DEPARTMENT OF ARTILLERY,—UNITED STATES ARTILLERY SCHOOL.

ESSAY.

DEVELOPMENT OF POWER

IN THE

MODERN MILITARY RIFLE.

BY

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Development of Power in the Modern Military Rifle.

PART I.

HISTORICAL SKETCH.

In 1842, a large part of the Prussian Infantry was armed with the Needle Gun, which may properly be termed the original of the modern military rifle. Its existence was, of course, known to the military world but failed to disturb the equanimity of those using the old muzzle-loading system. The new rifle was criticised because it permitted the escape of gas at the breech; and it allowed the soldier to waste his ammunition,—the latter, especially, being looked upon as a fatal defect. For more than twenty years, the soundness of these criticisms was scarcely questioned and individual enterprise was mainly directed towards an improvement in the bullet, whereby certainty and sufficiency of rotation could be given it, and excessive fouling of the bore prevented.

The *carabine a' tige*, having a solid spindle at the bottom of the bore which was forced by blows from the rammer into a cavity in the base of the bullet thus expanding it into the grooves, and the Minié bullet, in which an iron cup took the place of the spindle and was driven by the gas into the cavity, are the best illustrations of the lines of improvement adopted between the years 1850 and 1861. There were exceptions, of course, and among the more enlightened inventors was M. Chassepot, who was then at work on the rifle which several years later raised an unfortunate enthusiasm in the French Army. The Crimean War convinced many military men that the rifle, as it then existed, was a failure. In one instance, a British officer brought away from the battle-field a gun in which he afterwards found the remains of eight different bullets, the iron cups having been successively blown through them, leaving the leaden cylinders in the bore. Still no change in the right direction was made. It was thought that the only disideratum was a bullet that could be easily loaded and made certain to take the grooves. About this time reduction of calibre began to be discussed with the sole view of decreasing the weight the soldier had to carry. Its effect upon the ballistic properties of the arm was not then, nor is it now, fully appreciated. The following table gives the principal data in regard to the smallest calibred rifles used by the great powers in 1859. It is taken from a work, by M. Mangeot, a French officer, published in Paris, in 1860. The table has been reduced to English weights and measures. The column headed $\frac{d^2}{w}$, has been computed and added, and an inspection of it, in connection with the subsequent discussion of this ratio and the corresponding column in the table appertaining to modern rifles, will be interesting. It will be noted that France was at this time using a rifle of .35″ calibre, but the small charge of thirty grains and the large value of 5 for the factor $\frac{d^2}{w}$, shows that the change had not been made upon a scientific basis. If the designer of the Russian arm had started out to select for it the worst combination of elements, he could scarcely have succeeded better.

TABLE.

Country.	Rifle.	Cal.	Weight of bullet in grains.	$\frac{d^2}{w}$	Weight, ch. grs.	Length of bullet in calibres.	Twist in inches.
England.	Model 1853.	.577	519.14	4.492	68	1.47	78
Austria.	Sharpshooters' rifle.	.547	450	4.656	62	1.84	62
Spain.	Model 1852.	.598	448	5.602	69	1.73	63
United States.	Sharpshooters' rifle.	.535	501	4.001	76	1.97	62
France.	....	.354	176	4.995	31	.....	29.5
Prussia.	Sharpshooters' rifle.	.576	489	4.760	51	1.80	37
Prussia.	Needle Gun.	.61	451	5.780	66	1.63	45
Russia.	Cossack rifle.	.55	176	12.04	31	1.39	45
Sweden.	Navy rifle.	.57	401	5.685	77	1.55	78
Switzerland.	Federal rifle.	.413	257	4.652	62	2.44	35

By the American Civil War the military students of the world were given a complete course in the art and science of war, and the department of Small-Arm development was unsurpassed. There was little system or uniformity of armament; companies, regiments and corps receiving the best attainable, thus giving all promising systems and inventions the opportunity to undergo the test of service. Changes were rapidly made; and, starting with the old .58″ calibre, muzzle-loading Springfield, a few years witnessed the introduction of the breech-loading magazine-rifles of Spencer, Henry, and Ball-Lamson.

It was now admitted, in this country at least, that rapidity of fire was highly advantageous, and that it was perfectly practicable to obtain an effective obturation in breech-loading small-arms. This latter was effected by the use of metallic cartridge-cases, an innovation which, like its predecessors, met with a storm of ignorant opposition. A good illustration of this is furnished by the experience of Colonel Hope of the British Army, who, while military attaché at Washington just before the outbreak of our Civil War, was so favorably impressed with a rifle then newly invented by a Mr. Morse, of Louisiana, that he made a special and minute report recommending it to his government. He was directed to purchase one, with 1000 rounds of ammunition, and send it to England for experiment. Being at home a few years afterwards, he found, upon inquiry, that a committee had condemned the rifle and its ammunition for the reasons: 1st, It fired too quickly, 12 rounds per minute; 2d, The cartridges were metallic, and 3d, they contained the principle of their own ignition. The lessons from our own and the Dano-Prussian War of 1864, penetrated the British mind at about the same time, and resulted in the immediate appointment of a commission and the publication far and wide of a call upon inventors for a new breech-loading rifle. This celebrated advertisement, demanded that the successful weapon should fulfil the three following *sine qua non* conditions; 1st, It must not fire less than 12 rounds per minute; 2d, The cartridges must be metallic, and 3d, they must contain the principle of their own ignition. The result of this call was the adoption of the Snider system of conversion for the muzzle-loading Enfields then in service.

On the Continent, the old prejudice held on still longer. Many eminent military students appreciated the fact that the Prussian success of 1864 was due more to their soldiers than to their rifles. The faults of the arm were very apparent. It used a paper cartridge-case which could not stand exposure; the escape of gas was great, and the relation between the charge, calibre and bullet was such that its ballistic properties were very poor, much inferior, in fact, to many of the muzzle-loading systems. The fixing of the point of ignition at the front instead of at the rear of the charge, however, was a feature which is now regarded favorably. To reach the fulminate, a long needle had to penetrate the entire length of the charge, and was naturally very liable to rust, corrode and break.

