February 14, 1860.

GEORGE PARKER BIDDER, President,
in the Chair.

No. 1,014.—“On the Construction of Artillery, and other Vessels, to resist great internal pressure.”¹ By JAMES ATKINSON LONGRIDGE, M. Inst. C.E.

IN bringing before the Institution the subject of the present Paper, the Author wishes, in the outset, to define the limits within which he conceives the Civil Engineer may fairly work, without trenching upon the field of his military brethren.

Not only in the present day, when the profession of the Civil Engineer has risen to an importance second to no other, but even in its infancy, those who followed that and its cognate pursuits, have distinguished themselves by their inquiries and experiments on this subject; and when it is borne in mind, that the names of Robins and Hutton in bygone times, and recently, those of Nasmyth, Whitworth, Mallet, and Armstrong are intimately connected with the mechanism of warfare, the Author feels that he is not going too far, in bringing the subject forward for the consideration of the Members of this Institution.

He does not propose to make a complete survey of the very wide field which contains the science of gunnery; but to confine himself to a small portion of it. Small as that is, it appears to him to be the foundation of the whole; for however perfect may be the theory, and however expert the practitioner, it is the amount of force at his disposal which must limit his efficiency, and unless he can command this force in sufficient quantity and intensity, the results will ever fall short of his desires.

The invention of gunpowder, and more recently of gun cotton, gives a source of enormous power, but unless that power be controlled, its full value can never be utilised; and striving after greater and still greater effects, the probable result may be, that the Engineer will be “hoist with his own petard.”

The first point, then, in the science of gunnery, and that which

¹ The discussion upon this Paper extended over six evenings, but an abstract of the whole is given consecutively.

limits its future, appears to be, the construction of guns of sufficient strength to curb and govern the utmost force of the explosive compound which may be used in them.

So long as gunpowder can burst guns and mortars, so long it is unmanageable, and wanting in that perfect obedience which is the first principle of effective service.

Therefore, leaving aside, for the present, all the other interesting and important questions which meet the Military Engineer on every hand, during his onward way, the Author proposes to limit himself to the investigation of the method of making a gun, which shall give the gunner the mastery over gunpowder;—in other words, a gun which gunpowder cannot burst.

And this is a question, which, in his opinion, no one is more able to deal with than the Civil Engineer of the present day. Exercised in the application of metal to purposes of construction,—with experience still limited and greatly below what is desirable, yet an experience which a few years ago was non-existent,—the Civil Engineer should be more conversant with the properties of the useful metals, than his military brethren. And when, moreover, it is remembered, that structures requiring for their success, an intimate knowledge of these properties, have of late become realities, such as the Britannia, the Victoria and the Saltash Bridges, and the Great Eastern Steamship, there may be fairly claimed for the Civil Engineer, such an acquaintance with the use of metal as to justify him in discussing the question, how to make a strong and effective gun.

The attention of the Author was drawn to this subject early in 1855. He was previously aware of the difficulty, experienced by manufacturers of hydraulic presses, in making cylinders of large size to resist the moderate pressure of 3 tons, or 4 tons per square inch; and in common with others, he knew the explanation thereof, first given, as he believes, by Professor Barlow, (Hon. M. Inst. C.E.,) with the clearness which distinguishes all the works of that accomplished mathematician.

Fully satisfied of the general correctness of Professor Barlow's views, the Author was led to consider, how the inherent defect of any gun composed of material more, or less homogeneous, such as cast iron, or gun metal, could be remedied. He was not long in concluding, that the object to be attained, was to construct a vessel in such an initial state of equilibrium, that when the varying strain caused by the internal pressure should come upon it, the initial strain should be, as it were, complementary to the induced strain, and the sum of the two should be constant throughout.

Supposing the strain caused by the explosion to be some function of the distance from the centre, it was first necessary to

ascertain the nature of this function, and then to find a mode of construction, such that the state of the particles before the explosion, should make up the difference between the strain so determined and the constant tensile force of the material employed.

It was evident, that neither cast metal, nor forged metal in mass could possess the required properties. The Author at once saw, that the best chance was, in putting on layer after layer and giving to each the due initial tensile strain. This he thought might be nearly accomplished, by wrapping the successive layers of wire round an internal core and coiling them on with the proper tension. The facility of execution of such an idea was greatly in its favour, and the Author proceeded, as soon as circumstances permitted, to submit it to experiment. The result of these experiments, which will be hereafter given in detail, was to his mind so satisfactory, that he lost no time in bringing the matter before Lord Panmure, then Secretary at War, and as usual, the proposition was referred to the Select Committee at Woolwich.

The Author submitted his views to that tribunal, as well as he was able, during the short interview he had with it, and left a brass cylinder covered with wire, with the request that it might be fairly tried, as to its power of endurance.

His request was partially acceded to, but other engagements prevented him from being present at the trial, and, as will be hereafter fully explained, the result was, not that the cylinder was burst, but that the end was blown off, owing entirely to the method of conducting the experiment.

It is due to Lieut. Colonel Eardley Wilmot, under whom the experiment was conducted, to state, that he expressed to the Author his opinion, that the result was in no degree decisive as to the principle, and that he felt anxious to see further experiments.

The Author however found it not so easy to accomplish this. He urged upon the authorities the advisability of making further experiments, and offered to construct a gun on this principle, the whole expense of which he would guarantee should not exceed a very limited amount. It was, however, in vain. On the 25th of October, 1855, he was informed that the matter had been referred back to the Select Committee, and that they did not consider it desirable, that further experiments should be made on guns so constructed.

The Author finding no chance of obtaining such a trial as he desired, continued the experiments for his own satisfaction, until he was convinced, that the requirements of the theory were capable of practical realisation.

It was about this time, that he was called upon by Captain Blakely, who had then, and has since, devoted both time and money to the development of the same principle; although, at that period, Captain Blakely appeared to consider the practical solution

was by means of concentric rings, or hoops shrunk, or forced on, in successive layers over a central shell.

At the same time, although unknown to the Author, Mr. Mallet, (M. Inst. C.E.), was engaged in devising and constructing mortars on the same principle, and was assisted in his calculations by the mathematical ability of Professor Hart, of Dublin.

Mr. (now Sir William) Armstrong, (M. Inst. C.E.), was also engaged in the construction of a gun, depending for its strength upon external concentric layers; but the Author believes he did not then attach them under the varying initial tensions, which form the essential feature of the mode of construction advocated in this Paper.

And here it may be stated, by way of saving the time of the Institution, both now and during the discussion which may arise, that the principle brought forward is not simply that of strengthening guns by outer hoops. This mode of construction is probably the most ancient of all, and many specimens of it are to be met with, not only in Europe but in India and in China. It was subsequently abandoned, when the art of casting arrived at greater perfection, and has since only been reverted to as a means of strengthening cast-metal guns.

The principle alluded to is that of building up a gun, layer by layer, and in such manner, that each successive layer, proceeding outwards from the centre, shall be laid on with a tension exceeding that of those below it; so that in fact, the inner layers are in their normal state, in compression. It is to the validity of this principle, that the Author particularly invites discussion.

It has already been said, that the problem to be solved, is to make a gun that cannot be burst by gunpowder.

The first information required, is, therefore, an answer to the question,—what is the ultimate force of gunpowder; that is to say, supposing a close vessel to be filled with gunpowder and the gunpowder then exploded, without means of exit, what will be the pressure within the vessel?

According to Robins, the ultimate strength of gunpowder was valued at 1,000 atmospheres, or nearly 7 tons per square inch.

By Dr. Hutton, it was carried as far as 2,000 to 2,400 atmospheres, or from 14 tons to 17 tons per square inch.

It seemed, however, desirable to the Author, to ascertain, for himself, this important point. It occurred to him, that the most satisfactory way of doing this, was to prepare vessels of certain known strengths, then to fill them with powder, and having plugged them up so as to prevent escape, to fire the powder in the inside. He therefore made application for a quantity of Government cannon powder, and had a series of thin cast-iron cylinders prepared, each 1 inch in diameter, and $\frac{1}{16}$ th of an inch thick. These were bored and turned, so as to be exactly of the same dimensions,

and were purposely made of very hard and brittle iron, so as of themselves to give the minimum of strength. These cylinders were wrapped round with iron wire, the tensile strength of which was ascertained by actual experiment. The number of coils varied according to the degree of strength required, and each coil was laid on with the initial strain, which the Author's calculations led him to believe would, at the moment of bursting, cause all the coils to give way together.

These cylinders were filled with powder and the ends secured, leaving no vent, beyond a touch hole, the size of a small pin, through which the powder was exploded. Several of these, of course, burst, but at length it was found, that a cylinder, as above described, with ten coils of wire upon it, could not be burst.¹

Now the diametral section of the cast iron is $\frac{2}{10}$ ths of an inch, and taking its strength at 8 tons per square inch the result is:—

$\frac{2}{10}$ ths of an inch $\times$ 8 tons per square inch =	Tons. 1·6
There were ten coils of wire, each wire by experiment	
broke with 60 lbs., and was $\frac{1}{8}$ th inch in diameter, there-	
fore the tensile strength of the two sides =	
$2 \times 28 \times 60 \times 10 \div 2240 =$	15·0
Total strength . .	<u>16·6</u>

The internal diameter of the cylinder was exactly 1 inch; consequently it appears, that the ultimate strength of the powder did not exceed 17 tons per square inch.

The Author would, however, wish it to be understood, that he does not hold this to be the maximum effect that may be produced. The explosion of powder is more of an impact than a pressure, and although, strictly speaking, impact is only a pressure of short duration, the question of the length of this duration is generally admitted to have great influence upon the effect produced.

For instance, Professor Rankine states, that “a bar, to resist with safety the sudden application of a given pull, requires to have twice the strength that is necessary to resist the gradual application and steady action of the same pull.”²

This being so, it follows, that the more rapid the explosion, the greater is the strain on the gun. Not, probably, that the ultimate pressure is any greater, but that being produced in less time, its effect is greater. This is, probably, the cause of guns being more liable to burst when they get hot. It is not that the iron is

¹ One of these cylinders was exhibited.—EDITOR.

² *Vide* “Manual of Applied Mechanics,” p. 287.

weaker, for Mr. Fairbairn, (M. Inst. C.E.,) has shown, that up to 600° the strength of cast iron is not materially diminished; but when the gun is heated, the gunpowder gets warmed and burns more rapidly, and the force is generated and applied more suddenly.

Therefore, although the Author found, that the bursting effect of cannon powder did not exceed 17 tons per square inch, he is willing to admit, that it may, under peculiar circumstances, exert a greater force. At any rate it seems to him, that if it is sought to make the most of the force of gunpowder, the vessels in which it is employed should be capable of resisting, at least, this strain.¹

According to Professor Barlow's theory, no vessel, however thick, can permanently resist an internal strain greater than the tensile strength of the material. This being so, and the tensile strength of cast iron being about 8 tons per square inch, it is hopeless to look to that material for such strength as is required; and it does seem strange, that the use of this material should be persisted in, and that experiment after experiment should be made, in search of that which is as impossible to be found as the philosopher's stone, viz., a means to make cast iron alone, endure more than its ultimate strength.

It may be true, as was remarked to the Author, by a military officer of high position, that formerly, guns did not burst as they now do. Possibly, guns in those days had not the same amount of work to do? The first rails laid on the Liverpool and Manchester Railway weighed about 35 lbs. per yard, and they did their work well, for a time; but when heavier engines and greater speeds were arrived at, heavier rails were required; and so it is with guns. Much greater care is now taken in testing the purity of the component materials of gunpowder, and therefore, it is probable, if not certain, that the rapidity of combustion must be greater. This, and the increased size of guns, will easily account for the greater number of casualties, without seeking for the cause, either in the assumed deterioration of iron, or the asserted dishonesty of contractors.

The Author is not disposed to think, that either the strength of English iron, or the honesty of English contractors is less, than in what used to be termed the good old days of the war; but he does think, that the strength of powder is greater and the results sought from it much greater, than in former days.

Therefore, without expressing any opinion on the policy of creating Government establishments for construction, he would raise his voice against the assertion, that such were rendered necessary by either the incapacity, or the dishonesty of private firms.

¹ *Vide* Note on the Strength of Powder in the Appendix, p. 322.

It has been stated, that no 68-pounder in the service can be fired, with safety, with a full charge of powder. It is, further, a matter of notoriety that several of the Lancaster guns were burst. Of the Sweaborg 13-inch mortars it is needless to speak. All this ought to prove, that cast iron has been taxed beyond its strength. As this does not seem to be universally admitted, it is necessary, before proceeding with the peculiar subject of this Paper, to say a few words on the causes of failure of cast-iron guns.

In the first place, the actual strength of the interior of a large gun, or mortar, is far below that of the average of ordinary castings, and always must be so, whilst guns are cast solid. So long as this is the case, the outside must cool and solidify first, whilst the interior, cooling more slowly, must be drawn and be rendered less dense, and consequently, *cæteris paribus*, less resisting. This is an operation of nature which no care in selecting material can overcome.

The worst part of this iron, in the chase of the gun, is afterwards bored out; but still the metal around the internal circumference is weakened below the average, and at the bottom of the powder chamber it is in the very worst possible condition. The sudden changes of dimensions, at various parts of the gun, are also sources of weakness, as has been pointed out by Mr. Mallet,¹ who bases his views upon the theory, that the principal axes of the crystals arrange themselves in the direction of the flow of heat outwards, and that whenever re-entering angles, or sudden changes of dimensions occur, planes of weakness are thereby produced.

