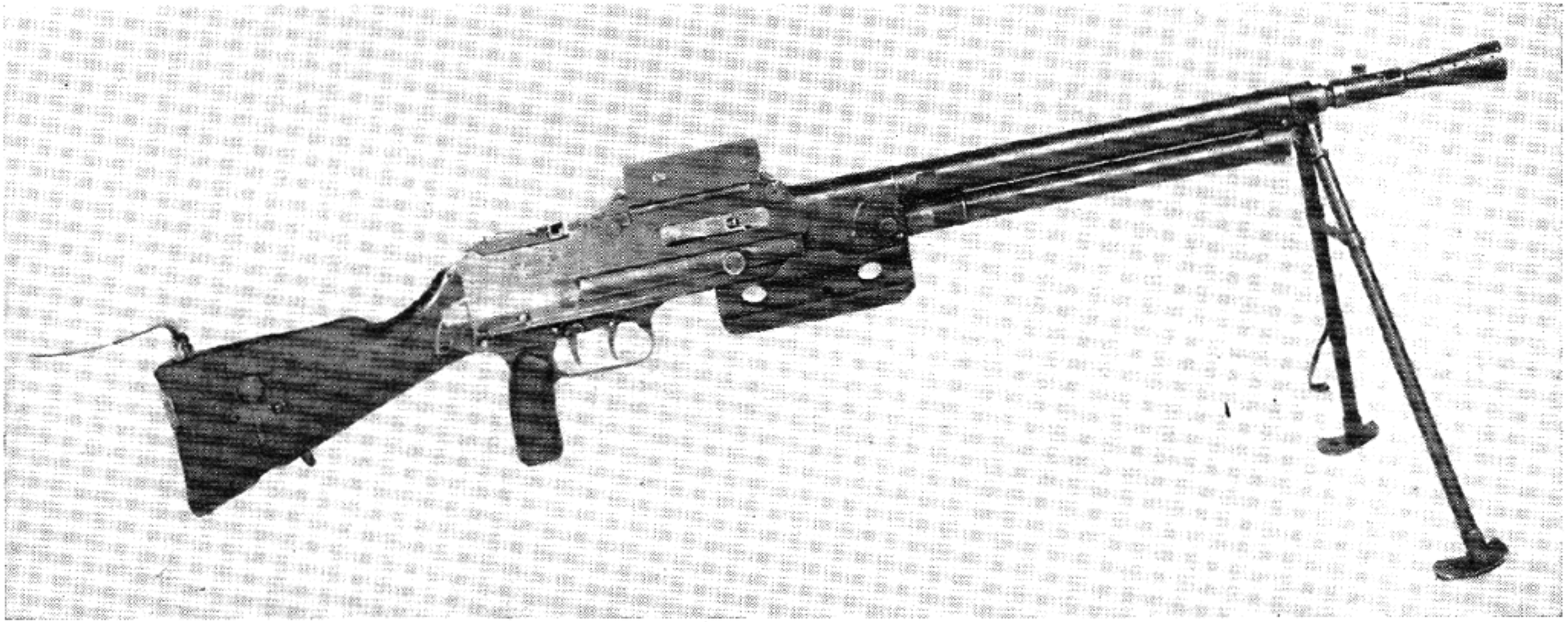
Of course, in practice a barrel is never fired enough to make it



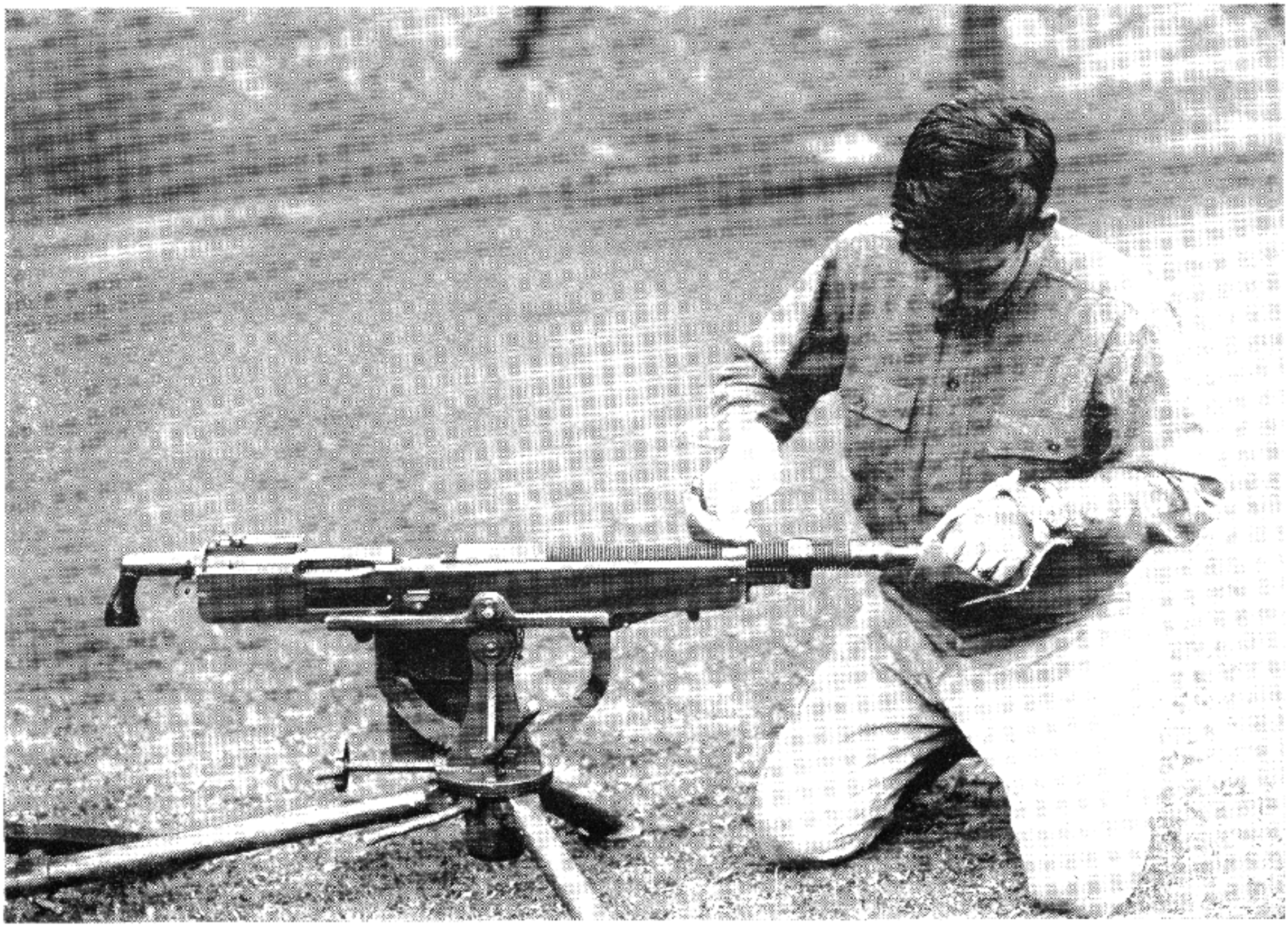
Mexican Mendoza machine gun. This gas operated, air cooled light machine gun weighs about 20 pounds, and has the barrel arranged so that it may be changed almost instantly when hot.



Japanese Model 99 (1939) light machine gun. This was the latest Japanese light machine gun to be used in World War II. It is gas operated, weighs about 20 pounds, and is simple and effective in design.



French 7.5 mm Chatellerault light machine gun Model 1924-29.



The author, protected by asbestos gloves, is removing the barrel from a Colt machine gun during World War I. These air-cooled guns heated up rapidly when fired, and a hot barrel could be replaced with a cool one as shown.

red hot, but several hundred shots will make the barrel of an air-cooled gun too hot for safety in case of a jam. In working with air-cooled guns some very exciting experiences will be had when a jam occurs with a very hot barrel and a cartridge stuck in the chamber, and with the breech partly open.

Once on the Mexican border I saw a student get a cartridge jammed in a hot gun with the breech partly open. He was looking right in it and I had visions of having the cartridge explode in his face, so I snatched him away from the gun and grabbed up a cleaning rod so as to knock the hot cartridge out before it had time to go off. The effort was just a little too late, however, for as I shoved the rod down the muzzle, the cartridge went off. This apparently happened just about the time the rod touched the bullet, for the bullet did not go out of the barrel. The cartridge case was blown to bits but no damage was done, as the breech, being open at the back, allowed the explosion to dissipate itself to a large extent. I knocked out the bullet and found that it was somewhat flattened where the point had rested against the cleaning rod. I still have this bullet and the remains of this cartridge case among my rather large collection of cartridge curios.

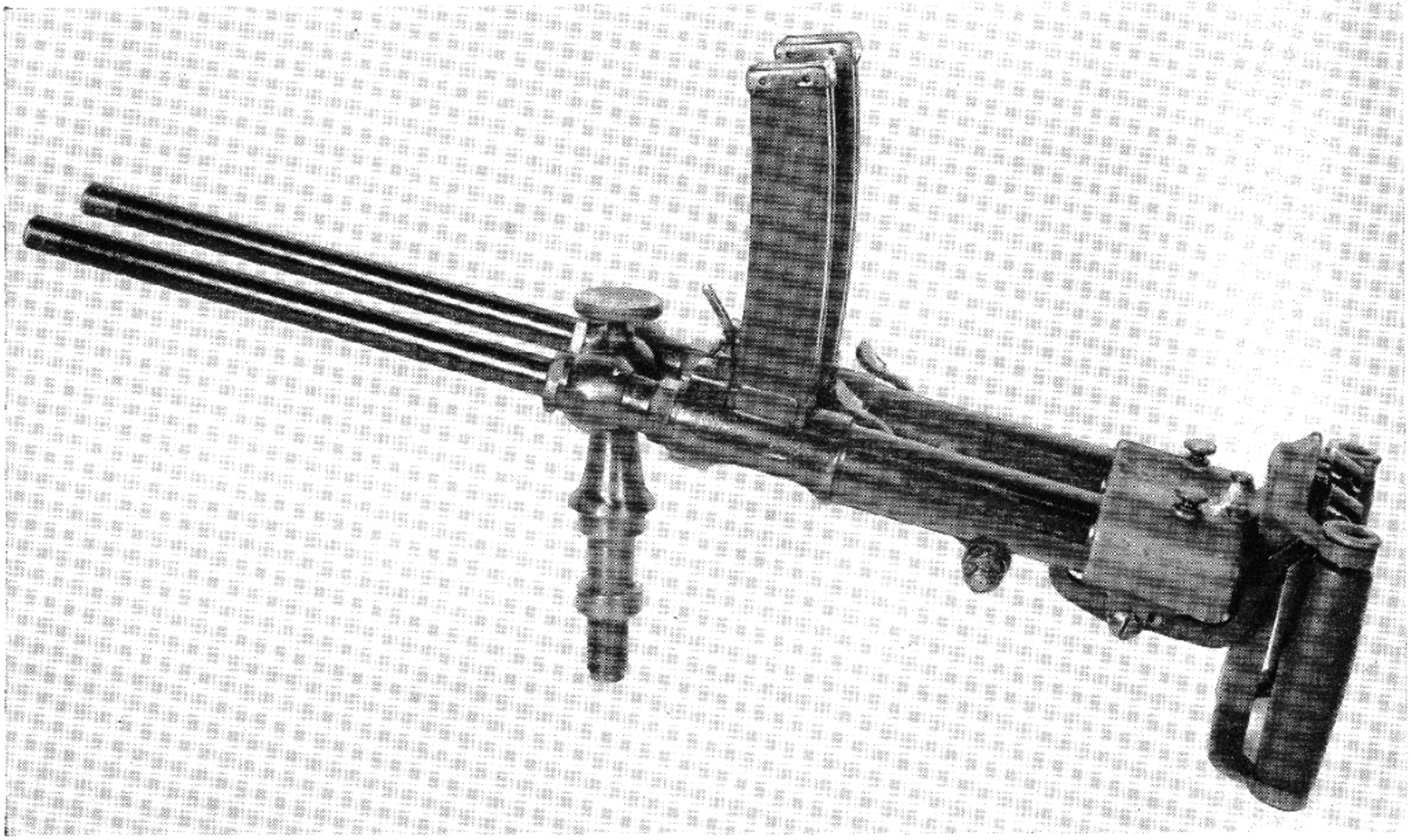
At the test of the Berthier machine rifle at Springfield Armory in 1917, a jam occurred, and when the handle of the gun was drawn back the hot cartridge was ejected but exploded in the air just in front of the group of men who were holding the gun. The bullet stuck in the cuff of one of the spectators.

Another time at Springfield Armory a cartridge exploded while I was extracting it from a hot Browning automatic rifle, but fortunately it was all the way out of the breech; and when a modern military rifle cartridge explodes in the open air it does not have much force, so no damage was done. Usually the explosion is just sufficient to tear open the cartridge case and send the bullet with very low velocity. Of course there is danger of getting pieces of brass blown into hands or eyes.

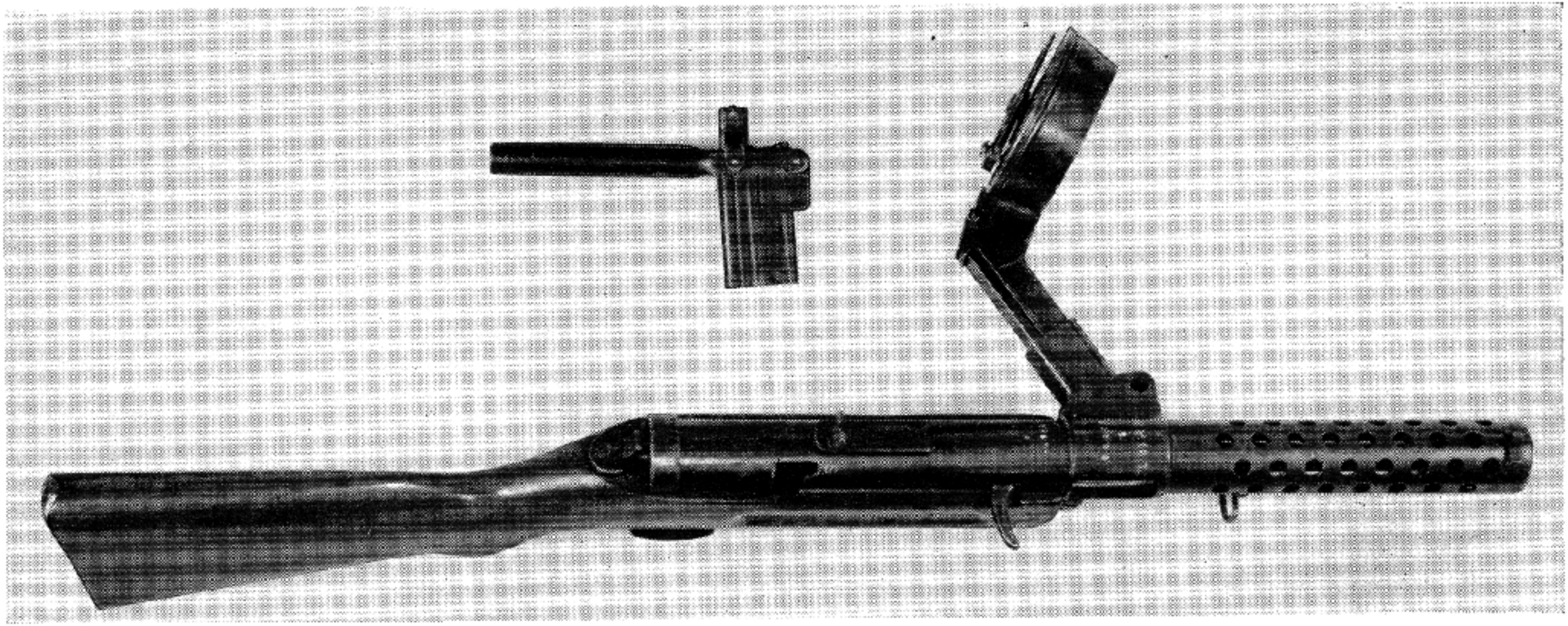
The greatest danger in a case like this is in having an explosion when the breech is jammed in a position very nearly closed. In this case the pressure is high and the explosion is violent, and some parts of the breech mechanism are likely to be blown out with sufficient force to do great damage. In this way, an extractor blew out of a Marlin gun and struck a soldier in the abdomen inflicting a wound from which he afterward died.

Submachine Guns or Machine Pistols

During World War I, the Germans introduced into actual and rather extensive use a type of machine gun which up to that time had been very little known, but which was very widely used in World War II. This is the machine pistol, or submachine gun, firing pistol ammunition, or in some cases, ammunition intermediate in



The first Submachine gun; the Italian Villar Perosa, shooting the 9 mm Parabellum (Luger) pistol cartridge. I tested this gun in 1917.



The German Bergmann Submachine gun of World War I, called the M.P. (Maschinen Pistole) 18. It has a straight blow-back action and shoots the 9 mm Luger pistol cartridge from a snail shaped magazine. The World War II submachine guns are no advance over this except in cheapness of manufacture due to their flimsy construction of tubing and stampings.

power between pistol and rifle ammunition. It was in 1917 that my first acquaintenance with submachine guns occurred in testing the Italian Villar Perosa gun, (sometimes called the Revelli). This was a two-barrelled weapon, shooting the 9 mm Luger pistol cartridge, and intended at that time to be used in arming airplanes. There were fifty cartridges in each of the two magazines, and on pressing the trigger, they were all fired in a little over a second, making the speed of the firing so rapid that the sound of the individual shots could not be distinguished at all. The sound of firing this gun was much like that of tearing a strip of canvas.

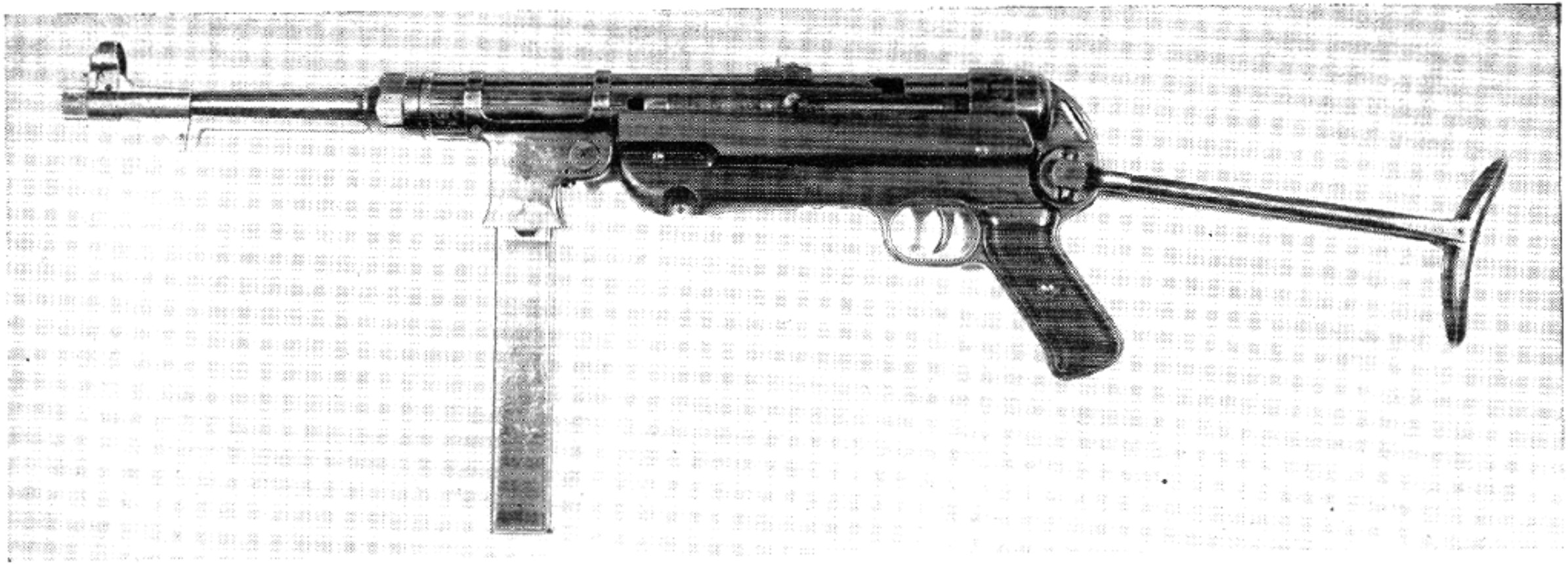
During the latter part of the first World War, the Germans used a number of submachine guns of a type called the Bergmann. This was straight blow-back gun used the Luger pistol ammunition from a so-called snail magazine, that is, one in which the cartridges lie in a spiral or snail shaped drum.

After the end of the first World War, General Thompson, a retired Army officer invented a submachine gun shooting the .45 automatic pistol cartridge. This weapon, known as the "Tommy Gun" became a favorite weapon of the gangsters during the prohibition era in the United States, and in this way received much publicity. It was adopted by the Army, and was a standard weapon during World War II.

Every nation that fought in World War II had some kind of submachine gun, and some had several varieties. Owing to the low power of the cartridge involved, these required no locking device, and they were therefore constructed on the straight blow-back principle. None of them showed any particular advance over the original German Bergmann of World War I, except in simpler magazine arrangements and cheapening of manufacture by the use of simple turned or stamped out parts. Examples are the British Sten, the Australian Austen and Owen, the German Schmeisser, etc.

Col. René R. Studler of our Army contributed to this field the U. S. Submachine gun Cal. .45 M3, which was a real advance in this category of weapons. It is characterized by the utmost simplicity and cheapness of manufacture. It is made so that by the substitution of a barrel and magazine together with some other parts, it can be almost instantaneously converted to shoot the 9 mm Luger or Parabellum ammunition almost universally used as the pistol cartridge by European nations.

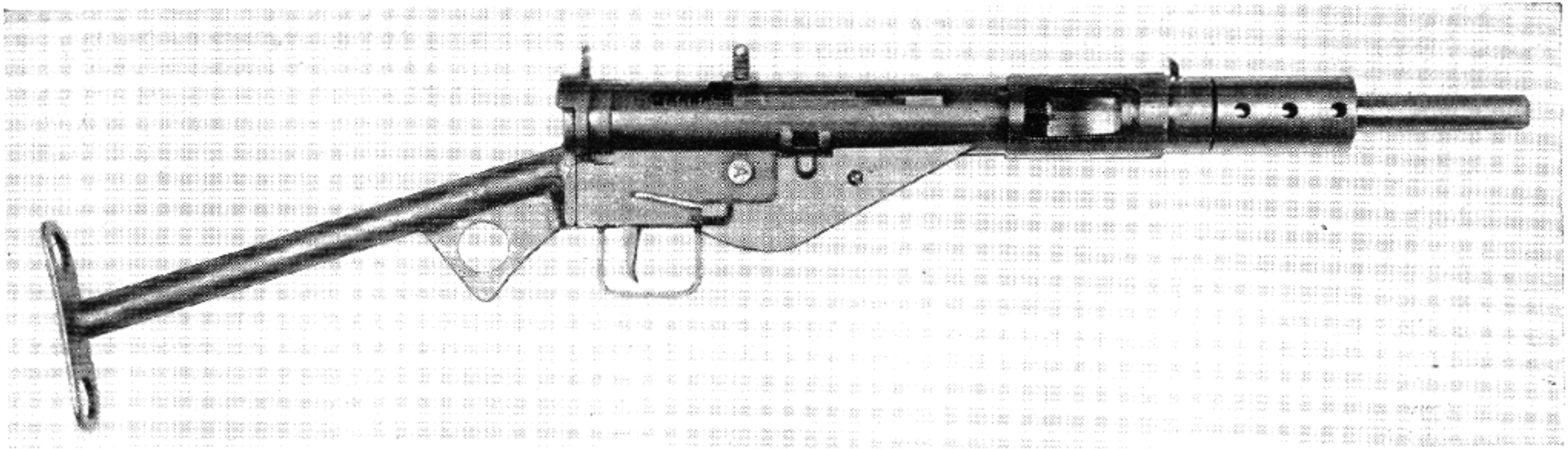
In 1943, the Germans introduced a so-called machine pistol which was entirely out of the class of the guns mentioned above. It was in reality a full-automatic carbine, made to shoot a special shortened version of the standard German 7.9 rifle cartridge. There were several models of this gun, differing only in details, called the MP 43, the MP 43/1 and the MP 44.



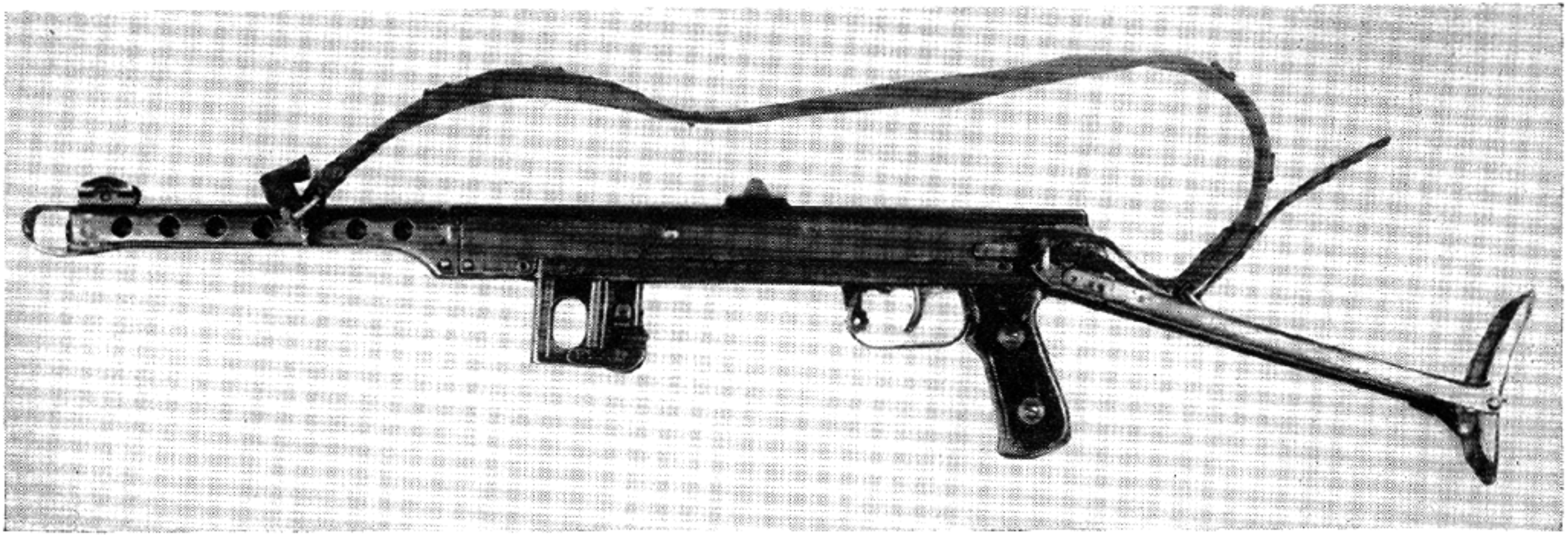
The German Schmeisser 9 mm submachine gun MP 40 using the Parabellum cartridge.



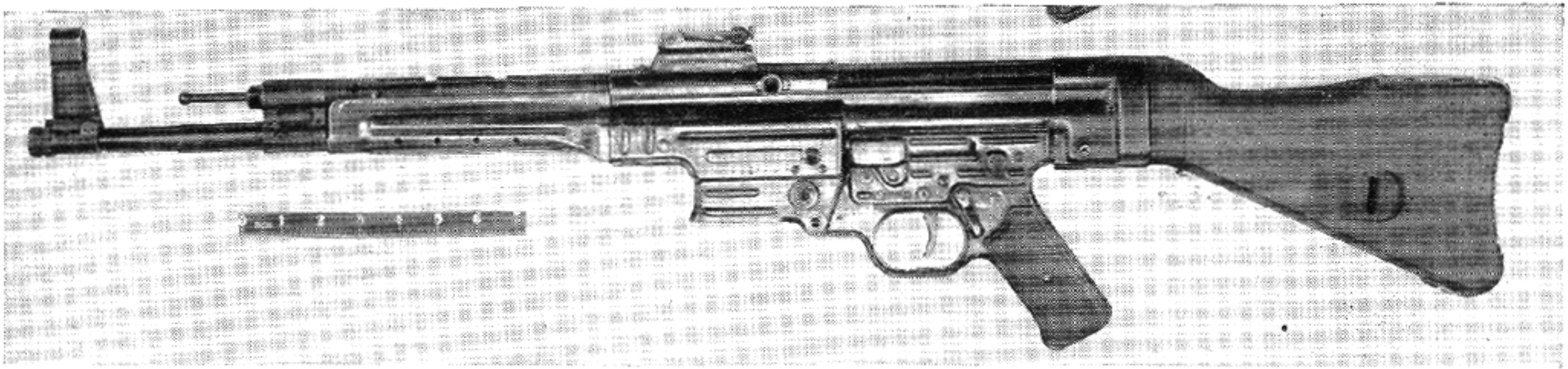
Australian Owen Submachine gun. Notable only for one thing: utter cheapness of construction.



British Sten Submachine gun Mark II. Essentially this is the B ergmann of World War I cheapened as much as possible. Like the Bergmann, it uses the 9 mm Luger cartridge. On account of its utterly crude construction and its clumsiness it was usually called by our soldiers the "Stench" gun.



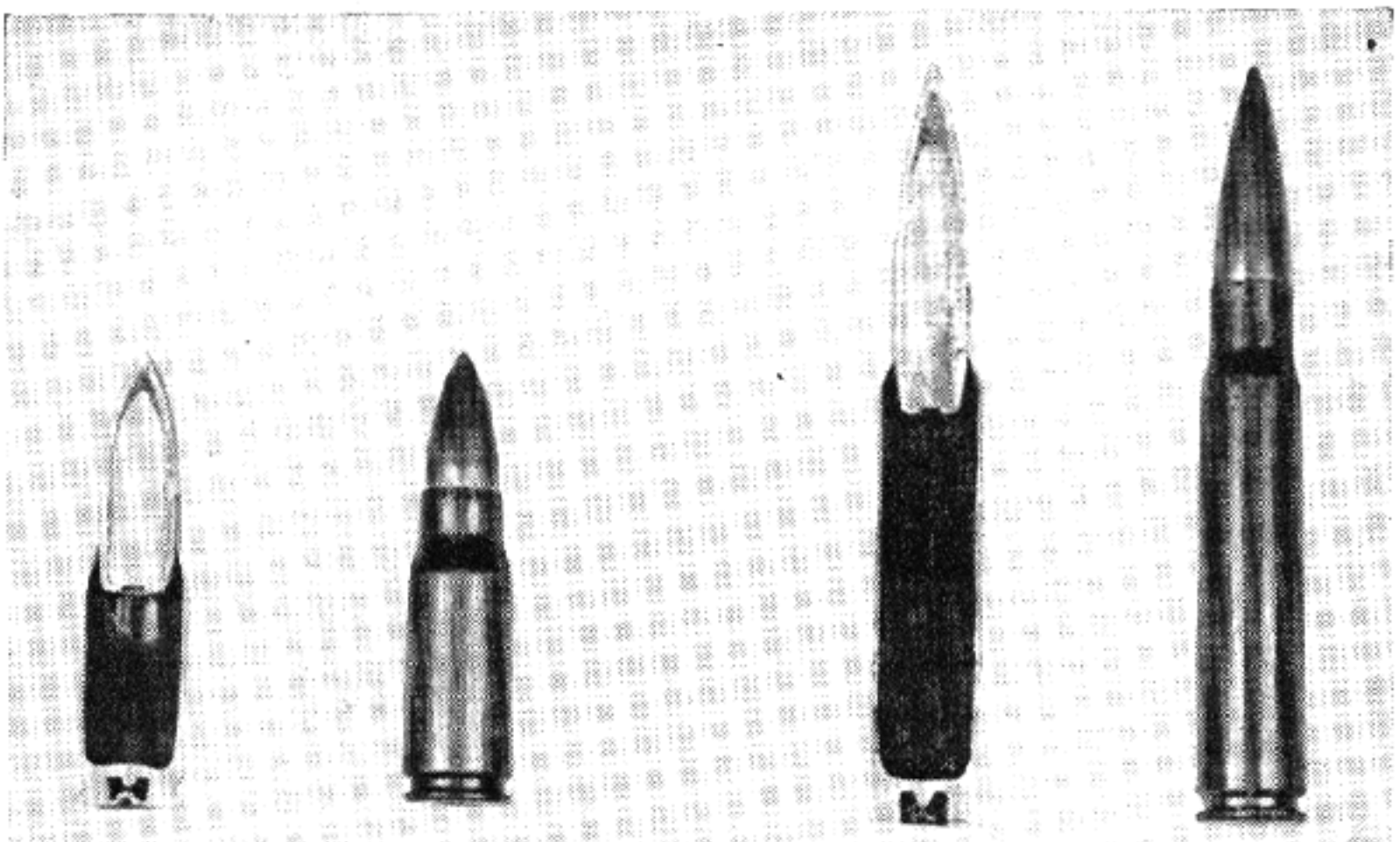
The Russian Sudiaev 7.62 mm machine pistol or submachine gun called PTS 1943.



German MP 44. This is a full automatic carbine shooting a shortened version of the 7.9 rifle cartridge. There were three variations of this weapon which differed only in unimportant details, called the MP 43, the MP 43/1, and the MP 44.

Machine Guns in World War II

During World War II, the standard American ground type heavy machine gun was the Browning in essentially the same form as that used in the first World War, and mounted on the same tripod. It is the Browning heavy belt fed water cooled machine gun, called the M 1917 A1, and the tripod is likewise the M 1917 A1. The only im-



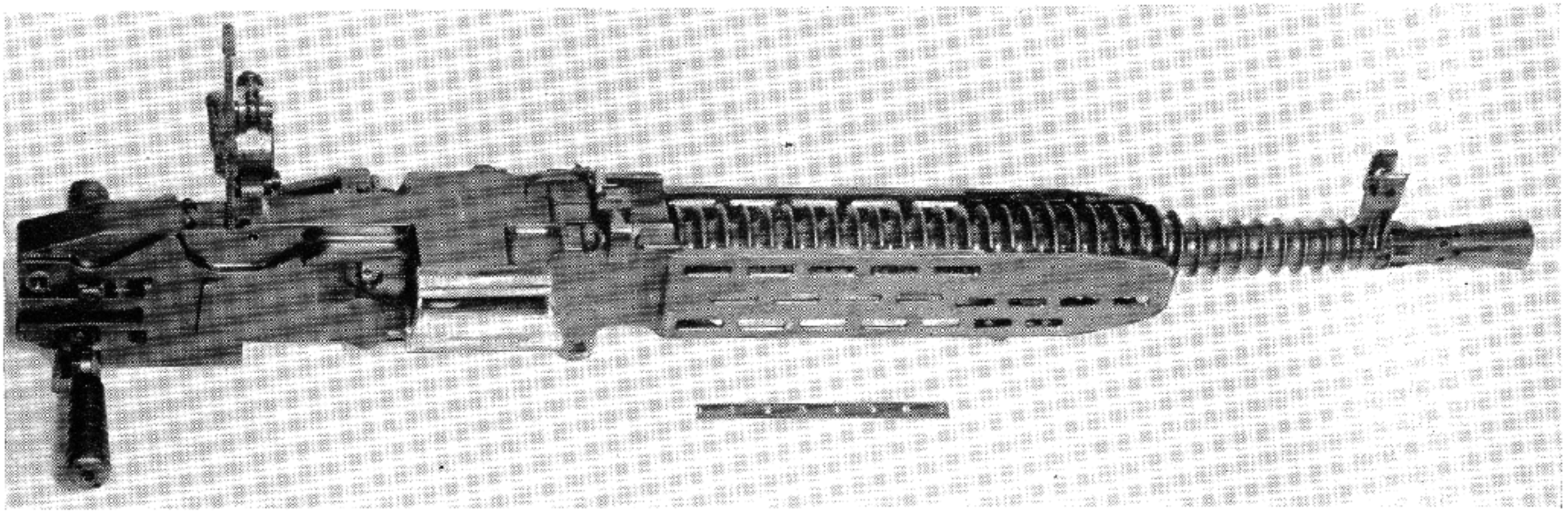
Ammunition for the MP 43 and MP 44 (left) compared with the regular German rifle cartridge (right).

portant change in the gun from the original design is the strengthening of the water jacket end cap, and an improvement of the fastening of the water jacket to the trunnion block. The receiver is also reinforced. The general appearance and functioning of the gun remain identical.

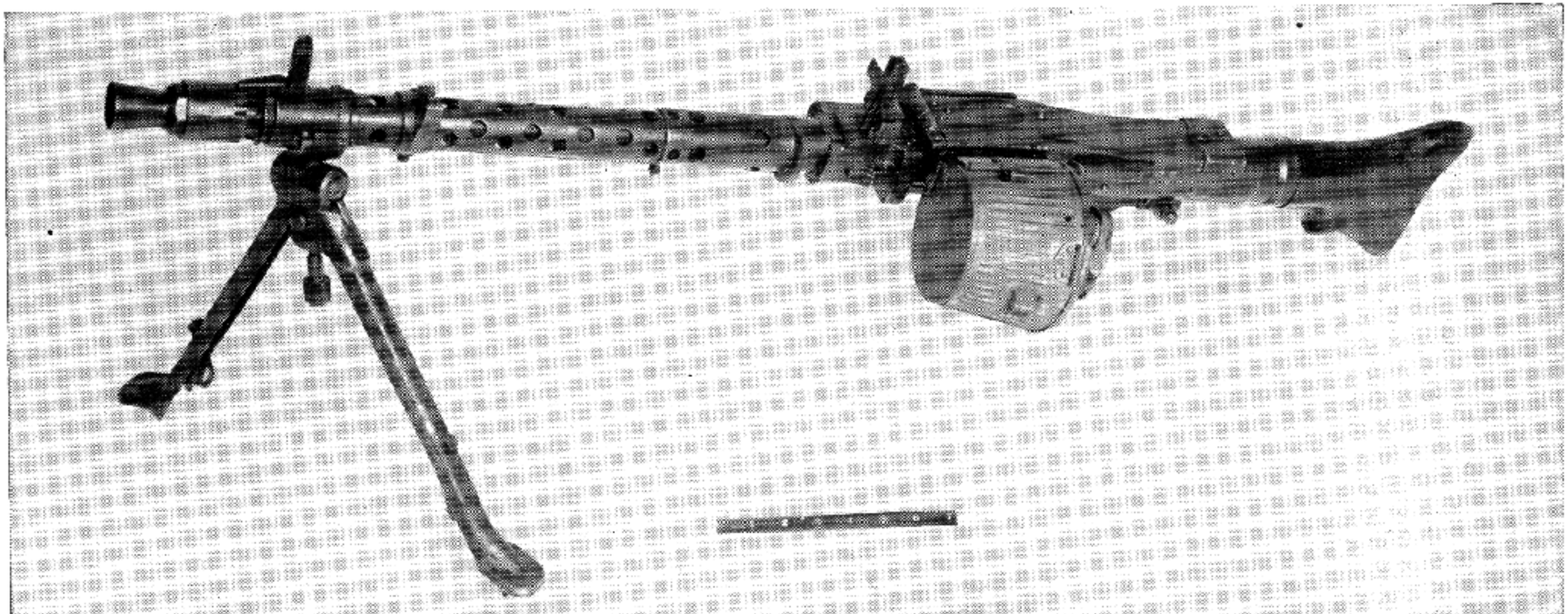
The light machine gun, called the Browning Machine Gun M 1919 A4, on ground tripod M 2, is a modification of the Browning Tank Machine Gun used in World War I. This gun has the usual Browning mechanism, but instead of a water jacket, it has a perforated barrel jacket or support, and a rather heavy barrel. It is air cooled.

During the recent war, a whole series of .50 caliber Browning machine guns was employed. They were used in both the water jacketed and the air cooled varieties, for both aircraft and antiaircraft, in combat vehicles and tanks, and for other uses. The varieties most used were: The Browning Machine Gun, Caliber .50, M 2, aircraft, basic; an air cooled, recoil operated, alternate feed gun, suited for any type of installation in aircraft.

The Browning Machine Gun, Caliber .50, water cooled, flexible,



The Besa machine gun. This was a heavy air cooled gas operated gun used by the British and the Germans in armored vehicles. The one shown in this cut is the Czech version called ZB 53.



German Dreyse-Solothurn machine gun, called MG 34/41. It is air-cooled, recoil operated, and belt fed.

type; a recoil operated, water cooled, alternate feed gun. There is a water chest with a pump for supplying a circulation of water through the jacket. This permits firing long bursts without cooling. This gun was used extensively for anti-aircraft work.

The Browning Machine Gun, Cal. .50M2, HB, fixed type; an air cooled, recoil operated, alternate feed gun, adapted to fixed mounting in tanks or combat vehicles.

The Browning Machine Gun, Cal. .50, M 2, heavy barrel, flexible; the same as the fixed gun except that it has a spade-grip back plate assembly, and is fitted for flexible mounting in tanks, combat vehicles, or on the Machine Gun Tripod Mount, Cal. .50, M 3.

Most of the Allies of course used .50 caliber Brownings furnished by the United States. Great Britain used the Bren as the principal light machine gun, with the Vickers still taking the heavy machine gun role. For use in combat vehicles, they used the Besa, in 7.92 caliber, an almost exact copy of this gun as originally made in Czechoslovakia.

The Germans also used the Besa, though in slightly different form from that used by the British. As ground machine guns they used light recoil operated guns, very similar in general characteristics to the '08/18 Vickers of World War I, but with smaller and lighter breech mechanisms. These guns were air cooled and belt fed, and were developed from the Dreyse MG 13 of World War I. The earlier model was the MG 34. A later development and refinement of this model was the MG 42.

An amazing light full automatic and semi-automatic rifle using the full powered 7.9 German service ammunition is the Fallschirmjaeger Gewehr or FG 42/44, intended, as the name indicates, for use by parachute troops. With its folding bipod it weighs only 11 pounds. This gun is a clear indication of the future trend in light machine guns, and will well repay study by designers of automatic weapons.

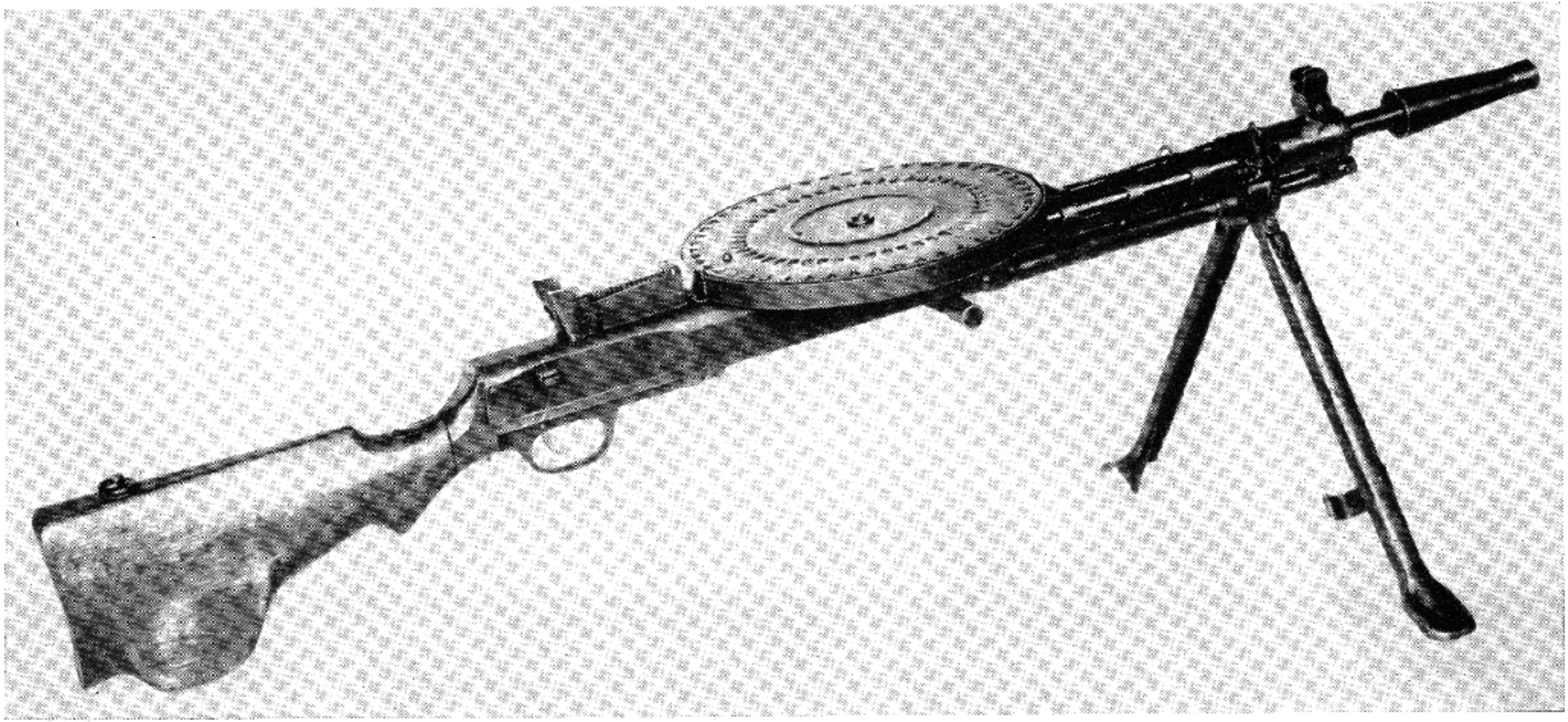
The Russians used, besides their old Maxim Model of 1910, a new heavy air cooled belt fed machine gun called the Degtyarev, Model 1939. With its heavy flanged air cooled barrel, this gives much the appearance of a Hotchkiss. Another gun of the same general type and appearance is the Guryonov, Model of 1943.

In the field of light machine guns, the Russians had a 20 pound gas operated air cooled gun, fed from a flat pan magazine holding 47 shots, called the Degtyarev Model DT, which has been in service since 1926.

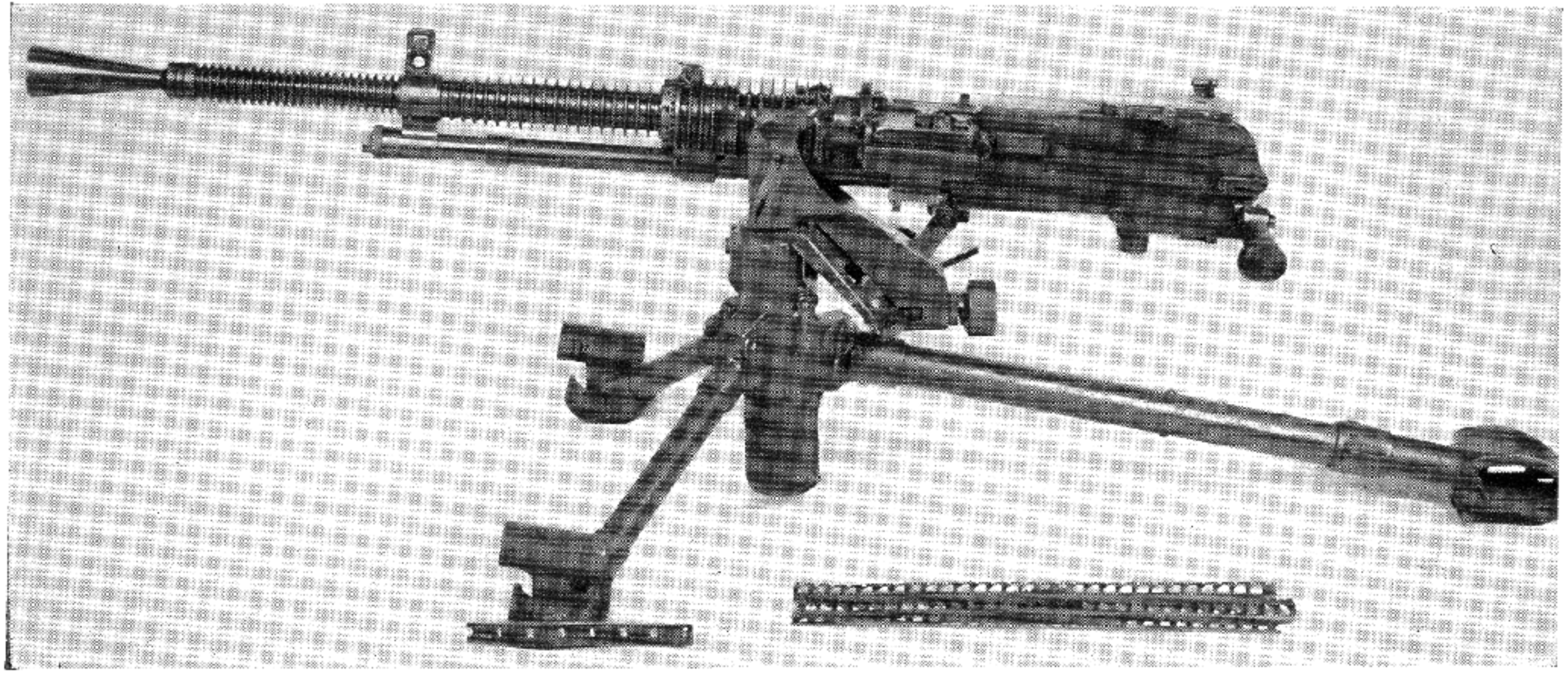
The Japanese used weapons of the Hotchkiss type as their principal heavy machine guns. They were called the Model 92 (1932) 6.5 mm machine gun, and the Model 01 (1941) 7.7 mm machine gun. Following the usual Hotchkiss principles, they were gas operated, air cooled and strip fed. They used the same 30 shot feed strips that we used in our old Benet-Mercié, that was standard in our Army



German Fallschirm Jaeger Gewehr 42, or F.G. 42, automatic rifle. Intended, as indicated by the name, for use by parachute troops. An extremely light weight gun of advanced design, weighing, complete with bipod, only a little over 11 pounds.



Russian Degtyarev light machine gun, Model DT. It is gas operated, air cooled and weighs about 20 pounds.
In this Photo the Flash Hider is reversed.



Japanese heavy machine gun, Hotchkiss type, Year 01 Model (1941).



Japanese Nambu machine gun, Model 11 (1922). Except for the hopper feed, it follows the Hotchkiss principle of design.



Japanese copy of Browning aircraft machine gun.

from 1909 to 1916. When I saw hundreds of these familiar looking feed strips strewn along the beach at Saipan in 1944, it reminded me of my Mexican Border Days of 1916 as machine gun instructor.

A lighter gun of the general type of a Hotchkiss was the Japanese Nambu Model 11 (1922) 6.5 mm Light Machine Gun. It looks a lot like the old Benet-Mercié, but uses a hopper for the cartridges instead of feed strips. It is air cooled, gas operated, and weighs about 22 pounds. It was largely superseded by the later light machine guns.

The model 96 (1939) 6.5 mm light machine gun is a lot like the Bren in appearance, but different in mechanism. It is gas operated, air cooled, and weighs 20 pounds. It is a very effective weapon.

The Model 99 (1939) 7.7 mm Light Machine Gun is a weapon similar to that just described, except that it is made for the newer 7.7 mm (or .303 inch) cartridge. It also is a highly effective weapon. The Japanese also made and used excellent copies of the Browning and Lewis machine guns.

Johnson Light Machine Gun

A gun that showed great promise, but never attained any wide use in the War is the recoil operated light machine gun designed by Captain Melvin M. Johnson, of the United States Marine Corps Reserve.

This gun, which has some quite novel and desirable features, had the bad luck to make its appearance just at a time which made it most difficult for it to attain the recognition that it otherwise probably would have received. It was adopted by the Dutch in 1941, but before it had gotten well into production, the Dutch Colonial possessions passed to the Japanese, and this market for the new gun passed out of existence.

It is a short-recoil operated air cooled light machine gun weighing, without magazine, only 12.3 pounds. The barrel can be removed and replaced in 8 seconds while the gun is hot.

It is fed from removable box magazines weighing 14 ounces and holding 20 rounds. The feeding lips which guide the cartridges into the chamber are machined out of the solid metal of the receiver, instead of being shaped out of the thin metal of the magazine, which is easily deformed. This feature removes a common cause of malfunctions. The gun can have additional cartridges clip fed into the magazine from the right side of the gun while the magazine is in place. Thus a partly empty magazine can be replenished, or a different type of cartridge, tracer, for example, can be brought into use in an instant.

A clever arrangement of the breech mechanism makes the gun fire from an open breech when executing full automatic fire, thus removing the danger of having a cartridge "cook off" if fire is interrupted while the gun is hot; but when the gun is used as a semi-automatic,



The Johnson Light Machine Gun, Model 1941.



Johnson Light Machine Gun, Model 1944 E 1.

the breech closes and locks on the cartridge, after which a pull on the trigger fires the gun, thus making easier the attainment of accuracy.

The gun that was adopted by the Dutch was called the Model of 1941, and guns of this model were used by parachute troops and raiding parties in our own Army and Marine Corps, uses to which its unusually light weight made it particularly adaptable.

About the time World War II ended, an improved experimental model called Model 1944 embodied some new features shown to be desirable by combat experience. This was further developed into the Model 1945, which with attached monopod rest weighs only 15.5 pounds. This gun has a gas assist to boost the recoil of the barrel and increase the cyclic rate. Barrels on this model can be changed in six seconds, and this should be done every 1000 to 1200 rounds when firing at the rate of 50 shots per minute.

Commencing with the gun empty, one man can load and fire 180 shots in 1 minute full automatic, and 60 aimed shots in 1 minute semi-automatic.

A two man team of loader and gunner can load and fire 100 shots in 18 seconds or 200 in 37 seconds, thus maintaining a rate of over 300 shots per minute. A three man crew, with spare magazine and spare barrel can deliver 1000 shots in six minutes, though they will have changed barrels 9 times during that period. Of course, unless it is necessary to fire at the maximum rate, the number of barrel changes would be much less.

It will be seen that this gun has some very advanced features, and it is a highly effective weapon of its type.

VI

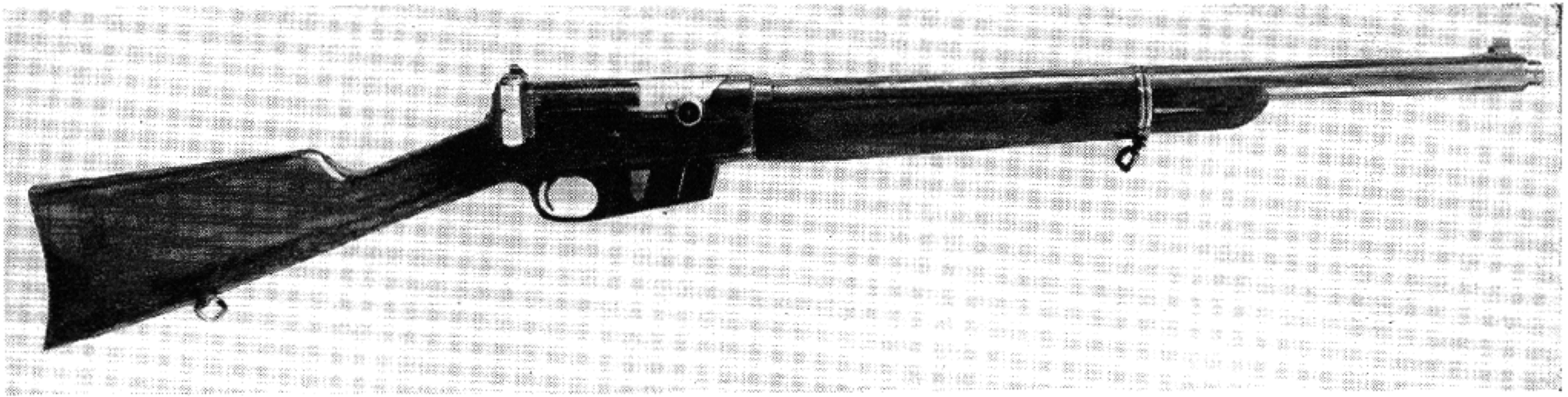
The Military Semiautomatic Rifle

WHAT is the reason for a semiautomatic rifle, was not the Springfield good enough? A very little reflection will answer this question. Consider a soldier engaged in a skirmish. He is lying prone on the ground with his rifle, trying to make himself as inconspicuous as possible. Somewhere in the distance one of the enemy soldiers shoots at him. The chances are he does not know where the bullets are coming from. In World War I one of the things that surprised our soldiers at first was the fact that many of them went through several entire battles without seeing any of the enemy soldiers. Suppose our soldier does locate an enemy's helmet, barely distinguishable against the landscape 200 or 300 yards away. He has detected some movement and he knows that this is all he can see of one of the enemy soldiers, so he decides to use it as a target. He takes careful aim and fires, and a puff of dust a little in front of and a little to the right of the point of aim shows where his bullet struck. Then, in his excitement, he yanks back the bolt, shoves it forward again, turns it down and locks it, and what happens? The chances are that the resulting movement of his rifle has disturbed his line of sight for the moment, and when he looks back he can no longer locate the object. Then, again, he has made quite a movement himself and the alert eyes of the enemy may have detected this, and he may, in turn, be serving as a target.

Consider, however, that this soldier has a semiautomatic rifle. He takes careful aim, presses the trigger, and observes a puff of dust a little in front of and a little to the right of where he was aiming. Immediately, without taking his eyes from the sights, he shifts his point of aim a little to the left and a little higher, presses his finger to the trigger, and this time his bullet will probably find its mark.

Many years ago, the Army recognized the desirability of having the service rifle operate on the self-loading principle, and sent out frequent invitations to inventors to submit models for test; but during a period of some thirty years, little success attended these efforts.

For a while, the recoil operation seemed to be a favorite with inventors, but they ran into several difficulties, such as trouble in attaching a bayonet. At this writing, the bayonet may be considered as obsolete, but that was not so a few years back. The fact that the barrel cannot be fixed rigidly to the receiver or stock, but must be free to slide back, posed a problem. Some inventors met it by encasing the barrel in a tube, but while this is all right for a hunting rifle,



The Remington autoloading rifle, model 8 (now model 81) fitted for military use. During the years around 1930, when we were trying to find a suitable semiautomatic rifle for adoption, a number of these Remingtons, in .35 caliber were fitted up like this and issued to the Army for tactical tests to determine the best way to use a semiautomatic rifle in various situations.

which is fired only occasionally, it will not do for a military gun, which must stand continued firing; the heating of the barrel is too severe.

Finally a recoil operated gun was designed by Capt. Melvin M. Johnson, U. S. Marine Corps Reserve, which overcame the previous objections to this method of operation. This came after the Garand had already been adopted by the Army, but the Netherland Indies government ordered a larage number of these guns, and some of them saw service with our forces in the Southwest Pacific. In actual service they were not liked as well by their users, the U. S. Marine Corps, as were the Garands. The Johnson gun was nevertheless, a fine serviceable weapon, probably second only to the Garand among the semiautomatics of World War II.

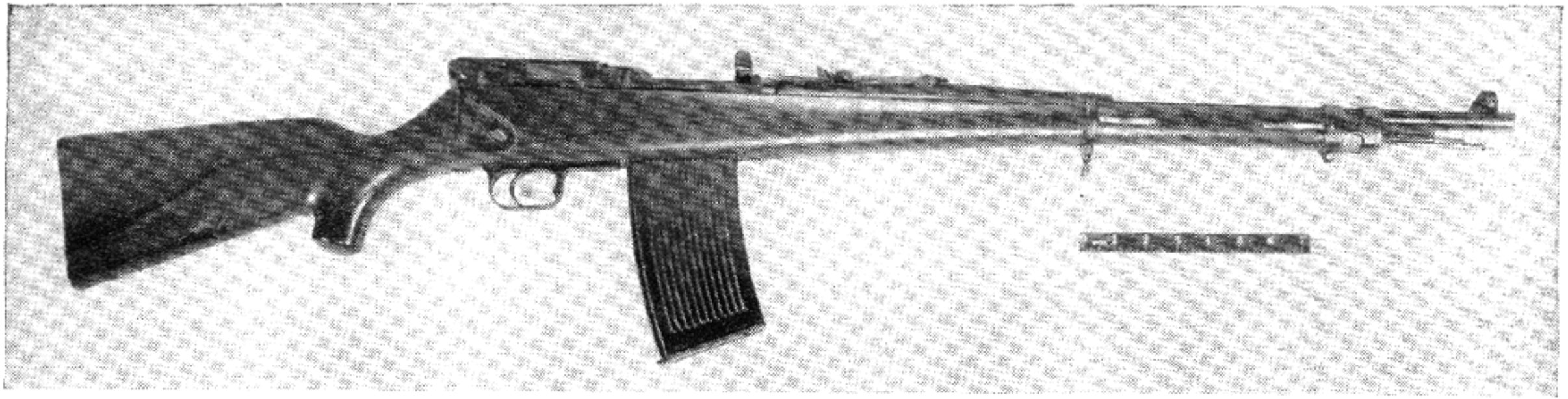
Early Ordnance Designs

In 1916 our Ordnance Department attempted to design a semiautomatic rifle at Springfield Armory, and another at Rock Island Arsenal. Both of these guns were gas operated, and the already difficult problem of gas operation was complicated by the requirement laid down by our thrifty government that the guns must be made so that if possible the regular hand operated Springfields could be converted.

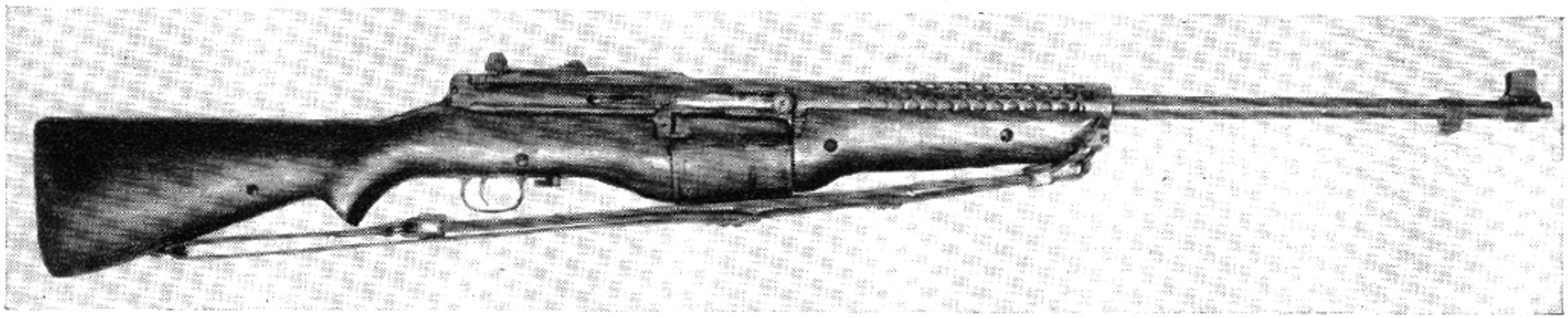
Both of these guns were extremely crude, though the Rock Island model was better than that produced by Springfield. This Rock Island gun had a sort of sliding cage over the breech, with a cam in it to operate the bolt handle, and when I showed this to Mr. Browning in 1917, he remarked with a dry smile, "Where do you put on the cheese?" We saw the point at once, for the resemblance to a rat-trap was rather marked.

Many of the models submitted by inventors were of the gas operated type, and the presence of a gas cylinder under the barrel, or at the side of it, or on top of it, inevitably added quite a bit of weight and bulk.

Then another trouble with these guns was that gas was tapped off the barrel at such tremendous pressure that it was hard to handle it without introducing severe strains on the gun. When the bullet passes the gas port in the barrel, the pressure at that point will be anywhere from 40,000 down to 5,000 or 10,000 pounds per square inch, depending upon where the port is located. The closer to the breech it is, naturally, the higher will be the pressure. Assuming that the port is at the point where the pressure is 25,000 pounds to the square inch, a sudden application of this enormous pressure on the head of the piston slams the breech-block open with extreme violence, and the result is not only undesirably quick opening, tearing the heads off the empty cartridge cases, and such troubles as these, but also excessive breakage of parts.



The Mauser 7.92 semiautomatic (experimental, 1916).



The Johnson Semiautomatic Rifle Model 1941.



Left: Farquhar-Hill rifle, tested at Springfield Armory in 1917.
Middle: Gas operated semiautomatic rifle designed at Springfield Armory, 1916.
Right: Gas operated semiautomatic rifle designed at Rock Island Arsenal, 1916.

The logical thing to do was to move the gas port as far forward as possible, where the pressure would not be so great, and reduce the area of the port so that the gas was throttled down to a lower pressure before striking the piston. By doing these things a number of very successful gas-operated guns have been made; but there is another disadvantage to the gas-operated system, and that is the hole bored in the barrel to form the gas port. It is difficult to clean this



Top: Rychiger recoil operated rifle. This rifle, made in Switzerland, was based on the straight pull Schmidt Rubin action, and was chambered for the Swiss service ammunition.

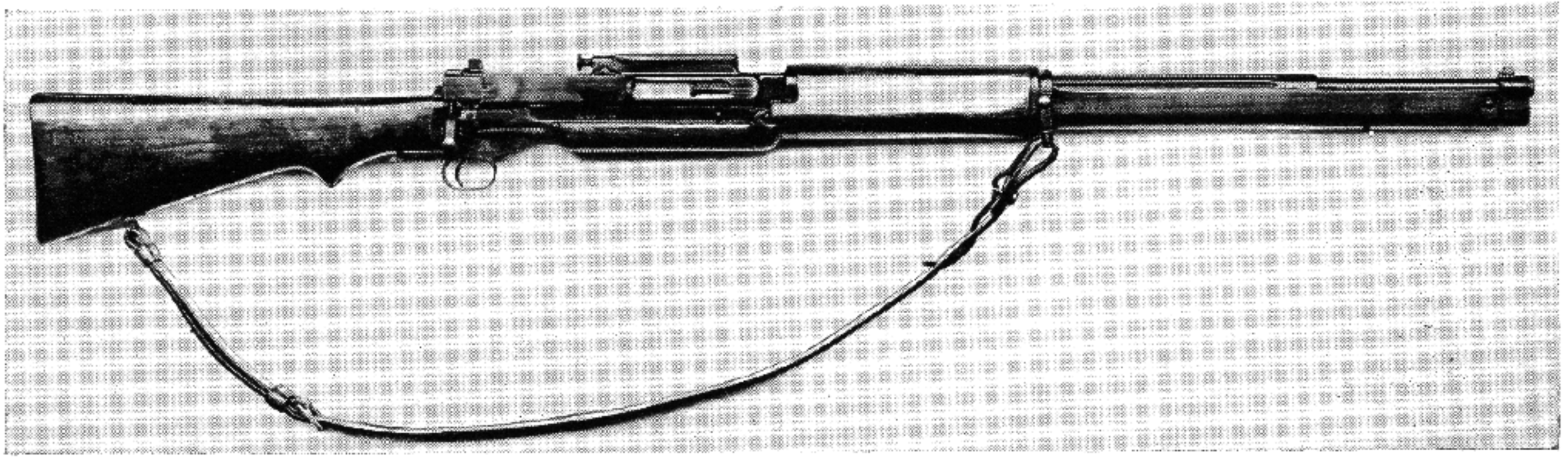
Middle: Rychiger type rifle, made for the U. S. Service ammunition by Major Elder of the Ordnance Department during 1918.

Bottom: Bommarito recoil operated rifle submitted for test during 1918. It has a toggle jointed breech lock, like that on the Luger pistol.

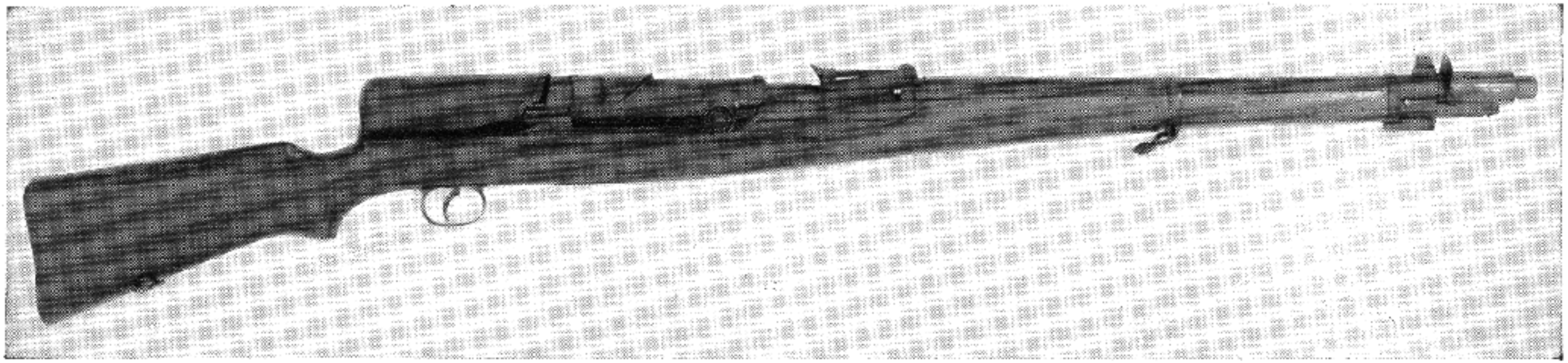
hole, so that it is always a point where rust and corrosion are likely to start.

Gas operation was successfully applied to machine guns long before it was to shoulder rifles. In machine guns, the moving parts can be made heavy enough to absorb the sudden and powerful impact of the gas. Moreover, the pressure of the gas on the piston endures for only a very small time interval, and if the piston can be made rather heavy, it will have a better chance to absorb enough energy during this very brief interval to carry it through its stroke.

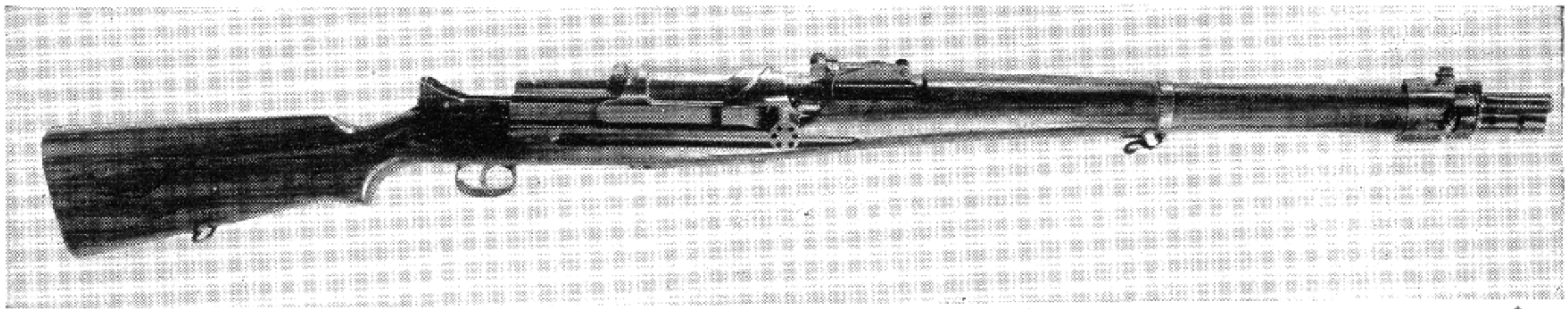
With the shoulder rifle; conditions are very much more difficult.



An early example of the semiautomatic rifle submitted for test by the United States Machine Gun Company. Based on a Berthier design.



The Bang semiautomatic rifle, model of 1911. This gun is operated by the pull of the muzzle blast on a sliding cap over the muzzle. The pull is transmitted to a lever in the breech through a thin rod. This gun passed a most creditable test, but failed of adoption principally because the very thin barrel heated up too much in rapid fire. The gun is shown with a muzzle protector in place over the end of the barrel. It must be removed before firing.



The improved .256 Bang rifle submitted by Mr. Bang to the Ordnance Department in 1927. It did not differ greatly from the original Bang. The action is shown closed.

The piston and other moving parts cannot be made heavy or the gun will weigh too much; and light parts do not have enough inertia to carry through the rearward motion after the gas pressure is gone unless the impact of the gas is made extremely violent. The result has been that in most gas-operated shoulder rifles the light piston gets up energy enough to open the breech against the spring action by being slammed to the rear with very high speed, and this violent action is conducive to very high breakages.

The Bang Rifle

In 1911, Soren Hansen Bang, of the Danish Recoil Rifle Syndicate, Copenhagen, submitted a rifle which passed a remarkably satisfactory test. Its performance was better than that of any other semi-automatic rifle submitted up to that time or for many years to come. It is described on page 62.

