ON

THE PRACTICABILITY

OF

CONSTRUCTING CANNON OF GREAT CALIBER,

CAPABLE OF

ENDURING LONG-CONTINUED USE

UNDER FULL CHARGES.

BY

DANIEL TREADWELL,

VICE-PRESIDENT OF THE AMERICAN ACADEMY, AND LATE RUMFORD PROFESSOR IN HARVARD UNIVERSITY.

[From the Memoirs of the American Academy.]

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On the Practicability of Constructing Cannon of Great Caliber, capable of enduring long-continued Use under full Charges.

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THE importance of constructing cannon of a size larger than any now in use, to every nation that may be called upon to encounter the trials of war, is one of those facts acknowledged alike by the soldier and the civilian; and to obtain such instruments, capable of throwing projectiles larger and heavier, and to greater distances, than has hitherto been attained, is now occupying the attention of the scientific engineers and projectors of Europe more than any other question open to them. The present age has witnessed a remarkable increase in the size of all the great instruments of human industry. Ships within twenty years have been doubled in their dimensions, and steam-engines are now constructed which compare with those of the last age as giants compare with common men. But although the want is fully acknowledged, and attempts have been made in hundreds of forms, no one has succeeded in producing a cannon essentially more powerful than those used in the days of Napoleon and Wellington.

I propose, in this paper, to search for the causes of these failures, to examine the action of the forces, both active and passive, which are called into operation in throwing shot and shells by gunpowder, and, at last, shall endeavor to show that our present cannon do not approach the size and power of those that may be constructed.

I have said that no essential improvement has been made during the present age in the size of cannon. It is true that they have been increased in caliber from seven, up to eight and ten inches, and a few bomb-cannon have been made of twelve inches. But in the use of these the charges are so diminished, to be brought within the limits of safety, that the initial velocities, as inferred from their short ranges, are not so great as those of the old forty-two pounders; while with mortars, those of thirteen inches were used in the time of Vauban, and this remains, stereotyped, as the limit at the present day.

But to my examination. The properties or qualities of hardness and of tenacity or strength are the qualities indispensable to all cannon, and the superiority of one cannon over another is measured by the excess in which it possesses them. Inertia * is like-

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* This word is used throughout this paper in its strictly technical sense, as the force, or power of resisting all change of state,

wise required, in a certain amount, to prevent excessive recoil. Now these properties of strength and hardness are possessed in an eminent degree by bronze and cast-iron, and these bodies alone constitute, in practice, the materials for cannon; for although various attempts have been made to introduce steel and wrought-iron, it is enough for my present purpose to say, that there are not twenty cannon in use in the world, that are not made of bronze or cast-iron. For strength, bronze is generally taken at 30,000 pounds to the square inch; that is, that it will require a weight of 30,000 pounds to tear asunder a bar of good gun-metal bronze of one inch area. Following the mean of many experiments, cast-iron has generally been taken at 20,000 pounds. But that I may be sure not to under-estimate the strength of this material, and as it has been considerably improved by gun-makers within a few years, I shall estimate it at 30,000 pounds, or as equal to bronze, although it is not to be relied upon as so constant in its strength as the latter material. For hardness cast-iron greatly exceeds bronze. This renders it more suitable for very large guns, and it has, in truth, become so exclusively the material for everything above the size of field-pieces, that I shall deal with it alone in the examination proposed in this paper.

Before examining the force of gunpowder it may

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whether it be from rest to motion or from motion to rest; and I use, without a doubt of its accuracy, the square of the velocity by the mass, as the measure of this force.

be well enough to say a word upon the time of its explosion. Is the firing of gunpowder instantaneous? This question has been discussed, and experiments made upon it, by Mr. Robins, Dr. Hutton, Count Rumford, and many others, besides a special committee of the Royal Society. If it be instantaneous, then it must be evident that no other substance can be fired with a greater rapidity. For instantaneousness, bearing the same relation to time, that a point does to space, can admit of no degrees. Both are existences without extension, and we cannot say of any two events that one is more instantaneous than the other, without implying duration to one at least, which also implies that it is not instantaneous. Now many of the fulminating powders, and even gun-cotton, are, as is well known, fired much more rapidly than gunpowder. The firing of this last cannot, therefore, be instantaneous, and we might rest with this logical solution of the question; but, like many other logical solutions, it adds but little to our wisdom, and the amazing rapidity with which a large mass of powder is inflamed, when in a close cavity, awakens our attention to the course of the events causing, or at least accompanying, this inflammation, and I shall notice two experimental results which seem to me to indicate the state of things during that whole course.

First, Count Rumford has proved that the burning of the grains is slow, or that a sensible time is required with each grain before it is wholly converted into the gaseous state; and secondly, various experiments made in England and in Prussia have shown that there is no sensible difference produced in the velocity of the shot by communicating the fire to the centre rather than to one end of the charge, which ought evidently to take place if the fire is communicated from one grain to another in succession, as this communication, being in both directions, when proceeding from the middle, would require but half the time that is required when proceeding from one end, and ought to produce a sensible increase in the velocity of the shot. I think, therefore, that these two facts warrant the following inference as to the course of the action during the production of the force. When the fire reaches the charge from the touchhole, the nearest grains become kindled; the hot fluid evolved is thrown farther into the charge, and the burning succeeds successively until the pressure becomes so great as to condense the air contained between the grains sufficiently to produce the heat required for firing those grains, which are then consumed more or less rapidly, as they are fine or coarse. We have, then, first the burning in succession of a small part of the charge; then the immensely rapid, though not instantaneous, kindling of every grain composing it; and then the consumption of those grains, which is not accomplished without time. It is a task for the conception to grasp these events, following one another in distinct succession; each having its beginning, middle, and end, and all being comprised in the period of $\frac{1}{200}$th of a second (gun 4 feet long, *formula* $t = \frac{2s}{v}$). When we have mastered the imagination of these, we may go further and combine with them the connected and contemporaneous action of the ball, which passes from rest to motion, and through every gradation of velocity up to 1,600 feet a second, and leaves the gun as our historical period of $\frac{1}{200}$th of a second expires.

