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A treatise on gun-powder, a treatise on fire-arms, and a treatise on the service of artillery in time of war

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138. There may be some defects so slight as not to merit attention; while there are others that must be prejudicial, according to their nature and extent; as the eccentricity of the bore, the number, depth and situation of the flaws or cavities, the wrong position of the vent, or a failure in other points previously concerted with the contractor. As, on the one hand, nothing should induce officers to receive guns that cannot be depended on; so, on the other, they should not be over scrupulous in their examination, lest the founders under pretence of the minute strictness of the scrutiny enhance their price.

139. Iron guns should be subjected to the same proof and examination: but as the hardness of the metal is ascertained, there will be no reason to apprehend any orbicular cavities being formed in the charging cylinder, or any impressions made by the shot in the bore. If properly cast of metal of a good quality, they may be proved with iron shot without fear of damaging or hurting them; the quantity of powder should be determined by the thickness of metal, agreeably to the rules laid down in the 6th chapter.

140. The same precautions and care should be taken in proving and examining mortars: but any little hollows or flaws in the chase may be disregarded, unless from their number and proximity, there be reason to apprehend an essential defect in the interior of the metal.

S E C O N D P A R T .

OF PROJECTILES.

141. **T**H E R E are two general methods of annoying an enemy: with missile weapons; or with pointed and cutting instruments. Under the first head, the ancients made use of the *balista* and *catapulta*, for throwing large stones and arrows to great distances; and of *slings* and *bows* for throwing them to shorter distances.

The

The invention of the powder gave rise to the casting of guns and mortars; which project iron shot and shells of different sizes to very great distances, for the destruction of men, and the demolition of fortifications and buildings. The non-commissioned officers and soldiers of artillery perform the operations requisite for producing these effects. The theoretical part of the profession consists in certain principles and rules, with which the officers ought to be fully acquainted: as from mere practical knowledge they can never hope to be distinguished; nor can their country reap from their exertions the advantages expected from a corps, purposely set apart in all armies for this particular service.

Our ancestors feeling the necessity of regulating their practice by fixed principles, were soon convinced, that, to expertness and adroitness in the mechanical parts, it behoved them to join a just theory; that from a knowledge of causes they might be enabled to account for effects, and conduct their experiments without the confusion and absurdity inevitably attendant on an erroneous system.

If it hath not already been sufficiently proved, that an artillerist should be conversant in physics and mechanics; the second part of this work will clearly demonstrate, that unassisted by science, he never can ensure facility and œconomy in execution, which is the most certain and ready method of obtaining victory, the sole object of military operations.

142. To this end, *each shot should strike the object in the manner that will produce the best effect that circumstances admit of; or in other words, the projectile should produce the greatest effect possible in any particular case.* The officer then, who commands a battery, should examine the calibre, shape and dimensions of the artillery; the qualities and proportions of the powder: the causes that may modify in any considerable degree the initial velocity of the projectile; the resistance of the air to its movement; its nature and form: the quality and size of the objects against which the fire is to be directed; their relative and absolute situation; the position of the enemy's troops; and the nature of the ground. Each of these circumstances merit a particular discussion.

C H A P. I.

OF THE INITIAL VELOCITY OF PROJECTILES.

143. **T**HE initial velocity of shot and shells must be indispensably known, before the problems in projectiles can be solved: but as it may be much diversified by the quantity and quality of the powder, the force used in ramming the wads, the elevation of the guns, and the length of the bore; it is necessary to treat all these circumstances more in detail: the powder will be supposed to be the fine war-powder in a good state of preservation.

1. The largest service charges for heavy guns, are equal to $\frac{1}{2}$ of the weight of the shot in 32 and 16 prs. and to $\frac{3}{4}$ in 8 and 4 prs. These charges are only used on particular occasions; the wads are well rammed, that the powder being closely collected at the bottom of the bore, may all take fire in the piece; and that the inflammation of each grain being as instantaneous as possible, the shot may have the greatest initial velocity.

2. The medium charges are $\frac{3}{8}$ of the weight of the shot in 32 and 16 prs. and $\frac{1}{2}$ of its weight in 8 and 4 prs. These charges are commonly used in sieges, for demolishing works, dismounting the enemies artillery, or enfilading troops; two gunners give five strokes of the rammer to the wad over the powder, and three to that over the shot.

3. The smaller charges are equal to $\frac{3}{4}$; and the least to $\frac{1}{2}$ of the medium charge. These are only used in particular cases, which will be hereafter pointed out; and are always supposed to be wadded in the same manner as the medium charges, in order to compare the initial velocities of shot, impelled by different quantities of powder.

4. As the difference in the diameter and weight of shot causes a great difference in the initial velocity, the shot are supposed to be of the diameter and weight, and the guns of the calibre prescribed by the king's order, and cast agreeably to the proportions laid down in the first part of this work. Shot made, as directed in the

first

first book of artillery, have been found adequate to every purpose; nor can their surface be more polished, or their figures more perfect, without incurring an exorbitant and unnecessary expence.

144. The initial velocities of shot are determined from experiments made with skill and discernment, and conducted with care and circumspection: before we proceed to the method of determining them, it will be necessary to mention the principles adhered to in carrying on the experiments.

1. The piece was always loaded in the same manner, and placed exactly in the same position, lest the result might be erroneous.

2. Since effects are always proportioned to their causes, when any remarkable difference arises in the course of the experiment, it should excite no amazement; as it must proceed from negligence or accident. Some practitioners take the mean result of all experiments, but conclusions drawn from thence must be faulty.

3. In spite of the utmost precaution, there will be sometimes a slight difference, proceeding from the manner of placing or wadding the powder, &c.

If the variations be not very great, a few more rounds may be fired; but the mean result only of those taken that approach nearest to each other: this may then be considered as the absolute result. If, for example, the question be concerning the length of ranges; the mean only of those should be taken, whose differences do not exceed 2 in the 100, and no regard paid to the others. But, should the ranges vary considerably, it will then be necessary to examine carefully every part of the process, to discover the cause of the variations, and be enabled to make fresh experiments in a more exact manner.

145. There are three methods of determining the initial velocity of shot:

1. By measuring their penetrations into a homogeneous butt of a known consistency.

2. By analysing and resolving into its simple movements, the curve described by the projectile on quitting the piece.

3. By deducing it from the thickness of metal of the fire-arm, when it is in equilibrio with the pressures of the elastic fluid, in every point of its length. The

third method is applicable to fuzils and pieces of very small calibre; but not to guns of large calibre, fired with the common charges of powder: because in the latter, the initial velocities are compounded of the impulsion and pressure, as has been explained in the first part.

146. The initial velocities are found very nearly by the first method (145, No. 1.) if the butt be perfectly homogeneous and consistent. To determine its consistence, fire a piece of small calibre, with an iron shot 1 inch in diameter = D : and measure the initial velocity = $u = 1200$ feet, (Treatise on Powder 164, 165). Then the piece being loaded and fired as before, the penetration of this shot into the butt will be 15 inches = S ; and substituting these data in the formula $fS = D U^2$; we shall have $f \times \frac{5}{4} = \frac{1}{12} \times 1200^2$; then $f = 96000$ for the consistence of the butt: let it be written in the formula, which then becomes $96000 S = D U^2$. Place the gun, the velocity of whose shot is sought, very near the butt, and fire some rounds in a horizontal direction, in order to obtain the mean = S of the penetrations of the shot; suppose it = 8 feet, and the diameter D of the shot = 4 inches; then by substituting these data in the for-

mula, $96000 \times 8 = \frac{4}{12} U^2$; hence $U = \sqrt{\frac{96000 \times 8 \times 12}{4}} =$

1517 feet, the initial velocity sought. In these experiments, the penetrations should be at such a distance from each other, that the loosening of the earth by the first shot, may not facilitate the entrance of the others; the least difference will be then perceptible, since the penetrations of the same shot are as the squares of the initial velocities.

147. To determine the initial velocities, by analysing the curve (145, No. 2); let us take the first part of the curve, where the effect of gravity has not been sensibly altered by the resistance of the air. It is a matter of indifference, whether the space that the shot pass through by the gravitating or impelling power, be first considered; since the latter may be deduced with equal facility from the former, as the former from the latter. Let us in the first place examine the space passed through by the power of gravity.

(Pl. 5, Fig 14.) Let the gun AB , mounted on its carriage, be placed on an even and solid platform, and laid in a horizontal direction AC ; so that the shot at the first graze
may

may touch the earth in the point G of the horizontal line D F: the vertical distance K G between the two planes, expresses the space = S passed through by the gravitating power, and the horizontal line D G = A K expresses the length of the range, or the space = q passed through in the same time by the impelling power. If the known value

K G be substituted in the formula $S = \frac{32.18 t^2}{2}$, it will give

with great precision the time $t = \sqrt{\frac{2 K G}{32.18}}$, in which the

shot is driven from A to K by the impelling power. Having fired several rounds, and measured the length D G of the ranges, take the mean = q (144, No. 3); and considering this space as uniformly passed through, establish the following proportion; the time = t, is to the space passed

through = q, as one second, is to the space = $\frac{q}{t}$; which the

shot would move through in one second, if there were no resistance from the air; this space is termed the initial velo-

city. For example, K G = 4 feet, then $t = \sqrt{\frac{2 \times 4}{32.18}} = \frac{1}{2}$

second; and suppose A K = 700 feet, then $\frac{q}{t} = \frac{q}{\sqrt{\frac{2 K G}{32.18}}} =$

$\frac{700}{\frac{1}{2}} = 1400$ feet, the initial velocity sought. The initial ve-

locity thus found, is not absolutely just, since the shot, from the moment of quitting the piece till it touch the ground at G, has been retarded by the resistance of the air. If from the nature of the ground, where the experiment is made, the vertical line K G be shortened, the initial velocity will be greater, and approach nearer the truth.

148. To determine the length of the movement of impulsion A M, in order to deduce from it the space passed through by gravity; place vertically in M a butt L M N, lay the gun in a horizontal direction, or nearly so, and at M where the line of direction cuts the butt, draw transversely a

L 4

horizontal

horizontal line. Fire some shot into the butt as nearly as possible in the same direction, so that after each round the vertical distance MH between the horizontal line marked on the butt, and the hole H made below it by the shot, may be exactly measured: take the mean $MH = S$ (144,

No. 3) and substitute it in the formula $t = \sqrt{\frac{2MH}{32.18}}$; then

by measuring the distance $DL = AM = q$, it will give the space passed through in the same time by the movement of impulsion; and considering this space, as uniformly passed

through, $\sqrt{\frac{q}{\frac{2MH}{32.18}}}$ will be the initial velocity sought

(147). For example, let $AM = 200$ feet, $MH = 6$ inches,

then $t = \sqrt{\frac{2 \times \frac{1}{2}}{32.18}} = \frac{1}{8}$ of a second, and $\sqrt{\frac{q}{\frac{2MH}{32.18}}} =$

$\frac{200}{\frac{1}{8}} = 1200$ the velocity sought. The nearer the piece is

brought to the butt, the shorter will be the time, and of course so much nearer to reality will be the initial velocity.

149. These methods of determining the initial velocity may be applied to guns of all lengths and calibres. The velocities may be compared together when the experiments have been made under a constant state of the atmosphere; but as its frequent changes affect the explosion of the powder, the following rules should be observed:

1. To make the experiments under a mean state of the atmosphere both with respect to heat and moisture; as the inflammation and explosion of the powder are then much more uniform.

2. In order to know if the variation of the atmosphere be the cause of any alteration that may occur, some rounds should be fired from time to time from a gun of smaller calibre of a known initial velocity, as a wall-piece, placed very close to a butt perfectly homogeneous, to ascertain whether the penetrations be regular.

3. If the results be constant, it will be a proof that the process has been just in every particular, and that the

the state of the atmosphere has not varied. Any irregularity found in the results from the gun alone, will denote that some necessary precaution has been neglected: but if the results from both pieces are irregular, it will be proper to defer the prosecution of the experiments till another day, when the atmosphere is more settled: in the mean time the utmost attention should be paid to rectify any error in the apparatus, or in the mode of conducting the experiments.