In 1866, the second Prussian success with their breech-loader turned the scale in the minds of the few remaining sceptics, and, as soon as it could possibly be done, all important military powers were armed with the breech-loader. Economy, and not the science of ballistics, was the ruling consideration in making these changes. France took the lead, as she generally does in such matters, and, at the beginning of the war of 1870-71, her Chassepot rifle was far ahead of any system in general use. How unfortunate this was for her, the sequel proved. Her enthusiasm over it and her mitrailleuse, led her into the war; and, in forecasting the results, she failed to appreciate the fact that the fighting machine is represented by the product of two factors, the gun and the soldier. While her Chassepot was superior to the Needle Gun, the Frenchman was, in discipline and perseverance, inferior to the Prussian. For thirty years, the Prussian Government had been pursuing a system opposed to prevailing opinions and her soldiers had been armed with a weapon which had been the subject of ridicule. Her military authorities were phlegmatic, but earnest and studious, and, when thoroughly convinced of the advisability of a step, they took it and persevered in it, dispite adverse criticism. It was necessary to move cautiously in the matter of change of armament, but, in so far as the training of the soldier was concerned, there could be no doubt; and, to their thoroughness in this direction, was due the superiority of the German fighting machine of 1870-71. Notwithstanding the failure of the French in that war, the advantage of a superior infantry armament was manifested. When, in the attack upon the village of St. Privat, the 2d and 4th Grenadiers, and the 1st and 3d Foot Guards of the German Army, lost each one-third of its strength, in the short space of 30 to 45 minutes, and, principally, from Infantry fire delivered at from 800 to 2000 paces, the military world opened its eyes in wonder; and, as a result, the inventor in his closet, and the workman at his anvil, bent their respective energies to the solution of the great problem of small-arm development.

Up to this time, there had been little attempt to apply the science of ballistics; but the gradual appreciation of the results of Professor Bashforth's experiments (begun in 1865) led to the conviction that the next step was to obtain a proper relation between the three quantities, charge, calibre and bullet, and make the other attributes of the arm conform to the requirements of this relation. This was an important step. Without any great outlay of money, the bugbear that had kept most governments from giving proper attention to the subject of small-arm development, many were enabled to greatly increase the efficiency of their weapons by simply changing the cartridge. This was notably so with the Werndl arm in Austria, which, by the adoption of a new cartridge about 1877, passed from one of the lowest to the highest position in the order of merit of military rifles. The result of this scientific investigation was, naturally, first felt in England, and it took the shape of the Martini-Henry rifle, which made its appearance about 1869, was issued to English troops in 1871, and was, for a long time, granted the first place among military small-arms. This gun was made up of a combination of the Henry barrel with the Martini breech action, and this latter was, in principle, almost a complete copy of the Peabody breech mechanism invented in the United States. Starting with a given barrel, d was constant; so that the only variables in the ballistic combination were the charge and the bullet, and the values adopted for these were very judicious ones. The slight superiority over this arm of the Springfield having the same calibre, is due to superiority of cartridge manufacture and the 20 grains excess in weight of bullet. The question of further decrease of calibre was, of course, considered, but it was objected to on several grounds. It was thought that a large bullet was necessary for killing purposes and, especially, for use against cavalry. It is now thought better to wound than to kill, and for reasons both humane and politic. A wounded man requires two uninjured ones to take him to the rear, and, as some one has facetiously remarked, there are always half a dozen such ready for the duty. For use against cavalry, it is suggested that the lightness of the bullets will be more than compensated for by their greater number and greater penetration. It was also thought that a smaller bullet meant greater fouling of the bore. After the war of 1870-71, the Germans discarded their old Needle Gun for the Mauser, model '71, and the French abandoned their boasted Chassepot for the Gras, model '74. No attempt was made to change the calibre from .433″ the main feature of the change being the substitution of a metallic cartridge for the paper one used with the discarded arms.

Several better rifles of smaller calibre were adopted by the minor powers, and up to a very recent date, Sweden, with her Jarmann, had an Infantry armanent superior for general purposes to that of any of the great powers. Switzerland's small army has been supplied with the Vetterli repeating-rifle since 1869.

For the last 8 or 10 years, the subject of small-arm development has attracted considerable attention, and the great centre of interest has been the reduction of calibre. Professor Hebler has brought out in Germany a gun of .296″ calibre, and claims to attain a volocity of 1968 f. s. in a 225 grain bullet. Italy is now experimenting with two new arms, the Freddi recoil rifle of .315″ and the Pieri of .323″ calibres respectively,—the latter claiming to attain a velocity of 2057 f. s., in a 284 grain bullet. The distinguishing feature of the Freddi invention, is the attempt to reduce recoil and utilize the force of discharge, by allowing the barrel a motion of translation at the time of discharge, a strong spiral spring being attached to resist this motion and bring it back to its proper position. The breech bolt goes back with it, but, by means of a stop, is prevented from returning, and thus the empty shell is extracted. The new cartridge is then inserted into the receiver, and, by pressing a button, the breech bolt is closed by a spring, forcing the cartridge into the chamber, and cocking the firing-pin. A quick loading device, consisting of a leather case attached to the side of the gun, enables the soldier to fire as rapidly as 24 shots per minute. It is claimed that the spiral spring lessens the velocity, and hence the severity, of recoil, to such an extent that the weight of the gun may be reduced from 10 to 7 pounds.

The Germans have converted their Mauser into a magazine gun, with a tubular magazine under the barrel; but the ballistic properties of the arm are so far behind the modern standard that a total change of armament is now under consideration. Austria has adopted an entirely new arm, the Manlicher repeater, which, unlike the others, cannot be used as a single loader. England decided some time ago to adopt the Enfield-Martini, which was nothing more than the Martini-Henry, with its calibre and weight of bullet reduced to .402″, and 386 grains, respectively; and, with a great deal of self congratulation, ordered all expedition to be made in manufacturing a sufficient number of them to supply her entire army. After 100,000 had been completed, she became stampeded by the success of continental rifles of greatly reduced calibre, and, according to latest reports, has again changed front, ordering the sale of these arms and the construction of a new model of .30″ calibre, which is to be a magazine gun with a bolt breech mechanism.

France has again taken the lead and claims to have discovered a new motive force, which she calls a *smokeless* powder, and with which her lately adopted Lebell rifle gives to a steel bullet of *386 grains a velocity of 2,034 f. s., which

* The French Government has made extraordinary attempts to keep secret the details of this arm.

While preparing this paper I wrote to Major Lottiz, of the French Legation at Washington, and asked him to give me any information that it was not the policy of his government to conceal. He very kindly responded and the following is an extract from his letter:

"The calibre is 8 millimeters, *i. e.*, 3 millimeters less than the calibre of the old rifle. The length of the bullet is increased *in order that the weight may be the same* . . . The bullet possesses a greater power of penetration because it is made of low steel." [The italics are mine.]

With this as a foundation, I made the calculations and deductions which are noted further on. Some of them are so surprising that we naturally feel inclined to question our data or else admit that the "smokeless" powder has indeed revolutionized small-arm trajectories. Even supposing Major Lottiz to have been misinformed, it is still interesting to note the results that should follow in case we ever are able to fire advantageously a bullet 9 calibres in length. In an article published in the issue of Engineering of November 11th, 1887, Captain James states, that the Lebell cartridge is about 28 per cent. lighter than that of the Gras. If the same be true of the bullet, its trajectory is inferior to that of the Pieri.

corresponds to an energy of 3,543 foot pounds, greater by 1,664 foot pounds than the initial energy of the Springfield bullet. Her sharpshooters are to be armed with the Chalons rifle, a still more powerful weapon, whose ballistic data I have been unable to obtain. If these reports be true, it looks as if history were going to repeat itself, and that as soon as the French troops are thoroughly equipped with these arms, we may look for a renewal of the conditions preceding the struggle of 1870-71.