This explanation depends too much upon, what appear to the Author to be, arbitrary assumptions, to enable him to place much confidence in it. He has examined carefully many cases of fracture of cast iron, but in no instance has he been able to satisfy himself, that the crystals have that definite direction which would justify him in determining thereby, a plane of weakness. They have always appeared to be a confused mass of more, or less, defined crystals, but certainly not so arranged, that he could ascertain any uniform direction of what Mr. Mallet calls their principal axes.

The Author thinks, that without having recourse to this theory, the law of cooling alone will fully account for the source of weakness in the cases in question. Whenever a variation in thickness occurs, a difference in the rate of cooling must also take place. This alone must give rise to a state of varied stress, amongst the particles of the metal, which, without doubt, diminishes its effi-

¹ Vide "On the Physical Conditions involved in the Construction of Artillery." By R. Mallet. 4to. Dublin, 1856.
[1859-60. N.S.]

ciency as a resisting substance. In ordinary castings this is too well understood and admitted, to require further remark. But the same law operates in guns, though, perhaps, to a less obvious extent.

Take, for instance, the accompanying sketch of a gun, (Fig. 1,) distorted in its proportions, for the sake of illustration, and sup-

Fig. 1.

pose it to have cooled down after casting. Although, in the present state of knowledge of the subject, it would be impossible to determine the absolute position of the isothermal lines, at any period of cooling, yet it is certain, they must approximate to the dotted lines, shown in the sketch; and following these lines according to some definite law, would be the lines of equal stress of the particles of the gun, when cold.

When, therefore, the gun is bored out, it is evident, that the inner circumference of the bore must be in a state of varying strain, and that strain is one of tension. Consequently, the internal part of the gun is, throughout, in an initial state of more, or less tension; and as regards its power to resist a tensile strain, it is inferior to the normal, or average strength of the material.

But beyond this, whenever a change of dimensions occurs, the cooling will give rise to varying strains, which may account for fracture taking place, at those particular places.

The Author does not, however, propose to follow this subject further. His main object is to show, that the inner portion of a gun, which has the greatest strain to resist, is by the process of construction, already weakened below the average strength of the material. How much below, he does not pretend to say, but a few well-devised experiments would throw great light on the subject.

The Blue Book recently issued, records the results of the experiments conducted by Lieut. Colonel Eardley Wilmot, at Woolwich. It contains a mass of information respecting the properties of a certain number of irons, but is altogether silent upon this most important element in the question of the use of these irons, in the construction of guns. The Author, therefore, contents himself with the statement of the fact, that the strength of the material next the inner circumference, is below the average strength of that material, as shown by experiments recorded in the Blue Book in question.

The next point to be considered, is the amount of strain to which guns are now subjected. In former days, guns were generally of less calibre, the powder was slower in combustion, and the windage was probably greater. But beyond all this, the modern introduction of the principle of elongated, instead of round shot, and of rifling, has to be taken into account.

A long shot has much more inertia, in proportion to its diameter, and to obtain the full benefit of rifling, it must fit tightly within the gun. Thus there is an increase of inertia and of friction, with a decrease of windage. The result is, that the shot is displaced more slowly, and the pressure of the powder behind is greatly increased; and, as practice shows, it is increased to such an extent, that the guns cannot bear it. Another point, not to be overlooked, is the increase of range, that is, of initial velocity, sought for in the present day. Under the old system, it is well known, the range was necessarily very limited. If the charge of powder was increased, beyond a certain point, the range was but slightly extended, for the simple reason, that as soon as the inertia of the ball was overcome, it moved forward and prevented the back pressure from accumulating; and it often happened, that part of the powder was actually blown out of the gun in an unconsumed state. But with a long tight-fitting, rifled shot, the pressure accumulates, to an extent previously unknown.

Enough has probably been said, to explain why it is, that guns, which formerly stood well, are incapable of resisting the strain now put upon them. The Author will only further observe, that it does seem to him remarkable, that persistent efforts should be still made, to do that which experience had shown to be impossible.

Guns of the ordinary construction have been handed over to mechanics of the greatest ability, to be rifled. The Author

ventures to predict, that utter failure will be the result. They were scarcely strong enough to bear their old work, and must inevitably give way, when a vastly increased strain is put upon them. The fact of cast-iron guns failing has, however, become admitted; but, unfortunately only so far, that the failure has been laid at the door, either of inferiority of material, or of dishonesty of purpose. As a result, a national Gun Foundry has been established, at enormous expense, for the express purpose of making cast-iron guns.¹

The Author does not doubt, that by great care in selecting and manufacturing the best material, results may, perhaps, be arrived at superior to the average under the old system. At the same time he feels, and believes, that many will participate in the feeling, that a new establishment of any description must always labour under disadvantage, when compared with old-established firms, who having obtained a reputation, and having abundant means at their command, are actuated quite as much by the wish to maintain that reputation, as by the desire of making money. Such firms know well, that their power of money-making depends on keeping up their character; and though the former is the essence of all commercial transactions, it is very far from being antagonistic to the production of a first-rate article.

To return to the subject. Cast iron has been tried and found wanting. The initiative, in seeking a new material, has not been taken by Government establishments, but by private individuals, who have devoted much time and money to the subject.

Wrought iron and steel have been tried, and in point of workmanship magnificent results are arrived at, though at enormous expense, as regards large guns. Taking the tensile force of the one at 20 tons and of the other at 40 tons per square inch, and the force of gunpowder, as above stated, at 15 tons, it would appear, that either of these materials would comply with Professor Barlow's requirements. But in practice is it so? Upon this, the Author is not able to pronounce a definite opinion; but the same objections apply, as to guns of cast iron, viz., that the inner part of the gun must be in a state of initial tension. The expense and difficulty of manufacture are, also, very great.

As the finest specimen of that kind of manufacture, the steel gun forged by M. Krüpp, and afterwards bored and mounted in a cast-iron jacket at Woolwich, may be instanced. That gun is stated by Mr. Mallet² to have been bored out to 8 inches, and to have been from 4 inches to $4\frac{1}{2}$ inches thick. Taking the tensile force of hammered cast steel at 40 tons per square inch, the resist-

¹ This was written in November, 1859.—AUTHOR.

² *Vide* Mallet's "Construction of Artillery, &c.," Appendix, p. 235.

ance would be from 320 tons to 360 tons, which, if the strain had been uniform throughout, would have been equal to between 40 tons and 45 tons per square inch, on the diameter; yet the gun burst at the first discharge, with 25 lbs. of powder and a 260-lbs. shot.

Mr. Mallet next mentions a wrought-iron 8-inch gun, forged at the Gospel Oak Ironworks, and proved at Woolwich, on the 12th of July, 1855, which burst into several pieces at the first discharge. This gun is stated to have been of very nearly the same dimensions as the established cast-iron guns of the same calibre. The thickness at the breech end was, therefore, about 9 inches; and taking the tensile force at 20 tons per square inch, the material, provided it had been uniformly strained, ought to have resisted a diametral strain of 360 tons, or about 45 tons per square inch. This gun, which to the eye, presented, both externally and internally, an appearance of entire soundness and perfection of material, burst with a proof charge of 28 lbs. of powder and two spherical 8-inch shot.

The next gun spoken of by Mr. Mallet is that which burst on board the United States frigate, 'Princeton,' in 1842, or 1843. He gives the very interesting Report of the Committee of the Franklin Institute on this gun, and on the material of which it was made. Amongst other experiments, were those made to determine its tensile strength. First, in the original bar; secondly, in a bar cut from interior of the gun; thirdly, in a bar made from a portion of the gun, re-worked under the hammer.

The mean tensile strength per square inch of the original bar was :—

1st Bar	46,086 lbs.
2nd „	38,595 „
3rd „	52,521 „

Other experiments made from the same iron gave the following results :—

- “ 1. The average tensile force with which the specimens from the interior of the gun broke, when strained in the direction of the fibre, is less than 32,100 lbs.
2. The specimen from the interior, strained in a direction across the fibre, gave 23,700 „
3. The specimens from the outside of the gun, across the fibre, gave an average of less than 45,333 „
4. Annealed specimens from the interior, strained lengthwise of the fibre, gave an average of 36,067 „

5. The average of all the specimens from the gun, not hammered, is 33,300 lbs.
6. The average of the specimens worked down under the hammer, is 63,475 „

“The general conclusions, from these results, are the same as those from the experiments made by the Committee in Boston, so far as the two series can be compared.

- “1. The average strength of the iron, as it existed in the gun, from both series, is . . 33,586 lbs.
2. The average strength of the iron from the gun, after being drawn down with the hammer, from both series, is 59,824 „
3. The average strength of the original bars from the experiments of the first series, is . 46,950 „ ”

Consequently, taking the original strength as 100, that of the average of the iron, as existing in the gun, was 72, showing a deterioration of 28 per cent. ; and if the tensile force of the interior is taken, when strained in a direction across the fibres, that being the actual direction of the strain in the gun, the proportion to the original bar is as 50 to 100, or a deterioration of 50 per cent.

The Committee state, in conclusion, their “opinion, that, in the present state of the arts [in 1844], the use of wrought-iron guns of large calibre, made on the same plan as the gun now under examination, ought to be abandoned, for the following reasons:—

- “1. The practical difficulty, if not impossibility, of welding such a large mass of iron, so as to insure perfect soundness and uniformity throughout.
2. The uncertainty, that will always prevail, in regard to imperfections in the welding ; and
3. From the fact, that iron decreases very much in strength, from the long exposure to the intense heat necessary in making a gun of this size, without a possibility, with the hammers at present in use in this country [in America], of restoring the fibre by hammering.”

The Author, though dissenting from the views expressed in the last paragraph, inasmuch as he does not believe that long exposure to heat alone will deteriorate the iron, nor that any amount of hammering will restore its fibre, is inclined to agree with the two first reasons, for abandoning the construction of forged wrought-iron guns of large dimensions.

It is true, that the Mersey Iron Company, by great skill, and a thorough knowledge of their trade, and by the appliances at their command, have succeeded in forging the magnificent gun which, with a liberality equal to their enterprise, they presented to the nation. But so far as the Author knows, that gun is as yet only an

experiment; and he has even seen it stated, that already it is beginning to show symptoms of cracking in the interior.

Speaking of wrought-iron guns, Mr. Mallet says:—¹ “The facts [which he has previously stated] are worthy of notice, as indicating the absolute uncertainty that ever must exist as to the trustworthiness of wrought-iron guns, forged in one great mass, although executed without regard to cost, and by parties anxious faithfully to produce a result of the highest excellence. Some of the evils incident to this gun might have been avoided by greater experience and judgment; but the main evil is inherent, and inseparable from every huge forging, and most so where the weldings are most numerous.”

On the other hand it should be mentioned, that Mr. Clay, of the Mersey Iron Works, differs from Mr. Mallet, and very justly observes, that “the several failures in the manufacture of wrought-iron guns should not be a matter of surprise; for it is hardly reasonable to expect immediate success in any new fabrication.”²

Mr. Clay, in the same publication, gives an account of experiments to determine the tensile strength of the iron from which the monster gun was made, and of the same iron, after manufacture into the gun. The results were as follows:—

Experiment.	Description of Iron.	Breaking strain in lbs. per sq. in.	Average.
No. 1.	Original iron of which the gun was made	48,384	49,504
No. 2.	Ditto ditto	50,624	
No. 3.	Cut across the grain from muzzle of gun	41,644	43,390
No. 4.	Ditto ditto	43,904	
No. 5.	Ditto ditto	50,624	
No. 6.	Cut with the grain from muzzle of gun	48,384	50,624
No. 7.	Ditto ditto	50,624	
No. 8.	Ditto ditto	52,864	
No. 9.	Borings from gun re-worked with coal	60,584	61,704
No. 10.	Ditto ditto	62,824	
No. 11.	Borings from gun re-worked with charcoal	76,584	76,584
No. 12.	Swedish iron as imported, $\frac{3}{4}$ inch square	60,584	60,584

Taking the average of the first two experiments, and comparing it with that of the following three, there is a decrease of strength of about 13 per cent., whilst on the other hand, as compared with

¹ Vide Mallet's "Construction of Artillery, &c.," page 239.

² Vide Orr's "Circle of the Industrial Arts," page 331.

the 6th, 7th, and 8th, there is a gain of strength of 2 per cent. These experiments are not, however, so conclusive as those previously quoted, as the iron was cut from the muzzle of the gun, and not from the interior, at the breech, where the thickness is greatest, and the deterioration is, necessarily, the most.

To sum up this part of the question, the Author is, perhaps, justified in saying, that the manufacture of large forged wrought-iron guns is an operation of great difficulty, expense, and uncertainty, and however the difficulty and expense may be decreased, the uncertainty must still remain. Moreover, at the best, it is but substituting for cast iron a material of a higher tensile strength; the radical defect of a homogeneous mass still remaining, viz., the unequal distribution of the strain, from the inner to the outer circumference. The same remarks apply, with still greater force, to guns of hammered cast steel of large dimensions.

The Author has already pointed out the principle, which appears to be the basis of a sound and reliable construction. It is that of manufacturing the gun of successive layers, laid on with an original increasing strain from the centre to the circumference.

