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LECTURE.

Friday, January 17th, 1873.

Admiral Sir ALEXANDER MILNE, G.C.B., Lord of the Admiralty,
in the Chair.

POWDER PRESSURES IN THE FIRST 35-TON GUN.

By Commander W. DAWSON, R.N.

*"With hard projectiles having * * * * studs, there will generally be a slightly oblique movement of the axis of the projectile."*—MODERN ARTILLERY.

"The gun rifled on the French" (Woolwich) "system has decidedly the lowest velocities."—ORDNANCE SELECT COMMITTEE, 1861.

"It is the maximum pressure which causes the failure of the stud."—SIR W. G. ARMSTRONG, 1870.

The CHAIRMAN: Gentlemen, having been requested by the Council to take the chair at this, the first meeting of the year, it affords me great pleasure to do so, because I have always felt that this Institution has been of great value to both our Services. I think it is only right for me to say, that the lecturers who have appeared before us here on previous occasions, have not only benefited the Institution, but have conferred a general benefit on the Services at large. I do not attend here to-day in my official capacity, but I come here as your Chairman, to act independently in that capacity, and so doing, I have very great pleasure in introducing to your notice Commander Dawson, who will now proceed to deliver his lecture.

Commander DAWSON: The Surveyor-General of the Ordnance observed, 2nd March, 1872, "that he should be glad if the Committee turned their attention to the remarkable results of firing large charges of pebble-powder. He has never been satisfied with the discrepancies as to the amount of pressure produced by a comparatively small increase in the charge of powder."* The Committee on Explosives report, 1st April, 1872, that: "*When*

* See "Extracts from the Proceedings of the Department of the Director of Artillery," vol. x, Part II, page 86.

"a charge of any description of powder is increased beyond a certain limit, wave or local pressures are set up which strain the gun unduly, without affording an equivalent of useful effect on the projectile." And the Special Committee report, 12th February, 1872, "that heavy guns, proved under the existing regulations, are subjected to very undue local pressures, resulting in local enlargements, dents, and even occasionally in cracked tubes."† * * "The Committee are perfectly aware of the great strength of our heavy guns, and of the fact that they do stand the existing proof without danger of bursting, but they cannot consider the local enlargements of the bore, the dents, &c., which frequently occur on proof, as at all desirable."‡ The "proof" charges here referred to, except in the case of the 35-ton gun, are $1\frac{1}{4}$ times those diminished weights of gunpowder, which are mis-called "battering charges," and are fired horizontally with the ordinary service projectiles. After "proof," and during cool training-practice with reduced charges, similar liabilities obtain, so that Inspectors of Ordnance are appointed to register the damages inflicted upon the bore during the exit of every fifty projectiles. These Inspectors are told in the *Official Text Book of the construction and manufacture of the rifled ordnance in the British Service*, corrected up to January, 1872, p. 175, that "there are certain defects to which all guns are liable, such as 'tool marks,' or 'irregularities in the boring and rifling during manufacture; 'dents' or 'abrasions,' caused by the bursting of a shell in the bore; and 'wearing at the sides of the 'grooves' from the friction of the studs of projectiles." "Woolwich" rifled guns are also liable to erosion from the escaping gases, or hard, deep, roughness in the lands and grooves over, and in front of, the seat of the projectiles. The studs and the walls of the projectiles are also liable to certain marks and injuries of so serious a nature, that every recovered service projectile has to be destroyed§, and the "proof" ones restudded.

It seems not impossible that some connection may obtain between the Surveyor General's question about "the discrepancies as to the amount of pressure produced by a comparatively small increase in the charge of powder," and the "dents," "abrasions," "local enlargements," and roughnesses of the bore, alluded to by the Special Committee; as well as with the shearing or wedging of the studs and the base-marks and compression of the walls of the projectile referred to elsewhere by the talented Superintendents of the Royal Gun Factories and of the Royal Laboratory, and in the official work on *Ammunition*, part II, pages 58, 73, &c. This idea seems not unreasonable, as the learned Professor of Artillery points out that "with hard projectiles having * * * studs, there will generally be a slightly oblique movement of the axis of the projectile." The force of this wriggling action would naturally increase with the greater violence of

† See "Extracts from the Proceedings of the Department of the Director of Artillery," vol. x, Part II, page 81. ‡ Ibid., page 85.

§ The recovered projectiles, whether chilled or not, are sent to the Royal Laboratory, where the brass studs are drilled out—a costly operation—and the old iron is then returned to the furnace.

large powder charges, and with the obstructions experienced by the studs of the escaping projectile. This view is further confirmed by comparing the Report of the late Ordnance Select Committee upon a large number of similar 7-inch projectiles fired under identical conditions except as to the agency for producing rotation, that the gun rifled "on the French (Woolwich) system, has decidedly the lowest velocities" * with the damaged condition of 70 per cent. of the recovered studded shell and the position of the injuries to the lands and grooves of the gun which had thus absorbed within its bore the force represented by the difference between the speed of the fastest competitive shot and of the studded one which had "decidedly the lowest velocities." (See Plate III.)

The History of the late 35-ton Gun.—The powder pressures registered in the late 35-ton gun afford the best known means of investigating Sir Henry Stork's problem. Of no other heavy gun, has the history of its conception, manufacture, trial, and failure been so carefully registered and published. Though the official examinations do not appear to have extended to the recovered projectiles, and those of the bore do not appear to have been made with scientific exactitude, until the gun gave way, yet the published register of each of the 73 rounds fired, with the corresponding pressures, is full of fruitful lessons.

The Intended Charge.—From "the Report of the Ordnance Council "on the proposed 35-ton gun competition," 4th May, 1870, we learn that Colonel F. A. Campbell, R.A., the talented Superintendent, Royal Gun Factories, designed the 11·6-inch bore for a charge of 120 lbs. and a 700-lbs. projectile. Sir W. G. Armstrong and Co. also proposed "a charge of 120 lbs. of powder, and a projectile weighing 700 lbs. for this (12-inch) gun;" adding, "but we are willing that any charge and weight of projectile which may be used with a competing gun of equal weight, should be used also with our gun." Sir William Armstrong further "points out that in future, where much milder powder will be used, the strain upon the studs will be proportionally less, because, of course, it is the maximum pressure which causes the failure of the stud, and as you reduce the maximum pressure, so you increase the stability of the stud." Sir Joseph Whitworth substantially agreed with these two great artillery authorities as to the power of useful powder-consumption to be expected from the 35-ton gun, inasmuch as he fixed the powder charge, for such a 12-inch gun with polygonal rifling, at 117 lbs. with 750-lbs. projectiles, his proposed armour shells being $3\frac{1}{2}$ and 5 diameters long, of 880 and 1,250 lbs. weight, and containing 36 lbs. and 58 lbs. bursting charges respectively, instead of the 8½-lbs. bursters now used.

The Present "Proof" Charge.—The powder charge now adopted has been reduced from 120 lbs. to 110 lbs. and 85 lbs. of the "milder powder," with projectiles of 700 and 616 lbs. in weight. Moreover, even these reduced charges are intended to be very sparingly used, for the second 12-inch 35-ton gun had been, at the end of the year, eight months at Shoeburyness for range finding, and had only fired

* See "Extracts from Reports, &c., Ordnance Select Committee," vol. ii, p. 292, sec. 13.

nineteen 110-lbs. reduced charges at low elevations and at considerable intervals of time, besides 46 small 85 lbs. P. charges. It appears also that, even for the "proof" of 35-ton guns, two rounds of service shot with reduced charges are alone used; though the usual proof in other heavy guns is two rounds with service shot, and $1\frac{1}{2}$ times the amount of powder in the highest service charge. But we are officially told that this latter test results, in other guns, "in local enlargements, dents, and "even occasionally in cracked tubes." And, the official "*Extracts of Artillery Proceedings*" tell us, 4 : 3 : 72, that the Superintendent, Royal Gun Factories, "proposes that the proof charge for the 12-inch gun of 35-tons shall be 115 lbs. To this the Committee have no objection, believing that two rounds of such a "reduced "charge will not be a dangerous proof. He also concurs with the Committee in thinking it advisable that the proof of heavy guns should commence with a service charge. Therefore, the proof of the present "pattern 12-inch gun of 35-tons would be:—

<p>"1 round, 110 lbs. pebble powder" "1 round, 115 lbs. pebble powder"*</p>	}	<p>The gun having been designed to fire ordinarily, with elevation, and quick firing against a foe, 120 lbs. of powder.</p>
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"Projectiles of service weight being used in each case."

It will be observed that this "proof" with two reduced charges does not include firing with elevation, with heated chamber, with violent quick-burning powder, such as it may be necessary to employ on service, or with projectiles longer than 2.61 calibres capable of containing only 8½ lbs. bursters. In other words, not only does the maximum test come short of what the gun was originally designed to endure in ordinary service, but it also comes short of what the gun would still have to endure in an ordinary naval bombardment, using the reduced charge of 110 lbs. at high elevations, in continuous and rapid firing.

Lack of Endurance.—The ostensible cause of this reduction of powder-charge, and weight of common shell, is the irregular and excessive pressures registered in the chamber of the first 35-ton gun. But the real cause is the very limited and sickly life endured by the grooved portion of the bore of that gun. Whether this limited endurance of the grooves and lands be the cause or the effect of the erratic pressures within the powder chamber, is questioned. A brief life might, however, have been predicated for this gun, not only from a consideration of the inverse ratio of endurance to weight in other "Woolwich" ordnance, but also of the evidence given by the Superintendent of the Royal Gun Factories before the Ordnance Council, which assembled at the War Office on the 4th May, 1870. This Officer stated very clearly his misgivings as to the system of rifling to be adopted, and the difficulty of thus rotating efficiently a sufficiently long projectile without such an increase of grooves as would be most prejudicial to the gun. He said:—"The stud in the projectile confines us to giving a less twist "than I should like to give to any gun. * * * * In heavy guns the "liability to shear, necessitates an increased number of grooves if a

* Possibly two rounds of 115 lbs. P. and one 110 lbs. P. are intended.

"quicker twist than now employed is given. *The system has the great disadvantage of local scoring.*"

Milder Powder and Studs.—True, Sir William Armstrong unprophecically expressed "the greatest possible confidence that, with an accelerating twist and the milder form of powder that will hereafter be used, there is nothing to apprehend whatever from the stud shearing. * * I think they have stood perfectly well, and in standing perfectly well as they have done, we have a guarantee that they will stand better in future, because the strain upon them will be so very much lighter, not only from the milder powder, but from the mode of rifling;"* quite ignoring the fact, that the same sized stud is used to support and rotate a 700 lbs. shot as one of 115 lbs. weight.

Colonel Campbell does not appear to have shared either Sir William Armstrong's confidence as to the "milder powder," nor as to the endurance of the studs, stating that "the stud on the projectile confines us to giving a less twist than I should like to give to any gun. * * We are afraid on account of the shearing of the stud. * * * I have seen them shear as much as" one-tenth of an inch, "and for that reason I should be afraid to give a greater twist than I have."† Being cross examined as to his experience of studs, Colonel Campbell maintained his convictions as to the evil influence of short-bearing studs on rotation, and hence upon endurance.

The 11·6 inch 35-ton Gun.—The 11·6 inch 35-ton gun was built and rifled with an accelerated twist on the French stud, or 'so-called "Woolwich" system.

During the first four months of 1871, thirty-five 11·6 inch 700-lbs. shot were projected horizontally with charges of 75, 100, 110, 115 and 120 lbs. of W.A.P. and Belgian P. powder—one discharge, the 8th, being with 130 lbs., or ten pounds more than that originally intended. No great mischief to the gun appears to have resulted from this four months' work. The condition of the shot is not stated.

The 12-inch Bore.—The barrel was then bored up to 12 inches. By taking a shaving of two-tenths of an inch off the inside, the roughnesses and abrasions in the interior were erased, and the bore came out of the factory with a polished surface like a new gun. For all practical purposes the 12-inch bore may be safely regarded as making the 35-ton gun a new weapon.

During the three-and-a-half months, ending with the last day of January, 1872, thirty-eight 12-inch 700-lbs. projectiles were fired horizontally from this new bore, with 110, 115 and 120 lbs. W.A.P. and Belgian P. charges.

"At a weekly meeting held at the War Office, 6th February, 1872, it was decided to recommend that no further trial of this gun should be made at present." And some weeks later, the gun was removed into the factory, where its B. tube or chase was cut off, its interior steel barrel and its cascable bored out, and a new interior steel barrel, a new

* See Parliamentary paper, No. 308 of 1870, "Report of the Ordnance Council on the Proposed 35-ton Gun Competition," page 13.

† Ibid., pages 11, 12.

casable, and a new B. tube or chase substituted. Thus rebuilt, the gun will probably be as capable as before of enduring 38 horizontal discharges, spread over three and a half months.

The Practice Table.—The Report of the Committee on Explosive Substances, dated 1st April, 1872, has appended to it two very valuable though incomplete documents. One of these is a Practice Table, giving the detail of each of the 73 rounds fired from the 35-ton M.L.R. gun, showing the brand and weight of powder and the point of ignition in the cartridge, with the corresponding observed velocities at 110 and at 132 feet; and the maximum pressures registered by crusher-gauges at (A) the inner end of the bore in line with the axis, at (B) the vent, 12 inches outwards, and at (C) the base of the shot, which should sustain the greatest pressure when it has advanced about six inches from its seat, or (with 120-lbs. charge) about $33\frac{1}{2}$ inches from the inner end of the bore. I have divided this table into two parts for the 11.6-inch and for the 12-inch bores respectively, and I have added a column showing the correspondence, or, rather, lack of correspondence, between the expulsive pressure exerted upon the base of the projectile, and the striking force resulting therefrom at 110 feet from the gun.

The State of the Bore.—The other valuable document appended to the Committee's Report is the result of special examinations of the state of the interior before firing at all, and after the 6th, 8th, 20th, and 29th round with the 11.6-inch bore. These examinations do not appear to have been made with scientific exactitude, yet the pressures agree very fairly with the reported state of the bore. But no examination took place before boring out all the hard, deep roughnesses made by the gases in the lands and grooves, the local enlargement of the barrel, and the burrs on the edges of the grooves, *i.e.*, in the process of conversion into a 12-inch gun. Official examinations were made of the 12-inch barrel before firing, and of the damages inflicted upon it, whilst discharging 12, 33, and 38 projectiles.