The expansive force of gunpowder, which must be resisted by the strength of the cannon, depends almost entirely upon the circumstances under which it is fired. Count Rumford has shown, by his experiments made about sixty years ago, that if the powder be placed in a closed cavity, and the cavity be two thirds filled, the force will exceed 10,000 atmospheres, or 150,000 pounds upon the square inch; and he estimates that if the cavity be entirely filled with the grained powder, and restrained to those dimensions, the force will rise to 50,000 atmospheres. My own experience, made in bursting wrought-iron cannon the strength of which was known to me, leads me to believe that he has not over-estimated its power, although I am aware that it is generally considered as excessive. If, following an opposite course to that herein described, the powder be at liberty to expand upon any side, the force thrown in the other directions is very small. Thus, if a charge be placed loose in a gun, without shot or wad, the force upon the walls of the gun is very trifling; — no more than is produced by the restraint of the inertia of the charge itself, or the fluid formed from it. If we would divest a charge of this property of inertia, and fire it in a constantly maintained vacuum, it would not rend walls made of cartridge-paper, if a single end were left open for its escape. From the preceding statement, it will be seen that gunpowder will take any force, from perhaps 50,000 atmospheres, when confined to a close cavity, down to zero, if it be deprived of inertia and fired in a vacuum constantly maintained.

In artillery practice, the restraining power which causes the powder to act against the walls of the cannon is derived principally from the inertia of the shot. This is so much greater than the inertia of the powder itself, that the latter may be neglected in the considerations that are to follow. Now, bearing in mind what has been already said, let us compare the difference of the force of powder as exerted upon a small and a large gun respectively. It is perfectly well known, that, if we have a pipe or hollow cylinder of say two inches in diameter with walls an inch thick, and if this cylinder will bear a pressure from within of 1,000 pounds per inch, another cylinder, of the same material, of ten inches in diameter, will bear the same number of pounds to the inch if we increase the walls in the same proportion, or make them five inches thick. A cross-section of these cylinders will present an area proportional to the squares of their diameters, and if the pressure be produced by the weight of plungers or pistons, as in the hydrostatic press, the weight required in the pistons will be as the squares of the diameters, or as 4 to 100.

Now carry this to two cannon of different calibers, and take an extreme case. Suppose the caliber of one to be 2 inches in diameter and the other 10 inches, and that the sides of each gun equal, in thickness, the diameter of its caliber. Then to develop the same force, per inch, from the powder of each gun, the inertia of the balls should be as the squares of the diameters of the calibers, respectively; that is, one should be 25 times as great as the other. But the balls, being one 2 and the other 10 inches in diameter, will weigh 1 pound and 125 pounds respectively; the weights being as the cubes of the calibers. Hence each inch of powder in the large gun will be opposed by 5 times as much inertia as is found in the small gun. This produces a state of things precisely similar to that of loading the small gun with 5 balls instead of 1;* and although the strain thrown upon the gun by 5 balls is by no means 5 times as great as that by 1 ball, there can be, I think, no doubt that the strain produced by different weights of ball is in a ratio as high as that of the cube roots of the re-

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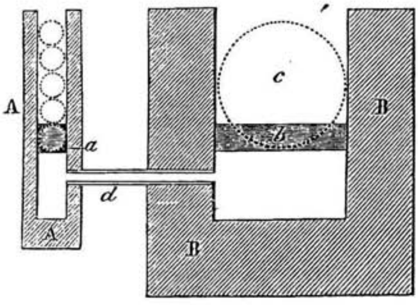

* The state of things here described will be comprehended by a glance at this figure. The two cylinders A and B, made in the proportions of 1 to 5, will resist an equal hydrostatic pressure, and the weights or plungers *a* and *b*, with which they are loaded, will remain supported upon the water in equilibrium, if an open communication be made between them by the pipe *d*. But if we load the larger one with

spective weights.* This would give, in the example before us, an increase of from 1 to 1.71, or the stress upon the walls of the 10-inch gun would be 71 per cent greater than upon those of the 2-inch gun.

The foregoing statement and comparison, however, do not present the whole case; for they are made upon the supposition that the charge of powder, in each instance, is as the square of the diameter of the shot, or that the cartridges of the 2 and the 10 inch guns are of the same length. This, if we take the charge of the small gun at $\frac{1}{3}$ of a pound, would give but $8\frac{1}{3}$ pounds for the large, or $\frac{1}{15}$ of the weight of the shot. The velocity obtained from this charge would produce neither range nor practical effect, and to obtain these results, that is, 1,600 feet a second, we must either increase the force through the whole length of the gun to 5 times that required for the small gun, or, the force remaining the same, we must provide

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the ball *c* instead of *b*, we shall require 5 balls, as shown in the small cylinder A, to balance the pressure of *c*.