The Author claims no exclusive merit for this idea. It appears to have been entertained both by Mr. Mallet and Captain Blakely, and perhaps by others. In 1855, when he mentioned the principle to Sir William Armstrong, and described the method he proposed for carrying it into effect, by means of wire, that gentleman said, Mr. Brunel had also entertained the same idea, and had spoken to him with reference to making a gun on this principle; but finding that the Author was already engaged on it, he had dropped the subject.

Leaving, therefore, aside the generally unimportant and always unsatisfactory inquiry as to priority of invention, the Author will describe his own course of proceeding, commenced in entire ignorance of what others either had done, or were doing.

In the outset, the Author foresaw great practical difficulty in the use of hoops, whether shrunk on, or forced on. Since then, the subject has been investigated mathematically by Dr. Hart, and more recently, at the Author's request, by Mr. C. H. Brooks, as given in the Appendix, (page 329,) to whose results attention is directed.

In the first place, then, there is an objection to the use of hoops from the want of continuity. The special requirement is, that each layer of the gun shall be in a definite initial state of tension, or compression, previous to explosion. If in Fig. 2, (page 297,) A B C D, represent a portion of a section of an 8-inch gun, of which A G B is the inner, and D F C, the outer circumference, the state of tension of any particle between G and F may be denoted by ordinates drawn at the points in question, those above G F representing tension, and those below, compression.

Fig. 2.

[1859-60. N.S.]

X

Fig. 3.

Fig. 4.

Fig. 5.

If, now, the gun is of any homogeneous material, such as cast iron, the state of tension at the time of explosion, and when the gun is about to burst, will be denoted by a curve $H I$, or $H i$, the former calculated according to Professor Hart, and the latter according to Professor Barlow's formula. Then, supposing the tensile force of the material to be 12 tons per square inch, and the thickness of the gun $6\frac{1}{2}$ inches, when the strain at G is $G H$, or 12 tons, at F it is $F I = 3$ tons, or $F i = 1\frac{3}{4}$ ton, according as the one, or the other formula is adopted. The areas of these curves give, of course, the total strengths of the gun at the bursting point, and are found to be $36\cdot72$ tons and $30\cdot871$ tons respectively, instead of 78 tons, which it would have been if uniformly strained at 12 tons per square inch.

Now the object sought to be attained, in the method of construction under consideration, is, that each particle such as K , shall, when explosion takes place, be equally strained with G . In order that this may be so, the initial state of the tension must be such as is represented by the curve $L N M$, those between G and N being in compression, while those between N and M are in tension.

If, now, it is attempted to accomplish this by means of hoops, it will be found impossible, inasmuch as each hoop is a homogeneous cylinder, and follows the same law throughout its thickness, as is represented by the curve $H I$.

Figs. 3, 4, and 5, (page 298,) represent the successive states of stress of our rings, put on so as that when the explosion takes place, they shall be all equally strained at their inner circumferences.

Fig. 3 shows two rings.

4 „ three „

5 „ four „

The figures denote the strains, in tons per square inch.

From this it will be seen, that when the four rings are put on, instead of the curve $L N M$ of Fig. 2, there are a series of abrupt changes, the two inner rings being in compression and the two outer in tension.

When the explosion takes place, the state of maximum strain is represented by the next diagram, Fig. 6, (page 300).

The area between the dotted and the full lines, shows the work done by the explosion, and taking the total thickness of the gun, it amounts to $10\cdot1$ tons per inch of thickness; whereas, had the construction been of very thin rings, or of small wire, it would have been represented by the area between the dotted line $L N M O H$, (Fig. 2, page 297,) and would have been = 12 tons per inch of thickness, showing a superiority of about 20 per cent. in favour of the wire, over the hoops.

This is upon the supposition, that the workmanship of the hoops is perfect, which in practice cannot be attained. To afford some

Fig. 6.

idea of the accuracy required, the radii of the several rings, shown in the above diagram, are given in the following Table :—

No. of Ring.	Inner Radius.	Outer Radius.	Thick-ness.	Differences.
1	4.0000	5.3222	1.3222	$R_1 - \rho_2 = .0031$
2	5.3191	7.2928	1.9737	$R_2 - \rho_3 = .0035$
3	7.2893	9.4633	2.1740	$R_3 - \rho_4 = .0035$
4	9.4598	11.8247	2.3649	

Thus, it appears, that in order to give the requisite amount of initial stress, the external radius of the first ring must be $\frac{31}{10000}$ ths of an inch, or about $\frac{1}{300}$ th of an inch larger than the internal radius of the second: the external radii of the second and third $\frac{35}{10000}$ ths of an inch greater than the internal radii of the rings next to them. Therefore, whilst the whole effect depends upon so small a quantity as about $\frac{1}{300}$ th of an inch, it is evident, that a very small error in workmanship will materially affect the result,

and may tend to the most serious deviations from the proper initial strains.

This is a point of so much importance, that the Author has prepared the following diagrams, (Figs. 7 and 8, page 302,) to show the result of an error in workmanship, of $\frac{1}{500}$ th part of an inch, in the size of the outer ring.

Fig. 7, represents the states of stress of the rings before explosion, and at the instant of maximum strain, when the rings are accurately put on.

Fig. 8, represents the states of stress of the same gun, when the outer ring has been made $\frac{1}{500}$ th of an inch too small.

The result is, that before explosion, the maximum compression of the inner ring is increased from 10·086 tons to 11·244 tons, and the maximum tension of the outer ring from 5·778 tons to 7·823 tons per square inch; whilst at the time of maximum strain, during explosion, the tension of the same ring is only 2·268 tons, although the outer ring is strained to 12 tons, its assumed ultimate strength. The absolute strength of the gun is thus reduced from an average of 10·5 tons to 6 tons per inch of thickness, or about 40 per cent., by an error of only $\frac{1}{500}$ th of an inch, in a ring of about 17 inches in diameter.

Rings, therefore, present practical difficulties, which are entirely avoided by the use of wire, as it may be coiled on with the exact strain indicated by theory.

The method adopted by the Author, was to coil a quantity of wire on a drum, fixed with its axis parallel to that of a lathe on which the gun was placed. On the axis of this drum, there was another drum, to which was applied a break, similar in principle to Prony's dynamometric break, so adjusted, as to give the exact tension required for each successive coil of the wire. The whole apparatus was extremely simple, and the wire was laid on with great regularity. Indeed it is evident, the apparatus might be so arranged, as that the process would proceed with the same ease and regularity, as winding thread on to a bobbin, and at the same time, with the greatest accuracy as regards the initial tension.

No such facility attends the use of hoops. They must be accurately bored, and after each layer is put on, the gun must be placed in the lathe, and the hoops be turned on the outside. Great accuracy of workmanship is indispensable; and not only is the amount of labour much greater, but it must be of a far higher, and consequently, of a more expensive class.

Then, as to accuracy of tension with hoops. The Author looks upon its attainment as almost impracticable. He is convinced, that the process of shrinking on is not to be depended upon. Not only is there a difficulty in insuring the exact temperature re-

Fig. 7.

Fig. 8.

The dotted lines denote the state before, and the full lines after, explosion.

quired, but scarcely any two pieces of iron will shrink identically, and when the $\frac{1}{500}$ th part of an inch of contraction would give rise to a great variation in tension, the necessity of perfect accuracy is apparent. But, it has been proposed, and the Author believes it is now solely advocated by Captain Blakely, that the hoops shall be forced, by hydrostatic pressure, on to a gun slightly conical, in longitudinal sections.¹ Here again occurs the practical difficulty of the attainment of extreme accuracy of workmanship, involving the highest class of skilled labour, and the greatest vigilance of supervision.

In the next place, hoops must always possess the defect of want of continuity of substance. However perfect the workmanship at first, the Author feels satisfied, that in large guns, the concussion of repeated firing would, ere long, shake them loose. Those who have had to do with heavy machinery, subject to violent jars, such as rolling mills, and forge hammers, well know how impossible it is to keep iron and iron, however well fitted, working together for any length of time, without shaking loose. The only remedy is to separate the pieces of iron from each other, by a packing of elastic material, so as to take off the jar. Now, the concussions in such machinery are insignificant, as compared with those in a large piece of ordnance, and, therefore, the use of hoops for large guns cannot prove satisfactory.

In the year 1854, Captain Blakely, R.A., laid this method of construction before the Ordnance authorities; but meeting with little encouragement, he took out a patent, in 1855, for a method of making guns. The specification of this patent, sealed 14th August, 1855, and dated 27th February, 1855, contains the following passage:—"I do not claim, as my invention, the method of forming guns, or cannon, by the application of collars, or rings heated, or shrunk upon a cylindrical inner tube, save and except, when the internal diameter of such collars, or rings, are, previously to being heated, so much smaller than the external diameter of the inner tube, on which they are shrunk, that after being cooled, the outer covering, formed by the rings, or collars, is in a state of tension, or permanent strain, similar to that produced, when the rings, or collars, are forced upon a conical surface, as before described, and the inner tube is, in both cases, similarly compressed."

This passage shows, that Captain Blakely clearly appreciated the advantages of the principle of construction which is the subject of this Paper, although seeking for practical results in a different method.

It is, however, due to Captain Blakely to record, that although

¹ In the course of the discussion, it appeared that this was the method now adopted by Mr. Whitworth.—AUTHOR.

he then looked chiefly to hoops, or collars, the idea of spirals, or rods of iron, or wire, was also present to his mind; for in a subsequent part of his specification, he distinctly refers to an outer covering of wire, or rods wound spirally in one, or more layers, for the purpose of strengthening old guns.

In an interesting lecture, delivered by Captain Blakely, at the United Service Institution, on the 21st of January, 1859, he gives an account of his experiments and endeavours to introduce this principle of construction to the notice of the Government authorities. In that lecture were recorded many very interesting facts and Captain Blakely's reasonings thereon; but it is to what was actually accomplished by Captain Blakely, that the Author wishes to direct attention.

Fig. 9.

Captain Blakely's first gun was an 18-pounder, (Fig. 9,) consisting of one series of wrought-iron rings, shrunk on a cast-iron cylinder, $5\frac{1}{2}$ inches in diameter inside, and $1\frac{3}{4}$ inch thick. The wrought-iron rings were from 2 inches thick downwards. The total thickness of the breech was $3\frac{3}{4}$ inches, that of the ordinary 18-pounder service gun being $5\frac{3}{4}$ inches. This gun was fired frequently and stood well. It was then bored out as a 24-pounder, but not being truly bored, the cast iron was reduced, on one side, to only $\frac{1}{2}$ inch thick. In this state, it sustained, without injury, several hours' firing, with charges varying from one shot and 4 lbs. of powder, to one shot, two wads, and 8 lbs. of powder. At the third round, with this latter charge, it burst. This gun had a thickness of only $2\frac{1}{2}$ inches round the charges, as compared with a service 24-pounder, of 6 inches in thickness.

Captain Blakely next got a 9-pounder turned down, from the trunnions to the breech, and on this part he put wrought-iron rings of such a size as to replace the metal removed. (Fig. 10.)

Fig. 10.

This gun was fired, round for round, with a cast-iron service gun of the same size and weight. The following Table gives the result :—

No. of Shot. Blakely.	Charge of Powder.	No. of Shot.	No. of Rounds Fired.		No. of Shot. Fired from Service Gun.
			Blakely's.	Service.	
	Lbs.				
4	8	2	2	2	4
86	3	1	86	86	86
26	4	1	26	26	26
5	5	1	5	5	5
10	5	2	5	5	10
636	6	2	318	110	Burst 220
3	6	3	1	..	..
4	6	4	1	..	..
5	6	5	1	..	..
6	6	6	1	..	..
7	6	7	1	..	..
8	6	8	1	..	..
9	6	9	1	..	..
1,580	6	10	158	..	..
2,389			607	234	351

Thus, it appears, that Captain Blakely's gun stood 607 rounds, and the government service gun only 234 rounds; the number of shot thrown being 2,389 and 351 respectively, or nearly as 7 to 1.

The subsequent experiments, made by Captain Blakely, are described in his lecture; but enough has been said to show, that he had gone a long way to prove, practically, the truth of the principle. He did not, however, succeed in convincing the Government officials, as may be gathered from his pamphlet, published in 1859. His calculations having been reported upon by Mr. Heather, a mathematician, the system was declared inapplicable to cannon, by the Ordnance Select Committee, in a letter from which the following paragraph is an extract:—

“I am directed by Mr. Monsell to acquaint you, that the Committee, taking into consideration the different expansive powers of wrought and cast iron, are of opinion that guns so constructed could never be considered safe, as they might burst at any time, and the splinters from them would be very dangerous, (as shown in the late experiments,) and the Committee do not therefore recommend further experiments to be made with guns of this description.”

In spite, however, of the opinion thus expressed by the Committee, it must be admitted, that Captain Blakely deserves great credit, for the spirit and perseverance with which he has, at great cost to himself, attempted to introduce a decided improvement into the arm of the service to which he belongs.

It was, however, in entire ignorance of what others were doing, or had done, that the Author arrived at the conclusion, that the construction, by means of wire, offered the greatest probability of

success, and to that construction exclusively he devoted his attention. The first point to be settled was, the amount of initial strain to be put on each coil.