I have summarised the Reports of these examinations in a column appended to each Practice Table, so as to place the pressures and the state of the bore in juxtaposition, and I have prepared Plate I to illustrate the longitudinal position of the principal injuries found in the interior of the 12-inch bore after the last discharge. The position of the damages are shown in the Plate by dark shading for the greatest enlargement and by thick lines for the other injuries, which are placed at the correct distances from the inner end of the barrel (A); but their vertical position could not be shown on a half section, and their *nature* could not be made visible on so small a scale. The Plate also shows the position of the shot,—1st, when in its seat; 2nd, when advanced six inches, where its base would register the highest pressures; and, 3rd, when advanced eight inches, where the rear-stud comes into "driving" bearing. The crusher-gauges are shown (A) at the inner end of the bore, where the highest pressures were usually registered; (B) at the vent 12 inches from A; and (C) in the base of the shot six inches in advance of its seat. The principal injuries are:—

Interior of
THE FIRST 12 INCH 35 TON M. L. R. GUN, AFTER 38 DISCHARGES.
The rear stud coming into "driving" bearing
Feb^y 1st 1872.

Scale $\frac{1}{8}$ to an inch.

State of the 12-inch bore, 1st February, 1872. See Plate I.	Distance from (A) inner end of bore.		Vertical position in the bore.
	Extremes.	Centre.	
Longitudinal crack in edge of groove.....	36½ to 52 in.	41½ in.	R. of down
" " " " " "	45½ to 52 "	48½ "	R. of up
" " " centre of groove ..	45½ to 48½ "	47 "	L. of down .
" " " " " "	42½ to 47½ "	45 "	L. of up
Slight fissures in centre of groove.....	41½ to 43 "	42½ "	Up
" " " " " "	40 to 41½ "	40½ "	L. of up
" " " " " "	47½ to 49½ "	48½ "	Up
" " " " " "	43 to 45½ "	44½ "	Up
Greatest enlargement .029 inches	40½ to 43½ "	42 "	Round
Roughness in lands and grooves	28½ to 65 "	46½ "	Above
Burrs on edges of grooves	not	given	
Rear stud in seat.....	According to length of cartridge	35½ in.	Down
Rear stud in "driving" bearing		44 "	Round
Front stud in seat and hammering		43 "	Up
Maximum P. powder pressure area		0 to 33½ "	} —

I should add, that it is generally understood that the report of the condition of the bore made when the gun was disabled, which is appended to the Committee's Report, does not altogether correspond in every detail with what was ascertained during the process of rebuilding. But, I am told, that the differences between the published Report and the subsequent examination, do not materially affect my argument. For no injury whatever has been discovered within the powder chamber or within the maximum powder-pressure-area, which extends to about 34 inches from the inner end of the bore where the highest pressures are registered; thereby showing that no injury whatever has resulted to the gun from the direct action of the maximum powder-pressures. Nor, as I understand, do these unpublished details vitiate the official examination made on the 1st February, 1872, the day after firing the last shot, as regards the longitudinal position of the damages, which are from 36½ to 52 inches from the point of maximum pressure at the inner end of the bore.

The "Driving" Contact of Rear Studs (Plate I).—The point where the front studs would strike, and where the rear studs come into "driving" bearing, tallies very remarkably with these injuries; for the shot moves eight inches from its seat, and attains about one-third of its velocity before the rear studs strike the "driving" edges of the grooves, the shot moving then with a striking force of 1,800 foot-tons. Now, the seat of the projectile and, consequently, the point where the rear studs come into "driving" bearing, and inflict a portion of this 1,800 foot-tons' blow, varies with the length of the cartridge. But, with the 120-lbs. charge, it is 44 inches from the point of highest pressure at the inner end of the bore. And if we suppose the operation of shearing off the rounded edges of the rear studs, and of wedging the gun-metal over the edges of the grooves, and of printing base marks

into the iron projectile, to be spread over a few inches of the shot's progress, the place in the bore where these suicidal operations would naturally be performed, corresponds with singular faithfulness to the central points of the four cracks, and the four slight fissures in the grooves, and with the maximum enlargement of the barrel.

The position of the burrs on the edges of the grooves is not given; but it is physically impossible that the rear-studs could make these burrs within the maximum powder-pressure-area, for they must then do so in rear of their own seat. It is most likely that the burrs are at, and in advance of, the point where the rear-studs strike their portion of the 1,800 foot-tons' blow upon the edges of the grooves, and commence to shear and override or wedge on the lands.

The roughness of the bore naturally begins above the seat of the base of the projectile, and therefore extends six inches within the maximum powder-pressure-area: Colonel Campbell ascribes "the great disadvantage of local scoring" to "the system" of rifling. This serious evil is caused, in the initial stages of combustion, by the rushing gases, in their effort to escape over the shot through the windage space, and through the wide, deep, almost-unoccupied upper grooves. This "local scoring" doubly effects the pressures, first, by striking down the base of the shot, nicely balanced on two points nearly under the centre of gravity, striking the front stud against the centre of its groove, and setting up a vertical "oblique movement of the axis of the projectile;" and, secondly, by roughening, like the bark of an elm tree, the surface which the studs have to traverse, thus impeding their exit, inducing shear and wedging, and enhancing the force of the "oblique movements" about the rear-studs.

Whatever be the cause, the position of every injury in the 12-inch bore is just in advance of the seat of the studs, outside the maximum powder-pressure-area, $3\frac{1}{2}$ to $4\frac{1}{2}$ feet from the point where the highest pressures were registered (See Plate I), and at a place where they would naturally obstruct the free exit of a non-centering projectile, liable to that "wriggling" action which the learned Professor of Artillery euphemistically styles an "oblique movement of the axis." Every such "roughness," "burr," "crack," and "fissure" in the grooves, is a sufficient obstructive to the exit of the soft metal studs, as they wedge their way over the lands out of the gun, to increase greatly the force of the "wriggle" natural to the shot.

The Omitted Document.—The omission from the Committee's Report of any examination of the injured studs and base-marks of the recovered 700-lbs. projectiles, is very remarkable, considering the great care displayed in registering the pressures yielded by each discharge. Had another column been added to the Practice Table, giving, if need be, a microscopic examination of the condition of the studs and projectiles on recovery, a comparison between the pressures and the resistances experienced by the escaping shot would have been most valuable. The omission is very remarkable, seeing Colonel Campbell's evidence against the studs and the rifling generally, before the 35-ton Gun Competitive Council; and what very opposite testimony was borne by Sir William Armstrong on the same occasion, as to the transcendental virtues of studs, and of that

increasing spiral which necessitates their use.* "With regard to the studs," said Sir William, "I would point out that, in future, where much milder powder will be used, the strain upon the studs will be proportionately less, because of course it is the maximum pressure which causes the failure of the stud." If, then, the defender of the stud-system himself stated of this very gun that "the maximum pressure causes the failure of the stud," why was not the extent of this "failure" noted?

Moreover, the Special Committee, in recommending, last February, a method of proving heavy guns with projectiles of double weight, evince their anxiety about the stability of the studs, and their influence on the endurance of guns, by suggesting that the proof should consist of "one round of battering charge of pebble powder and projectile of service weight, two rounds of battering charge of pebble powder and unstudded projectile twice the weight of the service projectile;" and even for the lighter M.L.R. guns, the Committee recommend the suggested proof projectile to be "unstudded," and the Superintendent of the Royal Gun Factories consistently agrees that, if such a mode of proving guns be adopted, "in such case the cylinder should not be studded."† Thus, it is evident that the Special Committee and the able Superintendent of the Royal Gun Factories are of one mind with regard to the effect of high pressures on the stud, and through the stud upon the gun, concurring, apparently, with Sir William Armstrong, that "the maximum pressure causes the failure of the stud."

Again, in all other heavy guns rifled on this most unmechanical system, the projectiles are so injured in their efforts to wriggle their way out of their bores that they are obliged, when picked up, to be re-melted; excepting, in the case of "proof" projectiles, which have, however, to be re-studded. Seeing that the rifle-bearing in each groove is precisely the same for 115-lbs. and for 700-lbs. shot, might not a similar, not to say an enhanced, destructive action be reasonably supposed to occur in the case of 700-lbs. shot?

Surely, then, the extent of "the failure of the stud," as to its shearing and wedging, as to its non-centering, and as to its keeping the iron part of the projectile from touching the bore, ought to have been carefully recorded before running off into such phrases as "wave pressures" and "local action," which mystify the unlearned and explain nothing. Let us exhaust scientific research into the tangible, and visible, and into every possible mechanical disturbing element, before giving the rein to fertile imaginations, and seeking refuge in inscrutable phenomena. Of course there are gas waves in the gun, but what makes these "wave pressures" to vary in intensity? When the waves of the sea overwhelm a ship, practical seamen ask not what was wrong in the waves? but what was the fault of the ship? And when "intense wave pressures" act unexpectedly upon a shot, practical gunners inquire what was wrong with the projectile?

"*The Oblique Movement.*"—In the absence of examinations of the

* See Parliamentary paper No. 303 of 1870, being the "Report of the Ordnance Council on the Proposed 35-ton Gun Competition," page 13.

† See "Extracts of Artillery Proceedings," &c., vol. x, Part II, pages 85, 86.

recovered 700-lbs. shot, they may be supposed to have had similar marks to those observed on all other recovered projectiles, which have, in consequence, to be destroyed or re-studded. Those marks generally coincide with that mechanical action of the studs, which gives rise to what the Professor of Artillery calls an "oblique movement of the axis of the projectile."

The official work on *Ammunition*, Part II, page 57, points out that "in all Woolwich guns, both the direction and twist are given by the bearing of the studs on the grooves, the *body of the shot never being intended to come into contact with the bore*;" and, page 58, "it may be observed that by the time the projectile reaches the muzzle of the gun, considerable wear has taken place on the driving edges of the studs," on the exactly rounded character of which all centering depends. Yet Colonel Owen rightly states that "in order to secure accuracy of fire, *it is essential that the axis of the projectile should correspond with that of the bore.*"

The studs are necessarily attached to the shot at a fixed angle; but the grooves they traverse are cut at ever-changing angles. The studs being fixed, cannot, therefore, touch the changing sides of the grooves at more than one angle, *i.e.*, at one point. The point selected for both studs to share the effort of rotation is twelve inches from the muzzle. In all other parts of the bore, this constantly changing angle in the spiral, necessitates the concentration of rotatory effort upon the rear-studs; that is to say, the length of bearing in each groove is the same, whether the weight of the shot to be rotated, be 115 lbs. or 700 lbs., or, as in guns designed, 1,200 lbs. The work to be done is vastly increased in the heavier shot, but the bearing in each groove is the same. As the studs won't stand the additional work, they shear or wear down their radial bearings, on which all centering action depends. Thus a most essential condition of all rifling is destroyed.

In its seat, the shot rests on the two studs in the lower groove, the other studs being only partially inserted into their grooves, the centre or axis of the shot is below the centre or axis of the gun, the whole of the windage is in the upper part of the bore, and no part of the projectile is in contact with the barrel except the two lower studs. These studs being nearly under the centre of gravity, the shot is balanced in unstable equilibrium, the "loading" edge of the lower studs touching the "loading" side of their grooves. All the roughnesses or scoring, which are caused by the escaping gases, are found above the seat of the projectile, and seldom occur in any gun, below its base, which is usually embedded in fouling matter. Hence, the concussion of the first part of the explosion takes effect upon and above the base. The blow from the gases in the initial stages of combustion as they escape above the shot, strikes the base down and the point up, hitting the upper groove a blow with the front stud, and setting up a vertical motion of an "oblique" character. Doubtless, the fouling matter in the gun may sometimes raise the base of the shot in its seat, admitting the gases below as well as above the projectile. Thus enveloped before starting, the resolution of forces would cause the initial movement of the shot to be upwards at the base, and down at

the point. Probably this occurs when the *centre* of a "down" groove is found cracked or fissured in the seat. But the marks and roughnesses generally found in "Woolwich" guns point to the first gases evolved from the ignition of the upper side of the cartridge, passing out above the seat, before the shot starts. It is clear that the vertical motion is the first movement initiated in the seat, and is begun during the initial stages of combustion.

If the shot were pushed gently forward for eight inches, the lower rear-stud would then touch on the "driving" side, and the other rear-studs, not being so deep in their grooves as the lower ones, would come *successively* into bearing against the "driving" edges. As the lateral bearing is at best only a ring of one-inch points, in rear of the centre of the shot, a tendency to turn upon those points sets up a horizontal motion of an "oblique" character. Any obstacle from roughnesses, enlargements, burrs, dents, fissures or cracks, which increases the friction on the rear-studs, enhances the force of the "oblique movements" about the studs. Thus, "oblique movements of the axis of the projectile" in two directions, are provided for in the mechanical action of the rear studs.

This mechanical action was thus described at the Civil Engineers' Institution, last year, by Mr. C. W. Lancaster:—"The 700-lbs. shot of the Woolwich 35-ton gun, before being fired, rested on the bottom of the bore, and had not only to be rotated by the action of the studs, but to be lifted as well, and then projected through the bore at the rate of between 1,300 and 1,400 feet per second, thus involving a double duty. When the shot rose, the bronze studs struck against the angles of the grooves. * * * In fact, so violent was the action, that not only were there numerous instances of sheared studs, but the impress of the grooves in the gun was left upon the body of the shell, to the depth of nearly one-tenth of an inch. That, he contended, was not fair play, either to the constructors of the gun, or to the country which had to pay for it."

Mr. Bashley Britten had pointed out that "The irregular action upon the studs was practically shown by the unequal wear they frequently sustained. When all went well, the studs of recovered shot were only moderately compressed and burnished; at other times the compression was considerably greater; and frequently, even when there had been no increase of charge, the studs were found to have been jammed and ground away to one-tenth of an inch or more, affording unmistakable evidence of the violence with which they had been pressed against the bore, and of the force of the charge thus thrown upon the gun."

The front studs are intended to come into "driving"-bearing 12 inches from the muzzle, when the shot is moving with a striking force of about 6,000 foot-tons. When they fulfil this evil intention, a second set of mechanical forces come into operation. But, as there is no evidence that the front studs performed their office in the 35-ton gun, it is unnecessary here to investigate their mechanical action.