* Hutton inferred that the velocities of balls of different weights with the same charges of powder, were inversely as the square roots of the weights, and Captain Mordecai, in his excellent book of experiments, makes the same inference. This would give no increase to the force of the powder, and must be impossible; and I find from comparing their experiments, and computing the forces developed by the same charges of powder with shot of different weights, that the forces are almost exactly as the cube roots of the shot. Thus Hutton's experiments with balls of 1.2 lb. and 2.9 lb., velocities 973 and 749, give forces almost exactly proportional to the cube roots of 1.2 and 2.9. Captain Mordecai's experiments with balls of 4.42 lb., 9.28 lb., and 21 lb., velocities 2,696, 2,150, and

for its acting through 5 times the space. Neither of these conditions can be practically accomplished. However, by an increase of both the charge and the length of the bore, the result may, in the limits under consideration, be attained. Thus, taking the large bore, if we double its length and make the cartridge 5 times as long, increasing the weight from $8\frac{1}{3}$ to $41\frac{2}{3}$ pounds, — or perhaps, having an advantage from the comparative diminution of windage and the better preservation of the heat, with a charge of from 30 to 35 pounds, — we may obtain the full velocity of 1,600 feet a second. But this again increases enormously the strain upon the gun.

It does not appear obvious, at a first view, how an increase in the charge should increase the tension of the fluid produced from it, if the cavity enclosing it be proportionably enlarged. If a steam-pipe a foot long will sustain the pressure of a given quantity of steam, of a given temperature, a pipe two feet long, of the same thickness and diameter, will sustain the pressure produced by a double weight of steam from the same boiler. Why then should the pressure upon a cannon be increased by a double length of cartridge? The difference seems to be this; with the steam, the press-

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1,520, all furnish, by computation, forces very nearly proportional to the cube roots of the respective weights of the balls. Every one knows that a small increase in the weight of the shot in a fowling-piece increases in a sensible degree the recoil, and the stress upon the gun. This is so universally received as true by ordnance officers, that it is a common practice to use two or more balls, instead of an increased charge, in proving guns.

ure is as in a closed cavity; with the powder, the tension depends upon the movement of the shot while the fluid is forming. Now, whether the charge be large or small, the motion of the shot commences while the pressure is the same in both cases, and before the charge is fully burned, and with the same velocity in both cases; but with the large charge the fluid is formed faster than with the small, while the enlargement of the cavity by the movement of the shot is nearly the same in both cases. This destroys the proportion between the sizes of the two cavities, and the tension must increase faster, and become greater, from the larger charge. The law of this increase cannot, from the complicate nature of the problem, be stated with any reliable exactness, but we may, I think, conclude, from the increased velocity of the shot, and many other effects, that the stress thrown upon the gun by different charges of powder, within ordinary limits, will not vary essentially from the square roots of those charges.* If then we increase, in the example

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* Hutton gives the velocities of the balls as the square roots of the charges, and the experiments of Captain Mordecai, although giving the velocities of the larger charges somewhat below this ratio, do not wholly contradict it. This assigns to the charges an effect, or power, that is, pressure multiplied by the space, which is directly as the charge. Now this result cannot be produced, with the larger charges, wholly by the continuance of the pressure during the last part of the passage of the ball through the bore, although a large portion of it may be derived from that source; but there must be a great increase of the tension in the fluid during the first part of the ball's motion, and an equal increase of the

under consideration, from a charge of $8\frac{1}{3}$ pounds to one of 32 pounds, the stress upon the gun, being as the square roots of these numbers, is raised from 2.88 to 5.65, or from 1 to 1.96. Having already increased the stress upon the gun, by the shot, from 1 to 1.71, if we multiply these together, we have a total increase of from 1 to 3.35. That is to say, if, under the conditions here stated, we load a gun of 2 inches' caliber with 1 shot and $\frac{1}{3}$ of a pound of powder, and a gun of 10 inches' caliber with 1 shot and 32 pounds of powder, the stress upon each square inch of the bores will be 3.35 times greater with the large than with the small gun; when at the same time, if the walls of both have a thickness proportional to the diameters of the calibers in each, the large gun will be incapable of sustaining a greater pressure per inch than the small one. Even with a charge of 12 pounds of powder, the stress upon the large gun must be more than double that upon the small gun when charged with one third the weight of its ball.

The preceding examination does not, I think, present the difficulties to be overcome in increasing the size of cannon as greater than they really are, and although the results that I have arrived at are from extreme cases, and may be said to be mere deductions, yet they are deductions legitimately drawn from the most reliable experiments that have been

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strain upon the gun. It appears to me that the hypothesis stated above, and the ratio of force there assigned to different charges, are in perfect accordance with these and other experiments.

made. How then can the necessary strength be obtained? Will it be answered, by an increased thickness? It is not necessary to examine the obvious objections of the great increase of size and weight that this implies, because no increase that can be given to the thickness will increase the strength to a sufficient degree to resist the force required. To prove this, I must ask attention to a further and somewhat elaborate examination.