The formula adopted by the Author was one based upon Professor Barlow's investigation, above referred to, and was :—

$$t = T \cdot \frac{x^2 - r^2}{x^2} \quad . \quad . \quad . \quad (1)$$

Since the publication of Mr. Mallet's book, the Author has become acquainted with Professor Hart's investigation, the formula obtained from which is, as given therein :—

$$t = T \cdot R \cdot \frac{x^2 - ry}{x(r + y)}.$$

This, in the case of small wire, is nearly :—

$$t = \frac{TR}{x} \cdot \frac{x - r}{x + r}.$$

These, however, are general formulæ which require modification, according to the varying circumstances of each case, before they can be applied to practice.

Without entering upon any discussion of these formulæ, the Author proceeds to describe the results obtained from his own experiments on cylinders prepared according to formula (1).

The method of conducting them was as follows. A number of brass cylinders were prepared exactly of the same dimensions, viz. :—

Internal diameter 1 inch.

External diameter $1\frac{3}{16}$ „

Thickness of brass $\frac{3}{32}$ „

These cylinders were accurately turned and bored, and had a flange $\frac{1}{4}$ inch in depth and $\frac{1}{8}$ th inch in thickness, at each end. Each end was widened out, so as to afford seating to two gun-metal balls, which were accurately ground to fit them. The total content of each cylinder, with the balls in their places, was 300 grains of best sporting powder, which was alone used in this series of experiments. When the powder was put into the cylinder, and the balls were placed at each end, the whole was bound together by a very strong wrought-iron strap, similar to the strap of a connecting rod, with a jib and cotter. The cotter was driven tightly home, and the powder was then fired through a small touch-hole, left in the side of the seating. (Fig. 11.)

The first experiments were to ascertain the effect of the powder on the cylinders, without any wire. They were commenced with charges of powder, beginning at 50 grains, and increasing till the cylinder burst.

After this, cylinders with different thicknesses of iron wire, were tried in a similar manner.

Fig. 11.

The results are given in the following Table :—

EXPERIMENTS ON BRASS CYLINDERS.

No. of Experiment.	No. of Cylinder.	Condition.	Charge of Powder.	Effect.
			Grains.	
1	1	Without wire	50	Slightly bulged.
2	„	Ditto	60	Bulged a little more.
3	„	Ditto	70	Ditto external diameter $1\frac{5}{16}$.
4	„	Ditto	80	Ditto ditto $1\frac{7}{16}$.
5	„	Ditto	90	Burst.
6	2	2 coils of wire $\frac{1}{32}$ inch.	90	No effect.
7	„	Ditto, one end loose .	100	Bulged at loose end.
8	3	Without wire	70	Bulged to $1\frac{11}{32}$.
9	4	Six coils $\frac{1}{64}$ wire . .	100	No effect.
10	„	Ditto	110	Ditto.
11	„	Ditto	120	Ditto, one end of wire came loose.
12	„	{ Same cylinder with one } coil of $\frac{1}{32}$ wire . . }	100	{ Burst—the end of the wire being badly fastened. Wire not injured.
13	5	Two coils of $\frac{1}{32}$ wire .	100	No effect.
14	„	Ditto	120	Ditto
15	„	Ditto	130	Ditto
16	6	Four coils of $\frac{1}{32}$ wire .	120	Ditto
17	„	Ditto	130	Ditto
18	„	Ditto	140	Ditto
19	„	Ditto	150	Ditto
20	„	Ditto	160	Ditto
21	„	Ditto	170	Ditto
22	„	Ditto	180	Ditto
23	„	Ditto	200	Ditto

The strength of the wire used in these experiments was ascertained, by trial, to be as resisting a dead tension :—

$$\begin{array}{rcl} \frac{1}{64} \text{ wire} & . & . \quad 23 \text{ lbs.} = 120,000 \text{ lbs. per square inch.} \\ \frac{1}{32} \text{ ,,} & . & . \quad 70 \text{ ,,} = 92,000 \text{ ,,} \quad \text{,,} \end{array}$$

If now, the expansive force of powder is taken to be inversely as the volume, its ultimate strength may be approximately arrived at from the last experiment. The powder then could not burst the cylinder. Now the strength of the cylinder, supposing all the material to be equally strained, could not exceed the following per lineal inch of cylinder :—

$$\begin{array}{rcl} \text{Wire} & . & . \quad 17,920 \text{ lbs.} \\ \text{Brass} & . & . \quad 3,136 \text{ ,,} \\ \hline & & 21,056 \text{ lbs., or } 9.4 \text{ tons.} \end{array}$$

And as the internal diameter was exactly 1 inch, it shows, that the ultimate force of the material in Experiment 23, did not exceed 9.4 tons per square inch. Assuming the law, as above, the ultimate pressure, supposing the cylinder to have been full, could not exceed $9.4 \times \frac{300}{200}$, or 13 tons per square inch.

The enormous strain, to which these cylinders were subjected, is evidenced by the effects upon the gun-metal balls, which were more, or less cut away by the gases, where they touched the cylinders.

These experiments, made on the 17th of May, 1855, were so satisfactory, that the Author proceeded to one on a larger scale. This consisted of a brass cylinder, of nearly the same internal dimensions as a 3-lb. mountain gun, say 3 inches in diameter, and about 36 inches long. The drawing of this cylinder has unfortunately been lost, but it is approximately represented in Fig. 12, from which it will be seen, that the thickness of the

Fig. 12.

brass was $\frac{1}{4}$ inch. At the breech end, it was covered with six coils of steel wire, square in section, and of No. 16 wire gauge, or $\frac{1}{16}$ th of an inch. These coils extended about 15 inches along the cylinder, and were gradually reduced to two coils only, towards the muzzle. Consequently, the thickness of the cylinder was as follows :—

At the breech $\frac{1}{4}$ inch brass + $\frac{3}{8}$ inch iron = $\frac{5}{8}$ inch.
 „ muzzle $\frac{1}{4}$ „ + $\frac{1}{8}$ „ = $\frac{3}{8}$ „

The thickness of the 3-pounder gun, with which it may be compared, being:—

At the breech . . . 2.37 inches.
 „ muzzle . . . 0.75 „

It will be seen, that this cylinder was not mounted as a gun. It had no trunnions. It was cleaded with wood; and the object of the deep steel ring, which was screwed on the muzzle, was simply to cover the ends of the cleading. The cleading had nothing to do with the principle involved, and was only used to screen the construction from general observation.

This cylinder was proved, with repeated charges, varying from $\frac{1}{2}$ lb. of powder and one round shot, to $1\frac{1}{2}$ lb. of powder and two shots. The cylinder was simply laid on the ground with a slight elevation, its breech abutting against a massive stone wall, so as to prevent recoil. It stood the proof without injury, and the Author, on the 19th of June, 1855, addressed a letter to Lord Panmure, then Secretary of War, describing the experiments and the results, and offering the invention to the country.

As was then the fashion, he was referred to the Select Committee, and on 5th of July, 1855, he had an interview with that body, when he explained his views, and exhibited the small brass cylinders as well as the larger one last referred to, which he left, with the request that it might be proved, first as a 3-pounder gun, and then by gradually increasing charges up to bursting.

He remained in London, for some time, hoping to be present at these trials; but other matters called him away, and it was not till the 28th of July, 1855, that the trials were made. Unfortunately as it happened, the Author was unable to be present. The next official communication was a letter from the Ordnance Office, dated the 17th of September, containing a copy of the Report of the Select Committee in the following terms:—

“ On the 28th of July a trial was made with Mr. Longridge’s gun. The gun was clamped on a block of oak with iron clamps, and allowed to recoil on a wooden platform. Two rounds were fired, the first with a charge of 1-lb. powder, 1 shot, (fixed to wood bottom,) and one wood over the shot: the recoil was 7 feet; the gun was found to have slightly shifted its position on the block; a trifling expansion of the wire had also taken place at the breech.

“ At the second round the gun was fired with 2 lbs. of powder, 1 shot, and 1 wad, and burst: the separation took place about 2 inches in front of the base ring; the breech was completely separated from the rest of the gun, and was blown 90 yards directly to the rear. The wire was unravelled to the length of

3 or 4 feet, the brass cylinder burst in a peculiar manner, turning its ends upwards and outwards. It also opened slightly at the centre of the gun ; but the wire did not give way at that point.

"The ordinary proof charge for a gun of this diameter would be $1\frac{1}{4}$ lb., 1 shot, and 1 wad.

"In order to try more particularly the effect of the wire in giving strength to the cylinder, this gun was, after bursting, sawn in two at the centre, and one end of each portion was plugged with a brass plug, which was secured in its place by iron bands and several coils of wire : these guns were then secured to slides of wood as in the former instance ; they were placed opposite the proof butt, and that made from the breech end was loaded with $\frac{1}{2}$ lb. powder and shot. It burst, the breech being blown out and the wire uncoiling to a considerable extent.

"The muzzle portion was then loaded with a similar charge ; it did not burst, but was much shaken by the discharge, and portions of the iron bands gave way. It was then loaded with a charge of 1 lb. of powder and 1 shot, which on discharge burst in two places, the breech being completely separated from the gun and the slide on which it had been fired was rent into several pieces."

Previous to the receipt of the official communication, the Author had, through the courtesy of one of the members of the Committee, been informed of the result obtained. Feeling satisfied that the failure of the cylinder was due to some unexplained cause, he wrote to Lieut. Colonel Eardley Wilmot, begging for some further information, and particularly with respect to the method adopted for firing the gun, during the trials. Colonel Wilmot kindly lost no time in forwarding a sketch, showing the method of mounting, and this sketch at once explained the whole affair. The cylinder had, in fact, not burst at all, but had been torn asunder by the recoil. Fig. 13, which is taken from Colonel Wilmot's sketch, shows how this occurred.

The deep projecting steel flange, at the muzzle, was in fact the *point d'appui*, and the only thing that surprised the Author was, not that it failed at the second trial, but that it stood the first.

The subsequent burstings, as they are termed in the above Report, were not burstings, but the plugs put into the ends as breechings were simply blown out.

The fragments of the cylinder were, afterwards, forwarded to the Author. Upon examination he found, that the metal was much honeycombed at the breech, where it gave way, and by bad boring had been reduced below $\frac{3}{16}$ ths of an inch in thickness on one side.

The Author, immediately after receiving the sketch, wrote again to Colonel Wilmot, pointing out the cause of failure. To this communication he received a reply stating, that Colonel Wilmot

believed, it was generally thought, that the experiment did not go to disprove the leading idea of his proposition, but that, on the contrary, the blowing out of the breech was an argument in favour of the barrel.

Fig. 13.

On the 21st of September, 1855, the Author again addressed the Ordnance Office, pointing out the cause of failure of the above experiment, and offering to construct a larger gun on the same principle.

In answer to this he received a reply on the 27th of September, 1855, the substance of which was contained in the following words:—"I am directed to inform you, that no further trial of your invention can be made at the public expense."

With, perhaps, some degree of obstinacy, the Author once more wrote to the War Department, repeating his reasons for desiring

another trial, and pointing out, that what had been done, had been at his expense, and not at that of the public. In answer to this he was informed, that the question was again referred to the Select Committee. Finally, he received a letter from the War Department, dated 25th of October, 1855, to the following effect:—"I have the command of the Secretary of State for War to inform you, that the Committee having referred to the details of an experiment made with it [*i. e.* the Author's invention], consider, that no further trial is necessary, with a gun of this construction."

Thus ended the Author's dealings with the War Department. The result was not encouraging, as regarded the prospect of getting the invention tried by the Government; but the Author had seen no reason to doubt the correctness of the principle. Other affairs imperatively claimed his attention, and the matter lay dormant, as far as he was concerned, for some months, when he commenced a new series of experiments.

Before describing them, he will, however, complete the history of the brass cylinder tried at Woolwich.

Having obtained possession of the fragments, he took a piece of the cylinder, about 2 feet long, and stripped off the wire, with the exception of two coils. It was then a brass tube 2 feet long and $\frac{1}{4}$ inch thick, with two coils of square steel wire, each $\frac{1}{16}$ th inch thick, making together $\frac{1}{4}$ inch of brass, and $\frac{1}{8}$ th inch of wire. In the middle of this, he put $1\frac{1}{2}$ lb. of Government cannon powder, and the ends were filled up with close fitting wood plugs, fixed tightly with iron wedges. A trench 3 feet deep was then dug in stiff clay, and the cylinder was laid at the bottom. At each end a railway sleeper was driven firmly into the clay, and the trench was then filled in with clay, well pounded with a heavy beater. (Fig. 14.) The powder was then fired by means of a patent fuze.

Fig. 14.

The wood plugs and sleepers were thrown out with great violence, and a large mass of clay at each end was blown out, but the cylinder was uninjured.

Determined, if possible, to burst it, the Author next put in 2 lbs. of powder, filled up the ends with close-fitting iron plugs, and bound the whole together with an iron strap, of a sectional area of 5 square inches, as shown in Fig. 15.

Fig. 15.

The powder was then fired, and the iron strap was torn asunder, but the cylinder was uninjured, except at the ends, where from the wire being imperfectly fastened, it uncoiled, and the cylinder was torn open. If the tensile force of the iron strap is taken at 18 tons per square inch, the force of the powder must have been above 13 tons per square inch, and yet this was resisted by $\frac{1}{4}$ inch of brass and $\frac{1}{8}$ inch of steel wire. The diametral strain must have been 39 tons, and taking the brass at 10 tons per square inch, it leaves 34 tons for the steel wire, which divided over the two sides, or $\frac{1}{4}$ inch, would give for the ultimate resisting strength of the wire so employed, not less than 136 tons per square inch of section. This wire, it should be observed, was of the finest quality.