The Bang gun was big and bulky, but very light. The lightness was obtained by hollowing out the stock so that in some spots it was little more than a shell, and by turning down the barrel so that it was reduced to the minimum in diameter.

While this gun passed a splendid test as far as the functioning was concerned, the barrel was far too light to stand the heat.

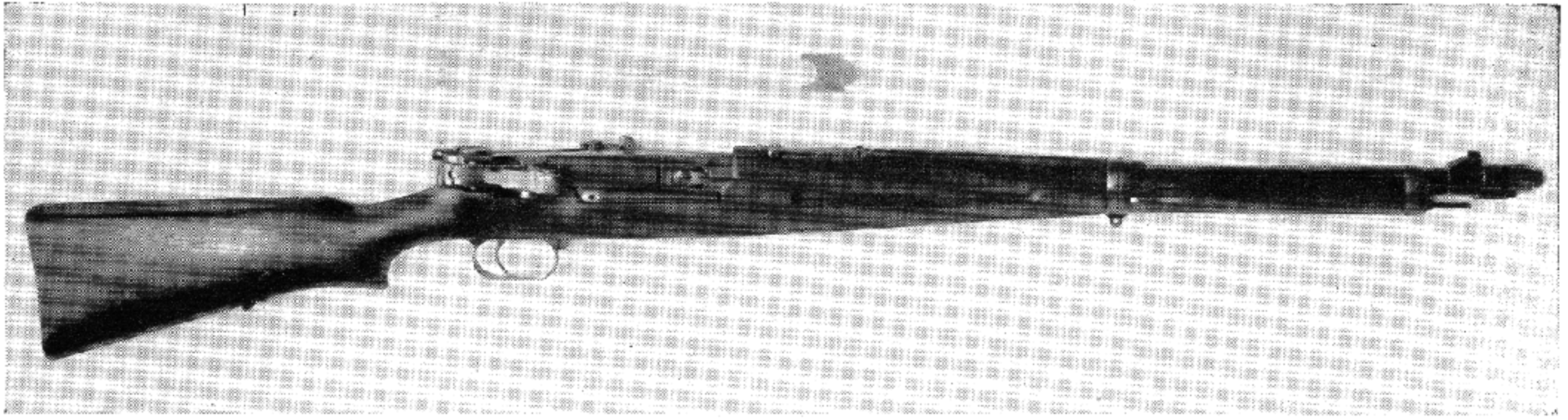
The muzzle cap used by Bang was much like one patented by Sir Hiram Maxim in 1885. Such a principle was experimented with by John Browning in 1889 on a model gun built by him. It was used, but not patented by Bang, probably on account of Maxim's patent. It was used in an auto-loading rifle built by Mr. Garrison of the Remington Arms Co., about the time of World War I, using the breech action of the Remington auto-loading rifle. Grant Hammond also patented some modifications of this principle. The rifle submitted for test at Springfield in 1921 by General Liu of China had the Bang muzzle attachment in almost the identical form in which Bang used it. The Puteaux Machine gun, used by the French for some years used a similar type of gas take-off. The Rheinmetall Semi-automatic rifle, designed by Karl Heinemann, and tested at Aberdeen Proving Ground in 1929 in the Pedersen .276 caliber had a muzzle cap almost exactly like the one used by S. H. Bang.

Hatcher Self Loading Rifle

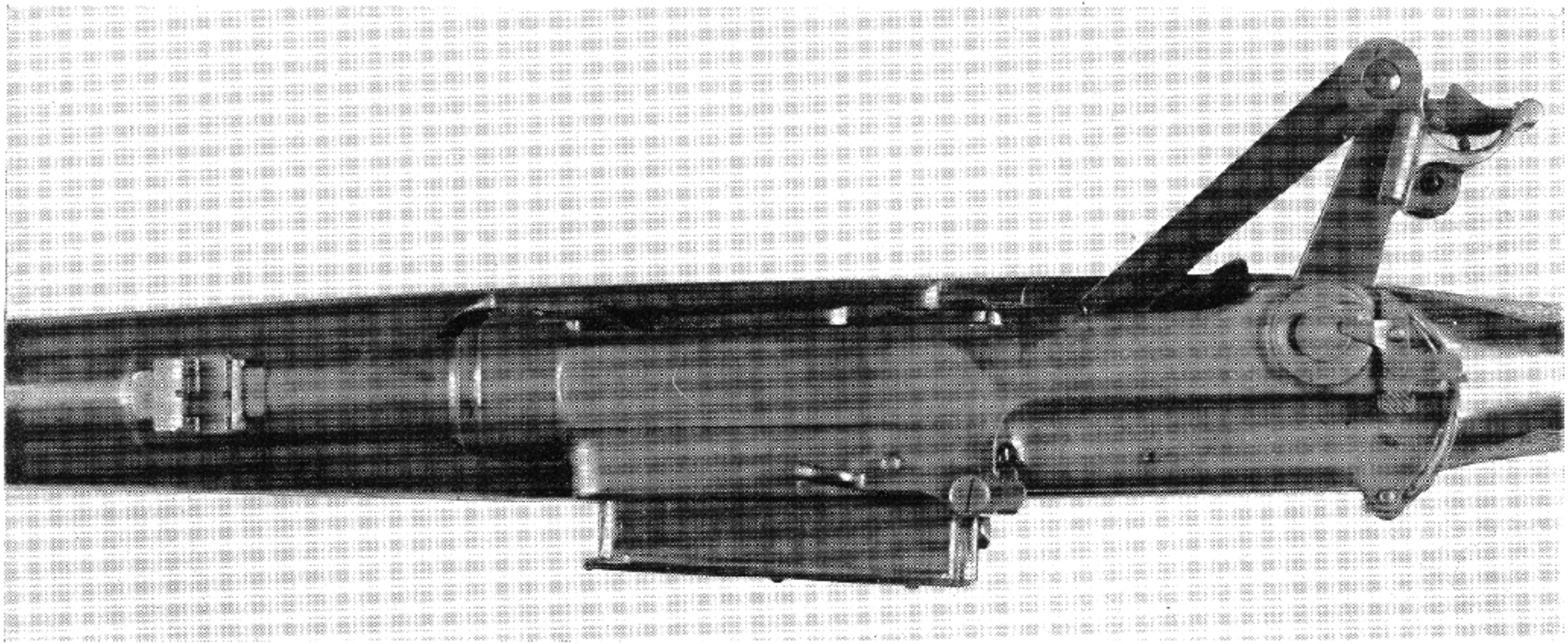
In 1920, Major James L. Hatcher, (now Colonel; brother of the writer) built a semiautomatic rifle at Springfield Armory, which had the same general type of muzzle cap gas take-off that Bang used, but which was a big improvement on the Bang as far as ruggedness was concerned, and eliminated the defects formerly noted in the original Bang. He completed his first model rifle in the phenomenally short time of four months, and while this rifle passed an excellent preliminary test, breakages eventually developed, indicating the need



Two models of the Liu semiautomatic rifle tested at Springfield in 1918. This Chinese designed rifle submitted by General Liu follows the Bang principles very closely.



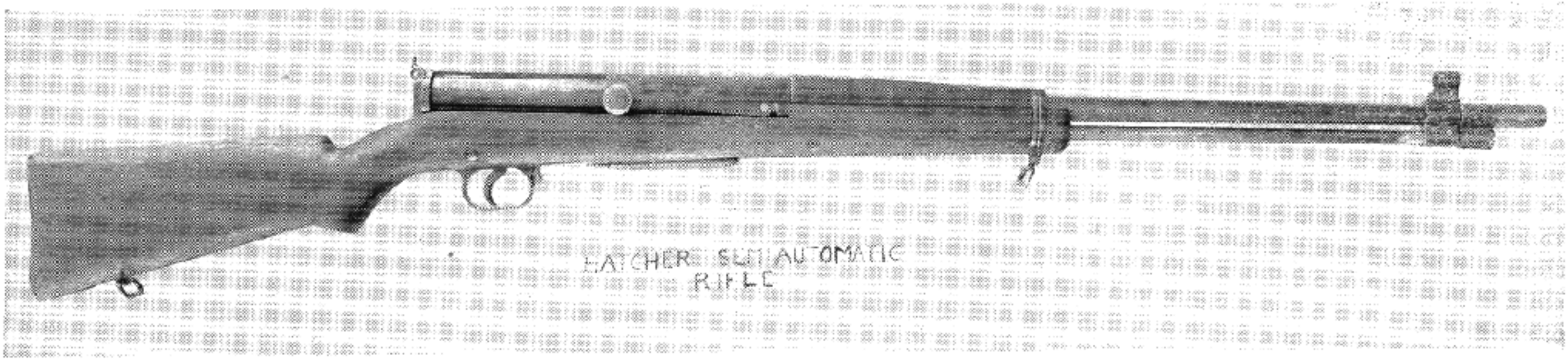
The Heinemann rifle, another modification of the famous and popular Bang, designed by Karl Heinemann and submitted by Rheinische Mettallwaren und Maschinen Fabrik. The muzzle attachment and gas operation are the same as in the Bang, but the breech closure is a toggle jointed breech block opening horizontally on the right side of the receiver. This gun embodies a neat device for overcoming the tendency of the breech block to bounce open slightly after slamming shut. The finger lever for opening the action by hand is pivoted loosely on the side of the breech block. When the breech block slams shut, the finger lever, which has been following along behind, catches up, and just as the block starts to bounce open, strikes a blow which kills the bounce completely.



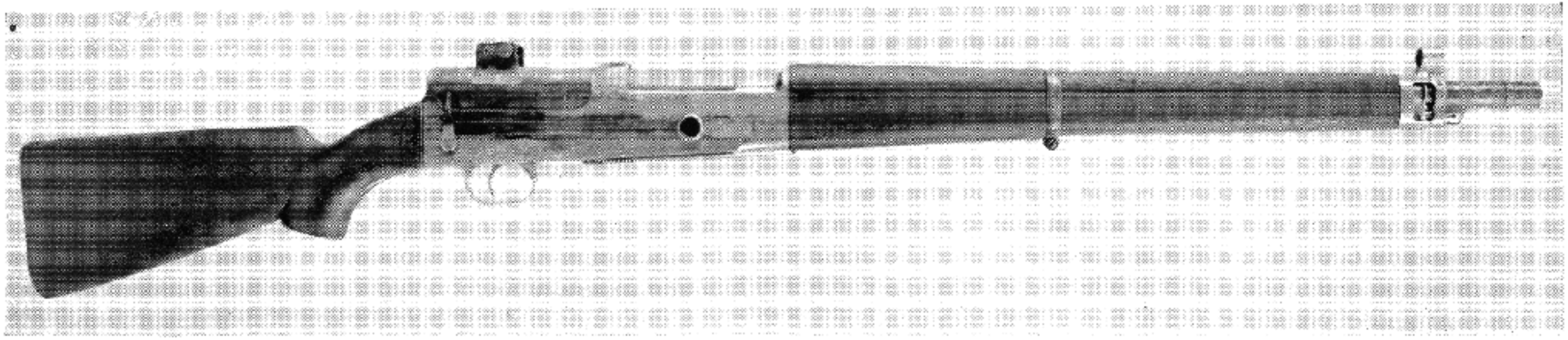
Close up view of the Rheinmetall semiautomatic rifle designed by Karl Heinemann. Toggle-action breech is in the open position. Note the loosely pivoted piece of metal attached to the finger hook to kill the rebound when the breech block slams shut.



Heinemann semiautomatic rifle, made for the 7.92mm German service cartridge, captured in Germany during World War II. This is very similar to the .276 model of this gun that was tested in Aberdeen Proving Ground in 1929.



Semiautomatic rifle built at Springfield Armory in 1920 by Major James L. Hatcher. It employed a sliding muzzle cap actuator, similar to that used by Bang. Though it was produced in the remarkably short time of four months, it was extremely simple, performed well, and gave great promise of success. Unfortunately, as the rifle was undergoing some changes found desirable in a preliminary test, the designer was ordered to other duty, and never had an opportunity to perfect the design.



Second semiautomatic rifle designed by Major (now Colonel) James L. Hatcher, constructed by him while stationed at Aberdeen Proving Ground in 1923, it used a muzzle sleeve actuator, of the Bang type as did his earlier model.

for redesign of some of the parts, as usually happens with an inventor's first model. The board which tested the gun suggested certain changes, but before they could be gotten underway, the designer was ordered to another station, thus effectively putting an end to this effort.

This gun business in those days was something like a horse race. There were a couple of favorites which seemed to be coming into the home stretch, and they had very heavy backing in some quarters, and certain information which came to me in a highly confidential way at that time led me to conclude that the change of station which interrupted this work was not accidental.

Major Hatcher was given permission to work on an improved model at his new station "in addition to his other duties." He did succeed under very great handicaps, in turning out a second model, but as far as I know, never did actually have it tested by the official board.

Thompson Autorifle

Another scheme for a semiautomatic rifle was based on the so-called Blish principle, already mentioned on page 44.

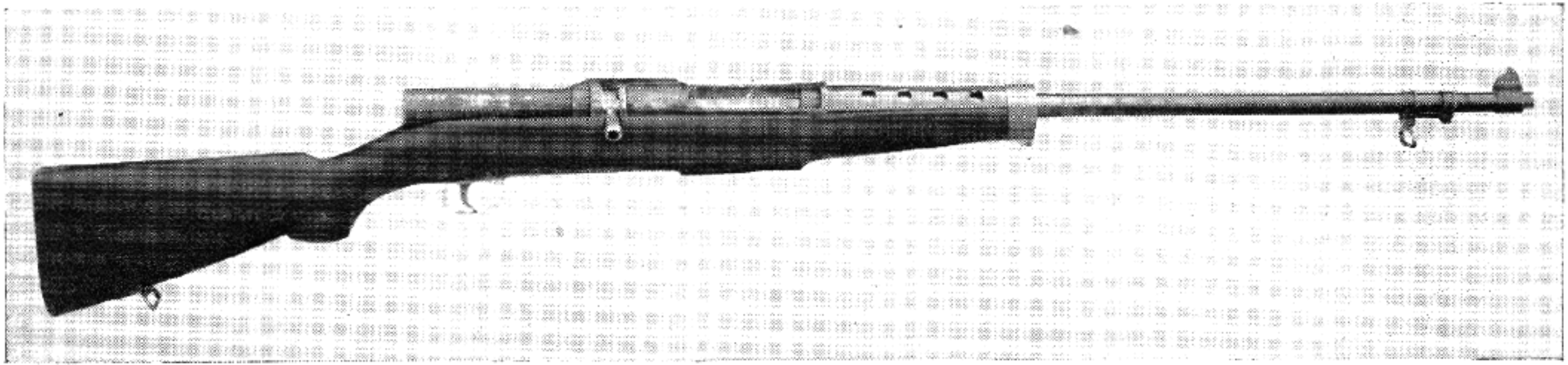
It was on this principle that the Thompson semiautomatic rifle was built by General J. T. Thompson, retired, formerly Chief of the Small Arms Division of the Ordnance Department.

The Thompson autorifle that I tested at Springfield Armory in 1921 worked as long as the oiled pads were used, but it opened with extreme speed and ejected the cartridges with such force that the empty shells in one test were actually stuck into a heavy wooden door about twenty feet to the right of the ejection port.

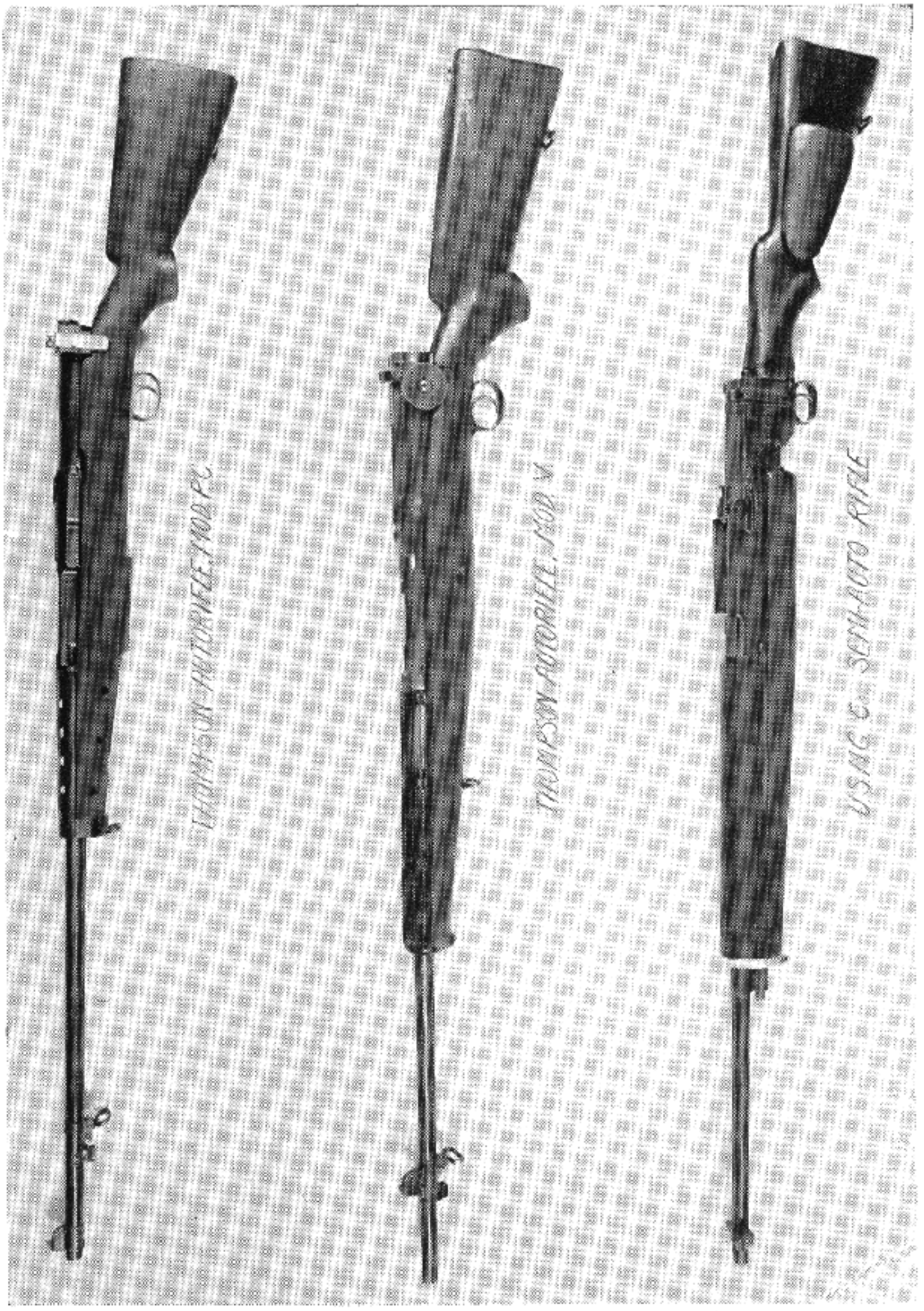
Anyone standing to the right of this gun could have been very severely injured by these flying missiles. Moreover the bolt handle came back with such speed that it would simply have sheared off the thumb if the operator had been so unwary as to put his thumb up alongside the receiver. Obviously the Thompson guns, of which a number of models were tested, never had a chance of adoption.

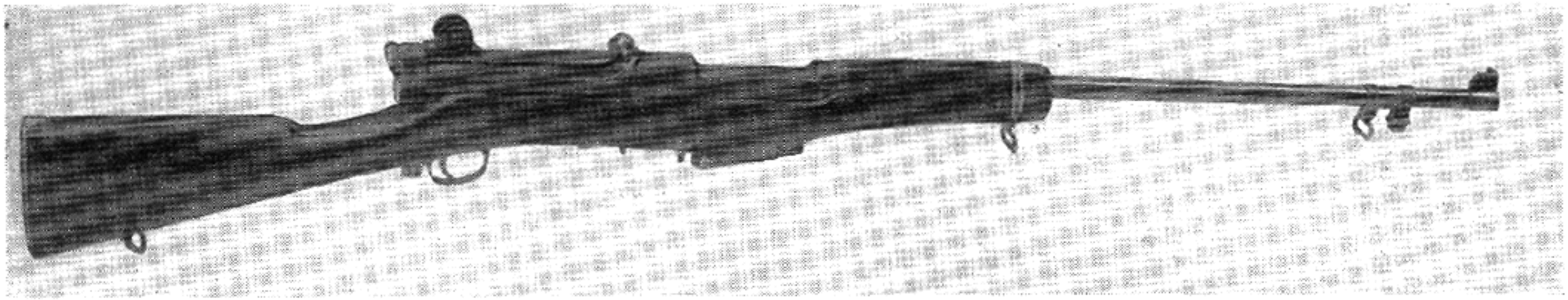
World War I Designs

During World War I, the French quietly placed on the firing line a long, heavy gas-operated rifle, using the 8 mm Lebel cartridge, which then was the standard French Service cartridge. This rifle, called the St. Etienne, was rather simple but effective. It used the cartridges in clips of five, which were placed, clip and all, in a hinged magazine under the receiver. The bolt was a straight-pull affair, and the thrust of the gas piston simply shoved the bolt handle to the rear, causing it first to rotate the bolt to the unlocked position by means of a cam, then to pull it open. The rifle had a rather violent opening action, owing to the uncontrolled thrust of the gas. The gun was used in the war, but not much was heard of it.

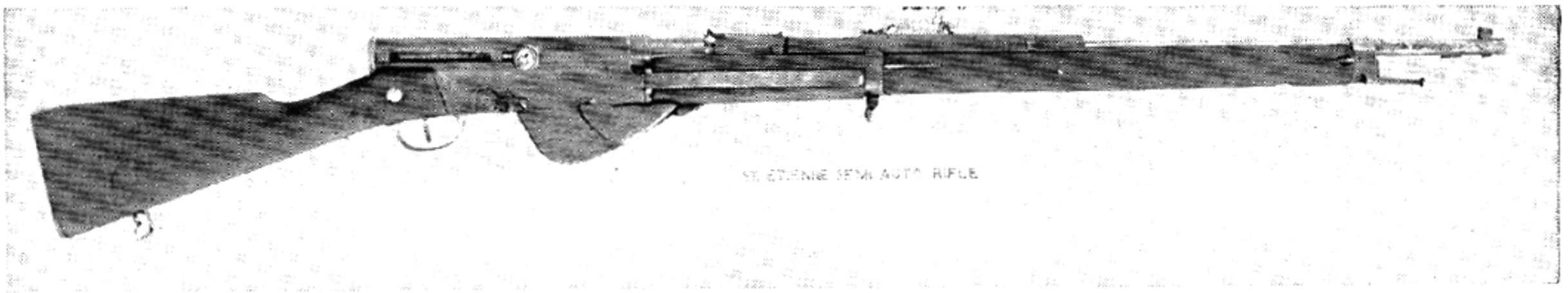


The Thompson Autorifle, Colt model 1921.


THOMPSON SUBMACHINE GUN, M1928A1
THOMPSON SUBMACHINE GUN, M1
U.S. CARBINE, CAL. .30, M1



The Thompson semiautomatic rifle called Autoriffe Style D. The breechblock was held shut by steep screw threads engaging in a bronze nut. The angle of the threads was so steep that the pressure of the discharge caused the bolt to unscrew and fly open, but the unscrewing retarded the opening sufficiently so that the gun would operate satisfactorily provided the cartridges were oiled. The ammunition rubbed against oil saturated felt pads built into the sides of the magazine.



St. Etienne semiautomatic rifle. This simple gas operated arm was used by the French in World War I, and was copied in our .30 caliber by Major Elder in 1918.



Top: Mondragon semiautomatic rifle, a gas operated design patented by Manuel Mondragon of Mexico, August 8, 1904, and adopted by Mexico in 1911. It was made in Switzerland by the Schweizerische Industriel Gesellschaft at Neuhausen, on the Swiss-German border. With the advent of World War I the production was diverted to Germany, and the use of the gun by Mexico was discontinued.

Middle: The Stergian rifle. This was not semiautomatic, but was manually operated in the same manner as a pump action shotgun, by means of the hand grip under the forearm. This was jointed so it could be folded into a slot in the stock when not in use.

Bottom: The Murphy-Manning gas operated semiautomatic, designed and built by two Springfield Armory employees about 1915.

During the war of 1914-1918, the Germans used quite a few gas operated rifles of the kind called the Mondragon, which had been adopted by the Mexican Government in 1911. This rifle was developed by the Mexican General Mondragon at the plant of the Sweizerische Industriel Gesellschaft, at Neuhausen in Switzerland. This is only a few miles from Germany; in fact it is so close that when I went there to investigate this rifle the train from the next Swiss town wandered back and forth across the border. The train went straight while the border wound in and out. As stated above, this gun had been adopted by the Mexicans just before World War I. When the war broke out, it was no longer possible to send the guns to Mexico, and the entire production was diverted to Germany. The Mondragon compares rather favorably with some of the gas

operated semi-automatics used in World War II, such as the Tokarev and the Gew. 43.

During the early months of our war with Germany in 1917 and 18, the Ordnance Department commisssioned as Major an arms designer of the Stevens Arms Co., named Elder, and gave him the task of attempting to get out a semiautomatic rifle that we could use in the war. Major Elder copied the St. Etienne in .30 caliber and did the same with a very promising Swiss short recoil rifle



Close up view of the toggle jointed lock of the Bommarito recoil action. A downward projecting arm on the rearward member of the breech block meshes in a depression in the frame, and is geared up so that as the barrel moves to the rear, the breech action is forcibly moved to the open position shown.

called the Rychiger. Major Elder, who worked under my supervision when I was Chief of the Machine Gun and Small Arms Section, Engineering Division, Ordnance, in 1918, produced some very creditable models, but the war ended before any of them had been actually put into production for war use.

The Pedersen .276

A rifle which is neither gas operated nor recoil operated was built by Mr. J. D. Pedersen. Mr. Pedersen is a gun designer of immense experience. Years ago he designed the Remington pump shotgun, which attained great commercial success, and afterwards he designed numerous rifles for the Remington Arms Company, including the slide-action .22. He also designed the Remington auto-



Top: U. S. Rifle, Cal. .30, model of 1903, for comparison with the semiautomatics shown below.

Middle: Garand's third model, a gas operated gun built to shoot the Pedersen 276 cartridge. This gun, later changed to .30 caliber, became the present M1.

Bottom: The Pedersen .276. A retarded blowback gun, which eliminated all the complications of gas operation or recoiling barrel by an exceedingly clever method of opposing the opening tendency of the breech by the inertia of the parts acting through a favorable leverage. It passed a highly satisfactory test, but used waxed cartridges, a fact which weighed against it, more on theoretical than on practical grounds.

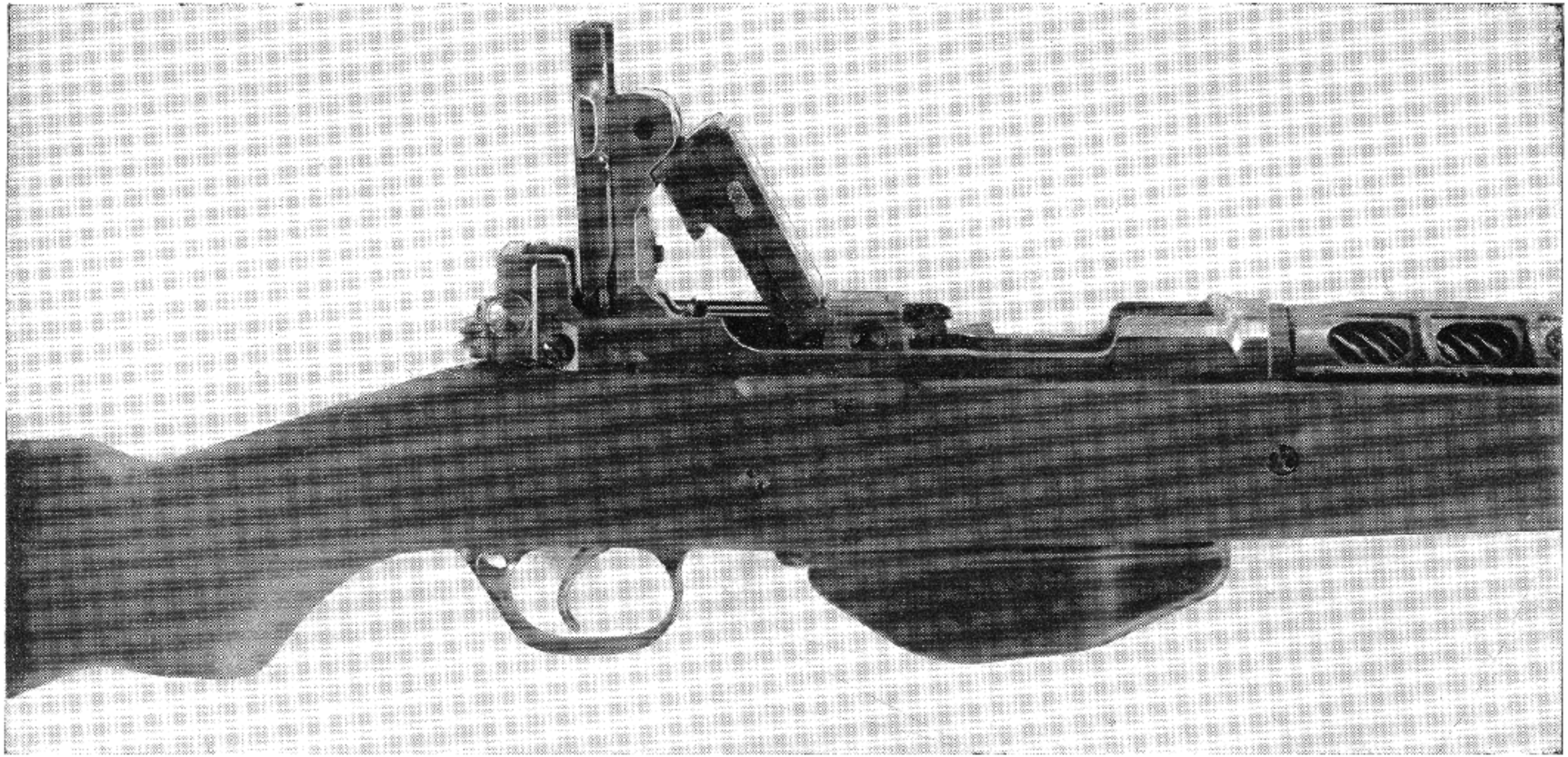
matic pistol, and the Pedersen device which was one of our most closely guarded secrets of World War I.

Along about 1922 Mr. Pedersen approached the Ordnance Department with a plan for a semiautomatic rifle on an entirely new design. The design was so promising and Mr. Pedersen's reputation as a designer so great, that the Ordnance Department decided to build the rifle. As a result Mr. Pedersen was employed and his rifle was built at Springfield Armory. The first test was successful, and twenty samples were built, which went out to the infantry and cavalry for service test. Some of these twenty rifles were also demonstrated from time to time at Camp Perry.

Mr. Pedersen's rifle, like General Thompson's is what may be called a delayed blow-back, but in this gun there are no screw threads on the breechblock. The breechblock is a toggle joint, or crank, very much in principle like what was described in connection with the Maxim machine gun, but with this difference, that this crank is never on dead center. It is always just a little bit out of line, so that the moment pressure comes on the cartridge the toggle joint begins to open. If it were merely a hinged crank with a pin joint where the connecting rod joins to it, it would open too fast. The crank and connecting rod are, however, not hinged together with a simple hinged joint, but each has a cam surface, and as the breech-block moves back and the toggle joint breaks, these two cam surfaces roll together in such a way as to delay the speed with which the line of thrust gets away from a straight line. Thus again this blow-back mechanism, while it does not have much weight, is as *hard* to move and as *slow* to move as if it did have the weight there. It is hard to move because, when the thrust comes on the head of the breech-block, it is transmitted almost in a straight line to the big pivot pin in the back of the frame. When this thrust is exerted, the center of the toggle joint moves upward, but this center must move up a considerable distance before the head of the bolt moves back appreciably. A *lot* of upward speed must be put into the center of the toggle joint before the head of the bolt goes back very far, and this delays the opening of the gun sufficiently to enable the powder pressure to fall before the cartridge case can get out.

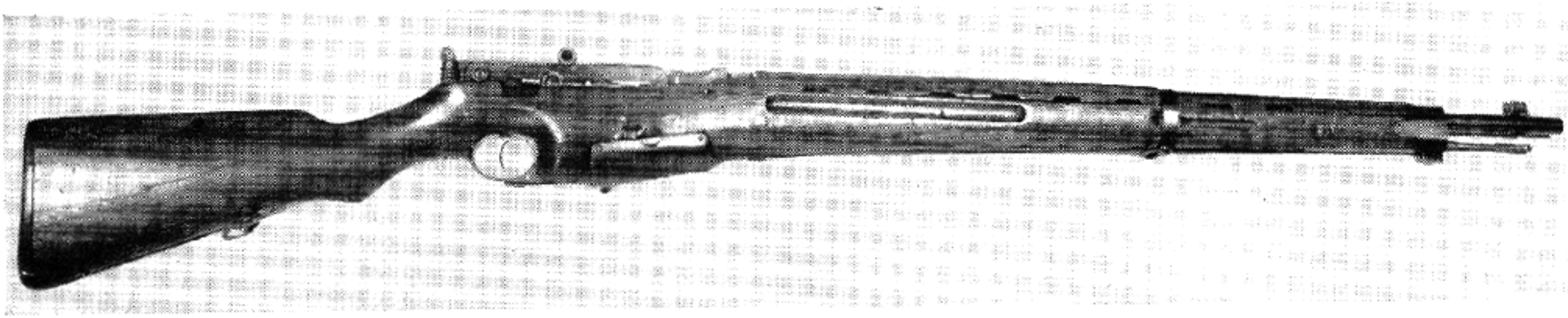
Mr. Pedersen finally completed twenty of his rifles at Springfield Armory in 1927, and these were sent out for service test. In the meantime Frankford Arsenal had been experimenting with .276 cartridges, and several hundred thousand of these cartridges were made up for use in testing the twenty Pedersen rifles.

In 1927 the Pedersen rifles were tested by the Infantry and Cavalry and were found to be suitable for military use. It was decided, however, that before adopting this rifle, we would make a thorough test of all the other models which were available, and accordingly notice was sent out to inventors that the War Department would



The Pedersen .276, shown with action open.

Pedersen .276 semiautomatic, showing action in closed position.



Japanese copy of the Pedersen semiautomatic rifle. Unlike the Pedersen, this rifle uses a rotary magazine similar to the Schoenauer type, or to that used in the Savage Model 1899, and is arranged to be loaded by stripping cartridges from a clip like that of the Springfield or Mauser.



Close up of the mechanism of the Japanese copy of the Pedersen semiautomatic rifle, showing rotary or spool type magazine. Only two samples of this rifle were found. They were in an arsenal about 7 miles from Tokyo, and were marked No. 1 and No. 2, respectively, so it is likely that they were experimental models, and that they were the only ones made.

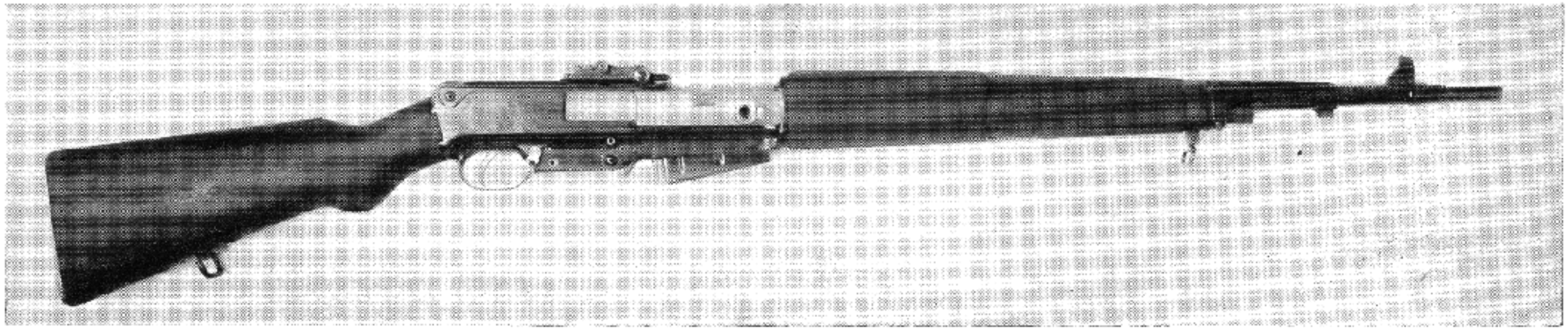
hold a test of semiautomatic rifles in July 1929. These rifles were to fire the new .276 ammunition which by that time had been approved for adoption as the service cartridge for any new semiautomatic that met the final tests.

The Improved Garand

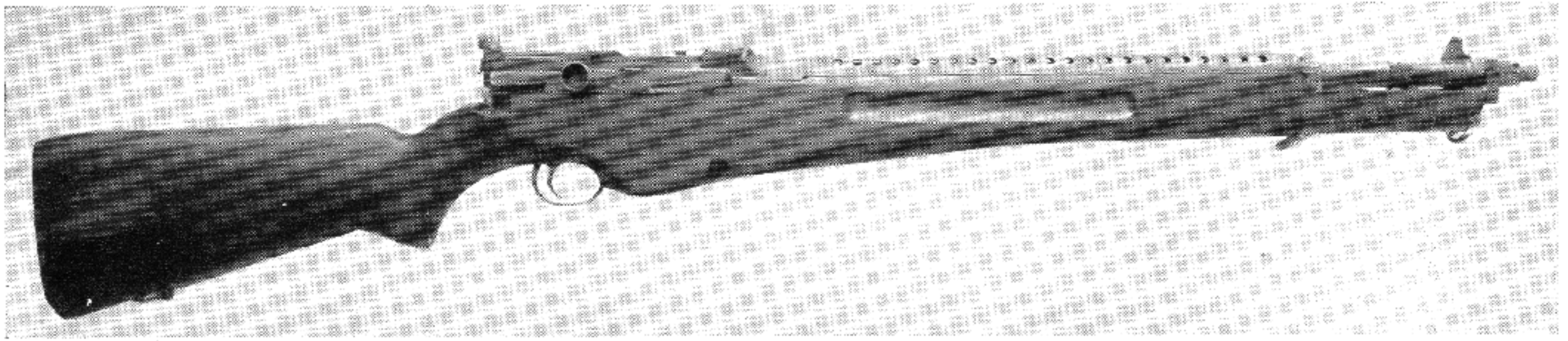
In 1928, Mr. Garand had started to work on an improved model, in which he had abandoned his primer operation in favor of gas operation. His new rifle was, of course, of the .276 caliber.

Mr. Garand's new gun, contrary to the usual practice in gas operation, did not have a gas port in the barrel. Instead, he used a cap over the muzzle, similar to the cap used by Bang, with this important difference; the Garand cap did not move. See page 58.

There is an entry in my notebook, made some years ago as follows: "Garand's muzzle cap patented by L. Silverman of Crayford, Kent, assigned to Vickers Sons and Maxim, U. S. Patent 618,743, Jan. 31, 1899."



Czech semiautomatic rifle tested at Aberdeen Proving Ground in 1929. It was designed by Holek, and submitted by the "ZB" firm, (Ceskoslovenska Zbrojovka, of Brno.) It was chambered for the Pedersen .276 cartridge.



The White semiautomatic .276. This was one of the rifles tested at Aberdeen in 1929. It had an unusually short compact action, and a system of admitting a small portion of gas into a hollow piston and then cutting off the supply, after the manner of a slide valve in a steam engine, so the gas could act by expansion and thus soften the blow of the piston.

Garand used this arrangement on his early production of M 1 rifles, but soon changed to the conventional gas port near the muzzle.

The Garand gas operated gun was characterized by extreme simplicity and clean design of all the parts. It had only about 60 pieces, which is considerably less than the number in the Springfield '03. The first of these guns weighed about the same as the 1903 Springfield. The gun had a ten round magazine, with an "en bloc" clip; a receiver peep sight, with clicks for both elevation and windage; a pistol grip stock, with more length that that of the Springfield '03, and with a higher comb for more comfort in prone shooting.

The official test, held at Aberdeen Proving Ground in 1929, included the Pedersen and Garand rifles, the Thompson rifle, a Browning of the short-recoil type made by the Colt's Patent Fire Arms Manufacturing Co., and three European rifles—the Brauning, invented by a Belgian (which should not be confused with the American-invented Browning guns made in Belgium), a Czechoslovakian gas-operated rifle, and a rifle invented by Karl Heinemann, who designed the German Parabellum aircraft machine guns during the first world war.

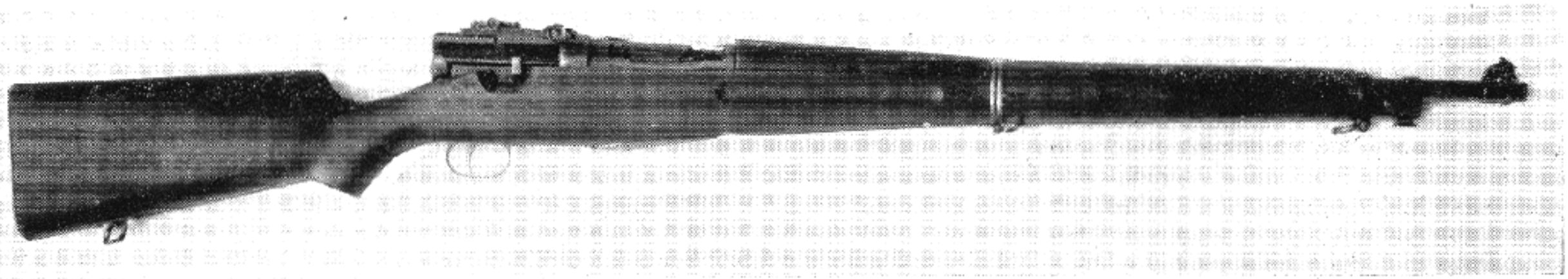
As a result of this Aberdeen test of 1929,—which I attended, as it came under my direct supervision as Chief of the Small Arms Division, Technical Staff,—the Garand .276 came out on top, and it was decided to make twenty of them for an extended service test, as had already been done with the Pedersen. The test was completed in 1932, and it then remained to determine which of these two highly satisfactory rifles would be adopted for service use by the army.

In the meantime the British apparently had shown a disposition to adopt the same rifle we finally chose, so Pedersen went to England and worked with Vickers, Ltd., tooling up for his rifle, which most people apparently thought it certain we would adopt.

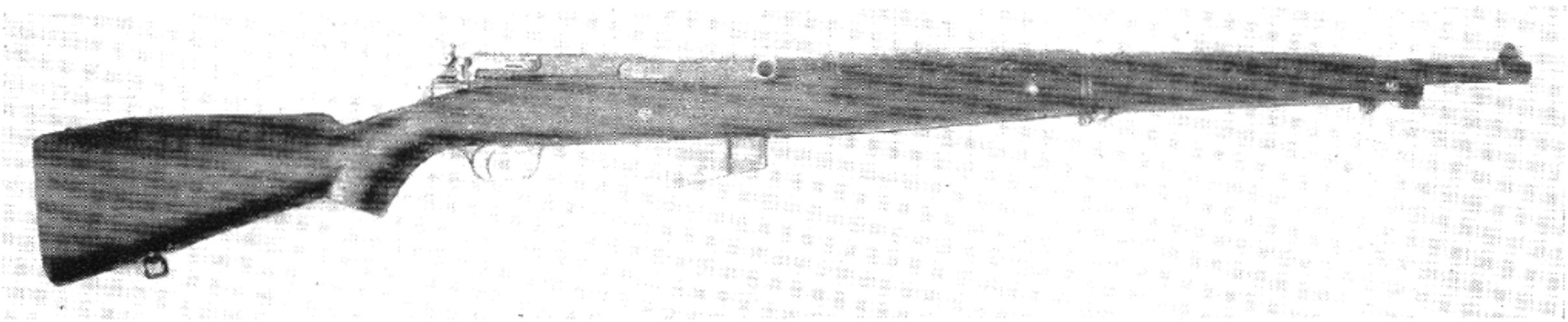
Apparently the Japanese thought so too, for recently I have seen a rifle of the Pedersen type, with variations such as a rotary magazine, two of which were found in an arsenal outside of Tokyo. These were marked 1 and 2, respectively. Most likely they were experimental models, and they may have been the only two made.

However, the decision of the Army board was to adopt the Garand .276 instead of the Pedersen, and the report recommending this action was laid on the Chief of Staff's desk, when a sort of a figurative atomic bomb burst in the semi-automatic rifle business. General MacArthur, U. S. Army Chief of Staff, disapproved the report, and stated that the recommendation had been made under a misapprehension; there would be no change in the caliber of the service ammunition.

This decision, which as proved by later events was eminently sound, ended the many years of work on the .276 rifles, and required a new



Thompson semiautomatic rifle in the .276 Pedersen caliber, submitted for test at Aberdeen in 1929.



Colt semiautomatic rifle tested in 1929. It was designed by a member of the Browning family, and was in the caliber .276 Pedersen.



First model of the present .30 caliber M1 rifle. Garand first built two successive models of primer actuated .30 caliber guns, then a .276 gas actuated gun to take the Pedersen .276 cartridge. The gun shown above duplicates his .276 in .30 caliber. Photo taken September 10, 1930



Japanese copy of the U. S. Garand M1 rifle. Guns like this, differing from the U. S. M1 only in minor details were found in the Japanese service towards the close of the war. Main differences were the caliber, which was the standard Japanese 7.7mm; the rear sight, which was of the ramp type, and the magazine, which was arranged for loading by having the cartridges stripped out of a clip as is done in the M1903 Springfield.

start to be made in the matter of the selection of a semi-automatic shoulder rifle. Fortunately Garand had already been working on a .30 caliber model, and he proceeded to submit it for test. Twenty of these rifles were submitted for service test, and the rifle was standardized Jan. 9, 1936, as the U. S. Rifle, caliber .30, M 1.

Soon after this an allottment of $80,000 was given to Springfield armory for the construction of 80 of these rifles, together with a considerable amount of tooling up for making them by production methods.

The first actual quantity production of parts started at Springfield Armory in January, 1937, and completed rifles started coming off the production lines in August of the same year.

During World War II, the Garand was produced by the Winchester Repeating Arms Co., as well as by the Springfield Armory, a total of 4,028,395, being produced.

Johnson vs. Garand

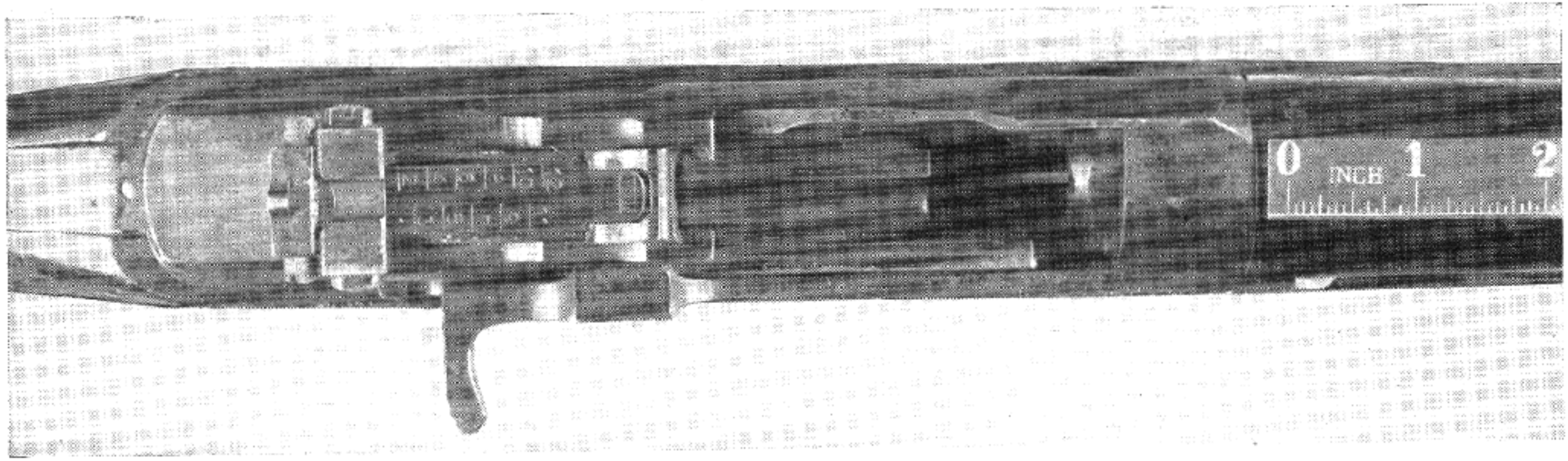
In 1936, Capt. Melvin M. Johnson, U.S.M.C. Reserve, started work on a much improved type of short recoil action, which he incorporated in both a semiautomatic rifle and a light machine gun. This gun was ready for production about the end of 1939, and was adopted by the Netherlands Indies Army and by the Royal Netherlands Navy.

There is no doubt that both the Johnson Automatic Rifle and the Johnson Light Machine Gun were excellent weapons, with many attractive and useful features. Some people thought that we should abandon the Garand and adopt the Johnson, though there was nothing to show that the Johnson was any better than the Garand, or for that matter, as good. The tooling up for the Garand has been completed at great expense, and some 50,000 of the new guns had been manufactured, so that even if the Johnson had been better, a change at that time was out of the question. Finally, experience by the Marines with both types in the Southwest Pacific demonstrated the fact that the Garand was unquestionably a better battle rifle than the Johnson. The Johnson rifles that the Marines had acquired were turned in and Garands obtained to take their place. The Johnson is nevertheless a splendid semiautomatic rifle, and Captain Johnson is entitled to a world of credit for his outstanding accomplishment in developing it in a very short time.

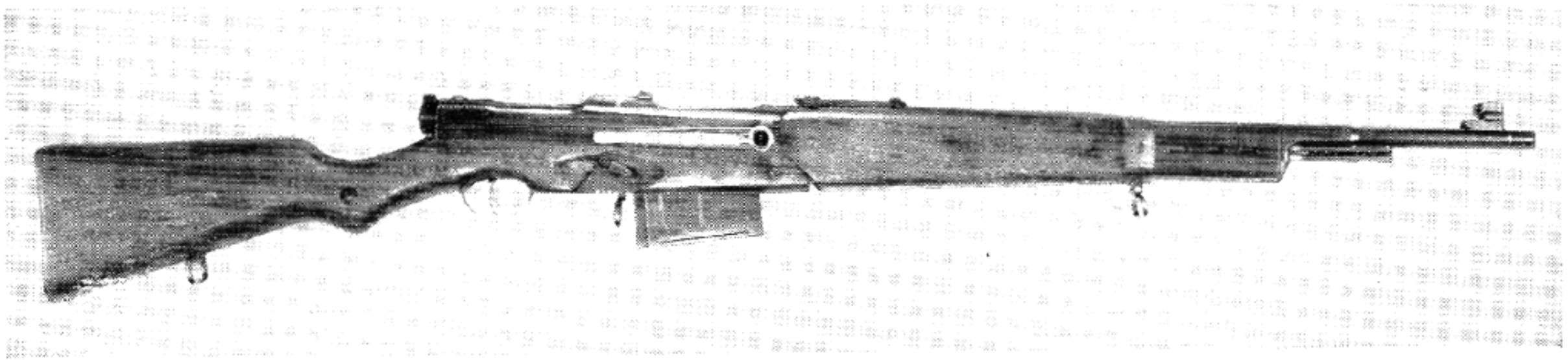
European Semiautomatics

Both Germany and Russia used a certain number of semiautomatic shoulder rifles during World War II. The best of these is probably the German Gewehr 43, later called K-43.

This is a gas operated gun, with a gas piston and operating rod lying on top of the barrel, under a wooden handguard. Contrary



Top view of the Japanese copy of the U. S. Garand M1, showing the ramp type rear sight and the magazine arranged to use the Springfield type clip.



Czech 7.92 ZH-37 semiautomatic rifle captured in Germany during World War II.

to usual practice, the piston is the fixed member; the cylinder is arranged to telescope over the fixed piston.

The gas is taken off ten inches from the chamber, and must pass through the port and then back through the 4 inch length of the fixed piston before it comes out at the rear of the piston and strikes the moveable cylinder. Thus the action of the gas is softened considerably.

The locking arrangement comprises two wing-like pieces pivoted in the breech block. As the firing pin goes forward, it wedges these pieces out into recesses in the receiver, thus locking the action. As the gun is fired, the operating rod is driven backward by the gas, striking the bolt carrier, and driving it to the rear. It, in turn, pushes back the firing pin, first camming the two locking wings inward and out of engagement with the locking shoulders, then carrying the bolt to the rear.

I have seen samples of this gun in both 22 and 24½ inch barrel. The longer barrel model weighs 9 lbs. 13 oz. with magazine, and is 46¾ inches overall. It has a ten shot detachable box magazine, inserted from the bottom. It has a base for telescope mounting on the right side of the receiver.

Previous German models were the Gewehr 41, the Gew. 41 M, and the Gew. 41 W. These were operated by a piston driven to the rear by gas action, but there was no gas port in the barrel; instead, there was a muzzle cap over the end of the barrel, something like that used by Garand on his first gas operated models. The gas is trapped inside this cap long enough to act on the piston. In the Gew. 41 and the 41 W, the breech action is almost a duplicate of the Gew. 43; the Gew. 41 M has a turning bolt with a straight-pull action.

The Russians had a Simonov semiautomatic in 1936, called Avs 36, which was both semiautomatic and full automatic. It was gas operated, with the piston and gas cylinder on top of the barrel. The lock is a hollow rectangular member which is cammed downward out of engagement with the breech block when the breech block carrier is driven to the rear by the backward stroke of the piston. As it was intended for optional full automatic fire, this gun had a muzzle brake or compensator to control the climb. This was continued on the later Tokarev models, though the full automatic feature was dropped.

Following the Simonev was the Tokarev, Model 1938 and later, Model 1940. This weapon, the invention of an engineer named Feodor Vasilyevitch Tokarev, is a gun of neat and effective design. It is chambered for the regular 7.62 mm cartridge, and is fed from a ten shot detachable magazine, inserted from the bottom. The magazine may also be clip fed while in place in the gun.

The gun is gas operated, with a gas cylinder on top of the barrel near the muzzle. The operating rod passes through a hole in the rear sight instead of straddling it as in the Simonev.

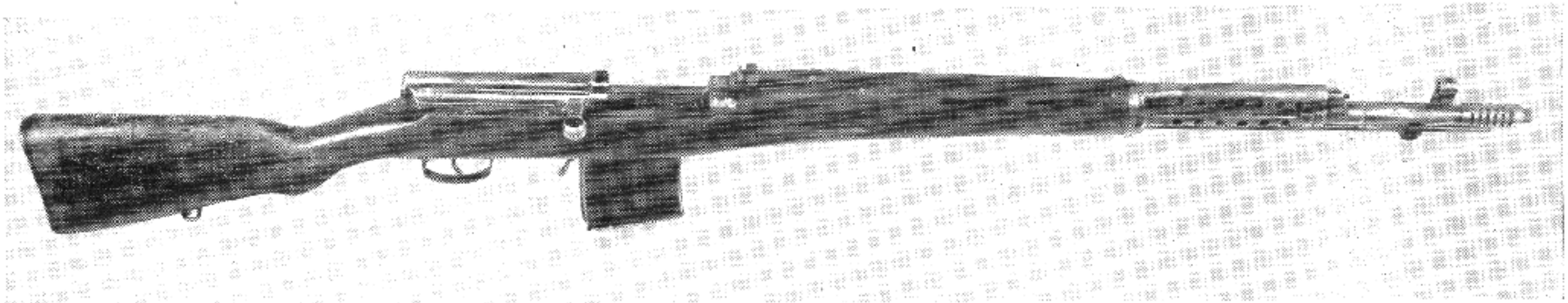


Another view of the Czech ZH-37 7.92mm semiautomatic rifle found in Germany in World War II.

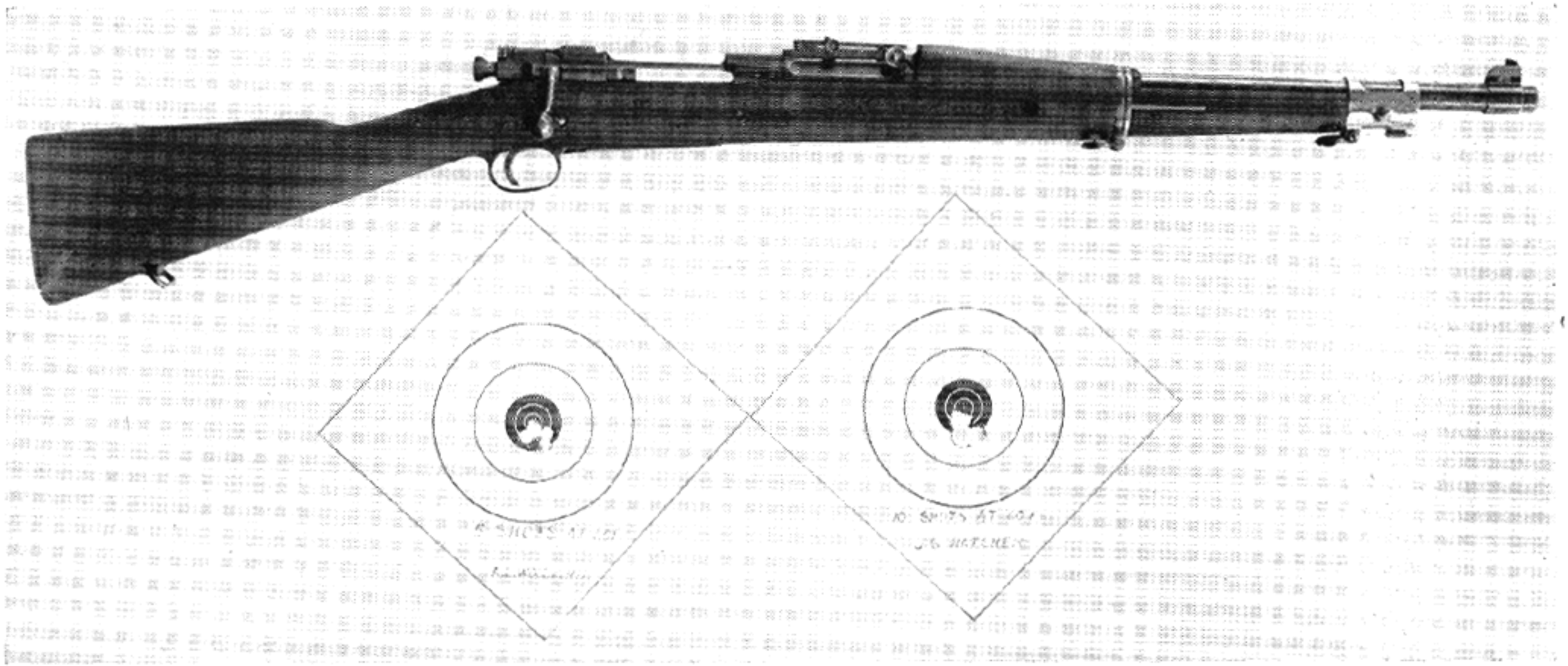


A second type of Czech experimental semiautomatic rifle found in Germany during World War II. It is made in the regular German 7.92 caliber, and is gas operated.

German semiautomatic rifles of World War II: 1. Gewehr 41M. 2. Gewehr 41W. 3. Gewehr 43. 4. Gewehr 43 with stock removed to show gas cyclinder



Russian Tokarev semiautomatic rifle Model SVT 1940.



Experimental Carbine, shooting the .45 caliber service automatic pistol cartridge, made at Springfield in 1921. It had a 20 inch barrel.

The bolt is of the rocking type, similar in locking principle to that on the old Colt Machine Gun, or the Winchester Model 12 shotgun. As the bolt carrier moves forward under the action of the return spring in closing the action, a cam tips the rear end of the bolt downward, locking it in front of a shoulder in the receiver. As the operating rod is driven to the rear under the impulse of the gas, it pushes the bolt carrier back; this action cams the rear end of the bolt up out of engagement with the shoulder in the receiver, thus permitting it to be carried to the rear.

The gun is remarakably light, weighing only 8½ lbs., with magazine. The barrel, including the integral muzzle brake, is 27 inches long; if the muzzle brake is not included, the length is 24½ inches. The overall length of the gun is 48 inches.

The U. S. Carbine, Cal. .30 M 1 and M 2

During 1940 the Ordnance decided to produce a very light semi-automatic rifle to take the place of the pistol in the armament of company officers, non-commissioned officers, communication units, engineers, tank units, artillery, etc.

The cartridge was developed in conjunction with the Winchester Repeating Arms Co., from their .32 self-loading rifle cartridge. It has a round nosed 110 grain bullet, driven at a muzzle velocity of 1975 f.s. by a charge of approximately 12.4 grains of Hercules Carbine Powder, called by the Army, Hercules Flake, or by a suitable charge of the Western Cartridge Company's Ball Powder.

The gun was to weigh not over 5½ pounds, and was to be capable of either semiautomatic action or full automatic fire.

An Ordnance test in 1941 was followed by a service test, which I was fortunately able to attend. A number of models were tested, submitted by Springfield Armory, Winchester, the Auto-Ordnance Co., Woodhull, Hyde, Savage Arms Co., and Harrington and Richardson. The Winchester model was adopted in the latter part of 1941.

The gun, which weighs 4¾ lbs. and has an overall length of 35 inches, with an 18 inch barrel, has a breech mechanism like that of the Garand, operated by a short stroke piston with gas take-off near the breech. For description of this system of operation see the previous chapter. A modification of the carbine called the M 1 A 1 has a folding skeleton stock in combination with a wooden pistol grip, to lighten the gun for use by parachute troops.

A further modification called the M 2 is arranged for either full automatic or semi-automatic fire at the option of the user, according to the position of a selecting lever.

European Carbines

The Germans produced a so-called Machine Pistol, the MP 43, which has already been mentioned under Submachine guns. This is not properly either a submachinegun or a machine pistol, but instead is a full automatic or semi-automatic carbine, arranged to shoot a shortened version of the 7.9 mm German service cartridge. This was by a big margin the most advanced European weapon in the carbine class.

Another gun which comes closer to being a carbine than a submachine gun is the Italian Beretta *Moschetto* or *little musket*. This is a carbine shooting the 9 mm Parabellum pistol cartridge.

VII

Experiments With Barrel Obstructions

THERE are some things about guns and shooting that are usually the subject of hearsay rather than of accurate first hand knowledge on the part of most of the shooting public, and one of these is the effect of the various abuses that are popularly supposed to result in a blown-up gun.

Perhaps the reason is that most people would rather hear about trouble than experience it, and so play safe; and the small minority who have enough curiosity to want to find out haven't the time or facilities.

It happens once in a while, however, that some individual is so placed by circumstances as to afford him an opportunity to investigate some of these things without too much trouble. That is just what happened to me. One thing alone that would guarantee me an opportunity to see a lot about how guns behave is the fact that I have been either Ordnance Officer or Ordnance Technical observer at nearly every National Match that was held between World Wars I and II.

The point of all this is that in all those years, I have rarely ever seen a gun failure cause any injury to the user, and what few injuries I have seen could mostly have been avoided by the use of shooting glasses.

I have tried almost everything I could think of, and in my early shooting days, I didn't know enough to wear shooting glasses, but I was lucky, and never received an eye injury. Now I wouldn't fire a shot with any kind of gun without shooting glasses on, or lacking special shooting glasses, ordinary eyeglasses would prevent the majority of eye injuries.

I have seen high powered rifles blown up by all kinds of fool tricks, such as buying a new gun and then firing it without ever looking in the barrel to see if it happened to be full of cosmoline; getting a cleaning patch stuck, with a rod wedged in the patch, and then trying to shoot both rod and patch out of the gun with a ball cartridge; loading a ball cartridge with blank cartridge powder, which just cannot be confined without causing a detonation; etc.

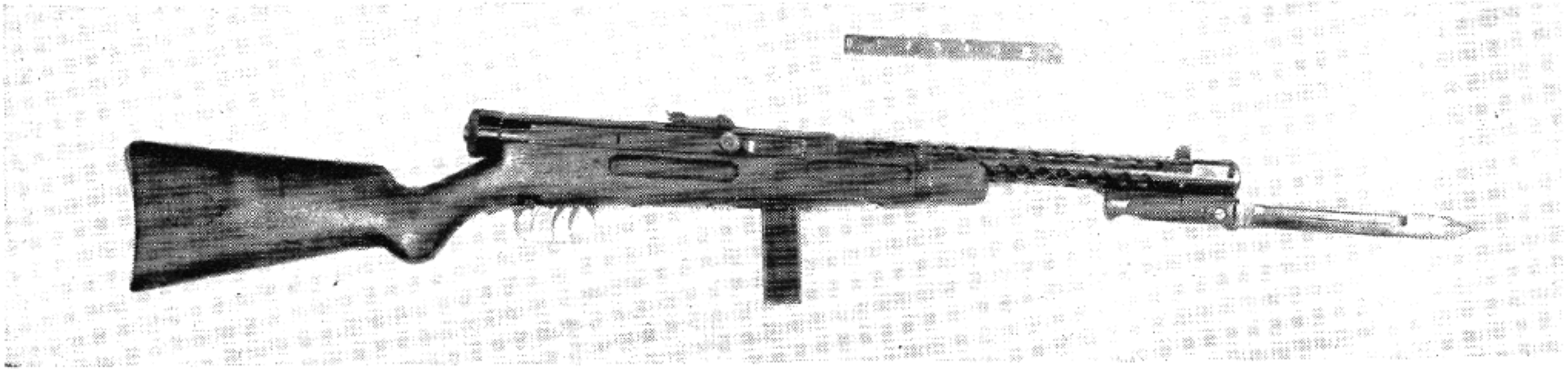
Lots of these incidents resulted in very narrow squeaks for the perpetrator of the stunt, but none that I have witnessed ever really hurt anyone. Once, for example, when I was in charge of the Experimental Department at Springfield Armory, we were trying to develop a blank cartridge attachment for the service .45. The special

barrel had a plug in the muzzle with a very small hole in it, and the chamber was made too small to accept a regular ball cartridge, but would take the special blank. These blanks worked all right when the closing wad could be made hard and brittle so it would break up in passing through the small hole at the muzzle. One lot, however, failed to dry out properly, and the wads, instead of being brittle, were gummy, and the first one choked the vent. I was firing at the time, and the next shot with that sensitive blank powder confined in the barrel, simply detonated, and blew the barrel and slide all to pieces, leaving me holding the handle of the gun and wondering why I hadn't been hurt.

I certainly don't want the statements made above to be construed as any encouragement to take chances with dangerous overloads, etc.; anyone who keeps on with that long enough is sure to be hurt. What I do mean is that if you take reasonable care and wear glasses, your chances of being hurt by your gun are slight. Also, when you look at the wrecked guns pictured in this book, remember that most of them didn't hurt anyone, after all.

Now getting to the subject of this chapter, barrel obstructions, I suppose that all of us have had accidental experiences along this line. I remember very well a certain .22 of childhood days (the days when cleaning a gun had not been heard of), which one time failed to bring down a sparrow at very close range; not only that, but it failed to even make him fly; and still worse, the whole contents of the magazine, shot in rapid succession, did not obtrude itself on his consciousness in any way, or produce any visible or audible result at all. The puzzled feeling of surprise occasioned by this unusual circumstance prompted an investigation which disclosed the astonishing fact that the barrel did not have a hole through it. The gun was taken to the village bicycle man, who acted as gunsmith, locksmith, and general utility man, to have the dozen or more bullets bored out.

The operation was conducted with expedition and economy, and while I have never inquired into how he conducted the boring out operation, or how he got out the remnants of lead that might have remained between the lands, I can say that the result was entirely satisfactory and was well worth the quarter it cost, and the old Winchester is still kicking around to prove it. Of course, the accuracy, measured by modern standards, is nil, but you can't expect much from a barrel that has endured many damp summers with little or no cleaning. The incident seemed to indicate that the .22 short has not power enough to blow up a gun, no matter what you do. This conclusion encouraged me to try shooting under water with a .22, an experiment that was completely satisfactory. The gun was loaded entirely under water, so that the barrel was filled. Good practice was had at tin cans some ten feet away, and the worst damage to the gun was the wetting.



Italian Beretta Moschetto, or carbine, Model 1938-A, using the 9mm Parabellum cartridge.

Another incident that is equally well impressed on my memory refers to a time some years ago, when I was trying out for a certain rifle team, and another member of the squad in pistol practice had the side of the cylinder on his .38 revolver lifted out by what seemed to be an extra heavy explosion. Investigation finally showed that the trouble was caused by a double charge of powder in the cartridge. It was factory loaded stuff, put up by one of our largest makers, and we heard a story of how it happened, which ran this way. The machine for putting in the powder charge was arranged to handle fifty cartridges at a time. Now this particular machine just once made two strokes instead of one, thus putting a double dose of powder into all fifty of the shells of that batch. When the lot of cartridges containing these fifty bad ones got onto the market, trouble started for both the revolver makers and the cartridge company, for soon complaints began to come in from widely separated points. After several such cases had been reported, and it was found that in each case a revolver had blown up while "A" ammunition of lot "B" was being used, the company realized where the trouble lay, and withdrew the whole lot of cartridges from their dealers, and also replaced all the revolvers that were damaged from this cause. Incidentally, they fixed the loading machines so that they could no longer put in more than one load of powder.

The damaged revolvers had the cylinder wall blown out, which is the way a revolver fails under very high pressure. Apparently no personal injuries resulted from any of these blow-ups. The lessons of this incident are, first, that a double charge of Bullseye doesn't do a revolver any good, and second, that an overcharge in a revolver may blow out the cylinder, but cannot injure the barrel. Damaged barrels result from other causes. For example, I once knew a young man who was annoyed one night by an owl. He was an excellent revolver shot, so he got out his .45 Model 1917, and took careful aim by the bright moonlight, and fired, without disturbing his feathered friend in the least. He took better aim, and fired again, and when the owl only opened his big eyes and looked puzzled, he took a quick shot with lots of temper behind it, and finally threw the revolver, which at least gave him the satisfaction of seeing the feathered pest flap away into the darkness. When he retrieved his gun and went to clean it, it wouldn't clean, and on examining for the reason, he found that the barrel was plugged. A steel drift and a hammer removed three service bullets. The barrel was slightly bulged.

Again, I have seen a .38 military model revolver with the barrel absolutely full of bullets (I think there were nine), and a .32-20 the same way. These were jacketed bullets. The barrels were sawed lengthwise for examination, so that there is no doubt that the bullets were there. The .32-20 was badly bulged, and .38 only slightly.

The chances are that such accidents are caused by a cartridge having a weak charge, or none at all. Perhaps in some cases the powder has been deteriorated from a trace of oil that in some way got into the case during manufacture. A weak charge might drive the bullet only part way into the barrel of the revolver, and the next bullet would be stopped by the obstruction.

Many cases like this have occurred with model 1917 revolvers, and in some cases the barrels are split along the line of lettering "U. S. Property" under the barrel, which forms a weak section. As far as has been heard, these accidents have not caused any injury to personnel. This trouble does not seem to occur with the automatic pistol. Perhaps it is because the barrel of the pistol is closed for its whole length, instead of having an opening, as the revolver does between the barrel and the cylinder, which would allow the escape of gas. With the closed barrel, even the defective charge will usually drive the bullet clear, and thus avoid trouble on the next shot.

If the head of the cartridge used in the automatic pistol is very soft, it is possible for it to blow out at the bottom, where the barrel is chamfered to permit easy feeding. This may split the grips of the pistol in the older model having wooden stocks. With the steel cartridge cases used in the recent war this would not happen.

I have rarely seen the service .45 pistol badly wrecked by an accident in service, but finally one came in, which is shown in a picture with this chapter. It seemed as if this must certainly have been due to a terriffic overload. This result was duplicated experimentally by a charge of Bullseye powder of nearly three times the proper amount.

I have already mentioned my experience with the blank cartridge in the .45. The barrel had no locking lugs, so that the pressure could blow the action straight back, and there was a choke, or plug, screwed into the end of the barrel which reduced the bore at this point to about an eighth of an inch, so as to confine the gas and give more power to work the action. A charge of about five grains of blank cartridge powder was used, which worked very well, except when the choke got stopped up by a wad. The first time this happened, a bulge occurred in the barrel, at the front end, just behind the choke, though there was no bullet, only powder, and the place where the bulge occurred was not the weakest part of the barrel, as there was a thin section over the chamber which was not nearly as strong.