Among inventions just appearing above the horizon of public notice, may be mentioned the Maxim and Paulson recoil rifles, in both of which the distinguishing feature is the utilization of the force of recoil. In the latest model of the former, the breech block is allowed a rearward motion under the action of the gases, compressing as it moves a strong spiral spring and extracting the shell. A system of levers works a revolving drum situated under the receiver to supply the new cartridge, which is pressed into place in the chamber by the breech block as it returns under the action of the spring. By continuing the pressure upon the trigger after the first discharge, the piece will load and fire automatically and becomes, virtually, a Maxim machine gun to the extent of its magazine, which contains seven cartridges. When it is desired to fire single shots, pressure upon the trigger must be released after each discharge.

In the Paulson system, the gases are allowed to enter a small hole in the barrel and, by their pressure, give motion to a long rod which is attached to the breech block and has a spiral spring attached to it. The force of discharge opens the breech mechanism, by means of the rod, and extracts the shell. After the cartridge has been inserted by hand, the spiral spring, operating through the rod, closes the mechanism. The arm may be converted into a repeater by using detachable magazines, placed on the side of the gun, and for their operation the recoil force is also used. One of the most interesting features of the rifle's development is the growth in efficiency of the breech mechanism; but limited space and the absence of drawings, which are absolutely necessary to a clear description of such complicated machines, has necessitated my passing over these details. It may be safely stated, however, that the fight between the block and bolt has long since been definitely settled. The following are some of the advantages of the bolt system:—1st. Simplicity and reduction in number of parts. 2d. The blow of the mainspring is delivered in the direction of the axis and consequently does not derange the aim. 3d. Better and more certain extraction of the shell. 4th. A stronger and better fermature, causing less stress upon the cartridge shells. 5th. The necessary motions in loading are easier and more natural than those required in the block system. 6th. With it, a greater rapidity of fire may be attained in single loaders. 7th. It is adapted to magazine fire.

England has finally been compelled to abandon the block, and the United States will soon have, among great powers, the sole credit (?) of remaining faithful to this now antiquated system.

PART II.

THEORETICAL CONSIDERATIONS.

In what follows, an attempt is made to give an approximate idea of the principles which influence the power of the modern rifle. For many of the deductions, the accuracy of a mathematical treatise is not claimed. They are based upon facts collected from experiments made at various times by our Ordnance Department, and upon generally accepted principles in regard to the explosive force of gunpowder. In all calculations of trajectories, the formulas and tables of "Exterior Ballistics" (Ingalls,) were used,—a standard density of atmosphere and a value of unity for the coefficient of reduction being assumed. To obtain exact values for the remaining velocities, the tabulated values should be multiplied by the ratio of the cosines of the angles of departure and fall; but since the object was to show the *comparative* powers of the different arms, it was not thought necessary to multiply the labor by introducing this refinement.

I. Charge.—The rifle is a machine for the production of work, the motive power being the expansive force resulting from the combustion of the charge, and the useful effect, or work performed, being measured by the muzzle energy of the projectile.

The theoretical amount of work obtainable from a given charge, (that is, one where all the elements, weight, rate of combustion, density of loading, etc., are stated) in a given gun, depends upon the number of volumes of expansion, or the relation between the space actually occupied by the powder and the cubic contents of the bore. This is always in excess of the useful work performed, because in theory, the conversion into gas is supposed instantaneous, so that each elementary portion of the expansive force would act over the entire path, varying its intensity according to the law of increasing volume; and, in practice, the conversion is gradual, a great portion of the powder not being burned at all until after the bullet has left the bore, and a large part of the power produced being absorbed in performing work other than giving energy to the bullet. The pressure, at any instant, depends upon the relation of the space occupied by the gases at that time to the space originally occupied by the powder burned up to that time. When dry gunpowder is burned in its own space, (*i. e.*, when the mean density of the products of explosion is equal to unity) the pressure is about 43 English tons to the square inch; and when this density is .66, or about what it would be in the combustion under similar circumstances of an uncompressed charge of service rifle powder, the pressure is about 19.58 tons, or 43,859 pounds, per square inch. This would be the pressure if the bullet were kept in place, without escape of gas, until the complete combustion of the charge.

The actual pressure in the present service rifle is shown by experiment to vary considerably, but the mean value of the maximum seems to be about 25,000 pounds. With the .50″ calibre Springfield and 450 grain bullet it was about 14,500 pounds. An account of trials of compressed charges in the .50″ calibre was published by our Ordnance Department in 1870. The best results were obtained when the air space was reduced to 1.45 per cent. of the volume of the charge, as compared to 34 per cent. in the uncompressed charge. By a central cylindrical perforation, and an unavoidable difference between the cubical contents of the compressed cylinder and the capacity of the shell, the air space was raised to 1.567 per cent. If this charge had burned without motion of the bullet, and without escape of gas, the theoretical maximum pressure would have been 65,340 as compared to the actual maximum of 15,833 pounds. The velocity was increased from 1,235 to 1,280 f. s. The pressure increases with an increase in density of loading, but the inertia and initial resistance of the bullet are overcome long before complete combustion. The path is constant, and, therefore, the work, or energy of projectile, must increase with the mean pressure, which, with a given charge and gun, can only increase with the maximum pressure. This latter increases, as we have seen, with any cause that increases the mean density of the gases. These causes are, increase of density of loading, and increase of initial resistance of bullet. The latter may be brought about by augmenting the bullet's inertia through an increase of weight, by crimping the shell tightly around it, and by increasing its resistance to taking the grooves. With the present charge and calibre, the muzzle energies of 200, 500 and 700 grain bullets are to each other as 1051, 1555, 1782, respectively. The weight of the bullet being limited by other considerations, initial resistance must be sought in other ways. A mean of 25 experimental shots, showed that, by crimping, the maximum pressure was increased about 2300 pounds, and the initial velocity about 30 f. s. The fact that the present service pressure has increased from 14,500, in the .50″ calibre, to 25,000 pounds in the present rifle, shows that some change must have been made. The force necessary to overcome inertia has been increased, both by the bullet's increase in weight, and by its decrease in diameter. (The latter change requires a greater pressure, per unit of area, to bring the entire pressure upon the base of the bullet up to the necessary value.) The shell is crimped more tightly than formerly and the density of loading is greater than it was in the old service charge. The advisability of increasing the resistance to taking the grooves is questionable, because, by continuing to act along the whole path, it would be liable to absorb not only the extra force produced, but probably more. It is done as a necessary evil in order to give proper rotation. Any useful device employed to detain the bullet, must cease to act as soon as the requisite pressure has been developed.