The Author will now proceed to give an account of the second series of experiments made by him in March, 1856.

Many of those to whom he had described the experiments above recorded, whilst admitting the great increase of strength obtained, were yet of opinion, that it would be only practicable to apply the wire, in combination with a metal of a soft yielding nature, such as yellow brass, or pure copper. It was maintained, that it would be impossible to use the wire in combination with cast iron, owing to the assumed brittleness of that material, and it was objected, that the soft brass, or copper, would soon be worn out by the action of the shot, and the guns be rendered useless.

The Author's views were different. He looked on the inner shell simply as a means of confining the gases, and of transmitting the internal pressure to the wire; and knowing that cast iron would resist a crushing force of 40 tons, he was not afraid of subjecting

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it to a strain in a normal direction, which, at the outside, could not exceed the strength of powder, or 17 tons per square inch. But he was quite aware, that no reasoning would suffice. Therefore, in his second series of experiments, which are about to be described, he resolved to use cast iron alone, in its hardest form,—as produced in a thin casting.

Two sets of cylinders were prepared. One set was intended to try the effect of wire, in enabling hard cast iron to resist a bursting strain; the other set, with a view of ascertaining whether it was possible to transmit the force of the powder, through a thin breech of cast iron, to a yielding substance, placed between that breech and the carriage of the gun. The view, taken by the Author, of recoil and its effects, was this. Action and reaction being equal and contrary, it is evident, that the recoil of the gun must increase, when the velocity, or weight of the ball is increased, and the distance of recoil must also increase, if the weight of the gun is diminished. If, therefore, the Author should succeed in throwing a 9-lb. shot, with a gun of the size of a three-pounder, some means must be devised, of providing for the increased recoil. There were two ways of meeting this. The first was by such a disposition of the material of the gun, as would absorb the blow, with the least possible strain upon the gun carriage, and the least internal stress on the gun itself. The recoil is due to a pressure, which begins at the moment of ignition of the powder, increases very rapidly and again decreases, as the ball moves along the chase of the gun. This pressure is, however, so rapid in its generation, that, practically, it is almost like the blow of a hammer. But it is still a pressure of short duration and great intensity, and its tendency is to tear a gun asunder, between the breech and the trunnions, to tear off the trunnions, or to fracture the carriage, and finally, to tear asunder the part of the gun beyond the trunnions, by its own inertia. Thus, in fact, the whole of the recoil induces a tensile force on the chase of the gun.

Now it is well known, that if it is desired to absorb the force of a blow, it is best effected, by interposing a heavy deep mass behind it, and therefore, the Author proposed to concentrate the weight of his gun, as much as possible, behind the breech.

The blow, thus coming, in the first instance, on a heavy mass of metal, would, to a great extent, diminish the jar upon the carriage. Again, the effect of any concussion is greatly diminished, by a yielding material placed between the body striking and the body struck. As it might be desirable, for practical reasons, to separate the gun itself from the mass of material intended to absorb the recoil, the Author wished to ascertain how far it was practicable to transmit the force through a thin breech, or diaphragm of a hard brittle substance, like cast iron, to a soft

yielding material, like lead, and through it to the absorbing mass behind the breech. He did not expect to diminish the amount of recoil, materially, but to avoid those vibrations, which are so destructive between two hard metals in contact, and which always shake loose any system of bolting, or riveting, however perfect originally.

It was, with this view, that two distinct sets of cast-iron cylinders were prepared.

The first set was intended to try the possibility of transmitting pressure, as just stated, through a thin diaphragm.

The cylinders were of the dimensions shown in Fig. 16, in which

Fig. 16.

A is the powder chamber ;

B and B, cast-iron plugs ;

C, the space between the bottom of the powder chamber, and the plug B, filled up with a soft material ;

D, a wrought-iron strap, with jib and cotter, for keying up the plugs B and B.

The object was to ascertain, whether the diaphragm at E E, would be shattered by the force of the explosion. Six cylinders were thus prepared, and loaded, and fired with charges, varying from 50 grains to 250 grains of Government cannon powder, the total contents of the cylinders being 310 grains.

The following Table gives the results :—

Cylinder.	Wire.	Charge.	Results.	Material behind the diaphragm.
		Grains.		
No. 0	2 coils	50	No effect.	Lead.
		50	Ditto.	"
		100	Ditto.	"
		120	Ditto.	"
		150	Burst.	"
" 1	4 coils	150	No effect.	"
		180	Top flange burst.	"
" 3	6 coils	180	No effect.	"
		200	Ditto.	"
		220	Ditto.	"
		240	Flange burst.	"
" 6	8 coils	240	Ditto.	"
" 8	8 coils	200	No effect.	Gutta-percha.
		220	Burst.	Gutta-percha, softened by heat.
" 9	10 coils	240	No effect.	Lead.
		250	Flange burst.	

Iron wire, No. 21 wire gauge, or $\frac{1}{28}$ th inch in diameter, was used. Its breaking strain was 60 lbs. In no case was the bottom of the cylinder injured, except in the second experiment with cylinder No. 8, when the gutta-percha was softened by the heat of the first explosion.

The lead transmitted the force perfectly in every case ; showing conclusively, to the Author's mind, that there is no practical difficulty in transmitting the force through even so thin a diaphragm as $\frac{1}{10}$ th of an inch, even when of so brittle a material as cast iron.

After these experiments, the Author needed no others, to satisfy himself of the suitability of even very hard cast iron to transmit the force of gunpowder to wire, or any other absorbing material. As, however, other cylinders had been prepared, he proceeded to try their strength.

These cylinders are shown in Fig. 17.

Fig. 17.

They each contained 305 grains, when full to the plug. The plugs were made to fit accurately, and the powder was fired through a small vent, or touch hole, not larger than a small pin.

The following Table gives the results :—

No. of Cylr.	Wire.	Charge.	Results.	Remarks.
		Grains.		
No. 0	None	40	No effect.	
	Ditto	50	Ditto.	
	Ditto	60	Ditto.	
	Ditto	70	Ditto.	
	Ditto	80	Burst.	
„ 2	4 coils	130	No effect.	
	„	150	Flange burst.	
„ 7	8 coils	200	No effect.	A wrought-iron flange, $\frac{1}{4}$ inch deep, contracted on flange.
	„	220	Ditto.	
	„	240	Ditto.	
	„	250	Ditto.	
	„	260	Ditto.	
	„	270	Ditto.	
	„	280	Ditto.	
	„	290	Ditto.	Hoop on flange shifted.
„ 5	8 coils	200	No effect.	
	„	220	Ditto.	
	„	230	Ditto.	
	„	240	„	Flange cracked.
„ 4	4 coils	200	No effect.	
	„	250	„	Flange cracked.
„ 10	10 coils	310	No effect.	

In these experiments iron wire, No. 21 wire gauge, or $\frac{1}{28}$ th inch in diameter was used. Its breaking strain was 60 lbs.; consequently the actual strength of the material in the cylinder per lineal inch was :—

No. 0 Cast iron $0.10 \times 2 \times \text{tons} = 1.76 \text{ tons}$ 1.76 tons.
Nil.

„ 2	{ Cast iron as above	1.76	„	
	{ Wire $4 \times 28 \times 2 \times \frac{60}{2240}$	6.00	„	7.76 „
„ 7	{ Cast iron	1.76	„	
	{ Wire $8 \times 28 \times 2 \times \frac{60}{2240}$	12.00	„	13.76 „
„ 5	Same as No. 7			13.76 „
„ 4	Same as No. 2			7.76 „
„ 10	{ Cast iron	1.76	„	
	{ Wire $10 \times 28 \times 2 \times \frac{60}{2240}$	15.00	„	16.76 „

The enormous force of the expansive gases, in these experiments, was shown by their action on the plugs, which although accurately fitted and of hard iron, were chiselled and grooved out, in an extraordinary manner, as may be seen in one specimen exhibited. The vents, too, were rapidly enlarged.

The results, as regards strength, were so conclusive, that the Author proceeded to construct a small gun, (Fig. 18). This gun

was 2.96 inches in bore and 36 inches long in the clear; it had on it twelve coils of No. 16 W. G. iron wire, at the breech, decreasing to four coils at the muzzle. The thickness of cast iron was $\frac{1\frac{1}{8}}$ ths of an inch at the breech and $\frac{1}{2}$ inch at the muzzle.

The gun was cast hollow, and a recess was left in the thick part of the breech, in which an india-rubber washer, $\frac{3}{4}$ inch thick, was placed. The trunnions formed no part of the gun, but consisted of a strap passing round the breech, with two side rods, extending about one-third of the length of the gun, and terminating in the trunnions themselves. Thus, the whole force of the recoil was transmitted through the heavy mass at the breech, then through the india-rubber, and along the side rods to the trunnions.

The whole was then mounted on a wood carriage, on four roller wheels, about 8 inches diameter.

The weight of the gun and wrought-iron trunnion strap was 3 cwt., and the carriage 2 cwt. 0 qr. 15 lbs., making a total of 5 cwt. 0 qr. 15 lbs.

The shot were cast as nearly the size of the bore as possible, so as to move freely, but with very little windage. The spherical shot weighed $3\frac{5}{8}$ lbs., and the conical shot from 6 lbs. to $7\frac{1}{2}$ lbs.

The following are the results with 7° elevation, the powder used being Government cannon powder.

FIRING ON CAMBOIS SANDS, 4TH JUNE, 1856.

No.	Description of Shot.	Weight.		Charge of Powder.	Range to First Graze.
		lbs.		oz.	
9	Round . .	$3\frac{3}{8}$	7°	11	1,400 yards.
4	Elongated . .	$6\frac{1}{2}$	7°	11	1,200 yards.
5	Ditto . .	6	7°	8	1,220 yards.
6	Ditto . .	$7\frac{1}{2}$	7°	11	1,542 yards.
8	Ditto . .	7	7°	11	Lost beyond 1,500 yards.
7	Ditto . .	7	7°	16	Lost beyond 1,800 yards.
10	Ditto . .	$6\frac{1}{2}$	7°	16	1,500 yards.
11	Ditto . .	$6\frac{1}{2}$	7°	16	Lost beyond 1,800 yards.

The variations in the range were due, partly, to not having any very exact means of adjusting the elevations, and partly to differences in the form of the shots. The trials, above recorded, were only intended as preliminary, it being the Author's intention to carry out a more complete series, at another time. Unfortunately this intention was frustrated by an accident, which destroyed the gun, and which the Author now proceeds to describe. He had an idea, that it might be possible to obtain more accuracy of flight by using a shot somewhat on the principle of an arrow, viz., with a long light shaft and heavy head. This shot is shown in Fig. 19. The head was of cast-iron, and weighed about $8\frac{1}{2}$ lbs.

Fig. 19.

The shaft was of fir-wood, fitted tight into the iron head. When fired, by mistake, with a heavy charge of powder, the result was that the wood was driven forward with great force, entering and splitting the iron head. This wedged it so tightly in the chase, that it never left the gun, but tore it asunder about 12 inches from the muzzle; the muzzle and the shot in it were thrown about 15 yards forward, and the wire was uncoiled, but not broken.

This accident, it will be easily seen, was due entirely to the action of the shot, and had nothing to do with the principle of construction of the gun.

Enough however had been done to show, that with a gun weighing only 3 cwt. a shot of $7\frac{1}{2}$ lbs. could be thrown from 1,500 to 1,800 yards,—a result, it is believed, not attainable by any 6-pounder in the service.

So ended the Author's experiments on guns. He had neither time, nor money, at his disposal to carry them further; and although he was thus reluctantly compelled to relinquish the subject, he was fully impressed with the thorough soundness and practical facility of the system, and this in spite of its having been pronounced by the highest authority, unnecessary to make further experiments with a gun of this description.

Another application of the same principle is to the CONSTRUCTION of the CYLINDERS of HYDRAULIC PRESSES. When these are of large size, they are of great weight, and are very liable to be fractured.

Cylinders bound with wire may be made of any size, with the greatest facility, and at considerably less first cost than the unwieldy cylinders now in use.

Taking, for example, a cylinder for a 10-inch ram, with a stroke of 40 inches; the weight of it, when rough, is 46 cwt., and when finished, 31 cwt., and its cost when finished, is about £22.

A wire-bound cylinder of the same strength would only weigh 7 cwt., and the cost would not exceed £10.

The difference in first cost, though considerable, is of less consequence than the decrease in the risk of failure, and the vastly increased portability of the wire-bound cylinders. This latter quality is of peculiar advantage in presses intended for exportation to India and to South America, where the means of transport are frequently quite inadequate to the carriage of heavy weights.

In discussing this question, with makers of hydraulic presses, the Author has generally been met with the objection, that the thinness of the cast iron would enable the pressure to force the water through. To try how far this was the case, he constructed a small cylinder, 6 inches in diameter, the metal of which was $\frac{3}{4}$ inch thick, and around it he put twelve coils of No. 16 iron wire, equal to a rim of $\frac{3}{4}$ inch.

This cylinder, represented by Fig. 20, was tested up to a

Fig. 20.

pressure of 6 tons per square inch, without any escape of water. At this pressure it gave way, by shearing the side walls off the bottom plate. The reason for this is obvious. The bottom plate prevented the side walls from expanding, which they were free to do where bound round with wire. The wire was not broken, nor were the side walls shattered.