About thirty years ago, Mr. Peter Barlow, of Woolwich, published a paper in the Transactions of the Society of Civil Engineers, on the hydrostatic press, in which he showed that hollow cylinders of the same materials do not increase in strength in the ratio of increase in thickness, but that the ratio of increase of strength is such, that, where they become of considerable thickness, the strength falls enormously below that given by the ratio of thickness. Mr. Barlow has carried out his reasoning in an analytical form, which I shall omit, while I endeavor to give the physical principles of the problem, as he has laid them down, in a form more clearly within the conception of all.* For this purpose let us suppose Fig. 1 to represent the cross-section of a hollow cylinder, like a cannon; A, the bore, 10 inches in diameter, B, the walls or body, 10 inches thick. Let this cylinder be distended by

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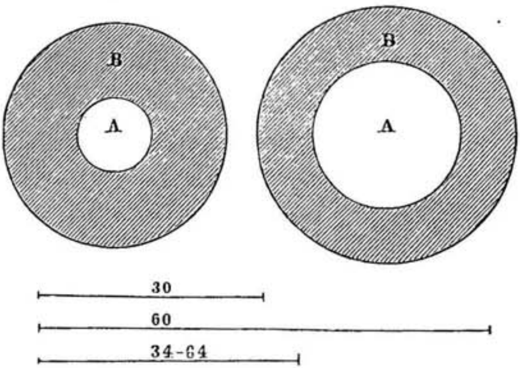
* Mr. Barlow's paper may be found in the first volume of the Transactions of the Society of Civil Engineers, and likewise in the Encyclopædia Metropolitana, and in the Treatise on the Manufactures of Great Britain, p. 326.

Fig. 1. Fig. 2.



internal fluid pressure until the bore is 20 inches in diameter, as in Fig. 2. The external diameter will be increased only to 34.641 inches. For in Fig. 1 the whole diameter is 30 inches, and contains an area of $30^2 = 900$ circular inches. From this take the area of the bore $10^2 = 100$ inches, and we have 800 inches in the area of the solid walls. Now after it is distended, the area of the bore becomes $20^2 = 400$ circular inches, and as the walls contain the same area as before the distention, viz. 800, we have $800 + 400 = 1200$ circular inches for the area of the whole section, and $\sqrt{1200} = 34.641$ for the external diameter. Before the distention the circumference of the bore was $10 \times 3.141 = 31.41$, and the external circumference of the body was $30 \times 3.141 = 94.23$. After the distention the circumference of the bore is $20 \times 3.141 = 62.82$, and the circumference of the outside solid is $34.641 \times 3.141 = 108.81$. Every inch of the inner portion of the wall, then, by the distention has been doubled in length, while the external circumference of the wall has been distended only in the ratio of 94.23 to 108.81, or from 1 to 1.155, less than one seventh part.

I have taken a case of extreme distention, for the purpose of showing more clearly the physical condition of the problem. But this makes the ratio of the differences less than they are when the distention is kept within the bounds of practice with iron cylinders. If, in the preceding case, the distention of the bore be made, what it may be in practice just before fracture, namely, $\frac{1}{1000}$th part of the diameter, we shall find that the external portion will be distended, practically, but one ninth part as much as the internal portion of the solid, and, if we take an infinitely small part for the distention, exactly one ninth. Now it is well known that with most bodies, including iron, within the strain of its elasticity the elongation is in exact proportion to the straining force. Hence with a cylinder such as I have described, if of cast-iron, the inner portion will be rent, or strained beyond its elastic power, at the instant that the outside portion is strained with only one ninth part of the load that it is capable of bearing. If the cylinder be made thicker than in my example, the load borne by the outside will be still less. If it be twice as thick as the diameter of the bore, the outside portion will be strained with only one twenty-fifth part of the load it is capable of bearing, when the inner portion is rent, and all the other parts must be rent in succession, without any increase of the load. The law of the diminution in the power of resistance may be stated as follows. Suppose such a cylinder to be made up of a great number of thin rings or hoops, placed one within another. Then the resistance of these rings, compared one with another, to any distending force, will be inversely as the squares of their diameters.* With these incontrovertible laws of resistance before us, we cannot fail to perceive how impossible it must be to increase the strength of cast-iron cannon, in any useful degree, by an increase of their thickness beyond that now given to them.†

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* If we make a cylinder of 41 concentric hoops of equal thickness, disposed one within another, and exactly fitting, so that the particles of each hoop shall be in equilibrium with each other, the diameter of the largest being 5 times that of the smallest, then the force of each, beginning with the innermost, to resist distention, will be represented by the following numbers:—

1000	250	111	62
826	225	104	59
694	207	98	56
591	189	92	54
510	174	87	51
444	160	82	49
391	148	77	47
346	137	73	45
309	128	69	43
277	119	65	41
			40

An inspection of these numbers must, I think, impress any one with the fact, that it is impossible to increase essentially the strength of cannon, by a simple increase of thickness.