Another barrel was then made, and it was tempered much harder. This time when the wad jammed, the barrel split wide open, blowing the slide off at the same time, but leaving the grip intact.

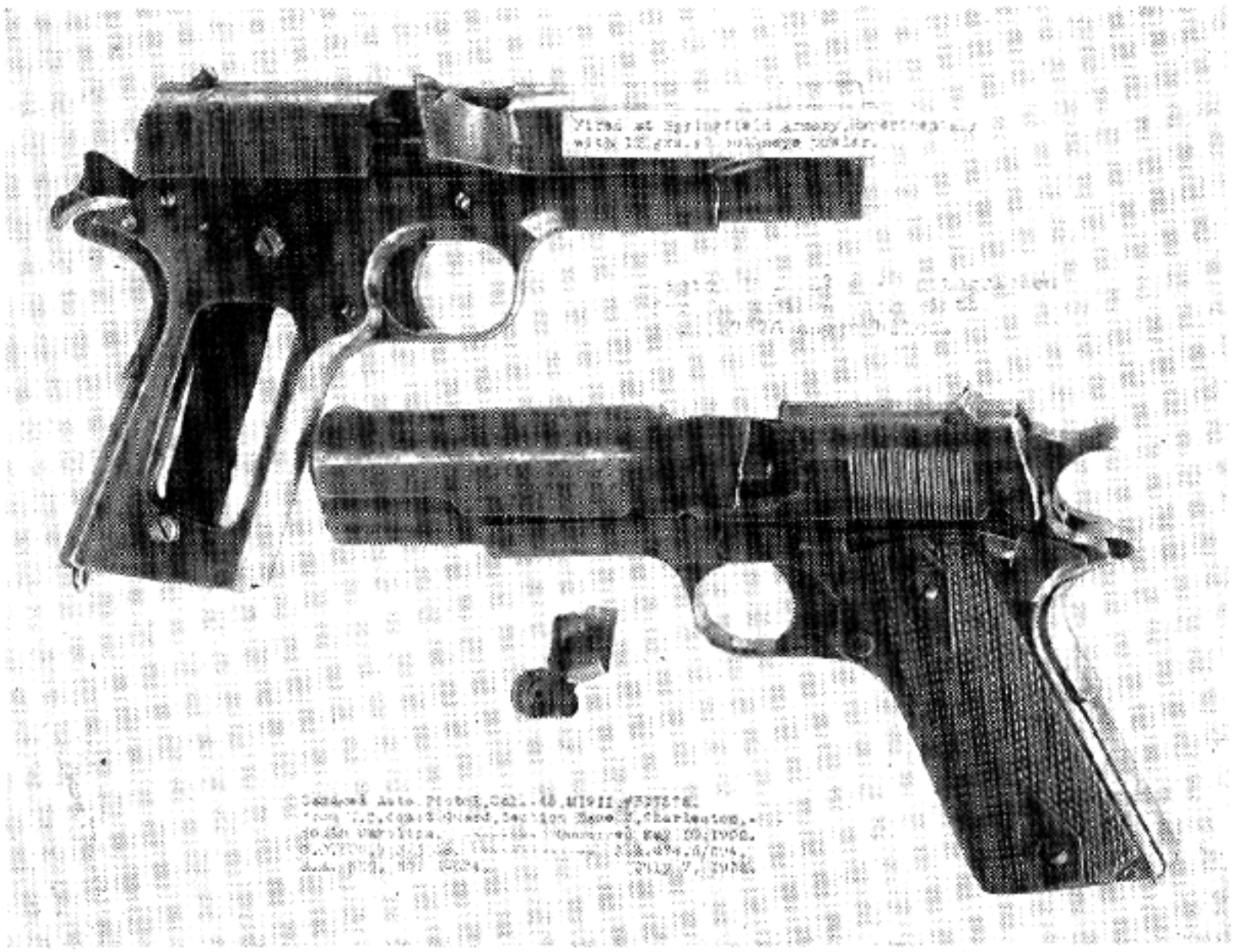
In speaking of blank cartridges, it may be remarked that the * E. C. blank cartridge powder used in this test burns with extreme speed.

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* E. C., for "Explosives Company."

The reason is clear when it is remembered that there is no bullet to confine the gas and cause a report, so that reliance must be placed on a powder that will burn all at once and give a sharp report even when it is not heavily confined.

This question of blank cartridges brings to mind the case of an enthusiast who once got hold of some of this powder, and being familiar with E. C. Shotgun powder, failed to realize that E. C. Blank cartridge powder is different, and loaded a batch of shells with



Effect of a heavy overcharge of Bullseye powder. The lower pistol was blown up in service. Springfield Armory duplicated the accident by using a charge of 12 grains of Bullseye instead of the normal charge of about 4.6 grains. As is usual in accidents of this kind, the firer was not injured.

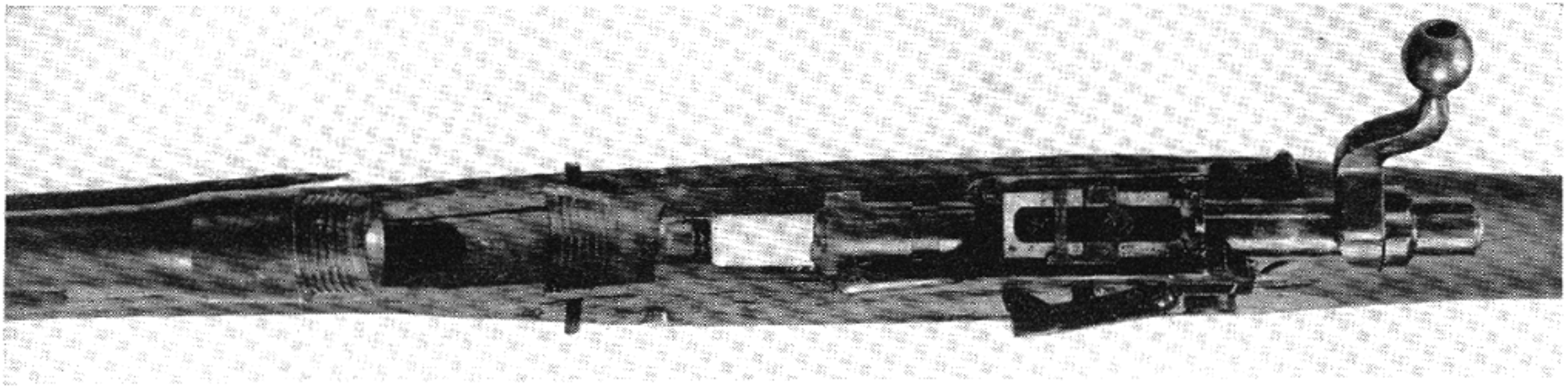
this fast-burning stuff. To try out his new load he got out his fine Lefever gun, and put up a target in the shooting gallery to get the pattern. Some of the loungers in the vicinity were watching, and they saw him swing up his gun and fire. There was a terrific detonation, and a big piece was blown out of the side of the barrel near the breech, and flew across the room, glancing off the wall and striking a bench, where it buried itself in the wood.

The owner of the gun was an inveterate experimenter, who had gotten into trouble once or twice before. Whether the shock dazed him, or whether he felt that he had better hide his mistake to prevent his friends from laughing at it, will never be known, but what hap-





This shows what will happen if the charge of pistol powder is increased to about three times the normal amount. Even so, there is not much danger to the firer.



The magic term "Nickel Steel" does not mean that the receiver cannot burst. This 1917 Enfield had a cleaning patch wedged in the barrel about 2 inches in front of the chamber, and the owner tried to shoot it out. The top of the receiver was blown away, but the bolt remained in place, held by the bottom lug, and no one was hurt.

pened is that he at once put on an indescribably ludicrous air of unconcern, as if he were perfectly unconscious that anything had happened, and marched down the room humming a snatch of song and swinging the gun in time to the tune. Quickly, and with a covert glance to be sure that no one had noticed, he slipped the gun into his locker and started to walk off to another part of the room.

But this would never suit the audience, who at once wanted to know "What's the trouble?" To which the victim replied that there was no trouble, he was just tired of shooting for a while. When his attention was drawn rather forcibly to the piece of gun sticking in the bench, he saw that he hadn't gotten away with anything. He blushed and stammered as he admitted that there must have been an accident, and tried to convince his now thoroughly amused audience that he hadn't noticed it before. The material lesson of this episode is plain. Don't use blank cartridge powder behind lead. The psychological lesson is not so plain, but was interesting to the observers.

Machine guns are a big source of experience in the behavior of small arms, for they are shot so much that many things can happen. This recalls an incident on the Border in 1916, when the Ordnance Department had sent some Lewis guns to the troops, and they were being instructed in the use of them. A factory expert was demonstrating, and had just fired several shots, when the gun stopped. He pulled back the handle, and out came an empty shell. I called to him not to shoot, but he had already pulled the trigger, and apparently nothing happened, for the gun went on shooting, but when it was dismounted that evening the barrel was found to have a lump on it the size of an egg. The shot that failed to work the gun had stuck in the barrel, and the next shot had caused the bulge. Perhaps the fact that the barrel was surrounded by the thick aluminum radiator had kept it from bursting.

As was mentioned in a previous chapter another peculiar incident occurred with the Benet Machine Rifle, when a student, who had fired the gun until it was nearly red hot, managed to get the breech mechanism jammed partly open with a live cartridge in the chamber. Hoping to be able to dislodge the cartridge before it exploded from the heat, I pushed a ramrod quickly down the barrel from the muzzle, and just as the rod came sharply against the bullet, the cartridge exploded. The breech was open, and the impact of the heavy rod prevented the bullet from moving forward as long as the cartridge case was perfectly free to move backwards. The result was that the cartridge case was blown out of the breech and torn to bits, without doing any harm, while the bullet remained in place.

This naturally brings up the question of what would happen if such a cartridge were extracted from the breech and should then

explode from the heat. I have seen this happen, as most people have who have handled the old air-cooled machine guns to any large extent. The result is only a very mild explosion, just sufficient to burst the brass case open and scatter burning grains of powder around. The reason that the explosion is not more violent is that the pressure necessary to rupture the cartridge case is not sufficient to cause the powder to burn rapidly enough to develop its full force. These accidents are not very dangerous, except for the possibility that small bits of brass may be blown into the eyes.

A hang-fire gives a similar result when it occurs after the cartridge has been entirely ejected, but if it should occur just as the bolt has been unlocked, and while the cartridge is still in the chamber, the result is likely to be serious, as the pressure will be held in sufficiently to develop a powerful explosion, which may blow the bolt back with violence.

One of the best ways to become acquainted with the causes of rifle trouble and their results is to have to examine, study and report on the various damaged rifles that are sent in from the service from time to time for post-mortem. On two separate occasions, once before the war and once afterwards, I have been stationed at Springfield Armory in charge of the experimental department, where this work is done. Many of the wrecks bore eloquent testimony to the destructive power of the improvised cleaning patch and the unsuitability of the old style service hat-cord for use as a pull-through. The hat-cord will pull, but it will not push, and when a soldier who is trying to clean his gun with one of them gets it all the way into his rifle barrel and then tries to dislodge it with a cleaning rod, trouble starts. No matter how you push it, the woozy, wobbly thing wedges together and cannot be moved an inch. Of course, if you had something like a corkscrew, and could get hold of the end to pull, it would come out easily enough, but ordinarily no such object is at hand, and some friend, with a quick but not cautious brain, sees a way out of the difficulty, and says "Let's shoot it out." "Of course! Why didn't I think of that before?" says the owner. In goes a cartridge, the trigger is pulled, and the next moment the air is full of flying splinters of the stock, and after the victim picks himself up and looks to see if he is all there, he glances at his rifle and finds the barrel split and the rest of the outfit looking pretty sick from the blast.

The shirt-tail cleaning patch is another trouble maker. The rifleman who has no cut patches and tears off an irregular piece of cloth to swab out his rifle often finds himself in a worse fix than he would if he made no attempt whatever to clean his gun. The ill-fitting piece of cloth requires undue force to push it through, so that frequently the cleaning rod pierces the patch and wedges so tightly that it is

a problem to get it out at all. If the shooting-out method is employed, the results are the same as with the hat-cord, only more pronounced.

The wrong way of using the regular cleaning patch may also cause trouble. To prevent the cleaning rod from piercing and wedging it, the corner of patch should be turned over, and the tip of the rod should be placed against the double thickness. If this is not done, but the rod is merely placed in the center of the patch against the single thickness of cloth, it may punch through and wedge.

An officer in charge of a company on the firing range will usually encounter cases where men will get obstructions in their rifles which cannot be removed by ordinary methods. A number of years ago when in charge of a rifle range, I employed a method of removing obstructions, which may be interesting, though for reasons which will appear later, it is distinctly not recommended now. I read in an old Ordnance manual printed in the days of muzzle loaders the results of a series of experiments to determine the effect of failing to ram the ball all the way down onto the charge before firing. The early experiments tried the effect of pushing the bullet nearly onto the charge and ring the piece. The pressure was found to be less than normal. The next time the ball was rammed only half way down, and this gave a pressure much less than before. Lastly, the ball was inserted near the muzzle and on firing a very low pressure was recorded. None of the barrels were harmed in the least by these experiments, and the conclusion was that firing a gun with the bullet not entirely seated on the powder could not injure the gun. But when two balls were employd at one time, one near the breech and another some distance away in the barrel the gun was burst.

This information seemed to indicate that if an attempt were made to blow out an obstruction with powder gas the pressure would be less than with a service charge, and no harm would result if the bullet were first removed from the cartridge. After a few cautious experiments along this line I applied this method as will be described. When a rifle was brought up with an obstruction in it, I removed the bullet and half the powder from a cartridge and then holding the muzzle elevated so that the powder would stay against the primer, I fired, blowing out the obstruction. Success was uniform for the few times this method was employed during several seasons on the range. Still I always had some misgivings as to just what might happen in unusual cases, so that I was quite pleased when an opportunity was presented to test out this matter thoroughly under proper experimental conditions.

The first question taken up was the removal of rags and cleaning patches stuck in the barrel. These were easily blown out with a cartridge from which the bullet had been removed, and no injury to the barrel resulted. Then several rags were tried at a time, as well

as patches wedged tightly in place, but all were removed without difficulty. Next we tried pieces of hat-cord which were wetted to make them stick more tightly. When these were successfully removed it began to look as if the method would prove worthy of recommendation as a standard method to be used for removing obstructions.

Finally, as a last grand demonstration as regards rags, a cleaning rod was filed off on a slant, and with it a couple of patches were wedged tightly in place. A cartridge minus bullet was then inserted and fired with all the confidence in the world that the cleaning rod and patch would go flying down the range, but strange to say no such thing happened. Instead, the only result was a loud prolonged hiss, as of escaping steam, and on cautiously opening the bolt it was found that the powder had all burned up without moving the obstruction in the least. Also it was noted that the cartridge case was partly filled with a thick black sludge, or mud, the residue of the powder when burnt under these peculiar conditions, and there was an acrid smell which was not at all like the regular smell of powder gas. The next thing that was tried was a heavier charge of powder, all that could be put into a cartridge case. Result, just the same as before. It appeared that with the regulation powder, which burns slowly like celluloid unless closely confined, the loosely woven porous cloth patch did not furnish enough resistance to make the powder burn quickly, so that the pressure leaked out as fast as it was generated. The obvious remedy was to use a quick powder, such as black. As a can of King's semi-smokeless was close at hand, a shell full of it was tried without success. Then a cartridge full of fine-grained black powder was used which finally blasted the obstruction loose, without injury to the barrel. After this experience the method did not look quite so good.

The next thing tried was dislodging bullets stuck in the barrel. It was found that a bullet lodged at any point was easily blown out, using the full charge of powder. This experiment was tried on an old discarded pressure gun and it was found that the pressures ran very much less than normal, as would have been expected, especially after reading the old experiments referred to above. When the bullet was seated at the muzzle, the pressure, with a cartridge case full of powder, was about half service pressure. No swelling or other injury to the barrel could be detected.

These results did not indicate any danger in this procedure, but there has been talk of the possibility that gas, in rushing down the barrel at high speed and being suddenly arrested at the base of the stationary bullet, might pile up at this point and expend its dynamic energy in a local ring of pressure that would not show on the pressure gage, but would still be capable of doing damage. To try out this idea a bullet was wedged tightly into the muzzle so that it would

offer considerable resistance to being expelled. Then the gun was loaded and the trigger was pulled, but nothing happened; not even the hissing that had been experienced with the tightly wedged rags. We wondered whether it was a misfire or whether the cartridge had gone off and all the gas was remaining penned up in the barrel ready to come out with a bang as soon as the breech was opened. In order to avoid casualties we pointed the breech in a safe direction and opened the bolt by tapping the handle with a piece of wood. No sooner was the bolt handle driven to a vertical position than the bolt suddenly flew open with a loud "pop" like a champagne cork, and the empty shell was ejected smartly. As the obstruction had not been removed a heavier charge was tried, then a mixture of black and smokeless, without success, though with plenty of fun opening the bolt each time. Finally, after two tries with black powder the bullet was blown out, but on examination the muzzle of the barrel was found to be slightly swelled. It was hard to tell just what had caused the swelling, for if the piling up of a gas pressure at this point had done it, it would seem that the swelling would be found just behind the bullet. In fact it was at the very end of the muzzle, almost at the front end of the wedged bullet!

The only thing that this test settled was the fact that more tests were needed to enable proper conclusions to be drawn as to just what was happening. It was therefore decided to go ahead and do some of the things that usually cause damage, so as to determine exactly how the various forces produce their effect. We knew that firing out an obstruction with a bullet usually results in disaster, so the next experiments were planned to show more plainly just what happens in this case.

The first thing tried was the effect of loose drops of water in the barrel, as might happen in case of rain. No effect could be detected. Apparently the mass of the water drops does not check the bullet enough to do damage. Next, small pieces of brass, such as are punched from the vent holes of cartridges in manufacture, were laid in the bore in front of the bullet in the position that might be occupied in case one of these punchings should be left in the cartridge in manufacture (as sometimes happens), and should follow the bullet a short way down the bore in firing, and then lodge and wait to cause a disturbance on the next shot. These punchings, singly or several at a time did not cause any trouble that could be detected. It seems clear that they cannot bulge or burst a barrel with the present service rifle and cartridge. After this an investigation of the effect of bullet *jackets* lodged in the barrel was undertaken. It was found that they always caused a slight bulge in the barrel. In one case the new bullet passed completely through the lodged jacket, and in so doing, pressed it slightly into the steel, so that it could not be dislodged. After this a number of other bullets were fired without

moving the lodged jacket, which became bedded down into the metal of the bore so that it could hardly be seen from the inside. In being pressed into the steel, it raised a slight bulge in the barrel, which could be detected from the outside.

Cleaning patches lodged loosely in the barrel gave a very slight bulge, or none at all, but two heavy patches jammed tightly in place gave a large bulge, and if the barrel had happened to be a scamy one, it would probably have split from end to end. A light piece of paper placed loosely in the barrel gave no effect.

These results suggested very forcibly the question, "Just what causes a bullet to ring a barrel?" Some people say with great confidence that it is the pressure of the air which is suddenly compressed between the moving bullet and the stationary obstruction. This theory seems extremely unlikely. Then other theorists say that checking the bullet as it strikes the obstruction causes the rapidly moving column of gas to be arrested suddenly on the base of the bullet, so that it spreads out sideways, changing its dynamic energy into static pressure which is momentarily exerted in a ring of local pressure which may cause the swelling. This theory is better than the first, but still it does not seem good enough. It is more likely that the "ring" seen so often in a barrel which has been fired with an obstruction is due entirely to the bullet, as a rough calculation will show that at any point in the barrel the moving bullet possesses about twelve times as much dynamic energy as the rushing gas behind it. The bullet is made of a plastic material of very great density. If the forward motion of the front end of this rapidly moving bullet is suddenly checked the inertia of the lead in the rear portion of the bullet, coupled with the pressure of the gas on its base, will cause it to "upset," or expand sideways, which is what I think must cause the ring. Any obstruction, such as a patch, causes the point of the bullet to wedge, and thus checks it, and the resulting ring is proportional to the amount of the checking effect.

It was argued that if this theory were true no bulge would be caused in shooting out a cleaning patch or other light obstruction, provided that the wedging could be prevented. To try this out it was decided to lodge a rag in the bore and then shoot it out with a bullet which was square in front and did not have any pointed end to wedge. The quickest way to do this seemed to be to use the back end of a regular bullet, so one was pulled out of the cartridge and put in again, back end forward, and a rag was shot out without a sign of a bulge, which may be taken as an indication in confirmation of the wedging theory, though it is of course by no means conclusive.

After this experiment with rags, it was decided to try the same thing with bullets as obstructions, to see what could be learned or deduced. A bullet was lodged in a condemned barrel, near the muzzle,

and a regular cartridge was inserted and fired, with the inevitable result; the barrel forward of where the bullet was lodged was blown completely away. It was not possible to tell whether the damage originated just at the location of the obstructing bullet, or behind it, as the barrel was too completely destroyed at this point. At least one thing was certain, though, and that was that this attempt to shoot out a bullet with another one caused terrible havoc. In order to see if the wedging effect had anything to do with it, the experiment was repeated with the remaining portion of the same barrel, and the bullet in the cartridge was reversed, as described above, so as to attempt to sweep out the stationary bullet without allowing any wedging effect. As was expected, the result was the same as if the bullet had been shot sharp end first; the barrel was "sawed off," so to speak, at the point of obstruction. There is really no contradiction between this result and the one obtained when the rag was shot out successfully with the square end of the bullet, for in the last experiment the mass of the stationary bullet was sufficient to cause the lead of the two bullets to expand, merely from the impact, without the necessity of any wedging effect to help the action along.

In this connection it should be noted that in all the experiments conducted with light obstructions, such as cleaning patches, etc., even where everything possible was done to make the conditions favorable for the greatest damage, the worst results obtained were rings or bulges, while with heavy obstructions, the destruction was complete.

To determine more definitely whether or not the gas pressure on the base of the bullet had anything to do with the damage, another experiment was decided on. A plug of cotton waste was put in the center of a condemned barrel, and some melted lead was poured in so as to form a slug about four inches long at about the middle of the barrel's length.

On firing the gas was all retained, as has been described before. This firing was repeated once or twice, when to our great interest a distinct bulge was observed at about the middle of the space occupied by the lead slug. Measurements showed that the lead had not moved. In attempting to account for the formation of the bulge at this point, it was thought possible that the lead might have been poured in so as to leave cavities or vacant spaces which would give the effect of two or more slugs separated by a certain space, which could be driven together by the force of the explosion, and thus ring the barrel as two bullets would when driven together. To eliminate this possibility, as well as to verify the result of the experiment, the test was repeated, taking great care to pour the lead so as to form a solid obstruction, without cavities or pockets. On firing, the ring again occurred, which would seem to indicate that the bulging of barrels is principally due to the upsetting, or sidewise expansion of the lead in the bullet. The hammering of the gas pressure on the

base of the lead plug is what caused the upsetting in this case, which leads to the conclusion that in firing a bullet with an obstruction in the barrel, the gas pressure on the base of the bullet aids the wedging effect in causing the bullet to upset sufficiently to ring the barrel.

During World War I an officer of the Ordnance Department conducted a series of experiments at one of the big commercial rifle plants to determine the effect of various barrel obstructions. These experiments, which were made with 1917 model rifles, should prove very instructive. At the time these tests were made, there was a lot of trouble with loose bullets in service cartridges, and it some times happened that when a gun was unloaded without firing, the case would be extracted, but the bullet would stick fast in the rifling. It was feared that if this should happen on a misfire, and another cartridge should be inserted and fired, the rifle would be blown up from the effect of the two bullets.

It was found that in no case could a bullet without any cartridge be forced into the rifling far enough to allow the insertion of another cartridge and the closing of the bolt. However, a bullet was inserted in this manner, and a cartridge was prepared by forcing the bullet down into the case until the base of the bullet rested hard on the powder, filling practically all the air space and projecting out of the cartridge case only about three-sixteenths of an inch. This prepared cartridge was inserted in a rifle behind the stationary bullet and fired without damage to the rifle, though the cartridge case showed evidence of excess pressure, as the primer was blown and the cartridge base was distorted.

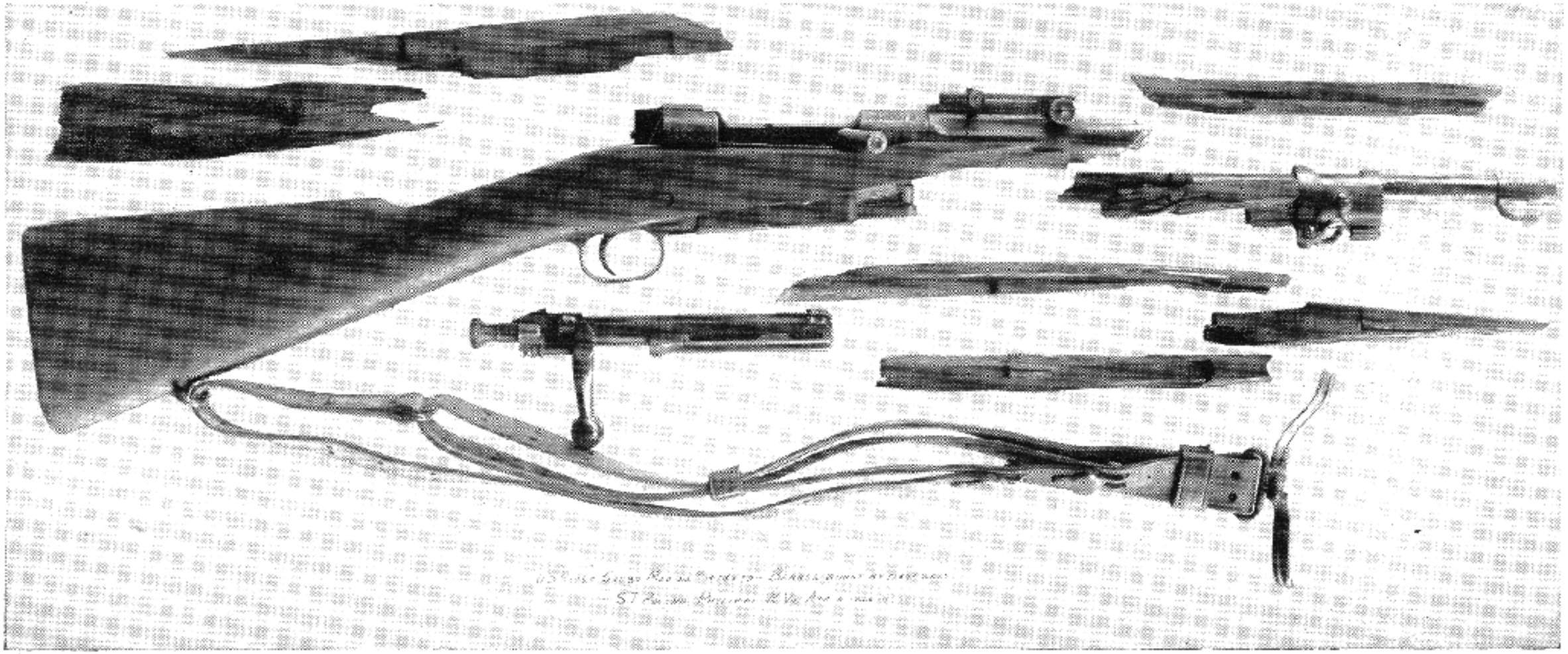
A bullet was driven into the rifling just far enough to permit another cartridge to be inserted and the bolt to be closed. On firing both bullets were ejected without damage to the gun, but the case showed evidence of high pressure.

A bullet was seated in the barrel with the base one inch ahead of the point of the bullet in the cartridge seated in the chamber. On firing both bullets were ejected without apparent damage to the barrel.

A bullet was then seated in the barrel at a point one inch further ahead than the one just described, or so that the base was two inches ahead of the point of the bullet seated in the chamber. On firing the barrel was burst from the receiver to the lower band.

In a barrel and action without stock, a bullet was forced into the rifling to a point one inch forward of the lower band and a cartridge was inserted into the chamber. On firing the barrel was split into three sections.

A bullet was seated in the barrel at a point one and three-fourths inches from the muzzle. On firing the barrel was bulged badly at the point of obstruction and the part forward of the bulge was split into four parts.



The barrel of this rifle burst on the first shot when the owner fired it with the barrel full of cosmoline. The low-numbered receiver No. 478,579 with its bolt, both of the old heat treatment, did not fail.

A dry cleaning patch was inserted one and one-half inches in the muzzle. On firing no apparent damage was done.

A dry cleaning patch was inserted to a point three inches to the rear of the lower band. On firing the barrel was split from the receiver to above the lower band and the lower part of the stock and the lower hand-guard were blown away. The front sight carrier was blown entirely off.

A cleaning patch of cotton cloth soaked with oil was rolled up and inserted in the muzzle for a length of about one and a half inches, as it would be in the case of a man inserting a plug or tompion in his piece to keep out the dirt or rain and forgetting to remove it before firing. On firing the muzzle was split about one inch, the front sight carrier was blown entirely off and the muzzle was slightly bulged.

A cleaning patch soaked in oil was made into a roll and pushed into the bore to a point about the lower band. On firing a decided bulge was made at this point, which is visible on the outside, but there was no rupture of the barrel.

The piece having been fouled by firing a few shots, the muzzle was inserted in sand and then shaken out, leaving a very small amount of sand or dirt in the muzzle. On firing no visible result was produced.

The same test as the preceding one was again made, leaving a greater amount of sand in the muzzle. No effect was evident.

One inch of sand was inserted in the muzzle, forming a solid plug. On firing the sand was blown out without apparent effect.

The test just described was repeated, putting one and one-half inches of sand in the muzzle. On firing the barrel was split in two pieces to below the lower band, blowing away the forward end of stock, handguard and front sight carrier.

The barrel was filled with warm cosmoline and allowed to drain naturally for a few moments, and the gun was then fired without cleaning. No damage whatever was apparent to the rifle or cartridge case.

The barrel was filled with warm cosmoline and allowed to cool over night, leaving a maximum of cosmoline in the barrel. On firing no effect whatever was visible on either the barrel or the cartridge case.

A fairly heavy dose of cold cosmoline was distributed through the barrel, not enough, however, to fully obstruct it at any one point. On firing no effect was visible.

The muzzle was filled solid with cosmoline to a depth of approximately one inch. On firing the barrel was split in two pieces to below the upper band, and the front sight carrier was blown entirely off.

A small wad of chewing gum was inserted in the muzzle, as on inspection a number of instances have developed where a man has put a wad of gum in the muzzle of his rifle and it was desired to

see what would result if such a wad should be left in while firing. A decided bulge was caused, but no fracture.

A study of the experiments that have been described will at least partly remove this subject from the realm of conjecture and will often enable the observer to tell from the examination of a wrecked gun the general cause of the trouble and will also enable one to know what to expect under certain circumstances. For example, some years ago a new front sight cover and protector was designed, which consisted of a cup-shaped steel stamping arranged to slip over the front end of the gun and protect both the muzzle and front sight. A rifleman, on being shown the design, objected that it would burst the barrel if the shooter forgot to remove it before shooting. In order to prove it the gun was fired with the muzzle cover on, with the expected result, which was that the bullet pierced the cover neatly and then proceeded on its way with no harm done to the rifle. In this case it could be stated with certainty that the rifle would not be injured because it was known that the service bullet could pierce a one-sixteenth-inch piece of sheet steel with such ease that it would not be checked seriously, and if the bullet were not checked the barrel would not be harmed. Thus besides having an academic interest, experiments of this nature give the designer reliable information that is at times invaluable.

VIII

The Strength of Military Rifles

ONE September day in 1920, I happened to be standing on the firing line at Camp Perry during a match, when the competitor directly in front of me fired a shot—and then couldn't see his rear sight! He rubbed his eyes incredulously, and looked again, then let out a howl that brought me to his side. It happened that I was the Ordnance Officer of the Matches, and thus was responsible for the condition and performance of the issue National Match rifle he was using. What was this about no rear sight? I dropped to my knees beside him and took a look. No rear sight at all—not even the sight base, but in the newly exposed barrel where the sight had been, a nice crack about an inch or more long. Then we began finding little bits of the sight lying around. It had broken into a dozen or more pieces, the breaks occurring on the lines that formed the range graduations.

So we issued him a new rifle and sent the damaged one back to Springfield for the investigation that was always made whenever a rifle failed from any cause. This one was due to a hidden seam in the metal of which the barrel had been made.

Of the damaged rifles which were returned to Springfield when I was in charge of the Experimental Department in 1917, and later, when I was Works Manager in 1919, '20 and '21, a fair per cent showed barrel failures. This might lead naturally to a question whether the barrel is properly designed as to strength, so let's look further into this subject.

Before any barrel is accepted for service it is proof fired with a high pressure test cartridge, or "blue pill," which gives about forty per cent higher pressure than the service load. These test cartridges are tin plated to make them look different from the regular cartridges, and this gives them a bluish white color, hence the name "blue pill."

When I was at Springfield, the regular service load gave a pressure of around 50,000 pounds per square inch, and the blue pill at first gave 70,000 pounds; which we later raised to 75,000 pounds, as will be explained further along.

Each finished rifle was given one high pressure proof charge, and this was followed by five service loads to test the functioning.

It would seem that this test should eliminate any barrel with a tendency to weakness of any kind; but, as we have seen, even National Match barrels can burst in service. What is the explanation?

As was stated above, every gun that failed in service was returned

to Springfield for examination, which almost always showed clearly the cause of the failure.

The object of this examination was, of course, to correct any faulty methods or design features that might be responsible. When, as was true in a large number of cases, the barrel showed a decided annular bulge or ring near the origin of the fracture, there was not much the Armory could do; the damage was plainly due to an obstruction in the bore.

A large and heavy obstruction, such as a bullet, will often make a lump as big as a walnut, and may split the barrel to pieces in addition, while a small or light obstruction, such as a cleaning patch, may leave a barely perceptible ring.

As intimated above, the barrel does not always burst when it is fired with an obstruction in it, though it generally does if the obstruction is a solid object.

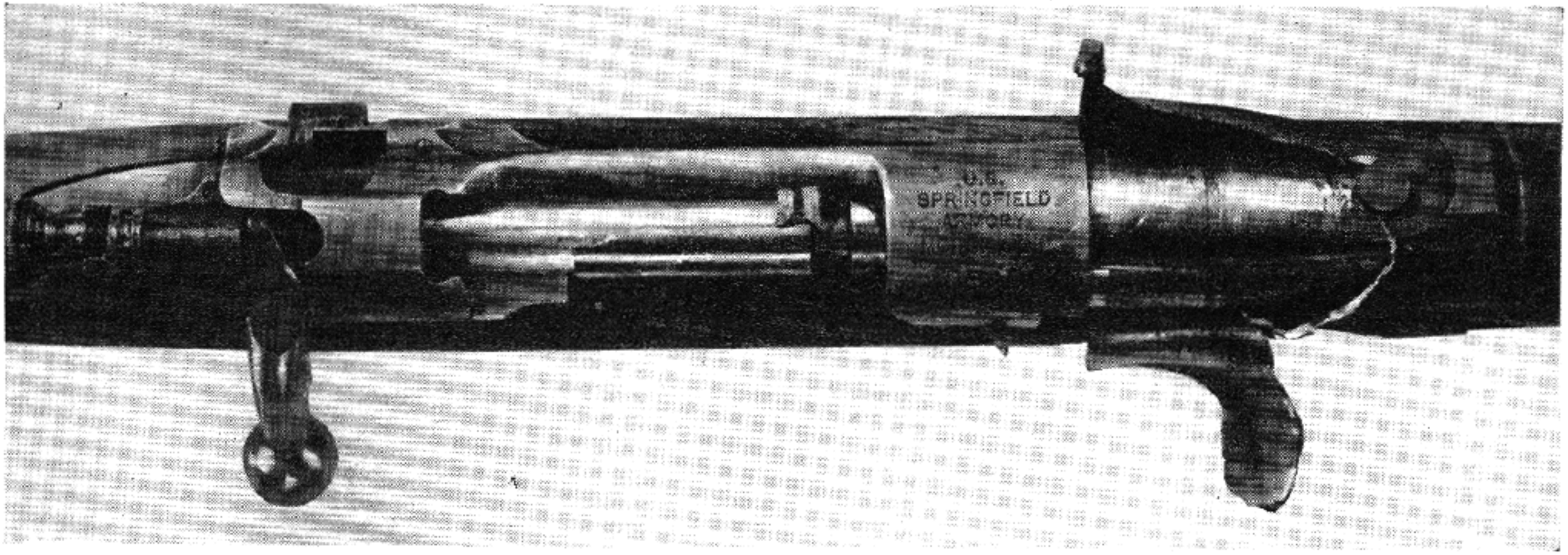
Twice I have seen a machine gun fired with a bullet already in the bore, and in neither of these cases did the barrel burst. In one case the accident was not even discovered until several hundred additional shots had been fired and though a large lump had been formed on the barrel, the functioning or the accuracy were apparently not affected.

I have seen a Springfield rifle, which, though it had a pronounced bulge near the muzzle, still shot very well indeed.

Besides obstructions there are two other occasional causes of barrel failure. One of these is seamy metal. Before any machine work is done on the barrels they come to the factory in the shape of billets of steel which are afterward heated and rolled to the approximate shape of the barrel. In this barrel steel, as in any other metal, flaws will occur. When the pieces of barrel steel are rolled out to a long shape to make the barrel blank, any flaws that they may contain are also stretched out in the same direction, so that instead of a bad spot, we get a bad streak.

Most of these streaks are discovered during the machining operations. After every turning operation on the outside or reaming operation on the inside, the barrels are carefully inspected, and any with flaws are thrown out. Once in a great while, however, it happens that a seam or flaw may be entirely inside the walls of the finished barrel. Luckily, the high pressure test eliminates most of these barrels. Some which the flaw does not greatly weaken may stand the high pressure test and get into the service. Then if by using grease on the neck of the cartridge, or by improper handloading, or in some other way an excess pressure is obtained, the barrel may fail.

Another trouble that was experienced after World War I was burnt steel. Before the war, the billets of steel were rolled into barrel blanks at Springfield Armory. But during the production rush of 1917 and 1918 outside sources were called on to do this work, and



Result of a hidden seam in the barrel. After the adoption in 1918 of a double heat treatment for the receiver and bolt, it was the practice to select a rifle occasionally from production and subject it to the highest pressure that could be obtained in a test cartridge. This rifle, selected at random from production on May 3, 1918, was first tested with ten 70,000 pound test shots, then was fired with a 125,000 pound test cartridge. The receiver and bolt held, as they invariably did with this double heat treatment, but the hidden seam in the barrel opened up, with the results shown.

the barrel blanks were bought from the steel makers already forged to shape. These factories, instead of rolling the barrel blanks to the finished shape, as Springfield did, took bars of steel which were of the right diameter for the main part of the barrel blank and formed the enlarged breech end by heating this part of the blank very hot and then upsetting or bumping up the large part.

In order to get quantity production, a great many of these blanks were heated at once, and in order to make them forge up easily and quickly, they were made good and hot. For this, as well as all other work, the steel companies had to contend with the shortage of skilled help that was felt everywhere during that War, as well as during the recent one. Under such conditions it was natural that once in awhile a piece was left too long in the furnace and became too hot.

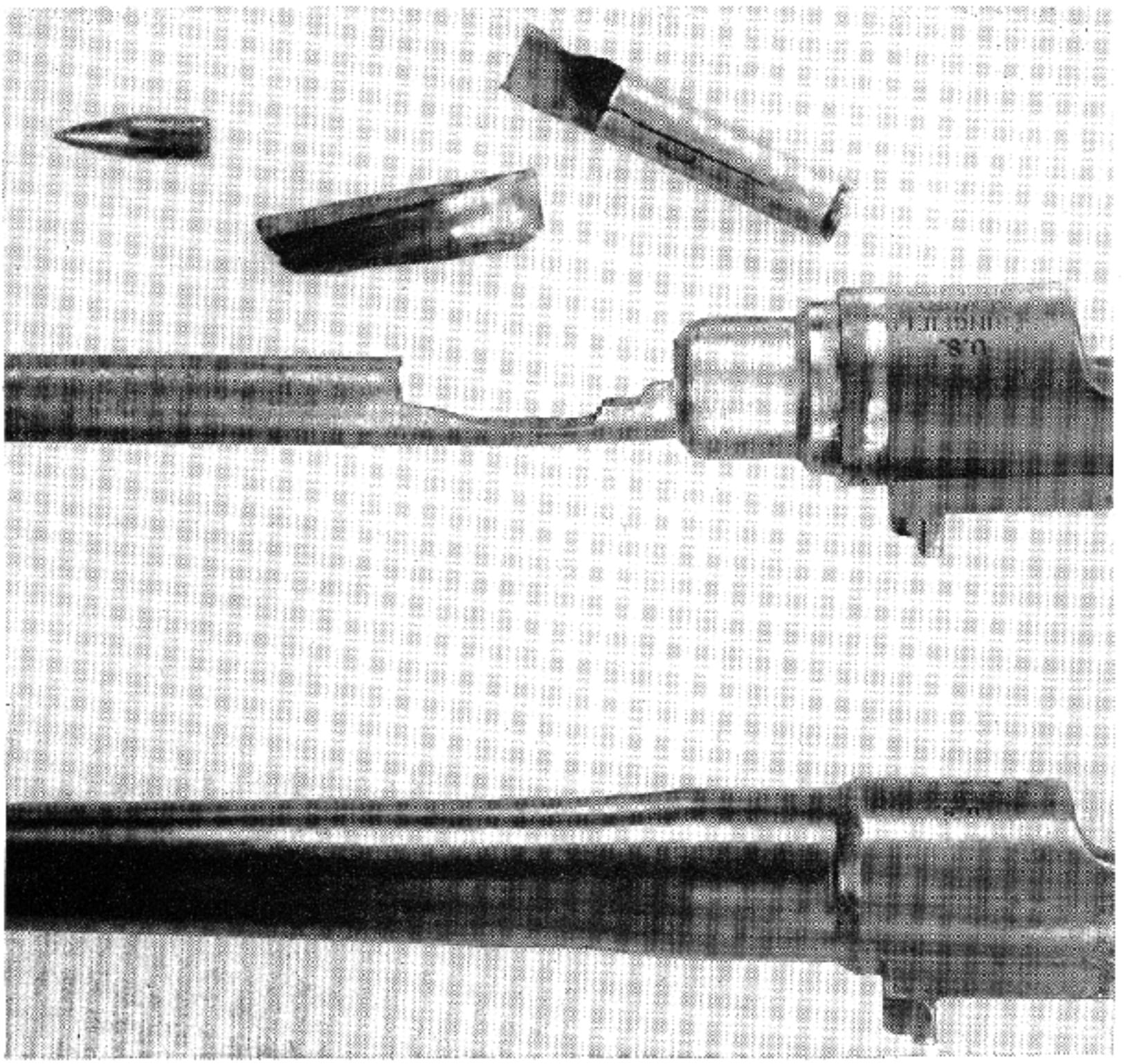
When steel becomes too hot, the fine crystalline structure that gives it its strength becomes ruined, and the metal separates into large, coarse grains with a gaseous film between them which takes away their power of cohesion and makes the steel weak and brittle. This condition is very hard to detect, because burnt steel looks like any other steel, and in automatic machinery any difference in the machining qualities could not be noticed. If such a blank should be made up into a barrel and pass the proof test it might, from the repeated shock of firing, gradually get worse in service until a break occurs.

Of course, this condition only occurs in an extremely small percentage of the blanks; perhaps one in two or three thousand, and most of these are detected by inspection or fail on proof. That the danger from this cause is small is evident from the fact that though all guns manufactured at Springfield Armory immediately after World War I had barrels made of this steel, several years passed before a barrel failure occurred which led to the discovery of this condition.

As there were several hundred thousand barrel blanks on hand at the end of the War, it meant that all barrels to be made for a long time had to be made from this steel. However, once the trouble was understood, every possible step was taken to prevent any defective barrels from being sent out. For the sake of greater safety, Springfield raised the proof charge to 75,000 pounds, instead of 70,000, to be more certain of eliminating all faulty barrels.

In the course of experiments on receivers some years ago, I used pressures up to 130,000 pounds without any apparent ill effects on the barrels. The late Sir Charles Ross, whom I knew well, had told me about his experiments on the thickness of barrels, and I had read some remarks by Newton on the same subject, but I couldn't get sufficiently authentic facts to satisfy me, so I collected some first-hand information by turning a Springfield barrel to 1/8 inch wall thickness and firing it with regular and high pressure cartridges. As

the results were not visible, I turned the barrel down so that it was only 1/16 inch thick over the chamber. It held three regular service cartridges perfectly. I then put a 75,000 pound shot through which blew a piece out of the side, as can be seen in the photograph. As



The upper barrel was turned down until it was reduced to the size shown. Three regular service charges were fired with no effect, but a 70,000 pound blue pill (high pressure test cartridge), lifted out a piece as shown. Lower barrel is for comparison to show size before any metal was removed.

the thickness of the regular barrel at this point is 5/16 of an inch, it is plainly evident that the strength should be sufficient.

Failures in the Action

Now that we have disposed of the barrel, lets consider the action. I once received a letter in which the writer inquired about the strength of the bolt. He stated that he had read in a magazine that the Springfield bolt was much weaker than that of the Krag-Jorgensen, and that the Springfield bolt was dangerous because of a tendency to blow out of the rifle, which the Krag would not do. Of course,

anybody who has any conception of rifle construction knows that either the Springfield bolt or the Enfield bolt with double lugs is far stronger than the Krag bolt with only one lug.

Even so, the Krag has entirely satisfactory strength for the range of pressures for which it was designed, that is, about 40,000 pounds maximum. In connection with its loading of Krag cartridges, the Ordnance Department determined that the pressures should never be allowed to go over 42,000 pounds per square inch.

These guns have been used by many persons with little regard for this limitation, and consequently we occasionally see a Krag with one locking lug cracked, or even broken entirely off; other Krag bolts have broken in two just back of the locking lug. However, these bolts *did not blow out of the gun;* there is a rib on the right side of the bolt that bears against a shoulder on the receiver, and this acts as a safety lug, and in addition, the bolt handle turns down into a slot at the rear, which acts as a further safety feature.

The Krag rifles have been in use since October, 1894, when the first issue of the so-called Model of 1892 was made. During the intervening period of over 50 years this fine rifle has made a great reputation for itself.

The 1917 Enfield will occasionally shed its lugs. One such case came to my attention in March, 1947. The bolt had both lugs cracked entirely off, but, as usual, stayed in the gun. The cartridge showed every evidence of extreme pressure, and was covered with a spotty black deposit of caked material which indicated that perhaps it had been covered with grease when fired, which would readily account for the high pressure. The owner sent along the damaged bolt and the cartridge case, accompanied by a letter which stated in part:

". . . This shot blew the bolt and locked it in the gun so that we couldn't get the empty shell out. On taking it down, we found the bolt had blown apart; that is, two pieces had blown off the shell extractor end. It looks to me like a person could have been hurt if the bolt could have come out. . . ."

While I don't believe the writer of the letter intended it as ironical, the last sentence is certainly a magnificent understatement. Fortunately for him the bolt, as usually happens, was held in place in spite of the loss of its lugs.

For a good many years most of the rifles damaged in service were returned to Springfield, and as far as I know, no one has ever seen a case where the bolt was actually blown out. I have heard people speak of cases where the "bolt blew out" but investigation or closer questioning has always shown that the statement was not accurate. I have never been able to run down one authentic case. In some of the low numbered Springfields, made before the heat treatment was revised, lugs have been known to crack off, but in all cases the safety lug kept the bolt from actually coming back.

Just how strong the lugs really are in relation to their normal load was very well shown by an experiment I made at Springfield some years ago. The lugs of the bolt, which have a standard length of four-tenths of an inch, were reduced to one-half that amount, and firing tests were conducted with both service cartridges and high pressure loads with no bad effects. The lugs were then reduced in thickness to one-tenth of an inch, or one-fourth of their original dimensions. Shots with service cartridges caused no trouble, but a 75,000 pound blue pill broke off the weakened lugs. Still, the safety lug held, and the bolt did not move.

This test indicates that the lugs on the bolt are about four times as strong as necessary to hold the service cartridge. Still, this test did not satisfy us. We thought we might as well find out exactly what the safety lug would do by itself, so we took another bolt and removed both lugs. The service shot crushed the safety lug slightly, but did not move the bolt. The high pressure shot sheared off the metal of the safety lug which was already crushed, and allowed the bolt to move back slightly. However, the bolt did not move far, for the safety lug sheared off at an angle, and the remaining part wedged under the right-hand wall of the receiver, bringing the bolt to rest after it had moved back about half an inch. If a bolt with the locking lugs entirely removed requires a blue pill to move it half an inch, the regular bolt, with all its lugs, must be pretty safe.

The Strength of the Receiver

The next subject, and perhaps the most important one of all, is the strength of the receiver. A broken receiver makes a bad mess, and once in a while we do see cases of this kind. It was in the spring of 1917 that I first came actively into contact with the question of receiver strength. I had just come to Springfield Armory from the Mexican border, and had been placed in charge of the Experimental Department, where one of my first duties was to examine two burst rifles and report on the cause of the trouble. Both rifles had failed while using a certain make of wartime ammunition. This, on the face of it, pointed to defective ammunition as the cause of the trouble, but only a cursory examination of the steel in the receivers was required to show that it was coarse grained, weak and brittle. I reported that soft cartridge cases had probably contributed to the failure, but that the real underlying cause was poor steel in the receivers. At first this report was received with skepticism. It was argued that the Springfield rifle had been used for years with no complaints, and that as both accidents had occurred with the same ammunition, the cartridges were to blame. The answer to this was, that aside from any fault in the cartridges, the steel was susceptible to a very considerable improvement, which should be made in order to give the rifle the greatest possible factor of safety, even with

bad cartridges. Finally this view prevailed; the Armory obtained the services of a highly skilled metallurgist and a staff of assistants, and completely revised the heat treatment of the receiver and bolt, as will be described in detail later on. Meantime, as Chief of the Experimental Department, I proceeded to find out all that I could about receiver strength and related matters.

One of our first steps was to try the effect of soft-headed cartridge cases. To do this, we took out the bullets, powder, and primer from a number of cartridges and annealed the heads of the cases, thus making the brass very soft. We then reloaded these cases and fired them.

We found that they were more dangerous than the high pressure cartridges. When they were fired, these soft-headed cases would spread out at the back end, or give way entirely, letting the gas at high pressure out into the receiver, with disastrous results. When gas at 50,000 pounds is pressing on the inside of the barrel, it does not have much surface to work on, and the total load is not great, but when it gets out into the bolt-well of the receiver, whose diameter is about an inch, it has more surface to push against, and the total load is enormous. A failure of this kind may burst a weak receiver, and even if the receiver is not injured, escaping gas is likely to do damage of other kinds, such as blowing off the extractor, splintering the stock, or blowing out the magazine floor plate. An extreme case of this nature occurred with soft cartridge case in a 1919 National Match rifle in which the receiver, bolt and barrel were too strong to be injured, but the stock was badly splintered.

Besides soft cases, we tried the effect of high pressures. As the rifles were constructed at that time, the average gun would stand about 80,000 or 90,00 pounds, but a 100,000 pound shot could be pretty well depended on to burst the receivers of almost any of the rifles then coming off the production line

One thing made evident by these tests is the fact that the weakest feature of most modern military actions is in the cartridge case itself. In the Springfield rifle the head of the cartridge case projects out of the rear end of the chamber a distance of from .147 to .1485 inch; in other words, there is a space of well over an eighth of an inch where the pressure is held in only by the brass. This is the weak point of the M 1903 Springfield, the M 1917 Enfield, the M 98 Mauser, and other high powered rifles using rimless cartridges.

When very high pressures are encountered, this brass wall either spreads or blows out, and the gas under high pressure gets loose and wrecks things. If the receiver is weak or brittle, it may be fractured; if it is strong, then the extractor may be blown off, the magazine well may be bulged, the stock may be splintered, and other damage may be done.

In the design of the U. S. Rifle Cal. .30, M1, Mr. Garand took

great pains to eliminate this source of weakness by arranging the rear end of the chamber and the front of the bolt so that the metal of the cartridge case is surrounded right down to the extractor groove by the chamber walls.

In spite of the fact that there were over four million Garand M1 rifles made during World War II, there has never yet been a case reported of a blown receiver or bolt on this rifle. It is true that as a result of firing grenades, the rear wall where the bolt is arrested in its backward stroke has cracked out in a few instances, but there has never at this writing, (June, 1947) been a case reported where the receiver has failed at the front end where the locking is accomplished.

In trying to determine the ultimate strength of the gun, Mr. Garand built up progressively higher proof loads in increments of 5000 pounds pressure, from the regular proof load of 70,000 lbs. to the extreme figure of 120,000 lbs, per square inch.

At this latter figure, cracked left lugs on the bolt began to be encountered. A gun in which the bolt had the left lug cracked by one of these excessive high pressure overloads was then fired an enduranace test of 5000 rounds of service ammunition, using the cracked bolt, which showed no further deterioration. The U. S. M1 Rifle thus has perhaps the strongest action of any military shoulder rifle in existence at this time.

The M 98 Mauser and the Model 99 (1939) 7.7 Japanese rifle are safer than the Springfield in this regard, because in each of these guns the supporting metal of the chamber comes to the forward edge of the extractor groove instead of leaving some of the actual cartridge case wall hanging out in the air, as do the Springfield and Enfield.

The Krag, which uses a rimmed case, does not have this weakness. The case enters the chamber right up to the rim, and there is little chance for the cartridge to fail at the head. That is the main reason why we never, or at least hardly ever, hear of a burst Krag receiver. A nearly similar condition is true of the Japanese Model 38 (1905) 6.5mm Arisaka rifle. It uses a semi-rim cartridge, which has only a very slight extractor groove, and the cartridge head is thus quite strong. As the cartridge walls are also particularly well supported near the head, the action of this rifle is harder to wreck than those of the Springfield, Enfield, or Mauser, all of which use the truly rimless cartridge with its weaker head construction.

Some Reasons for Cartridge Failures

As has been stated above, the modern military bolt action rifle is no stronger than the cartridge case; or stated another way, the first thing to fail is usually the case.

A serious weakness in poorly made cases is softness of the metal

near the head of the cartridge. Brass gets soft when it is heated, or *annealed;* and it gets hard when it is worked. In order to be able to draw the brass from sheets into long tubes, it is heated and thoroughly softened. After the tubes are drawn, the head must be hardened. This is done in the process of giving it its final shape, during which process the metal must flow into the shape given it by the dies. Forcing the primer pocket into the solid metal aids considerably in the hardening or working process. Another thing that helps is imprinting the lettering that gives the make and date. I remember in one series of cartridges where we wanted the heads particularly strong, to hold some high-intensity loads, we carefully changed to bigger and deeper



Cartridge case with longitudinal split in head and rear end of body. Note the off-center position of the ring crimp around the primer. The case was not held centrally on the supporting stem during the primer crimping operation, and the crimping punch struck harder on one side than on the other, thus over-stressing the metal on the high side, and making it too hard and brittle. The prevalence of this defect in cases of 1934 Frankford Arsenal manufacture led to a study which revealed the cause and led to a correction of the process to avoid a recurrence.

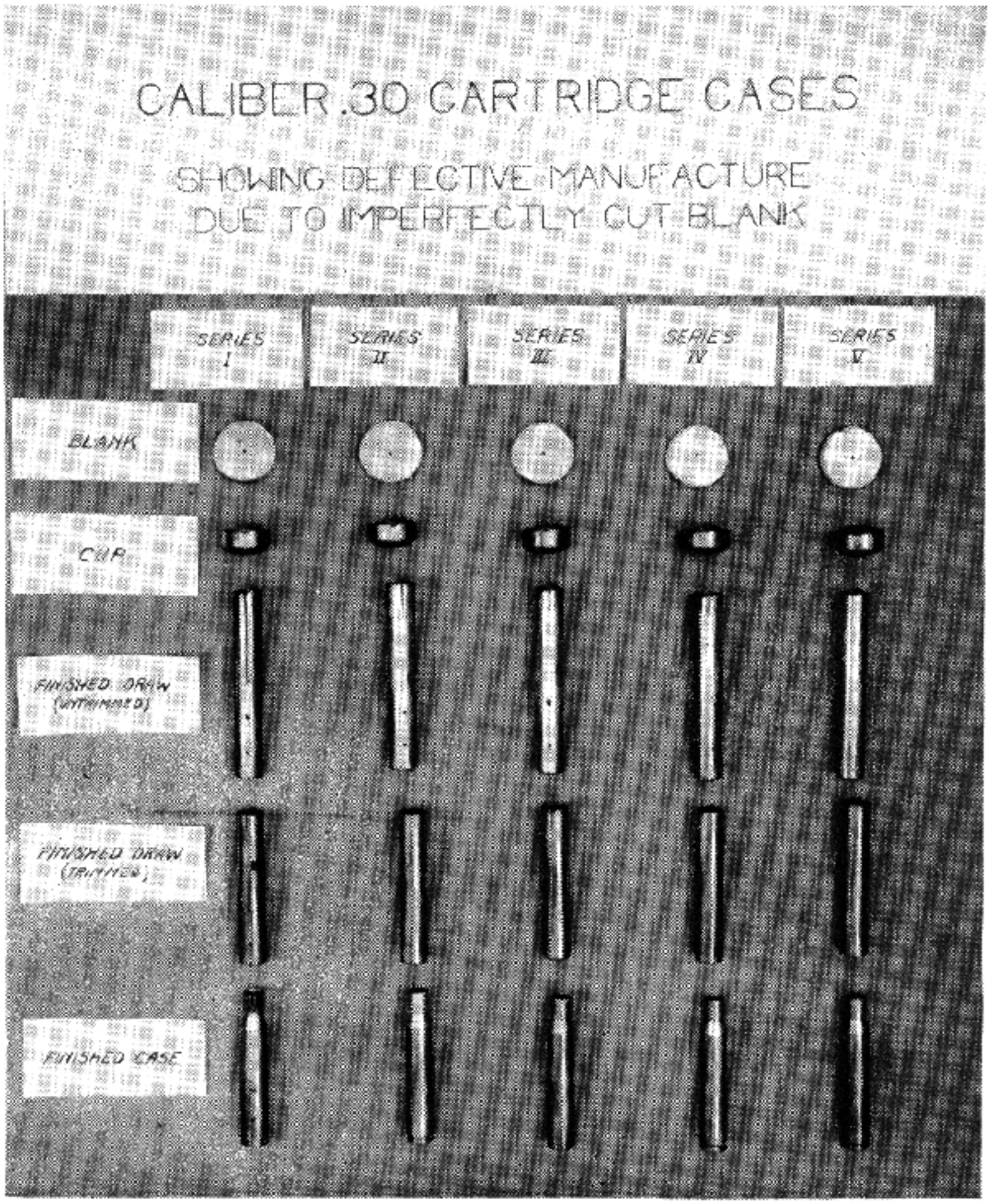
The case illustrated was sent in April 24, 1947, after the text describing such defects had already gone to press; thus it furnished excellent confirmation of the previously written material.

The shooter reported that he got "quite a blast of hot gas," but as he was wearing shooting glasses, he was not injured.

letters stamped on the head, and gained quite a bit of additional hardness and strength this way.

After the head is formed, the cartridges under process of manufacture must be heated again, so that the body can be tapered and the neck formed. This heating is often performed with the head of the case standing in water, so that it cannot absorb heat and thus become softened. If one of these should by some accident during manufacture have the head heated after it is formed, the head may spread and the primer pocket open out during the stress of firing, and damage to the gun may result. Thus in cartridges a soft head is a dangerous defect.

Another defect that is quite dangerous is a longitudinal split in the body of the case. The rear end of the case is rather thick, and the rear end of the chamber is made a little loose, so that cartridges can feed and extract easily. The thin front of the cartridge, that can expand and hug the walls of the chamber is depended on to keep the gas in. If the case should split near the back end, where the metal is too thick to hug the walls closely, gas will come back, and if



Photograph made at Frankford Arsenal to show how a slight nick in the disc from which a cartridge is drawn may cause a body split in the finished cartridge when it is fired. The nick is more pronounced in Series I and decreases in the others.

the shooter is not wearing glasses, serious eye injury may result. Always wear shooting glasses!

In well made cartridges, this defect of a longitudinal body split is not very common; but at one time Frankford Arsenal was having quite a bit of trouble from this cause. Master Mechanic Andrew H. Hallowell undertook to find out why the condition was occurring, and he finally traced it to the fact that when the discs from which

the cartridges are made were being cut from the sheet brass, they were spaced too closely together, so that occasionally there was a bit of overlapping, and the edge of one of the discs might be nicked slightly.

"Andy" found that when this occurred, the nicked place caused a tiny crack that extended some distance down along the side of the drawn cartridge case, and sometimes opened up under the pressure of firing. This is shown in the photo made at the time from blanks that were found to have a slight piece cut out of the edge.

As soon as the cause of this trouble was found, it was of course eliminated but some time later, the same defect cropped up again. This time it was found that the presses had been speeded up in an effort to gain more production per day; evidently if the cases were drawn too fast, the metal was worked and hardened more than was good for it, and became brittle. When the presses were returned to their former slower pace, the trouble again disappeared.

Once more, however, the defect of lengthwise splits in the rear part of the cartridge case body appeared, this time in the 1932 .30 caliber M 1 ball ammunition. Once more the shop "detectives" were put on the trail to find out why. After some cases were cut up and micro-photographs were made it was seen that on one side the brass crystals were smaller than they were on the other side, indicating harder brass there. It was also seen that the metal of the head was thicker on that side. Cases that had not yet had the primers crimped in did not show the streak of hardness down one side.

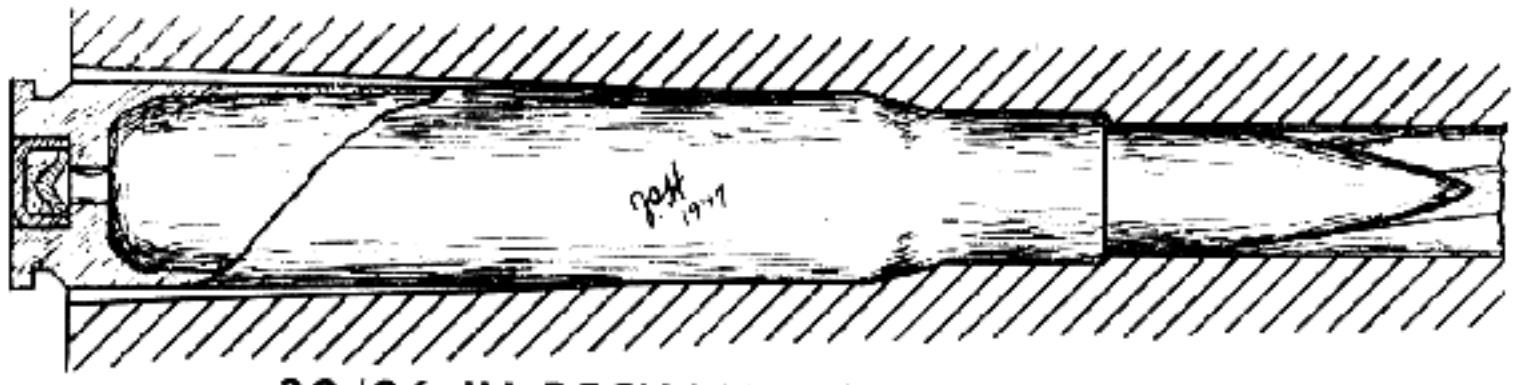
It was finally determined that the crimping-in of the primer was responsible for making a streak of hardness down one side of the cases that sometimes gave way in the form of a crack. In crimping-in the primers, the cases are held on a stem which acts as an anvil for supporting the case against the crimping punch. When one side of the head was thicker than the other, this supporting stem made contact with the inside of the case only on the high side, and when the ring-shaped crimping punch came down, this thick section was pinched, and a streak of hardness, and consequently, of brittleness also, extended down this side of the case, and it was at this place that the splits appeared.

In the cartridge making business, there is never a dull moment!

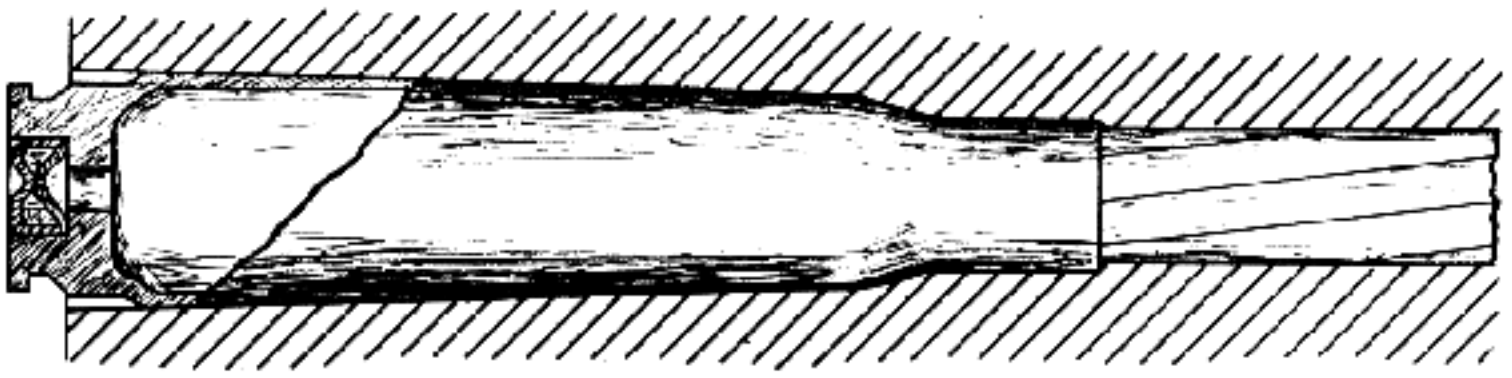
As stated above, longitudinal splits in the body of a cartridge case are dangerous, because they allow gas to come to the rear through the mechanism, and there is danger of injury to the firer, especially to the eyes. One thing that encourages such splits is a chamber which is very loose fitting at the rear.

It so happens that the Model 99 (1939) 7.7mm Japanese rifle has a bore only a little bit larger than ours; three thousandths, to be exact, as this rifle is a .303. The cartridge is a few thousandths larger than ours is at the rear end, and is shorter than ours. Therefore it is quite

easy to convert these Japanese rifles to shoot our ammunition by deepening the chamber; or our .30 caliber cartridges can be necked down to work in these guns. Unfortunately, however, the rear of the chamber is too big, and every time a U. S. .30-'06 cartridge is fired in one of these guns, there is a strain on the rear of the cartridge case, inviting it to split. If the brass is perfect with no flaws or



30-'06 IN RECHAMBERED 7.7MM.



SAME AFTER FIRING



GAS LEAKS IN CASE

Top: .30-'06 cartridge in rechambered Japanese 7.7mm. Note the clearance around the rear of the cartridge case, which for reasons of clarity is slightly exaggerated in the sketch.

Middle: .30-'06 cartridge case in rechambered 7.7mm Rifle after firing. Note that the thin walls of the case have expanded to fit the chamber, but the head of the case, where the metal is thick, has not expanded.

Bottom: When this .30-'06 cartridge was fired in a Japanese rifle, two longitudinal splits developed in the case as shown, permitting hot gas at high pressure to escape violently to the rear. The case, sent in by the member to whom the accident happened, is head stamped F.A. 39. Fortunately no serious injury resulted.

planes of weakness, there is slight chance of having this happen, but if the weakness is there, such a split will happen more easily than it will in the tighter chamber of the M 1903 rifle; and more gas will come back, as the loose chamber gives more room for it. So far, (March, 1947), I have seen only one case where this happened with the Model 99 (1939) 7.7 rifle chambered for our cartridge, but I expect to see more.

These Jap rifles are good strong rifles, but they are by no means

proof against blowing up if abused. Recently some boys tried shooting .35 Remington cartridges in one of these guns. The bolt closed so hard that the boys used a mallet to get it shut, and they actually fired two shots with no damage to the gun; but on the third shot the receiver gave way completely and the firer had a piece of steel embedded in his brain. I am happy to be able to state, however, that after a delicate operation, the life of this intrepid young experimenter was saved.

IX

Receiver Steels and Heat Treatment

The trouble with weak receivers that occurred in 1917, and which has already been mentioned briefly, led to a complete change in the heat treating methods at Springfield Armory, and to change of heat treatment and afterward, a change of steel at Rock Island. Both these important changes were later followed by others. In order to understand just what happened and the reasons for what occurred, it is necessary to go back into history a bit.

From the time the Springfield Rifle went into production in 1903, and up until 1927, the receiver and bolt were made of Springfield Armory Class C Steel, afterward W. D. 1325, having a composition as follows:

	Min.	Max.
Carbon	.20%	.30%
Manganese	1.10%	1.30%
Silicon	.15%	.35%
Sulphur		.05%
Phosphorus		.05%

The receiver was forged under a 2,000 pound drop hammer, hot trimmed, and then while hot was given one blow in the forging dies under the hammer to straighten it. It was next put in charcoal and allowed to cool very slowly. It was then pickled to remove the scale, and again put under the drop hammer cold to bring it to size, after which it went to the receiver shop where all machine operations were performed.

After machining was finished, the receivers were heated in bone, four in a pot, to 1500° F. and kept at this temperature four hours. This was in a muffle type oil furnace. The receivers were then quenched in oil.

At Rock Island receivers were made from the same steel until 1918. The treatment was as follows:

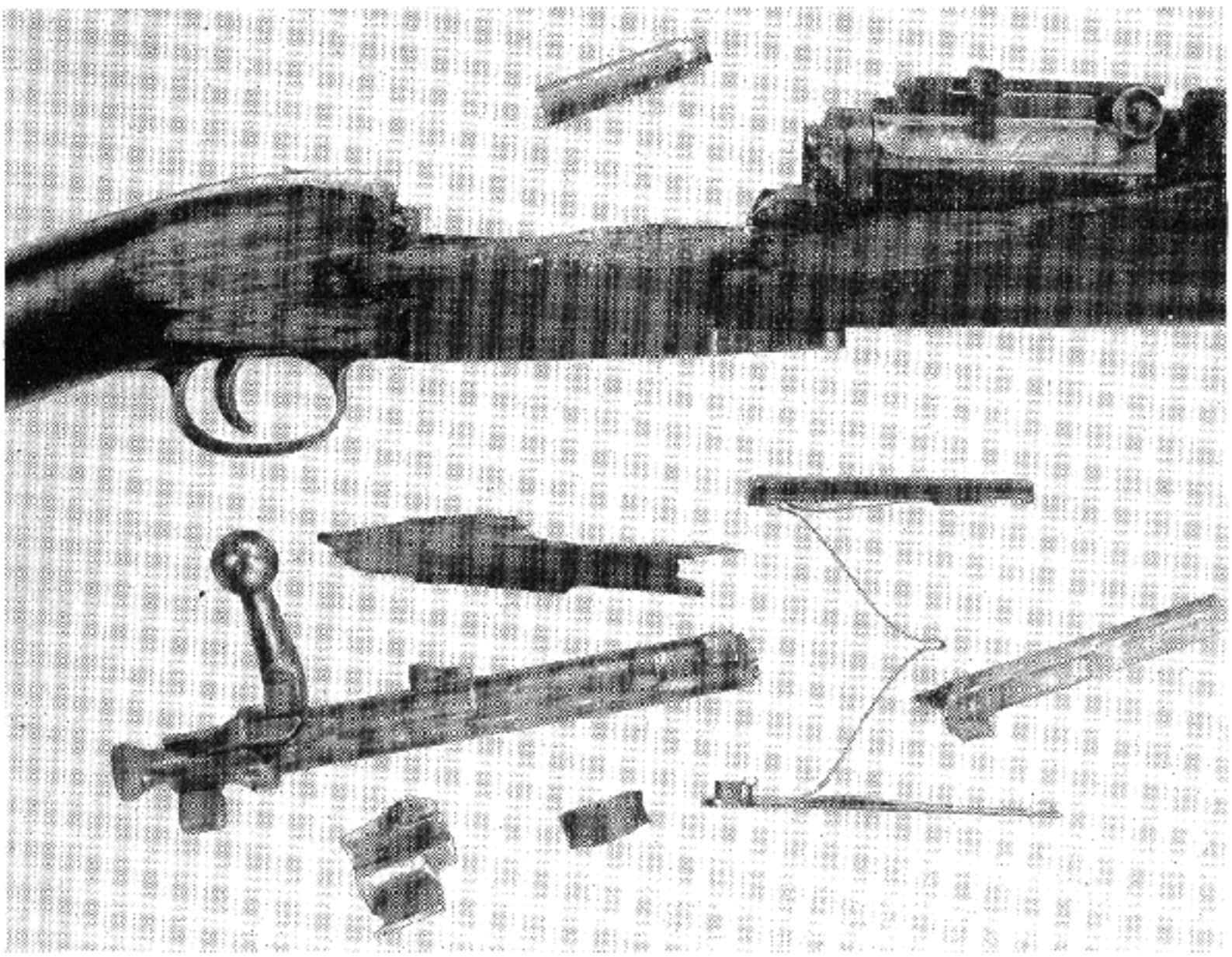
Pack in charred leather in pots. Heat to 1475 to 1500° F. and hold at this temperature for 3½ to 4 hours. Quench in oil.