Mechanical Causes of High Pressures.—If, when in its seat, the projectile be not gently pushed, but violently struck upon and above its

base, it is evident that the important element of time will be greatly diminished, and that the obstruction resulting from these "oblique movements of the axis" about the rear-studs, will increase in severity with the suddenness and violence of the blow. Thus, the mechanical obstruction offered to the free escape of the shot, would be more marked, and the accumulation of gases behind it be much greater:—

1. When more quick-burning, and therefore more sudden or violent powder is used, giving the wriggling shot *less time* to recover its direction.

2. When heavier powder charges are employed, also giving the wriggling shot less time to recover its direction.

3. When the temperature of the powder chamber has been highly raised by previous discharges, causing more sudden and complete combustion.

4. When the gun is so elevated that the influence of gravitation acts with greater power against the shot's escape.

5. When short shot are used in the same bore, the "oblique movements of the axis" round the studs causing an accumulation of gases, are obviously much more forcible, *e.g.*, a 600-lbs. shot gives higher pressures than a 700-lbs. shot in a 12-inch bore.

6. When a hard roughened surface, with steel furrows as deep as those on the bark of an elm tree, occurs in the path of the brass stud, so that the gun-metal may catch in the furrows, and the "oblique movement of the axis of the projectile" around the rear-stud be intensified, then the escape of the shot would be more difficult, and an accumulation of gases would take place in its rear (see Plate I).

These mechanical movements are naturally erratic, the "wriggling" being more or less severe, according to various conditions of an accidental character. Of course the more severe wriggles cause the highest pressures, and mark the bore most severely at the point of obstruction. Hence, a careful study of the marks within the gun and upon the projectile, is essential to any reliable deductions from tabulated powder-pressures.

The "Milder Powders" used.—Only two kinds of, what Sir William Armstrong calls, "milder powder," were used in the 35-ton gun, viz., Waltham Abbey P. and Belgian P. P. stands for "pebble" and "pellet" powders indifferently, both being similar in character; but a military critic says that the kind of P. used with the 35-ton gun was "pebble-powder."

The manufacture of gunpowder has reached such perfection that its explosive force can be perfectly controlled with exactitude and uniformity, being varied at will to ignite rapidly or slowly, and to burn slowly or quickly. Slow burning is, of course, characteristic of the slow action "milder powder" used in the 35-ton gun. Quick-burning distinguishes the violent "brutale" powder formerly in use. This change is managed by altering the granulation and density of the same thoroughly incorporated ingredients. In the P. powder, the mass of ingredients is divided into large irregular pebbles, shapely pellets, or split pellets, through the wide interstices of which the flame rushes freely, igniting all the pebbles rapidly; but, once ignited, the large

pebble takes time to consume, slowly burning from the outside to its centre. If the pebble be porous, the flame will penetrate to its centre more rapidly than if it be more closely pressed, i.e., more dense.

On the other hand, where the mass of thoroughly incorporated ingredients is divided into smaller grains, these lie closer together in the cartridge, and the flame cannot get between the grains from the point of ignition to the extremities of the charge so rapidly as when there are wide interstices. When, however, the flame does touch the outside of the smaller grain, its centre is soon reached, making combustion very rapid. The R.L.G. belongs to this type of quick-burning, violent powder, and was not, therefore, used in the 35-ton-gun.

The Belgian P. was more violent in its action than our W.A.P. This arose, I suppose, either from the ingredients being mixed in different proportions, or from the pebbles being more porous, and thus consuming more rapidly.

Diminution of violence is not the only result of enlarging the grains. The gases evolved from the combustion of slow-burning pebbles operate more gradually and for a longer period upon the shot, only attaining their maximum force, in the case of the 8-inch gun, when the projectile has moved 6 inches; whilst the quick burning R.L.G. powder attains double the force before the studded shot moves one quarter of an inch. But, though only half the pressure is evolved by the slow-burning P., it sticks to its work longer, and results in slightly greater velocity to the shot. Moreover, this more gradual application of force to the projectile, with half-pressure in the gun, enables larger charges to be safely employed, with increased velocity and striking force.

The able Superintendent of the Royal Gun Factories, however, remarks "that the very heavy charges of pebble powder, although they may not give the same pressures as the former charges of R.L.G., still really do much more real damage to the guns, and will render the necessity of re-venting, and, indeed, of re-tubing the guns, much more frequent."*

Register of Pressures in Guns.—The mode of determining the explosive force of gunpowder within guns, by means of crusher-gauges and chronograph, has already been described at this Institution in a most valuable paper, by Captain J. P. Morgan, R.A., the able Assistant Superintendent of the Royal Gunpowder Manufactory.† That paper, published in our Journal, I would cordially commend to everyone who wishes to understand what has been done in the past to determine powder-pressures; how little is at present understood on the subject; what an ocean of knowledge remains unexplored; and how invaluable such knowledge, when acquired, is likely to prove both to the manufacturer and to the artillerist. He will also find in Captain Morgan's paper some indications of the futility of trying to create laws for nature, and the advisability of scientific men confining themselves rather to ascertaining and interpreting the ex-

* "Extracts of Artillery Proceedings," &c., vol. x, Part II, page 101.

† "Journal of the Royal United Service Institution," vol. xv, No. 64, page 312 et seq.

isting and unalterable laws of nature. For example, when Robins, the father of scientific gunnery, estimates the maximum pressure evolved from ignited gunpowder at 6·7 tons per square inch; Gay-Lussac at 14·3 tons; Plobert at 64 tons; Bunsen and Schischkoff at 30 tons; Professor Bloxam at 62 tons; and Captain Noble of Elswick at 40 tons, may we not ask those who rest satisfied with such phrases as "wave pressures," "local action," &c., to examine more closely into the disturbing causes which produce the phenomena disguised under the above phraseology?

PRACTICE WITH 11·6 INCH 700-LBS. SHOT (TABLE I, pp. 16 and 17).

Let us consider the mechanical forces at work to influence the powder pressures registered in the 11·6-inch bore. The Practice Table shows that the registering arrangements were not so complete for the 35 rounds with this calibre, as for the 38 discharges from the 12-inch barrel. In 23 rounds, the pressure at the bottom of the bore, where it is usually highest, was not taken; in three rounds, no pressures at all were registered; on four occasions the cartridge was ignited at the rear-end and twice at the front, the remaining 29 charges being ignited at the usual service position, viz., 12 inches from the bottom; and in three instances, the less slow-burning, and therefore less mild, Belgian P. powder was employed. Eliminating such disturbing elements, we may still find a good many charges fired under precisely similar conditions, which, had the mechanical obstructions to the escape of the projectile been exactly alike, ought to have produced similar results.

As compared with the practice from the 12-inch barrel, the maximum pressures registered in the smooth unroughened 11·6-inch bore, were, as we should expect, more eccentric, and, therefore, higher in proportion to the resulting velocities and striking force. Obviously, for the gases to expand to equal bulks, it is necessary that the shot should move further from its seat in the 11·6-inch bore than in the 12-inch barrel. But the resistance offered by the lower studs on which the shot rest, is intensified by the extra rapidity and suddenness of the force applied to them. Hence the shot, being of the same weight, and of nearly the same length, we should expect, with the same P. charges, a more powerful, and therefore, more obstructive, "oblique movement" of the axis of the projectile about the rear-studs in the smaller bore, causing a more perfect combustion of powder and a greater accumulation of gases.

Rear-ignition in 11·6-inch Bore.—Comparing the two 75-lbs. P. charges ignited at the vent (Nos. 1·2) with the two (Nos. 9·10) ignited at the rear, the former appears to have resulted in the best powder combustion; but the resulting energy was a thousand foot-tons less than that evolved from a somewhat less base-pressure in the 11·6-inch bore (No. 31), and in the 12-inch barrel (No. 1·3·5·9·11). A vent-ignited 75-lbs. P. charge behind a shorter 600-lbs. shot, gave less expulsive pressure (16·6 tons) with 72 feet more velocity; and, according to the anomalous performances of studded shot, we should expect

less pressure behind the heavier 700-lbs. shot. Instead of following this "rule of contrary," No. 2 gives a higher pressure than with the lighter shot, showing that something unusual occurred, and inclining us to believe that, but for this irregularity, it ought to have been less than Nos. 9-10, *i.e.*, less than 14 tons per square inch.

This idea is confirmed by a comparison of the two 110-lbs. P. charges ignited at the rear (Nos. 18 and 19), with Nos. 11 and 13 ignited at the vent, when the opposite effects resulted. The pressure on the projectile was nearly $2\frac{1}{2}$ times greater when ignited at the rear (and not less as with the 75-lbs. charges); but no adequate increase of striking force resulted from this $2\frac{1}{2}$ times extra expulsive pressure, showing that this extra explosive powder did not arise solely from the point of ignition, but that extra impediments to escape were experienced by the 18th and 19th projectiles.

Front-ignition in 11.6-inch Bore.—Front-ignition would appear to have caused a more perfect combustion of 110-lbs. charges than ignition at the vent. But it is simply absurd to suppose that front-ignition accounts for 13 tons per square inch extra expulsive pressure in No. 14, when the striking force developed was very slightly increased; and the five extra tons pressure per square inch upon the 12th projectile, was evidently caused by the absorption of *seven hundred foot-tons* of energy within the gun as compared with Nos. 11-13.

It may be questioned by some whether this extra expulsive pressure was the cause or the effect of obstructive movements in the projectile, as changing the points of ignition did undoubtedly alter, in some degree, the relative conditions. Therefore, the effects of the "oblique movements of the axis of the projectile" about its studs could not be exactly predicated from these comparisons alone.

Belgian P. Charges in the 11.6-inch Bore.—The pressures and velocities registered from the three Belgian P. charges may be compared together, but cannot be compared with those of W.A.P., as it is well known that the more quick-burning powder operates for a shorter time upon the shot, and is productive, therefore, of lower velocities. It may, however, be noted that when 49.1 tons expulsive pressure was exerted against each square inch of the base of the projectile, *less* velocity and work resulted than when 46 tons pressure was registered, both charges being Belgian P. ignited under similar conditions, except that, perhaps, the chamber was warmer when the *smaller* pressure occurred.

The W.A.P. Charges in the 11.6-inch Bore.—Eliminating all exceptional conditions, it is evident that the velocity and striking force of projectiles fired under identical circumstances ought, when the same kind of powder is used, to bear a constant relation to the pressures exerted upon their bases. Where this relation is inconstant, the lowest expulsive pressure which gives the highest velocity, may be fairly taken as the nearer approach to the normal results to be expected from that charge with that kind of shot, as also the case of least "wriggling" obstruction to the exit of a studded projectile.

The 31st round would, at first sight, appear to be the normal 110-lbs. W.A.P. charge, as it gives the highest velocity with

[illegible]

† Pressure must have exceeded 60 tons.

* Charge doubtful.

the lowest explosive pressure, but I am inclined to doubt the accuracy of the registered pressure on the base, as it is so much less than that which occurred at the vent. Therefore, the 13th round would appear to be the normal 110-lbs. W.A.P. charge, giving, with 19·2 tons base-pressure on the square inch, a resulting blow of 7,508 foot-tons at 110 feet from the muzzle. These normal results appear to correspond very fairly with Nos. 11, 30, and 32. But contrast the normal 110-lbs. W.A.P. charge, No. 13, with No. 4, where six extra tons explosive pressure per square inch, with 100 lbs. of powder, gave a less blow; with No. 21, in which 1,829 foot-tons of work were absorbed by the escaping projectile, causing the crusher-gauge to go up seven extra tons; with No. 23 and 25, where the escaping projectiles absorbed in the "oblique movement of their axes" about the rear-studs, upwards of a thousand foot-tons of work, causing the gases to register 5 and 4 tons extra pressure; and with No. 7, where 12 extra tons per square inch on the base only produce about 700 foot-tons greater blow. What must have been the wriggling and stud-wedging in the gun and the condition of the studs which absorbed all this useful work?

It will be observed that Nos. 21, 23 and 25 were of the same brand, yet No. 21 projectile absorbed in its "oblique movements" within the gun 857 foot-tons of work more than that absorbed by No. 25, causing the gases to accumulate to $2\frac{1}{2}$ tons greater explosive pressure against its base.

Again, No. 29 approached nearest to the normal of the 115-lbs. charges, for its projectile would have struck a 7,839 foot-ton blow, as the result of 23·4 tons pressure per square inch upon its base. A blow of identical force was produced by nearly seven tons more base-pressure on the square inch, in No. 28. Whilst a comparison of the last round (No. 35)* with the normal 115-lbs. charge (No. 29) shows the projectile absorbing 1,446 foot-tons of work, causing the highest accumulation of gases registered with any similar charge. Indeed, comparing the first three 115-lbs. charges with the last three, I am inclined to think some roughening of the grooves must have taken place in advance of the seat of the studs subsequent to the last examination. The means of these 115-lbs. charges show clearly that the diminution of striking force produced an accumulation of gases in the gun. They are:—

115-lbs. W.A.P. 11·6-inch charges.	Mean velocity.	Mean pressure at			Mean striking force.
		Axis.	Vent.	Shot.	
	feet.	tons.	tons.	tons.	foot-tons.
Nos. 27, 28, 29 =	1,274	21·3	21·6	26·3	7,871
Nos. 33, 34, 35 =	1,199	29·4	23·8	30·9	6,978

* This No. 35 may possibly be a typographical error. But the Report throws little or no light upon the table, and the figures can only be accepted as given.