† I leave out of consideration another source of weakness, which comes from the unequal shrinking of the iron-casting. The heat from every casting is conducted away from the outside. Hence

Now, to obviate the great cause of weakness arising from the conditions before recited, and to obtain, as far as may be, the strength of wrought-iron instead of that of cast-iron, for cannon, I propose the following mode of construction. I propose to form a body for the gun, containing the caliber and breech as now formed of cast-iron, but with walls of only about half the thickness of the diameter of the bore. Upon this body I place rings or hoops of wrought-iron, in one, two, or more layers. Every hoop is formed with a screw or thread upon its inside, to fit to a corresponding screw or thread formed upon the body of the gun first, and afterwards upon each layer that is embraced by another layer. These hoops are made a little, say $\frac{1}{1000}$th part of their diameters, less upon their insides, than the parts that they enclose. They are then expanded by heat, and being turned on to their places, suffered to cool, when they shrink and compress, first the body of the gun, and, afterwards, each successive layer all that it encloses. This compression must be made such, that, when the gun is

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the outside *sets*, while the inside remains fluid. When the inside sets, the cooler solid shell that surrounds it contains more space than is required for the solid shrinking from the liquid state. This destroys the equilibrium amongst the particles, leaving them upon the *stretch*, or in a state exactly opposite to that in which, to give the greatest strength, they ought to be in, as we shall see hereafter. But the case, as I have shown it from other considerations, is so strong, or rather the gun is so weak, that I do not estimate this in this place, and only mention it in this note to show that I am aware of it, as all practical men must be.

subjected to the greatest force, the body of the gun and the several layers of rings will be distended to the fracturing point at the same time, and thus all take a portion of the strain up to its bearing capacity.

There may, at the first view, seem to be a great practical difficulty in making the hoops of the exact size required to produce the necessary compression. This would be true if the hoops were made of cast-iron, or any body which fractures when extended in the least degree beyond the limit of its elasticity. But wrought-iron and all malleable bodies are capable of being extended without fracture much beyond their power of elasticity. They may, therefore, be greatly elongated without being weakened. Hence we have only to form the hoops *small in excess*, and they will accommodate themselves under the strain without the least injury. It will be found best in practice, therefore, to make the difference between the diameters of the hoops and the parts which they surround, considerably more than $\frac{1}{1000}$th part of a diameter. The fixing the hoops in their places by the screw, or some equivalent, is absolutely necessary, not merely to reinforce the body against cross fracture, but to prevent them from starting with every shock of the recoil. I know, by experiment, that the screw-thread will fix them effectually. The trunnions must, of course, be welded upon one of the hoops, and this hoop must be *splined*, to prevent its turning by the recoil. Small *splines* should likewise be inserted under every hoop. It will, moreover, be advantageous to make the threads of the female screws sensibly finer than those of the male, to draw, by the shrink, the inner rings together endwise.

It will be seen that, with a gun made in this way, we must depend upon the cast-iron body to resist the strain tending to produce cross fracture, though this resistance will be in some degree supported by the outer rings breaking joint over the inner rings. But if the body be made to constitute half the thickness of the walls, it will be found sufficient for the purpose without any reinforcement from the rings. This results from a principle or law, which, so far as I know, was first published by me in the year 1845, in a pamphlet on wrought-iron and steel cannon. As I cannot now put this matter in a better form than that in which I have there given it, I will here quote the statement as then made.

"Let us suppose that we have a hollow cylinder, say twelve inches long, the caliber being one inch in diameter, and the walls one inch thick, giving an external diameter of three inches. Suppose this cylinder to be perfectly and firmly closed, at its ends, by screw plugs, or any other sufficient means. Let this be filled with gunpowder and fired. The fluid will exert an equal pressure, in every direction, upon equal surfaces of the sides and ends of the hollow cylinder. Let us next examine the resisting power of a portion of this cylinder, say one inch long, situated in the middle, or equally distant from the ends, so that it shall not be strengthened by the iron which is beyond the action of the powder. The fluid enclosed by this ring of one inch long contains an area of one square inch, if a section be made through it in the direction of its axis; and the section of the ring itself, made in the same direction, will measure two square inches. We have then the tenacity or cohesive force of two square inches of iron in opposition to an area of the fluid measuring one square inch; and if we take the tenacity of the iron at 65,000 pounds, the cylinder will not be burst, in the direction of its length, unless the expansive force of the fluid exceed 130,000 pounds to each inch. Next, let us suppose a section made through the cylinder and fluid, transversely. The area of the fluid, equal to the square of the diameter of the hollow cylinder, is one circular inch, and the area of the whole section, the diameter being three inches, is nine inches. Deduct from this the area of the caliber, and we have eight circular inches. That is, the section of the iron is eight times greater than that of the fluid; whereas in the former case, of longitudinal section, the iron gave but twice as much surface as the fluid; and if we take, as before, the iron at 65,000 pounds per inch cohesive force, it will not be broken unless the force of the fluid exceed 520,000 pounds. It will be found, upon a further examination, that the relations of these sections to each other may be varied, as we take the diameter of the caliber to be greater or less, as compared with the thickness of the sides, but their difference can never be made less than as two to one. Here then is a principle, or rather a fact, of the utmost importance in forming cannon of any material, the strength of which is different in different directions; for as a cannon made in the proportions above specified, if the materials be in all directions of equal strength, will possess four times as much power to resist a cross fracture as it does to resist a longitudinal fracture, it follows, that a fibrous material which possesses four times the strength in one direction that it does in another, will form a cannon of equal strength, if the fibres be directed round the axis of the caliber. It is this fact which gives the great superiority to the various kinds of twist gun-barrels. For in these, although the fibres do not enclose the caliber in circles, yet they pass around it in spirals, thus giving their resisting force a diagonal direction, which is vastly superior to the longitudinal direction in which the fibres are arranged in a common musket-barrel."'

The foregoing example supposes the cavity immovably closed at its ends, and gives to the powder more force than it actually exerts, in gun-practice, to produce cross fracture, compared with its force to produce lengthwise fracture, even at the part nearest to the breech of the gun; and as the recoil is resisted by the whole gun, the stress upon any part will diminish as the inertia, or weight, diminishes from the breech to the muzzle.