There are, doubtless, many other useful applications of this principle; but it is to its value in the construction of artillery, that attention is chiefly sought to be directed. There are many questions involved in the construction of an efficient gun, or mortar,

besides that of the absolute strength. These questions have not escaped the Author's attention ; and he believes, that the principle, now under consideration, affords very great facilities, and may be successfully carried into effect, for obtaining every desirable quality in destructive weapons of whatever description, whether for light field-artillery, such as breech-loading rifled guns, or even revolvers, or for heavy guns and mortars for land defences, or for siege purposes ; and he would commence the construction of a 15-inch gun, or a 36-inch mortar, with the utmost confidence in the results. He is quite prepared to meet with objections, and though perhaps the old ones, viz., that these guns would be too light, that cast iron and wrought iron would never work together, that their different rates of expansion would destroy the gun, and so forth, may not now be persisted in, facts having answered them ; still other difficulties may present themselves to the minds of those who have not fully studied the subject, or whose attention is now directed to it for the first time, and although the details of construction and arrangements, which are required to make an efficient weapon, scarcely come within the limits of this Paper, the Author will be glad to hear any objections which may appear to exist, and to reply to them to the best of his ability.

The Paper is illustrated by a series of diagrams, from which the woodcuts, (Figs. 1 to 26,) have been compiled.

APPENDIX.

ANTICIPATING the probability of the extension of the discussion beyond the subject of construction, the Author has prepared the two following Notes;—1°, on the strength of gunpowder; and, 2°, on the causes of deviation in projectiles, and the mode of counteracting the same by rifling. The mathematical investigations referred to in these Notes, as well as the investigation of the strength of hooped, or wired cylinders, by Mr. C. H. Brooks, are given in the latter portion of the Appendix; (page 329.)

1°. FORCE OF GUNPOWDER.

In the foregoing Paper, the initial and ultimate force of gunpowder has been estimated, by the Author, at from 17 tons to 20 tons per square inch. Various authorities have, however, assumed that the force attained was nearly double the Author's estimate.

Unfortunately, no means exist of accurately determining that important datum, owing to the absence of any exact knowledge of the rate at which powder burns in a gun.

It, therefore, still appears to the Author, that the method he pursued is that which is most likely to give reliable results; viz., to construct vessels of certain known strengths, and by actual trial, to ascertain what thickness of metal will resist the full force of powder when no escape is permitted.

The indirect methods are as follows:—

- 1st. From a deduction of the actual volume of gas generated, and thence by an estimate of the force of the gas, when compressed into its original bulk, and at the same time subjected to the great elevation of temperature due to the combustion.
- 2nd. From experiments with the ballistic pendulum, whereby the velocity of the ball leaving the gun is ascertained, and from this velocity the initial force of the powder is estimated.

Both these methods fail, from the absence of correct data. In the former case, the temperature is not known, nor is the index which represents the relation between pressure and volume, when, instead of Mariotte's law, the true law is applied.

In Captain Boxer's "Treatise on Artillery,"¹ the permanent gases evolved from 1 cubic foot of gunpowder, when reduced to ordinary temperature, are stated to be:—

Nitrogen	79.4 cubic feet.
Carbonic Acid . . .	238.0 "
	<hr/>
	317.4 "

This, if compressed into the bulk originally occupied by the powder, according to Mariotte's law, would give a pressure of 317.4 atmospheres.

To take in the effect of temperature, Captain Boxer estimates the temperature at 3,000° Fahrenheit; and assuming, that the expansion is $\frac{1}{480}$ th of the volume for each degree of Fahrenheit, he brings the total expanded volume of gases to

$$317.4 \times \frac{3,000 - 60}{480} = 2,154 \text{ feet; which, if compressed to the original volume of}$$

the powder, would give a pressure of 2,154 atmospheres, or 14.4 tons per square inch.

* Vide "Treatise on Artillery." 1854, p. 14.

The pressure may, however, be estimated by this law, represented by the equation to an adiabatic curve $p \propto \frac{1}{v^k}$, or $\frac{p}{p'} = \left(\frac{v'}{v}\right)^k$.

Here, p and p' are the pressures before and after compression, v and v' the corresponding volumes, and k the ratio of the specific heat at constant volume to that at constant pressure. In the case of air, $k = 1.41$; and if this be the same for carbonic acid and nitrogen, (which, however, is rather uncertain), the pressure after compression would be $= 317.4$.

$= 3,367$ atmospheres.

$= 22.17$ tons per square inch.

In estimating the initial force of powder from the velocity as ascertained by the ballistic pendulum, the method adopted by Dr. Hutton, and followed by other artillerists, is to find the value of n in the formula:—

$$v = 47.4 \sqrt{\frac{n h d^2}{p + w} \cdot \text{Log.} \frac{b}{a}}; \text{ from which is obtained}$$

$$n = \frac{(p + w) v^2}{47.4^2 h d^2 \text{Log.} \frac{b}{a}} \dots (1).$$

From this, Hutton found the value of n to be from 2,000 to 2,400 atmospheres, or from 13 tons to 16 tons per square inch.

The above formula is, however, based on two erroneous assumptions; first, that the variation of pressure is according to Mariotte's law; and secondly, that the whole of the powder is instantaneously converted into gas. The former assumption may be corrected by adopting the true thermo-dynamical law, and the formula then becomes:—

$$n = \frac{(p + w) v^2}{47.4^2 d^2 \frac{h^k (a^{1-k} - b^{1-k})}{k - 1}} \dots (2).$$

Now in the case of Mr. Whitworth's 80-pounder gun, the velocity of the shot is stated to be 1,300 feet per second, with a charge of 12 lbs. of powder, occupying 20 inches of the barrel. Therefore:—

d = mean diameter of gun . . .	$= 5.25$ inches.
b = length of gun . . .	$= 108$ "
a = length of charge . . .	$= 20$ "
w = weight of shot . . .	$= 80 \times 16$ ounces.
p = half the weight of powder . . .	$= 6 \times 16$ "
v = velocity of shot . . .	$= 1,300$ feet per second.
h = length filled with powder . . .	$= 19$ inches.
k = 1.41 (?), as above.	

Whence are obtained the following values of n :—

	Atmospheres.	Tons Pressure.
From (1) Hutton's formula, based on Mariotte's law . . .	2,638	$= 17.37$
" (2) Hutton's formula, based on the thermo-dynamical law . . .	3,733	$= 24.58$

These latter results, though probably approaching the truth, must be taken with the limitation involved in the fact, that the burning of the powder is not instantaneous, but is really a work of time. If the relation between the time and the increase of pressure were known, the initial force of the powder, and the maximum strain on the gun, might be determined with greater accuracy.

It may, however, be shown, that the actual strain is always below that given by the formula (2), and that it is less, as the rate of combustion is slower.

It has lately been asserted by the Secretary at War, Mr. Sidney Herbert, (Speech on Army Estimates, 17th of February, 1860,) that "we have been wrong for some time in using powder of so quick a detonating nature for artillery purposes, and

especially for rifled cannon, which require weaker and slower powder than that suited to other arms."

An assertion so extraordinary, coming from such a source, calls for careful examination.

This question may be briefly investigated in the following manner:—

In Fig. 21, let $A B C$ be the chase of the gun, and $A B$ the portion occupied by the powder before explosion. Now as soon as the powder begins to burn, the pressure

Fig. 21.

accumulates in $A B$, until it is equal to the resistance of the ball. Let this pressure be denoted by $B F$. The ball then begins to move towards C , and when it arrives at B, B'' , the pressure may be represented by the ordinates B, b, B'', b'' . Let the powder be all burnt when the ball arrives at B''' , and let the corresponding pressure be denoted by B''', b''' . Then the curve $F b, b'', b'''$ represents the curve of pressure, up to the point B''' . From this point to the end of the gun, the pressure will be represented by the ordinates of an adiabatic curve b''', E , and the total work done by the ball will be represented by the area $B F b''', E C B$. This is, of course, on the assumption, that there is no transmission of heat from the gases to the gun. Any such transmission would, of course, decrease the ordinates and the curve area; but the heat, so transmitted, is so small a proportion of the whole heat generated, that it may practically be neglected.

If now the adiabatic curve $E b'''$ be continued to $G, B G$ would represent the initial pressure, if the powder had exploded instantaneously, and the area $B G E C B$ the work done on the ball. It therefore appears, that the work actually done is less than the work of powder burning instantaneously, by the area $F b''' G F$.

If, then, $B G E C B$ represents the work done, as determined by formula (2), it is obvious, that to produce the same effect with a slow-burning powder, more of it must be used. If the length of powder is represented by $A D$, a curve results such as $D f e E, C D$, which must be equal in area to $B G E C B$, and the maximum pressure is represented by $H e$. Now $e E$, must be a portion of an adiabatic curve, descending from G , and G, D must be equal to $G B$, because each represents the same force, viz., the force of instantaneous explosion; consequently, $H e$ is always less than $G B$.

The result, therefore, is that with a slow-burning powder the strain on the gun is less, but the quantity of powder required is greater; and the necessity of a slow powder, adverted to by the Secretary at War, can only be caused by the

guns not being sufficiently strong to resist the more economical and more powerful quick-burning powder.

In concluding this Note, the Author would take the opportunity of expressing the hope, that a series of experiments may be instituted with rifled ordnance, and all the important appliances of the present day, somewhat similar to those conducted by Dr. Hutton. Such experiments, carefully conducted, could not fail to give results of great value to the science and practice of gunnery.

2°. EFFECT OF TWIST.

It is not proposed in this Note on the causes of deviation of projectiles, and the remedy by rifling, to do more than to make a few general remarks on the subject. They, however, appear to be called for by the great variety of opinions existing amongst the rifled-gun makers of the day. The following are the degrees of twist given in three cases :—

Mr. Haddan's	..	1 turn in 100 calibres.
Sir W. Armstrong's	..	1 " 38 "
Mr. Whitworth's	..	1 " 20 "

This great discrepancy in practice is very startling, and it may not be amiss to give some consideration to the subject.

The object of rifling being to diminish, as far as possible, the deviation from the line of aim attendant on ordinary shot, these should be first enumerated, and their causes be described.

They are as follows :—

- 1st. Action of the wind.
- 2nd. Rotation of the earth.
- 3rd. Want of symmetry of the shot around the longitudinal axis passing through the centre of gravity.
- 4th. Position of the centre of gravity before, or behind the centre of figure.
- 5th. Friction of the shot in the air.
- 6th. Want of horizontality of the axis of the trunnions.

The first two of these are incidental alike to all guns, and can only be dealt with by making allowances for their effects in practice ; the third, fourth, and fifth are those with which rifling has to do.

If the material of the shot is not homogeneous, or its form is not symmetrical, the resistance of the air causes the projectile to deviate from the true line of flight. Again, if the centre of gravity is behind the centre of the figure, the shot will turn over. Lastly, if the shot leaves the gun with a rotation arising from striking, or rubbing against the inside of the chase, and is not determined by any specific direction, it will fly off to one side, or the other, according to the accidental circumstances under which it leaves the gun.

In Fig. 22, let A B be a shot projected in the direction of the arrow. Now, if the front end is not symmetrical, but is formed as shown at B C, it is evident, that the resistance of the air will cause the shot to deflect in the direction D E, (Fig. 23,) and that its path, as projected on a horizontal plane, would be a curve to the left of D G. If, however, the shot rotates on its axis, the extent of lateral deviation is limited, and the shot is brought back from E towards the axis D G. Now, it is generally stated and believed, that this retrograde motion goes on, until the shot reaches a point F, as far to the right

Fig. 22.

Fig. 23.

of D G as E was to the left, and that, in fact, the shot travels in a spiral around the axis D G, its greatest deviation, at any part of its path, being the distance

Ee, or Ff. This, however, is not the case. As is shown in the investigation by Mr. C. H. Brooks, (page 335,) the path of the projectile is of a much more complex form, and results in a deviation, increasing uniformly with the distance from the gun, and depending as to its direction, on the direction of the deflecting force, at the moment of its first application. If A be the gun, (Fig. 24,) seen projected on a horizontal plane, and the deflecting force acts on the shot as it leaves the muzzle, in a vertical direction downwards, the general

Fig. 24.

projection of the line of flight will be a line AB, deviating to the right, or to the left of AC, according as the twist is left, or right-handed. If the deflecting force acts in the opposite direction, the shot will be deflected to the right of AC, and whatever be the direction of the deflecting force at the first exit of the shot, the deviation will be a uniformly increasing one at right angles to it. But the line AB is not absolutely a straight line; it is a curve of double curvature, and if projected on a vertical plane at right angles to the axis AC, would consist of a series of cycloidal curves, (Fig. 25,) increasing the distance of the shot from AC, by the length Aa, of one of these cycloidal curves at each revolution. The length of each of these cycloidal curves depends upon the amount of the deflecting force, and the number of them is equal to the number of revolutions made by the shot in its flight. The formula for calculating these curves will be found at page 336, and the following Table gives the results as calculated for the several guns therein mentioned, and the aggregate deviation from the line of axis of the gun, at a distance of 1,000 yards, and for a deflecting force, which would have given a deviation of 10 yards to a non-rifled shot, projected under the same circumstances:—

Fig. 25.