The normal 120-lbs. charge is the 20th, the "oblique movement of the axis of the projectile" about the rear-studs, being evidently *less* severe than in the case of the succeeding 115-lbs. charges, and only little more so than with the normal 110-lbs. charge (No. 13). Probably No. 20 is an accidental instance in which the shot escaped with a very slight "oblique movement," and its studs without any shear or wedging, and perhaps it may have nearly centered itself in the bore. Such a phenomenon would explain the fact that the shot escaped with 8,883 foot-tons of striking force in it, having sustained a base-pressure of only 21·7 tons. If the axis of every escaping projectile had corresponded with the axis of the piece, then every accretion of powder gases in the rear would have produced an increased striking force. But, on the contrary, with only one exception in which more than double pressures occurred (No. 6), every weaker blow with 120-lbs. charges (except No. 15)* was attended with higher accumulations of gases. Thus, as compared with the normal 120-lbs. charge, the 17th projectile absorbed 677 foot-tons of work, causing the gases to rise to nearly double the pressure; the 6th shot, projected by 25 ton per square-inch greater pressure, attained only 143 foot-tons greater energy; whilst 130 lbs. of similar powder (No. 8) exerted nearly three times the pressure of the normal 120-lbs. charge upon its projectile, yet resulted in 67 foot-tons *less* work. Now, Sir Wm. Armstrong says, "*of course, it is the maximum pressure which causes the failure of the stud,*" and the late Ordnance Select Committee reported that "*the gun rifled on the French ('Woolwich') system has decidedly the lowest velocities.*" May we not reasonably ask when this maximum pressure of 63·7 tons was registered on the base with low velocity in the projectile, what was the extent of "the failure of the stud"? and what became of the expulsive force developed by the 130 lbs. of similar powder? As the bore within the maximum powder-pressure-area was not strained, where was the power of these gases absorbed? The "local action" was on the base of the shot, where did the shot convey it to, as it was not carried out of the gun?

Sir Henry Storks "has never been satisfied with the discrepancies as to the amount of pressure produced by a comparatively small increase in the charge of powder." The expulsive pressure per square inch given by the normal 120-lbs. charge was 21·7 tons on the base of the projectile, that given by the 130-lbs. charge was 63·7 tons. The same powder was employed under identical conditions. When 130-lbs. charges are exploded in torpedoes, in mines, or anywhere except in a French-rifled gun with short rifle-bearings, is the explosive force evolved, found to be three times that of 120-lbs. charges? It is the fault of the powder-manufacturer say some—but is it found that small charges of similar powder produce these anomalous results? And do not the

* Cases like those of No. 15, where a lower base-pressure was productive of a lower velocity, may arise from the "oblique movement" or wriggle taking place nearer the muzzle, as when the front studs come violently into bearing 12 inches from the outer end of the bore. Then the velocity would be checked, but the accumulation of gases would not, except in very severe wriggles, exceed the maximum powder pressure which had already been registered after the shot had moved 6 inches.

Committee report that "when *any description* of powder is increased "beyond a certain limit," these "discrepancies as to the amount of "pressure produced" always occur?

Perhaps, say others, the pebbles may have fallen evenly together in the cartridge, so as to fit like bricks in a wall, leaving no interstices between;—but, in that impossible case, the shot would be driven out slowly long before the flames reached the centre of the compact mass, and the crusher in its base would register a lower, not a higher pressure. It's all those "intense wave pressures," say others;—but, why do "gas waves" vary in height to three times their usual altitude? Grant that the injuries sustained by every recovered and broken-up projectile are inflicted within the gun; that there is "an oblique movement of the axis of the projectile" about the rear-studs; that "it is "the maximum-pressure which causes the failure of the stud;" and that, in short, mechanical forces are at work during the exit of the shot, checking its progress, and causing an unwonted accumulation of gases in its rear, and the greater part of the phenomena is solved.

PRACTICE WITH 12-INCH 700-lbs. SHOT (TABLE II, pp. 22 and 23).

The Practice Table of the 12-inch barrel is very complete as regards both the pressures and the examinations of the bore, though, as before, we have no account of the injuries sustained by the several projectiles. The increase of calibre was, of course, attended with diminished pressures from similar charges. The bore, however, began to develop at an early stage those roughnesses, burrs on the edges of the grooves, and enlargements in front of the seat of the studs, which, by obstructing the path of the studs, intensify the "oblique movement of the axis "of the projectile" about the rear ring, thus checking its escape and causing an accumulation of gases in the powder chamber. This can be very clearly traced in Table II by comparing the earlier with the later pressures, and observing how these are generally attended with an absorption of useful work within the gun. This table is, in this respect, far more instructive than the less perfectly-recorded practice with the 11·6-inch bore.

The Belgian 12-inch P. Charges.—The seven quicker-burning Belgian P. charges naturally gave high pressures which acted for shorter periods upon their projectiles, and therefore produced relatively inferior results; but these pressures ought to have been as regular in the gun as they would have been in a shell, in a mine, or in a torpedo, unless some forces operated in the gun which find no place in the shell, in the mine, or in the torpedo. The bore presenting a polished surface when the three 110-lbs. Belgian P. charges were fired, the irregularities are very remarkable; still, we find the first one (No. 2 discharge) yielding six tons more pressure than the other two, without any adequate increase of striking force.

The four 115-lbs. Belgian P. charges acted more violently on the wriggling shot, giving them less time to recover their true direction. No. 10 shot appears to have suffered least, as it took away with it 8,936 foot-tons of useful work as the result of 26·4 tons' expulsive

pressure. But the 12th and 14th shot found or formed a slight enlargement of the bore at the point where their rear-studs come into bearing and the front-studs hammer, which would naturally intensify "the oblique movement of the axis of the projectile" about the rearing of studs; and, accordingly, the gases accumulated behind these shot, to the extent of 23 and 21 tons per square inch extra expulsive pressure respectively, without any noteworthy increase of velocity and striking force. There were "intense wave pressures" no doubt, but the powder and all its apparent conditions were alike, and you might as well blame the "waves of the sea" for overwhelming a badly-balanced ship, as say that this vast absorption of expulsive force within the gun was caused by "wave pressures."

The Waltham Abbey 12-inch P. Charges.—The "milder" slow-burning W.A.P. charges evinced at least four clearly-defined effects:—

1st. The pressure on the base of the shot was, generally, several tons less than that registered at the inner end of the bore, and, in the higher ones, a little more than that at the vent.

2nd. All the earlier discharges, when the 12-inch bore was fresh from the factory, gave very regular and low pressures, with very fairly corresponding striking forces.

3rd. When the bore was roughened, burred, enlarged, fissured and cracked just in front of the seat of the studs, the pressures were very high and very irregular, with an utter lack of correspondence in the resulting striking forces.

4th. The space within which the maximum powder pressure is confined by the projectile, is, except as to erosion over the base of the shot, wholly uninjured from the intense pressures; whilst the centres of the injuries are upwards of $3\frac{1}{2}$ feet from the point where the maximum powder pressures were registered, and correspond, as nearly as possible, with that point in the bore where the front-studs would strike, and where the rear-studs were driven into bearing, and where "the oblique movement of the axis of the projectiles" about their rear rings of studs would necessarily be most intense. (See Plate I.)

To make these points quite clear, Table III has been formed, in which are given, 1st, the results with each charge when the "oblique movement of the axis of the projectile" was at a minimum, being the least objectionable or normal mechanical condition; 2nd, the mean results when the bore was fresh from the factory; and 3rd, the mean results when the bore was roughened, burred, fissured, cracked, and enlarged by the front-studs and in front of the point of driving contact of the rear-studs. (See Plate I.)

Cause and effect are brought out very clearly in Table III, establishing a *prima facie* case against the projectile, which a more minute examination of the detailed Table II fully justifies.

POWDER PRESSURES

TABLE II.—PRACTICE WITH THE FIRST 12-INCH 35-TON M.L.R. GUN.

STUDDEN shot, 700 lbs. The pressures were determined by crushers fitted by means of a copper cup at the bottom of the bore (Δ), by a screw-gauge inserted instead of the vent-plug (B), and by a gauge screwed into the base of the projectile (C). The gun was fired by an electric tube placed in the cartridge at 12 inches from the bottom, the wires passing through a groove in the shot to the muzzle.

Date of the discharge.	No. of the round in all.	No. of the 12-inch discharge.	Powder Charge.		Observed velocity.		Maximum pressure by crusher-gauge in tons per square inch.				Striking force at 110 feet in foot-tons.	State of the 12-inch Bore. (Powder Chamber uninjured). See Plate I.
			Brand.	Weight.	At 110 feet.	At 132 feet.	A. Axis, or end of bore.	B. Vent, or 12 inches from end of bore.	C. Bases of shot, when about 23½ in. from end of bore.			
Oct. 19, 1871.	36	1	W.A.P., Oct. 18, 1870.....	lbs. 110	Feet. 1,274	Feet. 1,266	20.2	20.0	17.2	7,880	Before the Experiment:— Bore clear and polished. After 12th Discharge:— Maximum enlargement .009 in., 43½ to 46½ inches from A. i.e., 10 inches outside the area of maximum powder pressure, and extending where rear-studs come into "driving" bearing, and where front studs hammer.	
"	37	"	Belgian P., March, 1871.....	"	miss	1,301	28.4	23.6	30.5	8,220		
"	38	3	W.A.P., Oct. 18, 1870.....	"	1,265	1,269	20.0	19.2	16.8	7,768		
"	39	4	Belgian P., March, 1871.....	"	1,299	1,302	23.6	21.8	24.2	8,191		
"	40	5	W.A.P., Oct. 18, 1870.....	"	miss	1,272	20.2	19.8	17.6	7,852		
"	41	6	Belgian P., March, 1871.....	"	1,296	1,306	24.8	21.2	24.4	8,154		
"	42	7	W.A.P., Oct. 18, 1870.....	115	miss	1,389	23.2	19.6	19.8	8,060		
"	43	8	Belgian P., March, 1871.....	"	1,316	1,323	30.4	23.2	29.0	8,408		
Oct. 20, 1871.	44	9	W.A.P., Oct. 18, 1870.....	"	1,291	1,292	22.0	19.8	15.8	8,090		
"	45	10	Belgian P., March, 1871.....	"	miss	1,327	28.0	23.2	26.4	8,936		
"	46	11	W.A.P., Oct. 18, 1871.....	"	1,230*	1,242*	23.2	20.0	17.4	7,341*		
"	47	12	Belgian P., March, 1871.....	"	miss	1,360	48.0	34.6	49.6	8,973		
Oct. 24, 1871.	48	13	W.A.P., Oct. 18, 1870.....	"	1,285	miss	21.7	20.4	20.8	8,015	After 33rd Discharge:— Longitudinal crack in edge of groove, R. of D., 38 to 62 in. from A. Longitudinal crack in edge of groove, R. of Up., 40 to 62 in. from A. Longitudinal crack in centre of groove, L. of D., 45½ to 47½ in. from A. Longitudinal crack in centre of	
"	49	14	Belgian P., March, 1871.....	"	1,358	miss	43.8	32.9	47.2	8,940		
"	50	15	W.A.P., Oct. 18, 1870.....	120	miss	1,312	20.0	18.4	18.0	8,352		
"	51	16	"	"	1,311	miss	27.6	20.8	23.4	8,341		

IN THE FIRST 35-TON GUN.

23

Nov. 23, 1871.	52	17	W.A.P., Nov. 11, 1870	miss	1,305	25.6	21.2	23.4	8,264	groove, L. of Up., 43 to 45½ in. from A.
"	53	18	"	115	1,283	28.0	20.8	29.2	7,991	Maximum enlargement, .022 in., 40½ to 43½ in. from A.
"	54	19	"	120	1,322	20.8	21.6	26.4	8,498	40½ to 43½ in. from A.
"	55	20	"	"	1,312	32.4	25.8	31.6	8,352	Roughness in lands and grooves by gas, 28½ to 65 in. from A. Up.
"	56	21	"	"	1,337	32.4	25.8	31.6	8,674	Hairs on the edges of the grooves. N.B.—All these injuries (except the roughness by gas) are outside the max. pow. press. area and about where the rear-studs come into "driving" bearing, and where front studs hammer.
Nov. 24, 1871.	57	22	W.A.P., Nov. 7, 1870	"	1,314	28.8	22.6	31.0	8,733	
"	58	23	"	"	1,312	28.8	23.2	31.0	8,382	
"	59	24	W.A.P., Nov. 9, 1870	"	1,332	38.8	29.8	39.0	8,876	
"	60	25	W.A.P., Nov. 7, 1870	"	1,334	38.4	28.6	37.4	8,615	
Dec. 1, 1871.	61	26	W.A.P., Oct. 7, 1870, No. 64.	"	1,364	46.8	35.2	45.4	9,056	
"	62	27	"	"	1,360	66.0	42.6	53.2	8,973	After 38th Discharge.—
"	63	28	W.A.P., June 24, 1871, No. 11	"	1,336	44.6	34.2	46.8	8,662	Longitudinal crack in edge of groove, R. of D., 30½ to 52 in. from A.
"	64	29	"	"	1,334	37.6	27.0	39.0	8,639	Longitudinal crack in edge of groove, R. of Up., 43½ to 52 in. from A.
"	65	30	W.A.P., No. 64	115	1,319	43.0	30.8	43.2	8,412	Longitudinal crack in centre of groove, L. of D., 45½ to 49½ in. from A.
"	66	31	"	"	1,306	48.4	28.8	43.2	8,276	Longitudinal crack in centre of groove, L. of D., 45½ to 49½ in. from A.
"	67	32	W.A.P., No. 11	"	1,323	44.0	30.6	41.6	8,500	Longitudinal crack in centre of groove, L. of Up., 42½ to 47½ in. from A.
"	68	33	"	"	miss	1,318	42.6	41.8	8,431	Slight fissures in centre of groove, Up., 41½ to 43 in. from A.
Jan. 25, 1872.	69	34	W.A.P., No. 64	110	1,291	33.0	17.8	27.1	8,090	Slight fissures in centre of groove, L. of Up., 40 to 41½ in. from A.
Jan. 26, 1872.	70	35	W.A.P., No. 11	"	1,310	27.8	20.8	27.2	8,330	Slight fissures in centre of groove, Up., 43 to 45½ in. from A.
Jan. 29, 1872.	71	36	"	"	1,287	miss	19.8	24.4	8,037	Maximum enlargement, .029 in., 40½ to 43½ in. from A.
Jan. 30, 1872.	72	37	W.A.P., No. 64	"	1,303	32.8	20.8	28.0	8,242	Roughness in lands and grooves, by gas, 28½ to 65 in. from A. Up.
Jan. 31, 1872.	73	38	"	"	1,293	36.4	25.8	33.0	8,118	Hairs on edges of grooves. N.B.—The rear-studs come into "driving" bearing, and the front stud hammers about 43 in. from A, near where the greatest enlargement and all the cracks and fissures occur. The max. pow. press. area extends to about 3½ inches from A, and is wholly uninjured, except for a few inches, by gas roughening.