Thus we see, that the increase of power in the Springfield has been obtained at the expense of a greatly increased maximum pressure. The Hebler rifle fires a compressed charge with a much larger central perforation than that used by our Ordnance Department, and it is claimed for it that it yields results far superior to those obtained by us; and that it does this upon the principle of long sustained, rather than increased maximum, pressure. The charge is compressed from both ends into a steel shell, into the base end of which a copper cup is afterwards inserted, containing the fulminate and acting as a gas check. The Pieri experimental rifle is more powerful than the Hebler, but the details of its cartridge and the maximum pressure are not known.

What is the effect of increasing the charge, other things remaining constant?

Since the density of loading is the same, and the bullet begins to move under the same force that started it in the first case, the greatest density of the gases and, consequently, the maximum pressure should not be greatly increased. The rate of combustion corresponding to given positions of the bullet in motion in the bore would be greater on account of increased temperature, and the surface of combustion would be largely increased by the greater number of grains. As a result, the pressure should be better *sustained* and the energy increased. The unburnt portions of the grains, however, have the effect of adding their weight to that of the bullet, and, to that extent, absorbing part of the increased motive force. After passing a certain point, this absorption exceeds the production of useful energy, and further increase of charge causes decrease of energy in the bullet. With the service rifle and 405 grain bullet, the energies corresponding to 70, 90, 120 and 140 grain charges, are to each other as 1,565; 1,886; 2,111; 2,005 foot pounds, respectively, showing that beyond 120 grains there is no useful effect to be obtained from increase of charge.

The difficulties in the way of obtaining from gunpowder a regular and evenly sustained pressure, have led to many attempts to substitute another motive force. One of the latest developments is the previously mentioned "smokeless" powder invented in France, and whose composition has been kept a secret. It is said that in addition to the absence of smoke, there is also very little sound, it being difficult to hear the report boyond 70 or 80 yards.

When our Ordnance Department experimented to find out the effect of increasing the length of barrel of the Springfield, it was found that with the 112 inch barrel, corresponding to the maximum energy for the given charge and bullet, there was scarcely any smoke and a very little noise accompanying the explosion, while with the short barrel of 5 inches in length, there was a perfect cloud of smoke and a deafening noise. These phenomena are natural results of the complete combustion of the charge in the bore. It would not be a matter of surprise to see gunpowder in the near future entirely superseded as a motive force in guns.

II. Bullet.—We have briefly considered the means of storing up in the bullet the maximum amount of energy, and the next thing should be to provide one that will keep this energy for the greatest length of time under the action of atmospheric resistance, and, with any given energy, produce the greatest effect, *i. e.*, have the greatest penetration.

Its ability to do the former varies inversely as the factor $\frac{d^2}{w}$, as shown by the expression for its retardation,—$\frac{dv}{dt} = A \frac{d^2}{w} f(v)$ (Exterior Ballistics, Ingalls,) in which A is constant for a given value of v, and d, w, and v are the diameter, weight and velocity of the bullet, respectively. Thus we see, that no matter what the calibre of the gun may be, w should be as large as possible. Its increase in a given gun, however, is limited by the difficulty in giving sufficient rotation to the bullet, which increases rapidly with its length in calibers; and also by the objection to using too much of a limited motive force for this purpose. Most of the modern rifles have, up to the introduction of the very latest patterns, fired bullets of about 2½ calibres in length. The Springfield 500 grain bullet is 2.8 calibres in length, and for a long time this seemed to be considered as about the limit. It is perfectly practicable, however, to increase this limit. As far back as 1856, Whitworth fired, at Manchester, projectiles of 2, 3, 4, 5, 6, and 7 calibres in length, and succeeded, after varying the twist, in keeping them all coincident with the trajectory. The Hebler rifle fires a bullet of 4.46 calibres, and the Lebell is said to fire one of about 9 calibres in length. It requires a largely increased mean pressure to give proper rotation to such projectiles, and, at the same time, give them the initial energy claimed for them. The manufacturers of the above arms claim to obtain this increase by using, one a cartridge of gunpowder whose rate of combustion is much better arranged than in our service cartridge, and the other a new powder altogether.

For the purposes to which they are usually applied, it is assumed that the penetrative powers of two bullets of equal energy will vary directly with the amount of energy per unit of greatest circumference. This requires d to have its minimum limit, and thus we see that both conditions seem to require the reduction of the factor $\frac{d^2}{w}$.

Lead has always been used as the material of bullets because of its density and cheapness, and on account of the ease with which it can be made to take the grooves. The great objection to it is its low tenacity, which permits leading and fouling of the bore. The least obstruction, due to specks of rust or other causes, will retain small portions of the passing bullet which are added to by each discharge until, finally, the grooves are, in some cases, almost filled. This causes deformation of the bullet, imperfect rotation, and unequal distribution of stress,—which in turn produces vibrations in the barrel,—and all these results affect, to a greater or less extent, the accuracy of the arm, while all of them increase rapidly in magnitude with an increase of the twist. The consequence has been a necessary change in the material of the modern bullet. In the Hebler gun, it is covered with a sheet of soft steel, and in the Lebell, it is said to be composed entirely of low steel.

Professor Hebler uses steel in preference to copper because of the former's cheapness and the latter's tendency to form verdigris. His first objection would not apply with equal force in the United States, and his second is not thought to be of much practical importance.

III. Recoil.—It has long been a generally accepted opinion that the further development of power in the rifle must be attended by increased recoil and that the latter was already equal to the average soldier's endurance. Practical soldiers are aware of the fact that it is generally the recruit who suffers most from recoil, and that after a little education and practice in firing his piece, all trouble of this nature disappears. It is also known that sporting arms, generally, have a far greater recoil than military rifles. By using the sling in the firing positions so popular in our army to-day, many times the recoil of the service Springfield could be sustained without inconvenience. Thus it is by no means certain that the soldier would look with disfavor upon an increased recoil, provided he saw it accompanied by a proportional augmentation in power and accuracy.

But increase of power is *not necessarily* attended by increased recoil. Of two bullets, one may start with less and yet reach a given range with a greater energy.

Many conflicting opinions are held on the subject of recoil. The cardinal principle of action and reaction is a sufficient foundation for any argument, and this tells us that the resultant pressure upon the base of the bore must be equal to that upon the base of the projectile. The force necessary to overcome friction and the resistance to taking the grooves, finds a reacting agent in the longitudinal strength of the barrel. The resistance due to the inertia of the bullet and the column of air in front of it, must be equal to the inertia developed in the gun, where it is free to move. The work performed in overcoming recoil must be equal to that required to give energy to the bullet and the column of air in front of it. In firing blank cartridges, there is quite a perceptible recoil, but in this case the gases expand much more rapidly and, consequently, the energy of the particles of air is much greater than when bullets are used. In the latter case, no greater error is committed by disregarding the energy of the particles of air.