4. If any interval of time be suffered to elapse between the commencement and the prosecution of the experiments, and there be a difference in the initial velocity of the wall-piece, it will be proper to fire some rounds from the gun, in order to compare it with the preceding experiments. For example; if in the morning the initial velocity of a 32 pr. be 1383 feet, and that of the wall-piece 1696 feet; and in the afternoon the initial velocity of a 16 pr. be 1424 feet, while that of the wall-piece be only 1600; a few rounds should be fired from the 32 pr. the initial velocity of which must be necessarily less than it was in the morning; suppose it to be 1315 feet: the following proportion

$$\text{will be formed, } 1315 : 1383 :: 1424 : \frac{1383 \times 1424}{1315} = 1498$$

which would be the initial velocity of the 16 pr. if the atmosphere were in the same state as in the morning. By this mode of operation, experiments made at any interval of time, at different seasons, and under different states of the atmosphere, may be compared together with sufficient accuracy.

150. If under a mean state of the atmosphere, with respect to heat, density, and moisture, these experiments be made with guns of medium length loaded as before (143); it will be found, on firing them in a horizontal direction:

1. That with the largest charges the initial velocities are nearly as follows:

Nature of Guns		Initial Velocities.
	<i>Prs.</i>	<i>Feet.</i>
Shot	32	1517
	16	1618
	8	1696
	4	1720

2. That

2. That with the medium charges they are very nearly as follows ;

Nature of Guns.		Initial Velocities.
	<i>Prs.</i>	<i>Feet.</i>
	32	1350
	16	1416
	8	1449
	4	1467

3. That with the less charges (143) they will be about $\frac{1}{8}$ less than with the medium charge; for instance, a shot from a 32 pr. charged with $7\frac{1}{4}$ lbs. of powder, will be impelled with an initial velocity of about 1180 feet, and a shot from an 8 pr. with $2\frac{1}{2}$ lbs. of powder, with an initial velocity of about 1260 feet.

4. With the least charges (143, No. 3) the initial velocities will be about $\frac{3}{10}$ less than those with the medium charge; for instance, a shot from an 8 pr. charged with 1 lb. 10 oz. of powder, will be impelled with an initial velocity of 1061 feet; and a shot from a 16 pr. with $2\frac{1}{4}$ lbs. of powder, with an initial velocity of 1028 feet. It should be recollected, that with small charges, the least difference in the mode of loading the gun, makes a great alteration in the initial velocities, while with large charges its effects would be scarcely perceptible. The surest mode of keeping all circumstances as nearly equal as possible, is always to ram the wads well.

151. In experiments with three or four guns of the same calibre, but of different lengths, loaded as above (150, No. 2); the following rule will furnish an approximation sufficiently exact to draw from it conclusions applicable to practice. (Pl. 5, Fig. 15.) E B F represents the bore of a gun of any calibre; the medium charge of powder D and the wad S are so placed, that the shot A is distant from B

three diameters of the bore FE: make $FC = \frac{2AF}{3}$ and

from the point C as centre, with the radius CA, describe the arch AKPR, representing the scale of initial velocities, by lines drawn perpendicularly from AF to the arch. To determine the initial velocity of a shot fired, for instance, from a long gun BL (66), loaded in the same manner (150, No.

No. 2); a normal line LQ drawn perpendicularly from the point L in the line AC , will correspond to the relative initial velocity. To have the absolute initial velocity, make the following proportions: the relative velocity FP of a gun of the length BF is to its absolute velocity, as the relative velocity LQ of the gun BL is to its absolute velocity; by the same method the initial velocity of a shot impelled from a gun of any length as BG may be found. The scale AKR would serve for longer guns, but it should not be used (65).

152. Experiments made with a view to determine how much the initial velocities of shot are affected by the difference in the lengths of the guns, fired with different charges of powder, will be found to vary very little, from those computed on the preceding principles.

153. From the theory of the inflammation of the powder in guns of cylindric bores, when all the grains are fired in the piece, the following modifications ought to occur;

1. In diminishing the charges in guns of the same calibre but of different lengths, the initial velocities of shot from the short pieces should correspond more nearly those from the longer ones, as the charges of the latter are diminished; since the shot has its greatest initial velocity, when in the short piece the largest charge is all fired in the gun.

2. The greatest velocity of a shot projected from a short gun, is with the largest charge that is all fired in the gun: it is only in very short guns that this does not hold good. (Treatise on Powder).

154. In computing these initial velocities, the guns have been supposed to be fired horizontally, or nearly so: but the velocities increase as the guns are elevated, which proves that the entire inflammation of the powder is accelerated by the greater resistance opposed to the explosion (Treatise on Powder). If a 32 pr. be fired with the medium charge (150, No. 2) at 20° elevation, the initial velocity will exceed 1350 feet, and increase very much, if fired at 36° .

In the following chapter will be shewn the method of determining the initial velocities of shot fired from guns at high elevations.

C H A P. II.

OF THE CURVE DESCRIBED BY CANNON SHOT.

155. **T**HE charges of powder for common service have been already mentioned (150, No. 1 and 2); the objects against which they are directed should not be very high; and to fire with effect, be less than 1000 yards distant: even then the air's resistance to the shot is very great, though its effects on the gravitating principle be almost insensible. When the line of descent is less than 260 feet, and the time of the shot's flight not more than 4 seconds, the shot's path is a curve of the second kind; so denominated to distinguish it from the curve of the fourth kind, where the movements of impulsion and gravitation are both greatly affected by the resistance of the air. In the Treatise on Powder, it was demonstrated that the air's resistance considerably retarded the movement of leaden bullets; and in the last chapter on hydrostatics, the air's resistance to military projectiles is expressed in pounds. In this chapter we propose to determine the law by which the air retards the movement communicated by the impelling power, in another manner, viz. directly by its forces.

156. To solve this problem, we must find experimentally *the scale of spaces passed through during the time of an impulsive movement, retarded by the medium that the shot flies in*: the initial velocities may be found by the method expressed in the last chapter. Hitherto we have only considered the effects of the alterations in the state of the atmosphere, on the inflammation and explosion of the powder, and consequently on the initial velocities of shot; we will now examine how far they can vary the air's resistance to the shot, and render the former conclusions erroneous.

The barometer will in some degree point out any changes that may take place, and for greater accuracy, two small guns may be fired against a homogenous butt, at any distance not less than 160 yards; to ascertain by the one, if the initial velocities be constant (149); and by the other, if the air's resistance continue the same. An elevated spot should be chosen for these experiments, where, the gun laid horizontally, may be directed to the right or left, that the first grazes

of

of the shot may severally be on planes one below the other. Let these different planes be 4, 16, 36, 64, 100, and 144 feet below the gun's axis; then the time of the shot's flight through the several spaces will be $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, and 3 seconds; thus, the equation of the scale will be more easily found.

Then, with a charge that gives a known initial velocity, fire some rounds towards the place, 4 feet below the plane of the gun, in order to obtain the mean of the horizontal ranges (144, No. 3) which may be called dg (Pl. 5, Fig. 17): turn the gun to the place 16 feet below its plane; fire some rounds, and call the mean rp ; let nb be the mean to the place 36 feet, and Ky to the place 64 feet below the gun. On the directrix aK set off the times $t =$

$$\sqrt{\frac{2S}{32 \cdot 18}} = a d, a r, a n, a K, \text{ corresponding to the lines of}$$

descent 4, 16, 36, and 64 feet; and erect from the points d, r, n, K , perpendiculars to the line aK , respectively equal to the means of the ranges already found; the line $agpb$ passing through the extremities of these perpendiculars, will be the scale of spaces passed through during the times of the retarded movements of impulsion.

157. If no convenient place can be found for this purpose the experiments may be made in another manner: on the side of a hill or mountain as (Pl. 5, Fig. 16) $H L A$, at the bottom of which is a horizontal plain $M Z$, chuse the stations A, L, H , of different heights; and from them fire the gun in the horizontal directions $A K, L F, H X$: then the perpendicular lines $G K, P F, Z X$ will be spaces that the shot fall through by the power of gravity. The longest of these lines should be less than 260 feet, that the resistance of the air may not sensibly affect the gravitating power, and that the difference of the heights may not occasion any alteration in the inflammation of the charge. From each of the points A, L, H , fire some rounds with charges of which the initial velocities are known, in order to obtain the mean of the ranges (144, No. 3); then supposing that from the point A the mean of ranges is $= D G$, from the point $L = R P$, from the point $H = N Z$; mark upon the directrix $a K$ (Pl. 5, Fig. 17.) the times corresponding to the vertical lines $G K, P F, Z X$; erect from the points d, r, n , the normal lines dg, rp, nb equal to the means of ranges already found, and

and drawing a line through the points $agpb y$, it will be the scale of spaces in the times of the retarded movements of impulsion.

158. Having constructed this scale (156, 157), the result of the experiments should be examined to see that there be no error, and as it is the scale of a retarded movement, it should have the properties expressed in the treatise on moving bodies: in the first place, the line $agpb y$ should be a curve concave towards the directrix, and the differences pm, bo, Ly between the ordinates, should decrease in a regular progression from a to y ; wherefore, if the scale be a right line, or a curve convex toward the directrix, it is a proof that some errors have been committed in making the experiments, or in taking the results. But if they differ a little in one or two points only, it is immaterial, since small errors are inevitable: when this occurs, the differences should be judiciously corrected. To this end, deduct the second differences from the first: and if the results be still erroneous, take the third differences; in the latter, the least irregularity in carrying on the experiments will considerably disturb the order of progression. To set this matter in a clear point of view, suppose the following to have been the result of the experiments.

Spaces passed through by the Shot from the impulsive motion in corresponding times.

Seconds of Time.		Feet.	Differences.		
			First.	Second.	Third.
1	—	1302	—	—	—
2	—	2394	1092	—	—
3	—	3310	916	176	—
4	—	4082	772	144	32
5	—	4730	648	124	20
6	—	5284	554	94	30

If no error be perceptible in the first; but in the second, the progression does not decrease regularly, and in the third the difference after decreasing from the first term 32 to the second 20, increases from the second term 20 to the third term 30, to correct these errors, let the results be modified as below; then will all the differences decrease in a regular progression and be sufficiently accurate.

Results

Results modified.				Differences.		
Seconds of Time.		Feet.		First.	Second.	Third.
1	—	1302	—	—	—	—
2	—	2394	—	1092	—	—
3	—	3310	—	916	176	—
4	—	4082	—	772	144	32
5	—	4736	—	654	118	26
6	—	5292	—	556	98	20

159. When the scale thus modified has the properties expressed in the preceding paragraph, we should proceed to examine whether the results are just and conclusive.

FIG. 17. For this purpose, if $agpby$ be an equation of this scale, and $ifbe$ the equation of the scale of velocities in corresponding times (Treatise on Moving Bodies), which should be a curve-line convex toward the directrix, whose greatest ordinate ai drawn from a the beginning of the times must be equal to the initial velocity of the shot, the other ordinates will decrease in proportion as the times increase, and the scale $ifbe$ will approach the directrix, and touch it when the shot has entirely lost its impulsive motion. For example, suppose the equation of the curve $agpby$ to be $q^2 + nq = mt$; where q expresses the space passed through by the shot from the impulsive motion, t the time; m and n are two constant quantities which express the initial velocity: if from this equation be deduced the equation

of the velocities in the times, $U = \frac{m}{2\sqrt{\frac{n^2}{4} + mt}}$ will

have all the properties that belong to the retarded motion; whence it may be inferred that the experiments have been properly conducted.

Fig. 17. If on the contrary, the equation for the scale $agpby$ be $pt^2 = q^2$, where p is a constant quantity, and

the scale of the velocities in the times be deduced; $U = \frac{2pt}{3q^2}$

where $t=0$; the velocity is then equal to 0, which is a manifest absurdity, since it must be equal to the initial velocity of the shot. Again, if $pt - t^2 = q^2$ be the equation for $agpby$

by where p is a constant quantity; and the equation for the scale of velocities in the times be deduced, $U = \frac{p-2t}{2\sqrt{pt-t^2}}$,

which is an absurdity; since when $t=0$, the initial velocity is infinite.

160. In fine, if the scale of velocities in the times be conformable to the retarded movement, the scale of the air's resistance to the shot at each instant may be deduced from it; if this scale be a convex curve, and its greatest ordinate at a with a progressive series analogous to the scale of velocities, it will be a certain proof that the result is just: but should the scale of resistances not have the requisite properties, the results must be faulty. From the equation of the

scale of velocities $U = \frac{m}{2\sqrt{\frac{n^2}{4} + mt}}$ may be deduced the

scale of pressures $=p$; then $p = \frac{m^2}{n^2 + 4mt \times \sqrt{\frac{1}{4}n^2 + mt}}$

is an equation that combines all the requisite properties.