With these facts, principles, and laws, thus stated, I proceed to give some calculations to show the strength of a cannon constructed in the way that I have pointed out, as compared with one made in the usual manner. Take a cannon of 14 inches' caliber, which will carry a spherical solid ball of 374 pounds, with sides 14 inches thick, made up of 7 inches of cast-iron, and two hoops or rings, $3\frac{1}{2}$ inches each, of wrought-iron. The external layer of cast-iron will, from its position, as before explained, possess but one fourth of the strength of the inner layer, or whole strength of the iron, and the mean strength of the whole will be reduced one half. Take cast-iron at 30,000 pounds to the inch area, and we have $30{,}000 \times \frac{1}{2} = 15{,}000$ pounds to the inch. The thickness, of both sides, is 14 inches, and $15{,}000 \times 14 = 210{,}000$ pounds for the strength of the casting, to each inch of its length. The first hoop has its strength reduced from 1 to a mean of .8. Take the strength of wrought-iron at 60,000 pounds to the inch, and we have $60{,}000 \times .8 = 48{,}000$ pounds to the inch. The thickness, of both sides, is 7 inches, and $48{,}000 \times 7 = 336{,}000$ pounds. The outside ring must be reduced in strength by the same rule, for its mean, from 1 to .832, which gives it 49,920 pounds per inch, and for the 7 inches 349,440 pounds. We have then, for each inch in length,

Cast-iron body of the gun	210,000	pounds.
Inner wrought-iron hoop	336,000	"
Outer wrought-iron hoop	349,440	"
	895,440	pounds.

The diameter of the bore being 14 inches, we have $\frac{895440}{14} = 63{,}960$ pounds, as the resistance to oppose to each square inch of the fluid from the powder. The gun will bear, then, a pressure of 4,264 atmospheres.

The resistance to cross fracture at the part nearest to the breech will be, from the cast-iron, $28^2 - 14^2 = 784 - 196$ circular inches, equal to 460 square inches.

Cohesive force, unreduced, 30,000 pounds, and 30,000 $\times 460 = 13{,}800{,}000$ pounds, the whole strength. The bore contains 153 square inches, and $\frac{13800000}{153} =$ 90,196 pounds to resist each square inch of the fluid, or 26,236 pounds to each square inch more than is provided to resist the longitudinal fracture; and this excess will be further reinforced by the wrought-iron rings, which, being screwed upon the casting, and the outer layer breaking joint over the inner, will add to the resistance to a great amount, which however need not be computed.

Let us now examine a gun made of a single casting of the dimensions that are given above; that is, of 14 inches' bore, and sides 14 inches thick. Taking the normal strength of cast-iron as before at 30,000 pounds per inch, we must reduce it, according to the laws before explained, to one third, or a mean of 10,000 pounds per inch; and the thickness of both sides being 28 inches, we have $10{,}000 \times 28 = 280{,}000$ pounds for the whole strength, and $\frac{280000}{14} = 20{,}000$ pounds to each inch of the fluid pressure, or 1,333 atmospheres, or $\frac{20000}{63960}$, or less than one third of the first example. Against a cross fracture the cast gun will possess a great excess of strength, which I do not like to call useless, although I do not perceive how it can be of any essential, practical advantage.

Let us next inquire, What force is required to give a ball of 14 inches' diameter a velocity of 1,600 feet a second? We shall obtain a better conception of this force by estimating it in the height required by a fluid column to produce it. Suppose the ball impelled by the pressure of a column of the same substance, which would be in this case a column of fluid iron. Then (from the formula $v = \sqrt{2gh}$) we obtain $\frac{1600^2}{64} = \frac{2560000}{64} = 40{,}000$ feet, for the height of the column. But this would produce a jet forming a continuous stream. Suppose this stream to be 14 inches in diameter, and divided into a series of short cylinders, each of which, to equal a ball of 14 inches' diameter, must be $9\frac{1}{3}$ inches long. Now in giving 1,600 feet velocity to this series of cylinders by a superincumbent column, the force will act upon each cylinder only through a space equal to its length. But in a cannon the powder acts, though with a variable force, through the whole bore of the gun. The variation of this force must depend, in every case, upon the quickness of the powder, arising from its composition, fineness of grain, dryness, and the heat received from the gun from previous firings; and most essentially from the amount of the charge; and we do not know the exact law of the variation for any one case or condition. Our best judgment, therefore, must be but an approximation to the truth, entirely empirical. But if we cannot determine the truth with exactness, we can at least assign limits within which it must be contained, and upon a comparison of the velocities produced by different lengths of bore, the effect upon the gun itself at different parts of its length, and various other grounds of comparison, I think that we may take the effect of the charge through the whole bore, supposing it to be 112 inches from the ball to the muzzle, and the charge

80 pounds, as equal to the action of the maximum force through a space of not less than one half, nor more than two thirds, of its length. But that I may be sure to assign the maximum so great as to cover all anomalous or accidental conditions, I will take it as sufficient to produce a velocity of 1,600 feet a second, if acting constantly through one third the length of the bore. This will give $37\frac{1}{3}$ inches, or exactly 4 times the length of the cylinder which forms the equivalent of the shot. Then (from the formula $v=\sqrt{fs}$) the 40,000 feet above given for the height of the column, becomes $\frac{40000}{4}=10,000$ feet; * and if we take the whole force of the powder as equal to its maximum force, acting through two thirds the length of the bore, or $74\frac{2}{3}$ inches, our column will become 5,000 feet high. In all cases of providing strength, we must take the force to be resisted at its maximum.