This quenching from a high temperature made the receiver fairly hard all the way through, though the surface and the material near the surface into which the carbon from the charred leather had penetrated were harder than the interior, so that the piece was actually case-hardened.

Now the harder the steel, the greater its tensile strength, and these receivers, being quite hard, were very strong and highly resistant to

a *slowly* applied load. Also, the harder the steel, the more brittle it is when subjected to a *sudden shock.*

The very hard surface had excellent wearing qualities, and made a fine smooth working action. When properly headspaced and used with ammunition of good quality, these receivers gave excellent re-



Springfield rifle with low numbered receiver, burst at Sandy Hook, N. J., October 24, 1921, by having a 7.9 German service cartridge fired in it. Such a cartridge fired in a Springfield rifle results in a pressure of over 75,000 lbs. per square inch. It may burst a low-numbered receiver, but tests have shown that the double heat treated receivers will stand this mis-treatment without giving way. For full report see Chapter 18, p. 458.

sults. The Springfield rifle had then been in use for some fourteen years, and there were about 700,000 of them in existence, and there had never been any complaint, though it was later found that some of them, while showing a high static strength, would shatter under a sudden blow.

The maximum working pressure for the service cartridge was 50,000 pounds per square inch. Each finished rifle was proof fired with a test cartridge or blue pill giving a 40% overload, or 70,000 pounds per square inch, after which it was function fired with five service cartridges. This eliminated most of the weak ones. Very rarely one would break in service, but usually this could be traced to some abuse, and anyway, it happened so seldom that it caused no comment.

When World War I came along, the production of rifles was stepped up to the maximum possible, both at Springfield and at Rock Island, and at the same time several new companies tried their hand at making ammunition, and some of the new cartridges were far from satisfactory in quality.

This was the situation when, as already described, I was given the job, in the spring of 1917, of investigating the cause of the damage to two rifles sent in from the new cartridge factory of the National Brass and Copper Tube Co., at Hastings-on-Hudson. In both of these rifles the receivers has been demolished, but the barrels were intact, with the cases, or what remained of them, still in the chambers.

This was only a year after my graduation from the Ordnance School of Technology at Watertown Arsenal, where I had taken, among other subjects, a course on the metallurgy of iron and steel under Dr. Fay of Massachusetts Institute of Technology. I was by no means a skilled metallurgist, but at least I thought I knew burnt steel when I saw it and this is what the fractured surface of the first rifle looked like to me.

The gun had been fired only 252 rounds when it gave way. The engineers who examined the rifle at the cartridge factory where it failed sent along a note which stated: "It is the judgment of everyone who has seen the broken edges of the receiver that the steel most emphatically is not properly case-hardened as per specifications, and that it has been heated too hot before quenching, creating crystallization and resulting in the greatest weakness. There is no wonder it burst."

I could quite agree that the steel appeared to have been weakened by overheating. Pieces of this receiver placed in a vise and tapped with a hammer simply fell apart.

On these two guns there was also evidence that the heads of the cartridge cases had been soft, and had expanded before the receiver failure, thus letting gas under high pressure get out into the receiver ring where it had such a large surface to work on that the load on the receivers was greatly increased.

My experiments resulted in a report which stated in effect that the damage had been caused by a combination of soft headed cartridge cases and receivers which were weak and brittle; and further, that similar weak and brittle receivers were still coming off the production line. Half a dozen new receivers were taken at random from the assembly room and fastened in a vise and struck with a hammer. Several of them shattered to pieces.

As has been stated above, this report led to the employment by the Armory of the best obtainable metallurgical staff, headed by Maj. W. H. Bellis, a well known specialist on the heat treatment of iron and steel.

One fact that this staff quickly developed was that the forging

temperature was not being sufficiently controlled. Too much reliance was being placed on the knowledge and experience of the furnace men who heated the receiver and bolt steel in the forge shop.

These men thought that they could tell when a piece had the right heat just by looking into the furnace. They were proud of their experience, skill, and ability, and believed that it took years of practice to become expert in judging the forging temperature. They were highly paid craftsmen, who were jealous of their exclusive skill, and who both hated and feared these new fangled pyrometers which threatened to make useless their special knowledge.

The first step taken by the metallurgists was to install pyrometers, when it was quickly found that the "right heat" as judged by the skillful eye of the old timers was up to 300 degrees hotter on a bright sunny day than it was on a dark cloudy one. This variation was of course made much worse by the fact that production had been stepped up to such a degree that many less skillful men had to be employed on this and all other critical jobs. The production rush had, as always happened, caused a drop in the quality of a product which even at best was not up to what could be obtained by the most modern controlled methods.

A further result of the fine work on the metallurgical improvement of the bolt and receiver by Major Bellis and also by Lieut. Col. W. P. Barba, Chairman of the Ordnance Department Board on Steel, and others, was the development of an entirely new so-called double heat treatment for the Springfield Armory Class C Steel, as follows:

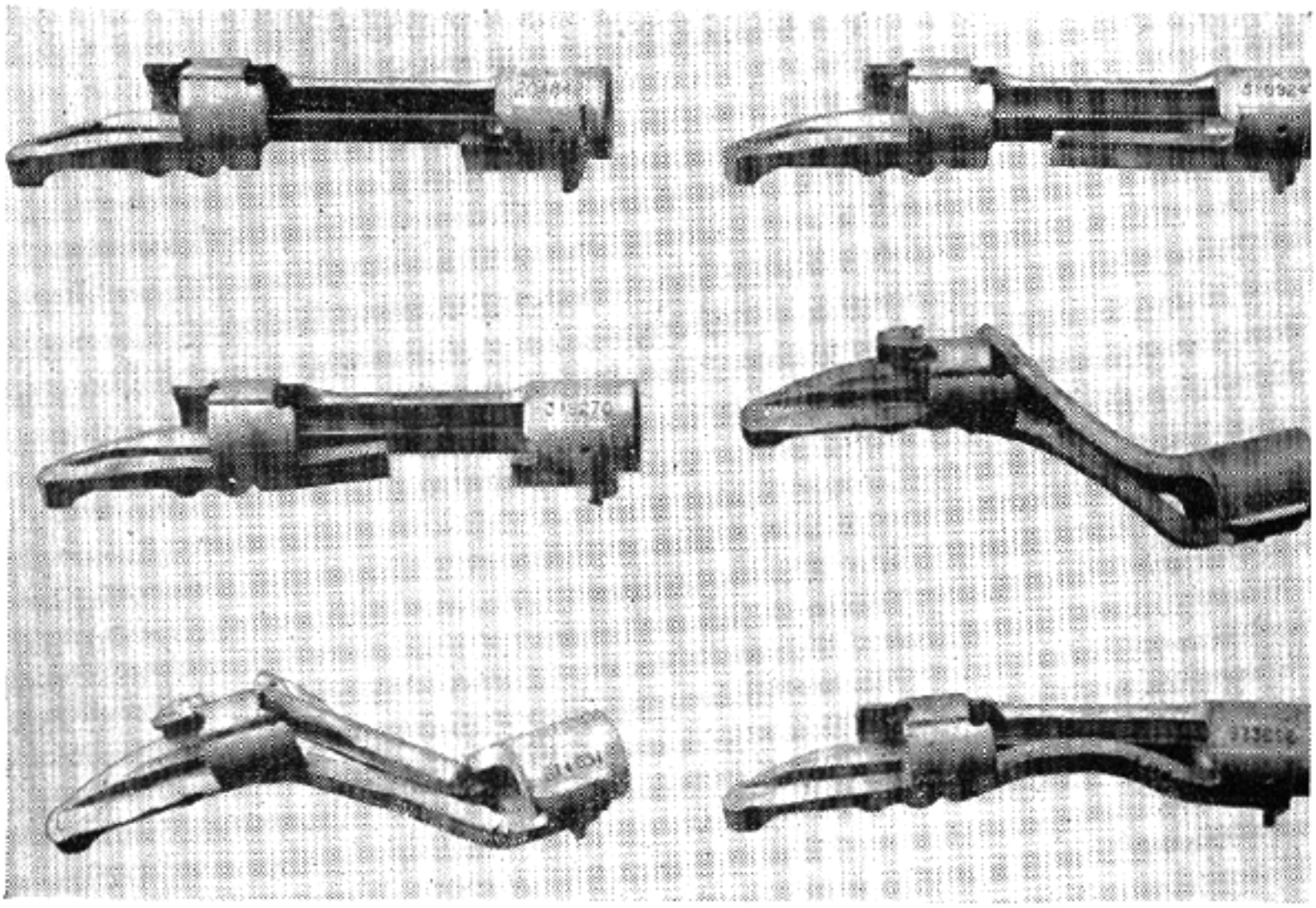
The receiver was forged under a 2000 pound drop hammer, hot trimmed, and then given one blow under the hammer to straighten it, after which it was allowed to cool in an open pan. It was then pickled to remove scale, cold trimmed, and brought to size cold, under the drop hammer. It was then annealed by packing in charcoal, heating to 1500 degrees F. for 2 hours, and cooling in the furnace, after which it was pickled, inspected, and machined.

After machining, the receiver was heated in bone in an American Gas Company Carburizing Furnace at 1500 degrees F. for 2½ hours, then quenched in oil. It was re-heated to 1300 degrees F. in a salt bath for 5 minutes, and again quenched in oil. It was next drawn at 350 degrees F. in an oil bath and air cooled, and tested for hardness with a Scleroscope, which should give a reading between 45 and 60. This would correspond roughly to from 33 to 44 Rockwell C.

The difference in the resulting receiver (and bolt) structure between the old and the new treatment can be outlined briefly as follows:

In both methods, the receivers (and bolts) were carburized so that the metal on and near the surface had a higher carbon content than did the inside. In the old method the receiver was simply heated above the hardening temperature of the steel and then quenched. This made

the receiver hard all the way through, though the carburized surface, having a higher carbon content came out harder than the lower carbon interior, which, however, was still hard enough to be brittle under shock.



Comparison of case hardened receivers as made at Springfield and Rock Island up to 1918, with the double heat treated receivers made at Springfield between 1918 and 1927.

Top left: Receiver No. 204,842. Top right: Receiver No. 318,924. Middle left: Receiver No. 319,270. These were all of the old case hardened type A light blow with a steel rod shattered the side rib of the receiver, showing that the steel, while strong, was too hard to resist impact.

Middle right: Receiver No. 808,549. Bottom left: Receiver No. 811,951. Bottom right: Receiver No. 833,698. These receivers, numbered above 800,000, all had the double heat treatment, giving a hard surface and a soft tenacious core. When repeated blows with a steel rod failed to shatter the side rib, which is the weakest part of the receiver, they were fastened in a heavy vise and belabored unmercifully with a heavy iron bar. Note that while cracks appeared in the hard surface where it was bent, the soft interior held the metal together. These double heat treated receivers fitted with bolts having the same treatment produced the strongest rifle actions ever made.

The new treatment was based on the fact that the higher the carbon content of the steel, the lower the temperature to which it must be heated to make it harden when quenched from this temperature.

As the reader is no doubt aware, the hardness of carbon steel is largely dependent on the form in which the carbon exists in the steel. If the carbon is in a form called Pearlite, the steel will be soft. If it is in a form called Martensite, the steel will be hard. If it is part one and part the other, the hardness will be intermediate. When steel is

heated, a point is reached at which it seems to absorb heat. At this so-called decalescence point, the Pearlite turns into Martensite. This is one of the "critical" points of steel. If the steel is heated to this point and then cooled slowly, another critical point, called the recalescence point, is reached some 200 to 250 degrees lower, where the steel stops cooling for a time and actually seems to give out heat as the Martensite turns back to Pearlite. Steel cooled slowly in this way will come out soft. But if, when the steel has reached the first critical point, it is cooled suddenly, as by quenching in brine or oil, the Martensite is trapped before it can change back and the metal becomes very hard. This operation is called hardening.

If the hardened steel is then heated, it begins to soften. If heated a little, it is softened slightly. If heated nearly to the critical point, it becomes very soft.

Now the newer double heat treatment takes advantage of the fact that, as noted above, the higher the carbon content of the metal, the lower the temperature to which it must be brought to make it harden when cooled suddenly.

Thus if the piece is quenched from a temperature just high enough to permit hardening the carburized outside surface, the lower carbon inside core will remain very soft.

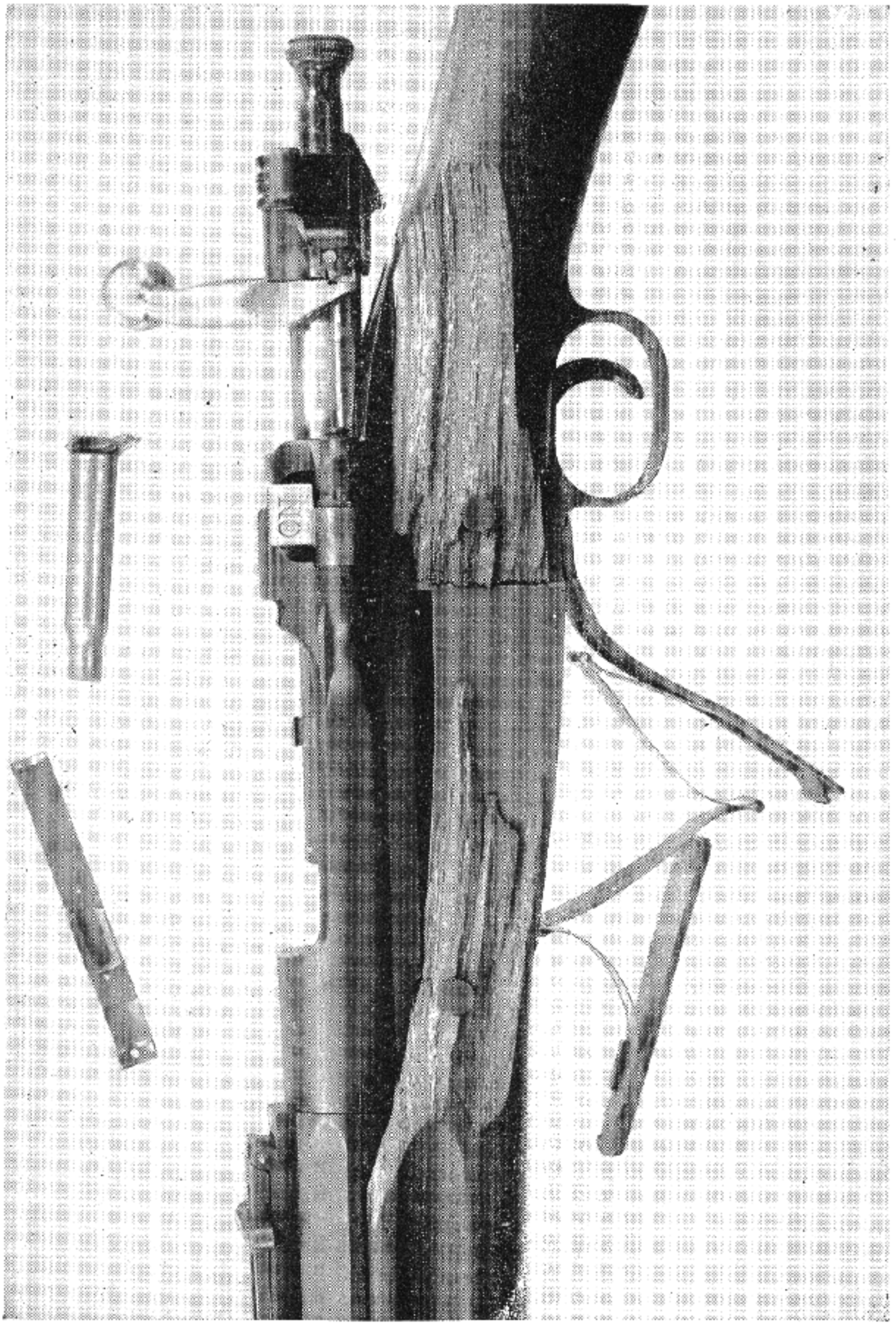
In the revised heat treatment, heating to 1500 degrees and quenching hardens the receiver through and through, and refines the grain. Re-heating to 1300 degrees draws the temper and softens the metal. This temperature is above the hardening point of the high carbon outside surface but not hot enough to cause the low carbon inside core to harden when quenched. When the piece at 1300 degrees is then plunged into oil, the outside surface becomes very hard, and the inside core remains soft and tough. Afterwards the receivers are heated to 350° F., which slightly reduces the hardness of the surface layer and adds to its toughness.

Typical of the old single heat treatment is the following test of three receivers:

After firing ten rounds of 70,000 pounds per square inch the increase in headspace was found to be from .003 inch to .006 inch. One of the three receivers tested was blown up with one round of 80,000 pounds per square inch and the other two receivers broke with the firing of one round each of 100,000 pounds per square inch.

On the other hand, receivers with the double heat treatment could not be broken with the highest proof loads that could be made up for this caliber, namely 125,000 pounds per square inch.

In 1926 a Board investigating this subject took from stock 24 rifles made in 1918 having double heat treated receivers and tested them with results as given below:



This double heat treated receiver and bolt withstood a destruction charge of 45 grains of bullseye behind a 170 grain flat based proof bullet, giving a pressure of around 133,000 pounds per square inch. The head of the case practically melted away, letting the gas out into the receiver well, where it messed things up a bit, and blew splinters off the stock, but the action held firm.

HEADSPACE

Receiver No.	At Start	After 10 70000 # sq. in. proof shots	After 1 80000 # sq. in. proof shot	After 1 125000 # sq. in. proof shot
853,398	1.945	1.946	....	O.K.
853,347	1.942	1.945	....	O.K.
859,213	1.942	1.945	....	O.K.
856,789	1.942	1.945	....	O.K.
857,661	1.942	1.944	....	O.K.
858,771	1.941	1.942	....	O.K.
859,576	1.941	1.945	....	O.K.
855,485	1.942	1.944	....	O.K.
859,797	1.942	1.944	1.944	O.K.
860,825	1.946	1.948	1.950	O.K.
860,995	1.942	1.944	1.944	O.K.
861,038	1.944	1.946	1.946	O.K.
862,031	1.941	1.942	1.945	O.K.
861,534	1.942	1.944	1.945	O.K.
862,747	1.942	1.945	1.945	O.K.
862,564	1.941	1.942	1.942	O.K.
860,651	1.942	1.945	1.945	O.K.
861,049	1.945	1.947	1.948	O.K.
863,998	1.940	1.940	1.940	O.K.
865,717	1.943	1.946	1.946	O.K.
866,906	1.940	1.941	1.942	O.K.
876,523	1.944	1.950	1.951	O.K.
868,526	1.940	1.941	1.941	O.K.
868,622	1.941	1.944	1.944	O.K.

Receivers made at Rock Island Arsenal as well as at Springfield Armory had been involved in the accidents occurring in 1917 and 1918 which caused the revision of heat treatment. Rock Island was using the same steel that Springfield specified, and they made some experiments that verified the Springfield results. Accordingly on May 11, 1918, beginning with receiver No. 285,507 they adopted an improved heat treatment, as described later on for the carbon manganese steel receivers and bolts. In addition, on August 1, 1918, but receiver No. 319,921, they adopted a nickel steel similar to that being used at the time for the 1917 rifles under manufacture by Winchester, Remington and Eddystone.

This .35% carbon, 3.5% nickel steel was given the following treatment:

Heat in salt bath to 1500° F., quench in oil, and draw in sodium nitrate at 600° F. for 30 minutes. Then test for hardness with Sclerscope which must be between 55 and 70 (this corresponds roughly to 41-52 Rockwell C.).

Tests made on these Rock Island nickel steel receivers gave the following results:

Treatment: Oil quenched from 1600° F. Reheated to 700° F.

Head Space	At Start	After 10 70000 lbs. sq. in. proof shots	After 1 80000 lbs. sq. in. proof shot	After 1 125000 lbs. sq. in. proof shot
Nickel Steel	1.941	1.944	1.949	O.K.
" "	1.941	1.942	1.951	O.K.
" "	1.942	1.948	Bolt jammed	
" "	1.940	1.941	Bolt jammed	
" "	1.940	1.946	Bolt jammed	

Treatment: Oil quenched from 1500° F. Reheated to 650° F.

Head Space	At Start	After 10 70000 lbs. sq. in. proof shots	After 1 80000 lbs. sq. in. proof shot	After 1 125000 lbs. sq. in. proof shot
Nickel Steel	1.941	1.943		O.K.
" "	1.940	1.943		Blew up
" "	1.941	1.943		Blew up

Treatment: Oil quenched from 1425° F. Reheated to 650° F.

Head Space	At Start	After 10 70000 lbs. sq. in. proof shots	After 1 80000 lbs. sq. in. proof shot	After 1 125000 lbs. sq. in. proof shot
Nickel Steel			Broke	
" "				Blew up
" "				Blew up

Some time after World War I the question arose as to just how receivers with the old heat treatment could be identified. Springfield stated: "The exact date of the change from the old to the new method is not known. Between receivers number 750,000 and 780,000 there seems to have been a shifting in heat treatment. Receivers No. 800,000 was completed on February 20, 1918, and it is known that all receivers after 800,000 received the double heat treatment."

While for practical purposes the division between the old and the new heat treatment at Springfield Armory may be taken as receiver number 800,000, this cannot be considered completely accurate, as it has been said that a few receivers of the old treatment, which had been set aside for some reason were put back in the assembly line just after number 800,000. It is significant that out of the 68 accidents reported between 1917 and 1929 in which receivers of the M 1903 rifle were shattered or fractured only one was supposed to be of the new Springfield double heat treatment, and that one, which occurred in 1929, involved receiver number 801,548. I have no doubt that this was actually a receiver having the old heat treatment.

As to Rock Island receivers, on September 24, 1926, Rock Island replied as follows: "There are no records to show the serial number at which a change was made from carbon to nickel steel. Miscellaneous shop memoranda indicate that this change occurred shortly after August 1, 1918. The serial numbers in August, 1918, run upward from 319,921. One fact seems clear and that is that all finished

receivers of nickel steel were stamped 'NS' on the face at the front end. This stamping is covered by the assembly of the barrel but can be seen on disassembled receivers. A fairly sure test can be made with a file as all nickel steel receivers cut easily, while filing makes no impression on the file-hard carbon receivers."

On September 27, 1926, the following supplemental information was furnished by Rock Island Arsenal: "Stock movement records have been found showing *both carbon and nickel steel* receivers being made *each month to include December 1918 and July 1919*. No separation of serial numbers was made.

"In February, 1918, the heat treatment of carbon steel receivers was changed to the following:

"Annealed at 1500° F. for 2 hours, dropped to 1050° in the furnace, then removed and air cooled. Hardened by heating to 1550 to 1600° F. for 15 minutes and quenched in Houghton's No. 2 quenching oil. Reheated to 1425° F. followed by quenching in oil. Washed in soda kettle. Drawn in oil at 500° F.

"Instructions were issued on March 2, 1918, to destroy all carbon steel receivers *having the old heat treatment* remaining on hand and to assemble only receivers having the new heat treatment after that date. Some 16,000 receivers were destroyed.

"The serial numbers of receivers manufactured at Rock Island Arsenal prior to February 1, 1918, run from No. 1 to No. 285,506. Manufacture was suspended on January 30, 1918, and none were made during February, March or April. On May 11, 1918, manufacture of receivers was resumed with serial number 285,507.

"It would seem that if it were necessary to replace those of Springfield Armory manufacture bearing serial numbers below 800,000 it it would be desirable to do the same thing with those of Rock Island Arsenal manufacture of serial numbers less than 285,507 as the heat treatment was the same at both arsenals."

After World War I was over and the Army was demobilized, the War Department began to consider the question of what, if anything, should be done about the low numbered receivers in service.

On December 2, 1927, a Board, consisting of Major Herbert O'Leary, Major James Kirk, Captain James L. Hatcher and 1st Lieutenant René R. Studler, was convened to recommend the policy to be adopted governing the use of Model 1903, caliber .30, rifle receivers of Springfield Armory manufacture bearing serial numbers below 800,000 and Rock Island receivers below 285,507.

The following extracts from the proceedings of the Board are of interest:

A statement by Frankford Arsenal, June 25, 1925; "In view of the large number of accidents occurring with rifles having serial numbers below 800,000, this Arsenal considers that all such rifles should be withdrawn from service and not used for any firing."

And a statement from Frankford Arsenal on April 23, 1926: "This Arsenal thinks that not only the firing of grenades in rifles manufactured at Springfield Armory with receiver serial numbers below 800,000 should be prohibited, but that the firing of all small arms ammunition in such rifles should be prohibited, and this opinion has been expressed by this Arsenal upon several occasions."

Springfield Armory on June 23, 1926, stated, referring to the above: "This Armory agrees. Receivers manufactured at Springfield Armory with receivers below 800,000 are known to be weak. The use of a rifle with such a receiver is dangerous if the pressures are above normal or the headspace is excessive."

In 1923 Springfield Armory undertook an investigation to determine the practicability of re-heat treating receivers with numbers below 800,000 to determine if they could thus be given strength equal to receivers of later manufacture. One hundred receivers were re-heat treated and tested. The result indicated a considerable variation in carbon content, many receivers being low enough to require re-carburizing before heat treating.

The test showed that while the old receivers were improved by re-heat treating, they were still likely to burst at pressures slightly in excess of 50 percent above normal, while the later double heat treated receivers would successfully withstand very high pressures. The Board stated: "The test brings out quite clearly the fact that uniform results cannot be obtained by re-heat treating old receivers which vary widely in chemical composition."

It may be noted that one trouble encountered with the low numbered receivers was that some of them were dangerously weak by reason of having been overheated, or burnt, during the forging process. *No amount of re-heat treating would cure this trouble.*

In one of the experiments at Springfield Armory, 48 receivers were carefully re-heat treated, after which 16, or one-third, failed on high pressure test.

The Board found:

(1) That low numbered receivers are not suitable for service use in their present condition.

(2) That means have not yet been determined for making such receivers suitable for service use.

(3) That it is considered impracticable, if not impossible, to re-heat treat these receivers in such a manner as to make them serviceable.

The Board recommended that the receivers be withdrawn from service and scrapped.

After considering the proceedings of the Board, the Chief of Field Service, Brigadier General Samuel Hof, on February 7, 1928, made the following recommendation to the Chief of Ordnance, which was approved as a policy:

"Our ammunition is getting worse and accidents may be somewhat more frequent. On the other hand, some of these early rifles have been in use for many years and undoubtedly some of them have worn out several barrels. I do not think the occasion merits the withdrawal of the rifles of low numbers in the hands of troops until the rifle is otherwise unserviceable. On the other hand, I do not think we are justified in issuing such rifles from our establishments. I recommend that we instruct our Ordnance establishments to no longer issue rifles with these questionable receivers, that such rifles be set aside and considered as a war reserve and the question of the ultimate replacement of the receivers be deferred. When rifles are turned in from the troops for repair the receivers having these low numbers should be scrapped."

During the twelve years from 1917 to 1929 inclusive, 31 receivers of Springfield manufacture are recorded as having blown up, together with 25 of Rock Island manufacture and 5 listed as unknown. Of these, one Rock Island receiver, No. 445,136, was definitely of new manufacture. Of the Springfield Armory receiver, No. 801,548, which oddly enough is the last one on the list in 1929, was *recorded* as having the new heat treatment. This, however, is doubtful because as above stated, it is known that just about No. 800,000 a small lot of old receivers which had been set aside for some reason were found and put in process, and the number, together with the fact that no other case is recorded of the breakage of a receiver of double heat treatment, indicates that this was probably one of this special lot. This receiver incidentally was burst by firing it with a 7.9mm German service cartridge.

Two Springfield receivers, with the double heat treatment, Nos. 946,508 and 951,718, were "deformed" and "bulged," respectively. This is typical of the double heat treated receivers when exceptionally high pressures are encountered. They will always hold together, even though the cartridge head may open up and allow enough gas to escape to bulge the magazine wall and splinter the stock.

In this latter case the report of the accident stated: "Damage was caused by excessive pressure which was sufficiently high to cause the cartridge case to fail suddenly and allow gas under very high pressure to escape into the action. The *receiver* was evidently properly heat treated because *it did not fracture*."

The complete tabulation and record of the investigation of all accidents to the U. S. Rifle Caliber .30, Model of 1903 which were reported between the years of 1917 and 1929 inclusive will be found in the last chapter.

Receivers and bolts for the Springfield rifle continued to be made of the carbon steel, double heat treated, until April 1, 1927, when a change was made to nickel steel with rifle No. 1,275,767.

While Rock Island had, as noted above, been using nickel steel

for part of their production since August 1, 1918, Springfield first approached a change to this material in 1926. In March of that year, after the manufacture of rifles had been discontinued at Rock Island, 25,600 unfinished nickel steel receivers, together with a number of other unfinished parts, were shipped to Springfield Armory to be finished. These Rock Island receivers were forged of steel stated to be Hot Rolled Nickel Steel, S. A. specification 35-NS. The analysis furnished at that time was as follows:

Carbon	.30%— .40%
Manganese	.45%— .50%
Phosphorus	.05% or less
Sulphur	.05% or less
Silicon	.10%— .25%
Nickel	3.25%—3.75%

Springfield Armory completed the manufacture of these receivers, the first one being finished about April 1, 1927, and numbered 1,-275,767.

In August, 1926, Colonel Schull, Commanding Officer of Springfield Armory, asked the Chief of Ordnance to approve the manufacture of an experimental lot of 100 receivers, bolts and cut-offs for the M 1903 rifle to be made of nickel steel, WD 2340.

In his letter, Colonel Schull stated that this experimental lot of bolts, receivers and cut-offs would be used in a comparison test with corresponding parts manufactured of the plain carbon steel, WD 1325. He further said, "It is believed the manufacture of this number of components would yield valuable experience in drop forging and heat treating and develop the necessary physical qualities, and in addition aid in determining whether or not machining operations with this higher grade of steel will be materially increased using present jigs, fixtures and methods." The same file also states, "Attention is invited to numerous complaints which have been made during the past few years concerning the manner in which bolts and cut-offs become unserviceable."

Approximately 100 receivers and bolts were manufactured from the WD 2340 steel, assembled into rifles and tested. The results of the tests performed were studied by the Ordnance Office, and on March 6, 1928, a letter was received from that office which stated: "It is directed that a suitable alloy steel be substituted for carbon steel heretofore used in the components named." Chemical composition of WD 2340 is as follows:

Carbon	.35%— .45%
Manganese	.50%— .80%
Phosphorus	Max. .04%
Sulphur	Max. .04%
Nickel	3.25%—3.75%

It will be noted that this steel differed slightly from the first nickel steel receivers made by Rock Island Arsenal and Springfield Armory between 1918 and 1927.

Except for the annual assembly of National Match rifles, the production of the 1903 rifle was suspended from the early 1930's until the beginning of World War II. The few rifles that were made during this period had receivers and bolts made of nickel steel WD 2340.

Likewise the WD No. 8620 Steel used in the bolts and receivers of the M1 Garand rifle and the M 1903 A3 and A4 rifles is a nickel-chromium molybdenum steel having about 60 points (.40% to .70%) of nickel and about 20 points (.15% to .25%) of carbon.

Recapitulation

For ready reference, the information given above as to steel compositions and heat treatments is collected together here along with some other material not already given, so as to present in easily available form the information on the material used in the various military rifles used in the Army over the last fifty years.

Krag Jorgensen Rifle. (U. S. Rifle Cal. .30, Model of 1898)

The Barrel was made of Ordnance Barrel Steel having the following composition:

Carbon	.45% to	.55%
Manganese	1.00% to	1.30%
Sulphur	Not over	.05%
Phosphorus	Not over	.05%

The Receiver was made of Springfield Armory Class C Steel.

Carbon	.20% to	.30%
Manganese	1.10% to	1.30%
Silicon	.15% to	.35%
Sulphur	Not over	.05%
Phosphorus	Not over	.05%

The Bolt appears to have been made of carbon steel having around .55% to .65% carbon with .45% to .55% manganese.

The Springfield Rifle, Model of 1903, with its alterations A1, A3, and A4

The Barrel, for rifles of Springfield Armory make, from serial No. 1 to serial No. 1,532,878. (This includes all the rifles made at Spring-

field Armory, and refers to the original barrel only, as some were rebarrelled in the course of repair using barrels of commercial make.)

Material: Ordnance Barrel Steel with composition as given above under the Krag.

Treatment: Quench in oil at 1600° F. and temper for 2 hours at 1200° F.

The Barrel for rifles having serial numbers over 3,000,000, made during World War II.

Material: War Department (WD) Steel No. 1350 Special, (resulphurized), Alternate, WD Steel No. 1350 Modified; with compositions as given below:

WD No. 1350 Special			WD No. 1350 Modified		
Carbon	.45% to	.55%		.45% to	.55%
Manganese	1.10% to	1.35%		1.10% to	1.35%
Silicon	.25% to	.35%		.25% to	.35%
Resulphurized	to	.06%	Sulphur	Not over	.05%
Phosphorus	Not over	.06%		Not over	.06%

Treatment: Before machining, heat to a temperature of 1525° to 1600° F.; oil quench, and temper to Brinell hardness of 229 to 285. Stress relieve not less than 900° F. after straightening if necessary.

Receivers and Bolts of Springfield Armory make, from serial No. 1 to serial No. 800,000.

Material: Springfield Armory Class C Steel as given under Krag.

Treatment: Carburize in bone, 4 in a pot at 1500° F. for 4 hours in a muddle type furnace, then quench in oil.

Springfield Receivers and Bolts from serial No. 800,000 to 1,275,767.

Material: Springfield Armory Class C Steel as given under Krag.

Treatment: Heat in bone in an American Gas Company Carburizing Furnace at 1500° F. for 2½ hours, then quench in oil. Reheat at 1300° F. in a salt bath for 5 minutes, and again quench in oil. Draw at 350° F. in an oil bath and air cool. Test for hardness with a Scleroscope, which must read between 45 and 60. (Roughly equivalent to Rockwell C 33 to C 44.)

Springfield Receivers and Bolts from Serial No. 1,275,767 to No. 1,532,878.

Material: Nickel Steel WD 2340.

Carbon	.35% to	.45%
Manganese	.50% to	.80%
Nickel	3.25% to	3.75%
Sulphur	Not over	.04%
Phosphorus	Not over	.04%

Treatment: Quench from 1600° F. and draw in sodium nitrate at 600° F. for 30 minutes.

Receivers and Bolts for rifles having serial numbers over 3,000,000, of World War II manufacture.

Material: Until March, 1942, Nickel Steel WD 2340, as above.

Treatment: Anneal in charcoal at 1450° F., cool in furnace. Heat in carburizing salt, 1425° to 1450° F.; quench in oil. Temper. Case depth, .003 inch to .005 inch. Rockwell C 42 to C 47 for core.

On March 4, 1942, the use of WD Steel No. 4045 was authorized; this had the following composition,

Carbon	.40%	to	.56%
Manganese	.70%	to	1.00%
Molybdenum	.20%	to	.30%
Sulphur	Not over		.05%
Phosphorus	Not over		.04%

Treatment: Anneal in charcoal, cool in furnace. Heat in carburizing salt at 1475° to 1500° F.; quench in oil. Temper. Case depth, .003 inch to .005 inch. Rockwell C 42 to C 47 for core.

On July 5, 1942, the use of an additional steel, namely WD No. 8620 Modified, was authorized. The composition of this steel was:

Carbon	.18%	to	.25%	
Manganese	.70%	to	1.00%	
Nickel	.20%	to	.40%	
Chromium	.20%	to	.40%	
Molybdenum	.15%	to	.25%	
Sulphur, resulphurized		to	.07%	max.
Phosphorus	Not over		.04%	

Grain Size 5 to 8 ASTM

Hardenability, Jominy C 20 Rockwell, minimum, at ⅜ inch from quenched end.

Treatment for bolt: Normalize before machining. Carburize .012" to .015"; oil quench. Temper at 350° F. Hardness, Rockwell D 62 to D 70 on barrel of bolt.

Treatment for receiver: Normalize before machining. Carburize .009" to .015"; oil quench. Temper at 350° F. for 1 hour at heat. Rockwell D 62 to D 70 on side rail.

M 1903 Rifles of Rock Island Make

The Barrel was made of Ordnance Barrel Steel as given above.

Receivers and bolts from serial No. 1 to serial No. 285,507.

Material: Springfield Armory Class C Steel

Treatment: Pack in charred leather pots. Heat at 1475° to 1500° F. for 3½ to 4 hours. Quench in oil.

Receivers and bolts from serial No. 285,507 to 319,921.

Material: Springfield Armory Class C Steel.

Treatment: Anneal at 1500° F. for 2 hours; drop to 1050° in the furnace, remove and air cool. Harden by heating at 1550° to 1600° F. for 15 minutes and quenching in Houghton's #2 quenching oil. Reheat to 1425° F. followed by quenching in oil. Wash in soda kettle. Draw in oil at 500° F.

Receivers and bolts over serial No. 319,921.

Material: *Both* Class C Steel *and* Hot Rolled Nickel Steel Specifications WD 35 NS. WD 35 NS had the following composition:

Carbon	.30% to	.40%
Manganese	.45% to	.50%
Nickel	3.25% to	3.75%
Silicon	.10% to	.25%
Sulphur	Not over	.05%
Phosphorus	Not over	.05%

Treatment: For nickel steel bolts and receivers: Heat in salt bath at 1500° F., quench in oil, and draw in sodium nitrate at 600° F. for 30 minutes. Scleroscope hardness must be between 55 and 70 (Roughly C-41 to C-52 Rockwell).

1917 Enfield Rifles

Barrel made of "Smokeless Barrel Steel" specified in Ord. Pamphlet No. 3098.

Carbon	.45% to	.55%
Manganese	1.10% to	1.35%
Silicon	.20% to	.30%
Phosphorus	under	.06%
Sulphur	under	.06%

Receiver and Bolt made of "3½% Nickel Steel" specified in Ord. Pamphlet No. 3098. This could be either made by the Acid Process or the Basic Process with compositions as follows:

	Acid Process		Basic Process	
Carbon	.30% to	.40%	.35% to	.45%
Manganese	.50% to	.70%	.50% to	.70%
Nickel	3.00% to	3.75%	3.25% to	3.75%
Silicon			.10% to	.20%
Phosphorus	under	.05%	under	.035%
Sulphur	under	.035%	under	.05%

U. S. Caliber .30 M-1 Rifle (Garand)

Barrel.

Material: WD Steel No. 4150 Modified, with composition as given below:

Carbon	.45%	to	.50%
Manganese	.60%	to	.90%
Chromium	.80%	to	1.10%
Molybdenum	.15%	to	.25%
Silicon	.15%	to	.35%
Phosphorus	Not over		.04%
Resulphurize to	.04%	to	.09%

Treatment: Before machining normalize if necessary. Oil quench from 1575° to 1675° F. Temper not less than 2 hours to meet physical properties as follows:

Tensile Strength, 130,000 lbs. per sq. in.
Yield Strength, 110,000 lbs. per sq. in.
Elongation in 2 inches, 16% minimum.
Reduction of area, 50% minimum.
Brinell hardness, 269-311 (Equivalent to Rockwell C-28 to C-34).
Process stress relief if required not less than 1 hour at 1000° F.

Bolt.

Material: (Prior to March, 1942)—WD Steel No. 3312.

Manganese	.30%	to	.60%
Nickel	.25%	to	3.75%
Chromium	1.25%	to	1.75%
Carbon	Not over		.17%
Sulphur	Not over		.05%
Phosphorus	Not over		.04%

Material: Authorized July 5, 1942, WD Steel No. 8620. Modified, with composition as given above under M1903 rifle.

Treatment: Normalize before machining. Carburize .015" to .020" at 1600° F.; oil quench. Temper 1 hour at 325° F. Rockwell C 55 to C 59 on locking lugs and rear end of bolt.

Receiver.

Material: Early production: WD Steel No. 3115.

Carbon	.10%	to	.20%
Manganese	.30%	to	.60%
Nickel	1.00%	to	1.50%
Chromium	.45%	to	.75%
Sulphur	Not over		.05%
Phosphorus	Not over		.04%

Material: Intermediate Production: WD Steel No. 3120.

Carbon	.15% to .25%
Manganese	.50% to .80%
Nickel	1.00% to 1.50%
Chromium	.45% to .75%
Sulphur	Not over .05%
Phosphorus	Not over .05%

Material: After July, 1942, WD No. 8620 Modified, same as for the bolt.

Treatment: Carburize .012" to .018" at 1600° F.; oil quench temper 1 hour at 480° F. Rockwell D 59 to D 67.

U. S. .30 Caliber Carbine M-1

Barrel.

Material: WD No. 1350 Special—(Carbon .50 to .60%; resulphurized to .04% to .10%; Fine grain, gun quality, billets macro-etch inspected). Alternate, WD No. 1350 Modified.

W. D. No. 1350 Special as Specified Above.

Carbon	.50% to .60%
Manganese	1.35% to 1.65%
Silicon	.15% to .35%
Resulphurized	.04% to .10%
Phosphorus	Not over .045%

Treatment: Normalize before machining if necessary. Oil quench 1350° to 1375° F. Temper not less than 2 hours at heat to physical properties specified in U. S. Army Spec. 57-107-25. (Tensile strength, 110,000 lbs. per sq. in.; yield point 80,000 lbs. per sq. in.; elongation in 2 inches, 18% minimum; reduction in area, 45% minimum; Brinell 229-277.)

Receiver and Bolt.

Material: WD 4140 Special—(Resulphurized .04% to .09%; fine grain, gun quality, billet macro-etch inspection required.)

Carbon	.35% to .45%
Manganese	.70% to 1.00%
Phosphorus	Not over .04%
Sulphur	.04% to .09%
Chromium	.80% to 1.10%
Molybdenum	.15% to .25%

Treatment, Bolt: Normalize before machining. Preheat 700° F.; oil quench from 1550° F. Temper 2 hours at heat, not less than 375° F. and not more than 450° F. Rockwell C 48-54.

Treatment, Receiver: Same as bolt except temper 1 hour at heat to Rockwell hardness specified, that is C 38-45.

German Mauser Gew 98

Analysis of the metal taken from several bolts and receivers indicates that they are made of plain carbon steel similar to SAE No. 1035, which has carbon .30% to .40% and manganese .60% to .90%.

Japanese 6.5 mm. Arisaka

Several bolts and receivers analyzed appear to be made of ordinary carbon steel similar to SAE No. 1085 which has carbon .80% to .90% and manganese .60% to .90%.

Steel Specification Numbers

The reader has noted that the steels used in recent years for rifle manufacture are defined above in terms of SAE or WD numbers.

The SAE numbers refer to standard specifications issued by the Society of Automotive Engineers and published in the SAE handbook and in other engineers handbooks such as *Machinery's Handbook* and *Kent's Mechanical Engineer's Handbook.*

Much valuable information on the composition, physical properties, recommended uses, and appropriate heat treatments of alloy steels may be obtained from the SAE handbook and the mechanical engineers handbooks mentioned above.

The steels defined under War Department or "WD" number have in general the same composition as steels with the corresponding SAE numbers. However it is the practice to use WD numbers in official specifications, as SAE compositions, not being under the control of the War Department might be changed without their knowledge, thus involving a change in the War Department specifications over which they would have no control. In addition under the WD specifications the percentage of one or more of the constituent alloys may be varied or held to closer limits to meet the exacting requirements of gun manufacture.

The numbers themselves are assigned according to a system in which the first digit refers to the type of steel, the second indicates the percentage of the main alloying ingredient while the last two figures give the carbon content in points, that is in hundredths of a per cent.

The key to the meaning of the first digit is as follows:

1. indicates carbon steel
2. indicates nickel steel
3. indicates nickel-chromium steel
4. indicates molybdenum steel
5. indicates chromium steel
6. indicates chromium-vanadium steel
7. indicates tungsten steel
8. indicates nickel-chromium-molybdenum steel
9. indicates silico-manganese steel.

Applying the system given above, it can be deduced that WD steel No. 2340 of which so many M 1903 bolts and receivers were made is a nickel steel with some 3% (3.25% to 3.75%) nickel and some 40 points (.35% to .45%) carbon.

X

Headspace

WHEN I first became acquainted with sporting rifles, hunters were plagued with a certain very distressing malfunction, which would often occur right in the middle of a hunting trip, and would usually put the gun out of action until the user could get back to a gunsmith.

This trouble was a separation of the cartridge case, usually about a quarter to a half an inch ahead of the rim. When the breech was opened, the head of the cartridge would be pulled out by the extractor, but the body of the case would remain tightly wedged in the chamber, effectively preventing the insertion of another round of ammunition.

The remedy that was most often resorted to was to carry in the kit a small device called a broken shell extractor, sold by most sporting goods stores. When by bad luck a cartridge separated the user would insert the broken shell extractor into the chamber and close the bolt; on opening it again, the extractor would pull out the broken shell extractor, together with the front half of the ruptured cartridge case. This was of course a cure but not a prevention.

In every instance, the cause of this trouble was what is known as excess headspace, but the term "headspace" was rarely heard in those days, and nobody ever talked or wrote of it. However, styles change in the shooting world as fast as they do anywhere else, and in the last few years a lot of things have been blamed on headspace.

In the years just before World War II, it became the fashion for gunsmiths all over the country to originate "wildcat" cartridges by "improving" some factory cartridge, and then giving it a fancy designation with the originator's own name added.

The improvement frequently involved necking down the standard case to take a smaller bullet, and it almost always provided increased powder capacity by expanding the case into an enlarged chamber. Usually in the process the shoulder was made considerably sharper than it was in the original. This sharper shoulder is supposed to hold back the powder as the bullet moves forward in the bore, thus giving the powder better burning characteristics.

Making the shoulder sharper does, of course, add powder space, and thus make possible higher velocities, accompanied of course by the inevitable higher pressure. It is conceivable that the sharper shoulders do help the burning of the powder, but as far as I can see, this has not been proved. Very carefully conducted experiments,

using chronographs and pressure gauges, with cases of the same caliber and cubic capacity, but with shoulders of different slopes have failed to show that the shape of the shoulder makes any difference at all.

With the increased powder capacity that these wildcat cartridges had, it was inevitable that increased pressures would be obtained. Usually the originator of one of these cartridges had no facilities for taking pressures, and depended entirely on the notoriously unreliable method of judging pressures by the appearance of the primer.

In many of these wildcats, the actual pressures obtained with some of the recommended loads must be fantastic, and it was no wonder that the usual crop of troubles with gas leaks and blown cases oc-

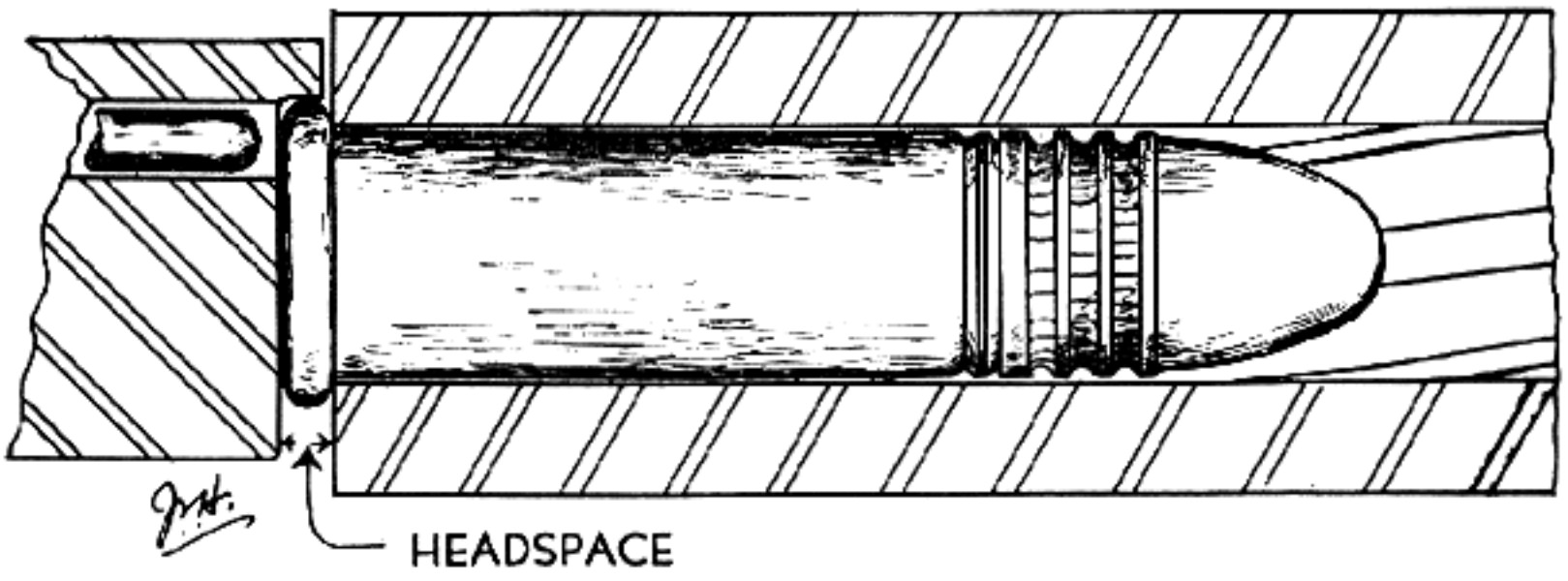


Figure 1. Headspace in a rifle using a .22 rimfire cartridge.

curred. For these the mysterious headspace formed a convenient scapegoat, and the term became a fashionable explanation for almost anything unpleasant connected with shooting these souped up loads.

Just what is this business of headspace that so many shooters are worried about these days? Let's get back to fundamentals a bit, and follow the thing through from the beginning of the term.

Early cartridges all had a rim, like the .22 caliber long rifle cartridges shown in Fig. 1. When such a cartridge is placed in the barrel of a rifle or pistol, the rim is the only thing that keeps it from going all the way in. As can be seen in the diagram, the rim stops against the rear face of the barrel. When the bolt is closed it comes up against the head of the cartridge. In front of the cartridge rim is the rear face of the barrel and behind it is the front face of the bolt. Between the bolt and the barrel there must be enough space to accommodate the head or rim of the cartridge, and this is the headspace.

Ordinary revolver cartridges are mostly of the rimmed variety, though there are some notable exceptions, such as the rimless .45 automatic pistol cartridge used in the Model of 1917 Colt and S. & W. revolver. In some revolvers the cartridge rims rest against the rear face of the cylinder, and in these the headspace is the distance

from the cylinder to the recoil plate, which is that part of the frame which supports the cartridge head during firing.

Some revolvers, especially those made for rim-fire cartridges and for the ultra-high-pressure center-fire loads, have the chambers counterbored so that the cartridges go in almost flush with the rear end of the cylinder, and the cartridge heads are each surrounded by a solid ring of metal. In these the headspace is the distance from the recoil plate to the shoulder against which the rim seats when the cartridge is in the chamber. In other words, just the rim thickness plus the necessary tolerance to accommodate ammunition of different makes.

Most revolver cartridges, such as for example the .38 special, are straight sided, just like the .22 rim-fire, and in these there is nothing

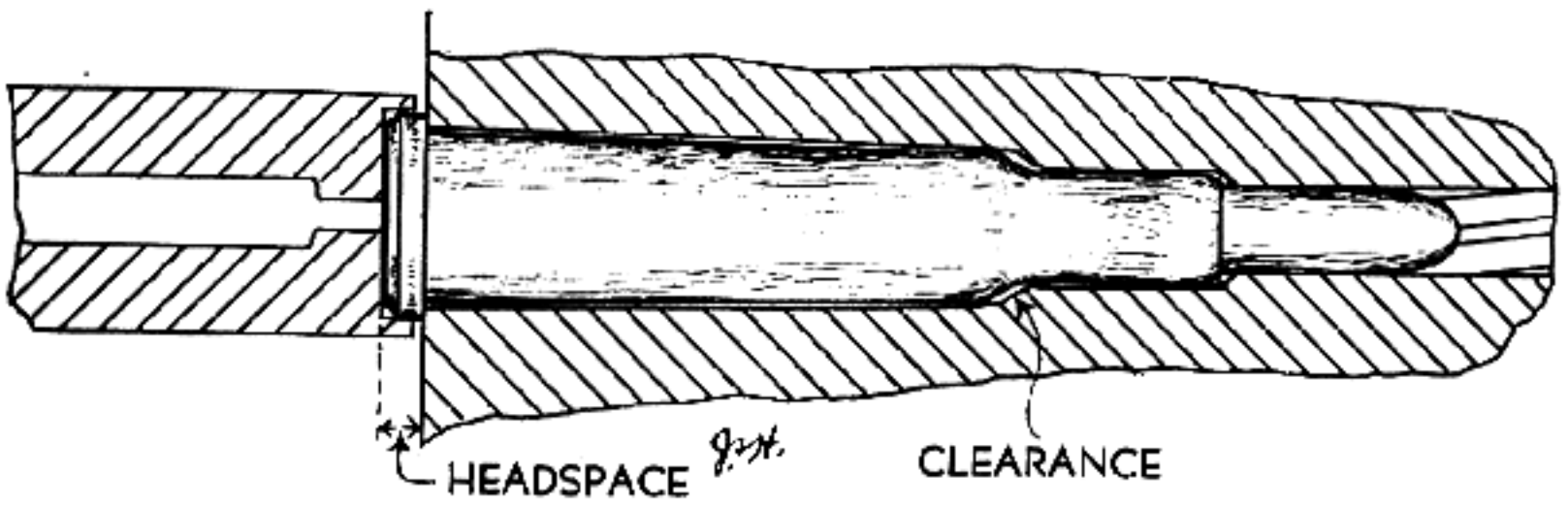


Figure 2. Headspace with a rim cartridge, such as the .30-40 Krag.

but the rim to prevent the cartridge from going all the way into the cylinder. On the other hand, most high powered rifle cartridges of the rimmed variety, such as for example the .30-40 Krag, otherwise known as the .30 U. S. Army, shown in Fig. 2 are tapered or bottle-necked so they couldn't go very far in even if they didn't have a rim. These always have a clearance at the shoulder, as shown in the sketch, so that the rim will be sure to bear on its seat before the shoulder can come into contact. When such a cartridge is fired, the brass expands until the case fits the chamber at all points, hence in reloading, the clearance, above mentioned, does not exist. As long as the reloaded cases are used in the same rifle this makes no difference. However, if used in another gun of the same caliber, they might bear at the shoulder before the rim seats, and difficulty would then be experienced in closing the bolt.

When repeating rifles having box magazines first came into use it was found that the rims on the cartridges made it difficult to produce magazines that would feed the cartridges smoothly. To overcome this difficulty, two new types of cartridges were produced, which look much alike to a casual inspection, but which really are quite different in principle. These are the rimless type, and the semi-rim, or as it is sometimes called, the semi-rimless.

The semi-rim type is seen in such well-known cartridges as the

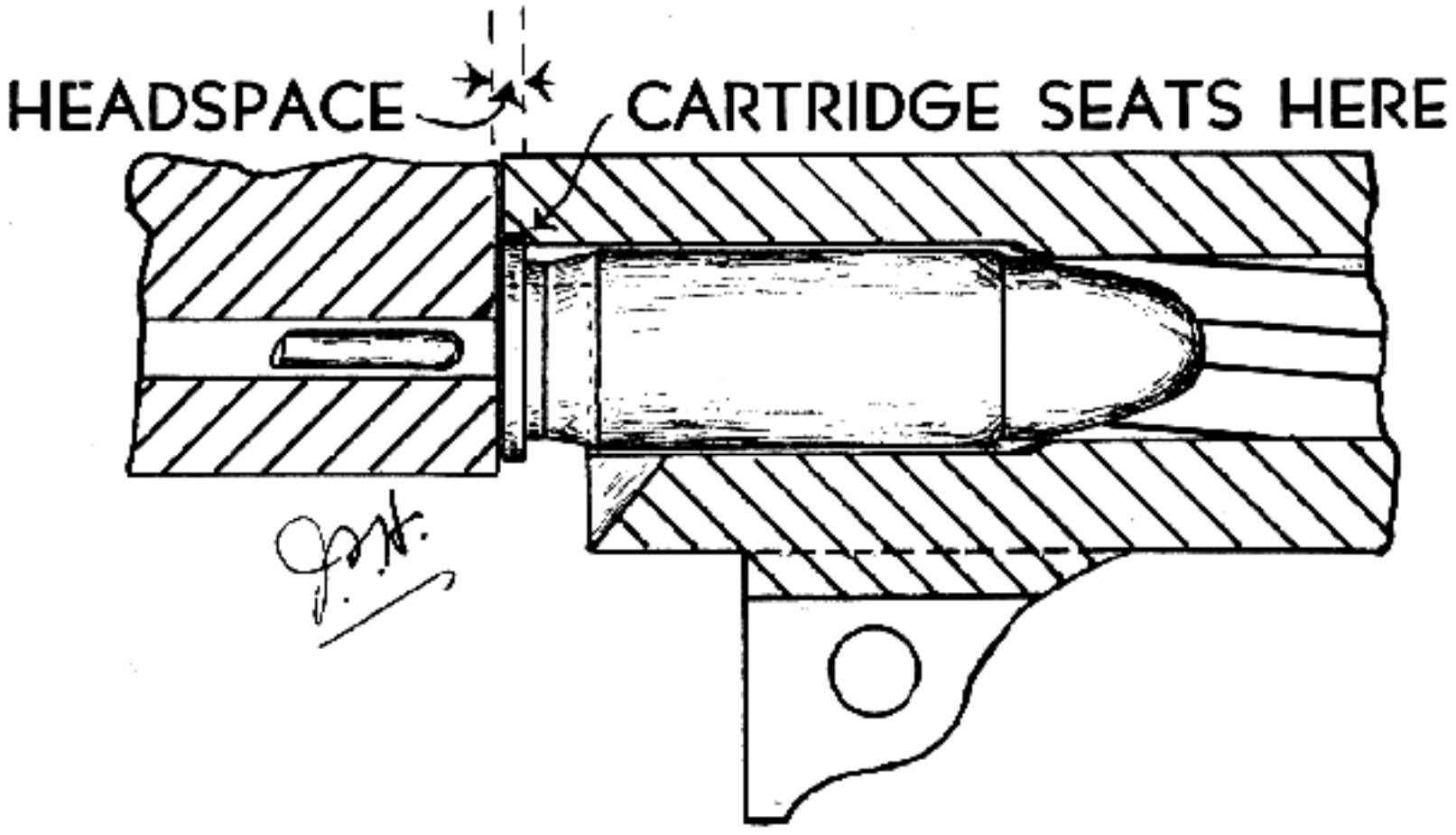


Figure 3. Headspace with a semi-rim pistol cartridge, such as the .38 ACP.

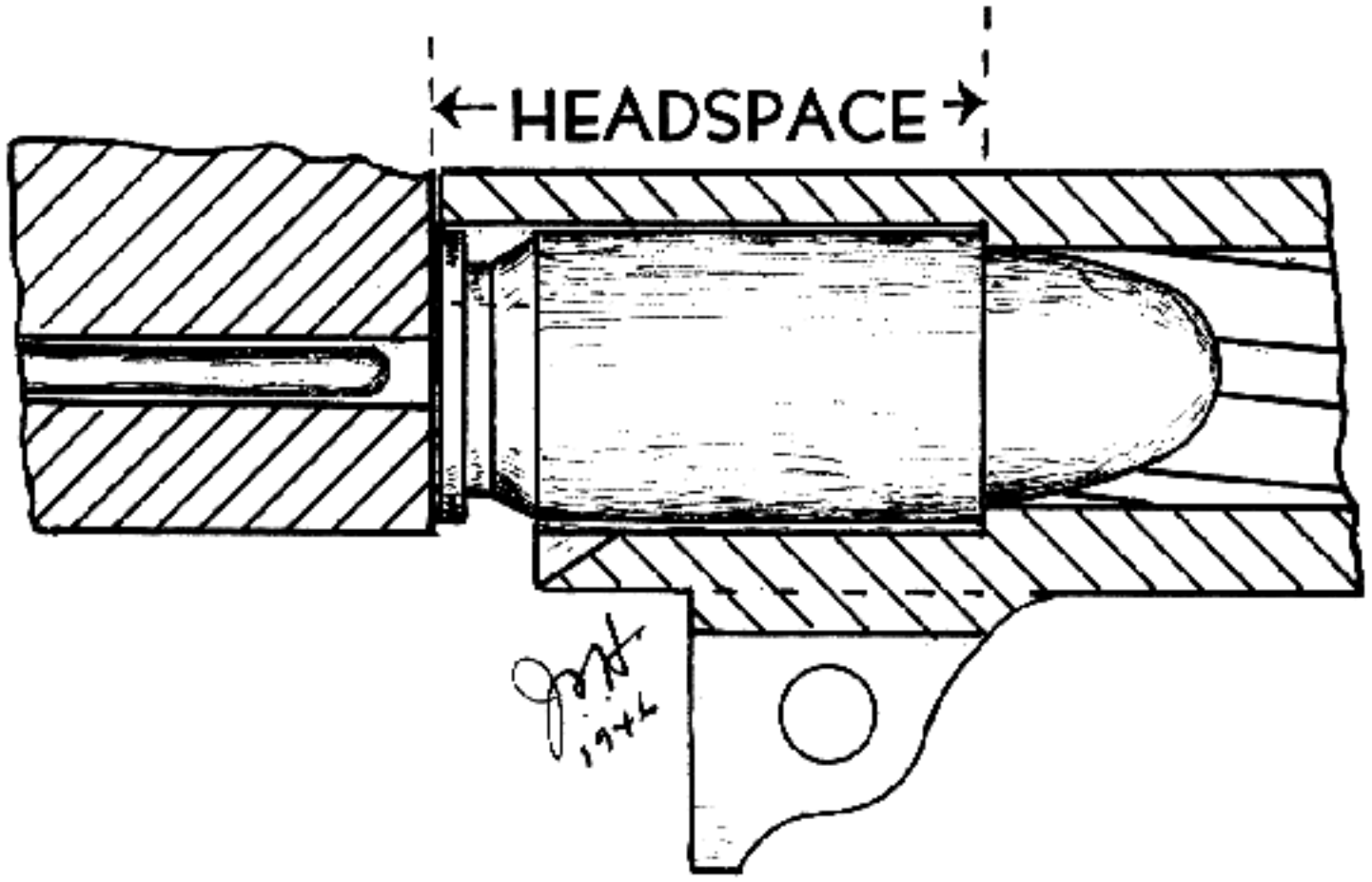


Figure 4. Headspace with a rimless pistol cartridge—the .45 ACP.

.351 and .401 Winchester self-loading and the .25, .32 and .38 A.C.P., the latter of which is illustrated in Fig. 3. The rim is made very little larger than the body of the cartridge, and there is a groove or cannelure cut into the body just forward of the rim, for the extractor to fit into. The semi-rim type works just like the rim cartridge. Even though the semi-rim is ever so little larger than the body of the case, this little is still enough to stop it positively at the right place.

Here also headspace is a distance equal to the thickness of the rim

plus the necessary tolerances to enable different makes of gun and cartridge to fit together.

The true rimless cartridge has a head which is no larger than the body of the cartridge is at some point further forward. It has a groove or cannelure cut around it just forward of the rim, for the extractor to hook into. As the rim is no larger than the body, it cannot be used to limit the forward motion of the cartridge when it is seated in the chamber, and this must be accomplished in some other manner. With the .45 A.C.P. cartridge this is done by leaving the forward end of the cartridge, that is, the mouth, square, instead of crimping it onto the bullet as is done with most other pistol or revolver cartridges. A square shoulder or ledge is left at the front end of the chamber and the mouth of the case seats against this square ledge. See Fig. 4.

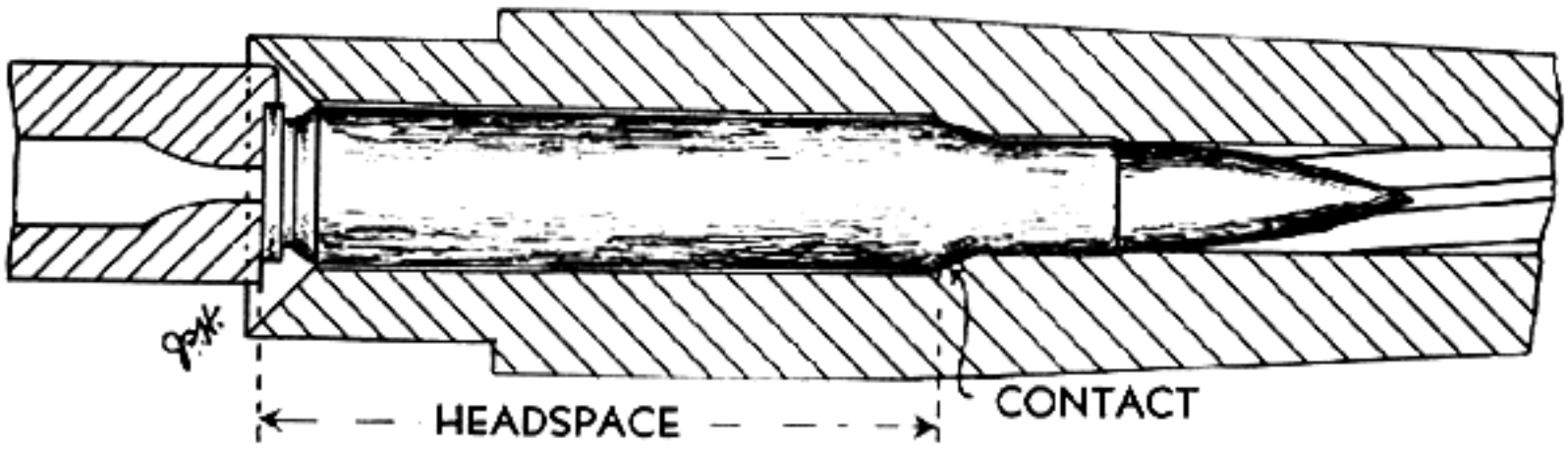
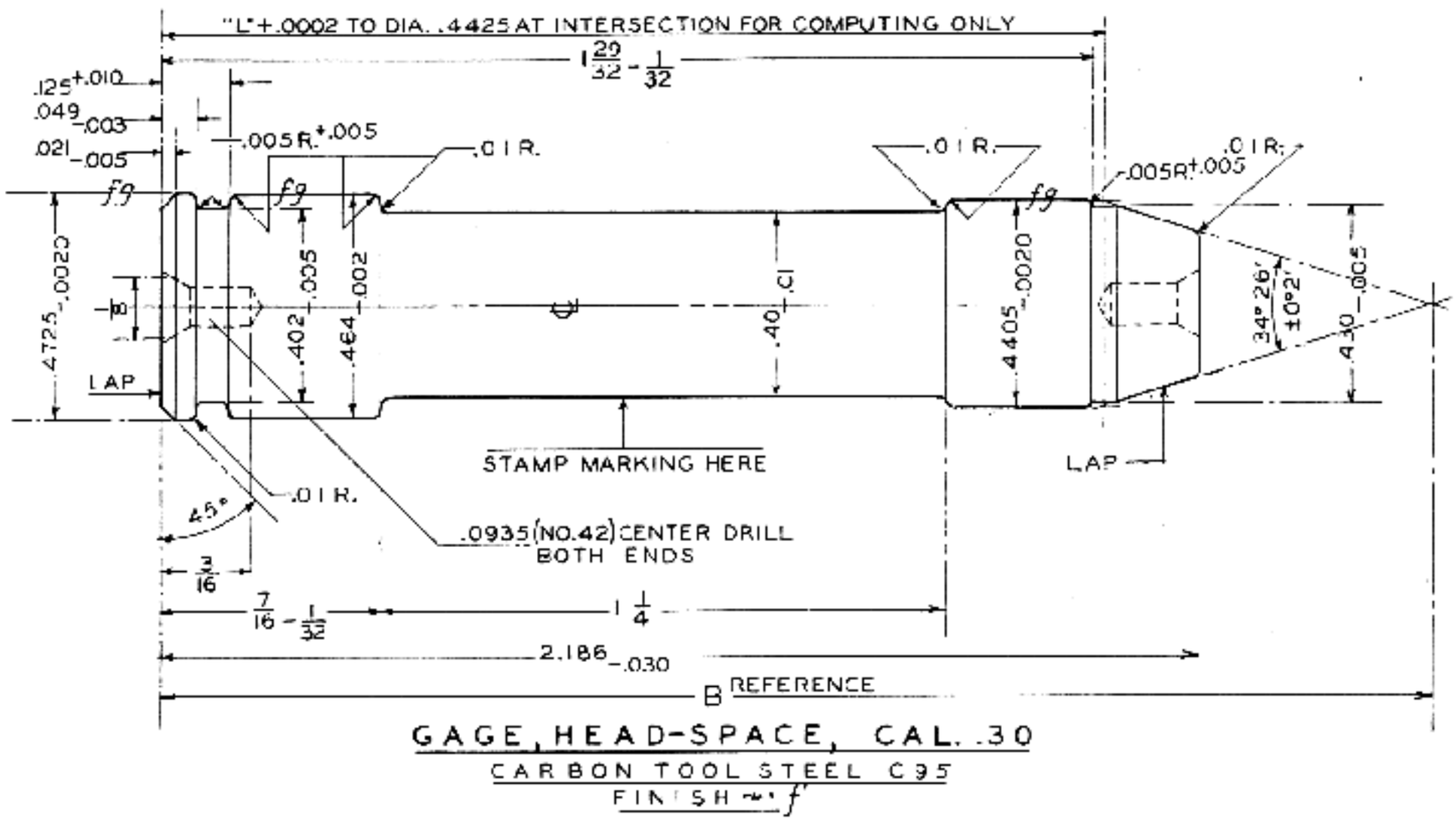


Figure 5. Headspace with a rimless cartridge, such as the .30-'06.

As there is nothing for the head or rim to seat against, the true headspace in the old meaning of the term has no significance, and when we want to determine tolerances as to cartridge seating we have to measure all the way from the breech block to the shoulder at the front of the chamber. For convenience, we now call this distance "headspace" also, when speaking of guns using rimless cartridges.

When the Mauser repeating rifles were designed, the inventor introduced the well-known rimless rifle cartridges, of which the .30-'06 is an example. As shown in Fig. 5, these cartridges seat on the tapered shoulder which connects the body of the cartridge to the neck. Hence, in the high powered rimless rifle cartridge the distance from the face of the closed bolt to some reference point on the shoulder in the forward part of the chamber is, for convenience and for want of a better term, called the "headspace." Note that the principal contact which positions the cartridge in the chamber is at the same point where a clearance is purposely left in the rimmed variety.

As a practical matter, it is impossible to measure this kind of headspace without special gauges, because the shoulders both on the cartridge and in the chamber blend into the slopes ahead of and behind them, and there are no sharp edges to measure from. Actually



HEADSPACE GAGE FOR U. S. SERVICE RIFLES CALIBER .30.

"L" is the headspace, and "B" is the breeching space, used for purposes of computation only; it is equal to "L" plus .714 inch.

Values of "L" are as follows:

For manufacture of the U. S. Rifle Caliber .30 M 1: minimum, 1.942; maximum, 1.944.

For the manufacture of other rifles: minimum, 1.940; maximum, 1.944.

As a maximum gage for inspection of overhauled rifles: 1.946.

For inspection as a field headspace limit for serviceable rifles: 1.950.

If desired, a semi-circular groove may be cut in the head of the gage to clear the ejector in the M 1 Rifle, and thus avoid having to remove the ejector when headspacing these rifles.

the 1.940 inch minimum to 1.944 inch maximum headspace of the '03 Springfield rifle is measured to a hypothetical intersection which does not exist and can only be located by measuring to a given point on a ring gauge that fits over the tapered shoulder of a steel gauge shaped like a cartridge. This will be better understood by reference to the official drawing for the .30-06 headspace gauge, which is shown herewith in simplified form, retaining the essential dimensions but omitting many confusing cross references.