161. The resistance of the air to the rapid movements of projectiles depends not only on the actual density of the atmosphere, but on the condensation of the air before the projectile, whenever its velocity exceeds 1300 feet; for a vacuum is then formed behind the shot, which becomes so much the greater as the velocity exceeds 1300 feet.

After repeated experiments and observations on this subject, it appears that when guns are fired with charges that give an initial velocity of about 1300 feet, the formula $q =$

$\frac{crt}{r+t}$ will express the retarded motion of impulsion with suf-

ficient exactness for practice, whenever the extent of the movement is less than 1350 yards: but if the initial velocities be much greater or less than 1300 feet, this formula will not serve. The letter q expresses the line of projection, which in shot impelled horizontally always corresponds to the length of the range; c the initial velocity of the shot, t the time that it takes to pass through the space $=q$; and r a number proportioned to the diameters of the several shot; this number is combined with the actual density of the atmosphere,

mosphere, and its value may be found by experiment. The diameters of the shot are as follows :

Nature of Guns.				Diameter of Shot.
<i>Pr.</i>				<i>Inches.</i>
32	—	—	—	5.760
16	—	—	—	4.566
8	—	—	—	3.653
4	—	—	—	2.881

If from the density of the air, $r=12$ in a 32lb. shot, the value of r for shot of other diameters may be found by analogy; hence in a 16lb. shot, $r=9.5$; in an 8lb. shot, $r=7.6$; and in a 4lb. shot, $r=6$. If from the density of the air, in a 32lb. shot $r=14$; then in a 16lb. shot $r=11.1$; in an 8lb. shot, $r=8.8$; and in a 4lb. shot $r=7$.

For example, suppose from the density of the atmosphere $r=12$ in a 32lb. shot, of which the initial velocity is 1349 feet= c ; and the value of g , the space passed through with this same velocity in different times, be required: by substituting these data in the formula; in two seconds of time,

$$q = \frac{1349 \times 12 \times 2}{12 + 2} = 2312 \text{ feet; and in three seconds, } q =$$

$$\frac{1349 \times 12 \times 3}{12 + 3} = 3237 \text{ feet. If the initial velocity be } 1517$$

feet, in three seconds the line of projection is 3640 feet.

In a 16lb. shot with an initial velocity of 1416 feet, the

$$\text{line of projection in two seconds is } q = \frac{1416 \times 9.5 \times 2}{9.5 + 2} = 2402$$

feet; and in 4 seconds is 3985 feet.

In an 8lb. shot with an initial velocity of 1696 feet, the

$$\text{line of projection in 3 seconds is } = \frac{1696 \times 7.6 \times 3}{7.6 + 3} = 3648$$

feet.

In a 4lb. shot, with an initial velocity of 1550 feet, the line of projection in 4 seconds is 3720 feet.

Supposing the atmosphere to become less dense, so that in a 32lb. shot $r=14$; then if the initial velocity be 1433 feet, the line of projection in 4 seconds is 4458 feet.

In a 16lb. shot, with an initial velocity of 1334 feet, the line of projection in 2 seconds is 2599 feet.

In an 8lb. shot, with the initial velocity of 1450 feet, the line of projection in 1 second is 1302 feet.

In a 4lb. shot, with the initial velocity of 1720 feet, the line of projection in 3 seconds is 3612 feet.

162. If from the equation $q = \frac{c r t}{r + t}$ be deduced the scale of velocities V in the times, (159) $V = \frac{c r^2}{r + t^2}$, which will

give the remaining velocities, after the shot has passed through the space q in the time t . For example, suppose from the density of the air $r = 14$ in a 32lb. shot; then if the initial velocity be 1349 feet, the remaining velocity after 4 seconds

will be $V = \frac{1349 \times 14^2}{14 + 4^2} = 816$ feet. A 16lb. shot, with the

velocity of 1416 feet, will have a remaining velocity after 3 seconds of 877 feet.

The remaining velocity of an 8lb. shot, with the initial velocity of 1686 feet, will after 4 seconds be 796 feet. The remaining velocity of a 4lb. shot, with the initial velocity of 1467 feet, will after 2 seconds be 887 feet.

Again, from the state of the atmosphere $r = 12$; then the remaining velocity of a 32lb. shot, with the initial velocity of 1517 feet, will after 2 seconds be 1114 feet: a 16lb. shot, with the initial velocity of 1484 feet, will after 4 seconds be 734 feet: an 8lb. shot, with the initial velocity of 1686 feet, will after 3 seconds be 866 feet; and a 4lb. shot, with the initial velocity of 1600 feet, will after 2 seconds be 900 feet.

163. The problems of the curve of the second kind (155) may be resolved by the formulas $q = \frac{c r t}{r + t}$, $S = \frac{32 \cdot 18 t^2}{2}$.

(Pl. 5. Fig. 16.) Given the initial velocity $= c$ of a 32lb. shot fired from A with the horizontal direction $A K$, to determine by experiment the value of r . Suppose that the shot touch the ground in the point G of the plane $D Z$, as the line of projection $A K = D G = q$, and the line of descent $K G$ are known; by substituting this last value in the formula

$S = \frac{32 \cdot 18 t^2}{2}$, it will give $\sqrt{\frac{2 K G}{32 \cdot 18}} = t$, and by substituting

the

the known values of q , c , t in the formula $q = \frac{crt}{r+t}$, the value of r will be found. For example; let $c = 1517$, and $A K$ be found by experiment $= 2655$, and $K G = 64$ feet;

then $t = 2$; and consequently $r = \frac{qt}{ct-q} = \frac{2655 \times 2}{1517 \times 2 - 2655} = 14$. Having thus found the value of r for the 32lb. shot, it may be found for the 16, 8, and 4lbs. from the proportion of the diameters of the shot (161).

164. The value of r being given, to find by experiment the initial velocity of a shot fired in any direction. Suppose in the first place, that when the gun is fired in a horizontal direction $A K$, the first graze of the shot is at G : the line of projection and the line of descent being known, by sub-

stituting this last value in the formula $S = \frac{32.18t^2}{2}$ the time

of flight will be found: the substitution of which in the other formula will give the value of c . For example, if an 8lb. shot be fired in the same resisting medium as in the preceding paragraph, $t = 8.8$: and supposing $A K = 3478$ feet, and $K G = 144$ feet, then $t = 3$; and consequently $c =$

$$\frac{q \times r + t}{rt} = \frac{3478 \times 8.8 + 3}{8.8 \times 3} = 1554.$$

Suppose, in the second place, (Pl. 6, Fig. 18) that the gun be fired in a direction $A M$, forming with the horizon the angle $M A R$, whose value is known; and, that the shot strike the ground in H : by measuring the horizontal distance $A R$, the line of projection $A M$ and the line of descent $M H$ will be found. If $M H$ be less than 260 feet, the initial velocity will be greater (154), than if the gun had been fired with the same charge in a horizontal direction. Let $M H = 100$ feet, then $t = 2\frac{1}{2}$: let $A M = 2920$, and the shot be a 4 pr. fired in the same resisting medium as above, $r = 7$; consequently $c = 1585$.

165. To determine the angle of elevation (Pl. 6, Fig. 19) $D A F$ under which a shot with a charge that gives a known initial velocity $= c$ will from the point A strike the object B , above or below the horizontal line $A F$.

Draw the perpendicular line $B D$, and suppose $D A$ to be the direction in which the gun must be fired. Then as the

angle BAF and the side AB in the rectangled triangle BFA are known, the sides AF, BF will also be found; call $AF=m$, $BF=n$. Since the line of descent $BD=$

$$S = \frac{32 \cdot 18 t^2}{2}, \text{ and the line of projection } AD = q = \frac{c r t}{r+t}$$

$DF = \frac{32 \cdot 18 t^2}{2} - n$, according as the point B is above or below F.

As in the rectangled triangle AFD, $\overline{AD}^2 = \overline{AF}^2 + \overline{DF}^2$, by substituting the analytical values we shall have

$$\text{the following equation, } \frac{c^2 r^2 t^2}{r^2 + 2rt + t^2} = m^2 + \frac{1035t^4}{4} - 32 \cdot 18 n t^2$$

+ n^2 : whence may be deduced the value of t . If the point B coincide with the point F and the butt be in the plane of the gun, the value of $n=0$, and may be struck out of the equation: the value of t being thus known, those of BD and AD may be afterwards found, which will give the angle of elevation DAF that was sought.

166. (Pl. 6. Fig. 20.) From the point B to hit the object L situated in the same plane as the gun: the value of t may be found in the following manner with sufficient accuracy for practice; since even when the amplitude of a 32lb. shot is 1348 yards, the difference in the elevation HBL will not be $\frac{1}{2}$ second.

The distance BL between the gun and the object, may

be considered as the line of projection $q = \frac{c r t}{r+t}$, and substituting in this formula, the data q, c, r , the value of t may be found; which being again substituted in the formula $S =$

$$\frac{32 \cdot 18 t^2}{2} \text{ gives the value of } S \text{ for the line of descent } LG:$$

draw the line BG; then, in the rectangled triangle BLG, the angle GBL will be known: make the angle LBH equal to the angle GBL; BH will then be the direction in which the gun should be fired to strike the point L. For example, if BL be 560 yards, and a 32 pr. be fired with the medium charge of powder, $c=1350$ feet (150); and from the resistance of the air $r=12$: by substituting these

$$\text{numbers in the first formula, } 1680 = \frac{1350 \times 12 t}{12+t}, \text{ and con-}$$

sequently

frequently $t=1.4$ again substituting this value in the second formula $S = \frac{32 \cdot 18 \times 1.4^2}{2} = 31$ feet = LG, and finding trigonometrically $\angle GBL = 1^\circ 3'$, the $\angle LBH$ that was sought is also $1^\circ 3'$.

167. From the preceding theory, (Pl. 6, Fig. 20) it will be easy to determine the value of r and the initial velocity = c , when these two quantities are unknown, by firing only two rounds. Fire a gun in any direction BD, provided that the line of descent be less than 260 feet; and, supposing the shot to strike the ground in E, find geometrically the line of projection $BD = q$, and the line of descent $DE = S$; and, by the formula $S = \frac{32 \cdot 18 t^2}{2}$ find the time; then substitute these

values in the equation $BD = q = \frac{c r t}{r + t}$. If the gun be again fired with the same elevation, and exactly loaded as before, but turned to the right or left, so that the shot may strike another point G, higher or lower than the former one E; having found geometrically the line of projection $BK = q$, and the line of descent KG, find the value of t , and substituting it in the equation $BK = q = \frac{c r t}{r + t}$; these two equations will give the values of c and r .

Suppose, in the first instance, that $BD = 1820$ feet, and $DE = 36$ feet; and, in the second, $BK = 3237$ feet, and $KG = 144$ feet: then substituting these numbers in the first formula, $1820 = \frac{c r \times \frac{3}{2}}{r + \frac{3}{2}}$; and again in the second, $3237 =$

$\frac{c r \times 3}{r + 3}$; from these two equations, $c = 1348$ feet, and $r = 12$.

In firing against the height, RH (Pl. 6, Fig. 18) having fired one round from A, in the direction AM; the gun should be advanced to L, or retired to P; and, from one of these two stations, a second round fired with the same elevation; since whenever it is altered, the initial velocities differ (154).

168. The elevation AD, (Pl. 6, Fig. 21) and the initial velocity = c being given, and the value of r and of the line of descent BD being known, to find the direction

and the quantity KB of compound velocity, with which the shot strikes the point B .

From BD deduce the value of t ; and by the formula $u = 32.18t$ of the velocities in the times through the movement of gravitation (Treatise on Moving Bodies 283) find the value of u , which set off from B to H : from the point

H draw HK parallel to DA , and by the formula $V = \frac{cr^2}{r+t^2}$

(162) find the remaining velocity $= V$ arising from the movement of impulsion after the time t ; then by setting off its value from H to K ; and drawing the right line BK , it will give the direction, and the quantity of compound velocity which the shot has at the point B . Let $BD = 144$ feet, then $t = 3$, and $u = 32.18 \times 3 = 96 = BH$; and sup-

pose $c = 1350$ feet and $r = 13$; then $HK = V = \frac{1350 \times 13^2}{13+3^2}$

$= 891$ feet; and since the $\angle BHK$ is equal to the $\angle BDA$ which is known, the direction will be found, and also the quantity of compound velocity BK .