The formula for calculating these curves will be found at page 336, and the following Table gives the results as calculated for the several guns therein mentioned, and the aggregate deviation from the line of axis of the gun, at a distance of 1,000 yards, and for a deflecting force, which would have given a deviation of 10 yards to a non-rifled shot, projected under the same circumstances:—

Name of Gun.	Amount of Twist.	Number of Turns in 1,000 yards.	Breadth of Cycloid.	Length of Cycloid.	Total Deviation in 1,000 yards.
Haddan .	1 in 50 ft.	60	$\frac{1}{30}$ th of an inch	$\frac{1}{30}$ th of an inch	2·0 inches
Armstrong	1 in 10 ft.	300	$\frac{1}{2250}$ th of an inch	$\frac{1}{750}$ th of an inch	0·4 inch
Whitworth	1 in 5 ft.	600	$\frac{1}{9000}$ th of an inch	$\frac{1}{3000}$ th of an inch	0·2 inch

The aggregate amount of deviation, even with the very slow twist of Mr. Haddan's gun, is very small, and this teaches, that as far as the correction of the deviation, due to want of symmetry, is concerned, the more rapid twists of Mr. Whitworth's and Sir W. Armstrong's are unnecessary.

It is, however, necessary that the rotative momentum be sufficient to keep up the spinning motion to the end of the flight of the shot, and this may require a greater degree of twist, than would be required simply for the purpose of correcting the deviation due to the deflecting force. Experiments are wanting, to show the decrease of rotation due to the friction of the projectile in the air. In Mr. Haddan's projectile, with an initial velocity of 1,300 feet per second, the number of revolutions would be twenty-six per second; and it does not appear likely, that this would be much reduced in the few seconds of the projectile's

flight, even to its most distant range. Therefore, in this respect also, the rapid twist adopted by Mr. Whitworth and Sir W. Armstrong appears unnecessary.

The next point for consideration, is the influence of the position of the centre of gravity before, or behind the centre of figure of the shot. The gyroscope affords an excellent means of illustrating this. If a weight is attached to the axis of this instrument, when in rotation, the axis will deviate in the same direction as the rotation, if the weight is behind the revolving disc, and *vice versa*.

The velocity of this horizontal deviation of the axis is smaller, as the rotative velocity is greater. If, then, in a rifled shot, the centre of gravity is behind the centre of the figure, the shot will deviate to the right, with a right-handed twist. If, on the other hand, the centre of gravity is forward, the deviation will be to the left; and these deviations will be greater, as the velocity of rotation is less; that is to say, as the twist is slower. Here, then, the advantages of a rapid twist is manifest, but it must be borne in mind, that the deviation here sought to be counteracted is solely due to the centre of gravity being placed before, or behind the centre of the figure; and if these centres coincide, no tendency to deviate exists.

The fifth cause of deviation is from the friction of the shot against the air.

If a body is revolving rapidly in any fluid pressing equally against it in every direction, it is obvious, that the only effect of the fluid is to diminish, and finally, to destroy the velocity, without changing the position of the axis A, (Fig. 26).

But if the fluid presses with a greater force on the side B, for instance, than on C, the axis will move in the direction D. Again, if the velocity of motion is greater at F than at G, the tendency is to move the axis in the direction A C.

Now in the case of an elongated rifled shot, both these actions take place. The pressure of the air is always greatest on the under side, and consequently, the axis is moved in the direction of the twist. Moreover, the side F is always meeting the air, with the velocity due to the sum of the velocity of rotation and the falling velocity of the shot; whereas the opposite side is meeting the air, with the velocity due to the difference of these two; consequently, the effect is to roll the shot upwards, in the direction F H, and sideways in the direction B K; the actual result being a deviation in some intermediate direction A M.

This deviation, which is unavoidable in all rifled shot, is greater as the twist is greater, and may possibly vary as the square of the velocity of rotation, *i. e.*, as the square of the rate of twist.

It will probably, also, be a good deal affected by the nature of the rifling, being, of course, greatest with a rough rifled surface.

The deviation due to the friction, as last described, is always in the direction of the twist. It may, therefore, be, to some extent, counteracted by the gyroscopic deviation of the centre of gravity, if the shot is placed in advance of the centre of the figure. This gives a deviation to the side opposite to the direction of twist, so that the actual deviation is, in one case, the sum, and in the other, the difference of the two deviations.

The sixth source of deviation is due to the want of horizontality of the axis of the trunnions.

The sights being vertical, when the trunnions are horizontal, it is evident, that if the axis of the trunnions is placed at an angle with the horizon, the line of sights will no longer coincide with the axis of the gun, when the gun is laid at any elevation.

If α be the error in azimuth, arising from this cause;

ϵ the angle of inclination of the trunnions with the horizon;

θ the elevation of the gun;

Then it is shown, at page 336, that

$$\text{tang. } \alpha = \sin. \theta. \text{ tang. } \epsilon :$$

from which it is easy to calculate the deviation in any given range.

Fig. 26.

The following Table shows the amount of lateral deviation, due to the axis of the trunnions being 1° out of the horizontal line :—

Angle of Elevation.	Azimuthal Error.	Range of Shot.	Lateral Deviation.
35°	42'	8,800 yards	110 yards
10°	$10\frac{1}{2}'$	4,000 „	12 „
5°	5'	2,300 „	$3\frac{1}{2}$ „

When it is considered, how difficult it is to detect, by the eye, so small a deviation from the horizon as 1° , it is evident, that for accurate practice some means must be adopted for accurately levelling the axis of the trunnions.

There may be other causes of deviation, than those above enumerated, but so far as the above investigation goes, it tends to show, that a very moderate amount of twist is all that is generally required, and that the only necessity of increasing the twist arises from the position of the centre of gravity of the shot being such as to make the gyroscopic deviation considerable.

It remains to be considered, what is the amount of force required to impart a certain rotative velocity, and what is the consequent strain on the gun.

Let P = force required at the circumference of the shot,
 r = radius of shot.
 ρ = radius of gyration (in a solid cylinder = $r\sqrt{\frac{1}{2}}$).
 w = weight of shot.
 v' = angular velocity.
 v = velocity of shot in direction of axis of gun.
 n = length of chase containing one complete turn.
 s = total length of chase.

Then it may be shown, that

$$P = \frac{W \pi r}{2 n g s} \cdot v^2.$$

Now the uniform force which would give the velocity v in the space s , is :—

$$P' = \frac{W}{2 g s} \cdot v^2;$$

Therefore :

$$P : P' :: \frac{W \pi r}{2 n g s} \cdot v^2 : \frac{W}{2 g s} \cdot v^2$$

$$:: \frac{\pi r}{n} : 1$$

And if m be the number of calibres in which the complete turn is made, $n = 2 m r$,

And

$$P' : P :: 1 : \frac{\pi}{2 m} :: 1 : \frac{1 \cdot 5708}{m}.$$

Comparing the work expended :—

$$W' : W :: P' m 2 r : P 2 \pi r ;$$

But

$$P' = P \frac{2 m}{\pi} ;$$

Therefore :

$$W' : W :: \frac{P 4 m^2 r}{\pi} : P 2 \pi r$$

$$:: \frac{2 m^2}{\pi^2} : 1.$$

Taking Whitworth's large gun, where $m = 20$,

$$W' : W :: 100 : 1 \cdot 236.$$

The force P is exerted tangentially, at right angles to the axis of the shot, and its effect may developed into two others :—

- 1st. A tensile force, tending to tear asunder the chase ;
- 2nd. A twisting force, acting by torsion.

These will be found to be :—

$$\text{Tensile force} = P \frac{2 \pi r}{\sqrt{n^2 + 2 \pi r^2}}$$

$$\text{Twisting force} = P \frac{n}{\sqrt{n^2 + 2 \pi r^2}}.$$

Taking Mr. Whitworth's large gun, the following will be, approximately, the forces required to give translation and rotation, when the shot weighs 80 lbs., and the velocity on leaving the gun is 1,300 feet per second :—

Mean force, to give translation	lbs.	306,900
Force, to give rotation	3,784	
Friction of shot in grooves, taken }	3,012	
at $\frac{1}{4}$ th pressure		
		6,796
Total force		<u>313,696</u>

Or, taking the total force at 100, the force to give rotation is $2 \cdot 16$:—

from which it appears, that even with the rapid twist of Mr. Whitworth's gun, the amount of force expended on the rifling, scarcely exceeds 2 per cent. of the total force of the powder.

INVESTIGATIONS BY MR. CHARLES HENRY BROOKS.

CONDITIONS OF STRESS OF A CYLINDER BUILT UP OF CONCENTRIC RINGS.

In a homogeneous cylinder of any material, let R_1 and ρ_1 be the external and internal radii respectively, and let f_2 be the normal, or fluid pressure on the exterior, and f_1 , that on the interior surface. Then it is shown in Rankine's "Applied Mechanics," Article (273), that the tension per square inch of the internal surface is :—

$$T = \frac{f_1 (R_1^2 + \rho_1^2) - 2 f_2 R_1^2}{R_1^2 - \rho_1^2} \quad \dots \dots \dots (1)$$

and in the same way it may be shown, that the tension of the external surface is :—

$$\tau_1 = \frac{2 f_1 \rho_1^2 - f_2 (R_1^2 + \rho_1^2)}{R_1^2 - \rho_1^2} \quad \dots \dots \dots (2).$$

To apply the above to the case of a cylinder composed of four concentric rings :—

Let	f_1	= normal pressure on the interior surface.
	f_2	= " " between the 1st and 2nd rings.
	f_3	= " " 2nd 3rd "
	f_4	= " " 3rd 4th "

Also let R_n and ρ_n be the outer and inner radii, respectively, before it is built up in the cylinder. When a ring is expanded, the greatest tension will be at its inner surface; hence, and in order that the cylinder may bear the strain in the best way, the inner surface of each ring must be strained to some tension T , not exceeding the tensile force of the material.

Then equation (1) being for the first ring, there will be similar equations for the second, third, and fourth rings; but with all the subscript numerals increased

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by one, two, and three units respectively; let these be denoted by (1.), (1..), and (1...), and let these four equations be denominated group (1.).

Also, for the outer tensions, τ_2 , τ_3 , and τ_4 of the other three rings, there will be equations similar to (2), but having the subscript numerals increased by one, two, and three units respectively; let this group of equations be (2.), (2...), and (2...),

Now if t be the tension at any radius x , and κ the modulus of extension, then the extension of that radius is $\frac{t x}{\kappa}$, and as the outer surface of the first ring is in contact with the inner surface of the second ring :—

$$R_1 + \frac{\tau_1 R_1}{\kappa} = \rho_2 + \frac{T \rho_2}{\kappa} \quad . \quad . \quad . \quad (3)$$

Similarly :
$$R_2 + \frac{\tau_2 R_2}{\kappa} = \rho_3 + \frac{T \rho_3}{\kappa} \quad . \quad . \quad . \quad (4)$$

And
$$R_3 + \frac{\tau_3 R_3}{\kappa} = \rho_4 + \frac{T \rho_4}{\kappa} \quad . \quad . \quad . \quad (5).$$

Thus there are eleven equations containing five f 's, or normal pressures, four τ 's, or outer tensions, four R 's, or outer radii, and four ρ 's, or inner radii; but of these seventeen quantities there may be assumed any particular values for five of the radii, and also one of the normal pressures, say f_1 , or f_5 may be taken, so that the unknown quantities being reduced to eleven, can be determined as follows :—

Subtracting (2) from (1), the result gives $\tau_1 = T - f_1 + f_2 \quad . \quad . \quad . \quad (6).$

And in like manner, from the corresponding equations of groups (2.) and (1.) are formed the other members of group (6.), viz. :—

$$\tau_2 = T - f_2 + f_3 \quad . \quad . \quad . \quad (6.)$$

$$\tau_3 = T - f_3 + f_4 \quad . \quad . \quad . \quad (6..)$$

$$\tau_4 = T - f_4 + f_5 \quad . \quad . \quad . \quad (6...)$$

Substituting in (3), the value of τ_1 from (6), and reducing :—

$$\rho_2 = \left(1 - \frac{f_1 - f_2}{T + \kappa}\right) R_1 \quad . \quad . \quad . \quad (7)$$

Similarly :
$$\rho_3 = \left(1 - \frac{f_2 - f_3}{T + \kappa}\right) R_2 \quad . \quad . \quad . \quad (7.)$$

And :
$$\rho_4 = \left(1 - \frac{f_3 - f_4}{T + \kappa}\right) R_3 \quad . \quad . \quad . \quad (7..)$$

Let, now, R_4 and ρ_4 be assumed of any given value, and let the external pressure $f_5 = 0$:—

Then from (1...):
$$f_4 = T \frac{R_4^2 - \rho_4^2}{R_4^2 + \rho_4^2} \quad . \quad . \quad . \quad (8)$$

And from (7...):
$$f_3 = (\kappa + T) \frac{R_3 - \rho_4}{R_3} + f_4 \quad . \quad . \quad . \quad (9)$$

in which equation R_3 must be assumed;

Then from (1.):
$$\rho_2 = R_3 \sqrt{\frac{2f_4 + T - f_3}{T + f_3}} \quad . \quad . \quad . \quad (10)$$

Also from (7.):
$$f_2 = \frac{(\kappa + T)(R_2 - \rho_2)}{R_2} + f_3 \quad . \quad . \quad . \quad (9)$$

in which R_2 must be assumed;

Then from (10.): $\rho_2 = R_2 \sqrt{\frac{2f_3 + T - f_2}{T + f_2}} \dots \dots \dots (..10)$

Then from (7), assuming a value for R_1 :—

$$f_1 = \frac{(\kappa + T)(R_1 - \rho_2)}{R_1} + f_2 \dots \dots \dots (..9)$$

And then from (1): $\rho_1 = R_1 \sqrt{\frac{2f_2 + T - f_1}{T + f_1}} \dots \dots \dots (..10).$

Having determined the radii and normal pressures by the seven last equations, the outer tension can be obtained from group (6).