There is still another variety of cartridge, and that is the belted type, such as is used in the H. & H. Magnum and other similar rifle cartridges. As shown in Fig. 6, it is really a modified rimmed cartridge, having a very wide and very shallow rim. The rim is not

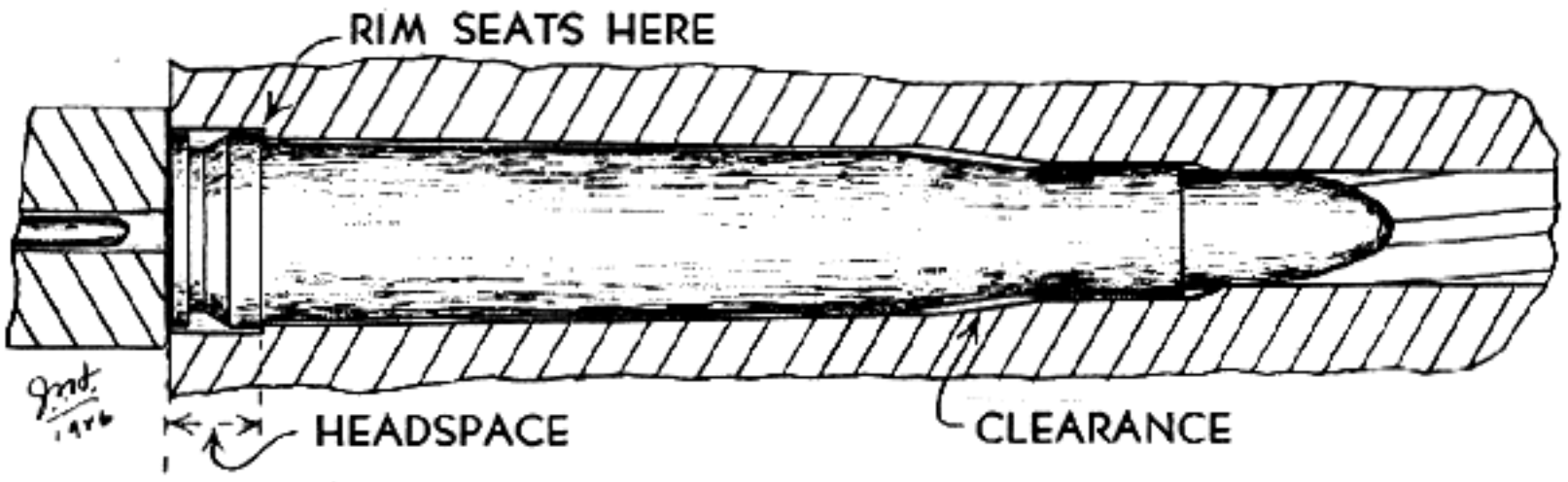


Figure 6. Belted cartridge showing headspace.

high enough to give a good place for the extractor to take hold, so there is an extractor groove cut into the rim itself. To explain it another way, it is like a rimless cartridge with a slight step just ahead of the extractor groove. In seating the cartridge this step comes to rest against a slight corresponding ledge in the chamber. This gives the same effect as that of a rimmed cartridge, and like it, always has a clearance at the shoulder until after it has been fired once.

I have tried above to show just what headspace is. The next question is how does it vary, and what do the variations do to the functioning of the gun.

Taking the rim fire cartridge first, it should be quite obvious that the headspace must not be less than the thickness of the rim. If it is, the rim of the cartridge will be squeezed when the bolt is slammed or forced shut, and premature discharge may result.

With the rim fire cartridge, excess headspace will result, in effect, in a shorter firing pin blow, and thus in poor ignition. As the .22 rim fire cartridge is notoriously sensitive to irregular ignition, excess headspace may result in variations in ignition that will have a very bad effect on accuracy.

With straight sided cartridges of the center fire variety, such as the usual pistol cartridge, headspace that is too small, that is, less than the minimum specified, will usually make it impossible to close

the breech of the gun after it is loaded. Naturally this condition does not often occur as a gun defect, though the same result will follow the use of a cartridge with a head that is too thick, which is a trouble sometimes seen.

With these cartridges, the principal result of excess headspace is to let the cartridge move further away from the breech block when it is struck by the breech block. This, in effect, gives a shorter firing pin blow, and if it is very excessive, it may cause hang-fires or misfires.

Thus it is quite possible to fire the .45 A.C.P. cartridge in the .455 Webley & Scott selfloading Pistol, even though with this gun and cartridge combination there is about ⅛ inch excess headspace. If the cartridges are loaded into the chamber singly, they go in so far that neither the firing pin nor the extractor can reach them, and they will not fire; but if they are loaded from the magazine, they rise up under the extractor hook and this holds them close enough to the breech block so that the firing pin can strike the primer, and they fire, extract, eject, and reload just as if they were intended for this gun, in spite of the ⅛ of an inch excess headspace. I have fired many rounds of this .45 Automatic Colt Pistol ammunition through the .455 Webley and Scott Selfloading Pistol.

Likewise the 9 mm short, or .380 A.C.P. cartridge, which is .080" shorter than the proper 9 mm Parabellum cartridge, may be fired from the magazine in the Luger or the P-38, but this little cartridge has insufficient power to eject and reload, so the slide must be pulled back by hand after each shot. I have fired many of these cartridges in both these guns with no trouble as long as they feed up from the magazine. If loaded in the chamber by hand, they will not fire because the extractor will not catch them at all in the Luger, and only part of the time in the P-38.

I have also fired the .455 Webley Revolver Cartridges Mark II in the .45 caliber Colt New Service Revolver with an excess headspace of .037", and I have fired the .455 Automatic Webley & Scott Pistol Cartridge in this same Colt New Service .45 with an excess headspace of .025".

Likewise, in trying everything I could think of, I have fired quite a few .45 Automatic Colt Pistol Cartridges in a Colt New Service Revolver Caliber .455, with an excess headspace for this combination of .051".

In all of the above shooting, accuracy was excellent, and no bad results of any kind were observed. The only trouble to be expected was a possibility of hangfires or misfires from having the primer too far away from the firing pin, but even this did not occur.

Shotgun shells come in the category mentioned above, of rim cartridges with straight sides and giving low maximum pressures; usually not over 8000 to 10,000 pounds per square inch. A moderate

amount of excess headspace in shotguns seems to make little or no difference, but a large amount, say a tenth of an inch or more, is dangerous, as there is nothing but the internal base wad of rolled cardboard and the thin brass wall to hold in the pressure where the shell is unsupported in the space between the end of the barrel and the face of the breech.

An acquaintance once told me that his pump action shotgun

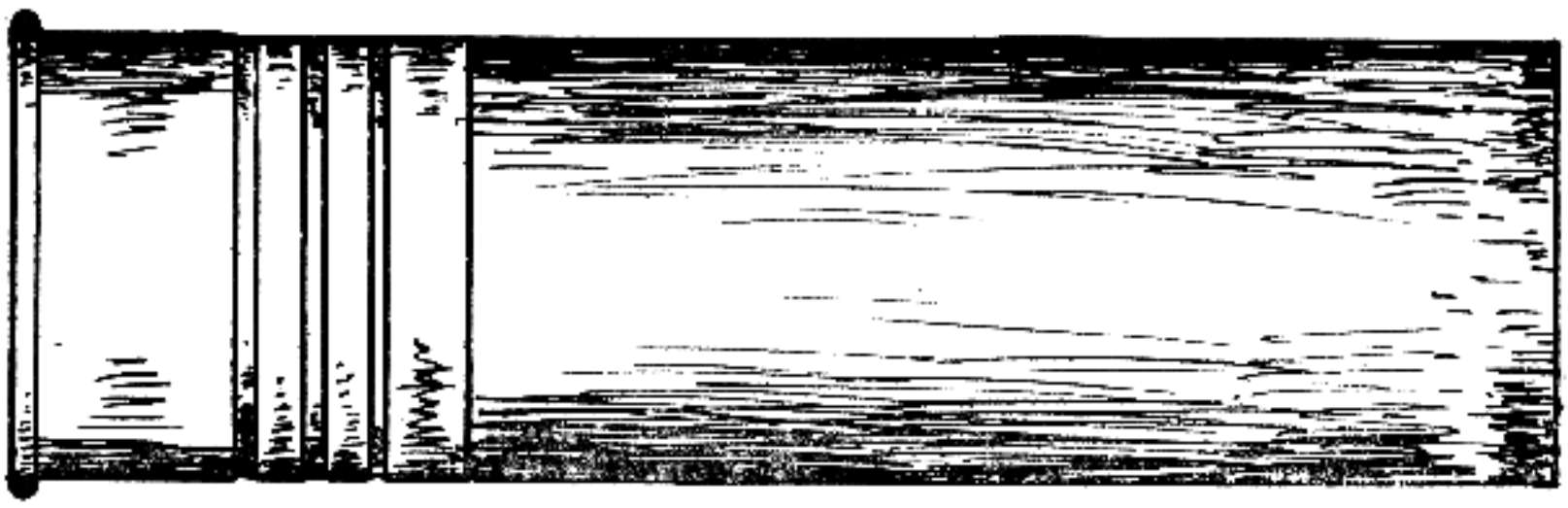






Figure 7. Upper: Shell after firing with normal headspace. Lower: Shell fired in gun with one-tenth inch excess headspace.

worked hard, and that after he had with some difficulty extracted the shells, they were badly bulged just ahead of the rim. I found that he had assembled his gun with the barrel just two threads forward of being fully seated in the receiver, and as the barrel had twenty threads per inch, this gave him just 1/10 inch more headspace than the gun would have had if it had been put together properly.

On November 1, 1946, Al Barr of the *American Rifleman* staff was helping me to pattern some shotguns, and we got to discussing this question, so we assembled a pump gun in this manner, and fired several shots with Federal Monark and also with Federal HiPower loads. I fired these loads myself from the shoulder, but was careful to wear my Rayban shooting glasses, and also to keep my forearm out

from under the ejection opening, just in case the head of one of those shells should fail to hold the pressure. Patterns were the same as usual, and everything worked all right, except that extraction was a trifle hard, though not excessive. The fired shells were swelled out as shown in Figure 7, but they held together, in spite of the 1/10 inch excess headspace, and no harm was done. These particular shells have a high and very strong inside base wad, and this helped.

It should be noted that most pump action guns, such as the Winchester and Remington models cannot be mis-assembled this way; the designers have put in mechanical devices to prevent it. There is one high grade pump gun in which this can be done, but this will be corrected in the near future.

With bottlenecked cartridges, whether rim or rimless, the matter is quite different. The powder gas pushes back on the base of the cartridge with several thousand pounds pressure, and exactly the same total pressure is exerted in a forward direction, part of it on the base of the bullet and the rest on the tapered inside of the case body and shoulder. This pressure forces the forward part of the cartridge case tight against the shoulder of the chamber and at the same time drives the head of the case back against the face of the bolt. If there is excess headspace, the case will be stretched; if the headspace is too excessive, the case will be separated or ruptured at a point about ½ inch from the head where the thick brass in the base of the case begins to thin out as it joins the walls. When the gun is opened, the base of the cartridge will come out with the extractor, but the forward part of the case will remain wedged in the chamber and the gun cannot be used again until this is removed.

Lever action rifles are rather more subject to this trouble than are bolt action, as the lever actions stretch and spring more. With good strong actions and moderate pressure loads, and especially if the shooting glasses are worn, this trouble is not particularly dangerous, but is annoying and inconvenient. Very little, if any, gas escapes to the rear, because the back end of the cartridge, which remains in the chamber, acts as a seal. In fact, it is just such short brass cups that the Germans have for years used as the breech seals in their heavy artillery, instead of the "mushroom head" and gas check pad of our big gun system.

It just happens that I have had an unusual amount of personal experience with this matter of excess headspace and separated cases. In 1916 and '17 as Captain of Ordnance, I had charge of the Army Machine Gun Schools, first on the Mexican Border, then at Springfield. In those days, Frankford Arsenal made the .30-'06 cartridge case of very hard brass to make extraction easier and to improve the functioning in machine guns. These hard, brittle cases gave marvelous operation when the headspace was normal but would separate in a hurry if the headspace got the least bit over the limit. The automatic

machine rifle, Caliber .30, M 1909, had detachable barrels, held on by a nut which could be tightened with a spanner. Let this nut get the least little bit loose and the case ruptured and the gun jammed because the following cartridge could not chamber fully. The ruptured case extractor was about the most important part of each gunner's kit. I experimented until I found how to fix the guns so they would fire a few shots, then chop off a case and jam.

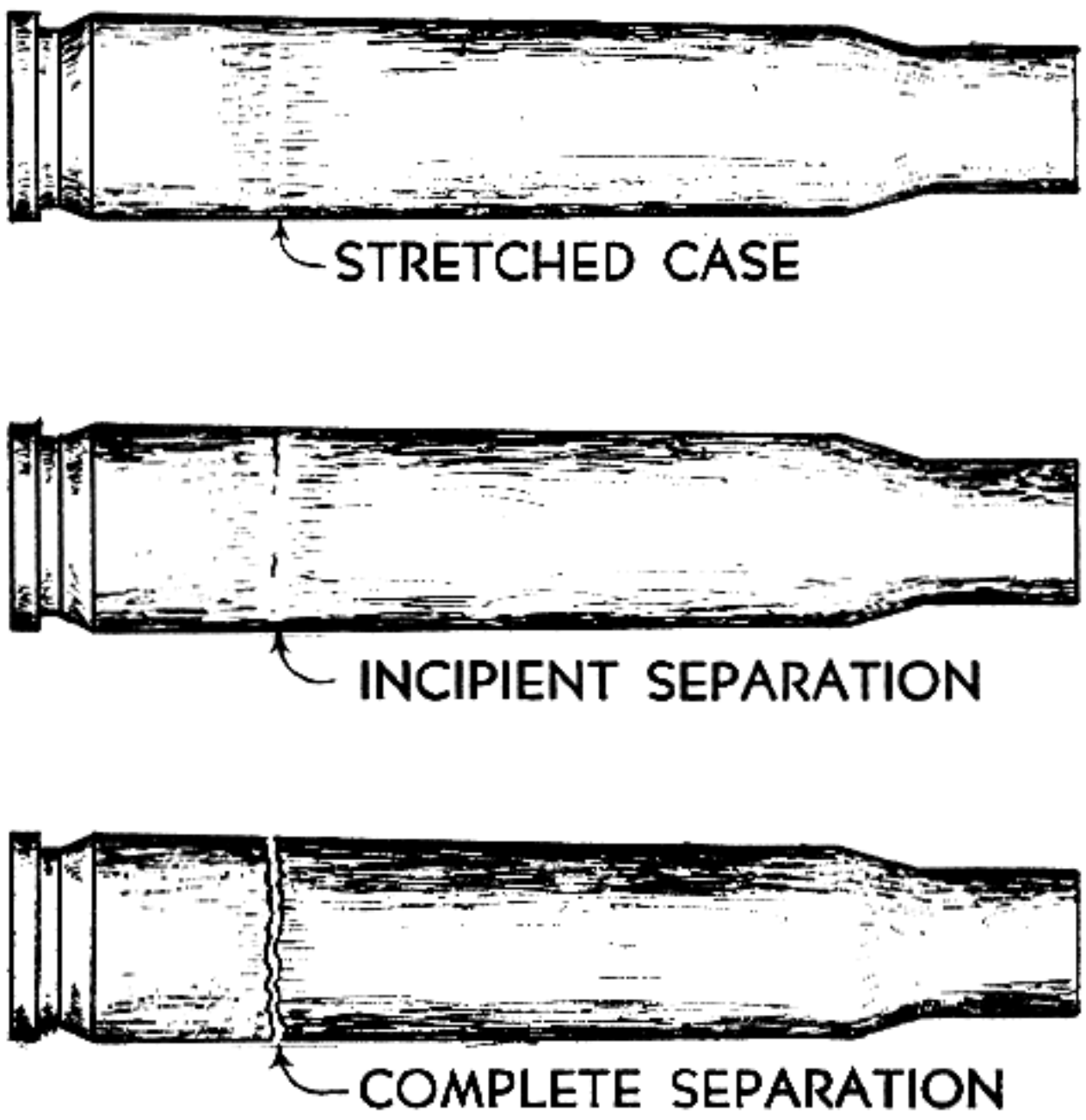


Figure 8. Results of excess headspace. Top: Stretched case due to moderately excessive headspace. Center: Incipient separation due to greater headspace than top picture. Bottom: Rupture due to very excessive headspace.

Every student had this situation thrown at him repeatedly until he could correct it in the dark. In my own experimental firing I encountered at least a couple of hundred such separations, and every one of my several thousand students had to experience and correct this situation several times and I never saw enough gas escape to hurt any one. However, bear in mind we were using the old .30-06 cartridge with 150 grain bullet, 2700 feet per second and not over 50,000 pounds pressure. With some of the super high intensity loads that are being used today, any headspace over the normal can be dangerous.

In 1917, Frankford Arsenal began making the cases much softer, just to get away from these separations. The soft cases have been

In the case of elongated bullets, rifling is even more necessary than it was with round balls, for in the absence of rifling, an elongated bullet will tumble end over end, and no sort of accuracy is possible.

The Greenhill Formula

A method for determining mathematically the amount of spin necessary to stabilize an elongated bullet was worked out in 1879 by Sir Alfred George Greenhill (1847-1927), who was at that time Professor of Mathematics to the advanced class of artillery officers at Woolwich. A discussion of this formula will be found on pp 288 and 289 of the British Textbook of Small Arms, 1929.

The abstruse mathematical work done by Greenhill resulted in a simple method of obtaining the spin required to overcome instability in an elongated projectile. A figure that for all practical purposes is satisfactory for bullets having a specific gravity of 10.9 can be obtained from the following rule:

The twist required (in calibers) equals 150 divided by the length of the bullet (in calibers). Note that lead itself has a specific gravity of 11.35; a jacketed lead bullet has specific gravity about 10.9.

To check out this formula, let's apply it to the 220 grain .30 caliber bullet such as was used in the old Krag rifle, and in the first M-1903 rifles. At that time it was determined that the necessary twist for this bullet was 1 turn in 10 inches, and that twist was adopted. Later, when the sharp pointed and shorter spitzer bullet was adopted, in 1906, the same twist was retained; while it might be slightly more twist than was required for the shorter bullet, it still enabled the use of heavier bullets should that become necessary. Let's see what twist the Greenhill formula says should have been adopted.

The length of the 220 grain .30 caliber bullet is 1.35 inches, or 1.35/.30=4.5 calibers, so the twist given by the formula would be 150/4.5=33 1/3 calibers, or 33 1/3 times the diameter of the bullet. 33 1/3 x .30=9.99 or in round numbers, 10 inches.

For bullets made of other materials than lead, the spin as given by the formula should be multiplied by the square root of the number found by dividing the specific gravity on which the formula is based (10.9), by the specific gravity of the material of which the bullet is made. Thus if it is made of aluminum, whose specific gravity is 2.7 we would divide 10.9 by 2.7, obtaining 4. Then take the square root of this number, which is 2, and multiply the spin by that, showing that the aluminum bullet would require twice as much spin as the usual jacketed lead one.

Another point to be considered is the fact that the Greenhill formula gives the spin necessary to stabilize the flight of the bullet in *air;* in denser materials, more spin is required. For a bullet to have a stable flight in any material other than air, the spin as worked out for air must be multiplied by the square root of a number found by

dividing the density of the material in question by the density of air. Water has a specific gravity about 900 times that of air, so that to be stable in penetrating water, the bullet would require a twist as given by Greenhill's formula, multiplied by the square root of 900, or 30. Thus the twist for stable flight in water would be 30 times as great as that for flight in air.

Note—To obtain the specific gravity of a bullet, proceed as follows:

1. Suspend the bullet by a thin light wire or thread from the pan of a balance.

2. Weigh the bullet while it is hanging this way.

3. Place a container of water under the scale so the bullet hangs in the water, and take the weight.

4. Subtract the second weight from the first.

5. Divide the weight of the bullet as obtained in (2) by the difference as obtained in (4). This result is the specific gravity.

Retardation of the Bullet by Air Resistance

One of the most noticeable results of air resistance on a bullet's flight is to slow the bullet down and thus reduce its maximum range. An idea of the magnitude of this effect may be gained by figuring how far a bullet at a given speed would go in a vacuum, then comparing it with the actual maximum range in air. Thus a bullet of any weight, size or shape, if fired in a vacuum at a muzzle velocity of 2700 f.s. and an angle of elevation of 45 degrees, would have a maximum range of 226,397 feet, or nearly 43 miles, while a 150 grain flat base .30 caliber M2 bullet at 2700 f.s. has a maximum range of only 3400 yards or 10,200 feet, or about 4½% of the distance it would go if air resistance did not hold it back. Moreover, in a vacuum, the maximum range is obtained at an elevation or angle of departure of 45 degrees, while in air the maximum range of the .30 caliber M2 bullet is obtained at an angle of departure of 29 degrees.

On p. 401 there will be found a table of fire for the .30 cal. 1906 ammunition, which is equally applicable to the 152 grain flat base .30 caliber M2. It will be seen that over the first 300 feet of its flight this bullet starting at 2700 f.s. loses 219 f.s. of its initial velocity during its .12 second time of flight. If it loses velocity at the rate of 219 f.s. in .12 second, that would be at the rate of 1825 f.s. in each second, and the backward acceleration of the bullet would be equal to that caused by a pressure of over 56 times its own weight against its nose, holding it back. In other words, the negative acceleration caused by air resistance at the average speed the bullet had in the first 100 yards of its flight is equal to over 56 times the acceleration of gravity. This retardation is greater at higher speeds, less at lower ones. From 900 to 1000 yards where the speed of the bullet has

dropped to about the velocity of sound, it loses only 76 f.s. over 300 feet of flight, and takes .29 second to do it, which is at the rate of 262 f.s. per second or 8 times gravity.

The way this retardation varies at other points and at other bullet speeds can be seen from the tabulation which follows:

152 grain flat base .30 cal. M2 bullet, 2700 f.s.

Range Yards	Remaining Velocity f.s.	Loss in 100 yards	Time required sec.	Rate of loss f.s. per sec.	Neg. acceleration —times gravity
0	2700	...	..	....	....
100	2481	219	.12	1825	56.67
200	2267	214	.13	1643	51.
300	2059	208	.14	1485	46.1
400	1858	201	.15	1340	41.6
500	1664	194	.17	1141	35.4
600	1481	183	.19	963	29.9
700	1315	166	.22	754	23.4
800	1174	141	.24	587	18.2
900	1065	109	.27	403	12.6
1000	989	76	.29	262	8.1

It will be noted that if the bullet continued to lose speed at the same rate that it does during the first 100 yards of its flight, it would be completely stopped in less than 1½ seconds; however, the loss in velocity gets less and less as the speed diminishes, so that actually it has over 1100 f.s. of velocity left at the end of 1½ seconds. This tabulation shows clearly how much greater the retardation is at higher than at lower velocities.

Formula for Air Resistance

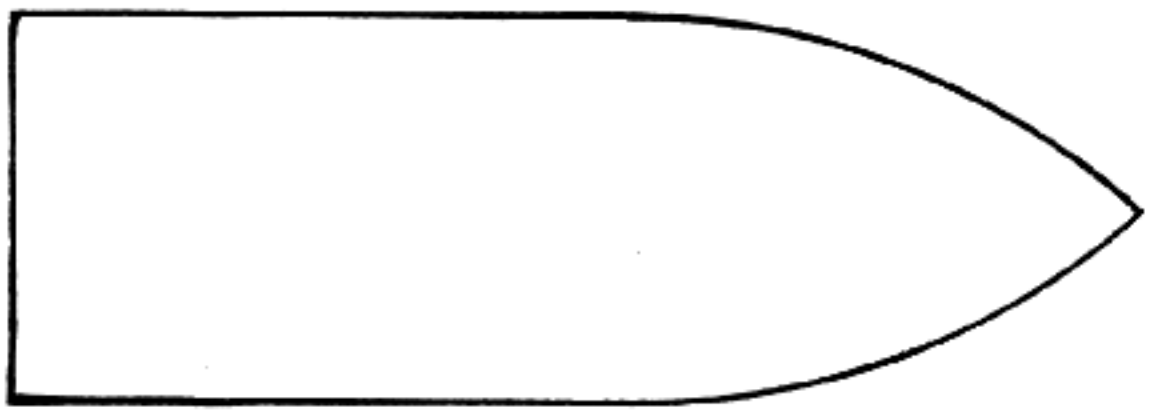
Sir Isaac Newton (1642-1727), turned his attention to this subject, and after making experiments by dropping glass spheres filled with air, water and mercury from the dome of St. Paul's Cathedral, he concluded that the air resistance was proportional to the square of the velocity. His experiments were of course at lower velocities than are usual with small arms bullets.

Later experiments made in various countries and by various governmental bodies and scientific commissions gave results that seemed to show that Newton's assumption of the square law was not true, as at certain speeds, especially those in the neighborhood of the velocity of sound, the resistance increased much faster than this rule provided.

Such experiments and studies were carried out in England (1866-1880); in Russia (1868-69); in Germany (1881); in Holland (1883); and especially by the Commission d'Experience de Gavre in France (1873-1898). The earlier of these studies were largely confined to obtaining remaining velocities at various velocities and over different distances, and from them attempting to derive a mathematical formula for the relation between velocity in the air and retardation.

Notable work in this field was done by the Russian Colonel Mayevski from a study of firings done by Krupp at Meppen in Germany in 1881, using a projectile about 3 calibers long with a flat base and an ogival head with a 2 caliber radius.

From this study, Mayevski concluded that it was possible to express the retardation as proportional to some power of the velocity in a restricted zone of velocities, using another power of the velocity in the next zone of velocities, and so on.



General shape of projectile used in the Krupp and Gavre firings. It is 3 calibers long and has an ogival head with 2 caliber radius.

He found a good agreement with the results of the experimental firings could be obtained if the retardation were expressed in the form Av^n where both A and n are constant in a restricted velocity zone, but where the values of both A and n change when this velocity zone is passed.

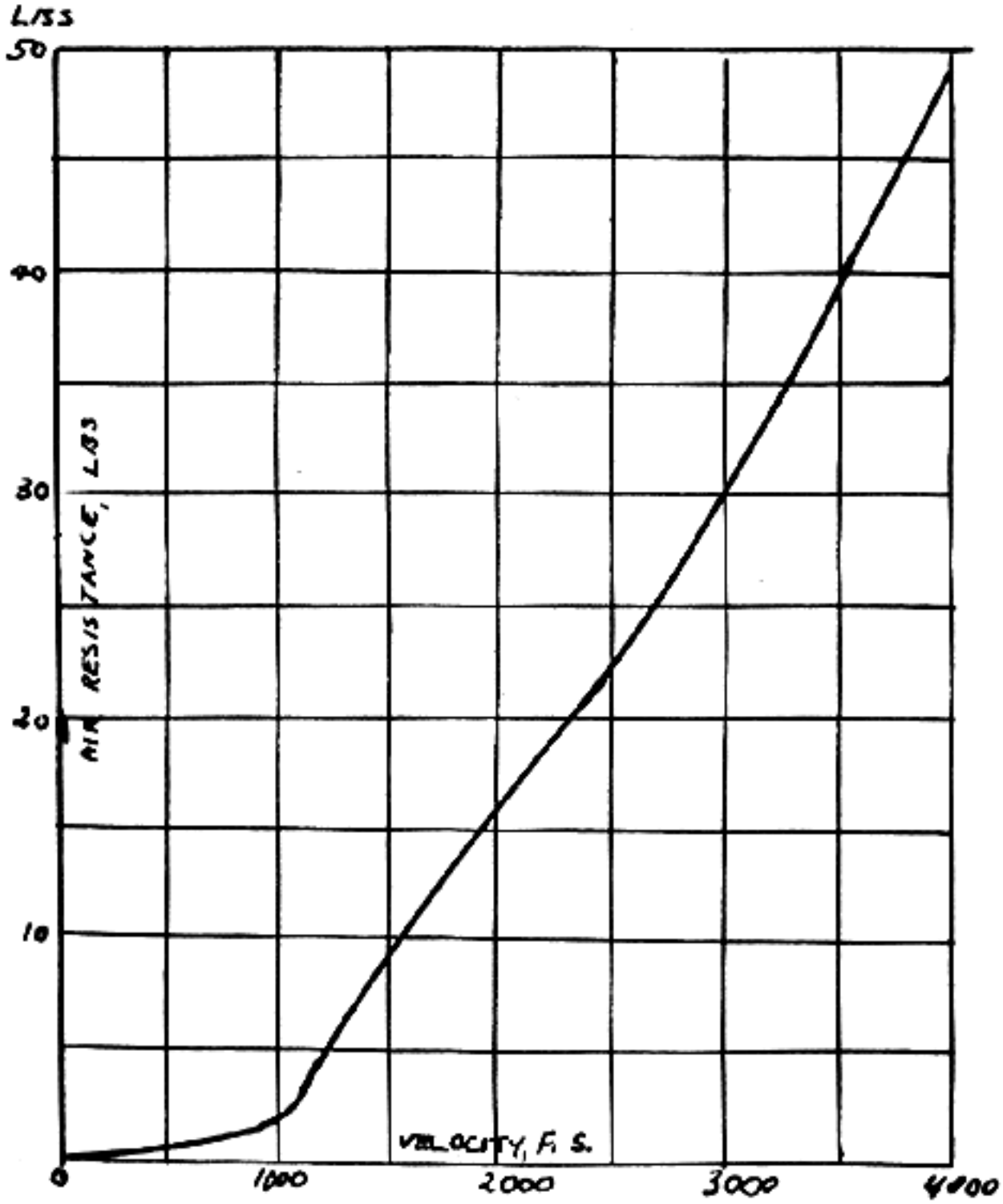
Values for both A and n were computed for the standard projectile mentioned above, and the results were applied to other projectiles of other sizes and weights by means of a constant multiplier called the ballistic coefficient, and designated as C. The ballistic coefficient and its meaning and use will be more fully discussed later.

Col. Ingalls converted Mayevski's results into English units, and based his famous ballistic tables on them.

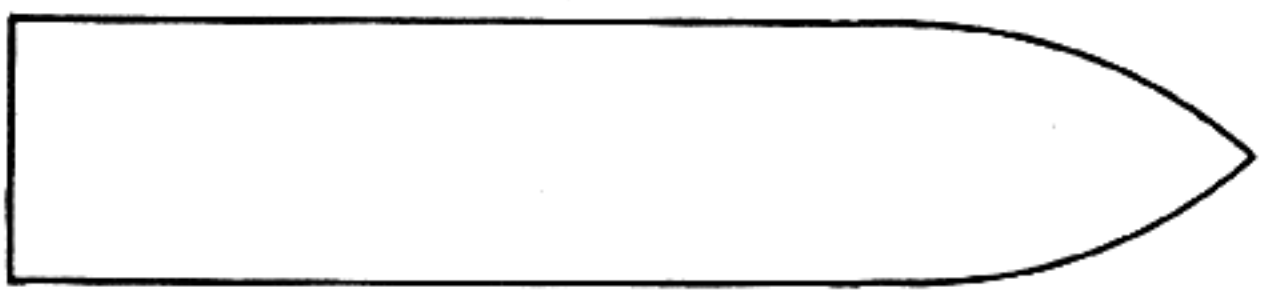
Following are Mayevski's functions, where R is the retardation of the standard projectile in f.s. per second. R divided by the proper ballistic coefficient gives the retardation r for any other projectile.

$R = Cr = Av^2$	for velocities from	0 f.s.	to	790 f.s.	In this range log A = 5.6698914-10
$R = Cr = Av^3$	for velocities from	790 f.s.	to	970 f.s.	In this range log A = 2.7734430-10
$R = Cr = Av^5$	for velocities from	970 f.s.	to	1230 f.s.	In this range lot A = 6.8018712-20
$R = Cr = Av^3$	for velocities from	1230 f.s.	to	1370 f.s.	In this range log A = 2.9809023-10
$R = Cr = Av^2$	for velocities from	1370 f.s.	to	1800 f.s.	In this range log A = 6.1192596-10
$R = Cr = Av^{1.7}$	for velocities from	1800 f.s.	to	2600 f.s.	In this range log A = 7.0961978-10
$R = Cr = Av^{1.55}$	for velocities from	2600 f.s.	to	3600 f.s.	In this range log A = 7.6090480-10

In 1904-1906, the British, using elaborate apparatus, carried out retardation firing experiments up to very high velocities, and from the results deduced a formula very similar to that announced some years previously by Mayevski. They concluded that for the standard



Graph of the resistance function found by the British in their firings of 1904-06.



Type of projectile for which British 1909 tables are computed. It has an ogival head with 2 caliber radius, is 1 inch in diameter, and weighs 1 lb.

experimental projectile of unit diameter and weight and with a 2 caliber ogive, the retardation can be obtained from this formula:

$$R = Av^m; \text{ also } R = Cr = pg; \text{ where}$$

R = retardation of the standard projectile in f.s. per second.

r = retardation of any other projectile of ballistic coefficient C.

v = the velocity of the projectile.

m = the index of a power of the velocity in a restricted zone of velocities.

A = a constant modifying m, and applying only in a restricted zone of velocities.

C = the ballistic coefficient of any projectile as compared with the standard.

p = air resistance in pounds on the nose of the standard projectile.

g = the gravirational constant.

The values of A and m for various zones of velocity under normal conditions of projectile stability and of atmospheric density are as follows:

Limits of velocity. f. s.		f. s.	Value of A	Value of m
0	to	840	$\frac{74,422}{10^7}$	1.6
840		1040	$\frac{59,939}{10^{12}}$	3
1040		1190	$\frac{23,385}{10^{22}}$	6.45
1190		1460	$\frac{95,408}{10^{12}}$	3
1460		2000	$\frac{59,814}{10^8}$	1.8
2000		2600	$\frac{58,495}{10^7}$	1.5
2600		4000	$\frac{15,366}{10^7}$	1.67

It was as a result of these firings that the British computed their ballistic Tables of 1909, which are almost identical with those of Ingalls.

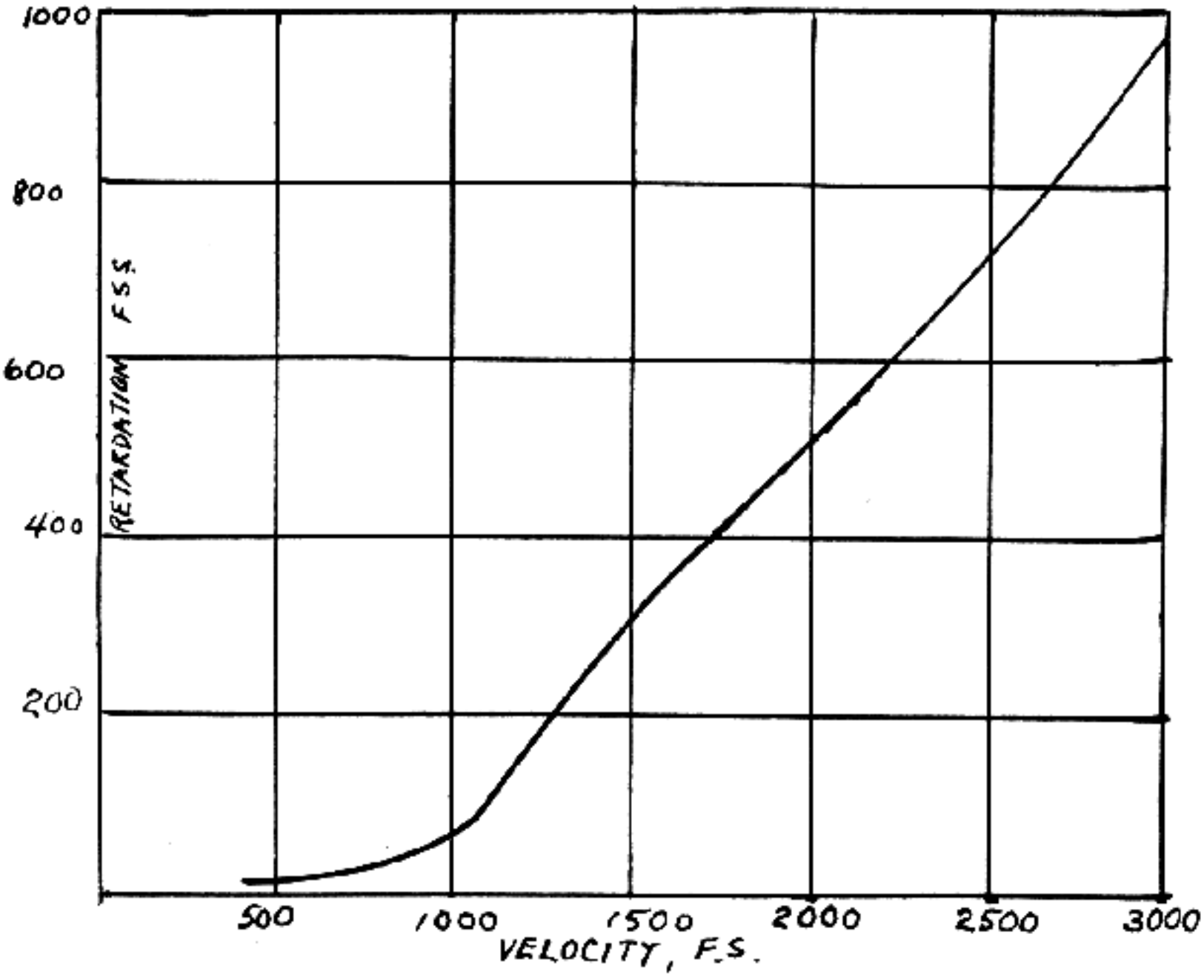
Let us return now to the Gâvre Commission, which, as stated above, carried out a series of firings and studies lasting from about 1873 to 1898. They made firings of their own up to the previously unattained velocity of 6000 f.s., and in doing this, they anticipated the device the Germans used to obtain very high velocities with the

Paris long-range gun of 1918, which was a long smooth bored extension attached to the muzzle of a cannon.

The Gâvre Commission not only carried out their own firing experiments, but also they reviewed and studied all previous resistance firings in all countries, of which the records were available; and in 1898, they formulated and published the results of their own experiments and of their study of the previously reported experiments. Their report showed conclusively that the resistance of the air could not simply be taken as proportional to the square of the velocity, or to any other one power.

Instead of announcing their results in the form of a formula, the Gâvre Commission reduced them to a table showing retardations for each velocity, and this relation became known as the Gâvre function, and was accepted extensively both here and abroad as the basis of ballistic calculations. In general its publication marked the end of the long search for a single formula for calculating air resistance, and substituted instead a table of actual values for each velocity found from experiment.

In the United States, a slightly modified form of the Gâvre function, usually referred to as the G-function, and later designated by



Graph of Gavre Function.

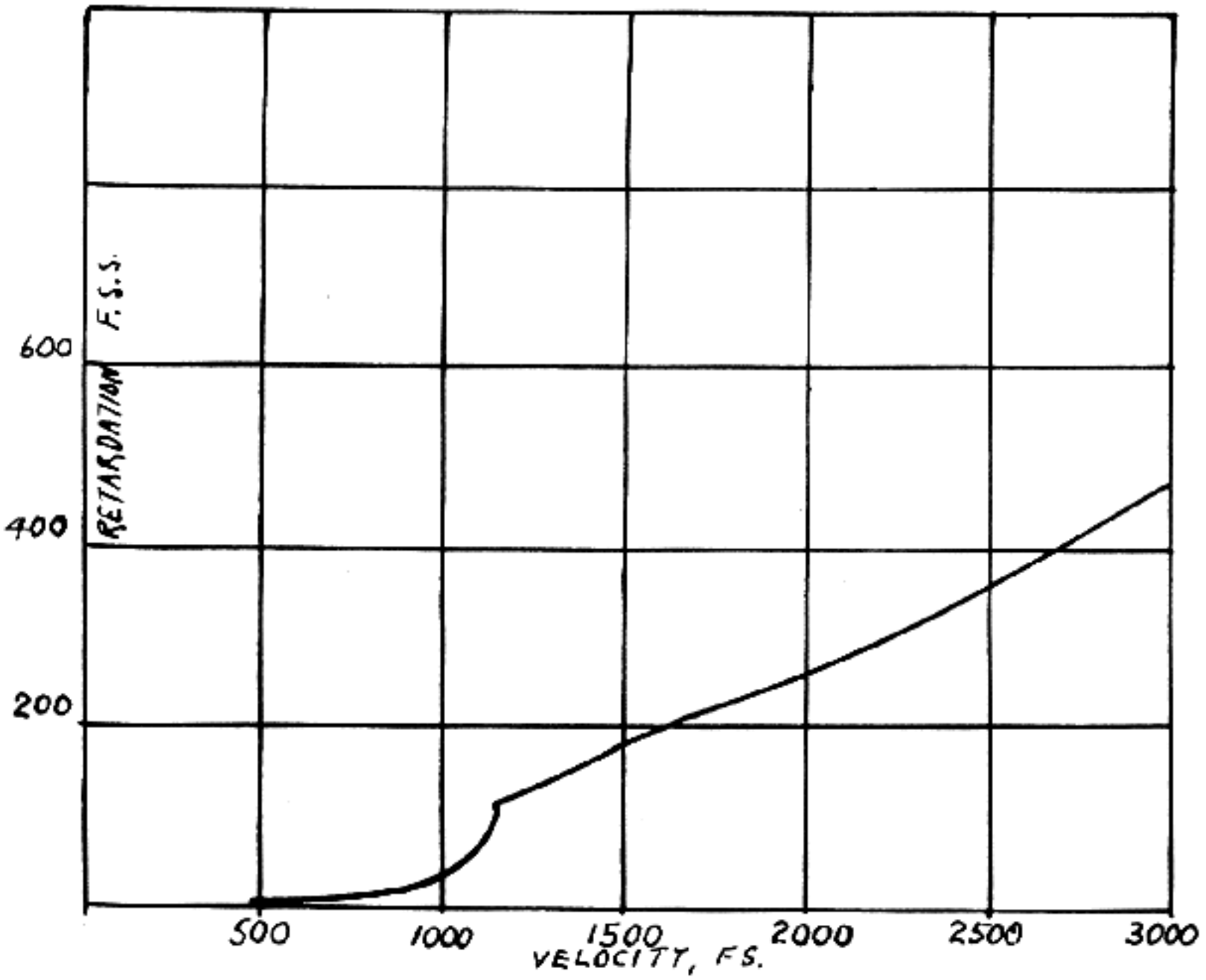
the Ballistic Section of Aberdeen Proving Ground as G_1, has been widely used in the computation of trajectories.

In effect, the G-function is a table showing the relation between velocity and retardation; that is, a table from which may be found directly the retardation corresponding to any given velocity for any projectile having the same shape as the standard projectile used in the Gâvre firings and studies a flat based projectile having an ogival head with a 2 caliber radius.

A graph of the G-function is included here. Note the sharp rise in retardation just at the velocity of sound.

An individual effort that should be mentioned here mainly because it was directed specifically at small arms resistance functions was a series of firings carried out in England in 1897 and 1898 by the late Col. Henry Mellish and the late Lord Cottesloe, (T. F. Fremantle, author of The Book of the Rifle, 1901, who died June 1956).

Col. Mellish and Lord Cottesloe, (with whom I was personally acquainted), set up a specially designed ballistic pendulum behind the 8-inch hole in the center of the bullseye of a heavy iron target, and with it obtained actual striking velocities at 1000 yards with the .461 Gibbs bullet of 570 grains weight. From these striking velocities



Graph of J Function.

an attempt was made to deduce a formula for air resistance vs velocity, but without success.

Further notable resistance firings were made at Aberdeen Proving Ground by the Ordnance Department in 1922-26, using several different shapes of projectile, as by this time long capped projectiles had come into use by heavy Army & Navy cannon, and it had become obvious that for such shells range tables computed from resistance functions based on a rather blunt ogive left something to be desired.

One of the several projectiles used in the Aberdeen firings had a long pencil-pointed nose and a boat tail or tapered base. This projectile, labelled "J" in the tests, was the basis for the Army's ballistic tables for boat tailed and sharp pointed projectiles, called the "J" tables, and based on what was at first called the "j"-function of resistance, (afterward called by Aberdeen the G_2 function).



Projectile for which the British 1929 Tables were computed. It is one inch in diameter, weighs one pound, and has an ogival head of 8 calibers radius.

In 1921 firings were carried out by Mr. F. W. Jones, at Hodsock, in England, with a .303 caliber flat based spitzer bullet, using the same 1000-yd. ballistic pendulum arrangement that has just been described as having been used by Col. Mellish and Lord Cottesloe. In 1922, Mr. Jones carried out further experiments with a similar bullet having a boat tail or tapered base.

From these firings by Mr. Jones a set of resistance functions for spitzer pointed small arms bullets was developed, and from them a set of ballistic tables was worked out, which were known as the Hodsock tables. They were published, but eventually went out of print. However, they have now been reprinted in a revised and improved form as a final chapter in the book, Notes on Sporting Rifles by Major Sir Gerald Burrard, D.S.O., 4th Edition, 1953. (Edward Arnold & Co., London).

Additional firings for retardation were made by the British War Office with a flat based projectile having a long ogive point of 8 calibers radius, and the tables for sharp pointed projectiles that were printed in the British Textbook of Small Arms, 1929 were computed from these firings.

Thus it will be seen that there are several different sets of ballistic tables available that may be used with small arms bullets. The Ingalls

tables, and the almost identical British 1909 tables are most suitable for the ordinary hunting bullet, either the rounded nose type such as the full metal cased .30-30, or the modified spitzer shapes, such as the 222 Remington soft point; while the Hodsock tables or the British "Sharp Point" tables of 1929 give slightly closer results with very sharp pointed spitzers, such as the military .30-06. The Ordnance Department's J tables give closer results for boat-tailed spitzer bullets, though it should be observed that at velocities above the speed of sound it makes little difference whether the base of the bullet is boat-tailed or not.

Comparison of Retardation Functions

At this point it may be of interest to compare the retardations obtained in several of the various resistance firings previously referred to. Accordingly a tabulation is included here, giving velocities in one column, and listing in adjacent columns the results of—(a) the Krupp firings at Meppen in 1881, on which Mayevski's formula and the Ingalls tables were based; (b) the Gâvre function; (c) results of the British firings of 1904-06 using the same shape of projectile as was used by Krupp and at Gâvre; (d) the Aberdeen firings with the "J" projectile; (e) firings by the Germans with a flat based spitzer; (f) firings made by Jones at Hodsock in 1921 with a flat based spitzer; and (g) firings made in 1922 by Jones at Hodsock with a boat-tailed spitzer bullet of .303 inch caliber.

Construction of a Ballistic Table

For those who may be curious about how a set of ballistic tables can be made up from only a formula for air resistance, the following brief explanation is included.

Mayevski's formula for the retardation in f.s. per second of the standard projectile of unit weight and diameter and with a 2 caliber radius of ogive, gives the retardation as Av^n where A and n have different values in different velocity zones.

Suppose we decide to find the space traversed by the standard projectile while it is being retarded from 3600 f.s. to 3580 f.s., which is the first interval covered in Ingalls' tables.

The average velocity over this space is evidently close to $\frac{3600 + 3380}{2}$ or 3590 f.s., so the first step is to find the retardation of the standard projectile for this velocity.

We see by Mayevski's formula, as already quoted, that in the velocity zone from 2600 f.s. to 3600 f.s., n is 1.55 and A is the number whose logarithm is 7.609.048−10.

First we take the logarithm of 3590 which is 3.555094 and multiply it by 1.55, getting 5.510,396. To it we add log A, which is 7.609,048−10,

RESULTS OF SOME HISTORIC RETARDATION FIRING TESTS

Retardation, f.s. per second for standard projectiles 1 inch in diameter and 1 lb. in weight.

Velocity f.s.	Krupp	Gavre	British 1904-06	Aberdeen "J"	German Spitzer	Hodsock flat base	Hodsock boat-tail
800	26.2	28.8	32.8	22	24.1	...	...
850	30.6	34.7	36.76	25	27.3	...	...
900	36.2	42.6	43.75	28	31.2	...	...
950	43.3	53.3	51.45	32	36.2	...	...
1000	54.2	68.0	59.81	38	44.7	...	...
1050	73.3	88.2	72.14	48	60.3	...	...
1100	107.0	112.7	96.8	95	87	...	...
1120	120	123.4	108.74	102	99	...	...
1150	141	139.6	128.96	111	116	...	...
1200	175	166.4	164.86	122	141	128	125
1250	195	191.8	186.34	132	152	135	135
1300	213	216.2	209.36	141	164	150	143
1400	258	261.6	261.76	160	187	176	159
1600	343	347.1	349.90	195	233	222	195
1800	426	429.2	432.23	225	280	268	230
2000	509	510.5	522.60	265	325	303	263
2200	598	593.0	603.00	295	371	364	296
2400	692	678.5	686.93	337	407	410	328
2600	795	769.3	774.73	375	464	454	359
2800	904	867.1	876.68	423	509	502	390
3000	1015	973.0	983.77	463	555	523	420
3200	1135	1087.5	1095.69	514	601	...	...
3400	1265	1213.2	1212.75	...	...	...	...
3600	1410	1349.3	1333.99	...	...	...	...
3800	1565	1495.5	1460.06	...	...	...	...
4000	1730	1649.6	1590.63	...	...	...	...

getting 3.119,444. The number corresponding to this logarithm is found to be 1316.5, which is the retardation in f.s.s. for the standard projectile at 3590 f.s.

The usual formula for the space passed over by a uniformly accelerated (or retarded) body in passing from speed V to speed v is

$$\frac{V^2 - v^2}{2r} \quad \text{which in this case is} \quad \frac{3600^2 - 3580^2}{2 \times 1316.5} = 54.5 \text{ feet.}$$

Looking now at Ingalls tables, p. 583, we see that this is indeed the first entry in column S (u), the space function. This represents the actual distance in feet that would have been traversed by the standard projectile while its speed fell from 3600 f.s. to 3580 f.s. if it had been projected with an initial velocity of 3600 f.s., and its path had remained horizontal throughout.

The quantity u used in the expression S(u) is the *pseudo-velocity*, which is the projection of the actual velocity along the trajectory

Moreover, there is necessarily a great uncertainty as to just exactly what the retardation is at low velocities, for as a practical matter it is almost impossible to measure retardations experimentally at these low velocities. For example, according to Ingalls' tables, it takes the standard projectile only 274.4 feet to slow down from 3600 f.s. to 3500 f.s., and according to the British 1909 tables, it takes 272.2 feet, and requires 0.07 seconds.

However, the space required to slow down from 200 f.s. to 100 f.s. as given in the British 1909 tables is 6672 feet, while in Ingalls' tables it is 14,822 feet, and requires 23 seconds. In 23 seconds the bullet would drop 8464 feet, so it can readily be seen that it would be impossible to chronograph a bullet at the beginning and end of this interval.

This situation was impressed on my mind when I once plotted both the Ingalls tables and the supposedly almost identical British 1909 tables on cross-section paper, starting with 100 feet as the origin of the plot. The two curves were for the most part identical in shape, but the Ingalls curve lay considerably farther to the right. I puzzled over this for a while, then remembered the facts mentioned above, and repeated the work, but this time took 3600 f.s. as the origin of the plot. This time the curves practically coincided everywhere until the very low velocities were reached.

In view of the fact that the very low velocities are of no importance in the usual ballistic calculations, and that the thing that matters is the *difference* between the space or time function for some velocity under consideration and the space or time function for some other velocity, this discrepancy in the very low velocity ranges makes no difference at all to the average user of these tables.

Pressure in Pounds on the Nose of the Projectile

If a force of p pounds acts on a body of mass m, it will cause an acceleration of p/m f.s. per second. Mass is weight divided by gravity, so the retardation of the projectile by the air resistance of p pounds on its nose will be pw/g. However, with the standard projectile of unit weight which was used in making up the ballistic tables, w is 1, and the formula for retardation becomes r= p/g, and from this we have p = r/g. Thus we can find p simply by dividing the retardation by 32.16.

As the retardation of the standard projectile at a velocity of 3590 f.s. was found to be 1316.5 f.s. per second, the actual force on the nose at that speed is 1316.5/32.16, or 40.95 pounds.

Proceeding in this way, we can make up a table of retardations and nose pressures for Mayevski's standard projectile for several different velocities, as follows:

Velocity f.s.	Retardation f.s. per second	Pressure p lbs. on nose of projectile
3600	1323.5	41.15
3500	1271.0	39.51
3400	1203.9	37.43
3300	1152.1	35.82
3200	1097.9	34.1
3100	1045.6	32.51
3000	995.0	30.93
2500	708.0	22.01
2000	508.9	15.82
1500	293.1	9.1
1200	154.3	4.7
1100	99.7	3.10
1000	61.2	1.90
900	42.53	1.32

As was stated above, this table is for a projectile of unit diameter; in other words, the diameter is 1 inch, and consequently the diameter squared is also unity. This fact makes it extremely simple to find the rearward pressure in pounds for any other projectile of the same nose shape, but of a different diameter; for to convert the figures in the table to another projectile of the same shape it is only necessary to multiply the figures in the table by the square of the diameter of the projectile.

Thus for a .30 caliber projectile having an effective diameter of the caliber plus the depth of 1 groove, or .304, and a shape of nose similar to that of the standard projectile, the pounds rearward force on the nose at any speed would be that in the table multiplied by .304 x .304, or .0924.

Thus for a .30 caliber bullet with about a 2 caliber ogive, at 2500 f.s., we would expect to have a nose resistance of 22.01 x .0924 = 2.034 lbs.

Form Factor

Now considering the .30-06 service bullet, we know from the way it acts when chronographed that it actually experiences a nose pressure at 2500 f.s. of about 1.14 lbs. The fact that the pressure is less should be no surprise, however, for this bullet has a much sharper point than the standard projectile for which the Ingalls tables were computed. Instead of a 2 caliber radius, it has one of 7 calibers, which obviously would pierce the air much more easily.

We see therefore, that to compensate for the sharper point of the .30-06 spitzer as compared to the standard Ingalls shape, we must multiply the figures given in our resistance table above by .56.

This multiplier is called the coefficient of reduction, or form factor, and is variously designated by different ballistics writers as c, (as distinguished from C, the ballistic coefficient), as n, and as i.

onto the horizontal. With the very small angles of departure used in small arms firing, it differs so little from the actual velocity v that u is disregarded, and v is used instead without introducing any noticeable error.

Dividing the space passed over, which is 54.5 feet, by the average speed over this distance, or 3590 f.s., we get 0.015 for the time required for the projectile to have its speed changed from 3600 f.s. to 3580 f.s. by the air resistance encountered at that speed.

Thus we see that using only Mayevski's formula, and without recourse to higher mathematics, we have been able to fill in the first two values in the space function and time function columns of the ballistic tables. The entire table could be completed that way without any great error, providing only that the intervals between each two calculations are taken small enough.

What the Ballistic Tables Mean

To the average user of ballistic tables, they are just a seemingly interminable string of figures with the magical property of giving good ballistic information when used according to directions. Actually, however, when in the form of Ingall's tables they are rather simple when considered from the viewpoint of what the figures actually are.

As was seen above, the figures in the Space function column simply indicate spaces passed over by the bullet while its velocity is changing, (or being retarded by the air resistance), from some starting velocity to the velocity to which the particular figures apply; and the difference between the S figure for any one velocity and any other velocity represents the space passed over by the projectile while its speed is changing from one of the two velocities to the other. Likewise, the figures in the T or time function column represent the time occupied by the projectile in changing its speed from one velocity to the other.

It may be noted that the Ingalls tables, as well as most other American ballistic tables, start at the high velocity end of the velocity scale, and consider that the bullet is started off at 3600 f.s., and for the first increment of the space function and time function columns give the space and time required for the velocity to drop to the next lower figure.

The British, on the other hand, start their tables with 100 f.s. velocity, and for the first increment of the time and space function columns they give the time and space required by the bullet to be slowed down to 100 f.s. from some slightly higher velocity, say, 110 f.s.

The American system seems more logical, for it follows what the bullet actually does when fired; that is, it starts out with some high speed (the muzzle velocity), and then slows down.

This book will follow the practice of Artillery Circular M and call it the form factor, designated by i.

It should be understood, and firmly borne in mind, that there is no *absolute* form factor for any bullet; the form factor is always for a *particular ballistic table*, and is determined by comparison of the retardation of the bullet in question with the retardation of the standard table for which the ballistic table was made.

While the form factor is best found by experimental firing, there are ways of estimating it fairly closely from the shape. One simple way is by comparing the bullet with a chart of bullet shapes, each with its coefficient of form marked thereon. Such a chart, by Edgar Bugless and Wallace H. Coxe, Ballistic Engineers of the DuPont Co. formed a part of a series of ballistic charts called "A Short Cut to Ballistics" published by the DuPont Co. By permission of the DuPont Company, this chart is reproduced herewith.

Instructions for using the chart.

Given a bullet; to estimate the coefficient of form, i.

1. Lay the bullet on the group of ogive curves marked with the proper caliber for the bullet.

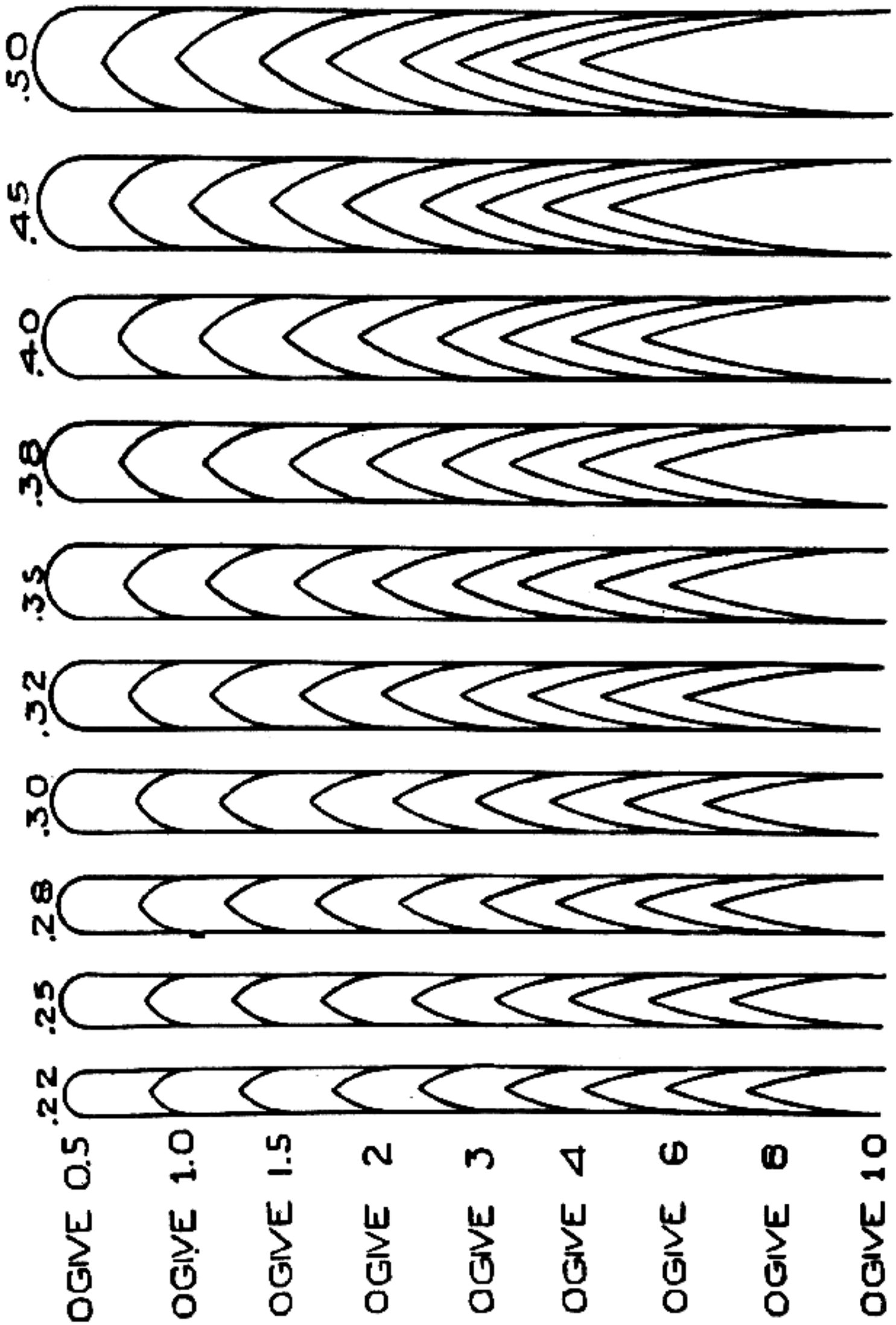
2. Slide the bullet along until it matches one of the ogive curves as closely as possible.

3. Refer to the instruction page and read off the coefficient of form.

As an example, to estimate the coefficient of form for the .30 M2 bullet which has a 7 caliber ogive and a point which has a small blunt point about .03″ in diameter, lay the bullet on the set of curves marked .30, and slide it along until it seems to match an ogive curve. It will be seen that it is a bit too slim for the ogive 6 and a bit too fat for ogive 8, so the ogive evidently has a 7 caliber radius.

Referring to the instruction page, we see that for velocities over 2000 f.s. an 8 caliber ogive with a 0.1 caliber flat point has a coefficient of form of 0.55, and one with a 6 caliber ogive has a coefficient of form of 0.60. Hence one with a 7 caliber ogive will have a coefficient of form equal to the average of these two, or about .575.

BULLET FORM	NORMAL POINT	VALUE OF i: Diam. of Hollow Point or Flat Nose in Calibers 0.1	0.2	0.3	0.4	0.5
Blunt Projectile, Cylindrical	2.30					
Blunt Projectile, Taper Sides 0.9 Cal.	1.85					
Blunt Projectile, Taper Sides 0.8 Cal.	1.50					
Blunt Projectile, Taper Sides 0.7 Cal.	1.30					
Blunt Projectile, Taper Sides 0.6 Cal.	1.10					
Head Radius of 0.5 Cal.	1.40					
Head Radius of 1.0 Cal.	1.10	1.15	1.20	1.25	1.30	1.40
Head Radius of 1.5 Cal.	0.95	1.00	1.10	1.15	1.25	1.35
Head Radius of 2.0 Cal.	0.85	0.90	0.95	1.00	1.10	1.25
Head Radius of 3.0 Cal. M.V. 2000–3500 f.s.	0.70	0.75	0.80	0.90	1.00	1.10
Head Radius of 3.0 Cal. M.V. under 2000 f.s.	0.75	0.80	0.85	0.95	1.05	1.15
Head Radius of 4.0 Cal. M.V. 2000–3500 f.s.	0.60	0.65	0.70	0.75	0.85	1.00
Head Radius of 4.0 Cal. M.V. under 2000 f.s.	0.70	0.75	0.80	0.85	0.95	1.10
Head Radius of 6.0 Cal. M.V. 2000–3500 f.s.	0.55	0.60	0.65	0.70	0.80	0.95
Head Radius of 6.0 Cal. M.V. under 2000 f.s.	0.65	0.70	0.80	0.85	0.95	1.10
Head Radius of 8.0 Cal. M.V. 2000–3500 f.s.	0.49	0.55	0.60	0.65	0.75	0.90
Head Radius of 8.0 Cal. M.V. under 2000 f.s.	0.60	0.65	0.70	0.75	0.85	1.00
Head Radius of 10.0 Cal. M.V. 2000–3500 f.s.	0.44	0.50	0.55	0.60	0.70	0.85
Head Radius of 10.0 Cal. M.V. under 2000 f.s.	0.55	0.60	0.65	0.70	0.80	0.95
Balls with M.V. under 1000 f.s.	2.00					
Balls with M.V. between 1000–1300 f.s.	1.70					
Balls with M.V. over 1300 f.s.	1.40					


.50
.45
.40
.38
.33
.32
.30
.28
.25
.22
OGIVE 0.5
OGIVE 1.0
OGIVE 1.5
OGIVE 2
OGIVE 3
OGIVE 4
OGIVE 6
OGIVE 8
OGIVE 10

The British Textbook of Small Arms, 1909, gives a formula for caluculating the form factor for ogival pointed bullets, such as the .30-06 spitzer, which gives close results. It is $i = \frac{2}{n}\sqrt{\frac{4^n - 1}{7}}$

where i is the form factor, and n is the radius of the ogive expressed in calibers.

Thus the .30-06 bullet has an ogive with a radius of 2.1 inches, or 7 calibers, and the form factor computed by that formula comes out .56

For ogival pointed bullets the radius of the ogive, n, can be determined rather easily by first measuring the diameter and the length of head of the bullet, and then using the formula $n = \frac{4\ L^2 + 1}{4}$

where L represents the length of the head of the bullet expressed in calibers.

The Ballistic Coefficient

The ballistic tables given in this book are made for a standard projectile of 1 inch diameter, 1 lb. weight, and with a shape corresponding to that of the projectile used in the resistance firings on which the particular table is based. As stated above the space and time functions in the tables represent actual spaces and times required by *this projectile* to pass from one velocity to another. If any other projectile is used, the spaces and times will be different.

Of course, the heavier the projectile is, all other things being equal, the less it will be retarded. If we want to use the tables with a projectile having the same shape and diameter, but twice the weight, we must multiply all figures in the table by 2, for it will go twice as far and take twice as long in slowing down from one velocity to another as will the standard projectile.

Again, suppose that we have a projectile of the same shape of nose and same weight as the standard projectile for which the tables were made, but of half the diameter. As cross-sectional area varies with the square of the diameter, this projectile will have only one-quarter the cross-sectional area of the standard projectile, and will meet only one-quarter the air resistance, so it will slow down only one-quarter as fast, and all figures in the table will have to be multiplied by 4. Such a multiplier is what is called the *Ballistic Coefficient* of the projectile for the particular ballistic table to be used. The ballistic coefficient of any bullet takes into account the weight, cross-section area, and shape of the bullet as compared to those qualities for the standard projectile on which the table is based, and also it takes into account the density of the air at the time of firing as

compared to the standard density for which the tables were computed.

As will be seen from what has been said about the effect of weight and cross section, the ballistic coefficient is proportional to w/d^2 where w is the weight of the bullet in pounds, and d is its diameter in inches. The quantity w/d^2 is called the *Sectional Density*.

Use of the Form Factor

Obviously, the form factor of the bullet under consideration as compared to the standard projectile for which the tables were computed enters importantly into the ballistic coefficient, for the shape of the point of the bullet has a large effect on the magnitude of the air resistance it encounters in flight; the sharper the point and the smaller the form factor, the more easily the bullet can bore its way through the air.

Thus when the form factor is included, the ballistic coefficient becomes $C = \frac{w}{i\ d^2}$ where w is the weight of the bullet in pounds, d is its effective diameter (usually taken as the caliber plus the depth of 1 groove) and i is the form factor.

Correction of C for Changes in Air Density

There is another factor that enters into the complete expression for the ballistic coefficient, and that is a correction for variations in the density of the air from standard. The density of the air is affected by variations in temperature, in moisture content of the air, and in barometric pressure. The density is considered to be standard for ballistic calculations when the temperature is 60 deg. F., the barometer is 30 inches, and the air is two-thirds saturated with moisture.

It is usual to represent the density of the air by the symbol delta (δ). δ represents the actual density at the time and place of firing, while δ_1 represents the standard density. On p. 430 will be found a table of $\frac{\delta_1}{\delta}$ for various temperatures and barometer readings. While such corrections are vitally important in long range artillery firing, they are relatively unimportant in small arms firing at the usual ranges used in hunting or target practice, and hence may be disregarded.

However if it is desired to use them, it is only necessary to multiply the ballistic coefficient by $\frac{\delta_1}{\delta}$ as found from the table on p. 430 for the temperature and barometer at the time of firing.

Drag Coefficient

The reader who merely desires to use the ballistic tables at the end of the chapter may skip what follows, and turn directly to the tables.

However, for those who may desire as a matter of interest to study the subject of air resistance further, there follow a few paragraphs on the subject of the drag coefficient.

It was said above that Sir Isaac Newton decided that air resistance to a moving body is proportional to the square of the velocity, and that resistance firings seemed to show that this is not so. Further light is thrown on this subject by the following, quoted from the Ordnance School Text on Ballistics, prepared by Dr. L. S. Dederick for use in the Ordnance School in 1939 at the time when I was head of that school. The direct quotation starts here—

Dimensional Analysis

Before it is possible to give a complete and intelligible account of the assumptions made at the present time about the laws of air resistance, it is necessary to make a digression into a rather general subject of physical theory, that of dimensional analysis.

In order to specify the magnitude of any physical quantity, it is necessary to name the unit as well as the numerical measure. Thus a length of 5 is not determined unless we know whether it is 5 inches, 5 feet, or 5 of some other unit of length. The same is true of an area or a volume, but the three things are related. We know that if we change our unit of length from feet to inches, the number of units in a given length is multiplied by 12, the number of units in a given area is multiplied by the square of 12, and that in a given volume by the cube of 12.

This is briefly expressed by saying that the dimensions of area and volume are respectively two and three in length, or that the dimensional formulas for area and volume are L^2 and L^3. In the same way, most physical units can be expressed in terms of a small number of fundamental units, the most commonly used being length, mass, and time, and denoted by L, M, and T respectively. Thus we may say the dimensional formula for velocity is LT^{-1}, since velocity is obtained as a distance divided by a time. Since an acceleration is a velocity divided by a time, its dimensional formula is LT^{-2}.

Again, since a force is determined as a mass multiplied by an acceleration its dimensional formula is MLT^{-2}. Likewise the formula for density is ML^{-3} since density is mass divided by volume.

If any mathematical equation involves terms representing physical quantities, it must be homogeneous in the dimensional formulas of these quantities; that is, the degree of any one of the letters M, L, and T in the dimensional form of one term of the equation must be

the same as that in any other term. The reason is that the equation may be supposed to represent a physical fact which is independent of the units used. A change of any unit will multiply every term by the same factor and so preserve the equality if the equation is homogeneous, but will not in the contrary case. This principle is commonly used as a check, but may also be used to discover new facts.

A very commonly used example of this procedure is the following. The time of oscillation t of a pendulum for a given amplitude may be supposed to depend conceivably on its length L, its mass M, and the intensity of gravity g. We write an equation in the form

$$t = kL^{\alpha} M^{\beta} g^{\gamma}$$

where k is a constant, assumed to be dimensionless, and the exponents α, β, and γ are to be determined.

The dimensional formula for the left side is of course T. For the right side it is

$$L^{\alpha} M^{\beta} (MT^{-2})^{\gamma}$$

Comparing the exponents of L, M, and t respectively in the two formulas, we get $\alpha + \gamma = 0$, $\beta = 0$, $-2\gamma = 1$. Hence $\alpha = \frac{1}{2}$, $\beta = 0$, and $\gamma = -\frac{1}{2}$, and we can infer that $t = k\sqrt{l/g}$

While the value of k is not given by this process, the result is rather substantial for the small amount of labor involved.

Of course in this sort of investigation we must take account of all relevant considerations. We assumed here that the oscillations were of a given amplitude. Dimensional analysis will tell us nothing about angles, since they are dimensionless, that is, they are independent of the units of length, mass, and time used.

Application to Air Resistance

We shall now apply the method of dimensional analysis to the law of air resistance. We have already assumed that the drag depends on the velocity of the projectile, the air density, and the shape and size of the projectile. Since we have seen that there is experimental evidence that there are different drag functions for different shapes, we need only consider size, which is then determined by any one linear dimension, such as diameter. We may write then

$$D = K_D d^{\delta} u^{\beta} \rho^{\gamma}$$

where D is in the air resistance, or drag, K_D is the coefficient of drag, d is the diameter of the projectile, u its velocity with respect to the air, and ρ the air density.