169. A combination of the formulas $S = \frac{32.18 t^2}{2}$, $q =$

$\frac{c r t}{r+t}$ (163) will give the equation $S = \frac{32.18}{2} \times$

$\frac{q^2 r^2}{c^2 r^2 - 2crq + q^2}$ appertaining to the curve of the second

kind (155), by means of which all the preceding problems may be solved. For example, if the initial velocity be known, and the value of r of a shot of given calibre be required; it will be sufficient to fire a round in a direction AD corresponding to the given velocity; and supposing the shot strikes in B , by finding geometrically the values of the line of projection $AD = q$, and the line of descent $BD = S$, and substituting them in the equation of the curve, it will give the value of r . Again, to find the initial velocity, and the value of r ; it will be necessary to make two experiments with the same charge, and at the same elevation (167); in each of them the values of the lines of direction and descent must be found and substituted in the formula $S =$

$$\frac{32.18}{2}$$

$\frac{32.18}{2} \times \frac{c^2 r^2}{c r - q}$, whence the values of c and r may be deduced.

The application that will be made in the following chapters of the doctrine here laid down on the unequal movement of impulsion (161) will enable us with a moderate share of discernment, to derive the greatest advantages (141) from the use of artillery.

170. To determine the curve of the fourth kind; when the resistance of the air to the two unequal movements that constitute it is great, and the ranges are long; it is necessary to make a course of experiments, which from the continual variation in the state of the atmosphere, and other circumstances, are very tedious, and require much accuracy and intelligence in those that carry them on. As I had not an opportunity of making all the experiments I deemed satisfactory on this head, I have here only laid down the fundamental principles, that others may be enabled the more easily to prosecute the enquiry. Among the different methods that may be taken to determine the laws of this curve (156), the following appears the best.

Chuse an elevated situation, where the gun may be turned to any side; so that the shot may severally strike points, one below the other, in such a proportion that the lines of descent may be 848, 1696, 3046, 5088 feet. From this spot fire several rounds in a horizontal direction towards the same object, with a charge that gives a known initial velocity, in order to obtain a medium of horizontal ranges and of lines of descent. Persons should be stationed at different parts with second watches, to reckon exactly the time that the shot takes from the instant they see the smoke of the gun, till it touch the ground. Having found the mean of the two movements of impulsion and gravitation, turn the piece towards another object, in order to obtain a different medium, then towards a third and a fourth, with the same precautions as before.

These experiments should be repeated with a gun of a very different calibre, with the same care and attention (156), that the results may not be affected by the variations of the atmosphere. Shot much lighter than the common shot may be made for the occasion, by suspending in the center of the mould a sphere of well-tempered clay, which will be thus

completely enveloped by the melted metal ; the resistance of the air to these projectiles will be much more sensible. If this hollow shot be to a solid one of the same diameter, as the weight of a shell full of powder is to a shell of the same diameter cast solid, the results may be applied to mortars in a much more simple manner.

After the experiments, construct two scales for each gun : one for the space passed through during the time of a retarded movement of impulsion ; the other for the movement unequally accelerated by gravity. The last scale should give a curve convex towards the directrix. The two scales may be analysed in the manner above shewn (158, 159, 160); and if the experiments have been made with care, the equation of each movement will be so expressed as to serve for all the different states of the atmosphere.

171. While the state of the atmosphere remains the same, the results of the experiments (170) will be conclusive, if they have been carried on with proper attention ; but the same inference must not be drawn in the former case (157). For if a gun be fired from the different heights A, L, H, (Pl. 5, Fig. 16) and the lines of descent GK, PF, ZX, be very considerable as 848, 1696, 3046, and 5088 feet, the results will be false and inconclusive, even if there be no alteration in the state of the atmosphere ;

1. Because shot fired from different heights are opposed by air of different densities ; the law therefore of the inflammation and explosion of powder is altered, though the quantity be the same : of course the initial velocities will differ.

2. The lines of descent GK, PF, ZX, and the lines AK, FL, HX, which express the movement of impulsion, traverse in an inverse order the air which is of different densities at different heights ; whereas by firing always from the same place H (170), the shot will at the first graze strike the points M, B, E, T, with corresponding lines of descent ; and traverse the air in the natural order ; the lines which express the movement of impulsion will be in the direction HX.

To ascertain the modifications that take place in the inflammation and explosion of powder, and in the resistance of the air to projectiles, owing to alterations in the state of the atmosphere, the following experiments may be made : Let a musquet be fired very close to a butt in the bottom of a valley ;

a valley; and another be fired with an equal quantity of powder of the same quality against the same butt, at the distance of 675 feet: at the same time let another person, at a place 5000 or 6000 feet above the former situation, discharge a bullet from a musquet of the same calibre equally charged, and at the same distances as the former one, against a butt equally homogenous and consistent: the penetrations will be much deeper from the musquet fired near the butt at the foot of the mountain, than from that fired near the butt at the higher situation; but will be much less at the distance of 675 feet, than from the upper one at 675 feet. These effects were so sensible in the campaigns of 1743, 1744, and 1747, in the ALPS, that there were days when the musquets fired at the top of the mountains ranged $\frac{1}{3}$ more than the same musquets at the bottom: sometimes the mountains were enveloped in thick clouds, while the vallies beneath were perfectly clear; at other times the atmosphere in the vallies was loaded with vapour, while those on the heights enjoyed a cloudless serenity: in short, so great and frequent were the alterations, that the experiments of one day bore no analogy to those of the next.

172. To determine in another manner the law of each of the unequal movements that constitute the curve of the fourth kind; let a gun be frequently fired from a horizontal plain PAK, (Pl. 6. Fig. 18.) at the foot of a mountain KIH, with the same elevation KAM, and with a charge that gives a known initial velocity. Fire some rounds from A, so that the medium of the lines of descent may be from 600 to 700 feet: fire again from P, at a greater distance from K the foot of the mountain, that the shot falling in I, the lines that express the movements of impulsion and gravitation, may be longer: remove the guns still farther from K, and fire as before; and, having taken the mean result, retire the gun to a still greater distance from the mountain, so that the shot falling on the plane PL, may give the longest lines of projection and descent possible, under these circumstances; always using a second watch to mark the time of flight of the shot; and, taking every precaution to know whether the state of the atmosphere remain the same. From these results two scales applicable to the uses before expressed (170) may be constructed. Experiments conducted in this manner cannot be very erroneous, but, their results are more complicated than the others, (170) since

since the shot in ascending, passes continually from a dense to a more rarified medium, while the reverse takes place when the shot descends.

C H A P. III.

OF THE EFFECTS OF CANNON SHOT ON WORKS.

173. **T**HE use of heavy artillery (64) is to ruin and demolish permanent fortifications and works.

In the attack of fortresses, 32 prs. are used for battering in breach, when the ramparts are of great solidity; but, from the great expence attending these heavy guns, and the difficulty of transporting them, 16 prs. serve for dismounting the artillery in the outworks, and beating down the defences. For ricochet and hot-shot firing, 4 and 8 prs. are used, as they require less ammunition, and fewer men to work them.

In the defence of places, against which the besieger can establish any number of batteries he pleases, the proportion of 32 prs. should not exceed a third of the whole number of guns in the garrison; as 8 prs. will serve for firing against the opening of the trenches, and 16 prs. against the approaches: but, if the situation of the ground be such, that the artillery of the place has a decided superiority over any batteries the besieger can erect; then, to take full advantage of this circumstance, the number of 32 prs. should be increased: long 4 prs. will keep the enemy in respect around the place, and a few short light pieces (66) may be held in readiness for making sallies.

174. To use fire-arms to the greatest advantage, the effect of each shot should be observed: (141) for this purpose;

1. The guns and carriages should be constructed with the utmost accuracy.
2. The guns should be served with care and judgment, and placed at a proper distance from the objects intended to be battered.

175. In the former part of this treatise, the principles of the best construction for guns were fully explained: but, as an officer is sometimes obliged to use guns defective in some material point, he ought to consider by what expedient he

can

can best remedy the defect: the charge should be lessened, when it proceeds from the want of proper weight in the gun, or of a due thickness of metal in the breech.

The knowledge of an artilleryist should be both theoretical and practical: to ascertain the nature of the curve described by a projectile, develope the causes that influence its formation; thence deduce rules applicable to the various cases that occur on service, and be able in the best and most expeditious manner, to repair any accident that may happen, is the part of the theorist, and of the officer. The non-commissioned officers and soldiers are instructed in the part purely practical: they are taught

1. To load the guns in a regular and uniform manner, and to ram the wads when the same charge is used, with equal force; a neglect in this point is the cause of great irregularity, particularly when the guns are depressed.
2. In laying the gun, to remove every obstacle that can tend to derange the firing.
3. Having by two or three rounds ascertained the direction for hitting the object, to continue it without variation.

176. That the gun may be placed at a proper distance from the object (174, No. 2); the shot's path must be considered, and allowance made for every circumstance that can affect the range: the relative size and position of the object must be particularly attended to; for, when it is much higher than the gun, though very distant and narrow, it is more easily hit, than when lower and of greater extent; so that the lower the object is, the nearer the gun must be brought to it. In the attack and defence of places of low profile, the height of the works against which the fire is directed in the first part of the attack, does not exceed 7 feet, as the parapets, the exterior of the embrasures, the heads of saps, &c. The greatest distance at which guns should be fired against such low objects, has been fixed in our military treatises, at 680 yards.

177. After hitting the object, the next point is to consider the degree of force requisite to overcome its resistance: for, if this be superior to the impetus of the shot, no effect will be produced; and, when greatly inferior, it may be sometimes proper to diminish the force of the projectile, in order to produce a greater effect, and avoid spoiling the guns

guns before the siege is over, by firing with large charges. The following considerations may perhaps assist an officer commanding a battery, in forming his judgment on this occasion.

1. The largest charges are only used when a great force is required, and exactness in firing is not absolutely necessary; as battering in breach from the crest of the glacis. But, in firing from great distances to dismount the enemy's guns, batter the trenches, heads of saps, or other low works, the medium charges are sufficient, that the violence of explosion may not produce irregularities (7, 8, 9).

2. The less, and even the least charges will serve for battering towns or villages surrounded with a single wall, unsupported with a rampart of earth; since a shot impinging on a thin wall with great force, makes a hole without shaking the contiguous parts: thus it requires a greater number of rounds with large charges to demolish them, than if the charges were diminished. Should the situation of the ground permit the gun to be laid on an oblique direction at the object, the medium, and even the largest charges may be used: in this case the effects of the shot are in the ratio of the angles of incidence.

178. The force of the direct shock of hard bodies, is calculated from their mass multiplied into their velocity; and the force of the oblique shock, by multiplying the former product by the right sine of the angle of incidence, divided by the whole sine (Treatise on Moving Bodies). If the force $=f$; the weight of the shot $=m$, the velocity with which it impinges $=V$, the right sine of the angle of incidence $=a$;

then $f = m V \times \frac{a}{\text{whole sine}}$ is the general formula in which

the fraction $\frac{a}{\text{whole sine}}$ is equal to unity in the direct shock.

If the value V of the remaining velocity (162) be found, the impetus with which shot of the same or different diameters impelled with different initial velocities, impinge on objects at different distances, may be compared. For instance, let the distance between the gun and the object be expressed by the line of projection, and in a 32 pr. $r = 12$; then

then in the direct shock, the force with which a 32 lb. shot with an initial velocity of 1350 feet, impinges on an object placed very close to it, is to its force at 4056 feet, as 1350 : 759 : and the force with which a 16lb. shot, with an initial velocity of 1416 feet, strikes an object at the distance of 932 feet, is to its force at 3229 feet, as 1226 : 817. On comparing in the same manner shot of different diameters, it appears, that the force with which a 32lb. shot, with an initial velocity of 1350 feet, strikes an object at the distance of 330 feet, is to the force of a 4lb. shot, with an initial velocity of 1467 feet, at the distance of 3520, as $32 \times 1300 : 4 \times 528$; that the force of a 16lb. shot, with an initial velocity of 1416 feet, at the distance of 3886 feet, is to the force of an 8lb. shot, with an initial velocity of 1449 feet, at the distance of 350 feet, as $16 \times 716 : 8 \times 1361$. If under similar circumstances, the shocks be oblique, so that with a 16lb. shot the angle of incidence be 20° , and with an 8lb. shot 75° , the two shocks will be to each other : : $16 \times 716 \times 34202 : 8 \times 1361 \times 96592$.