The principle requiring the quantity of motion generated in the gun and in the bullet to be the same is useful as a means of measuring recoil, only when the motion of the gun is opposed by its inertia alone. When opposed also by some extraneous force we should have to know the latter's equivalent in mass in order to determine the velocity of recoil of the system, and hence of the gun. The more useful principle is that of equality of work, and this tells us that the shorter the path, the greater must be the intensity of the resisting force and *vice versa.* In the case of the rifle fired from the shoulder, the greater the intensity of the resisting force, the nearer do the conditions approximate to those governing the reception of a blow. If there were no limit to the path, the best plan would be to hold the gun as loosely as possible to the shoulder; but since it is limited, the best plan is to press it against the shoulder with a force which, when multiplied into the path, will produce the work of recoil. When the rifle is held very loosely, it passes over the greater portion of the path with small resistance, and, consequently, small production of work, necessitating a high resistance in order to perform the greater part of the work over the small remaining portion of the path. On the other hand, when the gun is pressed very tightly against the shoulder, the condition of great reduction in entire length of path is imposed, and again a high resistance is necessary. Thus we see that in both extremes, the soldier receives a blow instead of a pressure, and it is easy to understand how his trouble over the subject of recoil originates. He probably first tries holding the gun very loosely, and finds that it hurts him. He then goes to the other extreme with the same result, and considerable practice is necessary before he finally determines the exact amount of pressure to put upon the butt in order to best receive the recoil. The introduction of a spring into the moving system would naturally have the effect of distributing the resistance over the entire path and it is for this reason that the severity of recoil is reduced by the Freddi invention. The spring has also the effect of lengthening the path and thereby greatly increasing our capacity for recoil work. The entire stock might easily be made of one immense spring formed into proper shape.

IV. Calibre.—After the powder, the factor exercising by far the greatest influence over the power of the rifle, and the one attracting the greatest amount of attention at present, is that of its calibre. The prevailing popular opinion seems to be that the reduction of this factor is the only thing necessary to obtain a more efficient weapon. Let us consider some of the evident difficulties that must be encountered in this reduction.

1*st*. *Loss of power.*—We cannot increase the length of our gun on account of its limited weight, and, consequently, our new barrel must have a capacity bearing to that of the former the inverse ratio of the squares of the two calibres. The number of volumes of expansion allowed the gaseous products is correspondingly reduced, and, therefore, the work performed is less. This is made still more plain from another standpoint. To produce the same effect we must have the same cause, or the mean pressure upon the bases of the two bullets (supposed of equal weights and different diameters) must be the same. To fulfil this condition, the pressure per unit of area upon the base of the smaller bullet must be greater than the corresponding pressure upon the base of the larger one, and in the direct ratio of the squares of their diameters. A still further increase of power would be necessary in order to perform the greater work of giving sufficient rotation to the smaller and longer bullet.

2*d*. *Fouling and leading of the bore.*—These would increase with the reduction of calibre unless prevented by some change in the material of the bullet.

3*d*. *Vibrations.*—Supposing the necessary increase of power attained, vibrations in the barrel would be greater on account of the largely increased pressures. To assume that these vibrations exist, and that they vary with the pressure directly, is the only reasonable way of accounting for certain observed anomalies.

Commander Folger, United States Navy, by boring out the chamber of a .50″ calibre Remington to fit a longer shell, obtained in a 450 grain bullet a velocity of over 2,000 f. s., and yet, for accuracy at 500 yards, this gun was far inferior to what it was under the old service conditions. Unfortunately, his report does not show that he tried the effect of securing the barrel in such manner as to prevent or at least decrease the vibrations.

These are grave difficulties, and to counterbalance them, the advantages must indeed be great.

It is claimed that the new guns give flatter trajectories and longer ranges, and an inspection of the appended tables and diagrams will show that these claims are well founded. We look to the ballistic data for an explanation of this, and—taking the Hebler rifle for instance—we see that the departures from the old model, as represented by the Springfield, consist in the introduction of a bullet 4.4 calibres in length, instead of 2.8 calibres as in the Springfield, and the rapid twist of about one turn in four inches, which is made necessary by the long bullet. By this change, a value of 2.726 is obtained for the factor $\frac{d^2}{w}$ as compared to 2.835 in the Springfield. We also note the high initial velocity of 1968 f. s. If the calibre of the Springfield were reduced to .296″, that of the Hebler, and our service cartridge used, the realized energy would be about 812.52 foot pounds, which is given by the proportion,

$$\text{Service energy} : \text{new energy} :: .45^2 : .296^2.$$

This would correspond in the Hebler 225 grain bullet to a velocity of 1276 f. s., and shows that Professor Hebler does more than decrease the retardation—*his motive force is 2.38 times that of the Springfield.* This is not due to the reduction of calibre but to an improvement in his cartridge, either in its composition or its arrangement. The only difference in arrangement is that it is compressed and perforated. Our Ordnance Department experimented with compressed and perforated charges without attaining anything like the above increase of power. Since Professor Hebler does not claim to use any special powder, we can only conclude that our Ordnance Department did not carry its experiments as far as it might have done. The trajectory of the Pieri rifle, with which experiments are now being conducted in Italy, is superior to that of the Hebler, but the latter has been selected for comparison because our knowledge in regard to its details is more complete.

From all the information that I have been able to gather, the actions of various nations on the subject of reduction of calibre have not been governed by any general principle or plan. All seemed satisfied until the advent of the Hebler gun showed them that a much flatter trajectory could be obtained. There was no one to dispute the fact, often stated but not necessarily true, that a reduction of d caused a reduction of the factor $\frac{d^2}{w}$. (For, as is subsequently shown, when the condition is imposed that the bullet shall be a certain number of calibres in length, a reduction of *d* causes an *increase* of the retardation). There has been a general rush towards the least obtainable calibre, and France, Italy, and Portugal, have either adopted, or are about to adopt, calibres varying but little from .31″. England, at first satisfied with .402″, has, as before stated, determined to follow the flock and adopt .31″, trusting to obtain from this change all the advantages claimed by the Hebler and Lebell rifles.

At first glance, one is impressed with the idea that the exact effects of reduction of calibre should be susceptible of theoretical deduction, and that, if this be so, it is unwise to rush into the field of experiment like a blind man groping in the dark. If the Hebler and Lebell guns get their results principally by improving the motive force, is it logical to contrast them with the older type of guns which have not the benefit of this improvement, and then ascribe the inferior trajectories of the older arms to their larger calibres? Most assuredly not, and yet this is what is universally done. If we suppose the motive force to be increased in our Springfield in the same ratio that obtains in the Hebler rifle, we should have a muzzle energy of 4473.4 foot pounds instead of 1877.9, and an initial velocity of 2007.9 f. s., instead of 1301; and if we were then to change the bullet from one 2.8 to one 4.4 calibres in length, to correspond to the Hebler, our initial velocity would fall below its value of 2007.9 f. s., but our value for $\frac{d^2}{w}$ would be 1.804 as compared to the Hebler value of 2.726.