Now a bar of cast-iron 1 inch square weighs 3.2 pounds to the foot in length; we have then $10,000 \times 3.2 = 32,000$ pounds' pressure to each square inch of surface, or $\frac{32000}{15} = 2,133$ atmospheres, on the supposition that the whole action of the powder is equal to its maximum force through one third the bore of the gun. If we take the whole action as equal to its maximum through two thirds of the bore, the column,

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* This whole matter may be taken from the formula $\frac{v^2}{2gs}=f$, which gives the force 12,860 times gravitation. But I have preferred to give the more circuitous course, from the pressure of a column, as fixing a better conception of its enormous amount upon the mind.

5,000 feet high, gives 16,000 pounds, or 1,066 atmospheres. It cannot be less than this, and although it may never come up to the greater number, or 2,133 atmospheres, it would not be safe to estimate it at less when providing the means to resist it. We require, then, a pressure of 32,000 pounds to the inch, to obtain for a 14-inch shot an initial velocity of 1,600 feet a second. We have seen that a gun formed as I have proposed will be capable of resisting a pressure of 63,960 pounds to the inch, or very nearly twice the pressure required to produce the velocity sought, while with a gun made in the usual way, of one piece of cast-iron, the power of resistance is limited to 20,000 pounds to the inch, or less than two thirds that which may be required to obtain the velocity.

We have seen that a cannon constructed in the manner recommended, of whatever size, having its walls equal in thickness to the diameter of its bore, will sustain a pressure of 63,960 pounds, equal to a column of fluid iron 20,000 feet high, very nearly. This is half the strength required to support a column capable of keeping up a continued stream with a velocity of 1,600 feet a second. Suppose that we construct such a cannon with a bore of 30 inches, and of such length that the ball shall receive the force of the powder while it moves through a space of 10 feet, and that this force be equal to a constant action of 4,266 atmospheres through 40 inches. It will be at once perceived that it will impress the above velocity upon a cylinder $\frac{40}{2} = 20$ inches long, or upon its equivalent, a sphere 30 inches in diameter. Such a sphere of solid iron will weigh 3,670 pounds, and at this point the *calculated* power of the gun meets the force required to give a velocity of 1,600 feet a second.

Although this size may be beyond practical reach, the contemplation of it as a theoretical perfection may stimulate us to attempt an approximation to it. A ball of a ton weight, with a range of, say 6 miles, would, as a mere display of mechanical force, be worthy of a great effort.

The following columns show the stress that the several kinds of guns, as mentioned, will bear, by calculation, and the pressure required to give the velocity of 1,600 feet a second. The third column shows the proportion between the required and the actual strength.

	Atmospheres.		Atmospheres.	
Hooped cannon for 14-inch shot will bear	4,266;	required	2,133	100 : 200
Cast-iron gun, 14-inch shot, will bear	1,333;	"	2,133	100 : 62
Cast-iron 32-pounder cannon, 6¼ inches thick, will bear	1,333;	"	920	100 : 142
Hooped cannon 30 in. diam. 3,670 lb. shot,	4,266;	"	4,266	100 : 100

By this it appears that a common cast-iron 32-pounder, having but 42 per cent more strength than is required, is less reliable than a hooped gun of 14 inches. It will be recollected that the numbers given above in the second column, as showing the required strength, represent the utmost force ever exerted by a charge intended to produce a velocity of 1,600 feet a second.

In this paper, my principal object has been to show a mode of construction by which, with our present materials and knowledge, it will be perfectly practicable to make guns of great size capable of standing the requirements of the service. It follows almost of course, that the same form of construction must be the best possible for guns of smaller caliber, and that by adopting it, not only will the use of guns of enormous size be rendered practicable, but, if applied to cannon of smaller size, their bursting will be rendered almost impossible. If it be necessary to use the word *cost* in connection with the object to be attained, I *know* that when the manufacture is mastered, with a good machine-shop, the difference between the last of these and common cast-iron guns will be altogether insignificant to the nation.

I abstain from opening the subject of different forms of bore and of shot, although I believe that in the end some cylindrico-conical form, lightened with cavities in the rear portion, and perhaps with some form of spiral grooves to produce rotation from the air, will be substituted for the solid spheres now used.

I shall likewise forbear all description of apparatus for restraining recoil, by friction, although it will be necessary to resort to such means for the full development of the advantages of the form of cannon herein pointed out.

I should, however, leave the subject of this paper but very imperfectly treated, if I neglected to mention one most important effect of the force of the explosion, which is not indicated *a priori* by any theory, and which is so inconstant and uncertain in amount, that it can be appreciated only by a careful observation of its practical effects upon the gun, but which, unless guarded against, must essentially disturb the conclusions which I have herein deduced. I allude to what is known to artillerists as the lodgment or indentation of the ball. This first shows itself at the point immediately under the ball, where it rests at the moment of the discharge. It is best observed in a soft bronze or wrought-iron gun, and from the first instant of its appearance, as a slight impression of the under surface of the ball, it goes on increasing at every discharge, until it becomes so deep as to deflect the ball upwards at the instant of its flight, to strike the upper surface of the bore, where a second indentation is made, considerably in advance of the first, and from this a third, still more advanced, upon the under side. These indentations go on increasing in number and size, and at length bulges appear upon the outside of the gun, which becomes oval near the muzzle, and is at last destroyed.