179. In the preceding paragraph it was supposed, that the compound velocity BK of the shot, when it impinges on an object, was equal to the remaining velocity HK, which is in the ratio of the retarded motion of impulsion : this is the case not only in this particular instance, but in all others that do not admit of geometrical precision. Nevertheless, on ascertaining the greatest difference that can be between these two velocities, in the common service of guns, we shall find it to be too inconsiderable to occasion any material error ; for, if the value of the compound velocity BK be determined (168), the gun having been fired at the highest elevation the carriage will admit of, BK is less than HK in the proportion of about $\frac{3}{4}$ in the 100 ; that is BK : HK : : 397 : 400 ; and if the gun be depressed as much as possible, BK will exceed HK in the proportion of about $\frac{1}{8}$ in the 100 ; that is BK : HK : : 801 : 800.

180. Among the several works against which cannon are fired ; there are some which do not yield to the most violent shocks ; and others of very slight resistance. Of the first kind are those cut out of the solid rock, the hardness of which joined to the cohesion is such, that the most violent shocks cause no disunion in the parts. If the weight of the shot = m , the velocity with which it impinges = V and n = the object impinged on ; the whole effect of the shot on
this

this work, is a slight tremulous motion in the point of impact, incapable of producing the least separation of the parts: so much does its mass exceed the mass of the shot. There is in this case no method of making a breach but by mining, however tedious or difficult the operation may be.

181. There are three ways in which works that yield to cannon balls (180) may be destroyed:

1. By separating the constituent parts, when the shot cannot penetrate.
2. By penetrating without splitting or shivering them.
3. Or by producing both these effects at the same time.

In the first case, the upper parts being by repetition of the shocks deprived of their base fall down; as in walls built very solidly of hard stones, cemented with mortar: the more speedily to effect this, shot of the largest calibre should be projected with the greatest initial velocity, and the guns placed very near to the object, and fired in *salvos*; that the several shocks being made at the same instant, may be the more efficacious. The 64lb. shot formerly in use, were well adapted to this purpose; as they demolished the wall in a very little time, even with an initial velocity less by $\frac{1}{2}$ than that of a 32lb. shot; since from the greater quantity of movement, they sooner separate and open works of masonry (Treatise on Moving Bodies, 370, 371, 372). These observations on walls constructed of hard stone and lime, are in some degree applicable to works cut out in soft or friable stone; with this difference that the upper part of the rock being by its nature firmly fixed in the ground, is less shaken than a wall supported by earth, which though an adjunct, is little affected by the shock; whereas, the rock being one body, the shock is communicated to its whole mass; and is so generally diffused, as to be almost insensible. Supposing the two works to be of equal tenacity, that cut out of the rock will suffer less from the shot.

182. Works are destroyed in the second manner (181, No. 2) when the shot penetrating to different depths, disunite the contiguous parts; as in turf, earth, &c. The formula $fS = Du^2$ (246), serves to determine precisely the penetrations of shots of different diameters, into works of this kind: the penetration of a 32lb. shot, which with an initial velocity of 1517 feet, impinges on a work of this sort, is to that of a 4lb. shot, with the velocity of 1010 feet, as 5.760

$\times 1517^2$;

$\times 1517^2 : 2. 881 \times 1010^2$ (161). If a 32lb. shot (146) with an initial velocity of 1517 feet, penetrate a butt of earth to the depth of 20 feet, a 4lb. shot with the velocity of 1010 feet, will under the same circumstances, penetrate only to the depth of $4\frac{1}{2}$ feet; therefore, intrenchments 5 feet thick cannot be pierced by 4lb. shot that impinge with this velocity. The same formula will determine the diameter or velocity that shot ought to have to penetrate a parapet of a given consistence and thickness (146): if the thickness $= S$ be 8.43 feet, and the consistence $= F$ be 37046, by substituting these data in the formula, we shall find that shot which have a velocity of 1012 feet, to pass through this parapet, ought to be 3.653 inches in diameter, which corresponds to an 8lb. shot (161).

183. To determine the relative penetration of shot of different diameters, fired at different distances against a penetrable and homogeneous butt, the remaining velocity $= V$ with which the shot from the distance $= q$ with an initial velocity $= c$ impinges, must be found from the movement of

impulsion: for this purpose the formula $q = \frac{c r t}{r + t}$, (161) will

give the time $= t$; and, the value of r being given, the

time may be substituted in the formula $V = \frac{c r^2}{r + t}$ (162).

Having thus found the value of V , the compound velocity with which the shot impinges, may be considered as equal to the remaining velocity (179) without any material error; on this principle, the following table of the relative penetrations of shot of different diameters, impelled from guns loaded with the largest and the medium charges, against a penetrable and homogeneous butt, from four different distances has been calculated; the initial velocities are as before expressed (150) and from the resistance of the air, in a 32lb. shot $r = 12$. By firing one round, the absolute penetration of a shot into a given butt will be determined; and, from the relative penetration it will be easy to ascertain the absolute penetration of other shot, under the same circumstances into the same butt. For example, if a 32lb. shot with the largest charge, fired close to the butt, penetrate to the depth of 22 feet, an 8lb. shot fired with the largest charge, at the distance of 1000 yards, will penetrate only

to the depth of 6 feet. If a 16lb. shot with the medium charge, fired at the distance of 340 yards, penetrate 10 feet, a 4lb. shot with the medium charge, at the distance of 680 yards, will penetrate only to the depth of $3\frac{1}{2}$ feet.

The relative penetrations of shot, projected from different distances, with given initial velocities.

Nature of Guns.	Weight of Powder.		Diameter of Shot.	Value of r	Initial Velocities.	Relative Penetrations.			
	lbs.	oz.				Inches.	Feet.	Close to the Butt.	At 340 yards.
32	13	2	5.760	12	1517	33210	26355	20726	16015
16	6.	9	4.566	9.5	1618	29952	22877	17082	12452
8	4	$14\frac{3}{4}$	3.653	7.6	1696	26000	18696	13069	8837
4	2.	$7\frac{1}{2}$	2.881	6	1720	21328	14122	8902	5290
32	9.	$13\frac{1}{2}$	—	—	1350	26240	20262	15356	11430
16	4	$14\frac{1}{2}$	—	—	1416	22932	16754	11935	8255
8	3.	$4\frac{1}{2}$	—	—	1450	19229	13106	8566	5311
4	1	$10\frac{1}{4}$	—	—	1467	15516	9563	5458	2867

184. To judge of the total effects of shot, it should be observed; that the larger the shot are, the sooner the upper parts are deprived of their base, and fall down. If $D u^2$ expressing the penetration of shot, be multiplied by D^2 a quantity proportional to the base of the cylindrical cavity, made by the shot, $D^3 U^2$ will be expressed by the size of the hole; that is to say, the holes made by the shot are in the compound ratio of the weight of the shot, and the square of its velocity. The effects of a 64lb. shot impinging on a parapet of earth, with a velocity of 1247 feet, are to the effects of a 32lb. shot, with an initial velocity of 1350 feet, as $64 \times 1247^2 : 32 \times 1350^2$ or as 43 : 25 nearly.

Hence it appears, that 64 prs. are in both cases (181) more proper for battering in breach than 32 prs. and the sole reason why they are not used in the attack of places, is the difficulty of transporting and working them.

185. Since

185. Since solid and resisting bodies are demolished by the division of their parts, and those that are less tenacious by the penetration of shot into them (182, 183); bodies partaking of these two physical qualities, are demolished in a compound manner (181, No. 3): of this kind are walls built of brick or similar materials. The effects of shot on walls are much modified by the proportion that the force of percussion bears to the resistance. When two shot of different diameters penetrate to great depths, the holes are in the ratio of $D^3 u^2$ (184): but, if one penetrate to a great depth, and the other but a little way, this proportion will not be just; for, the hole made by the latter, is less than what results from the expression $D^3 u^2$; so that if its force be only sufficient to overcome the resistance, it will bury but a small part of its circumference. Hence it is easy to comprehend, why shot projected from 8 and 4 prs. are sometimes insufficient to beat down walls of this kind; while that they produce all the effects expected from them, when fired against other walls. The direction of the shock, considered relatively to the thickness of the wall, likewise contributes to modify its effects: a shot that with great impetus impinges with a direct shock on a thin wall, passes through, and only makes a hole, without shaking or disuniting the contiguous parts: but, if a wall of the same quality be thick enough to receive all the force of the shot, it, beside making a hole, shakes and loosens the rest of the wall. A single wall is soonest demolished by firing against it directly with small charges, or obliquely with large ones; since the shot not being able to pass through, it receives all its force: the service of artillery in ricochet and hot-firing, is discussed in the subsequent treatise.

CHAP. IV.

OF THE EFFECTS OF CANNON SHOT IN ENGAGEMENTS.

186. **I**N forming a train of artillery for the service of an army in the field, there are several points to be considered: the nature and disposition of the ground; the kind of war that is to be carried on; the intended plan of operations;

N

ations;

rations; the number and quality of the troops that compose the army, and their manner of fighting.

A general commanding an army, should be acquainted with the effects of artillery, that he may know when it can be employed to advantage; and how far, when judiciously and skilfully served, it can contribute to the attainment of his object (141, 142).

187. In countries where the transport of carriages is attended with no great difficulty, the train of artillery that march with armies, are composed of medium guns, cast of metal containing $\frac{1}{8}$ of tin, and carrying balls of 16, 8, and 4lbs (64). These guns are divided into brigades: the heaviest should not weigh more than 32 cwt. as the bridges constructed by the peasants for their carts and waggons can seldom support a greater weight: beside, if the road be not hard, or have been spoiled by preceding rains, it will be impossible to move heavier guns, even at the opening of the campaign; and, in autumn, when the roads are generally deep, the cattle will be exhausted with the fatigues they have already undergone. Therefore, *the species of artillery should be always adapted to the nature of the country.*

In carrying on offensive operations in a champaign country, the train of artillery should be composed of 8 prs.; to which may be added a few 16 prs. for occasions of great exertion: there should be a few short light guns (97) to accompany any corps of the army that may be destined by rapid marches to fall on the enemy's convoys or cut off their detachments. In deep hilly countries, short 8 and 4 prs. should be the heaviest guns used: indeed, an exact knowledge of the nature of the country is the best rule for determining the calibre as well as number of the guns.

When the army is to remain on the defensive in a country where the roads are tolerably level and good, and there is no great probability of being obliged to make very long movements, the number of 16 prs. should be greater than would follow an army acting offensively in the same country; but if this defensive system be carried on in a strong country, where the transport of carriages is difficult, and long and rapid marches may be indispensibly necessary; the brigades of artillery should be so constituted as easily to keep up with the army. Any post that the general may wish to occupy and maintain during the campaign should be provided with guns of large calibre (71).

Having

Having already treated of the nature and importance of these posts in the 6th Book of Military Architecture, I leave it to the professors of the academies to explain them fully to the cadets of the royal corps of artillery; that being equally masters of the principles of tactics and fortification, as of their own profession, the service may on every emergency reap the greatest benefit from their knowledge and exertion.

188. These guns are able to bear the largest charges; yet they should not be used but in cases of absolute necessity and when they cannot derange the firing: in all other cases, the charges ought to be proportioned to the initial velocity that the projectile should have to produce the desired effect. For example, the medium charge may be used in enfilading columns of troops; as the shot from its greater velocity will destroy a greater number of men: but if the less charge will impel the shot from front to rear of the column, the medium charge would serve no other purpose than unnecessarily to heat the gun. Against an enemy drawn up three or four deep, the less charges should be used; as the least charges may from some neglect in wadding be uncertain in their execution.