Another striking fact is, that if we assume 4.5 calibres as the length of bullet, we find the value of $\frac{d^2}{w}$ for a calibre of .35″ to be 2.268, and for a calibre of .30″, 2.648. This shows that for a bullet of a given number of calibres in length, a *decrease* of calibre causes an *increase* in retardation. Let us investigate this subject a little more in detail.

Assuming the bullet to be cylindrical in shape, the following equation holds for the Springfield service bullet which is 1.26 inches in length and weighs 500 grains.

(1). $$\frac{1.26 \times \pi \times .45^2 \times \text{weight 1 cu. in. lead}}{4} = 500.$$

And for any other bullet of the same material and shape, we should have, representing its length in inches by l, its diameter in inches by d, and its weight in grains by w,

(2). $$\frac{l \times d^2 \times \text{weight 1 cu. in.}}{4} = w.$$

Dividing (2) by (1), solving with respect to $\frac{d^2}{w}$ and multiplying both members by 7,000, in order to express the weight in pounds, we have,

(3). $$\frac{d^2}{w} = \frac{1.26 \times .45^2 \times 7{,}000}{500\, l} = \frac{(0.5529235)}{l}$$

Substituting for l, xd, x being the length in calibres, equation (3) becomes,

(4). $$\frac{d^2}{w} = \frac{(0.5529235)}{xd}$$

which shows that, for any value of d, the retardation decreases with an increase of the length of the bullet in calibres. The limit to the increase of x, is found, as before stated, in the difficulty in giving rotation, and must be determined for any given motive force by experiment. From the discussion under the head of bullet, it will be recalled that, according to the standard of the latest and most advanced experience, 4.5 is about the maximum value that may be given to it when gunpowder is used. Making this substitution and reducing, equation (4) becomes,

(5). $$\frac{d^2}{w} = \frac{(\bar{1}.8997110)}{d}$$

Regarding $\frac{d^2}{w}$ and d as the two variables, we recognize this as the equation of an equi-lateral hyperbola. The three curves in the diagram (fig. 1), correspond to values of x, of 9, 4.5, and 2.8, respectively. All the principles previously deduced are here shown graphically. The ordinates are the values of $\frac{d^2}{w}$ and the abscissas of d, and, from the rapid increase of the former in the ascending branch for small decrements in the latter, *it will be seen that each reduction of calibre will be at the expense of a great sacrifice of power.*

The dotted lines parallel to the axis of $\frac{d^2}{w}$, are drawn to show the relative sacrifice of power produced under the different suppositions, by a reduction of calibre from .45″ to .30″. It will be noticed that the longer the bullet in calibres, the smaller this sacrifice becomes.

When our motive force enables us to increase the length of our bullet, the obvious effect is to lower the retardation for equal calibres.

Since all these disadvantages must be the results of a reduction of calibre, why is it ever advisable to reduce it? The reasons are plain. Suppose our service cartridge equal to the Hebler and that after trial we find the means at our disposal insufficient to enable us to do the work of recoil. The muzzle energy would have to be reduced, and while the old way would have been to reduce the charge, the new way is to reduce the calibre. This produces the necessary decrease with the minimum sacrifice of flatness of trajectory, and with the maximum increase of penetrating powers. We should not resort to this expedient until exhaustive attempts have been made to increase our capacity for recoil work. After the limit of muzzle energy is fixed, there are several variables to be determined, the principal one being the weight of bullet. The number of rounds of ammunition that the soldier is to carry, considered in connection with magazine guns, the relative value placed upon long and short range fire, and the limit to the increase of our motive force, are the three main points for consideration in fixing the weight of bullet. By substituting the selected value for w in equation (5), we obtain the best corresponding calibre. The recoil limit of energy fixes the limit of initial velocity, and this, in turn, fixes the charge. All of these conditions are so intimately blended, that, without some particular one being absolutely fixed, it would be difficult to get a starting point. This entering wedge is generally furnished by our limited motive force and upon this as a foundation, aided by extensive, accurate, and well designed experiments, the whole knotty problem should be slowly but surely untangled.

Let us consider the conditions of our present military arm, the Springfield rifle. Its bullet being only 2.8 calibres in length, its retardation, when compared with what it would be with a bullet 4.5 calibres in length, bears to it the relation of 2.835 : 1.804. A bullet of 4.5 calibres in length and .45″ in diameter would weigh about 800 grains, which is evidently above the limit. Substituting $\frac{1}{14}$ ℔. (500 grains) for w in equation (5), we find the corresponding value of d to be about .384″, and the retardation factor decreases from 2.835 to 2.066. The most disadvantageous case possible, would be to suppose a loss of energy in the ratio $.45^2 : .384^2$, and this would give to our new bullet an initial energy of about 1368 foot pounds, and a velocity of about 1110 f. s. From the experiments of our Ordnance Department, we have every reason to believe that the increased length in calibres would, by the increased initial resistance, augment the proportional resultant energy. With the same charge of powder, the energy obtained in the 500 grain bullet 2.8 calibres in length, bore to that obtained from one of 750 grains, 4.2 calibres in length, the ratio of 1 : 1.14. If the same thing held good in our .384″ calibre we should have instead of the above values, an energy of 1,559.5 foot pounds, and an initial velocity of 1,185 f. s.

Taking the first and most disadvantageous case, and comparing the trajectories, we see; (1) for elevation to give 1000 yards range, the service bullet would have a slight advantage of 12′, 15″; (2) in angle of fall for same range, the proposed one would have an advantage of 12′ 32″; (3) for maximum ordinate, same range, the proposed bullet would have an advantage of .1 foot; (4) *at* 1000 *yards range the proposed bullet would have a penetration* 1.3 *times that of the service one;* (5) *with equal elevations of* 15°, *the proposed one would have a range greater by* 212 *yards and at* 2650 *yards a penetration* 1.66 *times that of the service bullet at* 2429 *yards.* If we were to allow our .384″ bullet the supposed increase of muzzle energy, its disadvantages at the very short ranges would be almost obliterated, and its advantages would be proportionally increased. The Hebler motive force would give it a velocity of at least 1713 f. s., and comparing its trajectory under this supposition with the Hebler, we see; (1) for 1000 yards range, the elevations would be, Hebler 1° 39′ 32″, Springfield 1° 45′ 00″; (2) for angles of fall, same range, Hebler 2° 50′ 51″, Springfield 2° 40′ 57″; (3) for maximum ordinates, same range, Hebler, 29.66′ and Springfield, 29.29′; (4) *for* 15° *elevation the ranges would be, Hebler* 292.66 *yards, Springfield* 3,253.6 *yards, and their penetrations at these ranges would be as* 1 : 2.38, *in favor of the Springfield.* The same motive force in the .45″ calibre Springfield, would give an energy of 4473 foot pounds, and this would probably be too large a value for the work of recoil, even if the weight of the .45″ calibre bullet (4.5 calibres in length) were not too great. The muzzle energy of the .384″ calibre bullet (3257) is less than that claimed for the Lebell rifle, and as the initial velocity would also be less, the recoil would be less. Can there be any doubt about the urgent necessity for improvement in our Infantry armament?