* Doubtful.

TABLE III.—COMPARISON BETWEEN DISCHARGES FROM THE NEW AND FROM THE ROUGH 12-INCH BORE.

Number of 12-inch discharge, 700-lbs. studded shot.	W.A.P. charge.	Mean maximum pressure per square inch.			Mean observed velocity at 110 feet.	Mean striking force.	State of the 12-inch bore. (<i>Powder chamber uninjured.</i>) See Plate I.		
		A. Inner end of bore.	B. Vent, 12 inches from end of bore.	C. Base of shot when about 33½ inches from end of bore.					
Normal, No. 1..... 1, 3, 5 34, 35, 36, 37, 38	lbs. 110 " " "	tons. 20.2 20.1 31.3	tons. 20.0 19.7 21.0	tons. 17.2 17.2 27.9	feet. 1,274 1,272 1,297	foot-tons. 7,880 7,853 8,165	} Clear and polished. } Grooves roughened, burred, } fissured, cracked, and en- } larged in front of the seat } of the studs.		
	115 " " "	22.0 22.5 44.5	19.8 19.95 29.7	15.8 18.5 42.45	1,291 1,274 1,314	8,090 7,880 8,382		} Very slight enlargement in } front of the seat of the studs. } Grooves roughened, burred, } cracked, and enlarged in } front of the seat of the } studs.	
	120 " " "	20.0 24.0 48.7	18.4 20.1 34.7	18.0 21.6 46.2	1,312 1,309 1,349	8,352 8,319 8,832			} Slight enlargement in front } of the seat of the studs. } Grooves roughened, burred, } cracked (?), and enlarged } in front of the seat of the } studs.
	Normal, No. 15 15, 16, 17 26, 27, 28, 29	120 " " "	20.0 24.0 48.7	18.4 20.1 34.7	18.0 21.6 46.2	1,312 1,309 1,349			

The first three 110-lbs. W.A.P. discharges (Nos. 1, 3, 5) were so regular in their action, that the projectiles would appear to have slid over the polished surface of the bore with uniformity of movement; whilst the last four 110-lbs. discharges (Nos. 34, 35, 36, 37, 38) had no relation whatever to the first three, or to each other. No. 1 drove the projectile out by 17·2 tons expulsive pressure on the square inch, No. 38 did so with nearly double that pressure, and yet the resulting blow would only have been 238 extra foot-tons. There was thus, evidently, an impediment to the shot's escape somewhere; and such impediment caused the gases to accumulate in its rear to nearly double their wont. An impediment is found in the bore at the point of "driving" contact of the rear-studs sufficient to set up an intense "oblique movement of "the axis of the projectile" round the studs. (See Plate I.)

Now, 110 lbs. W.A.P. powder is the maximum service charge to which this gun is reduced. *If 38 horizontal discharges, spread over one hundred and four days, upwards of 24 hours elapsing between each of the last four rounds, doubles the pressures,—what might occur if, at the end of three years' training practice at sea, firing eight rounds every three months, or 96 discharges in all, the ship had to go into a naval bombardment—in which time is an important element—and fired with elevation at the rate of 20 rounds per hour for a few hours?*

The lowest pressure registered on the base of the 12-inch shot was 15·8 tons per square inch, with 115 lbs. W.A.P. (No. 9), the corresponding energy being 8,090 foot-tons. Eight 12-inch discharges with English P. powder gave *less* velocity and striking force, with *greater* expulsive pressure behind the projectiles. The 18th discharge exerted nearly double the pressure on the shot *with less* useful work. The 9th shot had evidently less "oblique movement" than any other 12-inch projectile; and every other shot did far too little work outside the gun, and far too much inside it, absorbing several hundred foot-tons of work at each discharge, to its own detriment and to that of the bore.

As the gun was designed to consume 120 lbs. of powder, the W.A.P. charges of this amount have peculiar interest. The first one, No. 15, justified Colonel Campbell, Sir W. G. Armstrong, and Sir Joseph Whitworth in fixing upon that charge for the gun. Notwithstanding the loss of power incidental to balancing projectiles upon two points, the "oblique movement of the axis" resulting therefrom, was least severe when the bore was smooth. The average pressures registered by 120 lbs. P. behind the 700-lbs. shot, when the 12-inch bore was smooth, without erosion, burrs, enlargements, &c., were only about six tons more on the square inch than those registered by 85 lbs. P. behind the 600-lbs. shot, whilst the pressure yielded by No. 15 was only three tons more.

M.L.R. gun.	Shot.	Powder charge.		Maximum pressure per square inch.			Observed velocity at 50 yards.	Remarks.
		Brand, W.A.P.	Weight.	A. Inner end of bore.	B. Vent.	C. Base of shot.		
	lbs.		lbs.	tons.	tons.	tons.	feet.	
12-in., 25-tons	600	18 May, 1870	85	18.0	16.8	15	1,290	{ Mean of ten rounds, except base pressure, one round. { Mean of three first 120-lbs. charges. { First 120-lbs. dis- charge, No. 15.
12-in., 35-tons	700	18 Oct., 1870	120	24.4	20.1	21.6	1,309	
" "	"	" "	"	20.0	18.4	18.0	1,312	

Taking this 15th (120-lbs.) discharge as the standard of comparison, it will be observed that the enlargement of the bore at the point where the front-stud hammers and of "driving" contact with the rear-studs had already commenced (see last column of Table II); and that the "oblique movements" of the next two shot fired under identical conditions, offered enhanced resistance to their escape, so that they did somewhat less useful work outside the gun, causing a rise of 5.4 tons in the base pressures.

The eccentricity in the velocities as compared with the irregularity in the pressures, rapidly increased as the bore roughened, culminating at the 28th discharge, when 66 tons' pressure was registered at the bottom of the bore, and 53.2 tons at the base of the shot, yielding only 621 foot-tons extra blow.

Thus, in the course of thirteen horizontal discharges, spread over five weeks, maximum pressures are evolved from two identical 120-lbs. W.A.P. charges, of 20 and of 66 tons respectively. The problem of the Surveyor-General of the Ordnance might well assume a different form, for it is not a question here of different amounts or different kinds of powder, of different elevations, or of different chamber temperatures. Every condition is identical. The gun was carefully nursed on both days. It was the third horizontal discharge on each day that we are comparing, and we may assume that the intervals between the discharges were equally large. Yet $3\frac{1}{2}$ times greater pressure is registered on one occasion than on the other. Why is this? Again I ask, has any powder-manufacturer found that carefully-made gunpowder varies in its explosive force to the extent of $3\frac{1}{2}$ times the pressure? Do shells explode with $3\frac{1}{2}$ times their wonted violence without cause? Do torpedoes manifest eccentricities to this extent? Do miners find that identical charges of similar powder, fired under like conditions, explode with $3\frac{1}{2}$ times their usual force? Vary the question as you will,

nowhere but in a Woolwich rifled gun, containing a non-centering shot balanced in unstable equilibrium upon two points, and restricted to a short rifle-bearing of 1 inch in each groove, there, and there only, do similar charges fired under like conditions, produce such anomalous results.

There are, of course, waves in a gun, just as there are waves in the sea; but when the waves of the sea singled out and engulfed a particular ship in the midst of a squadron, the common sense of seamen told them that the fault must have been in the ship and not in the waves. And when gunpowder plays such pranks in a gun, every intelligent gunner knows that it is not the gas-waves but the shot which must be at fault.

Again, we are told that it was "intense wave pressures" and "local action" which disabled the gun. Now this 66 tons' pressure was registered more than 3½ feet from the spot where the whole of the injuries are concentrated. (Plate I.) And if the shot had centred itself in the bore, even the 53 tons' pressure on its base could not have reached within several inches of the damages; so that it is perfectly clear that it was not the direct action of the maximum powder-pressure which disabled the gun, but the mechanical movements of the shot acted upon by these great pressures,—the two forces, viz., the wriggles of the shot and the combustion of the charge, acting and reacting upon one another.

The Loss of Striking Force.—Though the loss of endurance is a serious matter, the loss of power is hardly less serious, since it compels us to reduce the charges and then to employ a gun of 35 tons' weight to do the work of one of 25 tons, and again to build one of 50 tons' weight, of still less endurance (unless it be confined to reduced charges), to do the proper work of a 35-ton gun, and, possibly, a 70-ton gun to do the work of a 50-ton one. For not only is useful work abstracted from each powder-charge, but we are compelled to employ smaller charges than the bore could usefully burn. Thus, the 35-ton gun could easily burn the 120 lbs. of P. powder, for which it was designed, but, owing to these "oblique movements of the axis of the projectile," and to the resulting accumulation of gases in its rear, the Committee report "*that two rounds of such a charge (115 lbs. P.) will not be a dangerous proof,*" and the service charges are reduced from 120 lbs. to 110 and 85 lbs. P. The loss of striking force resulting (1) from the non-centering of the axes, and (2) from the reduction of powder charge, can hardly be less than 1,500 foot-tons, i.e., than *from one-fifth to one-sixth that which the gun is capable of yielding.*

Thus whereas, at its own muzzle, the 35-ton gun has now barely force to perforate 12-inch armour and backing at the extreme "biting" angle, its muzzle-blow would suffice, if it had not "decidedly the lowest velocities,"—and was not obliged to reduce its charge,—to perforate 14-inch armour and backing at the extreme "biting" angle. Two additional inches of armour perforation would thus be gained, whilst prolonging the life of this sickly "infant."

Captain Maitland, R.A., the Deputy-Superintendent of the Royal Gun Factories, stated at the Civil Engineer's Institution, last year, that "the object kept steadily in view by the authorities was to get

"the highest possible velocity out of a gun with the heaviest possible projectile, or, in other words, to get through the thickest armour-plate at fighting distance." And the learned Professor of Artillery stated on the same occasion, that "high velocities were most desirable, as they gave longer ranges, more accurate practice, and greater striking power than low velocities, and in some circumstances, such as firing at iron-plated vessels, they were indispensable. High velocities were fully appreciated in continental services, and by most eminent ordnance manufacturers or inventors, such as Krupp, Armstrong, Whitworth, Lancaster, Palliser, Scott, and others." Admiral A. Cooper Key, C.B., F.R.S., when Director of Naval Ordnance, enunciated the axiom that the first essential of a naval gun is endurance, and the second "penetrating power at ranges up to 1,200 yards."

In the face, however, of every artillery authority, and of the fact that perforating force varies as the squares of the velocities, we deliberately employ a rifling of which the official advocates themselves reported that, even when firing the same charges, it "has decidedly the lowest velocities," and which compels us to diminish the velocity and perforation still more by reducing the powder charges far below those which the several bores could usefully consume; whilst the 7-inch gun thus reported upon, itself stated by a steel engraving of its own, that its projectiles had destroyed its bore, in their attempts to attain even "decidedly the lowest velocities." (See Plate III.)

PRESSURES IN 25-TON GUNS.

But do other French or miscalled "Woolwich" rifled guns suffer in this way? Certainly they do; but the mischief increases with the weight of the shot to be projected, inasmuch as the rifle-bearing in each groove is less for a 700-lbs. shot than for a 115-lbs. projectile. Every heavy studded projectile which is fired is so injured in "wabbling" its way out of the gun, that it is obliged to be melted up. Now these heavy projectiles cost a good deal of money; 12-inch ones cost, for example, nearly £5. Are five-pound notes so plentiful that anybody can afford to burn them lightly, or without good cause? Is not this re-melting of recovered projectiles sufficient evidence that unmechanical contrivances have been absorbing work within the bores that ought to have been acting on hostile armour?

What mean those "local enlargements, dents, and even occasionally cracked tubes," testified to by the Special Committee,* as the result of proving guns with only $1\frac{1}{4}$ times their diminished or miscalled "battering" charges?

The Committee on Explosives tell us† "that, with a 12-inch calibre, the (25-ton) gun would probably consume 95 lbs. of powder with as good useful effect per lb. of powder, and with no greater pressure per square inch than it does 85 lbs. of powder with an 11-inch calibre." Why, then, are the miscalled "battering" charges of this gun 10 lbs.

* "Extracts of Artillery Proceedings," &c., vol. x, Part II, page 81.

† "Report" of 1st April, 1872, p. 3.

below its powers of combustion? Simply because, even with 85-lbs. charges and 600-lbs. shot, the maximum pressures vary from 14·4 to 20·5 tons on the square inch; and with 95 lbs. there is no saying what they might jump to.

Why should 600-lbs. shot in a 12-inch bore yield so much higher pressure than 700-lbs. shot in a similar bore? Does the gunpowder know instinctively that the weight of the gun is less? Does a short 12-inch gun 12 calibres in length, consume its charge better than a longer 12-inch gun of 13½ calibres? Or, is it not capable of easy demonstration, that the mechanical action of the shorter 600-lbs. shot about its rear-studs is more lively than that of the longer shot?*

The loss of endurance in the 25-ton gun is so great, that not one of the class has been subjected to an ordeal anything like what they would have to undergo in a naval bombardment; whilst the loss of velocity and striking force is such that, properly rifled, the 12-inch 25-ton gun would perforate the "Glatton's" turret easily, and penetrate whatever the present 35-ton gun can penetrate.

PRESSURES IN 18-TON GUNS.

The influence of length upon the "oblique movements" of the shot was evidenced by the 10-inch gun experiment with similar charges behind projectiles of varying length and weight.† The weights of the projectiles varied from 300 to 1,200 lbs., and it was found that with similar charges of P. the additional weight of shot, after 450 lbs., gave very trifling increase to the powder pressure, whilst the regularity of the pressures and the correspondence of the velocities was much enhanced. The results were still more confirmatory when the more violent quick-burning R.L.G. was used, for the wriggling movements of the short 300-lbs. shot caused higher pressures than those of the longer 600-lbs. shot, using the same (60-lbs.) charges; thus justifying the Official Report‡ that "*when any description of powder is increased beyond a certain limit, wave or local pressures are set up which strain the gun unduly, without affording an equivalent of useful effect on the projectile.*" Clearly, then, in the judgment of the Committee, the "description of powder" has nothing whatever to do with the erratic relations between the pressures and velocities.