189. From the desire of firing quick in action the greater part of the shot do not take effect; since in working the guns with such precipitation, there will most probably be a want of attention in loading, laying, or some other essential point. The frequency of firing should be regulated by the certainty of doing execution; those who are actuated by any other motive frustrate the designs of the general, and are the cause of all the bad consequences that may ensue: they can neither be justified by the anxious desire that the troops express to see them fire quickly, nor by a chimerical point of honour, which is by some individuals absurdly placed in firing so many rounds in a minute. Whenever the distance is so great or the object so small, that the chance of hitting it is very uncertain and precarious, it would be much better to cease firing and wait till by a nearer approach or by some movement of the enemy, an opportunity offers of doing effectual execution.

190. In engagements, the enemies troops are the objects against which cannon shot are directed; it is therefore highly necessary to know the effects that shot of different diameters, and with different velocities, can produce upon a body of troops, according to the distances at which they engage;

otherwise, the artillerist will in a variety of circumstances be unable to use his gun to the greatest advantage (141).

In firing at infantry, the height above the plane of the ground is about 6 feet, and in firing at cavalry not more than 10 feet; wherefore the distance should never exceed 680 yards, except when the enemy is drawn up so deep, that the shot can hardly fail of taking effect.

The execution of cannon shot in action is estimated from the number of men that are killed, or wounded in such a manner as to be disabled from further immediate service: it is unnecessary to consider the depth of the wounds; as a man struck by a cannon ball is generally incapacitated, at least for the present. The great object of the artillerist "is to endeavour to strike with each shot the greatest number of men possible" (141 142): this depends;

1. On the disposition of the enemy, and the nature of the ground.

2. On the calibre of the guns and the judicious use of round or case shot:

3. On the velocity with which the shot are impelled, and the distance between the battery and the enemy.

191. There are two cases with regard to the nature of the ground (190 No. 1); the first, when the two armies are drawn up on ground nearly on the same plane: the second, when they are on planes differently inclined. When they are both on the same plane, whether horizontal or inclined, the surface exposed to the fire of the cannon is a part of the first line; should this be the head of a column, or the flank of a body of troops ranged in order of battle, the shot by enfilading them will be very destructive. But if the enemy be drawn up three or four deep in front of the gun and within proper distance, case shot will do most execution; since a round shot can in this case, only carry off a file of three or four men, whatever be its diameter or velocity.

192. When the two armies are on different planes, the execution of the artillery must depend on the extent of front and depth of files: on considering the principal cases that can occur in the two general dispositions of an army, viz. drawn up in column, or line; it will appear:

1. That if the enemy be drawn up in column on the slope GF inclined towards F , the head only of the column G (Pl. 6. Fig. 21.) will be exposed to the cannon

non A : case shot will then be preferable to round shot, if the distance AG admit of it.

2. If the column be on the slope GE inclined towards E or on the height NBM; it will present to the cannon A an object of great extent, and be from its situation very much exposed: the closer the ranks are, and the deeper the column, the more destructive will be the fire of the artillery.

3. If AB be within range of case shot, its greatest effect will be at NBM, where from the divergence of the shot each may strike a man; while that in GE much nearer to the gun, the shot not having had time to spread, each man will be struck by two or three, and the execution will of course be less.

4. When the column reaches the horizontal plain PE, it will suffer less than in the former situation: if A and PE be nearly in the same plane, fewer men will be exposed than at AP: the case shot should then be composed of balls of the largest diameter that each of them may kill or wound more than one man; and then every ball that strikes will enfilade the whole disposition. If PE be lower than A, so that the guns at A must be much depressed; case shot composed of the smallest balls will be the best; since from the greater number their effect will be equal to that produced in the former instance by the large balls; there being in this case no probability of establishing an enfilade.

5. The enemies army drawn up three or four deep upon the height G will be exposed to the same danger, as when in column on the slope GF; but by retiring a little, G will serve as a parapet, under the cover of which they may securely fire at A.

6. Should the enemy be drawn up three or four deep upon the slope EG, the greatest effect of a round shot will be to carry off a file of men even when the ranks are very close: but if there be a considerable interval between them case shot, when the distance admits of it, will be most destructive, both in this instance and when the enemy has advanced to the horizontal plain PE.

193. The direction in which guns should be fired depends on the initial velocity of the shot, its diameter, and the distance

stance from the enemy; the formulas $q = \frac{crt}{r+t}$, $S = \frac{32.18t^2}{2}$

(165, 166) will give a solution of the problem.

The opinion of some artilleryists, that guns in time of action ought always to be fired horizontally, or at most with $\frac{1}{4}$ degree of elevation, can only be just in particular cases; the following example will evince the necessity of sometimes deviating from this maxim. Let the gun AB (Pl. 5. Fig. 14.) be fired in the horizontal direction AC with the charge that gives an initial velocity of 1416 feet; and from the resistance of the air, $r = 9.5$. Now supposing the gun and the enemy to be in the same horizontal plane; Let KG represent the vertical distance between the two planes AC, DF; KG will then express the space = S passed through by the power of gravity, and by substituting the value of KG

in the formula $S = \frac{32.18t^2}{2}$ it will give the time of the shot's

flight before it touch the ground in the plane DF: then by

substituting in the formula $q = \frac{crt}{r+t}$ the known value of t ,

the extent of the range $AK = DG = q$ will be found. For example, if $KG = 5\frac{1}{4}$ feet, the time = t will be 56 parts of a second; and by substituting the values of c, r, t in the formula, $q = 760$ feet. To strike the ground then in the same plane DF at a greater distance, the gun must be elevated in proportion to the increase of distance; should the enemy be at G where the shot touches the ground at the first graze it will only strike his feet; to hit him in the breast the gun must be elevated.

194. The more clearly to explain this theory, and enable others to apply it to the practice on several occasions that occur on service, the following table has been calculated: the gun and butt are supposed to be in the same plane, and from the resistance of the air $r = 12$ in a 32lb. shot; the wads are rammed with equal force and in the manner before expressed, (143, 150); except in the quick firing, when none are used.

Angles of Elevation for firing Guns of different Lengths and Calibres with different Charges of Powder, to project Shot to different Distances.

Nature of Guns.	Weight of Powder.	Initial Velocity.	Distant from the Butt.												
			340 Yards.			680 Yards.			1000 Yards.			Eleva- tion.			
<i>P_rs</i>	<i>lbs.</i>	<i>oz.</i>	Line of descent.	Eleva- tion.	Line of Descent.	Eleva- tion.	Line of Descent.	Eleva- tion.	Line of Descent.	Eleva- tion.	Line of Descent.	Eleva- tion.	Line of Descent.	Eleva- tion.	
			<i>Fect. In.</i>	<i>Deg. Min.</i>	<i>Fect. In.</i>	<i>Deg. Min.</i>	<i>Fect. In.</i>	<i>Deg. Min.</i>	<i>Fect. In.</i>	<i>Deg. Min.</i>	<i>Fect. In.</i>	<i>Deg. Min.</i>	<i>Fect. In.</i>	<i>Deg. Min.</i>	
Of the common length.	48	13 1/2	10	6	35	48	1	21	120	2	17	120	2	17	
			9	9	32	46	4	18	120	2	17	130	2	29	
			8	8	32	48	—	—	—	—	—	—	160	3	—
			7	10 1/2	33	52	9	28	169	3	14	191	3	38	
			6	10 1/2	44	63	7	47	191	4	30	236	4	30	
			5	7 1/2	44	67	4	53	220	4	4	220	4	11	
			4	7 1/2	45	75	—	—	—	—	—	—	278	5	17
			3	3 1/2	49	86	10	26	278	6	8	425	8	6	
			2	1	19	133	—	—	—	—	—	—	425	11	55
			1	10 1/2	26	164	6	44	633	4	30	633	11	34	
			without wads.	1	12	405	—	—	—	—	—	—	1843	31	—
			without wads.	—	13 1/2	675	3	41	596	16	18	—	—	—	—

195. Many practical inferences may be deduced from this table :

1. Guns of the common length loaded with the medium charge should be elevated half a degree above the horizon to range 340 yards, and $1^{\circ} 20'$ to range 680 yards ; the elevation must be greatly increased to range 1000 yards. The less the calibre of the gun is, the higher must be the elevation.

2. The elevation of short guns fired with the less charges must be greater than of guns of the common length to range the same distance.

3. If a short 4 pr. loaded with the less charge, range 1000 yards, the line of descent is 278 feet ; wherefore the shot's path being a curve of the fourth kind, it will do much less execution in enfilading troops, than shot fired from guns of the common length whose path is a curve of the second kind.

4. The elevation of short guns loaded with the least charge increase in the ratio of the distance : thus the curve described by shot fired from 8 and 4 prs. to the distance of 1000 yards is of the fourth kind ; from the angle of incidence they can be of no service in enfilading, and are very uncertain : the angle of incidence (168) at the distance of 1000 yards being much larger than the angle of elevation, if the shot fall on soft ground they bury themselves at the first graze.

5. Shot fired from short guns with the least charges and without wads, which range only 680 yards, also describe a curve of the fourth kind ; they are consequently useless in enfilading, and their execution is uncertain.

6. If to these reflections be added the consideration, that in pointing short guns the eye is more easily deceived, from the proximity of the two points of sight, than in longer guns ; and that in the latter the angle of elevation being less, the angle of incidence is less also ; so that the shot on touching the ground rise and from their ricochet are very dangerous : it will be evident that to derive from the use of artillery the greatest possible advantages, *long guns should ever be preferred to short ones of the same calibre.* The good effects resulting from this will be more fully displayed in the sequel.

196. To form a comparison of the effects that shot of different diameters with different initial velocities produce at different distances on a body of troops; they must be considered as a homogenous butt: then the formula $S=Du^2$ (183) will give the relative penetrations. The absolute number of men that a shot with a given initial velocity will pass through may be determined by experiment.

The relative penetrations in the following table have been calculated on a supposition that from the resistance of the air $r=12$ in a 32lb. shot, in order to compare together the number in this and the preceding table (183). The calculations are not carried beyond 680 yards, which is considered in field engagements as the greatest distance that shot can range to, with a certainty of doing execution; in extraordinary cases indeed, when the nature of the ground and the position of the enemy are very favourable (192), the range may be extended with tolerable success.

The relative Penetrations of Shot projected from different Distances with given initial Velocities.

Nature of Guns.	Weight of Powder.	Initial Velocity.	Close to the Butt.	At	At	
				340 yards.	680 yds.	
Com- mon length.	<i>Prs.</i> 16	<i>lbs. oz.</i> 3 10 $\frac{3}{4}$	<i>Feet.</i> 1240	17571	11878	8509
	8	2 7 $\frac{1}{2}$	1265	14625	9360	5743
	4	1 3 $\frac{3}{4}$	1283	11840	6754	3479
	8	2 7 $\frac{1}{2}$	1206	13329	8358	4919
Short Guns.	4	1 3 $\frac{3}{4}$	1222	10784	5933	2944
	8	1 10 $\frac{3}{4}$	978	8746	4874	2450
	4	— 13 $\frac{1}{2}$	978	6896	3230	1271
	8	without wads	10 $\frac{1}{4}$	675	4110	1738
4	wads	13 $\frac{1}{2}$	675	3241	1024	251

197. To reduce into numbers the relative penetrations inscribed in the tables (183, 196), make the following or similar experiment: with a charge that gives a known initial velocity, fire a gun against a butt, and measure the penetration of the shot: then place two horses or other cheap animals close to the same butt, and lay the gun so that the shot after passing through the most solid parts of their bodies may

may enter the butt : on measuring the penetration, it will be found less than the former; and by comparing them together, the number of horses that a shot of a given diameter, with the same initial velocity, could pass through, may be ascertained. On comparing the resistance of a horse's, with that of a man's body, the number of men that the same shot would pass through may be easily calculated. An 8 lb. shot, with an initial velocity of 1450 feet, will pass through 20 horses; and in this table it is presumed on tolerably just grounds, that the same shot would pass through double the number of men, even if it struck the most solid parts of their bodies; the number therefore that may be struck in less resisting parts of the body and disabled must be greater, and may even exceed twice the number of the former. The table has been deduced from the former proportions (183, 196).

Number of Men that can be pierced by Shot projected from different Distances with given Initial Velocities.