V. Strength of Barrel.—In the experiments made by our Ordnance Department, each increase of muzzle energy has been accompanied by a comparatively larger increase in maximum pressure; and although this is avoided by the Hebler where the maximum is about 16,000 as compared to our 25,000 pounds, yet, in view of the possible necessity for increasing our maximum, it becomes important to know what pressure a rifle barrel may be safely subjected to. It is impossible to give more than an approximate answer. Steel cylinders lately manufactured at the Midvale works for the 3.2″ rifles, showed an elastic limit as high as 54,000, with a corresponding tensile strength of 88,700 pounds per square inch. These values would decrease with percentage of carbon but I do not think it is going too far, to state that a barrel may be made capable of standing a service pressure of 40,000 pounds, and, if necessary, there is no reason why it should not be wire wound to produce an initial compressive stress. The Ordnance Memoranda give very carefully the weights of the proof charge and bullet, but leave us to imagine the maximum pressure. Two hundred and eighty grains of uncompressed powder, with only the service weight of bullet, and with no rifling to increase the initial resistance, would, it is believed, be no more of a test for strength than would the service charge where compression and crimping had been employed. It is stated as the result of experiment, that the barrel of the service Springfield has been filled with lead so tightly secured that the service charge, when exploded in the chamber, was unable to move the mass of metal in front of it; and yet no rupture of any kind was produced. If this be true, the barrel must be able to stand at least 43,000 pounds in its present condition.

It is interesting also to note, in view of the possible necessity for shortening the barrel in order to strengthen it, that, according to experiments made with the Springfield, with service charge of 70 grains of powder and 405 grain bullet, the initial velocity increased with the length of barrel until the latter reached as high a value as 112 inches or about 250 calibres; but for 26 inches or about 58 calibres, the velocity was over 88 per cent. of its maximum, and over 95 per cent. of the service velocity. With a powder of better regulated rate of combustion this percentage would be, perhaps, not quite so favorable; but in this case the maximum pressure would not be so high, and the necessity for shortening the barrel would disappear.

GENERAL REMARKS.

Theoretical perfection will never be attained, but we should not give up until we have accomplished, at least, as much as has already been done by others. We must not lose sight of the fact that the principal *cause* of the success of foreign arms and the *excuse* for their reduction of calibre, is the increase in motive force that has been obtained by better regulating the rate of combustion of their charges.

Our first attempt should therefore be made to improve our cartridge. The next should be to determine the maximum length in calibres that we can give to our bullet with the improved charge, and after that the maximum amount of work of recoil that we can perform. The theoretical charge is one in which the highest allowable pressure is developed before the bullet begins to move and is sustained from that time on by so regulating the rate of combustion that the increase in volume of gas is directly proportional to the increase of space behind the bullet. In our service the opposite conditions hold. The barrel can stand at least 30,000 and the average maximum is not above 25,000 pounds, and the most rapid evolution of gas is at the *beginning* instead of at the *end* of the bullet's motion in the bore.

The above will, it is hoped, show how fallacious is the opinion held by many that small-arm development has reached its maximum, and that the Springfield rifle is at the head of the list. In point of fact it is rapidly approaching the foot, and this too, without disturbing the confidence or stimulating to any great extent, the energy of those who should be much interested in the subject. To a European nation, maintaining a large army, complete change of Infantry armament would be almost synonymous with bankruptcy; but the United States, on account of her small army, is, of all other great nations in the world, best able to reap the immediate benefits of a satisfactory solution of this great problem. Theorizing can, at most, do no more than direct experiment into the proper channel, and there should be no delay in putting a capable board to work, and furnishing it with all necessary facilities for conducting experiments.

B. W. DUNN,
2d Lieutenant 3d Artillery.

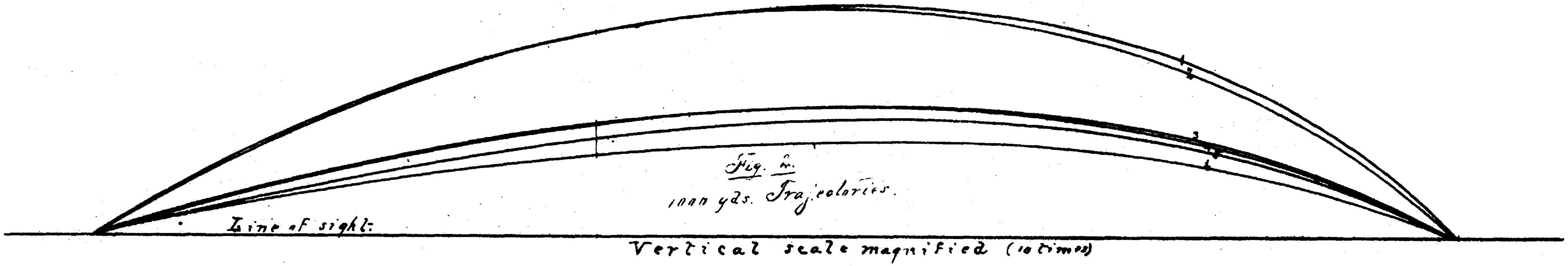

Fig. 2.
1000 yds. Trajectories.