The lodgment here described has been attributed wholly to the downward pressure of the fluid when escaping through the opening of the windage, which is all upon the upper side of the ball, the under side resting by its weight in contact with the bore. There must undoubtedly be a great escape, not only of the fluid, but of burning powder in grains, through this passage, and the downward pressure from these causes may present an excess over the opposite pressure of the powder upon the under side of the ball, capable of producing some impression upon the under surface of the bore. I am inclined, however, to attribute the indentation mostly, if not entirely, to the compression of the back hemisphere of the ball under the enormous blow of the explosion, producing a corresponding enlargement of the ball in its diameter transverse to the axis of the bore. The smith produces such a change of form in his bar of iron, at pleasure, by the blows of a sledge applied to its end. The operation is called *upsetting.* This enlargement must impress itself upon the part of the bore upon the under side upon which the shot rests, and is alone sufficient, in my mind, to account for the whole mischief.

This view of the subject is confirmed by the form of the lodgment, which consists, at first, of a single narrow impression, exactly corresponding to a very small segment of the ball, and not in the least in advance of the spot on which the ball rests before the discharge. Now this would be the exact form and place of an impression produced by a sudden enlargement of the ball, and an equally rapid recovery of its true figure, which it would derive from its elasticity. But if the lodgment were produced by the pressure of the fluid upon its upper surface, it ought to form a long groove or channel, ceasing only with the diminished pressure of the fluid near the muzzle. Furthermore, the lodgment is greatest when a hard oakum wad is used behind the ball. Now such a wad must prevent, in some degree at least, the escape of the fluid, and therefore diminish the downward pressure. But such a wad, driven hardest against the middle of the ball, in its rear, would act most advantageously to produce the lateral enlargement by *upsetting* it as before described.

Hard cast-iron guns do not exhibit this indentation in so great a degree, because, being unmalleable, they are incapable of a permanent change of form without fracture. With them, therefore, this pounding of the ball, being repeated a few hundred times, shatters the walls of the gun, which at length gives way at once and goes to pieces.

It must be obvious, that, if the lodgment be attributed to either or both of the causes which I have recited, it may be prevented by a most simple and easy means. This is nothing more than providing that the ball shall, at the moment of the explosion of the powder, have no part in contact with the bore of the gun, but that the windage space shall be equally distributed about the whole circumference. This may be entirely secured by enveloping the ball in a bag made of felt, or of hard woollen cloth, having an additional patch upon its under side to compensate for the weight of the ball. It would seem impossible that in this condition the ball, receiving the pressure of the powder equally distributed in the direction of the axis of the caliber, should touch the gun more than by a slight graze during its flight.*

* My observations upon the lodgment have been made upon wrought-iron cannon. Between the years 1841 and 1845, I made upwards of twenty cannon of this material. They were all made up of rings, or short hollow cylinders, welded together endwise. Each ring was made of bars wound upon an arbor spirally, like

Unless this or some equally efficient remedy is adopted, any considerable increase in the size of cannon must be hopeless; for a surface as hard as a smith's anvil would give way under the long-continued pounding of naked twelve-inch shot; and when-

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winding a ribbon upon a block, and, being welded and shaped in dies, were joined endwise, when in the furnace and at a welding heat, and afterwards pressed together in a mould by a hydrostatic press of 1,000 tons' force. Finding in the early stage of the manufacture that the softness of the wrought iron was a serious defect, I formed those made afterwards with a lining of steel, the wrought-iron bars being wound upon a previously formed steel ring. Eight of these guns were 6-pounders of the common United States bronze pattern, and eleven were 32-pounders of about 80 inches' length of bore, and 1,800 pounds' weight. Six of the 6-pounders, and four of the 32-pounders, were made for the United States. They have all been subjected to the most severe tests. One of the 6-pounders has borne 1,560 discharges, beginning with service charges and ending with 10 charges of 6 pounds of powder and 7 shot, without essential injury. It required to destroy one of the 32-pounders a succession of charges ending with 14 pounds of powder and 5 shot, although the weight of the gun was but 60 times the weight of the proper shot. If any of these guns are ever destroyed by firing them, the destruction will commence in the lodgment.

It was during a course of experimental firing with the soft wrought-iron gun, that I had an opportunity of observing the formation and increase of the lodgment; and here I was led to the experiment of placing the shot in a bag, as recommended in the text. My experiments were not sufficiently extended and varied to lead me to an assured conviction that the evil may be entirely prevented by this practice; but they were enough to lead me to a confident expectation of that result, as I could never detect the formation of any lodgment or any increase in one previously formed when the bag was used.

I cannot leave this subject without observing that I regard the ever hooped cannon may be made and used, it will be essential that the means of preventing the lodgment herein given be always and at all times carefully applied.

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late, and still continued, attempts to make wrought-iron cannon in Europe by the process of *fagoting* or *piling*, as a strange engineering delusion. It may not surprise us that *amateur* engineers, whose whole knowledge of the character of iron is derived from a printed page, should expect useful results from this attempt. But that men practically acquainted with working iron should expect to forge a serviceable gun of wrought-iron by the same process that is used to produce a shaft of that material, seems to me not very creditable to the *iron* knowledge of the age.