Nature of Guns.	Weight of Powder.	Initial Velocities.	Close to the Butt.			
			No. Men.	At 340 Yards.	At 680 Yards.	
	lbs. oz.	Feet.				
Common Length.	32	13 2	1517	70	55	44
	16	6 9	1618	63	48	36
	8	4 14 $\frac{3}{4}$	1696	55	39	28
	4	2 7 $\frac{1}{2}$	1720	45	30	19
	32	9 13 $\frac{1}{2}$	1350	55	43	32
	16	4 14 $\frac{1}{2}$	1416	48	35	25
	8	3 4 $\frac{3}{4}$	1450	40	28	18
	4	1 10 $\frac{1}{4}$	1467	33	20	12
	16	3 10 $\frac{3}{4}$	1240	36	24	17
	8	2 7 $\frac{1}{2}$	1265	31	20	13
Short Guns.	4	1 3 $\frac{3}{4}$	1283	25	14	8
	8	2 7 $\frac{1}{2}$	1206	28	18	11
	4	1 3 $\frac{3}{4}$	1222	23	13	7
	8	1 10 $\frac{1}{4}$	978	19	10	5
	4	— 13 $\frac{3}{4}$	978	15	7	3
	8	without wads. { 1 10 $\frac{1}{4}$	675	9	3 $\frac{1}{2}$	7 $\frac{8}{12}$
	8	— 13 $\frac{3}{4}$	675	9	3 $\frac{1}{2}$	7 $\frac{8}{12}$
	4	— 13 $\frac{3}{4}$	675	7	2	1 $\frac{7}{12}$

198. Several inferences of great practical utility may be drawn from this table :

1. Guns of large calibre fired at very short distances, with the large or even the medium charges against a corps of troops exposed to be enfiladed, will cause much more slaughter than 8 or 4 prs. especially if short with the least charges.

2. The relative effects of guns of different natures increase in the ratio of the distances; and there is greater difference between the calibres of the guns and the charges of powder.

3. Guns should never be fired without wads, except in particular cases, and when the enemy is very close. Thus when 4 prs. or short guns compose a field train, it is not because they are equal in their effects to longer guns of large calibre, but only because heavier guns cannot be transported with the same facility. When part of an army is to remain on the defensive in a fixed post, the same arguments will evince the propriety of giving the preference to longer guns of large calibre.

199. If the enemy troops be drawn up three or four deep, the effects of an oblique fire will be greater in proportion as the angle of incidence on their front is more acute; since the resistance not being sufficient to turn the shot, it will penetrate in the direction in which it impinges. On the contrary, the effect will be less, the nearer the angle of incidence approaches to a right angle; since it will then only destroy a single file, whatever be its diameter or initial velocity. In this case, if the two armies be within reach of musquet shot, the situation of the artillery men will be very perilous: for eight paces at least must be left between every two guns, to give the men room to work them; each gun is then exposed to the fire of eight file of musqueteers; or in other words, each artillery-man to the fire of three or four musquets. Thus at a single discharge, all the artillery men may be killed or wounded; while one round from each gun can only carry off a single file of the enemy: when half of the artillery-men are wounded, the gun must cease firing; but the fire of the musquetry will be incessantly kept up, in proportion to the number of men that remain.

200. The fluid generated in a piece of ordnance is so much the more abundant and elastic, as the body it must impel towards the muzzle is heavier (Treatise on Powder).

Whence

Whence it is easy to conceive; that in putting two shots into a gun, the velocity of each must necessarily exceed half of the velocity that one shot with the same charge would acquire; and the quantity of motion of the single shot is less than the sum of the quantities of motion of the two shot: but in ascertaining the effects of the three shot, their force after passing through the men and horses being supposed to be entirely spent, the equation $S = Du^2$ which expresses the effects of one shot must be changed; and to make up the excess, the initial velocity of each of the other two shot must exceed $u\sqrt{\frac{1}{2}}$; and each should strike a separate file. The proportion between the initial velocity acquired by one shot fired singly, and that acquired by each when two shot are fired together with equal charges, can only be determined by experiment, as it changes whenever the charge is altered; but it may be remarked, that in practice the velocity of each of the two shot is less than $u\sqrt{\frac{1}{2}}$: wherefore the expedient of putting two shot into a gun can be only advantageous when the enemy is drawn up in such a manner, that each shot has sufficient velocity to carry off a file. For example, suppose the enemy be drawn up eighteen deep, and each of two shot fired together from an 8 pr. could strike a separate file with an initial velocity of 978 feet, each of them would destroy 18 men (197): under this supposition there would be 36 men destroyed by the two shot; while a shot of the same diameter, fired singly with an initial velocity of 1450 feet, could destroy only 18 men; then its remaining velocity sufficient to destroy 20 more would be useless.

CHAP. V.

OF THE EFFECTS OF CASE OR GRAPE SHOT IN ENGAGEMENTS.

201. **T**HERE are several kinds of shot that come under this head: one is formed of small pieces of iron of different shapes and sizes put into cylinders of tin or pasteboard; the bases of which are closed by two circular pieces of wood. A second

A second called *case shot*, is composed of small iron balls put into tin cylinders; or regularly disposed in linen bags fastened to a wooden bottom, in the middle of which is a spindle, and wound round with cord or wire; the latter present the appearance of a bunch of grapes, and are called *grape shot*. The first kind is generally used in the defence of places; and fired from the low flanks, where in spite of their divergence they are useful in scouring the ditches and counter-scarps: the resistance of the air, from the irregularity of their figure, renders them in effect more uncertain than spherical shot; but as the objects against which they are fired are always very near, they have force enough to do execution. The second kind is generally designed for field service, as the balls diverge less, and, from their spherical figure encountering less resistance in the air, range farther.

202. In the late wars, our trains of artillery were formed of medium 4 prs. (64): the case-shot for these guns contained 63 or 64 leaden bullets, each weighing $\frac{3}{4}$ of an ounce; the whole weighed nearly as much as a round shot of the same diameter. In order to ascertain their effects, the officers of artillery in 1743 made the following experiments: a 4 pr. was fired against a target of plank 80 feet in length by 10 in height, erected on the same horizontal plane with the gun; so that some of the balls after grazing rose and struck the target: case and grape shot were fired, but no difference in their effects was perceptible. In the first experiments, the charge was 1 lb. 10 oz. of powder, and over the wad, which was well rammed, was placed the case: at the distance of 200 yards, only 3 or 4 balls struck the target. The gun being moved 30 yards nearer, 9 or 10 balls struck it; but the greater part did not go through the planks, which were an inch thick: those that struck were partly melted, and two or three were found in different places sticking together. At the second experiment, the case was placed immediately over the powder and a wad rammed over the whole: at the distance of 170 yards very few of the balls went through the planks, though the report of the explosion was as loud as at the former experiment; others had not force enough to enter, and those that struck were much more liquefied than before; 4 or 5, and at one time 15 were found sticking so closely together as to form a lump of lead. At other experiments, when the case was placed over
the

the powder without a wad, the balls at 170 yards struck the target with rather more force, and were not liquefied, though the report at the discharge was more feeble than at the second experiment. At each round, the number of balls that struck the target was between $\frac{1}{8}$ and $\frac{1}{6}$ of the whole; and $\frac{1}{2}$ or $\frac{2}{3}$ of these struck it below a horizontal line drawn 5 feet from the ground. The greatest divergence of the balls at this distance was 60 feet, but frequently not more than 33.

203. Some rounds being fired from the same gun at 170 yards, with $1\frac{1}{2}$ lb. of powder, the number of balls that struck the target was between $\frac{1}{8}$ and $\frac{1}{6}$ of the whole, but their force was less: in these, as in the former experiments, a wad was rammed over the powder; in the second, a wad over the whole; and in the third no wad was used. Two cases being put into a gun and fired together, the number of balls that struck the target was between $\frac{1}{8}$ and $\frac{1}{6}$ of the whole number in the two cases; many of those that touched the target had not force enough to penetrate. The gun being removed to 200 yards and fired again with two cases, about $\frac{1}{20}$ of the balls struck the target, but with much less force.

204. It results from these experiments (202, 203):

1. That case-shot of this nature should never be fired at a greater distance than 200 yards, against objects not exceeding 10 feet in height.

2. A wad should be put between the powder and case; but as sometimes in quick firings this must be dispensed with, the balls will yet have force enough at 200 yards to wound a man.

3. That the greatest possible effect of case shot is when fired against an enemy drawn up in form of a vast amphitheatre between 170 and 200 yards distant, by putting two cases into the piece and using the less charges of powder.

4. That with one case, 6 or 7 men of the front rank may be struck at 170 yards; and still a greater number when two cases are put into the gun: when advanced nearer to the enemy, the balls will pass through the bodies of the men in the front rank and wound those in the rear.

5. That the firing with case shot should commence at 170 yards in order to acquire a superiority over the enemy's musquetry; the effect of platoon firing at that distance

distance is uncertain, while case shot fired with judgment will strike at each round a certain number of men.

At other experiments (202, 203) with case shot composed of iron balls 1 oz. in weight, the whole case weighing as much as the round shot of the same diameter; it resulted that at 200 yards, 3 or 4 balls struck the target, and at 170 yards 8 or 10 struck it; the force of these balls seem to exceed that of the leaden bullets.

205. These conclusions agree with what has been advanced on the same subject, in the practice of artillery and the elements of tactics. It will be shewn in the sequel, that greater advantages may be derived from the use of field pieces than has been hitherto done, in constantly maintaining a decided superiority of fire over infantry drawn up in front of the guns (199) through the use of tin cylinders filled with iron balls weighing more than 1 oz.

To ascertain this, the force and direction with which each ball is impelled, and the proper elevation for the piece should be considered: the two following tables will give a just idea of their force; in the first are set down the relative penetrations calculated (183) on a supposition that the initial velocity is 1450 feet, and that from the resistance of the air to a 32 lb. shot $r=12$, in order to form a comparison between these and the former tables (183, 196): in the second are marked the results of the former experiments (197) and the penetrations inscribed in the first table are reduced to absolute numbers.

TABLE

Relative penetrations of iron case shot.

TABLE I.

Weight of ball. ozs.	Value of r	Close to the butt.	At 170 yards.	At 340 yards.	At 510 yards.	At 680 yards.
13	3.8	9614	6553	4283	2655	1538
$6\frac{1}{2}$	3.	7580	4642	2645	1365	620
$3\frac{1}{4}$	2.39	6040	3251	1524	604	181
1	1.65	4139	1621	470	74	2

TABLE II.

Number of men that can be pierced in the most solid parts of the body by case shot, of the following weight projected from different distances, with an initial velocity of 1450 feet.

Weight of balls. ozs.	Close to the butt. Men.	At 170 yards. Men.	At 340 yards. Men.	At 510 yards. Men.	At 680 yards. Men.
13	20	14	9	6	4
$6\frac{1}{2}$	16	10	6	$3\frac{1}{2}$	1
$3\frac{1}{4}$	13	7	$3\frac{1}{3}$	$1\frac{1}{2}$	$\frac{19}{8}$
1	9	4	$\frac{3}{6}$	$\frac{1}{7}$	$\frac{1}{9614}$

206. From these premises (190, 191, 192) it may be inferred.

I. That when balls of which case shot are composed weigh 13 oz. each, every ball can pierce a file of 20 men, when fired very close; and 4 men at the distance of 680 yards. If each ball weigh $6\frac{1}{2}$ oz. it can pierce 16 men when very near; 10 at 170 yards; 3 or 4 at 510 yards; and one only at 680 yards. If each ball weigh 1 oz. it can pierce 4 men at 170 yards; and mortally wound 1 man at 340 yards; the latter is expressed by

by the fraction $\frac{5}{8}$; the same ball at the distance of 680 yards will hardly make a contusion, which is expressed by the fraction $\frac{1}{2614}$.

2. Balls of 1 oz. at 170 yards, those of $3\frac{1}{2}$ oz. at 340 yards, those of $6\frac{1}{2}$ oz. at 510 yards, and those of 13 oz. at 680 yards, produce the same effect; viz. of destroying 4 men; which evinces the propriety of using cylinders filled with large balls for great distances, and with the smaller balls for short distances.

3. On comparing the numbers in the two tables (197, 205), we find that an 8 lb. shot, with an initial velocity of 1450 feet, will pass through a file of 40 men when fired very close to them; 28 at the distance of 340 yards, and 18 at the distance of 680 yards; while a $6\frac{1}{2}$ oz. ball will only destroy 16 men when very near, 6 at the distance of 340 yards, and 1 man at 680 yards; so that with case-shot of this nature, if 5 balls strike 5 separate files, the effects when very near will be $16 \times 5 = 80$ men destroyed, $6 \times 5 = 30$ men at 340 yards, and 5 only at 680 yards. Hence it results, that the effects of case shot fired under similar circumstances, are greater than of round shot of equal diameter, when the distance does not exceed 340 yards; but at 680 yards round shot have a decided advantage.