Firing its ordinary 70-lbs. P. and service 400-lbs. shot, the pressures in the 10-inch 18-ton gun show to a slighter extent the operation of similar mechanical forces within; but when the proof charge, 87½ lbs. P., was used, the eccentricity was quite as remarkable as in the 35-ton gun, the pressures rising to 63·4 tons. 29·8 tons per square inch pressure on the base ejected the shot with three feet more velocity than it had when driven out by 12 tons per square inch higher expulsive force. Clearly there was an enormous extra force applied to the shot which must have been conveyed by it, through its studs, to the gun, inasmuch as it did not carry this extra force out of the bore.

As might be expected, the quicker burning and more violept R.L.G.

* The mechanical action here referred to is the "oblique movement of the axis," not the rotatory force.

† "Extracts of Artillery Proceedings," vol. x, Part II, page 81.

‡ See "Report of Committee on Explosives," 1st April, 1872, page 7.

powder was even more erratic than the P. For, with the service 60-lbs. R.L.G. charge, the explosive pressures on the base varied from 22·5 to 33·9 tons, without any adequate increase of velocity. And when the proof 75-lbs. R.L.G. charge was employed, the maximum pressures jumped to 66·8 tons, exceeding any registered in the 35-ton gun, but without the slightest damage to the powder-chamber. Are the guns then uninjured by these irregularities? No. The lands and grooves which are traversed by the projectiles, but are not subjected to these excessive powder-strains, are marked "by local enlargements, dents, and even "occasionally cracked tubes." The position of all these abrasions clearly shows that they must have been made by the projectile, and the only part of the projectile which is supposed to touch the bore is the stud. (Plate II.) Obviously, wherever a stud makes a dent or local enlargement, the process of making it must check the exit, and the projectile must endeavour to revolve on that point, and, doing so, must wriggle with such severity as to still further obstruct its own escape, giving extra time for the more perfect combustion of the charge and causing the gases in the rear to accumulate.

Even when such small (40-lbs.) P. charges were employed that the maximum pressures did not exceed ten tons on the square inch, the explosive forces were occasionally highest when the velocities were lowest. But for this, the 10-inch gun might consume $87\frac{1}{2}$ lbs. of powder with advantage, striking a blow several hundred foot-tons heavier than at present; in fact, perforating armour which we are now obliged to employ a 25-ton gun to perforate.

Powder charge. 10 in. 400-lbs. shot.				Maximum pressure per square inch.				Striking force at 50 yards.	Position of base of shot when maximum powder pressure was registered. Plate II.
Brand.	Weight.	Length of cartridge.	Observed velocity at 50 yards.	A. Inner end of the bore.	B. 11 ins. from inner end of the bore.	C. 25 ins. from inner end of the bore.	I. 33·3 ins. from inner end of the bore.		
W.A.P..	70	25	1,413	23·7	21·3	20·9	19·9	5,539	{ Halfway be- tween C and I.
"	"	"	1,431	22·5	22·6	22·7	12·0	5,675	
W.A.P..	87½	20	1,527	25·0	29·8	30·0	29·8	6,466	{ Nearly at I.
"	"	"	1,524	63·4	41·6	37·0	41·9	6,443	
R.L.G...	60	25	1,317	57·8	29·4	31·1	18·2	4,807	{ At C.
"	"	"	1,325	36·5	27·0	22·5	16·5	4,868	
R.L.G...	75	28	1,388	41·8	22·8	21·3	16·6	5,314	{ Three inches outside C.
"	"	"	1,426	66·8	28·0	35·0	28·1	5,635	
W.A.P..	40	—	996	9·0	8·7	9·9	7·8	2,750	{ At C.
"	"	—	1,006	8·8	9·2	8·8	8·5	2,807	
W.A.P..	70	25	1,315	19·3	19·0	19·0	16·5	5,021	{ Halfway be- tween C and I.
"	"	"	1,360	20·1	18·8	17·1	16·3	5,128	

Interior of

10 INCH 18 TON M. L. R. EXPERIMENTAL GUN No 375.

3rd January 1872.

After 241 discharges. - Rear Stud coming into bearing

The state of the bore (Plate II) of this 10-inch 18-ton gun (Expl. No. 375), after the pressures were registered, shows that the studs had made and had to pass over a maximum enlargement of upwards of one-tenth of an inch in front of their seat, roughness of the bore, the deepest furrows of which were about the same spot, a fissure on the driving edge of the left groove, and wear on the driving edges of all the grooves: and this though only 241 rounds had been fired at wide intervals of time and horizontally, at the date of the examination, viz., 3rd January, 1872. Though these marks and injuries were not in themselves of a vital character, they would greatly intensify the force of the "oblique movements of the axis" of the 400-lbs. projectiles about their studs, and enhance the eccentricity of the maximum pressures with identical powder charges.

In Plate II, the 400-lbs. shot is shown in its seat with the longest service P cartridge, and again, in the corresponding position with the rear-studs coming into "driving" bearing. With the shorter cartridges, the rear-studs would be nearer the inner end of the bore. As illustrated, the seat of the rear-studs correspond with the centre of the maximum enlargement.

State of the 10-inch bore. Expl. No. 375, 3rd. January, 1872. (See Plate II.)	Distance from inner end of bore.		Vertical position in the bore.	
	Extremes.	Centre.		
Fissure in "driving" edge of groove	26½ to 36 in.	31½ in.	left groove	
Wear on "driving" edges of grooves	43 to 145 "	9½ "	all grooves	
Maximum roughness, or deep scoring	25 to 46 "	35½ "	up	
Maximum enlargement about ¼ inch	26 to 35 "	30½ "	round	
Rear-stud in seat.....	According to length of cartridge.	26 to 30 in.	28 in.	down
Rear-stud coming into "driving" bearing.....		32 to 36 "	34 "	round
Front stud hammering		32 to 36 "	34 "	up
Maximum P. powder pressure area		27 to 31 "	29 "	—

Colonel Campbell testified to the Ordnance Council, 4th May, 1870, that the Woolwich "system has the great disadvantage of local "scoring." And Mr. Bashey Britten told the Institution of Civil Engineers, that "those who had seen the inside of a Woolwich gun which "had done much work, would know that for from 12 to 24 inches from "the cartridge, the bore sometimes became as rough as the bark of a "moderate-sized elm tree; and it was up such a surface that the hard "studs had to slide. If the rifling acted uniformly, the pressures on "the gun would vary constantly with the *vis viva* imparted to the "shot; but in nearly all cases when extraordinary pressures were "detected, less *vis viva*, instead of more, was acquired by the projectiles. " * * * The liability of the studs to get jammed "was necessarily increased under such circumstances, and then they "could only be released by the pressure gathering behind them. The

"velocity of the shot might therefore be expected to be less, while the strain was greater."

Powder Pressures in the 11-inch 18-ton Gun, Expl. No. 375.—The injuries to the 10-inch bore (No. 375) were got rid of by boring it out to 11 inches calibre; and certain comparative experiments were made with 11-inch 400-lbs. projectiles. The larger the bore, the more perfect and regular the combustion of equal weights of powder, and the less violent the action upon the studs. Hence larger charges can be employed in larger bores with less "wabbling," and therefore lower and more regular pressures. Thus the 400-lbs. shot gave, with 85 lbs. P. charge, in an 11-inch bore, $8\frac{1}{2}$ per cent. less pressure, and 16·7 per cent. more work than when propelled by 70 lbs. P. powder in a 10-inch bore. The initial energy per inch of the shot's circumference being with the 11-inch shot 172·2, and with the 10-inch shot 161·8 foot-tons, or a total muzzle-blow of 5,855, and 5,016 foot-tons respectively; and the corresponding mean maximum pressures at the inner end of the bore, 17·8 and 19·4 tons per square inch.

Though the 11-inch bore, being fresh from the factory, had a polished surface, free from dents, abrasions, roughnesses, and wear on the edges of the grooves, and was, therefore, most favourable to regularity of action; still the "oblique movements of the axis of the projectile" are traceable in the milder pressures registered with the 11-inch 400-lbs. shot, e.g., 14·9 tons per square inch expulsive force on the base of the shot yielded 5,800 foot-tons blow, but nearly 2 tons per square inch more pressure gave, under apparently identical conditions, 43 foot-tons less blow, and nearly 1 ton more pressure yielded 157 foot-tons lighter blow.

P. Powder charge. 11-inch 400-lbs. shot.	Observed velocity. feet.	Pressure by Crusher-gauge per square inch.				Striking force. foot-tons.	Position of base of shot when maximum pressure was registered.
		A. Inner end of bore.	B. 11 ins. from inner end of bore.	C. 25 ins. from inner end of bore.	I. 33·3 ins. from inner end of bore.		
85 lbs., lot 863 ...	1,484	19·3	18·3	19·4	14·0	6,109	{ About halfway between C and I.
" " ...	1,465	18·1	17·0	18·0	12·6	5,952	
" " ...	1,466	20·7	16·0	15·6	14·0	5,961	
85 lbs., lot 1,404 ..	1,411	17·2	16·3	16·8	12·5	5,757	
" " ..	1,433	16·4	16·1	13·3	13·1	5,692	
" " ..	1,427	15·6	14·9	15·6	12·3	5,613	
" " ..	1,446	16·5	15·3	14·9	12·5	5,800	

NOTE.—See Mr. Bashley Britten's very able and instructive reply to the discussion at the Institution of Civil Engineers, appended to his paper on "The Construction of Heavy Artillery."

POWDER-PRESSURES IN OTHER HEAVY GUNS.

As every heavy projectile is damaged in escaping out of the bore, each shot must divert mechanical force to that object, and the necessary result is, that a great many guns have been more or less injured in slow firing with diminished charges of powder at low elevations during the past eight years. The Ordnance Inspector's Reports on these numerous injuries must be very bulky and dry literature. Yet, in the interests of the public service, I volunteered, at my own cost and labour, critically to examine the whole of those records, with the view of tabulating the positions of the several damages, in the hope of thus showing in each case how, when, and where the mechanical forces were misapplied, with the corresponding loss of endurance and of striking force, and I requested the oversight and approval of the Director of Artillery to such extracts as I might be permitted to make.

This laborious undertaking, which could be no possible personal benefit to myself, I would have performed gratuitously, free of cost to the State, in the hope of elucidating the mechanical forces in operation in each case, and, by studying the mechanical disease, arriving at such a mechanical remedy as would contribute to the efficiency and credit of the Service and to the safety of the country. But access to these official records was denied me. Why? Would they reveal anything unknown to the profession?

However, where so many guns are disabled and others injured every year, facts will ooze out; and I have examined the official records of a considerable number of marked and damaged bores. Moreover, I have studied, for sixteen months, the connection between the marks upon the bore and upon the projectiles, and variations in the Practice Tables and Powder-Pressures. I find that, in general, the principal marks in the bores are in one of two positions, viz., either a few inches in advance of the seat of the rear-studs, where they come into "driving" bearing, and where the front-stud hammers; or near the muzzle where the front-studs are intended to do their share of the work. There is also, of course, the roughness or erosion which is greatly intensified by the stud-system, as Colonel Campbell pointed out to the War Office Council on the 35-ton gun, saying—"The system has the great disadvantage of local scoring." A worn gun usually gives out less useful work on the target, combined with higher pressures in the chamber.

These things are so well known, that many shot fired from the 8-inch and other experimental guns have no studs at all. These particular guns have, therefore, shown great apparent endurance; but powder-pressures registered when the shot are unrifled afford no criterion whatever as to the pressures arising from "the oblique movements of the axis of the projectile" about its studs. The unstudded shot do not centre in the bore, and their pressures would, in consequence of the body of the shot being below the axis of the piece, and being in contact with the bore, vary according to the presence or absence of fouling matter in the gun. These pressures ought, therefore, to be higher but somewhat less erratic than when studs are employed.

Incautious students are apt to be betrayed into erroneous conclusions both as to endurance and as to pressures in these experimental guns, from ignorance of the above fact, which is not always stated in the published tables.

Mr. Bashley Britten pointed out at the Institution of Civil Engineers, last year, that "there was no reason why gunpowder should not act as "uniformly in rifled guns as in smooth bores, unless the rifling and the "projectiles were designed on unscientific principles. A rifle shot "had to perform in a gun the functions of a screw; and the power to "turn a screw working properly was definite and constant. If it "could not follow the thread it worked in, but overrode the sides, it "became locked. * * * The instant a shot was checked "by any obstacle in its course through the bore, the *vis viva* of the "column of gas moving in one direction was necessarily converted into "pressure on the gun. The 'grip at the muzzle' in the Armstrong "shunt gun was found to produce sufficient check to cause concussion- "fuzes, having movable strikers, to explode at the muzzle. The first "four 600-pounders were shunt guns, each costing £4,000, and weighing "23 tons. In the official Text Book it is stated 'of these four, by "March, 1867, two were rendered unserviceable during experimental "practice at Shoeburyness, by splitting their A-tubes and some of "the coils, and another by splitting its outer coil.' A 9-inch sh "gun burst into 42 pieces on one occasion, at the 402nd round. These "failures were officially attributed to the shunt rifling." Similarly a 9-inch 12½-ton "Woolwich" gun exploded into many pieces at the first "proof"-round in 1868; and a 7-inch 68-pounder "Woolwich" rifled gun exploded into 76 pieces, scattered over an area of 580 yards by 150 yards, in 1870, at the 165th round.

All "intense wave pressures," say some! But why at the 165th round? Oh! the powder was all wrong. But the committee say that "any description of powder" used in large charges is liable to these erratic and unaccountable "wave pressures." Is "any description of" *gun* subject to such irregular "wave pressures," except a Woolwich rifled one? 30-lbs. charges were used in the exploded 7-inch 68-pounder; do 35-lbs. charges in 12-inch shell play such extraordinary pranks?