EXAMPLE.—Let T = the greatest amount to which the material is to be strained, be = 12 tons per square inch.

κ = modulus of extension = 12,000 tons.

R_4 = outer radius of the 4th shell = 10 inches.

ρ_4 = inner " " = 8 "

Then from (8) f_4 = 2·634 tons per square inch.

Let R_3 = 8·003 inches.

Then from (9) f_3 = 7·114 tons per square inch.

" (10) ρ_3 = 6·1644 inches.

Let R_2 = 6·1674 "

Then from (9) f_2 = 12·953 tons per square inch.

" (10) ρ_2 = 4·4934 inches.

Let R_1 = 4·500 "

Then from (9) f_1 = 17·213 tons per square inch.

" (10) ρ_1 = 3·7873 inches.

And from (6) τ_1 = 7·740 tons per square inch.

τ_2 = 6·161 " "

τ_3 = 7·520 " "

τ_4 = 9·366 " "

In this example the internal radius is 3·7873 inches, but it is evident from the form of equations (8) to (10), that the pressures are not altered by taking any multiple of all the radii; and hence, if it were required, that the internal radius should be n inches, all that is necessary to be done is to multiply all the other radii, by the ratio $\frac{n}{3\cdot7873}$.

Suppose, for instance, that the internal radius was 4 inches, then multiplying the above radii by $\frac{4}{3\cdot7873}$, they become :—

$$\rho_1 = 4\cdot000 \quad R_1 = 4\cdot7526 \quad \therefore \text{thickness of 1st ring} = 0\cdot7526$$

$$\rho_2 = 4\cdot7510 \quad R_2 = 6\cdot5137 \quad \therefore \quad \quad \quad \text{2nd } \quad \quad \quad = 1\cdot7627$$

$$\rho_3 = 6\cdot5106 \quad R_3 = 8\cdot4523 \quad \therefore \quad \quad \quad \text{3rd } \quad \quad \quad = 1\cdot9417$$

$$\rho_4 = 8\cdot4492 \quad R_4 = 10\cdot5614 \quad \therefore \quad \quad \quad \text{4th } \quad \quad \quad = 2\cdot1122$$

And for the original differences of the radii of the surfaces in contact :—

$$R_1 - \rho_2 = 0\cdot0016$$

$$R_2 - \rho_3 = 0\cdot0031$$

$$R_3 - \rho_4 = 0\cdot0031$$

From this example, part of Fig. 7, (page 302,) has been prepared.

When three rings are put together, equation (5), and consequently (21), (24), and (27), do not exist; hence making $f_4 = 0$ in (26):—

$$f_2''' = - \frac{NP + S}{PL + Q} \quad \dots \quad (29)$$

then from (25):—

$$f_3''' = Lf_2''' + N \quad \dots \quad (30).$$

For four rings put together, equating (26) and (27) will give f_2'''' and then f_3'''' and f_4'''' from (25) and (26). In all these cases the values of the inner and outer tensions are found by (11) to (18).

For example, taking the case already given—

$$a = - \frac{2R_1^2}{R_1^2 - \rho_1^2} = - 6.857$$

$$b = \frac{R_2^2 + \rho_2^2}{R_2^2 - \rho_2^2} = 3.2726$$

$$c = \frac{2R_2^2}{R_2^2 - \rho_2^2} = 4.2724$$

$$d = \frac{R_3^2 + \rho_3^2}{R_3^2 - \rho_3^2} = 3.9173$$

$$e = \frac{2R_3^2}{R_3^2 - \rho_3^2} = 4.9172$$

$$g = \frac{R_4^2 + \rho_4^2}{R_4^2 - \rho_4^2} = 4.5556$$

$$L = \frac{b\rho_2 - 1 + aR_1}{c\rho_2} = 2.1373$$

$$N = \frac{\kappa(\rho_2 - R_1)}{c\rho_2} = - 0.99902$$

$$P = \left\{ 1 - \left(\frac{1-c}{d} \right) \frac{R_2}{\rho_3} \right\} \frac{d}{e} = - 1.4625$$

$$Q = \frac{1-b}{e} \cdot \frac{R_2}{\rho_3} = - 0.4624$$

$$S = - \frac{\kappa(R_2 - \rho_3)}{e\rho_3} = - 1.1876$$

Hence, from equations (28), (29), and (30), the following values are obtained:—

NORMAL PRESSURES DURING CONSTRUCTION.

1 Ring	$f_1' = 0$	$f_2' = 0$	$f_3' = 0$	$f_4' = 0$
2 Rings	$f_1'' = 0$	$f_2'' = 0.4674$	$f_3'' = 0$	$f_4'' = 0$
3 Rings	$f_1''' = 0$	$f_2''' = 0.9944$	$f_3''' = 1.1264$	$f_4''' = 0$
4 Rings	$f_1'''' = 0$	$f_2'''' = 1.4713$	$f_3'''' = 2.1456$	$f_4'''' = 1.270$

Also from (11) to (14) and (15) to (18), are found the tensions of the inner and outer surfaces, the accents denoting, as before, the number of rings put together.

	Inner Surfaces.	Outer Surfaces.
2 Rings.	$T_1'' = - 3.205$ $T_2'' = 1.5297$	$\tau_1'' = - 2.7376$ $\tau_2'' = 1.0623$
3 Rings.	$T_1''' = - 6.819$ $T_2''' = - 1.557$ $T_3''' = 4.411$	$\tau_1''' = - 5.825$ $\tau_2''' = - 1.425$ $\tau_3''' = 3.285$
4 Rings*	$T_1'''' = - 10.086$ $T_2'''' = - 4.355$ $T_3'''' = 2.161$ $T_4'''' = 5.778$	$\tau_1'''' = - 8.615$ $\tau_2'''' = - 3.680$ $\tau_3'''' = 1.285$ $\tau_4'''' = 4.508$

From the latter portion of this Table, part of Fig. 7, (page 302,) has been formed.

If in the example, (page 331,) R_1 had been taken = 4.501, instead of 4.500, the value of f_1 would have been found = 19.8917, and $\rho_1 = 3.3827$, the other radii and forces remaining the same, excepting τ_1 , which becomes $12 - 19.8917 + 12.953 = 5.051$; and if, as before, the inside radius is increased to 4 inches, the radii will be as under:—

Inner.	Outer.	Thickness.	Differences.
$\rho_1 = 4.000$	$R_1 = 5.3222$	1.3222	$R_1 - \rho_2 = .0031$
$\rho_2 = 5.3191$	$R_2 = 7.2928$	1.9737	$R_2 - \rho_3 = .0035$
$\rho_3 = 7.2893$	$R_3 = 9.4633$	2.1740	$R_3 - \rho_4 = .0035$
$\rho_4 = 9.4598$	$R_4 = 11.8247$	2.3649	

With the above radii and value of τ_1 , and with the values of $\tau_2 \tau_3 \tau_4$ from page 331, Fig. 6, (page 300,) was constructed.

Proceeding as before, the following values are obtained for the normal pressures and tensions during construction:—

NORMAL PRESSURES.

2 Rings	$f_1'' = 0$	$f_2'' = 1.0095$	$f_3'' = 0$	$f_4'' = 0$
3 Rings	$f_1''' = 0$	$f_2''' = 1.8851$	$f_3''' = 1.4082$	$f_4''' = 0$
4 Rings	$f_1'''' = 0$	$f_2'''' = 2.6458$	$f_3'''' = 2.6314$	$f_4'''' = 1.4272$

TENSIONS.

Inner Surfaces.	Outer Surfaces.
$T_1'' = - 4.6394$ $T_2'' = 3.3037$	$\tau_1'' = - 3.6299$ $\tau_2'' = 2.2942$
$T_1''' = - 8.6637$ $T_2''' = 0.1529$ $T_3''' = 5.5163$	$\tau_1''' = - 6.7786$ $\tau_2''' = - 0.3240$ $\tau_3''' = 4.1081$
$T_1'''' = - 12.1596$ $T_2'''' = - 2.5837$ $T_3'''' = 3.2900$ $T_4'''' = - 6.5018$	$\tau_1'''' = - 9.5138$ $\tau_2'''' = - 2.5981$ $\tau_3'''' = 2.0858$ $\tau_4'''' = 5.0746$

From which Figs. 3, 4, and 5, (page 298,) were formed.

If in the example, (page 331,) the value of ρ_4 had been taken = 8'4472, instead of 8'4492, the inner and outer tensions, when the four rings are put together, would be as follows :—

$$\begin{array}{llll} T_1 = -11\cdot244 & T_2 = -5\cdot339 & T_3 = 1\cdot364 & T_4 = 7\cdot823 \\ \tau_1 = -9\cdot604 & \tau_2 = -4\cdot473 & \tau_3 = 0\cdot577 & \tau_4 = 6\cdot104 \end{array}$$

In the case where $\rho_4 = 8\cdot4492$, the internal force (f_1) necessary to stretch all the rings at their inner surfaces to 12 tons tension, was found to be 17'213 tons, (page 331) ; but in the case where the value of ρ_4 is too small by '002 of an inch, the inner surface of the outer ring will be strained to 12 tons by an internal force = 9'908 tons, and the several tensions will be as follows :—

$$\begin{array}{llll} T_1 = 2\cdot268 & T_2 = 4\cdot534 & T_3 = 7\cdot28 & T_4 = 12\cdot0 \\ \tau_1 = 0\cdot492 & \tau_2 = 1\cdot570 & \tau_3 = 4\cdot752 & \tau_4 = 9\cdot362 \end{array}$$

These are represented by Fig. 8, (page 302).

In the preceding investigation, R and ρ have been taken to denote the original radii of the rings, before being built up in the gun. In reality, however, they denote the expanded radii, and by treating them as such, a different and neater method of investigation would result ; but the method here given is preferred, as being that by which the calculations for the diagrams in the body of the work were made.

ON THE EFFECT OF ROTATION IN CORRECTING THE DEVIATION DUE TO WANT OF SYMMETRY OF THE PROJECTILE.

The unsymmetrical form will cause the resistance of the air to have a preponderating effect on one side of the shot. Let the component of this effect perpendicular to the line of flight, be denoted by f ; then, this force f may be considered as acting always upon one determinate side of the shot, and consequently, it revolves at the same rate. Setting aside the parabolic form of flight, and supposing that the velocity of the shot, and consequently, the force f are constant, take two rectangular axes perpendicular to the line of flight, the origin in that line, and let the axis of x coincide with the initial direction of the force f , and at any time t , let it make an angle θ with the axis of x .

Then if w = weight of shot, the accelerating force on it will be $\frac{fg}{w} = a$ suppose.

Hence :—

$$\begin{aligned} \frac{d^2 x}{dt^2} &= a \cos \theta \\ \frac{d^2 y}{dt^2} &= a \sin \theta. \end{aligned}$$

But θ increases uniformly. Let $\theta = n t$, which substitute in the above and integrate, making the initial velocity, zero :—

$$\begin{aligned} \frac{dx}{dt} &= \frac{a \sin n t}{n} \\ \frac{dy}{dt} &= a \frac{(1 - \cos n t)}{n}. \end{aligned}$$

Integrating again, so as to make x and y vanish with t :—

$$x = \frac{a}{n^2} (1 - \cos n t) (1).$$

$$y = \frac{a}{n^2} (n t - \sin n t) (2).$$

Equation (1) shows, that at the end of each revolution, the point of application of the force f has made no progress in the direction of that force ; but from equation (2), the progress at right angles to that direction is $\frac{2 a \pi}{n^2}$, and after m revolutions the amount is $\frac{2 a m \pi}{n^2} (3).$

Draw the great circle ZCN, then the path of the ball will be in that plane, and the angle CZB, or its measure Bn, will be the azimuthal error.

Let Bn = α , BC = elevation of gun = θ :—

Then, in the spherical triangle BCn :—

$$\cos C B n = \tan B n, \cot B C,$$

which gives

$$\tan \alpha = \sin \theta \tan \theta. \quad (1.)$$

There will also be a small error in altitude. The altitude at which the gun really is set to is not BC, but nC,

$$\text{and} \quad \sin \text{true alt} = \sin \theta \cos e \quad (2).$$

EXAMPLE.—Let the tangent slide be set to 10° elevation, and let the trunnions have an accidental error of 2° . Then (1) gives the azimuthal error = $21' 9''$, and by (2), the actual altitude would be $9^\circ 59' 38''$, being an error of $22''$; and it is this small error which is generally believed to be the only one.

The following approximate rule is easily deduced from (1). Multiply together the degrees of elevation of the gun and the degrees of inclination of trunnions to the horizon, the product will be the minutes of azimuthal error, to which the horizontal adjustment of the sight may be arranged; or else allow half a yard per mile of range for each minute, and aim that amount to the side which has the most elevated trunnion.

EXAMPLE.—Let a gun be fired to the west, at an elevation of 10° , on a hill sloping $2\frac{1}{2}^\circ$ to the south; then the azimuthal error would be $10 \times 2\frac{1}{2} = 25'$; and if the range were two miles, the gun should be aimed 25 yards to the north of the object fired at.