Now the dimensional formula for D is MLT^{-2}, that for d is L, that for u is LT^{-1}, and that for ρ is ML^{-3}. We have then

$$MLT^{-2} = L^{\alpha} (LT^{-1})^{\beta} (ML^{-3})^{\gamma}$$

and hence, by comparing the exponents of L, M, and T, respectively,

$$1 = \gamma$$
$$1 = \alpha + \beta - 3\gamma$$
$$-2 = -\beta$$

Hence $\gamma = 1$, $\beta = 2$, and $\alpha = 2$. We have then that the drag is proportional to the air density, to the square of the diameter, and to the square of the velocity of the bullet through the air. If we replace α, β, and γ, by their numerical values, the equation for drag becomes

$$D = K_D d^2 u^2$$

where the quantity K_D is called the *drag coefficient*, and is a quantity of dimensions zero. The implication of this last is that the value of the drag coefficient is entirely independent of the other quantities in the equation, provided of course, that these are consistent. Thus if d is expressed in feet, u in feet per second, p in pounds per cubic foot, and the corresponding value of D in poundals, the value of K_D will be the same as if d were in centimeters, u in centimeters per second, p in grams per cubic centimeter, and the corresponding value of D in dynes. Of course the unit of force must be absolute and not gravitational; the use of a pound force or a gram force would arbitrarily introduce the units of g. Not only is K_D of dimensions zero, but any quantity on which it depends must also be of dimensions zero.

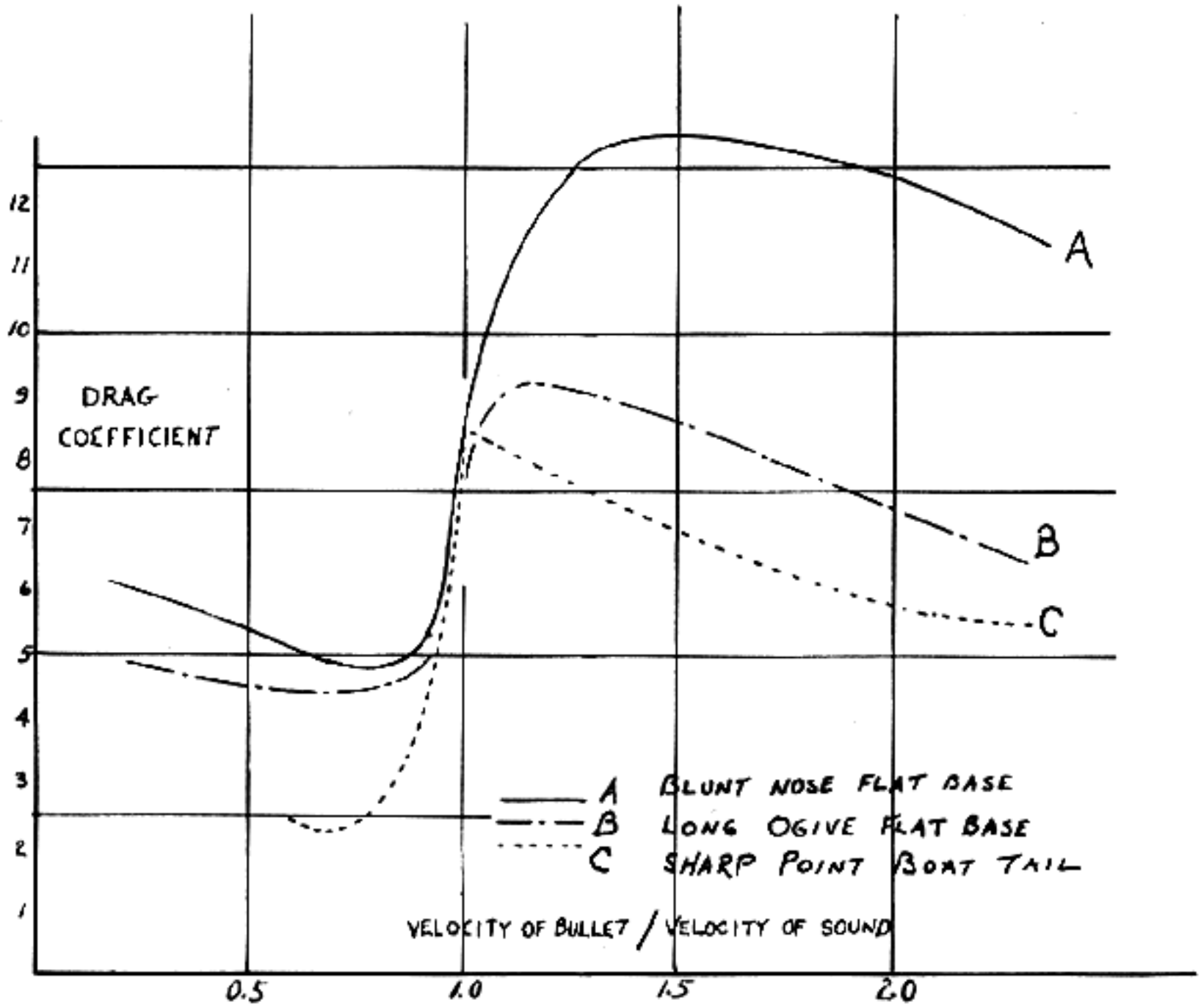
The indication that D is proportional to u^2 appears to be a very astonishing result, for it apparently brings us back to Newton's law of resistance, which had been discredited by all the firings made by the Gâvre commission, and the resistance firings performed at Aberdeen.

Any such inference as this, however, overlooks the fact pointed out previously, that dimensional analysis throws no light on the influence of a dimensionless quantity, such as an angle or any other number in the form of the ratio of two quantities of the same dimensions. Thus while dimensional analysis shows that the drag is proportional to the square of the velocity, the drag may depend on any way whatever on the ratio of the projectile velocity to some other independent velocity.

If the drag were actually dependent on the square of the velocity, and not dependent on the velocity in any other way, we should have D/u^2 equal to a constant for any particular projectile and air density. For a standard projectile, this will be proportional to G_T/u, (where G is the Gâvre function, which is the particular drag function based on the experimental evidence collected by the Gâvre commission, practically all of which pertained to projectiles of conventional pre-World War I shape,) and also to K_D.

If then we compute G/u as a function of u from a G table, we may learn the mode of variation of K_D as a function of u.

If now we plot or tabulate this result based on the Gâvre function



Drag coefficient plotted against ratio of bullet velocity to velocity of sound for three projectile shapes.

or any of the other drag functions, we get a function of u with the following properties. For small values of u it is nearly constant or decreases slightly; in the neighborhood of 1100 f.s. it increases very rapidly; it reaches a maximum shortly beyond this, and then decreases, but remains considerably larger than the value first mentioned.

For the different drag functions—that is for the drag functions pertaining to different projectile shapes—the abruptness of the increase, and the amount of the increase differ, but the value of u for which the increase is most rapid shows very little variation. This suggests forcibly that the rise is connected with the velocity of sound in air.

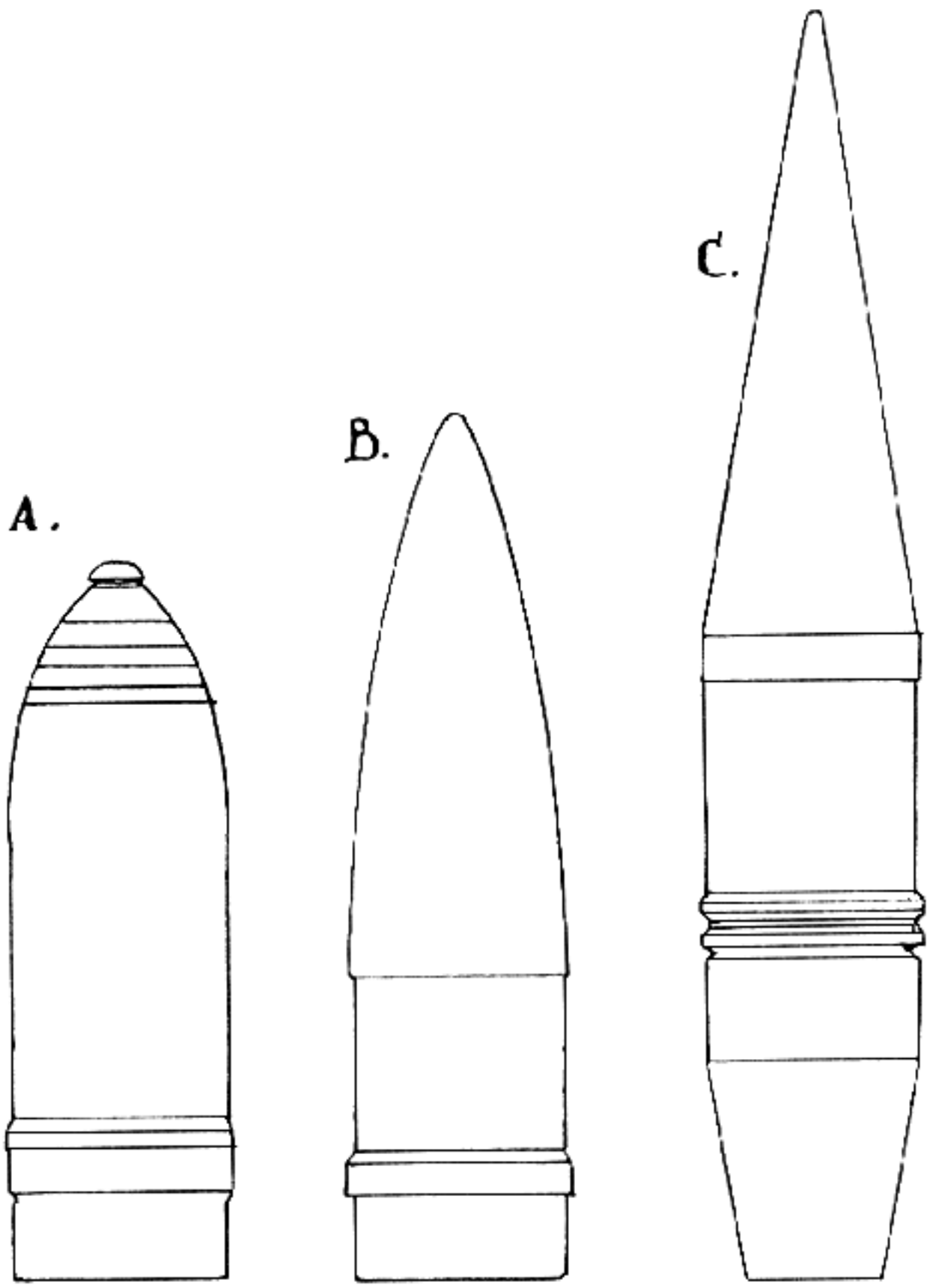
A set of three curves is given herewith, in which the drag function K_D is plotted against u/a for three different shapes of projectile. Curve A is for the Gâvre projectile, and the other two are for projectiles used in the Aberdeen firings of 1922. Projectile B has a long ogival point and a flat base, while projectile C, called the "J" projectile, has a long pencil-pointed nose and a tapered or "boat-tailed" base.

The fact that K_D has been made to depend on u/a rather than on u itself conforms to the requirement that K_D is not only of dimensions zero itself, but must also depend on arguments which are dimensionless.

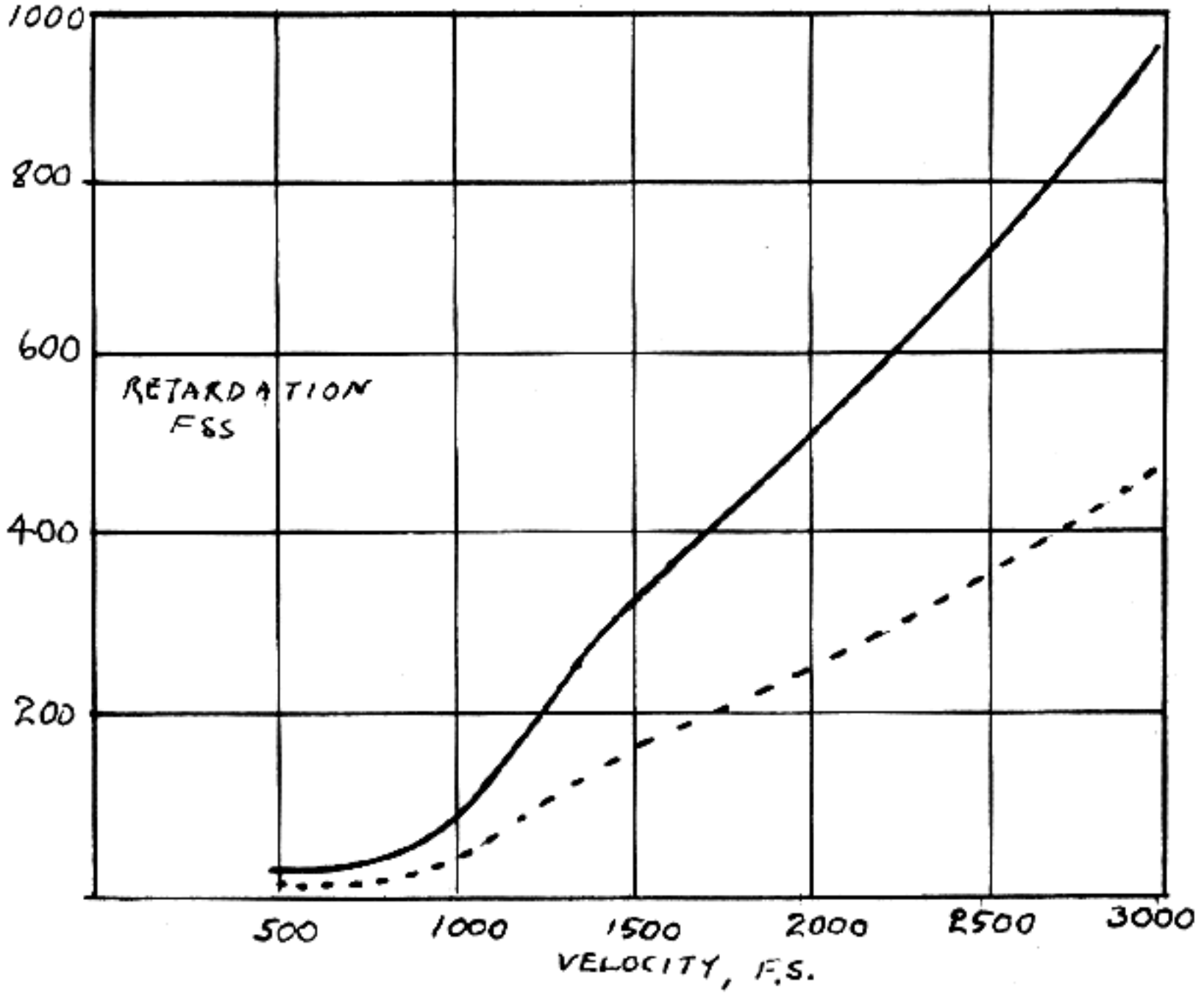
Only one argument has been mentioned so far, namely u/a. This is called Mach's number. A full treatment would require the consideration of the cross-wind force and the overturning moment and stability factor, but in this very brief chapter they will have to be omitted.

Change of Ballistic Coefficient With Velocity.

It will be noticed in working with ballistic tables that the ballistic coefficient often changes with changes in velocity. Theoretically the



The three projectiles for which the Drag coefficient is plotted in the accompanying graph. Projectile A is similar to the Gavre type, while C is the Aberdeen "J" projectile.



Full line shows Gavre function and dotted line shows resistance function for a projectile with Gavre shape and a ballistic coefficient of 2.0.

ballistic coefficient should remain constant regardless of velocity, but this is only so when the shape of the bullet is exactly similar to that of the standard projectile for which the ballistic table was computed.

Looking at the curve of K_D given herewith it can be seen that a projectile having a shape like that of projectile A will by no means follow a ballistic table computed for a projectile having a shape like that of projectile C.

Looking now at sketch No. 9, we see a graph of the G function, together with a graph of the retardation function of a projectile having the same form and weight but half the cross section area. It will have a ballistic coefficient of 2.0 and that will not change with velocity when used with tables computed for the Gâvre projectile.

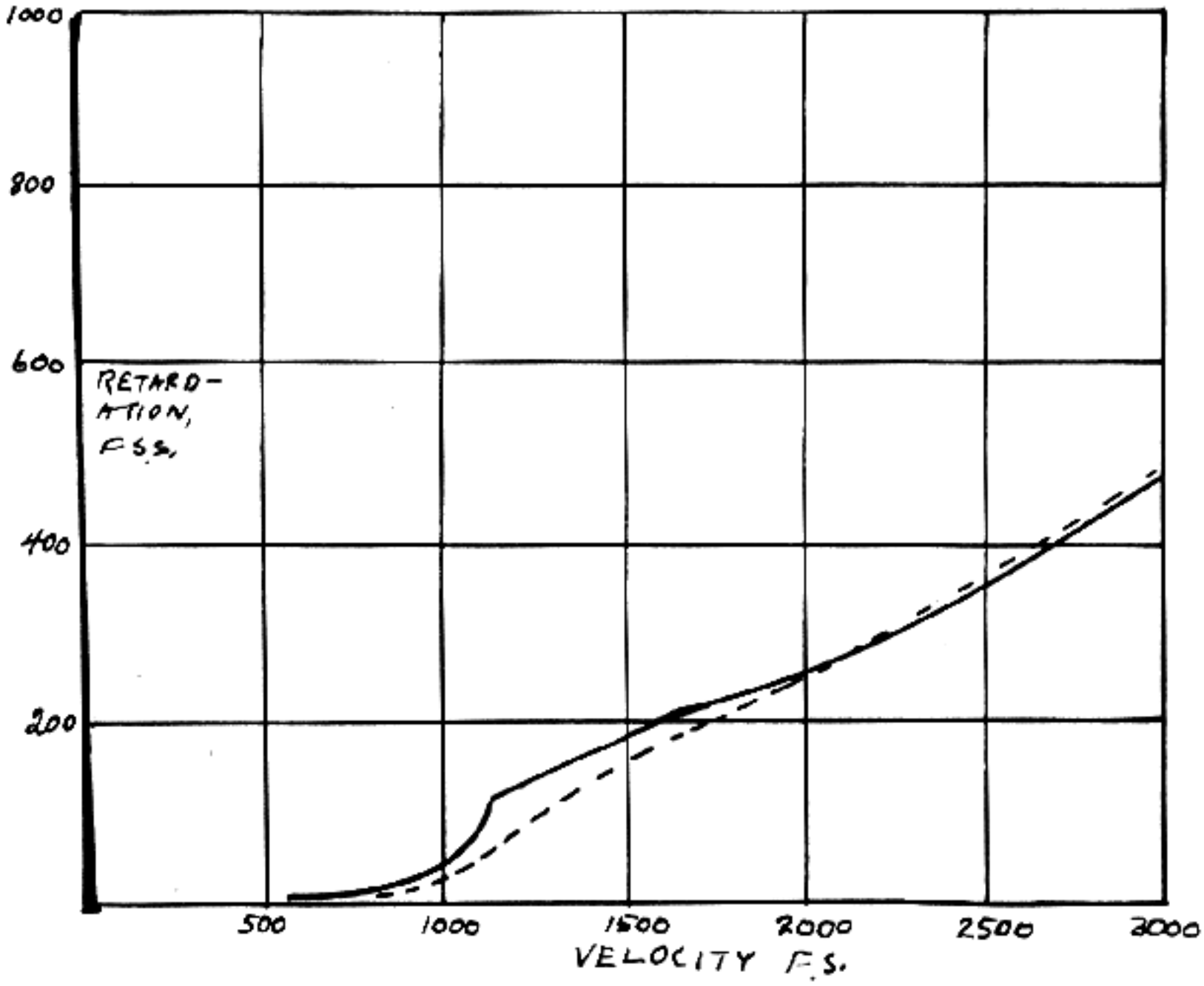
Now refer to sketch No. 10 to see what happens when a projectile having a shape similar to the J projectile is used with tables computed from the G- functions. At about 2100 f.s. velocity, where the two curves are together, the projectile will have the same ballistic coefficient when referred to ballistic tables computed from the G function as it will for those computed the J function. Where the

two curves coincide, it will make no difference which tables are used, but at other points, the ballistic coefficient will change when the G tables are used, while it will not change at any velocity if the J tables are used, because the projectile, being of the J shape, will follow the J function curve of resistance.

Comparison of the different Ballistic Tables

During many years work with ballistic tables, I have used the Ingalls tables, the British 1909 tables, (which are almost the same as the Ingalls), the British 1929 tables, based on a spitzer pointed flat based bullet with 8 calibers radius of point, and the Hodsock tables, which are also based on a spitzer shape.

We have several methods of judging which tables give the most nearly accurate results for any particular small arms bullet. For flat based spitzer bullets, such as the .30-06 or the .30 M2, we have a complete table calculated by the Ordnance Department up to 1000 yards, given on p. 401. Of all the tables we have used, the Hodsock tables give the closest results for *this* bullet, but the others are not



Solid line is the J function, while the dotted line is the G function reduced ½ as for a projectile having a ballistic coefficient of 2.0 referred to the G projectile.

far off. This is not surprising, for the Hodsock firings were done with a bullet of almost exactly the same shape.

The tabulation given below lists the Ordnance figures, together with those obtained with the 4 different ballistic tables mentioned in the second paragraph above.

150 Grain .30-06 Flat Based Spitzer Pointed Bullet at 2700 f.s.

Ordnance figures Range yds.	Remaining Velocity, f.s.	Hodsock Tables C = .2507 i = .92	British 1929 Tables C = .2346 i = 1.0	Ingalls' Tables C = .4107 i = .56	British 1909 Tables C = .4083 i = .56
100	2481	....	....	....	....
200	2267	2268	2263	2275	2272
300	2059	2057	2048	2081	2071
400	1858	1853	1838	1892	1881
500	1664	1658	1638	1720	1705
600	1448	1477	1448	1565	1543
700	1315	1316	1279	1421	1395
800	1174	1180	1150	1295	1240

In connection with this tabulation attention is invited to the different values of C for the different tables. This difference is entirely due to the difference in the form factor as referred to the particular standard projectile on which each table was based. Both the Hodsock and the British 1929 tables were based on a sharp pointed bullet not far from the shape of the .30-06, hence the form factor for each of these tables is close to 1.0, which means that the ballistic coefficient does not change much with velocity with these tables for this particular bullet.

On the other hand, the Ingalls tables and the British 1909 tables are both made for a much blunter bullet, and it will be seen that the form factor for both these tables is .56, and the ballistic coefficient of the .30-06 bullet changes considerably with changes in velocity with these tables.

Most of our modern hunting bullets are much closer to the form of the Ingalls shape; even a small blunting of the point of a spitzer bullet will greatly increase its form factor, and make the Ingalls tables give more consistent results for it.

To check this out, I have taken the .222 Remington cartridge with 50 grain bullet at 3200 f.s. muzzle velocity, for which the factory has run ballistic tests and furnished trajectory figures up to 500 yards. This comparison follows:

222 Remington with 50 grain bullet at 3200 f.s. Muzzle velocity

Factory figures		Ingalls Tables C = .1819 i = .78	British 1909 Tables C = .1792 i = .80	British 1929 Tables C = .0974 i = 1.47	Hodsock Tables C = .1025 i = 1.4
Range yds.	Remaining velocity				
0	3200	....	....	....	....
100	2660	....	....	....	....
200	2170	2180	2178	2143	2131
300	1750	1765	1750	1642	1637
400	1400	1420	1393	1227	1234
500	1150	1163	1143	1009	1031

It will be seen that with this bullet, as is the case with most modern American hunting bullets, the form factor is closer to unity as referred to the Ingalls tables than when referred to the British 1929 and the Hodsock tables, both of which were made for sharp pointed spitzer type bullets. It is true that the 222 Remington has the general shape of a spitzer with about a 6 caliber radius but the lead point of the soft nose bullet has a flat on it of about a tenth of a caliber, which greatly increases the form factor. Looking at the Du-Pont chart of form factors, we would estimate a form factor of about .80 for this bullet for the Ingalls tables, and this is close to what it turns out to be.

Thus for this bullet, as for most others commonly used in our present day small arms shooting, the Ingalls tables are closer than the others.

A number of spot checks on other bullets included in the ammunition maker's published ballistic data all show close agreement with the results of calculations made with Ingalls tables. This includes even the boat-tailed full metal jacketed .30-06 bullet of 180 grains weight, figures for which are included below.

Western Cartridge Company's 180 gr. full metal jacketed .30-06

Company's published ballistics		Ingalls Tables C = .512 i = .56	British 1909 Tables C = .50 i = .56	British 1929 Tables C = .286 i = .97	Hodsock Tables C = .305 i = .91
Range yds.	Remaining velocity				
Muzzle	2700	....	....	....	....
100	2520	....	....	....	....
200	2350	2348	2346	2341	2392
300	2190	2185	2179	2163	2166

These comparisons, together with many others I have made all add up to the fact that the Ingalls tables are about the most generally satisfactory ones available today for use in small arms ballistic calculations.

Acknowledgment

In preparing this chapter, I have received invaluable assistance from Colonel E. H. Harrison, Ordnance Corps, USA, retired, of the Editorial Staff of the *American Rifleman*, and from Mr. Homer S. Powley, Shaker Heights, Ohio. Both of these authorities are highly qualified in this field, and both have been most generous in making the results of their knowledge available to me. To both I desire to express my thanks and deep appreciation.

USE OF INGALLS' BALLISTIC TABLES

The space function S tabulated opposite a velocity V is the actual distance in feet that would have been traversed by the *standard projectile* of unit weight and unit diameter while its speed fell from 3600 f.s. to V f.s. if it had been projected horizontally with an initial velocity of 3600 f.s., and if its path had remained horizontal throughout. The letter u used in the expression S(u) represents the pseudo-velocity, which is the projection of the actual velocity onto the horizontal plane. For the small angles of departure used in small arms firing, u can be taken as equal to V.

The symbols have the following meaning:

X is the range in feet.
V is the initial velocity for range X (refer to column headed u).
v is the terminal velocity for range X.
T is the time of flight for range X.
C is the ballistic coefficient.
i is the form factor.
H is the maximum height of the trajectory in feet.
S(V) is the velocity function (from S(u) in the table) for V.
S(v) is the velocity function (form S(u) in the table) for v.
T(V) is the time function (from the table) for V.
T(v) is the time function (from the table) for v.
w is the bullet weight in pounds.
d is the bullet diameter in inches.

Formulas and Examples of How to Use the Tables

PROBLEM 1:

Given the muzzle velocity V, the range X, and the remaining velocity v at the end of range X, to determine the ballistic coefficient C.

Formula: $C = \dfrac{X}{S(v) - S(V)}$ where S(v) and S(V) are space functions for velocities V and v as taken from column S(u) in Table I.

Example 1. The 50 grain bullet for the Remington 222 cartridge has a muzzle velocity of 3200 f.s., and a remaining velocity of 2660 f.s. at 100 yds. Find the ballistic coefficient.

$$\begin{aligned} v &= 2660 \text{ f.s. and } S(v) = 2772.9 \\ V &= 3200 \text{ f.s. and } S(V) = 1124.4 \\ & \qquad\qquad\qquad\qquad\quad \overline{\qquad\qquad} \\ & \qquad S(v) - S(V) = 1648.5 \end{aligned}$$

$X = 100$ yds, $= 600$ feet, and $600/1648.5 = .1819 - C$

PROBLEM 2:

Given the muzzle velocity V, and the remaining velocity at the end of the range X, to find the form factor i.

Formula: $C = w/id^2$, hence $i = w/Cd^2$ where w is the weight of the bullet in pounds, and d is the diameter of the bullet in inches, generally taken as bore diameter plus the depth of 1 rifling groove.

Example 2. The 50 grain 222 Remington bullet has a muzzle velocity of 3200 f.s., a remaining velocity at 100 yds of 2660 f.s., and an effective diameter of .224 inch. Find the form factor.

First find the ballistic coefficient, as in problem 1. It was found to be .1819. Now find w/d^2 thus; $\dfrac{50}{.288 \times .288 \times 7000} = .1417$. This divided by the ballistic coefficient will give the form factor, thus $.1417/.1819 = .78$.

PROBLEM 3:

Given the muzzle velocity V, the ballistic coefficient C, and the range X; to find the remaining velocity v at the end of range X.

Formula: $S(v) = S(V) + \dfrac{X}{C}$

Example 3. Find the remaining velocity v at the end of 200 yards for the 50 grain 222 Remington bullet which has a muzzle velocity of 3200 f.s. and a ballistic coefficient of .1819.

$$\begin{aligned} \frac{X}{C} &= \frac{600}{.1819} = 3298.5 \\ V = 3200 \text{ f.s., and } S(V) &= 1124.4 \\ \text{Add } X/C &= 3298.5 \\ & \qquad\qquad \overline{\qquad\qquad} \\ S(v) &= 4422.9 \end{aligned}$$

$v = 2180$ f.s.

PROBLEM 4:

Given the muzzle velocity V, and the remaining velocity v at 100 yards, to find the remaining velocity at 200 yards, 300 yards, and so on.

Formula: S(v) for 200 yd = S(V) + twice $\{S(v) - S(V)\}$

also S(v) for 300 yd = S(v) + three times $\{S(v) - S(V)\}$

and so on. This is simply a short cut which follows from a consideration of problems 1 and 3.

Example 4. Find the remaining velocity at 200, 300, 400, and 500 yards for the 50 grain 222 Remington bullet which has a muzzle velocity of 3200 f.s. and a remaining velocity of 2660 f.s. at 100 yds.

v = 2660	S(v) =	2772.9
V = 3200	S(V) =	1124.4
	S(v) − S(V) =	1648.5

S(V)	=	1124.4
S(v) − S(V)	=	1648.5
S(v) for 100 yd	=	2772.9
Add		1648.5
S(v) for 200 yds	=	4421.4
Add		1648.5
S(v) for 300 yds	=	6069.9
Add		1648.5
S(v) for 400 yds	=	7718.4
Add		1648.5
		9366.9

Velocity at 200 yds = 2180 f.s.

Velocity at 300 yds = 1765 f.s.

Velocity at 400 yds = 1420 f.s.

Velocity at 500 yds = 1163 f.s.

PROBLEM 5: Given the initial velocity V, the ballistic coefficient C and the range X, to find the time of flight for range X.

Formula: T= C $\{T(v) - T(V)\}$ where T(v) and T(V) are taken from the column of time functions headed T(u) in Table I.

Example 5. Find the time of flight over a range of 500 yds for the 50 grain 222 Remington bullet having a ballistic coefficient of .1819.

First find the remaining velocity for 1500 feet as in problem 3. This is found to be 1163 f.s.

$$v = 1163 \text{ f.s.} \qquad T(v) = 4.7655$$
$$V = 3200 \text{ f.s.} \qquad T(V) = 0.3310$$
$$T(v) - T(V) = 4.4345$$
$$T = 4.4345 \times C = 4.4345 \times .1819 = .79 \text{ sec.}$$

PROBLEM 6:

Given the muzzle velocity, the range, and the ballistic coefficient, to find the maximum height of trajectory for the range X.

Formula: H in feet $= (2T)^2 = 4T^2$ and H in inches $= 48\ T^2$

Example 6: For a range of 300 yards, find the maximum ordinate H for the 50 grain 222 Remington bullet.

First find the remaining velocity at 300 yards. In problem 4 this was found to be 1765 f.s. Use this value to find the time of flight, as in problem 5. This is found to be .380 second, which is T. T^2 is .1444, which multiplied by 48 gives 6.93 inches as the maximum height of trajectory for 300 yards. Reference to the Western Ammunition Handbook shows that the maker's figure for this is 7 inches. (Note—ammunition maker's published ballistic tables give what is called MID-RANGE trajectory. The maximum ordinate occurs just a bit further along than mid-range, and is just a bit greater, but the difference is so small that the maximum ordinate as calculated above may be taken as mid-range trajectory without much error.

PROBLEM 7:

Given the maximum ordinate H for any range, find the time of flight for that range.

Formula: $T = \frac{1}{8}\sqrt{H}$ where H is in feet, or $T = \frac{1}{4}\sqrt{\frac{H}{3}}$ where H is in inches.

Example 7: Given that the 300 yard mid range trajectory of the 50 grain 222 Remington is 7 inches, find the approximate time of flight.

$$T = \frac{1}{4}\sqrt{\frac{7}{3}} = \frac{1}{4}\sqrt{2.333} = \frac{1.527}{4} = .38 \text{ seconds}$$

PROBLEM 8:

Given the velocity of a bullet at any point, and the bullet weight in grains, to find the energy of the bullet in foot-pounds at that point.

Formula: Energy in foot-pounds $= \frac{1}{2}\ mv^2 = \frac{1}{2}\ \frac{wv^2}{g} = \frac{wv^2}{2g}$

where w is the bullet weight *in pounds* and g is the value of the acceleration of gravity, 32.16 f.s. per second.

As there are 7000 grains in a pound avoirdupois, the bullet weight in grains must be divided by 7000 to bring it to pounds, and must also be divided by gravity to bring it to mass instead of weight. The formula thus becomes $\frac{wv^2}{2g \times 7000}$ And as 2x32.16 x 7000 = 450,240, the formula simplifies down to bullet weight in grains times velocity squared divided by 450,240, or simply $\frac{wv^2}{450{,}240}$ If multiplication instead of division is preferred, it will be found that 1 divided by 450,240 = 0.000002221, so in this case the formula becomes Energy in foot pounds = $0.000002221\ wv^2$

Example 8: The 50 grain 222 Remington bullet has a remaining velocity at 100 yards of 2660 f.s.; find the energy at that point in foot pounds.

$$\frac{50 \times 2660 \times 2660}{450{,}240} = \frac{50 \times 7{,}075{,}600}{450{,}240} = 785 \text{ ft. lbs.}$$

Use of Table A

This table is used to find the angle of departure. The following example will show how it is used.

PROBLEM 8: Given the muzzle velocity V, and the ballistic coefficient C, find the angle of departure a, for range X.

Formula: Sin 2a = A x C, where A is the quantity found in Table A under the proper velocity heading and opposite Z, where $Z = \frac{X}{C}$.

Example 8: Find the angle of departure for a range of 400 yards with the 150 gr. .30-06 bullet with a muzzle velocity of 2700 f.s., if the ballistic coefficient is .41

$X = 400 \times 3 = 1200$ feet.

$\frac{X}{C} = \frac{1200}{.41} = 2926.8$

Look at Table A under 2700 f.s. velocity, and under column Z.

We find no value for 2926.7 in the Z column, and as values for 2800 and 3000 are both given, it is necessary to interpolate.

A for Z of 3000 =	0.01708	
A for Z of 2800 =	0.01565	
Difference =	0.00143	0.00143 x 126.7/200 = 90.6
A for Z of 2800 =	0.01565	
Diff. to be added =	91	
A for Z of 2926.7 =	0.01656	

Sin 2 a = 0.01656 x .41 = .0067896
2 a = 23.91′ hence a = 11.5′

Checking with the table on p. 401, we see that the Ordnance range tables give the angle of departure for this bullet at 400 yards as 11.6′

BALLISTIC TABLES

The following tables will be found immediately following:
On pp. 583 to 609, incl., Ingalls' Table I, from Artillery Circular M.
On p. 611, an extension of Table I to 5000 f.s.
On pp. 612 to 617, incl., Ingalls' Table II from Artillery Circular M, ABRIDGED, and hence called Table A. It is used to find angles of elevation.
On pp. 617 & 618, a table of Natural Sines from 0 to 4 deg.
On pp. 619 to 621, Instructions and table for finding bullet drop.
On pp. 625 to 629 incl., the time and space functions from the British 1909 Ballistic Tables.

TABLE I.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
3600	0.0	54.5	0.00	1.72	0.03138	0.00027	0.000	0.015
3580	54.5	54.7	1.72	1.74	0.03165	0.00028	0.015	0.015
3560	109.2	54.9	3.46	1.76	0.03193	0.00028	0.030	0.016
3540	164.1	55.1	5.22	1.78	0.03221	0.00028	0.046	0.016
3520	219.2	55.2	7.00	1.80	0.03249	0.00029	0.062	0.015
3500	274.4	55.4	8.80	1.82	0.03278	0.00030	0.077	0.016
3480	329.8	55.5	10.62	1.85	0.03308	0.00029	0.093	0.016
3460	385.3	55.8	12.47	1.87	0.03337	0.00030	0.109	0.016
3440	441.1	55.9	14.34	1.89	0.03367	0.00031	0.125	0.017
3420	497.0	56.1	16.23	1.92	0.03398	0.00031	0.142	0.016
3400	553.1	28.2	18.15	0.96	0.03429	0.00016	0.158	0.008
3390	581.3	28.1	19.11	0.97	0.03445	0.00016	0.166	0.008
3380	609.4	28.2	20.08	0.98	0.03461	0.00016	0.175	0.008
3370	637.6	28.2	21.06	0.98	0.03477	0.00016	0.183	0.009
3360	665.8	28.3	22.04	0.99	0.03493	0.00016	0.192	0.008
3350	794.1	28.4	23.03	1.00	0.03450	0.00016	0.200	0.008
3340	722.5	28.4	24.03	1.01	0.03525	0.00016	0.208	0.009
3330	750.9	28.4	25.04	1.01	0.03541	0.00017	0.217	0.008
3320	779.3	28.5	26.05	1.02	0.03558	0.00016	0.225	0.009
3310	807.8	28.6	27.07	1.02	0.03574	0.00017	0.234	0.009
3300	836.4	28.6	28.09	1.03	0.03591	0.00017	0.243	0.008
3290	865.0	28.6	29.12	1.03	0.03608	0.00017	0.251	0.009
3280	893.6	28.7	30.15	1.04	0.03625	0.00017	0.260	0.009
3270	922.3	28.7	31.19	1.05	0.03642	0.00018	0.269	0.009
3260	951.0	28.8	32.24	1.06	0.03660	0.00017	0.278	0.008
3250	979.8	28.8	33.30	1.06	0.03677	0.00018	0.286	0.009
3240	1008.6	28.9	34.36	1.07	0.03695	0.00018	0.295	0.009
3230	1037.5	28.9	35.43	1.08	0.03713	0.00018	0.304	0.009
3220	1066.4	29.0	36.51	1.08	0.03731	0.00018	0.313	0.009
3210	1095.4	29.0	37.59	1.09	0.03749	0.00018	0.322	0.009
3200	1124.4	29.1	38.68	1.10	0.03767	0.00018	0.331	0.009
3190	1153.5	29.1	39.78	1.10	0.03785	0.00019	0.340	0.009
3180	1182.6	29.2	40.88	1.12	0.03804	0.00018	0.349	0.010
3170	1211.8	29.2	42.00	1.12	0.03822	0.00019	0.359	0.009
3160	1241.0	29.3	43.12	1.13	0.03841	0.00019	0.368	0.009
3150	1270.3	29.3	44.25	1.13	0.03860	0.00019	0.377	0.009
3140	1299.6	29.4	45.38	1.14	0.03879	0.00019	0.386	0.010
3130	1329.0	29.4	46.52	1.15	0.03898	0.00020	0.396	0.009
3120	1358.4	29.5	47.67	1.16	0.03918	0.00019	0.405	0.010
3110	1387.9	29.5	48.83	1.16	0.03937	0.00020	0.415	0.009
3100	1417.4	29.6	49.99	1.18	0.03957	0.00020	0.424	0.010
3090	1447.0	29.6	51.17	1.18	0.03977	0.00020	0.434	0.009
3080	1476.6	29.7	52.35	1.19	0.03997	0.00020	0.443	0.010
3070	1506.3	29.8	53.54	1.20	0.04017	0.00020	0.453	0.010
3060	1536.1	29.8	54.74	1.21	0.04037	0.00021	0.463	0.009
3050	1565.9	29.8	55.95	1.21	0.04058	0.00021	0.472	0.010
3040	1595.7	29.9	57.16	1.22	0.04079	0.00021	0.482	0.010
3030	1625.6	30.0	58.38	1.23	0.04100	0.00021	0.492	0.010
3020	1655.6	30.0	59.61	1.24	0.04121	0.00021	0.502	0.010
3010	1685.6	30.1	60.85	1.25	0.04122	0.00021	0.512	0.010
3000	1715.7	30.1	62.10	1.26	0.04163	0.00022	0.522	0.010

TABLE I.—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
3000	1715.7	30.1	62.10	1.26	0.04163	0.00022	0.522	0.010
2990	1745.8	30.2	63.36	1.27	0.04185	0.00022	0.532	0.010
2980	1776.0	30.2	64.63	1.28	0.04207	0.00022	0.542	0.010
2970	1806.2	30.3	65.91	1.28	0.04229	0.00022	0.552	0.011
2960	1836.5	30.3	67.19	1.29	0.04251	0.00022	0.563	0.010
2950	1866.8	30.4	68.48	1.30	0.04273	0.00023	0.573	0.010
2940	1897.2	30.5	69.78	1.32	0.04296	0.00022	0.583	0.010
2930	1927.7	30.5	71.10	1.32	0.04318	0.00023	0.593	0.011
2920	1958.2	30.6	72.42	1.33	0.04341	0.00023	0.604	0.010
2910	1988.8	30.6	73.75	1.34	0.04364	0.00024	0.614	0.011
2900	2019.4	30.7	75.09	1.35	0.04388	0.00023	0.625	0.010
2890	2050.1	30.8	76.44	1.36	0.04411	0.00024	0.635	0.011
2880	2080.9	30.8	77.80	1.37	0.04435	0.00024	0.646	0.011
2870	2111.7	30.9	79.17	1.38	0.04456	0.00024	0.657	0.011
2860	2142.6	30.9	80.55	1.39	0.04483	0.00024	0.668	0.011
2850	2173.5	31.0	81.94	1.40	0.04507	0.00025	0.679	0.011
2840	2204.5	31.1	83.34	1.41	0.04532	0.00025	0.690	0.011
2830	2235.6	31.1	84.75	1.42	0.04557	0.00025	0.701	0.011
2820	2266.7	31.2	86.17	1.43	0.04582	0.00025	0.712	0.011
2810	2297.9	31.2	87.60	1.44	0.04607	0.00026	0.723	0.011
2800	2329.1	31.3	89.04	1.46	0.04633	0.00026	0.734	0.011
2790	2360.4	31.3	90.50	1.47	0.04659	0.00026	0.745	0.011
2780	2391.7	31.4	91.97	1.48	0.04685	0.00026	0.756	0.011
2770	2423.1	31.5	93.45	1.48	0.04711	0.00027	0.767	0.012
2760	2454.6	31.5	94.93	1.50	0.04738	0.00026	0.779	0.011
2750	2486.1	31.6	96.43	1.51	0.04764	0.00027	0.790	0.012
2740	2517.7	31.7	97.94	1.52	0.04791	0.00027	0.802	0.011
2730	2549.4	31.7	99.46	1.53	0.04818	0.00028	0.813	0.012
2720	2581.1	31.8	100.99	1.54	0.04846	0.00028	0.825	0.012
2710	2612.9	31.9	102.53	1.56	0.04874	0.00028	0.837	0.012
2700	2644.8	31.9	104.09	1.57	0.04902	0.00028	0.849	0.011
2690	2676.7	32.0	105.66	1.59	0.04930	0.00029	0.860	0.012
2680	2708.7	32.1	107.25	1.60	0.04959	0.00029	0.872	0.012
2670	2740.8	32.1	108.85	1.60	0.04988	0.00029	0.884	0.012
2660	2772.9	32.2	110.45	1.62	0.05017	0.00029	0.896	0.012
2650	2805.1	32.3	112.07	1.63	0.05046	0.00030	0.908	0.013
2640	2837.4	32.3	113.70	1.64	0.05076	0.00030	0.921	0.012
2630	2869.7	32.4	115.34	1.66	0.05106	0.00030	0.933	0.012
2620	2902.1	32.5	117.00	1.67	0.05136	0.00030	0.945	0.012
2610	2934.6	32.5	118.67	1.69	0.05166	0.00031	0.957	0.013
2600	2967.1	32.6	120.36	1.72	0.05197	0.00031	0.970	0.013
2590	2999.7	32.7	122.08	1.72	0.05228	0.00032	0.983	0.012
2580	3032.4	32.9	123.80	1.73	0.05260	0.00031	0.995	0.013
2570	3065.3	32.9	125.53	1.75	0.05291	0.00032	1.008	0.013
2560	3098.2	33.0	127.28	1.76	0.05323	0.00033	1.021	0.013
2550	3131.2	33.1	129.04	1.77	0.05356	0.00033	1.034	0.013
2540	3164.3	33.2	130.81	1.78	0.05389	0.00033	1.047	0.013
2530	3197.5	33.3	132.59	1.81	0.05422	0.00034	1.060	0.013
2520	3230.8	33.3	134.40	1.83	0.05456	0.00034	1.073	0.014
2510	3264.1	33.5	136.23	1.84	0.05490	0.00034	1.087	0.013
2500	3297.6	33.6	138.07	1.86	0.05524	0.00035	1.100	0.013

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
2500	3297.6	33.6	138.07	1.86	0.05524	0.00035	1.100	0.013
2490	3331.2	33.6	139.93	1.88	0.05559	0.00035	1.113	0.014
2480	3364.8	33.8	141.81	1.89	0.05594	0.00035	1.127	0.014
2470	3398.6	33.8	143.70	1.91	0.05629	0.00036	1.141	0.013
2460	3432.4	34.0	145.61	1.93	0.05665	0.00036	1.154	0.014
2450	3466.4	34.0	147.54	1.95	0.05701	0.00037	1.168	0.014
2440	3500.4	34.2	149.49	1.97	0.05738	0.00037	1.182	0.014
2430	3534.6	34.2	151.46	1.98	0.05775	0.00038	1.196	0.014
2420	3568.8	34.3	153.44	2.00	0.05813	0.00038	1.210	0.015
2410	3603.1	34.5	155.44	2.02	0.05851	0.00038	1.225	0.014
2400	3637.6	34.5	157.46	2.04	0.05889	0.00039	1.239	0.014
2390	3672.1	34.6	159.50	2.06	0.05928	0.00039	1.253	0.015
2380	3706.7	34.8	161.56	2.08	0.05967	0.00040	1.268	0.014
2370	3741.5	34.8	163.64	2.10	0.06007	0.00040	1.282	0.015
2360	3776.3	35.0	165.74	2.12	0.06047	0.00040	1.297	0.015
2350	3811.3	35.0	167.86	2.14	0.06087	0.00041	1.312	0.015
2340	3846.3	35.2	170.00	2.16	0.06128	0.00042	1.327	0.015
2330	3881.5	35.3	172.16	2.18	0.06170	0.00042	1.342	0.015
2320	3916.8	35.3	174.34	2.21	0.06212	0.00042	1.357	0.016
2310	3952.1	35.5	176.55	2.23	0.06254	0.00043	1.373	0.015
2300	3987.6	35.6	178.78	2.25	0.06297	0.00043	1.388	0.015
2290	4023.2	35.7	181.03	2.27	0.06340	0.00044	1.403	0.016
2280	4058.9	35.8	183.30	2.30	0.06384	0.00044	1.419	0.016
2270	4094.7	35.9	185.60	2.32	0.06428	0.00045	1.435	0.015
2260	4130.6	36.0	187.92	2.34	0.06473	0.00046	1.450	0.016
2250	4166.6	36.2	190.26	2.36	0.06519	0.00046	1.466	0.016
2240	4202.8	36.2	192.62	2.39	0.06565	0.00047	1.482	0.017
2230	4239.0	36.4	195.01	2.41	0.06612	0.00047	1.499	0.016
2220	4275.4	36.4	197.42	2.44	0.06659	0.00048	1.515	0.016
2210	4311.8	36.6	199.86	2.46	0.06707	0.00048	1.531	0.017
2200	4348.4	36.7	202.32	2.50	0.06755	0.00049	1.548	0.017
2190	4385.1	36.9	204.82	2.52	0.06804	0.00050	1.565	0.016
2180	4422.0	36.9	207.34	2.54	0.06854	0.00050	1.581	0.017
2170	4458.9	37.1	209.88	2.57	0.06904	0.00051	1.598	0.017
2160	4496.0	37.2	212.45	2.60	0.06955	0.00052	1.615	0.018
2150	4533.2	37.3	215.05	2.62	0.07007	0.00052	1.633	0.017
2140	4570.5	37.4	217.67	2.65	0.07059	0.00053	1.650	0.017
2130	4607.9	37.6	220.32	2.68	0.07112	0.00053	1.667	0.018
2120	4645.5	37.6	223.00	2.70	0.07165	0.00054	1.685	0.018
2110	4683.1	37.8	225.70	2.73	0.07219	0.00055	1.703	0.018
2100	4720.9	38.0	228.43	2.77	0.07274	0.00056	1.721	0.018
2090	4758.9	38.1	231.20	2.80	0.07330	0.00056	1.739	0.018
2080	4797.0	38.2	234.00	2.83	0.07386	0.00057	1.757	0.019
2070	4835.2	38.3	236.83	2.86	0.07443	0.00058	1.776	0.018
2060	4873.5	38.4	239.69	2.90	0.07501	0.00058	1.794	0.019
2050	4911.9	38.6	242.59	2.93	0.07559	0.00060	1.813	0.019
2040	4950.5	38.7	245.52	2.96	0.07619	0.00060	1.832	0.019
2030	4989.2	38.9	248.48	2.99	0.07679	0.00061	1.851	0.019
2020	5028.1	38.9	251.47	3.03	0.07740	0.00062	1.870	0.019
2010	5067.0	39.1	254.50	3.07	0.07802	0.00062	1.889	0.020
2000	5106.1	39.2	257.57	3.10	0.07864	0.00064	1.909	0.020

TABLE I—Continued.

u	S (u)	Δ	A (u)	Δ	I (u)	Δ	T (u)	Δ
1550	7055.1	24.6	447.25	2.94	0.11947	0.00066	3.019	0.016
1545	7079.7	24.6	450.19	2.97	0.12013	0.00067	3.035	0.016
1540	7104.3	24.7	453.16	2.99	0.12080	0.00067	3.051	0.016
1535	7129.0	24.8	456.15	3.02	0.12147	0.00068	3.067	0.016
1530	7153.8	24.9	459.17	3.05	0.12215	0.00069	3.083	0.016
1525	7178.7	24.9	462.22	3.08	0.12284	0.00069	3.099	0.016
1520	7203.6	25.0	465.30	3.10	0.12353	0.00070	3.115	0.017
1515	7228.6	25.1	468.40	3.13	0.12423	0.00071	3.132	0.016
1510	7253.7	25.2	471.53	3.16	0.12494	0.00071	3.148	0.017
1505	7278.9	25.3	474.69	3.18	0.12565	0.00072	3.165	0.017
1500	7304.2	25.5	477.87	3.21	0.12637	0.00073	3.182	0.017
1495	7329.7	25.5	481.08	3.25	0.12710	0.00073	3.199	0.017
1490	7355.2	25.6	484.33	3.27	0.12783	0.00075	3.216	0.017
1485	7380.8	25.6	487.60	3.31	0.12858	0.00075	3.233	0.018
1480	7406.4	25.7	490.91	3.33	0.12933	0.00075	3.251	0.017
1475	7432.1	25.8	494.24	3.37	0.13008	0.00077	3.268	0.018
1470	7457.9	25.9	497.61	3.40	0.13085	0.00077	3.286	0.017
1465	7483.8	26.0	501.01	3.43	0.13162	0.00078	3.303	0.018
1460	7509.8	26.1	504.44	3.46	0.13240	0.00079	3.321	0.018
1455	7535.9	26.1	507.90	3.49	0.13319	0.00080	3.339	0.018
1450	7562.0	26.3	511.39	3.53	0.13399	0.00081	3.357	0.018
1445	7588.3	26.3	514.92	3.56	0.13480	0.00081	3.375	0.018
1440	7614.6	26.4	518.48	3.59	0.13561	0.00082	3.393	0.019
1435	7641.0	26.5	522.07	3.63	0.13643	0.00083	3.412	0.018
1430	7667.5	26.7	525.70	3.67	0.13726	0.00084	3.430	0.019
1425	7694.2	26.7	529.37	3.70	0.13810	0.00085	3.449	0.018
1420	7720.9	26.8	533.07	3.74	0.13895	0.00086	3.467	0.019
1415	7747.7	26.9	536.81	3.77	0.13981	0.00087	3.486	0.020
1410	7774.6	26.9	540.58	3.81	0.14068	0.00087	3.506	0.019
1405	7801.5	27.0	544.39	3.84	0.14155	0.00089	3.525	0.019
1400	7828.5	27.2	548.23	3.88	0.14244	0.00090	3.544	0.019
1395	7855.7	27.3	552.11	3.93	0.14334	0.00090	3.563	0.020
1390	7883.0	27.4	556.04	3.96	0.14424	0.00092	3.583	0.020
1385	7910.4	27.5	560.00	4.00	0.14516	0.00092	3.603	0.020
1380	7937.9	27.6	564.00	4.05	0.14608	0.00094	3.623	0.020
1375	7965.5	27.6	568.05	4.08	0.14702	0.00094	3.643	0.020
1370	7993.1	27.9	572.13	4.15	0.14796	0.00096	3.663	0.020
1365	8021.0	28.1	576.28	4.20	0.14892	0.00097	3.683	0.021
1360	8049.1	28.4	580.48	4.27	0.14989	0.00099	3.704	0.021
1355	8077.5	28.6	584.75	4.32	0.15088	0.00101	3.725	0.021
1350	8106.1	28.8	589.07	4.38	0.15189	0.00102	3.746	0.021
1345	8134.9	29.0	593.45	4.45	0.15291	0.00103	3.767	0.022
1340	8163.9	29.2	597.90	4.51	0.15394	0.00105	3.789	0.022
1335	8193.1	29.4	602.41	4.58	0.15499	0.00107	3.811	0.022
1330	8222.5	29.6	606.99	4.64	0.15606	0.00108	3.833	0.022
1325	8252.1	29.9	611.63	4.71	0.15714	0.00110	3.855	0.023
1320	8282.0	30.1	616.34	4.78	0.15824	0.00112	3.878	0.023
1315	8312.1	30.3	621.12	4.85	0.15936	0.00113	3.901	0.023
1310	8342.4	30.6	625.97	4.92	0.16049	0.00115	3.924	0.023
1305	8373.0	30.8	630.89	5.00	0.16164	0.00116	3.947	0.024
1300	8403.8	12.4	635.89	2.02	0.16280	0.00047	3.971	0.009

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
2000	5106.1	39.2	257.57	3.10	0.07864	0.00064	1.909	0.020
1990	5145.3	39.4	260.67	3.14	0.07928	0.00064	1.929	0.019
1980	5184.7	39.6	263.81	3.17	0.07992	0.00066	1.948	0.020
1970	5224.3	39.6	266.98	3.21	0.08058	0.00066	1.968	0.021
1960	5263.9	39.8	270.19	3.25	0.08124	0.00067	1.989	0.020
1950	5303.7	40.0	273.44	3.29	0.08191	0.00068	2.009	0.021
1940	5343.7	40.1	276.73	3.32	0.08259	0.00069	2.030	0.020
1930	5383.8	40.2	280.05	3.36	0.08328	0.00070	2.050	0.021
1920	5424.0	40.4	283.41	3.40	0.08398	0.00071	2.071	0.022
1910	5464.4	40.6	286.81	3.45	0.08469	0.00071	2.093	0.021
1900	5505.0	40.7	290.26	3.49	0.08540	0.00073	2.114	0.021
1890	5545.7	40.8	293.75	3.53	0.08613	0.00074	2.135	0.022
1880	5586.5	41.0	297.28	3.58	0.08687	0.00075	2.157	0.022
1870	5627.5	41.1	300.86	3.62	0.08762	0.00076	2.179	0.022
1860	5668.6	41.3	304.48	3.67	0.08838	0.00077	2.201	0.022
1850	5709.9	41.5	308.15	3.71	0.08915	0.00078	2.223	0.023
1840	5751.4	41.6	311.86	3.76	0.08993	0.00080	2.246	0.022
1830	5793.0	41.8	315.62	3.81	0.09073	0.00080	2.268	0.023
1820	5834.8	41.9	319.43	3.85	0.09153	0.00082	2.291	0.024
1810	5876.7	42.1	323.28	3.90	0.09235	0.00083	2.315	0.023
1800	5918.8	42.3	327.18	3.96	0.09318	0.00084	2.338	0.024
1790	5961.1	42.6	331.14	4.02	0.09402	0.00086	2.362	0.024
1780	6003.7	42.8	335.16	4.08	0.09488	0.00088	2.386	0.024
1770	6046.5	43.1	339.24	4.14	0.09576	0.00089	2.410	0.024
1760	6089.6	43.3	343.38	4.21	0.09665	0.00090	2.434	0.024
1750	6132.9	43.5	347.59	4.27	0.09755	0.00092	2.458	0.025
1740	6176.4	43.8	351.86	4.33	0.09847	0.00094	2.483	0.025
1730	6220.2	44.1	356.19	4.40	0.09941	0.00095	2.508	0.026
1720	6264.3	44.3	360.59	4.47	0.10036	0.00097	2.534	0.026
1710	6308.6	44.5	365.06	4.54	0.10133	0.00099	2.560	0.026
1700	6353.1	44.8	369.60	4.61	0.10232	0.00100	2.586	0.026
1690	6397.9	45.1	374.21	4.68	0.10332	0.00102	2.612	0.027
1680	6443.0	45.4	378.89	4.76	0.10434	0.00104	2.639	0.027
1670	6488.4	45.7	383.65	4.83	0.10538	0.00106	2.666	0.027
1660	6534.1	45.9	388.48	4.91	0.10644	0.00108	2.693	0.028
1650	6580.0	46.2	393.39	4.99	0.10752	0.00110	2.721	0.028
1640	6626.2	46.5	398.38	5.08	0.10862	0.00112	2.749	0.028
1630	6672.7	46.7	403.46	5.16	0.10974	0.00113	2.777	0.029
1620	6719.4	47.1	408.62	5.24	0.11087	0.00116	2.806	0.029
1610	6766.5	47.3	413.86	5.33	0.11203	0.00119	2.835	0.030
1600	6813.8	23.8	419.19	2.70	0.11322	0.00060	2.865	0.015
1595	6837.6	23.9	421.89	2.72	0.11382	0.00060	2.880	0.015
1590	6861.5	23.9	424.61	2.75	0.11442	0.00061	2.895	0.015
1585	6885.4	24.0	427.36	2.77	0.11503	0.00062	2.910	0.016
1580	6909.4	24.1	430.13	2.79	0.11565	0.00062	2.926	0.015
1575	6933.5	24.1	432.92	2.82	0.11627	0.00063	2.941	0.015
1570	6957.6	24.3	435.74	2.84	0.11690	0.00063	2.956	0.016
1565	6981.9	24.3	438.58	2.87	0.11753	0.00064	2.972	0.015
1560	7006.2	24.4	441.45	2.89	0.11817	0.00065	2.987	0.016
1555	7030.6	24.5	444.34	2.91	0.11882	0.00065	3.003	0.016
1550	7055.1	24.6	447.25	2.94	0.11947	0.00066	3.019	0.016

TABLE I.—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
1300	8403.8	12.4	635.89	2.02	0.16280	0.00047	3.971	0.009
1298	8416.2	12.4	637.91	2.03	0.16327	0.00048	3.980	0.010
1296	8428.6	12.5	639.94	2.04	0.16375	0.00048	3.990	0.010
1294	8441.1	12.5	641.98	2.06	0.16423	0.00048	4.000	0.009
1292	8453.6	12.5	644.04	2.07	0.16471	0.00048	4.009	0.010
1290	8466.1	12.6	646.11	2.08	0.16519	0.00049	4.019	0.010
1288	8478.7	12.6	648.19	2.09	0.16568	0.00049	4.029	0.009
1286	8491.3	12.7	650.28	2.11	0.16617	0.00049	4.038	0.010
1284	8504.0	12.7	652.39	2.12	0.16666	0.00050	4.048	0.010
1282	8516.7	12.7	654.51	2.13	0.16716	0.00050	4.058	0.010
1280	8529.4	12.8	656.64	2.14	0.16766	0.00050	4.068	0.010
1278	8542.2	12.8	658.78	2.16	0.16816	0.00051	4.078	0.010
1276	8555.0	12.9	660.94	2.17	0.16867	0.00050	4.088	0.010
1274	8567.9	12.9	663.11	2.19	0.16917	0.00051	4.098	0.010
1272	8580.8	12.9	665.30	2.20	0.16968	0.00052	4.108	0.010
1270	8593.7	13.0	667.50	2.21	0.17020	0.00052	4.118	0.010
1268	8606.7	13.0	669.71	2.23	0.17072	0.00052	4.128	0.011
1266	8619.7	13.1	671.94	2.24	0.17124	0.00053	4.139	0.010
1264	8632.8	13.1	674.18	2.25	0.17177	0.00053	4.149	0.010
1262	8645.9	13.1	676.43	2.27	0.17230	0.00053	4.159	0.011
1260	8659.0	13.2	678.70	2.28	0.17283	0.00053	4.170	0.010
1258	8672.2	13.2	680.98	2.30	0.17336	0.00054	4.180	0.011
1256	8685.4	13.2	683.28	2.31	0.17390	0.00055	4.191	0.011
1254	8698.6	13.3	685.59	2.33	0.17445	0.00054	4.202	0.010
1252	8711.9	13.4	687.92	2.34	0.17499	0.00055	4.212	0.011
1250	8725.3	13.4	690.26	2.36	0.17554	0.00056	4.223	0.011
1248	8738.7	13.4	692.62	2.37	0.17610	0.00055	4.234	0.010
1246	8752.1	13.5	694.99	2.38	0.17665	0.00056	4.244	0.011
1244	8765.6	13.5	697.37	2.40	0.17721	0.00057	4.255	0.011
1242	8779.1	13.6	699.77	2.42	0.17778	0.00056	4.266	0.011
1240	8792.7	13.6	702.19	2.43	0.17834	0.00057	4.277	0.011
1238	8806.3	13.7	704.62	2.45	0.17891	0.00057	4.288	0.011
1236	8820.0	13.7	707.07	2.46	0.17948	0.00057	4.299	0.012
1234	8833.7	13.8	709.53	2.48	0.18005	0.00058	4.311	0.011
1232	8847.5	13.8	712.01	2.49	0.18063	0.00059	4.322	0.011
1230	8861.3	13.8	714.50	2.51	0.18122	0.00059	4.333	0.011
1228	8875.1	13.9	717.01	2.54	0.18181	0.00060	4.344	0.012
1226	8889.0	14.0	719.55	2.56	0.18241	0.00060	4.356	0.011
1224	8903.0	14.1	722.11	2.59	0.18301	0.00061	4.367	0.011
1222	8917.1	14.2	724.70	2.61	0.18362	0.00061	4.378	0.012
1220	8931.3	14.3	727.31	2.64	0.18423	0.00062	4.390	0.012
1218	8945.6	14.4	729.95	2.67	0.18485	0.00062	4.402	0.011
1216	8960.0	14.5	732.62	2.69	0.18547	0.00063	4.413	0.012
1214	8974.5	14.6	735.31	2.72	0.18610	0.00064	4.425	0.012
1212	8989.1	14.7	738.03	2.74	0.18674	0.00064	4.437	0.012
1210	9003.8	14.7	740.77	2.77	0.18738	0.00065	4.449	0.012
1208	9018.5	14.9	743.54	2.80	0.18803	0.00066	4.461	0.013
1206	9033.4	15.0	746.34	2.83	0.18869	0.00066	4.474	0.012
1204	9048.4	15.0	749.17	2.86	0.18935	0.00067	4.486	0.012
1202	9063.4	15.2	752.03	2.89	0.19002	0.00068	4.498	0.013
1200	9078.6	15.3	754.92	2.92	0.19070	0.00068	4.511	0.013

TABLE I.—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
1200	9078.6	15.3	754.92	2.92	0.19070	0.00068	4.511	0.013
1198	9093.9	15.4	757.84	2.94	0.19138	0.00069	4.524	0.013
1196	9109.3	15.4	760.78	2.98	0.19207	0.00070	4.537	0.013
1194	9124.7	15.6	763.76	3.01	0.19277	0.00071	4.550	0.013
1192	9140.3	15.7	766.77	3.04	0.19348	0.00071	4.563	0.013
1190	9156.0	15.8	769.81	3.07	0.19419	0.00072	4.576	0.013
1188	9171.8	15.9	772.88	3.11	0.19491	0.00072	4.589	0.014
1186	9187.7	16.0	775.99	3.14	0.19563	0.00073	4.603	0.013
1184	9203.7	16.1	779.13	3.17	0.19636	0.00074	4.616	0.014
1182	9219.8	16.2	782.30	3.20	0.19710	0.00075	4.630	0.014
1180	9236.0	16.3	785.50	3.24	0.19785	0.00075	4.644	0.014
1178	9252.3	16.5	788.74	3.27	0.19860	0.00076	4.658	0.014
1176	9268.8	16.5	792.01	3.31	0.19936	0.00077	4.672	0.014
1174	9285.3	16.7	795.32	3.34	0.20013	0.00078	4.686	0.014
1172	9302.0	16.8	798.66	3.38	0.20091	0 00079	4.700	0.014
1170	9318.8	16.9	802.04	3.42	0.20170	0.00080	4.714	0.015
1168	9335.7	17.0	805.46	3.45	0.20250	0.00080	4.729	0.014
1166	9352.7	17.2	808.91	3.49	0.20330	0 00082	4.743	0.015
1164	9369.9	17.2	812.40	3.53	0.20412	0.00082	4.758	0.015
1162	9387.1	17.4	815.93	3.57	0.20494	0.00083	4.773	0.015
1160	9404.5	17.5	819.50	3.60	0.20577	0.00084	4.788	0.015
1158	9422.0	17.6	823.10	3.65	0.20661	0.00084	4.803	0.016
1156	9439.6	17.7	826.75	3.68	0.20745	0.00086	4.819	0.015
1154	9457.3	17.9	830.43	3.73	0.20831	0.00087	4.834	0.015
1152	9475.2	18.0	834.16	3.77	0.20918	0.00087	4.849	0.016
1150	9493.2	18.1	837.93	3.81	0.21005	0.00088	4.865	0.016
1148	9511.3	18.2	841.74	3.86	0.21093	0.00089	4.881	0.016
1146	9529.5	18.4	845.60	3.90	0.21182	0.00090	4.897	0.016
1144	9547.9	18.5	849.50	3.94	0.21272	0.00091	4.913	0.016
1142	9566.4	18.6	853.44	3.98	0.21363	0.00092	4.929	0.016
1140	9585.0	18.7	857.42	4.03	0.21455	0.00093	4.945	0.017
1138	9603.7	18.9	861.45	4.08	0.21548	0.00094	4.962	0.016
1136	9622.6	19.0	865.53	4.13	0.21642	0.00095	4.978	0.017
1134	9641.6	19.2	869.66	4.17	0.21737	0.00096	4.995	0.017
1132	9660.8	19.3	873.83	4.22	0.21833	0.00097	5.012	0.017
1130	9680.1	19.4	878.05	4.27	0.21930	0.00098	5.029	0.017
1128	9699.5	19.6	882.32	4.32	0.22028	0.00099	5.046	0.017
1126	9719.1	19.7	886.64	4.38	0.22127	0.00100	5.063	0.018
1124	9738.8	19.8	891.02	4.42	0.22227	0.00102	5.081	0.017
1122	9758.6	20.0	895.44	4.48	0.22329	0.00102	5.098	0.018
1120	9778.6	20.1	899.92	4.52	0.22431	0.00103	5.116	0.018
1118	9798.7	20.3	904.44	4.58	0.22534	0.00105	5.134	0.01
1116	9819.0	20.4	909.02	4.63	0.22639	0.00105	5.152	0.019
1114	9839.4	20.6	913.65	4.69	0.22744	0.00107	5.171	0.018
1112	9860.0	20.7	918.34	4.74	0.22851	0.00108	5.189	0.019
1110	9880.7	20.9	923.08	4.80	0.22959	0.00109	5.208	0.019
1108	9901.6	21.0	927.88	4.86	0.23068	0.00110	5.227	0.019
1106	9922.6	21.2	932.74	4.91	0.23178	0.00112	5.246	0.019
1104	9943.8	21.3	937.65	4.98	0.23290	0.00113	5.265	0.019
1102	9965.1	21.5	942.63	5.04	0.23403	0.00114	5.284	0.020
1100	9986.6	10.8	947.67	2.54	0.23517	0.00057	5.304	0.010

TABLE I.—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
1100	9986.6	10.8	947.67	2.54	0.23517	0.00057	5.304	0.010
1099	9997.4	10.9	950.21	2.56	0.23574	0.00058	5.314	0.010
1098	10008.3	10.9	952.77	2.58	0.23632	0.00058	5.324	0.009
1097	10019.2	10.9	955.35	2.59	0.23690	0.00059	5.333	0.010
1096	10030.1	10.9	957.94	2.60	0.23749	0.00058	5.343	0.010
1095	10041.0	11.0	960.54	2.62	0.23807	0.00059	5.353	0.010
1094	10052.0	11.0	963.16	2.64	0.23866	0.00060	5.363	0.011
1093	10063.0	11.1	965.80	2.65	0.23926	0.00060	5.374	0.010
1092	10074.1	11.1	968.45	2.67	0.23986	0.00060	5.384	0.010
1091	10085.2	11.2	971.12	2.69	0.24046	0.00060	5.394	0.010
1090	10096.4	11.2	973.81	2.70	0.24106	0.00061	5.404	0.010
1089	10107.6	11.2	976.51	2.72	0.24167	0.00061	5.414	0.011
1088	10118.8	11.3	979.23	2.74	0.24228	0.00061	5.425	0.010
1087	10130.1	11.3	981.97	2.75	0.24289	0.00062	5.435	0.010
1086	10141.4	11.3	984.72	2.77	0.24351	0.00062	5.445	0.011
1085	10152.7	11.4	987.49	2.79	0.24413	0.00062	5.456	0.010
1084	10164.1	11.5	990.28	2.81	0.24475	0.00063	5.466	0.011
1083	10175.6	11.5	993.09	2.82	0.24538	0.00063	5.477	0.011
1082	10187.1	11.5	995.91	2.84	0.24601	0.00063	5.488	0.010
1081	10198.6	11.6	998.75	2.86	0.24664	0.00064	5.498	0.011
1080	10210.2	11.6	1001.61	2.88	0.24728	0.00064	5.509	0.011
1079	10221.8	11.7	1004.49	2.89	0.24792	0.00065	5.520	0.011
1078	10233.5	11.7	1007.38	2.92	0.24857	0.00065	5.531	0.010
1077	10245.2	11.8	1010.30	2.93	0.24922	0.00065	5.541	0.011
1076	10257.0	11.8	1013.23	2.95	0.24987	0.00065	5.552	0.011
1075	10268.8	11.8	1016.18	2.97	0.25053	0.00066	5.563	0.011
1074	10280.6	11.9	1019.15	2.99	0.25118	0.00067	5.574	0.012
1073	10292.5	11.9	1022.14	3.01	0.25185	0.00066	5.586	0.011
1072	10304.4	12.0	1025.15	3.02	0.25251	0.00067	5.597	0.011
1071	10316.4	12.0	1028.17	3.05	0.25318	0.00068	5.608	0.011
1070	10328.4	12.1	1031.22	3.07	0.25386	0.00068	5.619	0.011
1069	10340.5	12.1	1034.29	3.08	0.25454	0.00068	5.630	0.012
1068	10352.6	12.1	1037.37	3.11	0.25522	0.00068	5.642	0.011
1067	10364.7	12.2	1040.48	3.13	0.25590	0.00069	5.653	0.011
1066	10376.9	12.3	1043.61	3.14	0.25659	0.00069	5.664	0.012
1065	10389.2	12.3	1046.75	3.17	0.25728	0.00070	5.676	0.011
1064	10401.5	12.3	1049.92	3.18	0.25798	0.00070	5.687	0.012
1063	10413.8	12.4	1053.10	3.21	0.25868	0.00071	5.699	0.011
1062	10426.2	12.4	1056.31	3.23	0.25939	0.00071	5.710	0.012
1061	10438.6	12.5	1059.54	3.25	0.26010	0.00071	5.722	0.012
1060	10451.1	12.5	1062.79	3.27	0.26081	0.00072	5.734	0.012
1059	10463.6	12.6	1066.06	3.29	0.26153	0.00072	5.746	0.013
1058	10476.2	12.6	1069.35	3.31	0.26225	0.00073	5.758	0.012
1057	10488.8	12.7	1072.66	3.34	0.26298	0.00073	5.770	0.012
1056	10501.5	12.7	1076.00	3.36	0.26371	0.00073	5.782	0.012
1055	10514.2	12.8	1079.36	3.38	0.26444	0.00074	5.794	0.012
1054	10527.0	12.8	1082.74	3.40	0.26518	0.00074	5.806	0.012
1053	10539.8	12.8	1086.14	3.42	0.26592	0.00075	5.818	0.012
1052	10552.6	12.9	1089.56	3.45	0.26667	0.00075	5.830	0.013
1051	10565.5	13.0	1093.01	3.47	0.26742	0.00076	5.843	0.012
1050	10578.5	13.0	1096.48	3.49	0.26818	0.00076	5.855	0.012