Studs in Uniform Spirals.—Where uniform spirals are adopted in connection with short-bearing studs, balancing the shot nearly under the centre of gravity, the tendency to "oblique movements of the axis "of the projectile" about its studs is equally present; whilst the absence of that ever-increasing resistance peculiar to the ever-increasing spiral, is evidenced by the tendency of the studs to hammer intermittently against the uniform grooves, and thus to mark themselves in steps, instead of in the wedge form peculiar to the accelerating twist. The injuries thus inflicted upon the uniform-twist bores are necessarily either at or in advance of the seat of the short-bearing studs, showing that the guns are not destroyed by the powder but by the projectile. True, the uniform spiral gives the studded shot a greater velocity, in consequence of the absence of that ever-increasing resistance which reaches its maximum in the ever-changing angle of spiral when the

shot is at its highest speed. But the short-bearing stud, even with an uniform twist, gives less velocity and perforation than the long-bearing centering shot, proving that work is taken up in the bore to the destruction of both projectile and gun. The position of the injuries in such uniform-spiral stud guns verifies the writings in the steel bores of increasing-spiral guns. As samples of the injuries inflicted by studded projectiles after 500 rounds from each gun, take the following 7-inch uniform-spiral guns:—

	Expl. No. 200, 7-inch gun, May, 1872.			Expl. No. 198, 7-inch gun, May, 1872.			Expl. No. 209, 7-inch gun, May, 1872.			Expl. No. 199, 7-inch gun, May, 1872.		
	Distance from inner end of bore.		Vertical position in bore.	Distance from inner end of bore.		Vertical position in bore.	Distance from inner end of bore.		Vertical position in bore.	Distance from inner end of bore.		Vertical position in bore.
	Extremes.	Centre.		Extremes.	Centre.		Extremes.	Centre.		Extremes.	Centre.	
	Inches.	Inches.		Inches.	Inches.		Inches.	Inches.		Inches.	Inches.	
Much wear on "driving" edge of groove.	23½ to 41	32½	Down	13½ to 19	16½	Down	12 to 22	17	Down	12½ to 20	16½	Down
Slight wear on "driving" edge of two other grooves.....	14½ to 21	17½	Up	—	—	—	—	—	—	—	—	—
Bore grazed by projectiles.....	39 to 48	43½	Up	—	—	—	3½ to 47	40½	Up	39 to 46	42½	Up
Ditto ditto ..	20 to 24½	22½	Left	16½ to 19	17½	Left	35 to 44	39½	Up	12½ to 14½	13½	Up
Indentation.....	—	14½	Down	—	—	—	—	—	—	—	—	—
Maximum roughness, or deep scoring ...	17 to 35	26	Up*	11½ to 20½	20½	Up	10½ to 24	17½	Up	10 to 25	17½	Up
Ditto ditto ..	16 to 31	23½	Down	10 to 22½	16½	Up	13½ to 24½	19	Down	14½ to 21	17½	Down
Maximum enlargement	(.125 in.)	22	Round	(.029 in.)	16	Round	(.039 in.)	16	Round	(.039 in.)	16	Round
Gun re-vented	Five times.						Twice.			Twice.		
Rear-stud inscal	11 to 14	12½	Down	11 to 14	12½	Down	11 to 14	12½	Down	11 to 14	12½	Down
Rear-stud con- ing into "driving" bearing	13 to 16	14½	Round	13 to 16	14½	Round	13 to 16	14½	Round	13 to 16	14½	Round
Front stud hammering	15½ to 18½	17	Up	15½ to 18½	17	Up	15½ to 18½	17	Up	15½ to 18½	17	Up
Maximum powder pressure	15 to 18	16½	(P.)	9½ to 12½	10½	(R.L.G.)	9½ to 12½	10½	(R.L.G.)	9½ to 12½	10½	(R.L.G.)
area												

* No. 200 was very much scored and enlarged. The scoring was so extensive that the gun had to be subsequently turned over, so that the hammering and scoring might change places.

Velocities in Uniform-Spiral 12-pounders.—The French Government have been trying the uniform-spiral Woolwich system against the long radial-bearing rib of Vavasseur, which is similar in its mechanical action to Scott's centering system. Two, otherwise identical 12-pounders, rifled on these two methods, were tried at Bourges last year, when the "Woolwich" stud projectile had, as usual, "decidedly the lowest velocities," escaping with 16 feet less initial speed, and attaining 338 yards less range, with less accuracy, when the long-bearing one reached 3,760 yards; thus showing—1. That useful work had been absorbed in the short-bearing gun; and 2. That further useful work was abstracted by imperfect rotation in the air.

The Woolwich-made 9-pounder presented to the French Government is somewhat heavier than the above guns, and throws a 9-lbs. projectile with $1\frac{3}{4}$ lbs. R.L.G., which is a proportionately heavier charge. The turned shot supplied with this gun from the Royal Arsenal have been fired at Bourges, and are now being rifled by Messrs. Vavasseur with long-bearings for the French Government, to be fired from the Vavasseur 12-pounder, as a conclusive comparative experiment.

M. J. Vavasseur has permitted me to verify the following figures by comparing them with the original letter of the President of the French Commission on Artillery at Bourges:—

Données relatives aux Canons Vavasseur et de Woolwich Expérimentés à Bourges en 1872.

Provenance des Canons.	Canon.					Projectile.					Charge.		Vitesse initiale.		
	Poids.	Anne de la pièce	Système.	Rajures.			Diamètre.	Longueur.	Poids.	Surface extérieure.	Poids.	Sorte de poudre.	Par seconde.	Pieds Anglais.	Mètres.
				Profondeur.	Largeur.	Pas en calibre.									
	En kilogrammes.	Longueur.	Diamètre.												
Vavasseur à rayures, No. 730	413	m.	mm.	Woolwich— 3 rayures ..	mm. mm.				mm. mm.	l.	brute de fusion.	2	0-307 R.L.G.	1255	382-8
Vavasseur à côtes sail- lantes, No. 743	413	1-612	76-2	Vavasseur— 3 côtes	4-45 10-16 25				74-68 241 5-443			2	0-307 R.L.G.	1271	330-4

Résultats des Expériences comparatives faites à Bourges des Canons Varasseur et de Woolwich.

Constructeurs des Canons.	Nombre de Coups.	Portée moyenne.	Écart longitudinal moyen.	Dérivation moyenne.	Écart latéral moyen.	Coefficient de justesse.		Dimensions du rectangle comprenant tous les coups.		Observations.
						En direction.	En portée.	Longueur.	Largeur.	
		P.	E.	A.	D.	$R = \frac{D}{P}$	$G = \frac{E}{P}$			
Angle de tir 12°. Vent faible.										
Varasseur à rayures, No. 730	12	3421.6	115.72	23.62 Dr.	17.89	0.0052	0.0338	512	37.2	
Id. à côtes conique en saillantes, No. 743	12	3760	88.44	13.57 "	10.84	0.0028	0.0235	365	65.0	
Id. à côtes conique en saillantes, No. 743	12	3754	44.53	12.80 "	12.518	0.0033	0.0118	159	34.9	
Angle de tir 14°. Vent faible.										
Varasseur à rayures, No. 730	14	3767.1	84.68	15.22 Dr.	5.39	0.0014	0.022	508	31.4	Un obus brisé dans l'âme.
Id. à côtes saillantes, No. 743	15	4088.6	47.95	46.52 "	5.71	0.0014	0.012	189	27.8	
Angle de tir 16°. Vent faible.										
Varasseur à rayures, No. 730	14	4125.4	123.1	1.17 Dr.	6.19	0.0015	0.030	434	27.7	Un obus brisé dans l'âme.
Id. à côtes saillantes, No. 743	15	4420.9	101.5	43.43 "	5.45	0.0012	0.023	373	23.7	

NOTE.—Les expériences pour chaque angle de tir sont faites le même jour et toutes les circonstances extérieures sont identiques pour chaque canon.

THE ORIGINAL 7-INCH "WOOLWICH" GUN.

Nothing has occurred to the 35-ton gun that might not have been predicated from the performances of the original 7-inch "Woolwich" gun in 1865. It had an increasing spiral, and a study of its Practice Tables, in connection with the Ordnance Inspector's Report, shows that:—

1. 70 per cent. of the recovered shell were found injured.
2. The struggles of the projectiles to escape from the ever-changing angle of spiral, destroyed the bore in 567 discharges.
3. So much force was absorbed through the studs in the destruction of the bore and projectiles, that the increasingly-resisted shot had "decidedly the lowest velocities," striking 220 foot-tons less muzzle blow than the competitive oval-bore, and 133 foot-tons less than the competitive long-bearing iron-ribbed shot.
4. The studded shot had a higher trajectory within 1,500 yards (the fighting distance), and to drive it so far, with the same elevation, took one-fourth (5 lbs.) greater weight of powder than did its competitive long-bearing iron-ribbed shot.

5. The studded projectiles were slightly less accurate than the iron radial-bearing ones at Admiral Key's fighting range.

On the other hand, the iron radial-bearing projectiles were uninjured, and their lands and grooves were left so perfect that this 7-inch gun was bored up to 8.03 inch calibre to throw shot of 180 lbs. weight instead of the 110 lbs. ones for which it was designed; thus showing a direct relation between endurance and useful work, and that, under otherwise identical conditions, "decidedly the lowest velocities" is the natural result of decidedly the worst endurance.

The powder-pressures were not registered in the original 7-inch Woolwich gun; but the Ordnance Inspector's Report shows that the position of the damages to the grooves and lands corresponded very nearly with the position of those in the 35-ton gun. (Plates I, III.) It seems, then, not unlikely that similar irregularities occurred in the powder-chamber.

The maximum powder pressure area in the original Woolwich 7-inch gun (using R.L.G.), extended from 9 to 18 inches from the bottom of the bore according to the cartridge in use. (Plate III.) The "driving" stud was sometimes in front and sometimes in rear. The elongated projectiles varied from $11\frac{1}{2}$ to 13.88 inches in length, and from 94 to 110 lbs. in weight, and the charges from 12 to 25 lbs. R.L.G. Striking a mean between these quantities, it will be seen that the principal destructive agencies operated very nearly as in the 35-ton gun. The vital cracks in both guns correspond with the spot where the front-stud hammers. The maximum enlargements, the abrasions, &c., in both guns agree as usual with the point of "driving" contact of the driving studs. No marks are recorded outside or inside these points, excepting certain chamber defects in the original Woolwich gun, the result of malformations subsequently remedied, and "the disadvantage of local "scoring." This tender relationship between the first, and, I hope,

Interior of
ORIGINAL 7 INCH WOOLWICH GUN, N° 200.
April 7 & 8 1865
*After 667 discharges Large Stud
coming into driving bearing*
Scale $\frac{1}{8}$ in an Inch

Interior of
SCOTT'S LONGBEARING
CENTERING 7 INCH M.L.R. GUN, No 199.
after 417 R.L.G. discharges.
Ribbed. 110 lb Shot in its seat
25 March 1865.
Scale $\frac{1}{8}$ " to an Inch.

the last of the mis-called Woolwich rifled guns—the venerable parent and delicate infant—ought not to pass unnoticed.

Plate III shows the original 7-inch Woolwich gun after its destruction, with the shot in its seat, and with the rear-stud coming into “driving” bearing, when long cartridges were employed. With shorter cartridges the positions of the shot would be nearer the powder-chamber.

Contrasting Plate III with Plate IV, which shows the competitive Scott long-bearing centering 7-inch gun after the last shot, it will be observed that, in the Scott gun, “*there is no apparent expansion of the bore,*” no cracks, no dents, and no wear on the edges of the grooves; whilst the roughness or erosion from the escaping gases is stated by the Ordnance Inspector to have been “slight.” The chamber defects in both guns were the result of the hemispherical form of the inner end of the bore, and was common to all four competitive guns. One of the other guns had its chamber squared at the end, after 40 discharges, and the eating way in the axis was entirely stopped. The hole at the axis of the chamber, shown in Plate IV, was subsequently plugged up in Scott’s gun, and the barrel bored up to 8·03 inch.

See Plates III and IV.	Original Woolwich 7-inch gun, (No. 200), 7th and 8th April, 1865.		Vertical position in bore.	Scott's long-bearing centering 7-inch gun, (No. 199), 25th March, 1865.
	Distance from inner end of bore.			Position in bore.
	Extremes.	Centre.		
	Inches.	Inches.		
Longitudinal crack	11½ to 19½	15½	Up	None
Dents in lands and grooves .	20½ to 21½	22½	Down	None
Wear on <i>loading</i> edge of groove	17½ to 31	24½	Down	None
Roughness or deep scoring..	10 to 40	25	Up	9 in. to 35 in. from A.
Maximum enlargement, .049 to .042 in.....	21 to 24	22½	Round	(slight) " <i>There is no apparent expansion in the bore</i> "
Slight fissures at vent	—	—	Up	Up
Defect from malformation of chamber	—	—	Axis	Axis, and 1¼ in. from A.
Base of shot in its seat	9 to 18	—	—	9 to 18 in. from A.
Front stud hammering.....	—	18½	Up	{ Uniform spiral and long-bearing centres in the bore at starting.
Rear-stud coming into bearing....	—	19½	Round	
Maximum powder pressure area....	0 to 18	—	—	0 to 18 in.

Conclusion.—I have patiently examined, seriatim, every pressure registered in the first 35-ton gun, and I have found that every variation of pressure, where similar charges were ignited under identical conditions, is traceable to the unmechanical method of balancing the shot on two points nearly under its centre of gravity, limiting the rifle-bearing to one inch in each groove, and not centering the projectile in the bore, an absurd contrivance which Mr. Charles Merrifield, F.R.S., the distinguished Principal of the School of Naval Architecture, recently described to the British Association, adding that “the consent of all mechanics and engineers with whom he had ever conversed was absolutely unanimous in the condemnation of the Woolwich system of rifling, and that he had never heard any serious defence of it.”

During the last sixteen months, I have myself consulted eminent mechanical engineers, manufacturers of guns, of powder, and of projectiles, scientific artillerists, and mathematical professors on every mechanical detail as it arose, communicating alike with those who are committed to this as well as to other systems. These gentlemen have instructed and aided me much, opening to me freely their rich stores of knowledge and experience; some have corrected my erroneous impressions, and to all I owe grateful thanks. But amongst all these experts, I did not come across a single unqualified supporter of the present system of rifling. Certain able and distinguished soldiers had opinions in favour of “the increasing spiral” on which the whole of these evils rest. But when I privately and publicly importuned them for a single reliable fact in support of “the increasing spiral,” they had not the shadow of a fact to allege,—nothing but “the baseless fabric of a vision.” Some imaginative individual had made a guess that the maximum pressure in the powder-chamber and the destruction to the gun, would be materially lessened if an increasing spiral were employed, and some dabbler in mathematics conclusively proved that if x and y were cleverly manipulated, powder and mechanical laws must follow wherever those two unknown quantities are directed. But not a single experiment was made to test the correctness of this guess.