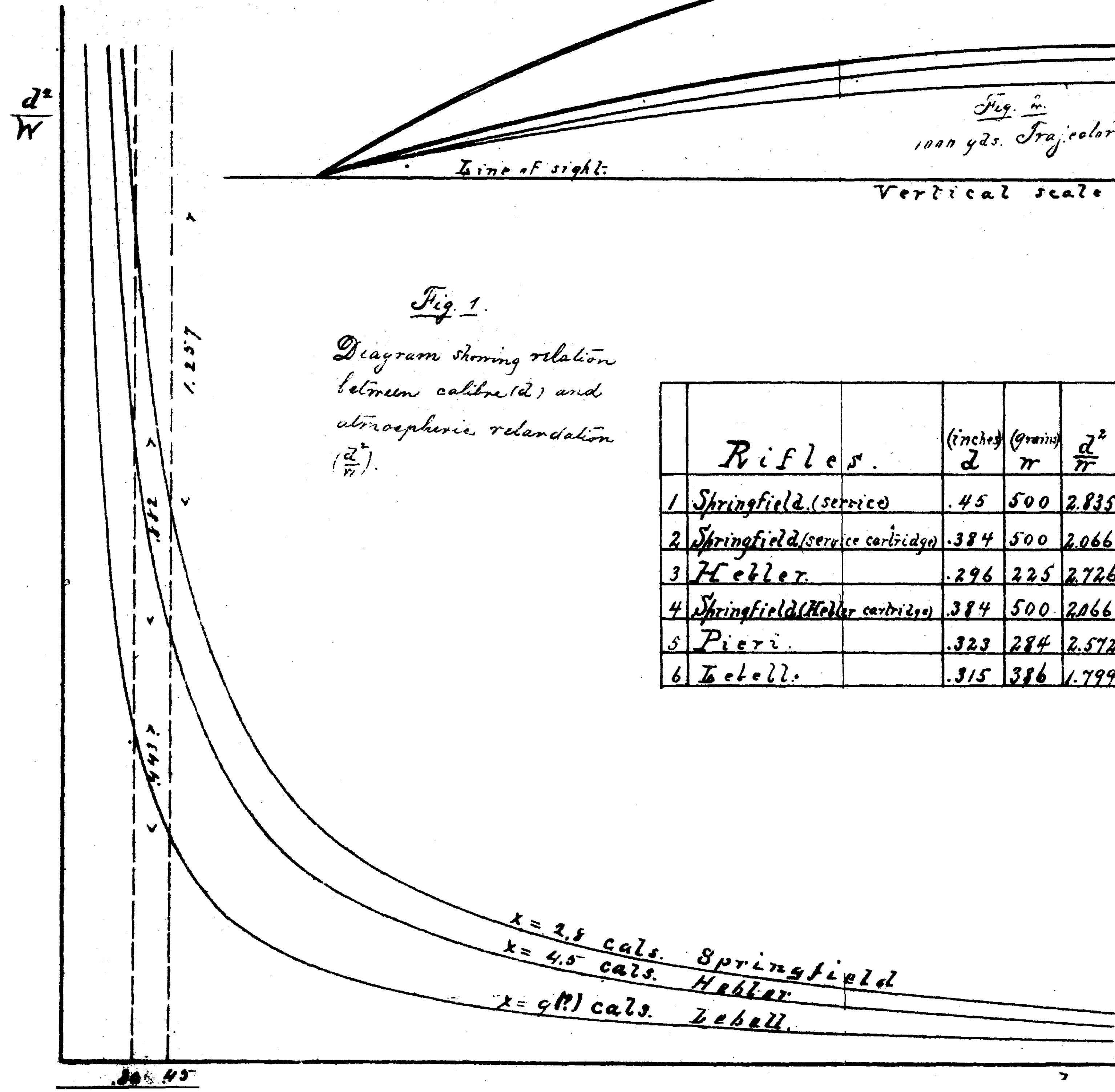

Fig. 1.
Diagram showing relation between calibre (d) and atmospheric retardation $\left(\frac{d^2}{w}\right)$.

	Rifles.	(inches) d	(grains) w	$\frac{d^2}{w}$	Muzzle.		1000 yds. Range.				15° Elevation.	
					Energy, per unit circum. (foot-pounds)	V	Elevation	Greatest Height. (feet)	Angle of Fall.	Remaining Energy per unit circum (foot pounds)	Range (yds.)	Remaining Energy per unit circum. (foot pounds)
1	Springfield. (service)	.45	500	2.835	1329.6	1301	2° 59′ 50″	48.49	4° 24′ 34″	359.9	2429.9	85.57
2	Springfield (service cartridge)	.384	500	2.066	1134.6	1110.7	3° 12′ 5″	48.39	4° 12′ 2″	478.7	2650.5	143.49
3	Hebler.	.296	225	2.726	2081.4	1968.	1° 39′ 32″	29.66	2° 50′ 51″	360.2	2928.6	56.22
4	Springfield (Hebler cartridge)	.384	500	2.066	2698.7	1713.	1° 45′ 00″	29.29	2° 40′ 57″	701.2	3253.6	133.85
5	Pieri.	.323	284	2.572	2627.7	2057.	1° 28′ 6″	26.16	2° 33′ 26″	460.5	3103.3	67.53
6	Lebell.	.315	386	1.799	3580.7	2034.	1° 11′ 13″	19.87	1° 54′ 00″	875.2	3789.8	140.1

Descriptive and Calculated Data for the principal Modern Military Rifles.

RIFLE.	COUNTRY.	Cal.	$\frac{d^2}{w}$	Charge (grs.)	Bullet (grs.)	Cartri'ge (grs.)	Length Bullet (Cals.)	Twist (Inches.)	Single Loader or Repeater.	Kind of Magazine. No. Cartridges.	Bolt or Block Mechanism.	Initial Velocity. (f. s.)	Muzzle energy per unit circum. (ft. pds.)	Remaining energy per unit circum. 1000 yards. (ft. pds.)	Remaining energy per unit circum. 2000 yards. (ft. pds.)
Hebler	....	.296	2.726	83	225	521	4.46	4.588	S. L.	....	Bolt	1968	2081.4	360.2	108.9
Lebell	France	.315	1.799	...	*386	.....	9	......	S. L. & R.	Tubular, 8	Bolt	2034	3580.7	875.2	437.5
Freddi	Proposed for Italy	.315	3.087	83	225	398	3.67	......	S. L. mag. atch.	....	Bolt	1640	1358.1	255.8	85.8
Guedez-Kropatschek	Portugal	.323	2.766	69.5	264	546	4.09	11.3	S. L. & R.	Box, 5	Bolt	1673	1617.4	336.1	126.2
Pieri	Experimental	.323	2.572	83	284	.....	4.3	12.1	....	....	....	2057	2627.7	460.5	183.6
Jarmann	Sweden	.397	3.274	77	337	620	2.75	21.8	S. L. & R.	Tubular, 8	Bolt	1536	1415.8	262.0	80.3
Vitali-Vetterli '70-87	Italy	.414	3.845	62	312	468	2.24	26.28	S. L. & R.	Box, 4	Bolt	1430	1089.6	184.0	46.0
Vetterli	Switzerland	.414	3.845	55	312	465	2.24	26.28	S. L. & R.	Tubular, 11	Bolt	1427	1084.9	183.7	45.8
Berdan	Russia	.42	3.337	77	370	610	2.55	21.65	S. L.	....	Bolt	1444	1295.7	259.7	79.7
Mauser	Germany	.433	3.4	77	386	663	2.42	21.66	S. L. & R.	Tubular, 8	Bolt	1571	1554.0	275.7	83.0
Kropatschek	French Navy	.433	3.4	81	386	676	2.42	21.66	S. L. & R.	Tubular, 7	Bolt	1430	1288.7	254.9	76.6
Manlicher 1885	Austria	.433	3.538	77	371	656	2.33	21.6	R.	Box, 5	Bolt	1575	1501.2	252.8	72.3
Gras 1874-80	France	.433	3.4	80	386	676	2.42	21.66	S. L.	....	Bolt	1430	1288.7	254.9	76.6
Remington 1871	Spain	.433	3.4	77	386	634	2.42	25.59	S. L.	....	Block	1340	1131.5	241.0	72.7
Martini-Henry	England	.45	2.953	85	480	766	2.69	22	S. L.	....	Block	1315	1302.8	333.2	117.9
Springfield	United States	.45	2.835	70	500	706	2.8	22	S. L.	....	Block	1301	1329.6	360.0	131.7

* See foot note, page 10.