TABLE I.—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
1050	10578.5	13.0	1096.48	3.49	0.26818	0.00076	5.855	0.012
1049	10591.5	13.0	1099.97	3.52	0.26894	0.00076	5.867	0.013
1048	10604.5	13.1	1103.49	3.54	0.26970	0.00077	5.880	0.012
1047	10617.6	13.2	1107.03	3.57	0.27047	0.00077	5.892	0.013
1046	10630.8	13.2	1110.60	3.59	0.27124	0.00078	5.905	0.012
1045	10644.0	13.2	1114.19	3.61	0.27202	0.00078	5.917	0.013
1044	10657.2	13.3	1117.80	3.63	0.27280	0.00078	5.930	0.012
1043	10670.5	13.4	1121.43	3.66	0.27358	0.00079	5.942	0.013
1042	10683.9	13.4	1125.09	3.69	0.27437	0.00080	5.955	0.013
1041	10697.3	13.5	1128.78	3.71	0.27517	0.00080	5.968	0.013
1040	10710.8	13.5	1132.49	3.73	0.27597	0.00080	5.981	0.013
1039	10724.3	13.6	1136.22	3.76	0.27677	0.00081	5.994	0.013
1038	10737.9	13.6	1139.98	3.79	0.27758	0.00082	6.007	0.013
1037	10751.5	13.7	1143.77	3.81	0.27840	0.00082	6.020	0.013
1036	10765.2	13.8	1147.58	3.84	0.27922	0.00082	6.033	0.014
1035	10779.0	13.8	1151.42	3.87	0.28004	0.00083	6.047	0.013
1034	10792.8	13.8	1155.29	3.89	0.28087	0.00083	6.060	0.013
1033	10806.6	13.9	1159.18	3.92	0.28170	0.00084	6.073	0.014
1032	10820.5	13.9	1163.10	3.94	0.28254	0.00084	6.087	0.013
1031	10834.4	14.0	1167.04	3.97	0.28338	0.00085	6.100	0.014
1030	10848.4	14.0	1171.01	4.00	0.28423	0.00085	6.114	0.014
1029	10862.4	14.1	1175.01	4.03	0.28508	0.00086	6.128	0.013
1028	10876.5	14.2	1179.04	4.06	0.28594	0.00086	6.141	0.014
1027	10890.7	14.2	1183.10	4.08	0.28680	0.00087	6.155	0.014
1026	10904.9	14.2	1187.18	4.11	0.28767	0.00087	6.169	0.014
1025	10919.1	14.3	1191.29	4.14	0.28854	0.00088	6.183	0.014
1024	10933.4	14.4	1195.43	4.17	0.28942	0.00088	6.197	0.014
1023	10947.8	14.4	1199.60	4.19	0.29030	0.00089	6.211	0.015
1022	10962.2	14.5	1203.79	4.23	0.29119	0.00089	6.226	0.014
1021	10976.7	14.6	1208.02	4.25	0.29208	0.00090	6.240	0.014
1020	10991.3	14.6	1212.27	4.29	0.29298	0.00090	6.254	0.014
1019	11005.9	14.7	1216.56	4.31	0.29388	0.00091	6.268	0.015
1018	11020.6	14.7	1220.87	4.35	0.29479	0.00092	6.283	0.014
1017	11035.3	14.8	1225.22	4.38	0.29571	0.00092	6.297	0.014
1016	11050.1	14.8	1229.60	4.41	0.29663	0.00093	6.311	0.015
1015	11064.9	14.9	1234.01	4.44	0.29756	0.00093	6.326	0.015
1014	11079.8	15.0	1238.45	4.47	0.29849	0.00094	6.341	0.014
1013	11094.8	15.0	1242.92	4.51	0.29943	0.00094	6.355	0.015
1012	11109.8	15.1	1247.43	4.53	0.30037	0.00095	6.370	0.015
1011	11124.9	15.1	1251.96	4.57	0.30132	0.00095	6.385	0.015
1010	11140.0	15.2	1256.53	4.60	0.30227	0.00096	6.400	0.015
1009	11155.2	15.2	1261.13	4.63	0.30323	0.00096	6.415	0.015
1008	11170.4	15.3	1265.76	4.67	0.30419	0.00097	6.430	0.015
1007	11185.7	15.4	1270.43	4.70	0.30516	0.00098	6.445	0.016
1006	11201.1	15.4	1275.13	4.73	0.30614	0.00098	6.461	0.015
1005	11216.5	15.5	1279.86	4.77	0.30712	0.00099	6.476	0.015
1004	11232.0	15.6	1284.63	4.80	0.30811	0.00099	6.491	0.016
1003	11247.6	15.6	1289.43	4.84	0.30910	0.00100	6.507	0.015
1002	11263.2	15.7	1294.27	4.87	0.31010	0.00101	6.522	0.016
1001	11278.9	15.8	1299.14	4.91	0.31111	0.00101	6.538	0.016
1000	11294.7	15.8	1304.05	4.94	0.31212	0.00102	6.554	0.016

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
1000	11294.7	15.8	1304.05	4.94	0.31212	0.00102	6.554	0.016
999	11310.5	15.9	1308.99	4.98	0.31314	0.00102	6.570	0.016
998	11326.4	16.0	1313.97	5.02	0.31416	0.00103	6.586	0.016
997	11342.4	16.0	1318.99	5.05	0.31519	0.00104	6.602	0.016
996	11358.4	16.1	1324.01	5.09	0.31623	0.00104	6.618	0.016
995	11374.5	16.1	1329.13	5.12	0.31727	0.00105	6.634	0.016
994	11390.6	16.2	1334.25	5.17	0.31832	0.00105	6.650	0.017
993	11406.8	16.3	1339.42	5.20	0.31937	0.00106	6.667	0.016
992	11423.1	16.3	1344.62	5.24	0.32043	0.00107	6.683	0.016
991	11439.4	16.4	1349.86	5.28	0.32150	0.00108	6.699	0.017
990	11455.8	16.5	1355.14	5.32	0.32258	0.00108	6.716	0.017
989	11472.3	16.5	1360.46	5.36	0.32366	0.00109	6.733	0.016
988	11488.8	16.6	1365.82	5.40	0.32475	0.00109	6.749	0.017
987	11505.4	16.6	1371.22	5.44	0.32584	0.00110	6.766	0.017
986	11522.0	16.7	1376.66	5.48	0.32694	0.00111	6.783	0.017
985	11538.7	16.8	1382.14	5.52	0.32805	0.00112	6.800	0.017
984	11555.5	16.9	1387.66	5.56	0.32917	0.00112	6.817	0.017
983	11572.4	16.9	1393.22	5.61	0.33029	0.00113	6.834	0.017
982	11589.3	17.0	1398.83	5.64	0.33142	0.00114	6.851	0.018
981	11606.3	17.1	1404.47	5.69	0.33256	0.00114	6.869	0.017
980	11623.4	17.2	1410.16	5.73	0.33370	0.00115	6.886	0.017
979	11640.6	17.2	1415.89	5.77	0.33485	0.00115	6.903	0.018
978	11657.8	17.3	1421.66	5.82	0.33600	0.00117	6.921	0.018
977	11675.1	17.3	1427.48	5.86	0.33717	0.00117	6.939	0.018
976	11692.4	17.4	1433.34	5.91	0.33834	0.00118	6.957	0.017
975	11709.8	17.5	1439.25	5.95	0.33952	0.00118	6.974	0.018
974	11727.3	17.6	1445.20	6.00	0.34070	0.00119	6.992	0.018
973	11744.9	17.7	1451.20	6.04	0.34189	0.00120	7.010	0.019
972	11762.6	17.7	1457.24	6.09	0.34309	0.00121	7.029	0.018
971	11780.3	17.8	1463.33	6.13	0.34430	0.00122	7.047	0.018
970	11798.1	17.9	1469.46	6.19	0.34552	0.00122	7.065	0.019
969	11816.0	18.0	1475.65	6.24	0.34674	0.00123	7.084	0.018
968	11834.0	18.0	1481.89	6.28	0.34797	0.00124	7.102	0.019
967	11852.0	18.0	1488.17	6.31	0.34921	0.00124	7.121	0.019
966	11870.0	18.1	1494.48	6.35	0.35045	0.00125	7.140	0.018
965	11888.1	18.1	1500.83	6.38	0.35170	0.00125	7.158	0.019
964	11906.2	18.1	1507.21	6.42	0.35295	0.00126	7.177	0.019
963	11924.3	18.2	1513.63	6.45	0.35421	0.00126	7.196	0.019
962	11942.5	18.2	1520.08	6.49	0.35547	0.00127	7.215	0.019
961	11960.7	18.3	1526.57	6.53	0.35674	0.00127	7.234	0.01
960	11979.0	18.3	1533.10	6.56	0.35801	0.00128	7.253	0.019
959	11997.3	18.3	1539.66	6.61	0.35929	0.00128	7.272	0.019
958	12015.6	18.4	1546.27	6.64	0.36057	0.00129	7.291	0.019
957	12034.0	18.4	1552.91	6.67	0.36186	0.00129	7.310	0.019
956	12052.4	18.4	1559.58	6.72	0.36315	0.00130	7.329	0.020
955	12070.8	18.5	1566.30	6.75	0.36445	0.00131	7.349	0.019
954	12089.3	18.6	1573.05	6.79	0.36576	0.00131	7.368	0.019
953	12107.9	18.5	1579.84	6.83	0.36707	0.00132	7.387	0.020
952	12126.4	18.6	1586.67	6.87	0.36839	0.00132	7.407	0.019
951	12145.0	18.7	1593.54	6.90	0.36971	0.00133	7.426	0.020
950	12163.7	18.7	1600.44	6.94	0.37104	0.00133	7.446	0.020

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
950	12163.7	18.7	1600.44	6.91	0.37104	0.00133	7.446	0.020
949	12182.4	18.7	1607.38	6.99	0.37237	0.00134	7.466	0.019
948	12201.1	18.8	1614.37	7.03	0.37371	0.00134	7.485	0.020
947	12219.9	18.8	1621.40	7.06	0.37505	0.00135	7.505	0.020
946	12238.7	18.8	1628.46	7.11	0.37640	0.00136	7.525	0.020
945	12257.5	18.9	1635.57	7.15	0.37776	0.00136	7.545	0.020
944	12276.4	19.0	1642.72	7.19	0.37912	0.00137	7.565	0.020
943	12295.4	18.9	1649.91	7.23	0.38049	0.00137	7.585	0.021
942	12314.3	19.0	1657.14	7.27	0.38186	0.00138	7.606	0.020
941	12333.3	19.1	1664.41	7.31	0.38324	0.00139	7.626	0.020
940	12352.4	19.1	1671.72	7.36	0.38463	0.00139	7.646	0.020
939	12371.5	19.1	1679.08	7.40	0.38602	0.00140	7.666	0.021
938	12390.6	19.2	1686.48	7.44	0.38742	0.00140	7.687	0.020
937	12409.8	19.2	1693.92	7.48	0.38882	0.00141	7.707	0.021
936	12429.0	19.2	1701.40	7.53	0.39023	0.00142	7.728	0.020
935	12448.2	19.3	1708.93	7.57	0.39165	0.00142	7.748	0.021
934	12467.5	19.3	1716.50	7.62	0.39307	0.00143	7.769	0.020
933	12486.8	19.4	1724.12	7.66	0.39450	0.00143	7.789	0.021
932	12506.2	19.4	1731.78	7.70	0.39593	0.00144	7.810	0.021
931	12525.6	19.5	1739.48	7.74	0.39737	0.00145	7.831	0.021
930	12545.1	19.5	1747.22	7.79	0.39882	0.00145	7.852	0.021
929	12564.6	19.6	1755.01	7.84	0.40027	0.00146	7.873	0.021
928	12584.2	19.6	1762.85	7.88	0.40173	0.00146	7.894	0.021
927	12603.8	19.6	1770.73	7.92	0.40319	0.00147	7.915	0.021
926	12623.4	19.7	1778.65	7.98	0.40466	0.00148	7.936	0.022
925	12643.1	19.7	1786.63	8.02	0.40614	0.00148	7.958	0.021
924	12662.8	19.8	1794.65	8.07	0.40762	0.00149	7.979	0.021
923	12682.6	19.8	1802.72	8.11	0.40911	0.00150	8.000	0.022
922	12702.4	19.8	1810.83	8.16	0.41061	0.00150	8.022	0.021
921	12722.2	19.9	1818.99	8.21	0.41211	0.00151	8.043	0.022
920	12742.1	19.9	1827.20	8.25	0.41362	0.00152	8.065	0.022
919	12762.0	20.0	1835.45	8.31	0.41514	0.00152	8.087	0.021
918	12782.0	20.0	1843.76	8.36	0.41666	0.00153	8.108	0.022
917	12802.0	20.0	1852.12	8.40	0.41819	0.00153	8.130	0.022
916	12822.0	20.1	1860.52	8.45	0.41972	0.00154	8.152	0.022
915	12842.1	20.2	1868.97	8.51	0.42126	0.00155	8.174	0.022
914	12862.3	20.2	1877.48	8.55	0.42281	0.00156	8.196	0.022
913	12882.5	20.2	1886.03	8.60	0.42437	0.00156	8.218	0.023
912	12902.7	20.3	1894.63	8.66	0.42593	0.00157	8.241	0.022
911	12923.0	20.3	1903.29	8.70	0.42750	0.00158	8.263	0.022
910	12943.3	20.4	1911.99	8.76	0.42908	0.00158	8.285	0.022
909	12963.7	20.4	1920.75	8.81	0.43066	0.00159	8.307	0.023
908	12984.1	20.4	1929.56	8.86	0.43225	0.00160	8.330	0.022
907	13004.5	20.5	1938.42	8.91	0.43385	0.00161	8.352	0.023
906	13025.0	20.6	1947.33	8.97	0.43546	0.00161	8.375	0.022
905	13045.6	20.6	1956.30	9.02	0.43707	0.00162	8.397	0.023
904	13066.2	20.6	1965.32	9.07	0.43869	0.00163	8.420	0.023
903	13086.8	20.7	1974.39	9.12	0.44032	0.00163	8.443	0.023
902	13107.5	20.7	1983.51	9.18	0.44195	0.00164	8.466	0.023
901	13128.2	20.8	1992.69	9.23	0.44359	0.00165	8.489	0.023
900	13149.0	20.8	2001.92	9.28	0.44524	0.00165	8.512	0.023

TABLE 1—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
900	13149.0	20.8	2001.92	9.28	0.44524	0.00165	8.512	0.023
899	13169.8	20.9	2011.20	9.34	0.44689	0.00167	8.535	0.023
898	13190.7	20.9	2020.54	9.40	0.44856	0.00167	8.558	0.024
897	13211.6	21.0	2029.94	9.46	0.45023	0.00167	8.582	0.023
896	13232.6	21.0	2039.40	9.51	0.45190	0.00169	8.605	0.023
895	13253.6	21.1	2048.91	9.57	0.45359	0.00169	8.628	0.024
894	13274.7	21.1	2058.48	9.63	0.45528	0.00170	8.652	0.024
893	13295.8	21.1	2068.11	9.68	0.45698	0.00171	8.676	0.023
892	13316.9	21.2	2077.79	9.74	0.45869	0.00172	8.699	0.024
891	13338.1	21.3	2087.53	9.80	0.46041	0.00172	8.723	0.024
890	13359.4	21.3	2097.33	9.86	0.46213	0.00173	8.747	0.024
889	13380.7	21.3	2107.19	9.92	0.46386	0.00174	8.771	0.024
888	13402.0	21.4	2117.11	9.98	0.46560	0.00174	8.795	0.024
887	13423.4	21.5	2127.09	10.04	0.46734	0.00176	8.819	0.024
886	13444.9	21.5	2137.13	10.10	0.46910	0.00176	8.843	0.025
885	13466.4	21.5	2147.23	10.17	0.47086	0.00177	8.868	0.024
884	13487.9	21.6	2157.40	10.22	0.47263	0.00177	8.892	0.024
883	13509.5	21.6	2167.62	10.28	0.47440	0.00179	8.916	0.025
882	13531.1	21.7	2177.90	10.34	0.47619	0.00180	8.941	0.024
881	13552.8	21.7	2188.24	10.41	0.47799	0.00180	8.965	0.025
880	13574.5	21.8	2198.65	10.47	0.47979	0.00181	8.990	0.025
879	13596.3	21.8	2209.12	10.53	0.48160	0.00182	9.015	0.025
878	13618.1	21.9	2219.65	10.60	0.48342	0.00183	9.040	0.025
877	13640.0	21.9	2230.25	10.66	0.48525	0.00183	9.065	0.025
876	13661.9	22.0	2240.91	10.73	0.48708	0.00185	9.090	0.025
875	13683.9	22.0	2251.64	10.79	0.48893	0.00185	9.115	0.025
874	13705.9	22.1	2262.43	10.86	0.49078	0.00186	9.140	0.026
873	13728.0	22.1	2273.29	10.92	0.49264	0.00187	9.166	0.025
872	13750.1	22.2	2284.21	10.99	0.49451	0.00188	9.191	0.025
871	13772.3	22.2	2295.20	11.06	0.49639	0.00189	9.216	0.026
870	13794.5	22.3	2306.26	11.12	0.49828	0.00190	9.242	0.026
869	13816.8	22.3	2317.38	11.19	0.50018	0.00190	9.268	0.025
868	13839.1	22.4	2328.57	11.26	0.50208	0.00191	9.293	0.026
867	13861.5	22.4	2339.83	11.33	0.50399	0.00192	9.319	0.026
866	13883.9	22.5	2351.16	11.41	0.50591	0.00193	9.345	0.026
865	13906.4	22.6	2362.57	11.47	0.50784	0.00195	9.371	0.026
864	13929.0	22.6	2374.04	11.54	0.50979	0.00195	9.397	0.026
863	13951.6	22.6	2385.58	11.61	0.51174	0.00195	9.423	0.026
862	13974.2	22.7	2397.19	11.69	0.51369	0.00197	9.449	0.026
861	13996.9	22.8	2408.88	11.75	0.51566	0.00198	9.475	0.027
860	14019.7	22.8	2420.63	11.83	0.51764	0.00198	9.502	0.027
859	14042.5	22.9	2432.46	11.90	0.51962	0.00200	9.529	0.026
858	14065.4	22.9	2444.36	11.98	0.52162	0.00200	9.555	0.027
857	14088.3	23.0	2456.34	12.05	0.52362	0.00202	9.582	0.027
856	14111.3	23.0	2468.39	12.13	0.52564	0.00202	9.609	0.027
855	14134.3	23.1	2480.52	12.20	0.52766	0.00203	9.636	0.027
854	14157.4	23.1	2492.72	12.28	0.52969	0.00204	9.663	0.027
853	14180.5	23.2	2505.00	12.35	0.53173	0.00206	9.690	0.027
852	14203.7	23.2	2517.35	12.43	0.53379	0.00206	9.717	0.028
851	14226.9	23.3	2529.78	12.50	0.53585	0.00207	9.745	0.027
850	14250.2	23.3	2542.28	12.58	0.53792	0.00208	9.772	0.027

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
850	14250.2	23.3	2542.28	12.58	0.53702	0.00208	9.772	0.027
849	14273.5	23.4	2554.86	12.66	0.54000	0.00209	9.799	0.028
848	14296.9	23.5	2567.52	12.74	0.54209	0.00210	9.827	0.028
847	14320.4	23.5	2580.26	12.83	0.54419	0.00211	9.855	0.027
846	14343.9	23.6	2593.09	12.90	0.54630	0.00212	9.882	0.028
845	14367.5	23.6	2605.99	12.98	0.54842	0.00213	9.910	0.028
844	14391.1	23.7	2618.97	13.07	0.55055	0.00214	9.938	0.028
843	14414.8	23.7	2632.04	13.14	0.55269	0.00216	9.966	0.028
842	14438.5	23.8	2645.18	13.22	0.55485	0.00216	9.994	0.029
841	14462.3	23.9	2658.40	13.31	0.55701	0.00217	10.023	0.028
840	14486.2	23.9	2671.71	13.39	0.55918	0.00218	10.051	0.028
839	14510.1	23.9	2685.10	13.48	0.56136	0.00219	10.079	0.029
838	14534.0	24.0	2698.58	13.56	0.56355	0.00221	10.108	0.028
837	14558.0	24.1	2712.14	13.65	0.56576	0.00221	10.136	0.029
836	14582.1	24.1	2725.79	13.74	0.56797	0.00222	10.165	0.029
835	14606.2	24.2	2739.53	13.82	0.57019	0.00224	10.194	0.029
834	14630.4	24.3	2753.35	13.91	0.57243	0.00225	10.223	0.029
833	14654.7	24.3	2767.26	14.00	0.57468	0.00225	10.252	0.029
832	14679.0	24.4	2781.26	14.09	0.57693	0.00227	10.281	0.030
831	14703.4	24.4	2795.35	14.17	0.57920	0.00228	10.311	0.029
830	14727.8	24.5	2809.52	14.26	0.58148	0.00229	10.340	0.029
829	14752.3	24.5	2823.78	14.36	0.58377	0.00229	10.369	0.030
828	14776.8	24.6	2838.14	14.45	0.58606	0.00231	10.399	0.030
827	14801.4	24.7	2852.59	14.54	0.58837	0.00233	10.429	0.030
826	14826.1	24.7	2867.13	14.64	0.59070	0.00233	10.459	0.030
825	14850.8	24.8	2881.77	14.73	0.59303	0.00234	10.489	0.030
824	14875.6	24.9	2896.50	14.82	0.59537	0.00236	10.519	0.030
823	14900.5	24.9	2911.32	14.92	0.59773	0.00237	10.549	0.030
822	14925.4	25.0	2926.24	15.01	0.60010	0.00238	10.579	0.030
821	14950.4	25.0	2941.25	15.10	0.60248	0.00239	10.609	0.031
820	14975.4	25.1	2956.35	15.20	0.60487	0.00240	10.640	0.031
819	15000.5	25.1	2971.55	15.30	0.60727	0.00241	10.671	0.030
818	15025.6	25.2	2986.85	15.41	0.60968	0.00243	10.701	0.031
817	15050.8	25.3	3002.26	15.50	0.61211	0.00244	10.732	0.031
816	15076.1	25.4	3017.76	15.60	0.61455	0.00245	10.763	0.032
815	15101.5	25.4	3033.36	15.71	0.61700	0.00246	10.795	0.031
814	15126.9	25.5	3049.07	15.80	0.61946	0.00248	10.826	0.031
813	15152.4	25.5	3064.87	15.91	0.62194	0.00249	10.857	0.032
812	15177.9	25.6	3080.78	16.00	0.62443	0.00250	10.889	0.031
811	15203.5	25.6	3096.78	16.11	0.62693	0.00251	10.920	0.032
810	15229.1	25.7	3112.89	16.21	0.62944	0.00252	10.952	0.032
809	15254.8	25.8	3129.10	16.32	0.63196	0.00254	10.984	0.032
808	15280.6	25.8	3145.42	16.43	0.63450	0.00255	11.016	0.032
807	15306.4	25.9	3161.85	16.54	0.63705	0.00256	11.048	0.032
806	15332.3	26.0	3178.39	16.65	0.63961	0.00257	11.080	0.032
805	15358.3	26.0	3195.04	16.75	0.64218	0.00259	11.112	0.032
804	15384.3	26.1	3211.79	16.86	0.64477	0.00260	11.144	0.033
803	15410.4	26.2	3228.65	16.97	0.64737	0.00261	11.177	0.032
802	15436.6	26.2	3245.62	17.08	0.64998	0.00263	11.209	0.033
801	15462.8	26.3	3262.70	17.19	0.65261	0.00264	11.242	0.033
800	15489.1	26.4	3279.89	17.30	0.65525	0.00265	11.275	0.033

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
800	15489.1	26.4	3279.89	17.30	0.65525	0.00265	11.275	0.033
799	15515.5	26.4	3297.19	17.42	0.65790	0.00266	11.308	0.033
798	15541.9	26.5	3314.61	17.53	0.66056	0.00268	11.341	0.033
797	15568.4	26.5	3332.14	17.65	0.66324	0.00269	11.374	0.033
796	15594.9	26.6	3349.79	17.77	0.66593	0.00271	11.407	0.034
795	15621.5	26.7	3367.56	17.89	0.66864	0.00272	11.441	0.033
794	15648.2	26.8	3385.45	18.00	0.67136	0.00273	11.474	0.034
793	15675.0	26.8	3403.45	18.12	0.67409	0.00275	11.508	0.034
792	15701.8	26.9	3421.57	18.24	0.67684	0.00276	11.542	0.034
791	15728.7	26.9	3439.81	18.36	0.67960	0.00278	11.576	0.034
790	15755.6	27.1	3458.17	18.52	0.68238	0.00280	11.610	0.034
789	15782.7	27.1	3476.69	18.62	0.68518	0.00280	11.644	0.035
788	15809.8	27.1	3495.31	18.71	0.68798	0.00282	11.679	0.034
787	15836.9	27.2	3514.02	18.83	0.69080	0.00283	11.713	0.035
786	15864.1	27.2	3532.85	18.92	0.69363	0.00284	11.748	0.034
785	15891.3	27.3	3551.77	19.02	0.69647	0.00285	11.782	0.035
784	15918.6	27.3	3570.79	19.13	0.69932	0.00286	11.817	0.035
783	15945.9	27.3	3589.92	19.23	0.70218	0.00287	11.852	0.035
782	15973.2	27.4	3609.15	19.33	0.70505	0.00288	11.887	0.035
781	16000.6	27.4	3628.48	19.44	0.70793	0.00289	11.922	0.035
780	16028.0	27.4	3647.92	19.54	0.71082	0.00290	11.957	0.035
779	16055.4	27.5	3667.46	19.65	0.71372	0.00292	11.992	0.035
778	16082.9	27.5	3687.11	19.75	0.71664	0.00292	12.027	0.036
777	16110.4	27.5	3706.86	19.86	0.71956	0.00294	12.063	0.035
776	16137.9	27.6	3726.72	19.97	0.72250	0.00295	12.098	0.035
775	16165.5	27.6	3746.69	20.07	0.72545	0.00296	12.133	0.036
774	16193.1	27.6	3766.76	20.18	0.72841	0.00297	12.169	0.036
773	16220.7	27.7	3786.94	20.29	0.73138	0.00299	12.205	0.036
772	16248.4	27.7	3807.23	20.39	0.73437	0.00299	12.241	0.036
771	16276.1	27.8	3827.62	20.51	0.73736	0.00301	12.277	0.036
770	16303.9	27.8	3848.13	20.62	0.74037	0.00302	12.313	0.036
769	16331.7	27.8	3868.75	20.72	0.74339	0.00303	12.349	0.037
768	16359.5	27.9	3889.47	20.84	0.74642	0.00304	12.386	0.036
767	16387.4	27.9	3910.31	20.95	0.74946	0.00306	12.422	0.036
766	16415.3	27.9	3931.26	21.07	0.75252	0.00307	12.458	0.037
765	16443.2	28.0	3952.33	21.17	0.75559	0.00308	12.495	0.037
764	16471.2	28.0	3973.50	21.29	0.75867	0.00309	12.532	0.036
763	16499.2	28.1	3994.79	21.41	0.76176	0.00310	12.568	0.037
762	16527.3	28.1	4016.20	21.52	0.76486	0.00311	12.605	0.037
761	16555.4	28.1	4037.72	21.64	0.76797	0.00313	12.642	0.037
760	16583.5	28.1	4059.36	21.76	0.77110	0.00314	12.679	0.037
759	16611.6	28.2	4081.12	21.88	0.77424	0.00315	12.716	0.037
758	16639.8	28.2	4103.00	22.00	0.77739	0.00316	12.753	0.038
757	16668.0	28.3	4125.00	22.11	0.78055	0.00318	12.791	0.037
756	16696.3	28.3	4147.11	22.23	0.78373	0.00319	12.828	0.037
755	16724.6	28.3	4169.34	22.35	0.78692	0.00320	12.865	0.038
754	16752.9	28.4	4191.69	22.47	0.79012	0.00322	12.903	0.038
753	16781.3	28.4	4214.16	22.59	0.79334	0.00322	12.941	0.037
752	16809.7	28.5	4236.75	22.70	0.79656	0.00324	12.978	0.038
751	16838.2	28.5	4259.45	22.83	0.79980	0.00326	13.016	0.038
750	16866.7	28.5	4282.28	22.96	0.80306	0.00327	13.054	0.038

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
750	16866.7	28.5	4282.28	22.96	0.80306	0.00327	13.054	0.038
749	16895.2	28.6	4305.24	23.09	0.80633	0.00328	13.092	0.038
748	16923.8	28.6	4328.33	23.21	0.80961	0.00329	13.130	0.038
747	16952.4	28.7	4351.54	23.33	0.81290	0.00331	13.168	0.039
746	16981.1	28.7	4374.87	23.46	0.81621	0.00332	13.207	0.038
745	17009.8	28.7	4398.33	23.59	0.81953	0.00333	13.245	0.039
744	17038.5	28.8	4421.92	23.72	0.82286	0.00335	13.284	0.038
743	17067.3	28.8	4445.64	23.84	0.82621	0.00336	13.322	0.039
742	17096.1	28.8	4469.48	23.98	0.82957	0.00337	13.361	0.039
741	17124.9	28.9	4493.46	24.10	0.83294	0.00339	13.400	0.039
740	17153.8	28.9	4517.56	24.23	0.83633	0.00340	13.439	0.039
739	17182.7	29.0	4541.79	24.37	0.83973	0.00341	13.478	0.039
738	17211.7	29.0	4566.16	24.50	0.84314	0.00343	13.517	0.040
737	17240.7	29.0	4590.66	24.63	0.84657	0.00344	13.557	0.039
736	17269.7	29.1	4615.29	24.76	0.85001	0.00346	13.596	0.039
735	17298.8	29.1	4640.05	24.90	0.85347	0.00347	13.635	0.040
734	17327.9	29.1	4664.95	25.04	0.85694	0.00349	13.675	0.040
733	17357.0	29.2	4689.99	25.17	0.86043	0.00350	13.715	0.040
732	17386.2	29.2	4715.16	25.30	0.86393	0.00351	13.755	0.040
731	17415.4	29.3	4740.46	25.45	0.86744	0.00353	13.795	0.040
730	17444.7	29.3	4765.91	25.59	0.87097	0.00354	13.835	0.040
729	17474.0	29.3	4791.50	25.72	0.87451	0.00356	13.875	0.041
728	17503.3	29.4	4817.22	25.87	0.87807	0.00358	13.916	0.040
727	17532.7	29.5	4843.09	26.00	0.88165	0.00359	13.956	0.040
726	17562.2	29.5	4869.09	26.15	0.88524	0.00360	13.996	0.041
725	17591.7	29.5	4895.24	26.29	0.88884	0.00361	14.037	0.041
724	17621.2	29.5	4921.53	26.43	0.89245	0.00363	14.078	0.041
723	17650.7	29.6	4947.96	26.57	0.89608	0.00365	14.119	0.041
722	17680.3	29.7	4974.53	26.72	0.89973	0.00366	14.160	0.041
721	17710.0	29.7	5001.25	26.87	0.90339	0.00368	14.201	0.041
720	17739.7	29.8	5028.12	27.01	0.90707	0.00369	14.242	0.041
719	17769.5	29.8	5055.13	27.16	0.91076	0.00371	14.283	0.042
718	17799.3	29.8	5082.29	27.31	0.91447	0.00372	14.325	0.041
717	17829.1	29.9	5109.60	27.46	0.91819	0.00374	14.366	0.042
716	17859.0	29.9	5137.06	27.61	0.92193	0.00376	14.408	0.041
715	17888.9	30.0	5164.67	27.76	0.92569	0.00377	14.449	0.042
714	17918.9	30.0	5192.43	27.92	0.92946	0.00379	14.491	0.042
713	17948.9	30.0	5220.35	28.06	0.93325	0.00380	14.533	0.043
712	17978.9	30.1	5248.41	28.22	0.93705	0.00382	14.576	0.042
711	18009.0	30.1	5276.63	28.38	0.94087	0.00383	14.618	0.042
710	18039.1	30.1	5305.01	28.53	0.94470	0.00385	14.660	0.042
709	18069.2	30.1	5333.54	28.69	0.94855	0.00387	14.702	0.043
708	18099.3	30.2	5362.23	28.85	0.95242	0.00388	14.745	0.043
707	18129.5	30.3	5391.08	29.01	0.95630	0.00390	14.788	0.042
706	18159.8	30.3	5420.09	29.16	0.96020	0.00392	14.830	0.043
705	18190.1	30.3	5449.25	29.33	0.96412	0.00394	14.873	0.043
704	18220.4	30.4	5478.58	29.49	0.96806	0.00395	14.916	0.043
703	18250.8	30.4	5508.07	29.65	0.97201	0.00397	14.959	0.044
702	18281.2	30.5	5537.72	29.81	0.97598	0.00398	15.003	0.043
701	18311.7	30.5	5567.53	29.98	0.97996	0.00400	15.046	0.044
700	18342.2	30.6	5597.51	30.15	0.98396	0.00402	15.090	0.044

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
700	18342.2	30.6	5597.51	30.15	0.98396	0.00402	15.090	0.044
699	18372.8	30.6	5627.66	30.31	0.98798	0.00404	15.134	0.043
698	18403.4	30.6	5657.97	30.48	0.99202	0.00405	15.177	0.044
697	18434.0	30.7	5688.45	30.64	0.99607	0.00407	15.221	0.045
696	18464.7	30.8	5719.09	30.82	1.00014	0.00409	15.266	0.044
695	18495.5	30.8	5749.91	30.99	1.00423	0.00411	15.310	0.044
694	18526.3	30.8	5780.90	31.15	1.00834	0.00412	15.354	0.045
693	18557.1	30.9	5812.05	31.33	1.01246	0.00414	15.399	0.044
692	18588.0	30.9	5843.38	31.50	1.01660	0.00416	15.443	0.045
691	18618.9	31.0	5874.88	31.68	1.02076	0.00418	15.488	0.045
690	18649.9	31.0	5906.56	31.85	1.02494	0.00420	15.533	0.045
689	18680.9	31.0	5938.41	32.03	1.02914	0.00421	15.578	0.045
688	18711.9	31.1	5970.44	32.21	1.03336	0.00423	15.623	0.046
687	18743.0	31.1	6002.65	32.39	1.03758	0.00425	15.669	0.045
686	18774.1	31.2	6035.04	32.57	1.04183	0.00427	15.714	0.045
685	18805.3	31.3	6067.61	32.74	1.04610	0.00429	15.759	0.046
684	18836.6	31.3	6100.35	32.93	1.05039	0.00431	15.805	0.046
683	18867.9	31.3	6133.28	33.12	1.05470	0.00433	15.851	0.046
682	18899.2	31.4	6166.40	33.30	1.05903	0.00434	15.897	0.046
681	18930.6	31.4	6199.70	33.48	1.06337	0.00437	15.943	0.046
680	18962.0	31.5	6233.18	33.67	1.06774	0.00438	15.989	0.046
679	18993.5	31.5	6266.85	33.86	1.07212	0.00441	16.035	0.047
678	19025.0	31.6	6300.71	34.05	1.07653	0.00442	16.082	0.046
677	19056.6	31.6	6334.76	34.25	1.08095	0.00445	16.128	0.047
676	19088.2	31.7	6369.01	34.43	1.08540	0.00446	16.175	0.046
675	19119.9	31.7	6403.44	34.62	1.08986	0.00448	16.221	0.047
674	19151.6	31.7	6438.06	34.82	1.09434	0.00450	16.268	0.048
673	19183.3	31.8	6472.88	35.01	1.09884	0.00453	16.316	0.047
672	19215.1	31.9	6507.89	35.21	1.10337	0.00454	16.363	0.047
671	19247.0	31.9	6543.10	35.41	1.10791	0.00456	16.410	0.048
670	19278.9	31.9	6578.51	35.61	1.11247	0.00458	16.458	0.048
669	19310.8	32.0	6614.12	35.81	1.11705	0.00460	16.506	0.048
668	19342.8	32.0	6649.93	36.01	1.12165	0.00462	16.554	0.048
667	19374.8	32.1	6685.94	36.21	1.12627	0.00465	16.602	0.048
666	19406.9	32.1	6722.15	36.42	1.13092	0.00467	16.650	0.048
665	19439.0	32.2	6758.57	36.62	1.13559	0.00468	16.698	0.049
664	19471.2	32.2	6795.19	36.83	1.14027	0.00471	16.747	0.048
663	19503.4	32.3	6832.02	37.03	1.14498	0.00473	16.795	0.049
662	19535.7	32.3	6869.05	37.24	1.14971	0.00475	16.844	0.049
661	19568.0	32.4	6906.29	37.46	1.15446	0.00478	16.893	0.049
660	19600.4	32.4	6943.75	37.67	1.15924	0.00480	16.942	0.049
659	19632.8	32.5	6981.42	37.88	1.16404	0.00482	16.991	0.049
658	19665.3	32.5	7019.30	38.10	1.16886	0.00484	17.040	0.050
657	19697.8	32.6	7057.40	38.31	1.17370	0.00486	17.090	0.049
656	19730.4	32.6	7095.71	38.53	1.17856	0.00488	17.139	0.050
655	19763.0	32.7	7134.24	38.75	1.18344	0.00491	17.189	0.050
654	19795.7	32.7	7172.99	38.97	1.18835	0.00493	17.239	0.050
653	19828.4	32.8	7211.96	39.18	1.19328	0.00495	17.289	0.050
652	19861.2	32.8	7251.14	39.41	1.19823	0.00497	17.339	0.050
651	19894.0	32.9	7290.55	39.64	1.20320	0.00500	17.389	0.051
650	19926.9	32.9	7330.19	39.86	1.20820	0.00502	17.440	0.051

TABLE 1—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
650	19926.9	32.9	7330.19	39.86	1.20820	0.00502	17.440	0.051
649	19959.8	33.0	7370.05	40.09	1.21322	0.00504	17.491	0.051
648	19992.8	33.0	7410.14	40.32	1.21826	0.00507	17.542	0.051
647	20025.8	33.1	7450.46	40.56	1.22333	0.00509	17.593	0.051
646	20058.9	33.1	7491.02	40.78	1.22842	0.00511	17.644	0.052
645	20092.0	33.2	7531.80	41.01	1.23353	0.00514	17.696	0.051
644	20125.2	33.3	7572.81	41.25	1.23867	0.00516	17.747	0.052
643	20158.5	33.3	7614.06	41.49	1.24383	0.00518	17.799	0.052
642	20191.8	33.3	7655.55	41.72	1.24901	0.00521	17.851	0.052
641	20225.1	33.4	7697.27	41.96	1.25422	0.00524	17.903	0.052
640	20258.5	33.4	7739.23	42.21	1.25946	0.00526	17.955	0.052
639	20291.9	33.5	7781.44	42.44	1.26472	0.00528	18.007	0.053
638	20325.4	33.6	7823.88	42.69	1.27000	0.00531	18.060	0.052
637	20359.0	33.6	7866.57	42.94	1.27531	0.00534	18.112	0.053
636	20392.6	33.6	7909.51	43.19	1.28065	0.00536	18.165	0.053
635	20426.2	33.7	7952.70	43.43	1.28601	0.00538	18.218	0.053
634	20459.9	33.8	7996.13	43.68	1.29139	0.00541	18.271	0.053
633	20493.7	33.8	8039.81	43.94	1.29680	0.00544	18.324	0.054
632	20527.5	33.9	8083.75	44.18	1.30224	0.00546	18.378	0.053
631	20561.1	33.9	8127.93	44.45	1.30770	0.00549	18.431	0.054
630	20595.3	34.0	8172.38	44.70	1.31319	0.00551	18.485	0.054
629	20629.3	34.0	8217.08	44.96	1.31870	0.00554	18.539	0.054
628	20663.3	34.1	8262.04	45.22	1.32424	0.00557	18.593	0.054
627	20697.4	34.1	8307.26	45.49	1.32981	0.00560	18.647	0.054
626	20731.5	34.2	8352.75	45.75	1.33541	0.00562	18.701	0.055
625	20765.7	34.3	8398.50	46.02	1.34103	0.00564	18.756	0.055
624	20800.0	34.3	8444.52	46.28	1.34667	0.00568	18.811	0.055
623	20834.3	34.3	8490.80	46.56	1.35235	0.00570	18.866	0.055
622	20868.6	34.4	8537.36	46.83	1.35805	0.00573	18.921	0.055
621	20903.0	34.5	8584.19	47.10	1.36378	0.00576	18.976	0.056
620	20937.5	34.5	8631.29	47.38	1.36954	0.00579	19.032	0.056
619	20972.0	34.6	8678.67	47.66	1.37533	0.00581	19.088	0.056
618	21006.6	34.6	8726.33	47.93	1.38114	0.00584	19.144	0.056
617	21041.2	34.7	8774.26	48.22	1.38698	0.00587	19.200	0.056
616	21075.9	34.7	8822.48	48.49	1.39285	0.00590	19.256	0.057
615	21110.6	34.8	8870.97	48.78	1.39875	0.00593	19.313	0.056
614	21145.4	34.9	8919.75	49.07	1.40468	0.00596	19.369	0.057
613	21180.3	34.9	8968.82	49.36	1.41064	0.00598	19.426	0.057
612	21215.2	35.0	9018.18	49.64	1.41662	0.00602	19.483	0.058
611	21250.2	35.0	9067.82	49.94	1.42264	0.00604	19.541	0.057
610	21285.2	35.1	9117.76	50.23	1.42868	0.00607	19.598	0.057
609	21320.3	35.1	9167.99	50.53	1.43475	0.00611	19.655	0.058
608	21355.4	35.2	9218.52	50.82	1.44086	0.00613	19.713	0.058
607	21390.6	35.3	9269.34	51.13	1.44699	0.00617	19.771	0.058
606	21425.9	35.3	9320.47	51.43	1.45316	0.00619	19.829	0.058
605	21461.2	35.4	9371.90	51.74	1.45935	0.00623	19.887	0.059
604	21496.6	35.4	9423.64	52.04	1.46558	0.00626	19.946	0.059
603	21532.0	35.5	9475.68	52.36	1.47184	0.00629	20.005	0.059
602	21567.5	35.6	9528.04	52.66	1.47813	0.00632	20.064	0.059
601	21603.1	35.6	9580.70	52.98	1.48445	0.00635	20.123	0.059
600	21638.7	35.7	9633.68	53.30	1.49080	0.00638	20.182	0.059

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
600	21638.7	35.7	9633.68	53.30	1.49080	0.00638	20.182	0.059
599	21674.4	35.7	9686.98	53.62	1.49718	0.00642	20.241	0.060
598	21710.1	35.8	9740.60	53.94	1.50360	0.00645	20.301	0.060
597	21745.9	35.8	9794.54	54.25	1.51005	0.00648	20.361	0.060
596	21781.7	35.9	9848.79	54.58	1.51653	0.00652	20.421	0.060
595	21817.6	36.0	9903.37	54.91	1.52305	0.00654	20.481	0.061
594	21853.6	36.0	9958.28	55.23	1.52959	0.00658	20.542	0.061
593	21889.6	36.1	10013.50	55.6	1.53617	0.00661	20.603	0.061
592	21925.7	36.2	10069.10	55.9	1.54278	0.00665	20.664	0.061
591	21961.9	36.2	10125.00	56.2	1.54943	0.00668	20.725	0.061
590	21998.1	36.3	10181.20	56.6	1.55611	0.00671	20.786	0.061
589	22034.4	36.3	10237.80	56.9	1.56282	0.00675	20.847	0.062
588	22070.7	36.4	10294.70	57.2	1.56957	0.00679	20.909	0.062
587	22107.1	36.4	10351.90	57.6	1.57636	0.00681	20.971	0.062
586	22143.5	36.5	10409.50	58.0	1.58317	0.00685	21.033	0.063
585	22180.0	36.6	10467.50	58.3	1.59002	0.00689	21.096	0.062
584	22216.6	36.7	10525.80	58.6	1.59691	0.00693	21.158	0.063
583	22253.3	36.7	10584.40	59.0	1.60384	0.00696	21.221	0.063
582	22290.0	36.8	10643.40	59.4	1.61080	0.00699	21.284	0.063
581	22326.8	36.8	10702.80	59.7	1.61779	0.00703	21.347	0.064
580	22363.6	36.9	10762.50	60.1	1.62482	0.00707	21.411	0.064
579	22400.5	37.0	10822.60	60.4	1.63189	0.00710	21.475	0.064
578	22437.5	37.0	10883.00	60.9	1.63899	0.00714	21.539	0.064
577	22474.5	37.1	10943.90	61.2	1.64613	0.00718	21.603	0.064
576	22511.6	37.1	11005.10	61.5	1.65331	0.00721	21.667	0.065
575	22548.7	37.2	11066.60	62.0	1.66052	0.00726	21.732	0.064
574	22585.9	37.3	11128.60	62.3	1.66778	0.00729	21.796	0.065
573	22623.2	37.4	11190.90	62.7	1.67507	0.00733	21.861	0.066
572	22660.6	37.4	11253.60	63.1	1.68240	0.00737	21.927	0.065
571	22698.0	37.5	11316.70	63.5	1.68977	0.00741	21.992	0.066
570	22735.5	37.6	11380.20	63.9	1.69718	0.00745	22.058	0.066
569	22773.1	37.6	11444.10	64.2	1.70463	0.00748	22.124	0.066
568	22810.7	37.7	11508.30	64.7	1.71211	0.00753	22.190	0.067
567	22848.4	37.7	11573.00	65.0	1.71964	0.00757	22.257	0.066
566	22886.1	37.9	11638.00	65.5	1.72721	0.00761	22.323	0.067
565	22924.0	37.9	11703.50	65.8	1.73482	0.00764	22.390	0.067
564	22961.9	37.9	11769.30	66.3	1.74246	0.00769	22.457	0.068
563	22999.8	38.0	11835.6	66.7	1.75015	0.00773	22.525	0.067
562	23037.8	38.1	11902.3	67.1	1.75788	0.00777	22.592	0.068
561	23075.9	38.2	11969.4	67.5	1.76565	0.00781	22.660	0.068
560	23114.1	38.2	12036.9	67.9	1.77346	0.00785	22.728	0.068
559	23152.3	38.3	12104.8	68.4	1.78131	0.00790	22.796	0.069
558	23190.6	38.3	12173.2	68.8	1.78921	0.00794	22.865	0.069
557	23228.9	38.4	12242.0	69.2	1.79715	0.00798	22.934	0.069
556	23267.3	38.5	12311.2	69.7	1.80513	0.00802	23.003	0.069
555	23305.8	38.6	12380.9	70.1	1.81315	0.00807	23.072	0.069
554	23344.4	38.7	12451.0	70.5	1.82122	0.00811	23.141	0.070
553	23383.1	38.7	12521.5	70.9	1.82933	0.00816	23.211	0.070
552	23421.8	38.7	12592.4	71.4	1.83749	0.00820	23.281	0.070
551	23460.5	38.9	12663.8	71.9	1.84569	0.00824	23.351	0.071
550	23499.4	38.9	12735.7	72.3	1.85393	0.00829	23.422	0.071

TABLE I—Continued.

u	S (u)	Δ	A (u)	Δ	I (u)	Δ	T (u)	Δ
550	23499.4	38.9	12735.7	72.3	1.85393	0.00829	23.422	0.071
549	23538.3	39.0	12808.0	72.8	1.86222	0.00833	23.493	0.071
548	23577.3	39.1	12880.8	73.2	1.87055	0.00838	23.564	0.071
547	23616.4	39.1	12954.0	73.7	1.87893	0.00843	23.635	0.072
546	23655.5	39.2	13027.7	74.1	1.88736	0.00847	23.707	0.072
545	23694.7	39.3	13101.8	74.6	1.89583	0.00852	23.779	0.072
544	23734.0	39.3	13176.4	75.1	1.90435	0.00857	23.851	0.072
543	23773.3	39.4	13251.5	75.6	1.91292	0.00861	23.923	0.073
542	23812.7	39.5	13327.1	76.0	1.92153	0.00867	23.996	0.073
541	23852.2	39.6	13403.1	76.6	1.93020	0.00871	24.069	0.073
540	23891.8	39.6	13479.7	77.0	1.93891	0.00878	24.142	0.073
539	23931.4	39.7	13556.7	77.6	1.94767	0.00881	24.215	0.074
538	23971.1	39.8	13634.3	78.0	1.95648	0.00886	24.289	0.074
537	24010.9	39.9	13712.3	78.5	1.96534	0.00891	24.363	0.074
536	24050.8	39.9	13790.8	79.0	1.97425	0.00896	24.437	0.075
535	24090.7	40.0	13869.8	79.5	1.98321	0.00901	24.512	0.075
534	24130.7	40.1	13949.3	80.1	1.99222	0.00905	24.587	0.075
533	24170.8	40.1	14029.4	80.5	2.00127	0.00912	24.662	0.075
532	24210.9	40.3	14109.9	81.1	2.01039	0.00916	24.737	0.076
531	24251.2	40.3	14191.0	81.6	2.01955	0.00921	24.813	0.076
530	24291.5	40.4	14272.6	82.1	2.02876	0.00926	24.889	0.076
529	24331.9	40.5	14354.7	82.7	2.03802	0.00932	24.965	0.077
528	24372.4	40.5	14437.4	83.2	2.04734	0.00937	25.042	0.077
527	24412.9	40.6	14520.6	83.7	2.05671	0.00942	25.119	0.077
526	24453.5	40.7	14604.3	84.3	2.06613	0.00948	25.196	0.077
525	24494.2	40.8	14688.6	84.9	2.07561	0.00954	25.273	0.078
524	24535.0	40.9	14773.5	85.4	2.08515	0.00959	25.351	0.078
523	24575.9	40.9	14858.9	85.9	2.09474	0.00964	25.429	0.078
522	24616.8	41.0	14944.8	86.5	2.10438	0.00970	25.507	0.079
521	24657.8	41.1	15031.3	87.0	2.11408	0.00975	25.586	0.079
520	24698.9	41.1	15118.3	87.6	2.12383	0.00981	25.665	0.079
519	24740.0	41.2	15205.9	88.2	2.13364	0.00987	25.744	0.080
518	24781.2	41.3	15294.1	88.8	2.14351	0.00992	25.824	0.080
517	24822.5	41.4	15382.9	89.4	2.15343	0.00999	25.904	0.080
516	24863.9	41.5	15472.3	90.0	2.16342	0.01004	25.984	0.081
515	24905.4	41.5	15562.3	90.5	2.17346	0.01010	26.065	0.081
514	24946.9	41.7	15652.8	91.2	2.18356	0.01015	26.146	0.081
513	24988.6	41.7	15744.0	91.7	2.19371	0.01022	26.227	0.081
512	25030.3	41.8	15835.7	92.3	2.20393	0.01028	26.308	0.082
511	25072.1	41.9	15928.0	93.0	2.21421	0.01034	26.390	0.082
510	25114.0	42.0	16021.0	93.6	2.22455	0.01040	26.472	0.082
509	25156.0	42.0	16114.6	94.2	2.23495	0.01046	26.554	0.083
508	25198.0	42.2	16208.8	94.8	2.24541	0.01052	26.637	0.083
507	25240.2	42.2	16303.6	95.5	2.25593	0.01059	26.720	0.083
506	25282.4	42.3	16399.1	96.1	2.26652	0.01065	26.803	0.084
505	25324.7	42.4	16495.2	96.8	2.27717	0.01071	26.887	0.084
504	25367.1	42.5	16592.0	97.4	2.28788	0.01077	26.971	0.084
503	25409.6	42.6	16689.4	98.0	2.29865	0.01084	27.055	0.085
502	25452.2	42.7	16787.4	98.7	2.30949	0.01091	27.140	0.085
501	25494.9	42.7	16886.1	99.4	2.32040	0.01097	27.225	0.085
500	25537.6	42.8	16985.5	100.1	2.33137	0.01104	27.310	0.086

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
500	25537.6	42.8	16985.5	100.1	2.33137	0.01104	27.310	0.086
499	25580.4	42.9	17085.6	100.7	2.34241	0.01110	27.396	0.086
498	25623.3	43.0	17186.3	101.4	2.35351	0.01117	27.482	0.086
497	25666.3	43.0	17287.7	102.1	2.36468	0.01124	27.568	0.087
496	25709.3	43.2	17389.8	102.8	2.37592	0.01131	27.655	0.087
495	25752.5	43.2	17492.6	103.5	2.38723	0.01137	27.742	0.088
494	25795.7	43.4	17596.1	104.2	2.39860	0.01145	27.830	0.088
493	25839.1	43.4	17700.3	104.9	2.41005	0.01151	27.918	0.088
492	25882.5	43.5	17805.2	105.6	2.42156	0.01158	28.006	0.088
491	25926.0	43.6	17910.8	106.3	2.43314	0.01166	28.094	0.089
490	25969.6	43.7	18017.1	107.1	2.44480	0.01173	28.183	0.089
489	26013.3	43.8	18124.2	107.8	2.45653	0.01180	28.272	0.090
488	26057.1	43.8	18232.0	108.5	2.46833	0.01187	28.362	0.090
487	26100.9	44.0	18340.5	109.3	2.48020	0.01194	28.452	0.090
486	26144.9	44.0	18449.8	110.0	2.49214	0.01202	28.542	0.091
485	26188.9	44.2	18559.8	110.8	2.50416	0.01210	28.633	0.091
484	26233.1	44.2	18670.6	111.6	2.51626	0.01216	28.724	0.091
483	26277.3	44.4	18782.2	112.3	2.52842	0.01225	28.815	0.092
482	26321.7	44.4	18894.5	113.1	2.54067	0.01232	28.907	0.092
481	26366.1	44.5	19007.6	113.9	2.55299	0.01240	28.999	0.093
480	26410.6	44.6	19121.5	114.7	2.56539	0.01248	29.092	0.093
479	26455.2	44.7	19236.2	115.5	2.57787	0.01255	29.185	0.093
478	26499.9	44.7	19351.7	116.3	2.59042	0.01263	29.278	0.094
477	26544.6	44.9	19468.0	117.1	2.60305	0.01272	29.372	0.094
476	26589.5	45.0	19585.1	117.9	2.61577	0.01279	29.466	0.095
475	26634.5	45.0	19703.0	118.8	2.62856	0.01287	29.561	0.095
474	26679.5	45.2	19821.8	119.6	2.64143	0.01296	29.656	0.095
473	26724.7	45.3	19941.4	120.4	2.65439	0.01304	29.751	0.096
472	26770.0	45.3	20061.8	121.3	2.66743	0.01312	29.847	0.096
471	26815.3	45.5	20183.1	122.1	2.68055	0.01321	29.943	0.097
470	26860.8	45.5	20305.2	123.0	2.69376	0.01329	30.040	0.097
469	26906.3	45.7	20428.2	123.9	2.70705	0.01338	30.137	0.098
468	26952.0	45.7	20552.1	124.7	2.72043	0.01346	30.235	0.098
467	26997.7	45.9	20676.8	125.7	2.73389	0.01355	30.333	0.098
466	27043.6	45.9	20802.5	126.5	2.74744	0.01364	30.431	0.099
465	27089.5	46.0	20929.0	127.4	2.76108	0.01372	30.530	0.099
464	27135.5	46.2	21056.4	128.4	2.77480	0.01382	30.629	0.100
463	27181.7	46.2	21184.8	129.2	2.78862	0.01390	30.729	0.100
462	27227.9	46.4	21311.0	130.2	2.80252	0.01399	30.829	0.100
461	27274.3	46.4	21444.2	131.1	2.81651	0.01409	30.929	0.101
460	27320.7	46.5	21575.3	132.1	2.83060	0.01418	31.030	0.101
459	27367.2	46.7	21707.4	133.0	2.84478	0.01427	31.131	0.102
458	27413.9	46.7	21840.4	134.0	2.85905	0.01436	31.233	0.102
457	27460.6	46.8	21974.4	134.9	2.87341	0.01446	31.335	0.103
456	27507.4	47.0	22109.3	135.9	2.88787	0.01456	31.438	0.103
455	27554.4	47.0	22245.2	136.9	2.90243	0.01465	31.541	0.103
454	27601.4	47.2	22382.1	137.9	2.91708	0.01474	31.644	0.104
453	27648.6	47.2	22520.0	139.0	2.93182	0.01485	31.748	0.105
452	27695.8	47.4	22659.0	139.9	2.94667	0.01494	31.853	0.105
451	27743.2	47.5	22798.9	140.9	2.96161	0.01505	31.958	0.105
450	27790.7	47.6	22939.8	142.0	2.97666	0.01515	32.063	0.106

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
450	27790.7	47.6	22939.8	142.0	2.97666	0.01515	32.063	0.106
449	27838.3	47.6	23081.8	143.0	2.99181	0.01524	32.169	0.106
448	27885.9	47.8	23224.8	144.1	3.00705	0.01535	32.275	0.107
447	27933.7	47.9	23368.9	145.1	3.02240	0.01545	32.382	0.107
446	27981.6	48.0	23514.0	146.2	3.03785	0.01556	32.489	0.108
445	28029.6	48.1	23660.2	147.3	3.05341	0.01566	32.597	0.108
444	28077.7	48.2	23807.5	148.4	3.06907	0.01577	32.705	0.109
443	28125.9	48.4	23955.9	149.4	3.08484	0.01588	32.814	0.109
442	28174.3	48.4	24105.3	150.6	3.10072	0.01598	32.923	0.110
441	28222.7	48.6	24255.9	151.7	3.11670	0.01609	33.033	0.110
440	28271.3	48.7	24407.6	152.8	3.13279	0.01620	33.143	0.111
439	28320.0	48.7	24560.4	154.0	3.14899	0.01631	33.254	0.111
438	28368.7	48.9	24714.4	155.2	3.16530	0.01643	33.365	0.112
437	28417.6	49.0	24869.6	156.3	3.18173	0.01654	33.477	0.112
436	28466.6	49.1	25025.9	157.4	3.19827	0.01665	33.589	0.113
435	28515.7	49.3	25183.3	158.7	3.21492	0.01677	33.702	0.113
434	28565.0	49.3	25342.0	159.8	3.23169	0.01688	33.815	0.114
433	28614.3	49.4	25501.8	161.0	3.24857	0.01700	33.929	0.114
432	28663.7	49.6	25662.8	162.3	3.26557	0.01712	34.043	0.115
431	28713.3	49.7	25825.1	163.5	3.28269	0.01724	34.158	0.115
430	28763.0	49.8	25988.6	164.7	3.29993	0.01736	34.273	0.116
429	28812.8	49.8	26153.3	166.0	3.31729	0.01748	34.389	0.116
428	28862.6	50.0	26319.3	167.3	3.33477	0.01761	34.505	0.117
427	28912.6	50.2	26486.6	168.5	3.35238	0.01773	34.622	0.118
426	28962.8	50.2	26655.1	169.8	3.37011	0.01785	34.740	0.118
425	29013.0	50.4	26824.9	171.1	3.38796	0.01798	34.858	0.119
424	29063.4	50.5	26996.0	172.5	3.40594	0.01811	34.977	0.119
423	29113.9	50.6	27168.5	173.7	3.42405	0.01824	35.096	0.120
422	29164.5	50.7	27342.2	175.1	3.44229	0.01837	35.216	0.120
421	29215.2	50.9	27517.3	176.5	3.46066	0.01850	35.336	0.121
420	29266.1	51.0	27693.8	177.8	3.47916	0.01863	35.457	0.122
419	29317.1	51.1	27871.6	179.2	3.49779	0.01877	35.579	0.122
418	29368.2	51.2	28050.8	180.6	3.51656	0.01890	35.701	0.123
417	29419.4	51.3	28231.4	182.0	3.53546	0.01904	34.824	0.123
416	29470.7	51.5	28413.4	183.5	3.55450	0.01917	35.947	0.124
415	29522.2	51.6	28596.9	184.9	3.57367	0.01932	36.071	0.124
414	29573.8	51.8	28781.8	186.3	3.59299	0.01945	36.195	0.125
413	29625.6	51.8	28968.1	187.8	3.61244	0.01960	36.320	0.126
412	29677.4	52.0	29155.9	189.2	3.63204	0.01974	36.446	0.126
411	29729.4	52.1	29345.1	190.8	3.65178	0.01989	36.572	0.127
410	29781.5	52.2	29535.9	192.3	3.67167	0.02003	36.699	0.128
409	29833.7	52.3	29728.2	193.8	3.69170	0.02018	36.827	0.128
408	29886.0	52.5	29922.0	195.3	3.71188	0.02033	36.955	0.129
407	29938.5	52.6	30117.3	196.9	3.73221	0.20048	37.084	0.129
406	29991.1	52.7	30314.2	198.5	3.75269	0.02063	37.213	0.130
405	30043.8	52.9	30512.7	200.0	3.77332	0.02078	37.343	0.131
404	30096.7	53.0	30712.7	201.7	3.79410	0.02094	37.474	0.131
403	30149.7	53.1	30914.4	203.2	3.81504	0.02109	37.605	0.132
402	30202.8	53.3	31117.6	204.9	3.83613	0.02125	37.737	0.133
401	30256.1	53.4	31322.5	206.5	3.85738	0.02141	37.870	0.133
400	30309.5	53.5	31529.0	208.2	3.87879	0.02157	38.003	0.134

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
400	30309.5	53.5	31529.0	208.2	3.87879	0.02157	38.003	0.134
399	30363.0	53.7	31737.2	209.9	3.90036	0.02174	38.137	0.135
398	30416.7	53.8	31947.1	211.7	3.92210	0.02190	38.272	0.135
397	30470.5	53.9	32158.8	213.3	3.94400	0.02207	38.407	0.136
396	30524.4	54.1	32372.1	215.1	3.96607	0.02223	38.543	0.137
395	30578.5	54.2	32587.2	216.8	3.98830	0.02240	38.680	0.138
394	30632.7	54.3	32804.0	218.5	4.01070	0.02257	38.818	0.138
393	30687.0	54.5	33022.5	220.4	4.03327	0.02275	38.956	0.139
392	30741.5	54.6	33242.9	222.2	4.05602	0.02292	39.095	0.139
391	30796.1	54.8	33465.1	223.9	4.07894	0.02310	39.234	0.140
390	30850.9	54.9	33689.0	225.9	4.10204	0.02328	39.374	0.141
389	30905.8	55.1	33914.9	227.7	4.12532	0.02345	39.515	0.142
388	30960.9	55.2	34142.6	229.6	4.14877	0.02364	39.657	0.142
387	31016.1	55.3	34372.2	231.5	4.17241	0.02382	39.799	0.143
386	31071.4	55.5	34603.7	233.5	4.19623	0.02401	39.942	0.144
385	31126.9	55.6	34837.2	235.4	4.22024	0.02420	40.086	0.145
384	31182.5	55.7	35072.6	237.3	4.24444	0.02439	40.231	0.145
383	31238.2	55.9	35309.9	239.4	4.26883	0.02458	40.376	0.146
382	31294.1	56.1	35549.3	241.3	4.29341	0.02477	40.522	0.147
381	31350.2	56.2	35790.6	243.4	4.31818	0.02497	40.669	0.148
380	31406.4	56.3	36034.0	245.4	4.34315	0.02517	40.817	0.149
379	31462.7	56.5	36279.4	247.6	4.36832	0.02537	40.966	0.149
378	31519.2	56.7	36527.0	249.6	4.39369	0.02557	41.115	0.150
377	31575.9	56.8	36776.6	251.7	4.41926	0.02577	41.265	0.151
376	31632.7	56.9	37028.3	253.9	4.44503	0.02598	41.416	0.152
375	31689.6	57.1	37282.2	256.0	4.47101	0.02619	41.568	0.152
374	31746.7	57.3	37538.2	258.3	4.49720	0.02640	41.720	0.153
373	31804.0	57.4	37796.5	260.4	4.52360	0.02661	41.873	0.154
372	31861.4	57.6	38056.9	262.7	4.55021	0.02682	42.027	0.155
371	31919.0	57.7	38319.6	265.0	4.57703	0.02705	42.182	0.156
370	31976.7	57.9	38584.6	267.2	4.60408	0.02726	42.338	0.157
369	32034.6	58.0	38851.8	269.6	4.63134	0.02749	42.495	0.157
368	32092.6	58.2	39121.4	271.9	4.65883	0.02771	42.652	0.158
367	32150.8	58.3	39393.3	274.3	5.68654	0.02794	42.810	0.159
366	32209.1	58.5	39667.6	276.6	4.71448	0.02818	42.969	0.160
365	32267.6	58.7	39944.2	279.1	4.74266	0.02840	43.129	0.161
364	32326.3	58.8	40223.3	281.6	4.77106	0.02864	43.290	0.162
363	32385.1	59.0	40504.9	284.0	4.79970	0.02887	43.452	0.163
362	32444.1	59.2	40788.9	286.5	4.82857	0.02912	43.615	0.163
361	32503.3	59.3	41075.4	289.0	4.85769	0.02936	43.778	0.165
360	32562.6	59.5	41364.4	291.6	4.88705	0.02961	43.943	0.165
359	32622.1	59.7	41656.0	294.2	4.91666	0.02985	44.108	0.167
358	32681.8	59.8	41950.2	296.8	4.94651	0.03011	44.275	0.167
357	32741.6	60.0	42247.0	299.4	4.97662	0.03036	44.442	0.168
356	32801.6	60.2	42546.4	302.1	5.00698	0.03061	44.610	0.170
355	32861.8	60.3	42848.5	304.8	5.03759	0.03087	44.780	0.170
354	32922.1	60.5	43153.3	307.6	5.06846	0.03114	44.950	0.171
353	32982.6	60.7	43460.9	310.3	5.09960	0.03141	45.121	0.172
352	33043.3	60.8	43771.2	313.1	5.13101	0.03167	45.293	0.173
351	33104.1	61.0	44084.3	316.0	5.16268	0.03194	45.466	0.174
350	33165.1	61.2	44400.3	318.8	5.19462	0.03222	45.640	0.175

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
350	33165.1	61.2	44400.3	318.8	5.19462	0.03222	45.640	0.175
349	33226.3	61.4	44719.1	321.7	5.22684	0.03249	45.815	0.176
348	33287.7	61.5	45040.8	324.7	5.25933	0.03278	45.991	0.177
347	33349.2	61.7	45365.5	327.6	5.29211	0.03306	46.168	0.178
346	33410.9	61.9	45693.1	330.7	5.32517	0.03335	46.346	0.180
345	33472.8	62.1	46023.8	333.6	5.35852	0.03364	46.526	0.180
344	33534.9	62.3	46357.4	336.8	5.39216	0.03394	46.706	0.181
343	33597.2	62.4	46694.2	339.9	5.42610	0.03424	46.887	0.182
342	33659.6	62.6	47034.1	343.0	5.46034	0.03454	47.069	0.184
341	33722.2	62.8	47377.1	346.2	5.49488	0.03484	47.253	0.184
340	33785.0	63.0	47723.3	349.5	5.52972	0.03515	47.437	0.185
339	33848.0	63.2	48072.8	352.7	5.56487	0.03547	47.622	0.187
338	33911.2	63.3	48425.5	356.0	5.60034	0.03578	47.809	0.188
337	33974.5	63.5	48781.5	359.3	5.63612	0.03610	47.997	0.189
336	34038.0	63.8	49140.8	362.7	5.67222	0.03643	48.186	0.190
335	34101.8	63.9	49503.5	366.1	5.70865	0.03675	48.376	0.191
334	34165.7	64.2	49869.6	369.6	5.74540	0.03708	48.567	0.192
333	34229.9	64.3	50239.2	373.1	5.78248	0.03741	48.759	0.194
332	34294.2	64.5	50612.3	376.6	5.81989	0.03776	48.953	0.194
331	34358.7	64.7	50988.9	380.3	5.85765	0.03810	49.147	0.196
330	34423.4	64.9	51369.2	383.9	5.89575	0.03845	49.343	0.197
329	34488.3	65.1	51753.1	387.5	5.93420	0.03880	49.540	0.198
328	34553.4	65.3	52140.6	391.3	5.97300	0.03916	49.738	0.199
327	34618.7	65.5	52531.9	395.0	6.01216	0.03951	49.937	0.201
326	34684.2	65.7	52926.9	398.9	6.05167	0.03988	50.138	0.202
325	34749.9	66.0	53325.8	402.8	6.09155	0.04026	50.340	0.203
324	34815.9	66.1	53728.6	406.7	6.13181	0.04063	50.543	0.204
323	34882.0	66.3	54135.3	410.7	6.17244	0.04101	50.749	0.206
322	34948.3	66.5	54546.0	414.6	6.21345	0.04139	50.953	0.207
321	35014.8	66.7	54960.6	418.8	6.25484	0.04178	51.160	0.208
320	35081.5	66.9	55379.4	422.9	6.29662	0.04218	51.368	0.209
319	35148.4	67.2	55802.3	427.1	6.33880	0.04257	51.577	0.211
318	35215.6	67.3	56229.4	431.3	6.38137	0.04298	51.788	0.212
317	35282.9	67.6	56660.7	435.5	6.42435	0.04338	52.000	0.214
316	35350.5	67.8	57096.2	439.9	6.46773	0.04380	52.214	0.215
315	35418.3	68.0	57536.1	444.2	6.51153	0.04422	52.429	0.216
314	35486.3	68.2	57980.3	448.7	6.55575	0.04464	52.645	0.218
313	35554.5	68.4	58429.0	453.2	6.60039	0.04507	52.863	0.219
312	35622.9	68.6	58882.2	457.8	6.64546	0.04551	53.082	0.220
311	35691.5	68.9	59340.0	462.4	6.69097	0.04595	53.302	0.222
310	35760.4	69.1	59802.4	467.1	6.73692	0.04640	53.524	0.223
309	35829.5	69.3	60269.5	471.8	6.78332	0.04684	53.747	0.225
308	35898.8	69.5	60741.3	476.6	6.83016	0.04731	53.972	0.226
307	35968.3	69.8	61217.9	481.5	6.87747	0.04777	54.198	0.228
306	36038.1	70.0	61699.4	486.4	6.92524	0.04824	54.426	0.229
305	36108.1	70.2	62185.8	491.5	6.97348	0.04872	54.655	0.231
304	36178.3	70.5	62677.3	496.5	7.02220	0.04920	54.886	0.232
303	36248.8	70.7	63173.8	501.7	7.07140	0.04969	55.118	0.234
302	36319.5	70.9	63675.5	506.9	7.12109	0.05019	55.352	0.235
301	36390.4	71.2	64182.4	512.1	7.17128	0.05069	55.587	0.237
300	36461.6	71.4	64694.5	517.5	7.22197	0.05120	55.824	0.238