Eight years have been spent in trying to make the laws of nature conform to this arbitrary guess. All the talent of Woolwich Arsenal has been concentrated on the problem. Every nature of gun produced has had a different form of increasing spiral. Hundreds of thousands of pounds have been squandered on varieties of projectiles,* each variety devised to meet these impossible conditions. Gunpowder manufacturers have exhausted ingenuity to the same purpose. And what is the result? Simply that an “increasing spiral” causes oscillations of pressure from 20 to 66 tons on the square inch under identical conditions, both in an 18-ton and in a 35-ton gun; and that it has destroyed the latter in 38 horizontal discharges after most careful nursing. Is this the result that the increasing spiral was intended to produce?

* Up to last July, 770,282 projectiles had been studded. At the estimated cost of £77 per thousand, the expenditure on *studding* alone was £59,311. Many thousands of these projectiles have been destroyed, either in store or after having been fired.

At least six heavy guns, rifled with increasing spirals, have been disabled during the past year. Yet 1872 was a year of profound peace. Not a single gun was subjected, during that year, to anything in any way approaching to the ordinary conditions of a naval action. The Practice Tables of the late 35-ton gun show that pressures rise as bores get roughened by repeated discharges. If 32 discharges each, scattered over the whole year, have disabled six heavy guns in 1872, will these guessers and calculators tell us how many hours of elevated fire a worn 35-ton gun would endure at the rate of 20 rounds per hour?

Ships of war are but floating gun-carriages. The most recent ones cost about £100,000 per gun. If these weapons won't endure an ordinary naval action, is it worth while building floating carriages for them? All the intelligence of the Navy protests against being sent to do battle against "foemen worthy of their steel," with weapons that yield the minimum of perforating power, and won't even withstand combats against canvas targets.

If our guns are no longer to have "decidedly the lowest velocities," and decidedly the least perforation; if they are to employ the largest powder-charges which their several bores will burn; if they are to yield an endurance proportionate to their weight and admirable build; and if the powder-pressures are to follow regularly the apparent conditions of the powder-charges employed, every well-informed mechanic believes that we must:—

1. Give the shot the longest possible rifle-bearing in each groove.
2. Adopt cast-iron radial bearings which won't shear or wedge, and will strengthen the projectile.
3. Centre the axes of the shot and the bore during exit, on that plan which gives the greatest windage for loading foul guns.
4. Proportion the twist to the length of the projectile, rather than the converse.

This done, we shall hear no more of unaccountable "wave pressures;" of melting up all recovered projectiles; of Ordnance Inspectors to report, after every 50 discharges, upon injured bores and disabled guns; and I shall be able to return into private life, conscious that I have not dishonoured the Naval Profession by forgetting that, at whatever personal hazard, "England expects that every man shall do his duty."

The CHAIRMAN: Before I convey the thanks of this meeting to Commander Dawson and express to him the satisfaction we have had in hearing such an elaborate paper, and our sense of the enormous amount of research which it must have cost him to prepare that paper for your notice, perhaps some gentleman would like to offer some remarks upon this subject.

Admiral HALSTED: I fully agree with the main points of Commander Dawson's paper. I merely want to say this: Commander Dawson says he has consulted in every direction; but it is very curious that he has omitted to mention one of the most eminent practical mechanicians existing in the world—I mean Sir Joseph Whitworth. Is he already dead and buried? This very question of self-centering rifled projectiles is the original deduction of Sir Joseph Whitworth, obtained from his small-arms shooting gallery of 1857, out of which experience, step by step, have grown the identical rifling of his two 7-inch and two 9-inch guns which we now possess. Then the question of shells has not been touched. Sir Joseph Whitworth is again the only person who can produce a steel armour-shell of five calibres, containing, as Commander Dawson told us, in Sir Joseph's own proposal for his 12-inch rifle, 58 lbs.

of bursting powder, and being upwards of 1,200 lbs. in weight, the same weight as in the proposed Woolwich 45-ton gun. Let me mention this subject again with direct reference to the two 9-inch Whitworth guns which we have now got. What, I ask, is the normal bursting charge of their $3\frac{1}{2}$ calibres armour-shells? It is 15 lbs., and here we have the 35-ton Woolwich gun only capable of giving us about $8\frac{1}{2}$ lbs. But, then, what again is the bursting charge of Sir Joseph Whitworth's 5-calibre 9-inch armour-shell of the same gun? It is 25 lbs. Now, of two 2-turret ships with equal thickness of armour-plating: put two 35-ton guns into the turrets of the one ship, such as are those of the "Devastation" at this moment, and let those guns attack the couple of turrets in the other 2-turret ship armed with Whitworth's 9-inch guns of only 15 tons weight. Let there be equal penetration upon both sides, and who can doubt what must be the result of exchanging shot for shot between an armour-shell carrying a bursting charge of 25 lbs., and another armour-shell carrying a bursting charge of only $8\frac{1}{2}$ lbs.? How long is this going to last? Shell fire is the question of questions with regard to armour-plate artillery. It is not cold shot that we want, but shells. You may go on fighting with cold shot between well-designed ironclads of iron as long as you please. I will defy all the cold shot that shall be produced, say on the French side on the one part, and all that we can produce at Woolwich on the other, to make a hole some 10 or 15 feet under the water line 5 feet long and 4 feet wide, as in the recent case of the "Northumberland," and even when that shall have been done, you only get a couple of water-tight side compartments filled with water, and the ship sails away from Madeira to Gibraltar almost as if she had received a mere flea-bite. And when she gets to Gibraltar she does not go into a dock, but is only careened sufficiently to get a coffer dam over her side, and in less than a week the whole injury is repaired. That is the present state of our well-designed ironclads of iron; they are practically unsinkable by any cold shot you can fire at them. What cold shot could be fired equal in effect to the prow of the "Hercules?" What we want, if we are really to destroy each other in ironclad war, is not cold shot, but the most destructive shell, and you must have a gun able to deliver it; and if you can get guns capable of delivering 5-calibre armour-shells they will have the advantage over those which are only capable of delivering with safety 3-calibre shells. As I say, if only on this all-important question of "shell-fire," this Woolwich system ought never to have been adopted.

Captain JASPER SELWYN, R.N.: I wish to draw attention to the fact that hitherto we have not exactly discussed the paper. The question is not so much what is the best gun—we shall get at that by and by, but how to use best and not misuse the guns we have. I so thoroughly go with Commander Dawson in most of his paper, that I shall only note one point of difference in the explanation of the way in which an elastic gas acts on the base of a shot. It is not quite sufficient to consider that the gas will not pass as well underneath the shot as above, though it is perfectly and absolutely true that while the shot reposes on the bottom of the bore, as it must necessarily do with this system, there is a greater space above the shot than below, and therefore a greater rush of gas through the upper part than below, and that that will produce the tilting which Commander Dawson has described, yet we shall be open to the remarks of others who go into this question of powder waves if we fail to show that we understand that the elastic fluid passes in every direction and exerts in every direction the same pressure at the same time. Captain Scott, whose system deserves our closest investigation, foresaw that the shot must be centred: he was the first within my recollection to talk of the centering of a shot; he was the first to show us how we could do so by long bearings, by carefully brought-out inclines with those bearings, so that the shot once started into motion, would have no other tendency than to support itself evenly from point to base in the true axis of the bore, and that under these considerations, no wriggling, as Commander Dawson prefers to call it, could take place, and the shot would pursue its even path with the pressure behind it due to the increments of pressure coming either from pebble powder more slowly, or from fine grain powder more quickly. I entirely concur with Commander Dawson in everything he has said as to the utter nonsense of talking about waves of gas being excited by any other cause than suddenly increased pressures due to obstacles. Powder gas like all other gases does never increase sud-

denly in force unless it encounters such obstacles. That the guns hitherto made have not been made with different forms of rifling, I regard as a subject for the greatest regret. The guns which we might in future try, though they may not require to be either re-rifled or re-lined and re-made in the extraordinary way which Commander Dawson has spoken of, might be tried at no great expense to the country with different kinds of shot. I do not think that while we have such results as these, it is wise to ignore the fact that with the long bearing, however made, we have never yet had any destruction either of the shot or the gun. Let us try whether in those guns, without the increased spiral, which we know only last a certain number of rounds under present circumstances, the introduction of different shot will stop that destruction and enable us to trust to our guns for a greater number of rounds. I may state that there is a remarkable difference between the shot exhibited as Captain Scott's and that exhibited as Mr. Varasseur's, and it consists in the fact that if you take a cylindrical body of iron and cut pieces out of it whether in the form of stud holes or long grooves, you weaken that body; but that where you get long bearings cast on the shot you have two advantages—you do materially strengthen either shot or shell in certain lines, and you do also prevent those shot, if they are being knocked about and receive the damage due to careless handling, from being so likely to ruin your guns, though constructed on the best principles. I think the weight of this Institution, if it is brought to bear in any direction, ought to be given to the advocacy of more extended, more careful, more close experiments than have yet been made with more natures of shot. What we shall do with the guns afterwards in the way of getting rid of an idea of increasing spirals I won't say. If we consider the shot as issuing from the bore with a gradually increasing velocity, we shall see that even an even-spiral gives an increasing twist or speed of rotation in so many parts of a second to the shot in proportion as the speed of the issuing shot is itself increasing. It will do so very injuriously if at any point by reason of the bearings being short bearings, there be a wriggling of the shot in the bore, and where the spiral increases in the gun, with an even spirality of studs on the shot, as Commander Dawson has beautifully described it, you have to find out at which point to make your compromise between the two spirals. He has said, I think with perfect truth, that the increasing-spiral is the reason for the affection which exists at Woolwich for the studs; we cannot have a long bearing which we should like, simply because we have the increasing spiral. The increasing spiral again rests on theory, and has not succeeded in practice; the opposite is just the condition of the long bearing and even-spiral; it has not been advocated much in theory, but it has proved itself in practice. Now, as I have always been of opinion that an ounce of theory is a very good mixture with a pound of practice, I hope we shall have in future a little less of the first, and a little more of the second in this case.

The CHAIRMAN: I will, with your permission, return the thanks of this assembly to Commander Dawson for the very able paper which he has read to us.

There not having been time for Captain Dawson to reply to the remarks made in the discussion, he wishes the following note to be added:—

NOTE.—Commander DAWSON wished to express his thanks to those gentlemen who took part in the discussion, and, with reference to some observations made, to point out that the whole of the erosion or roughness caused by the escaping gases about the seat of the projectile was in the upper part of the bore, and none whatever below the shot. In those rare instances in which roughness or erosion from the gases was found in the lower side of the bore, it never extended inwards to the seat of the base of the shot. The reason of this appeared to be that the fouling matter from former discharges filled the spaces below the shot in its seat, and that nearly all the windage was above the seat, the upper grooves being only very partially occupied, whilst the initial stages of combustion took place on the upper side of the cartridge, and the first gases evolved naturally rose in the bore, and strove to escape through the wide grooves and open space above the shot. The initial movements of the shot were influenced by this initial stage of the process of combustion; but, no doubt, when this less-than-momentary stage was passed, the shot would be enveloped in the gases, as was noticed in some Woolwich-rifled

guns by a slight degree of roughness in the lower side of the bore outside the seat of the shot. The "oblique movements of the axis of the projectile" about its studs were, however, initiated vertically and horizontally before the shot had moved more than eight inches forward.

If we suppose that the shot, balanced in unstable equilibrium upon two studs, was surrounded by equal pressures of gas before it began to move, then the forces we should have to deal with would be simply those of a pressure against the base, and the resistance of friction and gravity acting through the lower rear-stud. The resultant of those two forces would be represented by a line from the lower edge of the base to a central point above the rear-stud. This resultant of forces would operate so as to throw the base up, and the point down, causing the front stud to hammer downwards in its seat instead of upwards; but still equally causing the vertical "oblique movement of the axis" referred to by the learned Professor of Artillery. We should in that case look for the "cracks," "fissures," "dents," "local enlargements," and other damages near the seat, in the lower side of the bore, and not in the upper. Now, as a matter of fact, in the late 35-ton gun, only two "cracks" are found "down," and all the other injuries are "up;" whilst one of these two "cracks" being *on the edge of the lower groove* would appear to have been due to the rear-stud coming into bearing, and not to the front studs hammering; the other crack "down" is in the *centre of the groove*, and might properly be ascribed to the front stud. On the other hand, the other *edge of a groove* found cracked is "up," showing that the shot *jumps* and does not act uniformly in the lower side of the barrel in accordance with the laws of gravitation. Moreover, it is generally found that when other "Woolwich" rifled guns are so eroded as to be obliged to be turned upside down and re-vented, the base of the shot partially obliterates the scoring at the seat, showing that at starting the base is thrown downwards and not upwards. It was a consideration of the marks found in the 35-ton and other "Woolwich" guns, which led me to reject the idea that the shot was enveloped on all sides in equal pressures of gas before starting, and to suppose that its initial movements were influenced by the initial stages of combustion. Speaking generally, I am inclined to regard the damages above the seat of projectiles as inflicted by the front studs, and those found below the seat, as the suicidal work of the rear-stud. Though invariably operating in the same longitudinal part of the bore, the vertical action of the studs is evidently erratic, as the position of some of the cracks and fissures in Woolwich-rifled guns, occasionally tally with that explanation which I have thought fit to reject, but which Captain Selwyn thinks most correct. The distinction between the two vertical actions, viz., of the gases acting above the base in its seat, and of their equally enveloping the shot before starting, is on scientific grounds worthy of careful investigation; but as to the practical question, Captain Selwyn and I are quite agreed that the 35-ton gun was disabled by the action of the front and rear-studs, within a few inches of their seat in the bore; and that the high and erratic powder pressures registered $3\frac{1}{2}$ to 4 feet off, at the inner end of the barrel, were the natural result of the "oblique movement of the axis of the projectile" about its studs at the point where these injuries are found; and that such "wriggling" would increase in force, offering a greater obstacle to escape, in proportion as the "roughnesses," "cracks," "fissures," "enlargements" and "burrs" enhanced the friction upon the rear-studs; and that such increased severity of "wriggle" would lead to still further irregularity in the powder pressures.