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
300	36461.6	71.4	64694.5	517.5	7.22197	0.05120	55.824	0.238
299	36533.0	71.7	65212.0	523.0	7.27317	0.05172	56.062	0.240
298	36604.7	71.9	65735.6	528.4	7.32489	0.05223	56.302	0.242
297	36676.6	72.1	66263.4	534.0	7.37712	0.05277	56.544	0.243
296	36748.7	72.4	66797.4	539.6	7.42989	0.05331	56.787	0.245
295	36821.1	72.6	67337.0	545.3	7.48320	0.05385	57.032	0.247
294	36893.7	72.8	67882.3	551.2	7.53705	0.05441	57.279	0.248
293	36966.5	73.1	68433.5	557.0	7.59146	0.05496	57.527	0.250
292	37039.6	73.4	68990.5	563.0	7.64642	0.05553	57.777	0.252
291	37113.0	73.6	69553.5	569.0	7.70195	0.05611	58.029	0.253
290	37186.6	73.9	70122.5	575.2	7.75806	0.05669	58.282	0.255
289	37260.5	74.1	70697.7	581.4	7.81475	0.05728	58.537	0.257
288	37334.6	74.4	71279.1	587.7	7.87203	0.05788	58.794	0.258
287	37409.0	74.6	71866.8	594.0	7.92991	0.05849	59.052	0.261
286	37483.6	74.9	72460.8	600.6	7.98840	0.05911	59.313	0.262
285	37558.5	75.2	73061.4	607.1	8.04751	0.05973	59.575	0.264
284	37633.7	75.4	73668.5	613.8	8.10724	0.06037	59.839	0.266
283	37709.1	75.7	74282.3	620.6	8.16761	0.06101	60.105	0.268
282	37784.8	76.0	74902.9	627.5	8.22862	0.06166	60.373	0.270
281	37860.8	76.2	75530.4	634.4	8.29028	0.06233	60.643	0.272
280	37937.0	76.5	76164.8	641.5	8.35261	0.06299	60.915	0.274
279	38013.5	76.8	76806.3	648.7	8.41560	0.06368	61.189	0.276
278	38090.3	77.0	77455.0	655.9	8.47928	0.06437	61.465	0.277
277	38167.3	77.4	78110.9	663.3	8.54365	0.06507	61.742	0.280
276	38244.7	77.6	78774.2	670.7	8.60872	0.06578	62.022	0.282
275	38322.3	77.9	79444.9	678.4	8.67450	0.06651	62.304	0.284
274	38400.2	78.2	80123.3	686.1	8.74101	0.06723	62.588	0.286
273	38478.4	78.5	80809.4	693.9	8.80824	0.06798	62.874	0.288
272	38556.9	78.7	81503.3	701.9	8.87622	0.06873	63.162	0.290
271	38635.6	79.1	82205.2	709.9	8.94495	0.06949	63.452	0.292
270	38714.7	79.4	82915.1	718.1	9.01444	0.07027	63.744	0.294
269	38794.1	79.6	83633.2	726.5	9.08471	0.07105	64.038	0.297
268	38873.7	80.0	84359.7	734.8	9.15576	0.07186	64.335	0.299
267	38953.7	80.2	85094.5	743.3	9.22762	0.07267	64.634	0.301
266	39033.9	80.6	85837.8	752.1	9.30029	0.07350	64.935	0.303
265	39114.5	80.8	86589.9	760.9	9.37379	0.07434	65.238	0.306
264	39195.3	81.2	87350.8	769.8	9.44813	0.07518	65.544	0.308
263	39276.5	81.4	88120.6	778.9	9.52331	0.07605	65.852	0.310
262	39357.9	81.8	88899.5	788.2	9.59936	0.07692	66.162	0.313
261	39439.7	82.1	89687.7	797.5	9.67628	0.07781	66.475	0.315
260	39521.8	82.4	90485.2	807.1	9.75409	0 07871	66.790	0.318
259	39604.2	82.7	91292.3	816.8	9.83280	0.07962	67.108	0.320
258	39686.9	83.1	92109.1	826.5	9.91242	0.08056	67.428	0.322
257	39770.0	83.4	92935.6	836.5	9.99298	0.08151	67.750	0.325
256	39853.4	83.7	93772.1	846.6	10.0745	0.0825	68.075	0.328
255	39937.1	84.0	94618 7	857.0	10.1570	0.0835	68.403	0.330
254	40021.1	84.3	95475.7	867.4	10.2405	0.0844	68.733	0.333
253	40105.4	84.7	96343.1	878.0	10.3249	0.0854	69.066	0.335
252	40190.1	85.0	97221.1	888.9	10.4103	0.0865	69.401	0 338
251	40275.1	85.4	98110.0	899.8	10.4968	0.0875	69.739	0.341
250	40360.5	85.7	99009.8	911.1	10.5843	0.0886	70.080	0.344

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
250	40360.5	85.7	99009.8	911.1	10.5843	0.0886	70.080	0.344
249	40446.2	86.1	99920.9	922.1	10.6729	0.0896	70.424	0.346
248	40532.3	86.4	100843.	934.	10.7625	0.0907	70.770	0.350
247	40618.7	86.8	101777.	946.	10.8532	0.0918	71.120	0.352
246	40705.5	87.1	102723.	957.	10.9450	0.0930	71.472	0.354
245	40792.6	87.4	103680.	969.	11.0380	0.0941	71.826	0.358
244	40880.0	87.8	104649.	982.	11.1321	0.0953	72.184	0.361
243	40967.8	88.2	105631.	995.	11.2274	0.0965	72.545	0.363
242	41056.0	88.6	106626.	1007.	11.3239	0.0976	72.908	0.367
241	41144.6	88.9	107633.	1020.	11.4215	0.0989	73.275	0.369
240	41233.5	89.3	108653.	1033.	11.5204	0.1001	73.644	0.372
239	41322.8	89.7	109686.	1046.	11.6205	0.1013	74.016	0.376
238	41412.5	90.0	110732.	1060.	11.7218	0.1027	74.392	0.379
237	41502.5	90.4	111792.	1074.	11.8245	0.1040	74.771	0.382
236	41592.9	90.8	112866.	1088.	11.9285	0.1053	75.153	0.385
235	41683.7	91.2	113954.	1103.	12.0338	0.1067	75.538	0.389
234	41774.9	91.6	115057.	1117.	12.1405	0.1081	75.927	0.392
233	41866.5	92.0	116174.	1132.	12.2486	0.1094	76.319	0.396
232	41958.5	92.4	117306.	1146.	12.3580	0.1109	76.715	0.399
231	42050.9	92.8	118452.	1162.	12.4689	0.1123	77.114	0.403
230	42143.7	93.2	119614.	1178.	12.5812	0.1138	77.517	0.406
229	42236.9	93.7	120792.	1193.	12.6950	0.1153	77.923	0.410
228	42330.6	94.0	121985.	1209.	12.8103	0.1168	78.333	0.413
227	42424.6	94.5	123194.	1226.	12.9271	0.1184	78.746	0.417
226	42519.1	94.8	124420.	1243.	13.0455	0.1199	79.163	0.421
225	42613.9	95.1	125663.	1260.	13.1654	0.1216	79.584	0.425
224	42709.0	95.6	126923.	1277.	13.2870	0.1232	80.009	0.428
223	42804.6	96.1	128200.	1295.	13.4102	0.1249	80.437	0.432
222	42900.7	96.5	129495.	1313.	13.5351	0.1265	80.869	0.436
221	42997.2	97.0	130808.	1331.	13.6616	0.1283	81.305	0.440
220	43094.2	97.4	132139.	1351.	13.7899	0.1301	81.745	0.444
219	43191.6	97.9	133490.	1369.	13.9200	0.1318	82.189	0.448
218	43289.5	98.4	134859.	1388.	14.0518	0.1337	82.637	0.452
217	43387.9	98.8	136247.	1407.	14.1855	0.1356	83.089	0.456
216	43486.7	99.2	137654.	1428.	14.3211	0.1374	83.545	0.461
215	43585.9	99.7	139082.	1447.	14.4585	0.1394	84.006	0.465
214	43685.6	100.2	140529.	1469.	14.5979	0.1413	84.471	0.469
213	43785.8	100.6	141998.	1491.	14.7392	0.1433	84.940	0.473
212	43886.4	101.1	143489.	1512.	14.8825	0.1454	85.413	0.478
211	43987.5	101.6	145001.	1535.	15.0279	0.1475	85.891	0.483
210	44089.1	102.1	146536.	1558.	15.1754	0.1496	86.374	0.487
209	44191.2	102.5	148094.	1580.	15.3250	0.1518	86.861	0.492
208	44293.7	103.1	149674.	1603.	15.4768	0.1539	87.353	0.496
207	44396.8	103.5	151277.	1626.	15.6307	0.1562	87.849	0.501
206	44500.3	104.1	152903.	1651.	15.7869	0.1585	88.350	0.507
205	44604.4	104.5	154554.	1675.	15.9454	0.1608	88.857	0.511
204	44708.9	105.1	156229.	1701.	16.1062	0.1632	89.368	0.517
203	44814.0	105.6	157930.	1727.	16.2694	0.1657	89.885	0.521
202	44919.6	106.1	159657.	1753.	16.4351	0.1681	90.406	0.527
201	45025.7	106.7	161410.	1780.	16.6032	0.1707	90.933	0.532
200	45132.4	107.2	163190.	1808.	16.7739	0.1733	91.465	0.537

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
200	45132.4	107.2	163190	1808	16.7739	0.1733	91.465	0.537
199	45239.6	107.8	164998	1835	16.9472	0.1759	92.002	0.543
198	45347.4	108.3	166833	1864	17.1231	0.1785	92.545	0.548
197	45455.7	108.8	168697	1893	17.3016	0.1813	93.093	0.554
196	45564.5	109.4	170590	1922	17.4829	0.1841	93.647	0.560
195	45673.9	110.0	172512	1953	17.6670	0.1869	94.207	0.565
194	45783.9	110.5	174465	1984	17.8539	0.1899	94.772	0.571
193	45894.4	111.1	176449	2015	18.0438	0.1928	95 343	0.578
192	46005.5	111.6	178464	2047	18.2366	0.1958	95.921	0.583
191	46117.1	112.3	180511	2080	18.4324	0.1990	96.504	0.589
190	46229.4	112.8	182591	2114	18.6314	0.2021	97.093	0.592
189	46342.2	113.5	184705	2148	18.8335	0.2053	97.689	0.606
188	46455.7	114.1	186853	2183	19.0388	0.2087	98.291	0.608
187	46569.8	114.6	189036	2219	19.2475	0.2121	98.899	0.614
186	46684.4	115.3	191255	2256	19.4596	0.2155	99.514	0.621
185	46799.7	115.9	193511	2294	19.6751	0.2191	100.13	0.63
184	46915.6	116.5	195805	2331	19.8942	0.2226	100.76	0.64
183	47032.1	117.2	198136	2371	20.1168	0.2263	101.40	0.64
182	47149.3	117.8	200507	2410	20.3431	0.2300	102.04	0.65
181	47267.1	118.5	202917	2451	20.5731	0.2339	102.69	0.66
180	47385.6	119.2	205368	2492	20.8070	0.2378	103.35	0.66
179	47504.8	119.8	207860	2536	21.0448	0.2418	104.01	0.67
178	47624.6	120.5	210396	2580	21.2866	0.2459	104.68	0.68
177	47745.1	121.1	212976	2624	21.5325	0.2502	105.36	0.69
176	47866.2	121.8	215600	2670	21.7827	0.2545	106.05	0.69
175	47988.0	122.4	218270	2717	22.0372	0.2589	106.74	0.70
174	48110.4	123.2	220987	2765	22.2961	0.2634	107.44	0.71
173	48233.6	121.0	223752	2814	22.5595	0.2680	108.15	0.72
172	48357.6	124.8	226566	2863	22.8275	0.2727	108.87	0.73
171	48482.4	125.5	229429	2914	23.1002	0.2775	109.60	0.73
170	48607.9	126.2	232343	2966	23.3777	0.2824	110.33	0.75
169	48734.1	126.9	235309	3021	23.6601	0.2875	111.08	0.75
168	48861.0	127.6	238330	3076	23.9476	0.2927	111.83	0.76
167	48988.6	128.5	241406	3133	24.2403	0.2981	112.59	0.78
166	49117.1	129.2	244539	3190	24.5384	0.3034	113.37	0.78
165	49246.3	130.0	247729	3250	24.8418	0.3091	114.15	0.79
164	49376.3	130.8	250979	3311	25.1509	0.3147	114.94	0.80
163	49507.1	131.7	254290	3372	25.4656	0.3205	115.74	0.81
162	49638.8	132.4	257662	3436	25.7861	0.3265	116.55	0.82
161	49771.2	133.2	261098	3501	26.1126	0.3327	117.37	0.83
160	49904.4	134.1	264599	3568	26.4453	0.3389	118.20	0.84
159	50038.5	134.9	268167	3637	26.7842	0.3451	119.04	0.85
158	50173.4	135.8	271804	3707	27.1296	0.3521	119.89	0.86
157	50309.2	136.6	275511	3780	27.4817	0.3588	120.75	0.87
156	50445.8	137.5	279291	3854	27.8405	0.3659	121.62	0.89
155	50583.3	138.4	283145	3931	28.2064	0.3730	122.51	0.89
154	50721.7	139.3	287076	4008	28.5794	0.3804	123.40	0.91
153	50861.0	140.2	291084	4088	28.9598	0.3878	124.31	0.92
152	51001.2	141.2	295172	4170	29.3476	0.3956	125.23	0.93
151	51142.4	142.1	299342	4255	29.7432	0.4035	126.16	0.95
150	51284.5	143.1	303597	4342	30.1467	0.4117	127.11	0.95

TABLE I—Continued.

u	$S(u)$	Δ	$A(u)$	Δ	$I(u)$	Δ	$T(u)$	Δ
150	51284.5	143.1	303597	4342	30.1467	0.4117	127.11	0.95
149	51427.6	144.0	307939	4430	30.5584	0.4200	128.06	0.97
148	51571.6	145.0	312369	4523	30.9784	0.4286	129.03	0.99
147	51716.6	145.9	316892	4616	31.4070	0.4374	130.02	0.99
146	51862.5	147.0	321508	4713	31.8444	0.4466	131.01	1.01
145	52009.5	148.0	326221	4813	32.2910	0.4559	132.02	1.03
144	52157.5	149.0	331034	4914	32.7469	0.4655	133.05	1.04
143	52306.5	150.1	335948	5020	33.2124	0.4754	134.09	1.05
142	52456.6	151.1	340968	5128	33.6878	0.4855	135.14	1.07
141	52607.7	152.2	346096	5239	34.1733	0.4959	136.21	1.08
140	52759.9	153.3	351335	5354	31.6692	0.5067	137.29	1.10
139	52913.2	154.4	356689	5471	35.1759	0.5177	138.39	1.11
138	53067.6	155.5	362160	5593	35.6936	0.5291	139.50	1.13
137	53223.1	156.7	367753	5717	36.2227	0.5409	140.63	1.15
136	53379.8	157.8	373470	5845	36.7636	0.5529	141.78	1.17
135	53537.6	159.0	379315	5978	37.3165	0.5654	142.95	1.18
134	53696.6	160.2	385293	6114	37.8819	0.5781	144.13	1.20
133	53856.8	161.4	391407	6255	38.4600	0.5913	145.33	1.22
132	54018.2	162.6	397662	6400	39.0513	0.6049	146.55	1.23
131	54180.8	163.9	404062	6549	39.6562	0.6189	147.78	1.26
130	54344.7	165.2	410611	6703	40.2751	0.6334	149.04	1.27
129	54509.9	166.4	417314	6862	40.9085	0.6483	150.31	1.30
128	54676.3	167.8	424176	7026	41.5568	0.6636	151.61	1.32
127	54844.1	169.0	431202	7195	42.2204	0.6795	152.93	1.33
126	55013.1	170.4	438397	7369	42.8999	0.6959	154.26	1.36
125	55183.5	171.7	445766	7550	43.5958	0.7128	155.62	1.38
124	55355.2	173.2	453316	7736	44.3086	0.7303	157.00	1.40
123	55528.4	174.5	461052	7927	45.0389	0.7483	158.40	1.43
122	55702.9	176.0	468979	8126	45.7872	0.7669	159.83	1.45
121	55878.9	177.5	477105	8331	46.5541	0.7861	161.28	1.47
120	56056.4	179.0	485436	8544	47.3402	0.8060	162.75	1.50
119	56235.4	180.5	493980	8763	48.1462	0.8267	164.25	1.52
118	56415.9	182.0	502743	8990	48.9729	0.8479	165.77	1.55
117	56597.9	183.6	511733	9224	49.8208	0.8699	167.32	1.57
116	56781.5	185.1	520957	9468	50.6907	0.8928	168.89	1.61
115	56966.6	186.8	530425	9720	51.5835	0.9163	170.50	1.63
114	57153.4	188.4	540145	9980	52.4998	0.9408	172.13	1.66
113	57341.8	190.1	550125	10250	53.4406	0.9661	173.79	1.69
112	57531.9	191.8	560375	10530	54.4067	0.9923	175.48	1.72
111	57723.7	193.5	570905	10820	55.3990	1.0195	177.20	1.75
110	57917.2	195.3	581725	11120	56.4185	1.0477	178.95	1.78
109	58112.5	197.1	592845	11432	57.4662	1.0769	180.73	1.82
108	58309.6	198.9	604277	11756	58.5431	1.1072	182.55	1.85
107	58508.5	200.8	616033	12093	59.6503	1.1388	184.40	1.89
106	58709.3	202.7	628126	12439	60.7891	1.1714	186.29	1.92
105	58912.0	204.7	640565	12803	61.9605	1.2054	188.21	1.95
104	59116.7	206.6	653368	13179	63.1659	1.2407	190.16	2.00
103	59323.3	208.6	666547	13571	64.4066	1.2773	192.16	2.04
102	59531.9	210.7	680118	13977	65.6839	1.3155	194.20	2.07
101	59742.6	212.8	694095	14400	66.9994	1.3551	196.27	2.12
100	59955.4	215.0	708495	14840	68.3545	1.3963	198.39	2.16

EXTENSION OF INGALLS' TABLE I TO 5000 FEET VELOCITY

Ingalls ballistic tables as contained in Artillery Circular M start at 3600 feet per second velocity. However, a few cartridges such as the 220 Swift and some wildcat cartridges have velocities higher than 3600 f.s.; and to permit ballistic calculations to be made for such cartridges, there is included here an extension of the space functions and time functions of Ingalls' Table I to 5000 f.s.

Because Ingalls' tables start with zero space and time at 3600 f.s., and the values get larger as the velocity decreases, it has been found convenient to assign negative values to the time and space functions for velocities above 3600 f.s.; the alternative would be to start with zero at 5000 f.s. and then increase every other time and space function figure in the entire Table I accordingly.

The instructions for using this extension to Table I are exactly the same as those for using Table I itself, remembering only that if one of two numbers to be added has a minus sign it must actually be subtracted, and that if a number to be subtracted already has a minus sign, then the two minus signs cancel, and the number actually must be added.

For example, consider the 220 Swift cartridge, which has a 48 grain bullet at 4110 f.s. muzzle velocity and 3490 f.s. remaining at 100 yards. To find the ballistic coefficient C, use the formula $C = \frac{S(v) - S(V)}{X}$.

X = 100 yd. = 300 ft.

v =	3490, and S(v)	=	302.1 from the Table
V =	4110 and S(V)	= (−)	1337.9
S(v)	−S(V)	=	1640.0

C = 300/1640 = .1828

To find the remaining velocity at 200 yards use the formula $S(v) = S(V) + \frac{X}{C}$ X = 600 ft. and $\frac{600}{.1828} = 3292.3$

V = 4110 and S(V)	= (−)	1337.9
X/C	=	3293.3
S(v)	=	1954.4

and hence v = 2921 f.s. from the table.

TABLE OF SPACE AND TIME FUNCTIONS

S(u) and T(u)

u=5000 f. s. to 3600 f. s.

An Extension of Table I, Artillery Circular M

u	S(u)	Δ	T(u)	Δ	u	S(u)	Δ	T(u)	Δ
5000	(−)3740.0	45.5	(−)0.818	9	4300	(−)1813.0	49.4	(−)0.461	12
4980	(−)3424.5	45.6	(−)0.809	9	4280	(−)1763.6	49.6	(−)0.449	11
4960	(−)3378.9	45.7	(−)0.800	9	4260	(−)1714.0	49.7	(−)0.438	12
4940	(−)3333.2	45.8	(−)0.791	10	4240	(−)1664.3	49.8	(−)0.426	12
4920	(−)3287.4	46.0	(−)0.781	9	4220	(−)1614.5	50.0	(−)0.414	12
4900	(−)3241.4	46.0	(−)0.722	10	4200	(−)1564.5	50.2	(−)0.402	12
4880	(−)3195.4	46.1	(−)0.762	9	4180	(−)1514.3	50.2	(−)0.390	12
4860	(−)3149.3	46.2	(−)0.753	10	4160	(−)1464.1	50.4	(−)0.378	12
4840	(−)3103.1	46.3	(−)0.743	9	4140	(−)1413.7	50.5	(−)0.366	12
4820	(−)3056.8	46.5	(−)0.734	10	4120	(−)1363.2	50.5	(−)0.354	12
4800	(−)3010.3	46.5	(−)0.724	10	4100	(−)1312.7	50.8	(−)0.342	12
4780	(−)2963.8	46.6	(−)0.714	9	4080	(−)1261.9	50.9	(−)0.330	13
4760	(−)2917.2	46.8	(−)0.705	10	4060	(−)1211.0	51.0	(−)0.317	12
4740	(−)2870.4	46.8	(−)0.695	10	4040	(−)1160.0	51.2	(−)0.305	13
4720	(−)2823.6	47.0	(−)0.685	10	4020	(−)1108.0	51.3	(−)0.292	13
4700	(−)2776.6	47.1	(−)0.675	10	4000	(−)1057.5	51.4	(−)0.279	13
4680	(−)2729.5	47.2	(−)0.665	10	3980	(−)1006.1	51.6	(−)0.266	13
4660	(−)2682.3	47.3	(−)0.655	10	3960	(−) 954.5	51.7	(−)0.253	13
4640	(−)2635.0	47.4	(−)0.645	11	3940	(−) 902.8	51.9	(−)0.240	14
4620	(−)2587.6	47.5	(−)0.634	10	3920	(−) 850.9	52.1	(−)0.226	13
4600	(−)2540.1	47.7	(−)0.624	10	3900	(−) 798.8	52.2	(−)0.213	13
4580	(−)2492.4	47.7	(−)0.614	10	3880	(−) 746.6	52.3	(−)0.200	14
4560	(−)2444.7	47.9	(−)0.604	11	3860	(−) 694.4	52.5	(−)0.186	13
4540	(−)2396.8	47.9	(−)0.593	10	3840	(−) 641.8	52.6	(−)0.173	14
4520	(−)2348.9	48.2	(−)0.583	11	3820	(−) 589.2	52.8	(−)0.159	14
4500	(−)2300.7	48.2	(−)0.572	11	3800	(−) 536.4	52.9	(−)0.145	14
4480	(−)2252.5	48.4	(−)0.561	11	3780	(−) 483.5	53.1	(−)0.131	14
4460	(−)2204.1	48.4	(−)0.550	11	3760	(−) 430.4	53.2	(−)0.117	14
4440	(−)2155.7	48.6	(−)0.539	11	3740	(−) 377.2	53.4	(−)0.103	15
4420	(−)2107.1	48.7	(−)0.528	11	3720	(−) 323.8	53.6	(−)0.088	14
4400	(−)2058.4	48.8	(−)0.517	11	3700	(−) 270.2	53.7	(−)0.074	15
4380	(−)2009.6	49.0	(−)0.506	11	3680	(−) 216.5	53.9	(−)0.059	14
4360	(−)1960.6	49.1	(−)0.495	11	3660	(−) 162.6	54.0	(−)0.045	15
4340	(−)1911.5	49.2	(−)0.484	12	3640	(−) 108.6	54.2	(−)0.030	15
4320	(−)1862.3	49.3	(−)0.472	11	3620	(−) 54.4	54.4	(−)0.015	15
					3600	0.0	54.5	0.000	15

TABLE A
Abridged from Ingalls'

$Z = \frac{X}{C}$ $A = \frac{\text{Sin } 2a}{C}$

Velocity	2000	2100	2200	2300	2400
Z	A	A	A	A	A
200	0.00163	0.00148	0.00134	0.00123	0.00114
400	0.00333	0.00301	0.00274	0.00251	0.00231
600	0.00509	0.00460	0.00419	0.00384	0.00353
800	0.00690	0.00625	0.00568	0.00520	0.00478
1000	0.00878	0.00795	0.00723	0.00661	0.00607
1200	0.01073	0.00971	0.00883	0.00807	0.00741
1400	0.01275	0.01154	0.01050	0.00958	0.00879
1600	0.01485	0.01344	0.01222	0.01115	0.01023
1800	0.01702	0.01541	0.01400	0.01278	0.01172
2000	0.01927	0.01744	0.01585	0.01446	0.01325
2200	0.02160	0.01955	0.01776	0.01620	0.01484
2400	0.02402	0.02175	0.01976	0.01802	0.01650
2600	0.02654	0.02403	0.02182	0.01990	0.01821
2800	0.02915	0.02638	0.02396	0.02184	0.01999
3000	0.03186	0.02882	0.02617	0.02386	0.02183
3200	0.03468	0.03135	0.02847	0.02596	0.02374
3400	0.03761	0.03399	0.03086	0.02813	0.02573
3600	0.04064	0.03673	0.03335	0.03040	0.02779
3800	0.04377	0.03957	0.03593	0.03274	0.02993
4000	0.04701	0.04252	0.03860	0.03517	0.03215
4200	0.05038	0.04557	0.04138	0.03770	0.03445
4400	0.05388	0.04875	0.04427	0.04033	0.03684
4600	0.05749	0.05204	0.04726	0.04306	0.03934
4800	0.06123	0.05545	0.05037	0.04589	0.04193
5000	0.06508	0.05898	0.05359	0.04883	0.04462
5200	0.06905	0.06263	0.05692	0.05187	0.04740
5400	0.07315	0.06639	0.06037	0.05504	0.05030

TABLE A—(Continued)

$Z = \frac{X}{C}$ $A = \frac{\text{Sin } 2a}{C}$

Velocity	2000	2100	2200	2300	2400
Z	A	A	A	A	A
5600	0.07736	0.07027	0.06394	0.05831	0.05331
5800	0.08170	0.07428	0.06763	0.06171	0.05643
6000	0.08615	0.07840	0.07144	0.06522	0.05966
6200	0.09073	0.08264	0.07536	0.06885	0.06300
6400	0.09542	0.08700	0.07941	0.07259	0.06646
6600	0.10022	0.09147	0.08357	0.07645	0.07004
6800	0.10513	0.09506	0.08784	0.08043	0.07373
7000	0.11016	0.10077	0.09224	0.08452	0.07754
7200	0.11531	0.10560	0.09675	0.08873	0.08146
7400	0.12057	0.11053	0.10138	0.09305	0.08550
7600	0.12594	0.11558	0.10612	0.09749	0.08965
7800	0.13142	0.12075	0.11097	0.10204	0.09391
8000	0.13702	0.12602	0.11593	0.10671	0.09829
8200	0.14273	0.13141	0.12101	0.11149	0.10278
8400	0.14856	0.13691	0.12620	0.11638	0.10739
8600	0.15449	0.14252	0.13150	0.12139	0.11211
8800	0.16054	0.14825	0.13691	0.12650	0.11694
9000	0.16670	0.15408	0.14244	0.13173	0.12188
9200	0.17298	0.16003	0.14808	0.13707	0.12693
9400	0.17937	0.16610	0.15383	0.14252	0.13210
9600	0.18588	0.17228	0.15970	0.14808	0.13738
9800	0.19249	0.17857	0.16568	0.15376	0.14277
10000	0.19922	0.18497	0.17177	0.15954	0.14827
10200	0.20607	0.19148	0.17798	0.16545	0.15388
10400	0.21304	0.19811	0.18429	0.17147	0.15961
10600	0.22013	0.20486	0.19072	0.17760	0.16545
10800	0.22733	0.21173	0.19727	0.18385	0.17140

$Z = \frac{X}{C}$ **TABLE A—(Continued)** $A = \frac{\text{Sin } 2a}{C}$

Velocity	2000	2100	2200	2300	2400
Z	A	A	A	A	A
11000.....	0.23465	0.21872	0.20394	0.19021	0.17747
11200.....	0.24209	0.22582	0.21072	0.19668	0.18365
11400.....	0.24966	0.23305	0.21762	0.20327	0.18995
11600.....	0.25734	0.24039	0.22463	0.20997	0.19636
11800.....	0.26513	0.24785	0.23177	0.21680	0.20288
12000.....	0.27305	0.25543	0.23902	0.22374	0.20952
12200.....	0.28109	0.26313	0.24639	0.23079	0.21628
12400.....	0.28926	0.27096	0.25389	0.23796	0.22315
12600.....	0.29755	0.27890	0.26150	0.24526	0.23014
12800.....	0.30598	0.28697	0.26924	0.25268	0.23725
13000.....	0.31453	0.29516	0.27709	0.26022	0.24448
13200.....	0.32321	0.30348	0.28506	0.26786	0.25183
13400.....	0.33203	0.31193	0.29317	0.27564	0.25930
13600.....	0.34098	0.32051	0.30140	0.28354	0.26690
13800.....	0.35006	0.32922	0.30977	0.29157	0.27461
14000.....	0.35928	0.33806	0.31826	0.29973	0.28245
14200.....	0.36864	0.34704	0.32689	0.30802	0.29041
14400.....	0.37814	0.35615	0.33565	0.31644	0.29850
14600.....	0.38778	0.36541	0.34454	0.32499	0.30672
14800.....	0.39755	0.37480	0.35357	0.33367	0.31507
15000.....	0.40747	0.38433	0.36272	0.34248	0.32355
15200.....	0.41754	0.39400	0.37201	0.35142	0.33216
15400.....	0.42776	0.40382	0.38145	0.36051	0.34091
15600.....	0.43812	0.41378	0.39103	0.36973	0.34979
15800.....	0.44864	0.42389	0.40075	0.37909	0.35881
16000.....	0.45930	$.43415	0.41062	0.38859	0.36796

$Z = \frac{X}{C}$ **TABLE A—(Continued)** $A = \frac{\text{Sin } 2a}{C}$

Velocity	2500	2600	2700	2800	2900
Z	A	A	A	A	A
200.....	0.00105	0.00097	0.00090	0.00083	0.00078
400.....	0.00212	0.00197	0.00183	0.00170	0.00158
600.....	0.00324	0.00300	0.00278	0.00259	0.00241
800.....	0.00439	0.00406	0.00377	0.00350	0.00326
1000.....	0.00558	0.00516	0.00478	0.00444	0.00413
1200.....	0.00681	0.00629	0.00583	0.00541	0.00504
1400.....	0.00808	0.00747	0.00691	0.00642	0.00597
1600.....	0.00940	0.00869	0.00803	0.00747	0.00694
1800.....	0.01077	0.00994	0.00920	0.00854	0.00794
2000.....	0.01218	0.01124	0.01040	0.00965	0.00897
2200.....	0.01364	0.01259	0.01165	0.01080	0.01004
2400.....	0.01516	0.01399	0.01294	0.01199	0.01115
2600.....	0.01673	0.01543	0.01427	0.01322	0.01229
2800.....	0.01836	0.01693	0.01565	0.01450	0.01348
3000.....	0.02005	0.01848	0.01708	0.01582	0.01470
3200.....	0.02180	0.02009	0.01856	0.01719	0.01597
3400.....	0.02362	0.02176	0.02009	0.01861	0.01728
3600.....	0.02551	0.02349	0.02169	0.02008	0.01865
3800	0.02747	0.02529	0.02334	0.02161	0.02006
4000.....	0.02950	0.02715	0.02506	0.02319	0.02152
4200.....	0.03161	0.02908	0.02684	0.02483	0.02305
4400.....	0.03381	0.03110	0.02870	0.02654	0.02463
4600.....	0.03609	0.03319	0.03063	0.02832	0.02627
4800.....	0.03845	0.03537	0.03263	0.03016	0.02796
5000.....	0.04091	0.03762	0.03469	0.03206	0.02971
5200.....	0.04346	0.03995	0.Q3684	0.03404	0.03154
5400.....	0.04611	0.04239	0.03908	0.03611	0.03344

$Z = \frac{X}{C}$ **TABLE A—(Continued)** $A = \frac{\text{Sin } 2a}{C}$

Velocity	2500	2600	2700	2800	2900
Z	A	A	A	A	A
5600	0.04887	0.04492	0.04141	0.03826	0.03542
5800	0.05174	0.04756	0.04383	0.04049	0.03748
6000	0.05471	0.05029	0.04634	0.04280	0.03961
6200	0.05779	0.05312	0.04895	0.04520	0.04183
6400	0.06098	0.05606	0.05167	0.04770	0.04414
6600	0.06429	0.05912	0.05449	0.05030	0.04655
6800	0.06771	0.06228	0.05742	0.05301	0.04905
7000	0.07124	0.06556	0.06045	0.05582	0.05164
7200	0.07489	0.06894	0.06359	0.05873	0.05433
7400	0.07866	0.07244	0.06684	0.06176	0.05713
7600	0.08253	0.07606	0.07021	0.06489	0.06004
7800	0.08652	0.07979	0.07368	0.06812	0.06305
8000	0.09062	0.08363	0.07727	0.07146	0.06616
8200	0.09484	0.08758	0.08097	0.07491	0.06939
8400	0.09917	0.09165	0.08478	0.07847	0.07272
8600	0.10361	0.09583	0.08871	0.08214	0.07617
8800	0.10816	0.10012	0.09275	0.08593	0.07972
9000	0.11283	0.10453	0.09690	0.08982	0.08339
9200	0.11761	0.10904	0.10116	0.09382	0.08717
9400	0.12250	0.11367	0.10553	0.09796	0.09106
9600	0.12751	0.11841	0.11001	0.10220	0.09506
9800	0.13262	0.12325	0.11460	0.10656	0.09917
10000	0.13785	0.12821	0.11931	0.11104	0.10338
10200	0.14318	0.13328	0.12412	0.11560	0.10771
10400	0.14863	0.13847	0.12905	0.12028	0.11214
10600	0.15419	0.14376	0.13408	0.12506	0.11668
10800	0.15986	0.14917	0.13923	0.12996	0.12133

$Z = \frac{X}{C}$ **TABLE A—(Continued)** $A = \frac{\text{Sin } 2a}{C}$

Velocity	2500	2600	2700	2800	2900
Z	A	A	A	A	A
11000	0.16565	0.15468	0.14448	0.13497	0.12610
11200	0.17155	0.16031	0.14985	0.14009	0.13098
11400	0.17756	0.16604	0.15533	0.14532	0.13596
11600	0.18368	0.17189	0.16092	0.15066	0.14106
11800	0.18993	0.17786	0.16663	0.15611	0.14626
12000	0.19628	0.18394	0.17244	0.16167	0.15157
12200	0.20275	0.19014	0.17836	0.16733	0.15699
12400	0.20934	0.19645	0.18441	0.17312	0.16252
12600	0.21604	0.20288	0.19056	0.17901	0.16817
12800	0.22286	0.20942	0.19683	0.18502	0.17394
13000	0.22979	0.21607	0.20322	0.19115	0.17981
13200	0.23684	0.22285	0.20972	0.19739	0.18580
13400	0.24402	0.22974	0.21635	0.20375	0.19190
13600	0.25131	0.23675	0.22308	0.21022	0.19812
13800	0.25872	0.25387	0.22993	0.21681	0.20445
14000	0.26626	0.25111	0.23690	0.22351	0.21089
14200	0.27392	0.25847	0.24399	0.23033	0.21745
14400	0.28170	0.26596	0.25120	0.23727	0.22413
14600	0.28961	0.27357	0.25853	0.24433	0.23092
14800	0.29765	0.28130	0.26598	0.25150	0.23783
15000	0.30581	0.28916	0.27355	0.25880	0.24486
15200	0.31410	0.29715	0.28125	0.26622	0.25201
15400	0.32252	0.30527	0.28907	0.27376	0.25928
15600	0.33108	0.31352	0.29703	0.28143	0.26668
15800	0.33977	0.32191	0.30510	0.28922	0.27419
16000	0.34859	0.33042	0.31331	0.29714	0.28183

$Z = \frac{X}{C}$ **TABLE A—(Continued)** $A = \frac{\text{Sin } 2a}{C}$

Velocity	3000	3100	3200	3300	3400
Z	A	A	A	A	A
200.....	0.00072	0.00068	0.00063	0.00060	0.00056
400.....	0.00147	0.00138	0.00129	0.00122	0.00114
600.....	0.00224	0.00210	0.00197	0.00185	0.00174
800.....	0.00304	0.00285	0.00266	0.00250	0.00236
1000.....	0.00386	0.00361	0.00338	0.00318	0.00299
1200.....	0.00470	0.00440	0.00412	0.00387	0.00364
1400.....	0.00557	0.00521	0.00488	0.00458	0.00431
1600.....	0.00647	0.00606	0.00567	0.00532	0.00500
1800.....	0.00740	0.00693	0.00648	0.00608	0.00572
2000.....	0.00836	0.00782	0.00732	0.00687	0.00645
2200.....	0.00935	0.00785	0.00819	0.00768	0.00721
2400.....	0.01037	0.00970	0.00908	0.00851	0.00800
2600.....	0.01143	0.01069	0.01000	0.00938	0.00881
2800.....	0.01253	0.01171	0.01095	0.01027	0.00964
3000.....	0.01367	0.01277	0.01194	0.01119	0.01051
3200	0.01485	0.01387	0.01296	0.01214	0.01140
3400.....	0.01607	0.01501	0.01401	0.01313	0.01232
3600.....	0.01733	0.01618	0.01511	0.01414	0.01327
3800.....	0.01864	0.01740	0.01624	0.01520	0.01426
4000.....	0.01999	0.01865	0.01741	0.01629	0.01527
4200.....	0.02139	0.01995	0.01862	0.01743	0.01633
4400.....	0.02285	0.02130	0.01989	0.01860	0.01743
4600.....	0.02437	0.02270	0.02120	0.01981	0.01856
4800.....	0.02594	0.02416	0.02255	0.02107	0.01974
5000.....	0.02758	0.02567	0.02395	0.02238	0.02096
5200.....	0.02927	0.02724	0.02539	0.02374	0.02222
5400.....	0.03103	0.02888	0.02690	0.02515	0.02353

$Z = \frac{X}{C}$ **TABLE A—(Continued)** $A = \frac{\text{Sin } 2a}{C}$

Velocity	3000	3100	3200	3300	3400
Z	A	A	A	A	A
5600.....	0.03287	0.03058	0.02848	0.02661	0.02489
5800.....	0.03477	0.03234	0.03012	0.02812	0.02630
6000.....	0.03674	0.03416	0.03182	0.02969	0.02777
6200.....	0.03874	0.03606	0.03361	0.03133	0.02929
6400.....	0.04084	0.03804	0.03546	0.03304	0.03088
6600.....	0.04304	0.04010	0.03737	0.03480	0.03252
6800.....	0.04535	0.04223	0.03934	0.03664	0.03423
7000.....	0.04776	0.04445	0.04136	0.03856	0.03601
7200.....	0.05030	0.04675	0.04345	0.04054	0.03785
7400.....	0.05293	0.04916	0.04565	0.04261	0.03978
7600.....	0.05564	0.05166	0.04795	0.04475	0.04178
7800.....	0.05844	0.05425	0.05036	0.04699	0.04386
8000.....	0.06134	0.05695	0.05288	0.04932	0.04602
8200.....	0.06436	0.05975	0.05551	0.05174	0.04827
8400.....	0.06747	0.06265	0.05824	0.05425	0.05061
8600.....	0.07068	0.06566	0.06106	0.05687	0.05305
8800.....	0.07401	0.06877	0.06398	0.05959	0.05558
9000.....	0.07745	0.07199	0.06699	0.06240	0.05821
9200.....	0.08100	0.07532	0.07010	0.06532	0.06093
9400.....	0.08465	0.07875	0.07332	0.06834	0.06376
9600.....	0.08842	0.08230	0.07665	0.07147	0.06669
9800.....	0.09230	0.08595	0.08009	0.07471	0.06973
10000.....	0.09628	0.08971	0.08364	0.07804	0.07286
10200.....	0.10037	0.09358	0.08729	0.08149	0.07611
10400.....	0.10458	0.09756	0.09106	0.08505	0.07946
10600.....	0.10889	0.10165	0.09493	0.08870	0.08291
10800.....	0.11331	0.10585	0.09890	0.09246	0.08647

$Z = \frac{X}{C}$ **TABLE A—(Continued)** $A = \frac{\text{Sin } 2a}{C}$

Velocity	3000	3100	3200	3300	3400
Z	A	A	A	A	A
11000.....	0.11784	0.11015	0.10299	0.09633	0.09014
11200.....	0.12248	0.11456	0.10718	0.10030	0.09391
11400.....	0.12723	0.11908	0.11148	0.10438	0.09779
11600.....	0.13209	0.12371	0.11589	0.10858	0.10177
11800.....	0.13706	0.12845	0.12040	0.11289	0.10586
12000.....	0.14213	0.13329	0.12502	0.11731	0.11006
12200.....	0.14732	0.13824	0.12975	0.12183	0.11437
12400.....	0.15262	0.14330	0.13459	0.12644	0.11878
12600.....	0.15803	0.14847	0.13954	0.13115	0.12329
12800.....	0.16354	0.15376	0.14459	0.13598	0.12792
13000.....	0.16917	0.15916	0.14976	0.14093	0.13265
13200.....	0.17491	0.16467	0.15504	0.14598	0.13749
13400.....	0.18076	0.17030	0.16043	0.15115	0.14244
13600.....	0,18673	0.17603	0.16592	0.15643	0.14750
13800.....	0.19281	0.18187	0.17153	0.16182	0.15266
14000.....	0.19900	0.18782	0.17725	0.16731	0.15793
14200.....	0.20531	0.19388	0.18308	0.17292	0.16332
14400.....	0.21174	0.20006	0.18903	0.17865	0.16882
14600.....	0.21828	0.20635	0.19508	0.18448	0.17443
14800.....	0.22494	0.21276	0.20125	0.19043	0.18014
15000.....	0.23172	0.21928	0.20754	0.19650	0.18597
15200.....	0.23862	0.22592	0.21394	0.20268	0.19192
15400.....	0.24563	0.23268	0.22046	0.20897	0.19797
15600.....	0.25277	0.23956	0.22710	0.21536	0.20414
15800.....	0.26002	0.24657	0.23385	0.22187	0.21043
16000.....	0.26739	0.25369	0.24072	0.22850	0.21683

$Z = \frac{X}{C}$ **TABLE A—(Continued)** $A = \frac{\text{Sin } 2a}{C}$

Velocity	3500	3600
Z	A	A
200.....	0.00053	0.00050
400.....	0.00108	0.00102
600.....	0.00164	0.00155
800.....	0.00222	0.00210
1000.....	0.00282	0.00266
1200.....	0.00343	0.00324
1400.....	0.00406	0.00384
1600.....	0.00472	0.00445
1800.....	0.00539	0.00508
2000.....	0.00608	0.00573
2200.....	0.00679	0.00641
2400.....	0.00753	0.00710
2600.....	0.00829	0.00781
2800.....	0.00907	0.00855
3000.....	0.00988	0.00931
3200.....	0.01071	0.01009
3400.....	0.01158	0.01090
3600.....	0.01247	0.01174
3800.....	0.01340	0.01261
4000.....	0.01435	0.01351
4200.....	0.01534	0.01444
4400.....	0.01637	0.01530
4600.....	0.01742	0.01639
4800.....	0.01852	0.01742
5000.....	0.01966	0.01848
5200.....	0.02084	0.01958
5400.....	0.02207	0.02073

Velocity	3500	3600
Z	A	A
5600.....	0.02333	0.02192
5800.....	0.02465	0.02314
6000.....	0.03602	0.02442
6200.....	0.02744	0.02575
6400.....	0.02891	0.02712
6600.....	0.03044	0.02855
6800.....	0.03203	0.03003
7000.....	0.03369	0.03158
7200.....	0.03541	0.03318
7400.....	0.03720	0.03485
7600.....	0.03906	0.03658
7800.....	0.04100	0.03838
8000.....	0.04300	0.04026
8200.....	0.04510	0.04222
8400.....	0.04728	0.04424
8600.....	0.04955	0.04636
8800.....	0.05191	0.04856
9000.....	0.05436	0.05084
9200.....	0.05691	0.05322
9400.....	0.05956	0.05570
9600.....	0.06230	0.05827
9800.....	0.06514	0.06093
10000.....	0.06809	0.06370
10200.....	0.07114	0.06657
10400.....	0.07430	0.06954
10600.....	0.07756	0.07261
10800.....	0.08092	0.07578

TABLE A— (Concluded)

$Z = \frac{X}{C}$ $A = \frac{\text{Sin } 2a}{C}$

Velocity	3500	3600	Velocity	3500	3600
Z	A	A	Z	A	A
11000.....	0.08439	0.07905	14000.....	0.14911	0.14079
11200.....	0.08796	0.08244	14200.....	0.15428	0.14579
11400.....	0.09164	0.08593	14400.....	0.15957	0.15083
11600.....	0.09543	0.08952	14600.....	0.16496	0.15602
11800.....	0.09932	0.09322	14800.....	0.17046	0.16131
12000.....	0.10331	0.09701	15000.....	0.17607	0.16670
12200.....	0.10741	0.10091	15200.....	0.18180	0.17221
12400.....	0.11162	0.10492	15400.....	0.18763	0.17784
12600.....	0.11593	0.10903	15600.....	0.19358	0.18357
12800.....	0.12035	0.11325	15800.....	0.19964	0.18942
13000.....	0.12488	0.11758	16000.....	0.20581	0.19537
13200.....	0.12951	0.12201			
13400.....	0.13425	0.12655			
13600.....	0.13910	0.13119			
13800.....	0.14405	0.13594			

TABLE S.

Natural Sines.

′	0°	1°	2°	3°	4°
0	.00000	.01745	.03490	.05234	.06976
1	29	774	519	263	.07005
2	58	803	548	292	034
3	87	832	577	321	063
4	116	862	606	350	092
5	.00145	.01891	.03635	.05378	.07121
6	175	920	664	408	150
7	204	949	693	437	179
8	233	.01978	723	466	208
9	262	.02007	752	495	237
10	.00291	.02036	.03781	.05524	.07266
11	320	065	810	553	295
12	349	094	839	582	324
13	378	123	868	611	353
14	407	152	897	640	382
15	.00436	.02181	.03926	.05669	.07411
16	465	211	955	698	440
17	495	240	.03984	727	469
18	524	269	.04013	756	498
19	553	298	042	785	527
20	.00582	.02327	.04071	.05814	.07556

TABLE S—(Continued)

Natural Sines.

′	0°	1°	2°	3°	4°
21	611	356	100	844	585
22	640	385	129	873	614
23	669	414	159	902	643
24	698	443	188	931	672
25	.00727	.02472	.04217	.05960	.07701
26	756	501	246	989	730
27	785	530	275	.06018	759
28	814	560	304	047	788
29	844	589	333	076	817
30	.00873	.02618	.04362	.06105	.07846
31	902	647	391	134	875
32	931	676	420	163	904
33	960	705	449	192	933
34	989	734	478	221	962
35	.01018	.02763	.04507	.06250	.07991
36	047	792	536	279	.08020
37	076	821	565	308	049
38	105	850	594	337	078
39	134	879	623	366	107
40	.01164	.02908	.04653	.06395	.08136

TABLE S—(Concluded)

Natural Sines.

′	0°	1°	2°	3°	4°
41	193	938	682	424	165
42	222	967	711	453	194
43	251	996	740	482	223
44	280	.03025	769	511	252
45	.01309	.03054	.04798	.06540	.08281
46	338	083	827	569	310
47	367	112	856	598	339
48	396	141	885	627	368
49	425	170	914	656	397
50	.01454	.03199	.04943	.06685	.08426
51	483	228	972	714	455
52	513	257	.05001	743	484
53	542	286	030	773	513
54	571	316	059	802	542
55	.01600	.03345	.05088	.06831	.08571
56	629	374	117	860	600
57	658	403	146	889	629
58	687	432	175	918	658
59	716	461	205	947	687
60	.01745	.03490	.05234	.06976	.08716

BULLET DROP

It is of interest to know how much a bullet will drop below the line of departure at various ranges.

An object falls a distance of $\frac{1}{2}gt^2$ where g is the acceleration of gravity and t is the time of fall. Calling gravity 32.16 this gives the distance of fall in feet as $16.08t^2$ or in inches as $193\ t^2$.

In a vacuum trajectory we could simply use the time of flight for any range as t to calculate the drop for that range. However, in actual practice, the effect of the air resistance on the bullet is to cause it to drop less than the amount given by the vacuum trajectory calculation. The British Textbook of Small Arms 1929, p. 309, says that it is very much as if the value of g were to fall off from 32 at the muzzle to 28 at 500 yards and 24 at 1000 yards.

On page 310 of that book, a formula by Mr. F. W. Jones gives a method of obtaining an adjusted value of g which he calls f. According to his formula, $f=g\left\{1-\frac{b\ (V-v)}{V}\right.$, and he suggest that taking b as 3/7 gives suitable values of f for small arms down to $v=V/3$.

McShane, Kelly & Reno, in their book *Exterior Ballistics* (University of Denver Press, 1953) give a formula for bullet drop which makes it possible to construct a table for obtaining the bullet drop for any range when the initial velocity, the terminal velocity and the time of flight are known. Such a table is given here.

The procedure is first to find the ratio of the remaining velocity at the range in question to the muzzle velocity. Simply divide the remaining velocity by the muzzle velocity to get this quantity, which is shown in the left hand column of the table under the heading V/V_0.

Then find the time of flight for the range under consideration, using the appropriate ballistic table. In the table, under the column for the appropriate time of flight, and opposite the proper value of V/V_0 find the drop in inches.

As an example, let us find the drop for the 222 Remington bullet at 500 yards. Referring to the maker's ballistics for this cartridge, given on p. 505, it will be seen that the muzzle velocity is 3200 f.s. and the remaining velocity at 500 yards is 1150 f.s., from which V/V_0 is .36. From the ballistic tables we find the time of flight for this bullet to 500 yards is .812 sec.

Opposite .36 in the left hand column of the drop table we see that for a time of flight of .80 sec. the drop is 90 inches and for a time of flight of .89 sec. it is 112 inches. Interpolating, we find the drop for a time of flight of .812 sec. would be 93 inches, which agrees with the figure given by Remington in their published ballistics.

Instead of interpolating, as was just done, we can, if desired, simply square the time of flight and multiply by the figure in the column headed f, which is opposite the proper value of V/V_0.

The square of .812 is .659, and this multiplied by 142 gives 93.5.

		DROP, IN INCHES											
		Time of Flight, Seconds											
V/V$_o$	f	0.14	0.20	0.28	0.34	0.40	0.49	0.57	0.69	0.80	0.89	1.13	1.20
1.00	193	3.78	7.72	15.1	22.4	30.9	46.3	62.7	91.9	123	153	247	278
0.98	192	3.76	7.68	15.0	22.3	30.7	46.1	62.4	91.4	123	152	246	276
0.96	191	3.74	7.64	15.0	22.2	30.6	45.8	62.0	90.0	122	151	244	275
0.94	190	3.72	7.60	14.9	22.0	30.4	45.8	62.0	90.9	122	151	244	274
0.92	187	3.67	7.48	14.7	21.7	29.9	44.9	60.8	89.0	120	148	239	269
0.90	186	3.64	7.44	14.6	21.6	29.8	44.6	60.5	88.5	119	147	238	268
0.88	185	3.63	7.40	14.5	21.5	29.6	44.4	60.1	88.1	118	146	237	266
0.86	184	3.61	7.36	14.4	21.3	29.4	44.2	59.8	87.6	118	146	236	265
0.84	182	3.57	7.28	14.3	21.1	29.1	43.7	59.2	86.6	116	144	233	262
0.82	181	3.55	7.24	14.2	21.0	29.0	43.4	58.8	86.2	116	143	232	261
0.80	180	3.53	7.20	14.1	20.9	28.8	43.2	58.5	85.7	115	142	230	259
0.78	178	3.49	7.12	14.0	20.6	28.5	42.7	57.9	84.7	114	141	228	256
0.76	176	3.45	7.04	13.8	20.4	28.2	42.2	57.2	83.8	113	139	225	253
0.74	175	3.43	7.00	13.7	20.3	28.0	42.0	56.8	83.3	112	139	224	252
0.72	174	3.41	6.96	13.6	20.2	27.8	41.8	56.6	82.8	111	138	223	251
0.70	172	3.37	6.88	13.5	20.0	27.5	41.0	55.9	81.8	110	136	220	248
0.68	170	3.33	6.80	13.3	19.7	27.2	40.8	55.3	80.9	109	135	218	245
0.66	169	3.31	6.76	13.2	19.6	27.0	40.6	54.9	80.4	108	134	216	243
0.64	167	3.27	6.68	13.1	19.4	26.7	40.1	54.3	79.4	107	132	214	240
0.62	166	3.25	6.64	13.0	19.3	26.6	39.8	54.0	79.0	106	131	212	239
0.60	164	3.21	6.56	12.8	19.0	26.2	39.4	53.3	78.0	105	130	210	236

0.58	162	3.18	6.48	12.7	18.8	25.9	38.9	52.7	77.1	104	128	207	233
0.56	161	3.16	6.44	12.6	18.7	25.8	38.6	52.3	76.6	103	128	206	232
0.54	160	3.14	6.40	12.5	18.6	25.6	38.4	52.0	76.1	102	127	205	230
0.52	157	3.08	6.28	12.3	18.2	25.1	37.7	51.0	74.7	101	125	201	226
0.50	156	3.06	6.24	12.2	18.1	25.0	37.4	50.7	74.3	100	124	200	225
0.48	154	3.02	6.16	12.1	17.9	24.6	37.0	50.1	73.3	98	122	197	222
0.46	152	2.98	6.08	11.9	17.6	24.3	36.5	49.4	72.4	97	120	195	219
0.44	150	2.94	6.00	11.8	17.4	24.0	36.0	48.4	71.4	96	119	192	216
0.42	148	2.90	5.92	11.6	17.1	23.7	35.5	48.1	70.4	95	117	189	213
0.40	145	2.84	5.80	11.4	16.8	23.2	34.8	47.1	69.0	93	115	186	209
0.38	144	2.82	5.76	11.3	16.7	23.0	34.6	46.8	68.5	92	114	184	207
0.36	142	2.78	5.68	11.1	16.5	22.7	34.1	46.2	67.6	90	112	182	204
0.34	139	2.72	5.56	10.9	16.1	22.2	33.4	45.2	66.2	89	110	178	200
0.32	137	2.69	5.48	10.7	15.9	21.8	32.6	44.2	64.7	87	108	174	197

Instructions for use of

TIME AND SPACE FUNCTIONS FROM BRITISH 1909 BALLISTIC TABLES

The British Ballistic Tables of 1909 are almost identical with Ingalls' tables, but they go up to velocities of 4200 f.s. whereas Ingalls' tables stop at 3600; therefore these are convenient for use with any cartridges that may give velocities above the highest included in Ingalls.

Functions up to and including 4000 f.s. are taken directly from the official British tables; values from 4000 f.s. to 4200 f.s. have been computed by the author.

Formulae for use with these tables are similar to those for use with Ingalls with the exception that, unlike the Ingalls tables, these start at 100 f.s. and go up instead of starting at 3600 f.s. and going down; therefore in these tables we find that functions of v are smaller than those of V, and instead of subtracting functions of V from those of v as in Ingalls' tables, we subtract functions of v from those of V. Thus the formulae already given for use with Ingalls Tables are changed as follows:

Formula 1 become $C = \dfrac{X}{S(V) - S(v)}$

Formula 2 is unchanged.

Formula 3 becomes $S(v) = S(V) - \dfrac{X}{C}$

Formula 4 becomes S(v) for 200 yd=S(V)−twice $\{ S(V)-S(v) \}$

Formula 5 becomes $T-C \{ T(V)-T(v) \}$

Formulae 6, 7, and 8 remain unchanged.

Time and Space functions extracted from
BRITISH 1909 BALLISTIC TABLES

Velocity f.s.	Space Function S	Difference For 1 f.s.	Time Function T	Difference for 1 f.s.
100	3,571.5	80.17	0.186	.7321
120	5,175.0	72.51	14,828	.5594
140	6,625.0	66.52	26.017	.4445
160	7,955.4	61.70	34.908	.3635
180	9,189.4	57.71	42.179	.3042
200	10,343.6	54.34	48.263	.2591
220	11,430.4	51.45	53.445	.2239
240	12,459.4	48.94	57.932	.1959
260	13,438.2	46.72	61.842	.1730
280	14,372.7	44.76	65.305	.1544
300	15,268.0	43.01	68.394	.1388
320	16,128.2	41.42	71.171	.1256
340	16,956.7	39.98	73.683	.1143
360	17,756.4	38.67	75.969	.1040
380	18,529.9	37.47	78.060	.0961
400	19,279.3	36.36	79.982	.0887

Velocity f.s.	Space Function S	Difference For 1 f.s.	Time Function T	Difference for 1 f.s.
420	20,006.6	35.34	81.757	.0822
440	20,713.4	34.39	83.401	.0764
460	21,401.2	33.50	84.930	.0713
480	22,071.2	32.67	86.356	.0666
500	22,724.7	31.90	87.689	.0626
520	23,362.7	31.17	88.941	.0588
540	23,986.1	30.48	90.117	.0554
560	24,595.8	29.84	91.226	.0520
580	25,192.6	29.23	92.273	.0495
600	25,777.2	28.65	93.264	.0470
620	26,350.2	28.10	94.204	.0446
640	26,912.2	27.58	95.096	.0424
660	27,463.8	27.08	95.944	.0404
680	28,005.4	26.60	96.753	.0385
700	28,537.5	26.15	97.524	.0370
720	29,060.6	25.72	98.261	.0351
740	29,575.1	25.31	98.966	.0337
760	30,081.3	24.91	99.641	.0324
780	30,579.5	24.53	100.288	.0310
800	31,070.2	24.16	100.909	.0298
820	31,553.5	23.81	101.506	.0287
840	32,029.8	23.09	102.080	.0271
860	32,491.7	22.05	102.623	.0253
880	32,932.6	21.06	103.130	.0237
900	33,353.9	20.15	103.604	.0221
920	33,756.9	19.29	104.047	.0207
940	34,142.7	18.48	104.461	.0195
960	34,512.4	17.73	104.851	.0182
980	34,867.1	17.02	105.216	.0172
1000	35,207.6	16.36	105.560	.0162
1020	35,534.8	15.72	105.884	.0153
1040	35,849.3	14.64	106.190	.0139
1060	36,142.2	13.22	106.469	.0123
1080	36,406.6	11.95	106.716	.0109
1100	36,645.6	10.82	106.935	.0097
1120	36,862.0	9.815	107.130	.0087
1140	37,058.3	8.920	107.304	.0077
1160	37,236.7	8.125	107.459	.0069
1180	37,399.2	7.455	107.598	.0062
1200	37,548.3	7.160	107.723	.0059
1220	37,691.5	6.930	107.842	.0056
1240	37,830.1	6.705	107.954	.0054
1260	37,964.2	6.500	108.062	.0051
1280	38,094.2	6.300	108.164	.0049
1300	38,220.2	6.100	108.262	.0046
1320	38,342.2	5.935	108.355	.0044
1340	38,460.9	5.750	108.444	.0042
1360	38,575.9	5.585	108.529	.0041
1380	38,687.6	5.425	108.611	.0039
1400	38,796.1	5.270	108.689	.0037
1420	38,901.5	5.130	108.764	.0035
1440	39,004.1	4.985	108.835	.0034
1460	39,103.8	4.890	108.904	.0033
1480	39,201.6	4.835	108.971	.0032
1500	39,298.3	4.790	109.036	.0031
1520	39,394.1	4.735	109.099	.0031
1540	39,488.8	4.685	109.161	.0030
1560	39,582.5	4.640	109.221	.0029
1580	39,675.3	4.595	109.280	.0029
1600	39,767.2	4.545	109.338	.0028
1620	39,858.1	4.505	109.395	.0027
1640	39,948.2	4.460	109.450	.0027
1660	40,037.4	4.415	109.504	.0026
1680	40,125.7	4.375	109.557	.0026
1700	40,213.2	4.330	109.609	.0025
1720	40,299.8	4.295	109.660	.0025
1740	40,385.7	4.255	109.709	.0024
1760	40,470.8	4.215	109.758	.0024
1780	40,555.1	4.175	109.805	.0023
1800	40,638.6	4.140	109.852	.0023
1820	40,721.4	4.105	109.898	.0022
1840	40,803.5	4.070	109.942	.0022
1860	40,884.9	4.035	109.987	.0021
1880	40,965.6	3.995	110.030	.0021
1900	41,045.5	3.970	110.072	.0021
1920	41,124.9	3.930	110.113	.0020
1940	41,203.5	3.905	110.154	.0020

Velocity f.s.	Space Function S	Difference For 1 f.s.	Time Function T	Difference for 1 f.s.
1960	41,281.6	3.870	110.194	.0020
1980	41,359.0	3.835	110.234	.0019
2000	41,435.7	3.815	110.272	.0019
2020	41,512.0	3.795	110.310	.0019
2040	41,587.9	3.775	110.347	.0018
2060	41,663.4	3.755	110.384	.0018
2080	41,738.5	3.740	110.421	.0018
2100	41,813.3	3.720	110.456	.0017
2120	41,887.7	3.705	110.492	.0017
2140	41,961.8	3.690	110.526	.0017
2160	42,035.6	3.670	110.561	.0017
2180	42,109.0	3.650	110.595	.0016
2200	42,182.0	3.640	110.628	.0016
2220	42,254.8	3.620	110.661	.0016
2240	42,327.2	3.600	110.693	.0016
2260	42,399.2	3.590	110.725	.0016
2280	42,471.0	3.575	110.757	.0015
2300	42,542.5	3.555	110.788	.0015
2320	42,613.6	3.540	110.819	.0015
2340	42,684.4	3.530	110.849	.0015
2360	42,755.0	3.510	110.879	.0015
2380	42,825.2	3.495	110.909	.0014
2400	42,895.1	3.485	110.938	.0014
2420	42,964.8	3.465	110.967	.0014
2440	43,034.1	3.455	110.996	.0014
2460	43,103.2	3.440	111.024	.0014
2480	43,172.0	3.425	111.052	.0014
2500	43,240.5	3.415	111.079	.0014
2520	43,308.8	3.400	111.106	.0013
2540	43,376.8	3.385	111.133	.0013
2560	43,444.5	3.370	111.160	.0013
2580	43,511.9	3.360	111.186	.0013
2600	43,579.1	3.345	111.212	.0013
2620	43,646.0	3.325	111.238	.0012
2640	43,712.5	3.310	111.263	.0012
2660	43,778.7	3.295	111.288	.0012
2680	43,844.6	3.275	111.313	.0012
2700	43,910.1	3.265	111.337	.0012
2720	43,975.4	3.245	111.361	.0012
2740	44,040.3	3.225	111.385	.0011
2760	44,104.8	3.215	111.408	.0011
2780	44,169.1	3.200	111.432	.0011
2800	44,233.1	3.180	111.454	.0011
2820	44,296.7	3.170	111.477	.0011
2840	44,360.1	3.150	111.500	.0011
2860	44,423.1	3.140	111.522	.0011
2880	44,485.9	3.125	111.544	.0010
2900	44,548.4	3.105	111.565	.0010
2920	44,610.5	3.095	111.586	.0010
2940	44,672.4	3.080	111.608	.0010
2960	44,734.0	3.070	111.629	.0010
2980	44,795.4	3.050	111.649	.0010
3000	44,856.4	3.040	111.670	.0010
3020	44,917.2	3.025	111.690	.0010
3040	44,977.7	3.015	111.710	.0010
3060	45,038.0	2.995	111.730	.0095
3080	45,097.9	2.990	111.749	.0095
3100	45,157.7	2.975	111.768	.0095
3120	45,217.2	2.960	111.787	.0095
3140	45,276.4	2.950	111.806	.0095
3160	45,335.4	2.935	111.825	.0095
3180	45,394.1	2.925	111.844	.0090
3200	45,452.6	2.910	111.862	.0090
3220	45,510.8	2.900	111.880	.0090
3240	45,568.8	2.885	111.898	.0090
3260	45,625.5	2.875	111.916	.0090
3280	45,684.0	2.865	111.933	.0085
3300	45,741.3	2.850	111.951	.0085
3320	45,798.3	2.840	111.968	.0085
3340	45,855.1	2.830	111.985	.0085
3360	45,911.7	2.810	112.002	.0085
3380	45,968.1	2.905	112.019	.0085
3400	46,024.2	2.795	112.035	.0080
3420	46,080.1	2.785	112.052	.0080
3440	46,135.8	2.775	112.068	.0080
3460	46,191.3	2.765	112.084	.0080
3480	46,246.6	2.750	112.100	.0080
3500	46,301.6	2.745	112.116	.0080
3520	46,356.5	2.730	112.132	.0075
3540	46,411.1	2.720	112.147	.0075

Velocity f.s.	Space Function S	Difference For 1 f.s.	Time Function T	Difference for 1 f.s.
3560	46,465.5	2.710	112.162	.0075
3580	46,519.7	2.705	112.177	.0075
3600	46,573.8	2.690	112.192	.0075
3620	46,627.6	2.680	112.207	.0075
3640	46,681.2	2.670	112.222	.0075
3660	46,734.6	2.660	112.237	.0070
3680	46,787.8	2.655	112.251	.0070
3700	46,840.9	2.640	112.266	.0070
3720	46,893.7	2.635	112.280	.0070
3740	46,946.4	2.620	112.294	.0070
3760	46,998.8	2.615	112.308	.0070
3780	47,051.1	2.605	112.322	.0070
3800	47,103.2	2.595	112.336	.0070
3820	47,155.1	2.585	112.349	.0070
3840	47,206.8	2.580	112.363	.0065
3860	47,258.4	2.570	112.376	.0065
3880	47,309.8	2.550	112.389	.0065
3900	47,360.9	2.550	112.402	.0065
3920	47,412.0	2.540	112.416	.0065
3940	47,462.8	2.535	112.428	.0065
3960	47,513.5	2.525	112.441	.0065
3980	47,564.0	2.515	112.454	.0065
4000	47,614.3	2.505	112.467	.0065
4020	47,664.4	2.495	112.480	.0065
4040	47,714.3	2.485	112.493	.0060
4060	47,764.0	2.475	112.506	.0060
4080	47,813.5	2.465	112.519	.0060
4100	47,862.8	2.455	112.531	.0060
4120	47,911.9	2.445	112.543	.0060
4140	47,960.8	2.435	112.555	.0060
4160	48,009.5	2.425	112.567	.0060
4180	48,058.0	2.415	112.579	.0060
4200	48,106.3		112.591	

Index, Part II

A.

Aberdeen Proving Ground, 556, 557
Air, Density of, 567
Air Resistance, formula, 551, 554, 569
American Rifleman, magazine, 506, 507
Ammunition Experiments, 535, 541
Ammunition Fires, 532, 533
Arctic Tests, 501
Artillery Circular M, 542, 563

B.

Ballistic Coefficient, 542, 552, 562, 566
Ballistic Missile, 546
Ballistic Tables, comparison, 575-76
Ballistic Tables, meaning of, 560
Berdan Primer, 492
Blasting Cap, 575
Borden Brook, Mass., 512
Brisance, 520
Briscoe Case, 526
British Textbook of Small Arms, 1909, 566, 619
British Textbook of Small Arms, 1929, 549, 557
Bugless, Edgar, 563
Bullet Drop, 619
Bullet, ignition of powder by, 528, 529
Burlington, Vt., 529
Burns, James E., 492
Burrard, Sir Gerald, DSO, 557

C.

Cap, blasting, 575
Cartridge, Caliber 222 Remington, 504-505-509
Cartridge, Caliber 243 Winchester, 505-507-509
Cartridge, Caliber 244 Remington, 506-507-509
Cartridge, Caliber 280 Remington, 508-509
Cartridge, Caliber 280 British, 495
Cartridge, Caliber 308 Winchester, 505-509
Cartridge, Caliber 358 Winchester, 505-507
Cartridge, Caliber 458 Winchester, 507-508-509
Cartridge, Caliber 44 Rem. Magnum, 509-510
Cartridge Dimensions, table of, 509
Cartridge NATO Cal. 7.62mm, 494-497, 499, 501
Cartridge T-65, 495-496, 499
Chrome Plating, 504
Churchill, Sir Winston, 498
Coefficient of Form, 562-567
Coefficient of reduction, 562, 567
Colloid, 527
Combat Course Test, 501
Cottesloe, Lord, 556
Coxe, Wallace H., 563
Curtis Bay powder fire, 528

D.

Daytona Beach, Fla., 512-514, 516, 518
Dederick, Dr. L. S., 568
Density of Air, 567
Detonation, 520
Dimensional Analysis, 568-569
Dix, Camp, 527
Dornberger, Gen. Walter, 516
Drag Coefficient, 568, 570, 571
Drift, 548
Drop of Bullet, 619
Drop, Table for calculating, 620
Dunn, Col. W. B., 523-525
DuPont, E. I. de Nemours Co., 563
Dynamite Cap, 575

E.

Escape Velocity, 518-519, 546

F.

Fabrique Nationale, 498-499
Falling Bodies, velocity of, 515
FN, 498-499
Flash Hider, 502
Form Factor, 562-563, 566-567
Fort Benning, Ga., 498-501
Frankford Arsenal, 493, 494, 523
Freemantle, T. F. (Lord Cottesloe), 556
Fulminate of Mercury, 492-494, 525

G.

Garand Rifle, 496, 499, 502
Gasoline, hazards of storing, 532
Gavre Commission, 551-555, 559, 570
Gavre Function, 570, 573
Gavre Function, graph of, 555
Gavre Projectile, 571-572
Greenhill Formula, 549
Greenhill, Sir Alfred G., 549

H.

Halifax Explosion, 521
Hardcastle, Maj., 513
Harrington & Richardson, 500
Harrison, Col. E. H., 493-494, 577

Herstal, Belgium, 418
Hicks, J. W., 513
High Explosive, 520
Hodsock Firings, 557, 559
Horney, Brig. Gen. Odus C., 573

I.

Ingalls, Col. James M., 542, 552
Ingalls Ballistic Table I, 583-609
Ingalls Table I extended, 611
Ingalls' Table II-A, 612-617
Initiators, 525
Instructions for using Tables, 577-578

J.

J-function, 556-559, 573-574
J projectile, 572
Jones, Mr. F. W., 557-558, 619

K.

Keith, Elmer, 510
Kelley, John L., 619
Kleanbore Priming, 492-493
Krupp Resistance Firings, 552-559

L.

Lake Denmark Explosion, 521-523
Lead Azide, 525
Lead Styphnate, 492-494

M.

Mach Number, 572
Machine Gun, Browning, 500, 504
Machine Gun, Heavy, 500
Machine Gun, M 60, 491, 503-504
Mann Barrel, 514
Mann, Dr. F. W., 511
Mayevski, Col., 552, 558, 561
Mayevski, Retardation formula, 552
McShane, Edw. J., 619
McShane, Kelley & Reno, Book, 619
McNellis, W. E., 532
Mellish, Col. Henry, 556
Meppen, resistance firings, 552
Mercury Fulminate, 492-494, 525
Miami, Fla., 512-518
Missile, Ballistic, 546
Mont Blanc, ship, explosion, 521
Muzzle Brake, 497

N.

Nansemond Ordnance Depot, 527
NATO, 496
Nato Cartridge, 494, 505
Newton, Sir Isaac, 551, 568
Nitroglycerine, 520
Non-corrosive Primers, 491-494

O.

Olin Mathieson Chemical Corp., 505
Orbiting bullet, 545
Orbiting Velocity, 546

P.

Page, Warren, 506
Patent, Rathberg, 492
Patent, Von Herz, 492
Pensacola, Fla., 516
Peterson, C. G., 510
Picatinny Arsenal, 522
Powder, Black, 526-527, 531
Powder, Bullseye, 530
Powder fires, 520, 526, 530
Powder, Red Dot, 531
Powder, Smokeless, 527
Powder, No. 2400, 531
Powder, No. 3031, 531
Powder, No. 4064, 531
Powder, No. 4676, 531
Powley, Homer S., 577
Pressure on projectile nose, 561-562
Primers, 526
Primer, F. A. No. 70, 493
Primer, Kleanbore, 492-493
Primer, Non-corrosive, 491-494
Primer, Red Phosphorus, 494
Pye, Rear Admiral W. S., 526

R.

Ramsay, Brig. Gen. N. F., 522
Rathburg, primer patent, 492
Red Phosphorus Primer, 494
Remington Arms Co., 492-493, 510
Reno, Franklin V., 619
Resistance Functions, British, 553-554, 559
Retardation of bullet, 550-554, 558-562
Rifle, BAR, 500
Rifle, M1, 496
Rifle, EM2, 498
Rifle, M14 & M15, 491, 502
Rifle, T20, 497
Rifle, T25, 497
Rifle, T44, 499-500, 502
Rifle, T47, 498-499
Rifle, T48, 499-502
Rifling, 548, 549
Rifling, Twist required, 549-550
Robins, Benj., 512

S.

Spt. Arms & Amm. Mfgrs Inst. (SAAMI), 532
Sectional Density, 567
Sines, Table of, 617
Smith, J. Bushnell, 529-530
Smith & Wesson, 510
Specific Gravity, finding, 550
Springfield Armory, 499-501
Stellite, 504
Sudan, Tests in, 502

T.

Tetracene, 492, 493, 525
Tetryl, 520
Tippins, Mr. R. L., 513
Trajectory, 543, 544
Trajectory .22 cal l.r., 544
Trajectory, .45 cal., 544
Tri-Nitro-Toluol (TNT), 520

V.

V-2 Rocket, 516
Vacuum, max. range in, 550
Vacuum Trajectory, 544-547
Velocity, Escape, 546
Von Herz, Primer Patent, 492

W.

Weapons System, new, 495, 497, 500
Wilhelm, Col. G. P., 512
Winchester Repeating Arms Co., 505