207. These remarks (205, 206) are applicable to every case that can occur, allowance being made for the difference of the initial velocities; wherefore the effect of the initial velocity on case shot impelled with a given charge of powder should be ascertained. It has been found experimentally, that when the balls are regularly arranged in the tin cylinder in the manner that will be hereafter pointed out, and are equal in weight and diameter to the corresponding round shot, the greater part of them are impelled with the same initial velocity as the round shot, but the remainder with less; provided the charges be equal. This result is constant; hence the effects of case shot fired from different distances with different charges of powder may be determined with sufficient accuracy for practice (205).

208. In firing case shot, the balls are observed at first to take a diverging direction, and for a certain distance to form a kind of a cone; the base of which is towards the object fired at, and the vertex towards the gun.

It is impossible from theory alone to determine the direction

rejection that each ball takes after the case is broken; since the contact of the balls and their reciprocal pressures at the discharge and at the commencement of their divergence are unknown: It must then as far as possible be ascertained experimentally.

Experiments made with the greatest attention have given the following results;

1. The conical figure is preserved for a certain distance; after which it is entirely lost.
2. The proportion between the formation of the cone and the point where it begins to lose the regularity of its figure depends on the size of the balls, and their initial velocity: the distance will be less in proportion as the balls are smaller, or their initial velocity less.
3. At equal distances, balls impelled from guns of the common length diverge much less than balls of the same weight and diameter impelled from shorter guns with the same charge. This must be a familiar remark to sportsmen who have used fowling pieces of different lengths.
4. When the balls are ranged in the cylinder in regular order, they diverge much less than when put in carelessly; those of 13, $6\frac{1}{2}$ and $3\frac{1}{4}$ oz. may be regularly disposed in tin cases of the diameter of 16, 8, and 4 prs.; and such only will be in future considered: 1 oz. balls should be disposed in the cylinder in the most convenient manner, and fired at any distance less than 220 yards.
5. From certain distances a greater number of men may be struck by case than by round shot; if the gun be properly laid.

209. The angle that the axis of the gun should form with the horizon is determined (165, 166) on a supposition that the balls in the tin case are impelled in the direction of the axis, which is not always just; as they sometimes quit the case under different angles. The least error in loading or pointing a gun may render a round shot of no effect, but be of little consequence in firing with case shot.

210. In order to shew in one part of view the most interesting particulars in the use of case shot, the following table has been calculated; the initial velocities of a 32 lb. shot are supposed to be 1450 and 1206 feet, and $r=12$ for the resistance of the air, to enable the reader to compare it with the former tables.

Angles

Angles of Elevation at which Guns should be fired with Case Shot, with the initial Velocities of 1450 and 1206 feet, from the following Distances, supposing the Battery and the Enemy to be in the same Plane.

Nature of case shot.	Initial velocity. Feet.	Distances between the battery and enemy.												
		170 yards.			340 yards.			510 yards.			680 yards.			
		Line of descent. Fi. In.	Elevation, Deg. Min.	Line of descent. Fi. In.	Elevation, Deg. Min.	Line of descent. Fi. In.	Elevation, Deg. Min.	Line of descent. Fi. In.	Elevation, Deg. Min.	Line of descent. Fi. In.	Elevation, Deg. Min.			
13 0½ 3¼	1450	2	16	10	8	33	1	15	77	2	12	77	2	12
		2	17	12	7	40	1	33	107	3	4	107	3	4
		2	18	15	1	55	2	6	179	5	5	179	5	5
		2	22	24	—	131	4	57	1298	32	41	1298	32	41
13 6½ 3¼	1206	3	24	17	—	57	2	7	140	4	5	140	4	5
		3	25	22	—	74	2	49	229	6	30	229	6	30
		3	27	25	10	114	4	15	574	13	55	574	13	55
		4	34	44	—	463	16	36	—	—	—	—	—	—

211. From this comparison the following practical inferences may be drawn;

1. Balls of $3\frac{1}{4}$ oz. that with an initial velocity of 1450 feet range 680 yards, describe a curve of the second kind; the remaining force at that distance may be expressed by the fraction $\frac{1}{172}$; but it is injudicious to fire case shot of this nature at such a distance, as their execution is trifling: 1 oz. balls ought never to range 680 yards, as they describe a curve of the fourth kind, and are totally useless in enfilading; their remaining force may be expressed by the fraction $\frac{1}{1014}$ and is hardly sensible.

2. Balls of $3\frac{1}{4}$ oz. that with an initial velocity of 1450 feet range 510 yards, describe a curve of the second kind, and may be of service in enfilading; but as they can destroy only one or two men, this is the greatest distance at which they should be fired: as to 1 oz. balls, though at 510 yards their curve is of the second kind, yet as the expression of their force is $\frac{1}{7}$, the distance is too great: 340 yards should be their longest range, the expression of each ball is then $\frac{5}{6}$.

3. As a ball of $6\frac{1}{2}$ oz. with an initial velocity of 1450 feet can only destroy one man at 680 yards, it should be considered as the greatest distance; though from the nature of the curve, it might still be useful in enfilading.

A ball of 13 oz. with the same velocity and at the same distance will destroy a file of 3 or 4 men.

4. When the initial velocity is 1206 feet, the curvature of the lines of descent is greater than when it is 1450 feet; consequently case shot with the former velocity are less proper for enfilading: they should only be used at short distances, in proportion to the difference between the actual velocity and 1450 feet.

5. A small charge of powder can only have the same effects as a large one, when the enemy is drawn up 3 or 4 deep, and so close that a single ball can carry off a whole file: the same observation holds good with respect to short guns, since from the initial velocity (151) their range is short.

6. The number of balls that, with velocities equal to or less than those above mentioned, will strike an object of certain dimensions at a given distance, can only

only be determined by experiment; since it is impossible to ascertain the particular direction of each ball.

212. The results of the preceding theory (205), whether the resistance of the air be considered as $r=12$ or of any other determinate value, will never exactly coincide with practice; since the absolute effects of case shot cannot be assigned, but only a proportion established between the greatest and least effects: wherefore artillerists, to use case shot from field pieces to the best advantage, should attend to the following particulars.

1. For 16 prs. there are four kinds of case shot: the first, composed of 16 balls of 13oz. is never fired with the medium charge above 680 yards against an enemy drawn up 3 or 4 deep; when they are disposed in deeper order, the distance should be less (206, No. 3): the second kind is composed of 32 balls of $6\frac{1}{2}$ oz. and its greatest range is 510 yards, when the enemy is disposed in few ranks: the longest range of the third kind composed of 64 balls of $3\frac{1}{4}$ oz. is 340 yards: the range of the fourth kind composed of 192 balls of 1 oz. should never exceed 220 yards.

2. There are 3 kinds of case shot for 8 prs.: the first contains 16 balls of $6\frac{1}{2}$ oz. and may with the medium charge be fired at the distance of 510 yards: the second contains 32 balls of $3\frac{1}{4}$ oz. its range should not exceed 340 yards: the third contains 96 balls of 1 oz. and may range 220 yards.

3. For 4 prs. there are but two kinds of case shot: the first contains 16 balls of $3\frac{1}{4}$ oz. and its range with the medium charge should not exceed 340 yards: the second contains 48 balls of 1 oz. and its greatest range should be 220 yards.

4. The number of balls in a 16 pr. case being double the number of balls of the same diameter in an 8 pr. case, if the two guns be fired from the same distance with the same initial velocity, the effect of the 16 pr. should be double that of the 8 pr. and the effects of an 8 pr. should be double that of a 4 pr. under the same circumstances; guns of large calibre also ranging farther, there will be still a stronger reason for preferring them to guns of smaller calibre, whenever the nature of the ground and of the service admits of it. If case shot be fired from a 16 pr. with an initial velocity less by $\frac{1}{2}$ than the initial velocity

of case shot containing balls of equal diameter fired from an 8 pr. and the distances be equal; the effects of the 16 pr. will in certain cases be greater than the effects of the 8 pr.; for the same reason, the short 8 pr. (66) is sometimes to be preferred to the common 4 pr. as in the instance of the enemy being formed on sloping ground in figure of an amphitheatre, (as happens in mountainous countries) and very near the battery; the 8 pr. case containing double the number of balls that the 4 pr. case does, will do more execution.

5. By increasing the number of balls in the case, the initial velocity, and of course the effect of each is sensibly diminished. When fired against troops disposed in very deep order (200) on an amphitheatre of hills, and very near the battery, the greater the number of balls is, the greater the slaughter will be; and as in this instance, two cases may be put into the gun at the same time, it will be sufficient if the weight of each be equal to that of the round shot.

6. When the enemy is drawn up in very deep order, the medium charge of powder should be preferred to the less, both with round and case shot; the distance at which each nature of shot should be used will be best determined by recurring to the preceding theory (206, No. 3), and the results of former experiments (211 No. 6).

7. If it be necessary in the course of a campaign to place some 32 prs. in a fixed post, five kinds of case shot should be prepared for them: the first with 16 balls of 26 oz. to range 850 yards: the second with 32 balls of 13 oz. the third with 64 balls of $6\frac{1}{2}$ oz. the fourth with 128 balls of $3\frac{1}{4}$ oz. the fifth with 384 balls of 1 oz. the four last may be fired under the restrictions already laid down. The two former may be of excellent service in the defence of places at the opening of the trenches; but as the balls spread very much, they should be used with caution, lest they hurt the detachments of the garrison posted in the advanced works.

213. Balls of hammered iron are the best for case-shot; but, if from motives of œconomy they be made of cast iron, the metal should be of a hard and tenacious quality, or they will break to pieces at the explosion: the number that break increase in proportion to the augmentation of the charge. Each shot therefore before it is put into the case, should be placed

placed upon an anvil, and receive a smart blow from a heavy hammer; if they stand this proof, they are fit for service. The cylinder of tin should be of the same diameter as the corresponding round shot; one end is closed by a wooden cylinder $1\frac{1}{4}$ or $1\frac{1}{2}$ inch thick, on which the first row of balls is regularly placed, putting into the interstices small pieces of wood to keep them firm: the balls of the second row are placed over the interstices of the first, and each row is fixed with chips or something of that kind to prevent their moving, when the ammunition waggons pass over rough and stony roads; which might break the cylinder or deform it, so that it would not enter the gun. All the rows of balls being thus disposed, the top of the cylinder is closed by a cylindrical piece of wood $\frac{1}{2}$ an inch thick, nailed to the tin, and marked so as to be easily distinguished from the base; and on the top is marked the diameter of the balls contained in the case, that the artillery men may make no mistake in the nature of the case-shot, or in the manner of placing it in the gun.

If mastic be used instead of chips, to fix the balls in the case, its tenacity will increase the force of the powder and the balls will diverge less. The best mastic for this purpose is made of melted pitch and powdered marble: but the quantity should be proportioned to the force of the charge; for if it be of such tenacity that the case reaches the object before it breaks, or breaks very close to it; all the advantage arising from the proper divergence of the balls would be lost: the effect of these projectiles being evidently as much diminished by too little as by too great divergence (190).

214. To derive from artillery in field engagements the fullest advantages (212), the following rules should be adhered to:

1. Brigades of the heaviest guns in the army should be posted at the points whence it is proposed to make the greatest efforts against the enemy, or where the briskest attack on their part may be expected: and the guns of smaller calibre placed so as to favour the principal attacks and distract the enemy's attention.

2. In posting brigades of artillery in a defensive situation, a parapet, ditch, hedge, pallisadoe, chevaux de frize, or other obstacle, should be placed before them, to keep the enemy in check; in case they advance with fixed bayonets.

3. There should be to each brigade a reserve of artillery

lery men covered by an epaulment or the ammunition waggons, to replace without loss of time any that may be killed or wounded. If it be judged expedient to draw up an army in two lines, that the troops of the second line may in case of necessity be brought forwards to replace those in the first; with equal reason should the number of artillery-men be sufficient to keep up the fire from the cannon with proper vivacity during the whole engagement, in spite of any loss that may be sustained.

C H A P. VI.

THE EFFECTS OF THE HOWITZER AND SPR. COMPARED.

215. **I**N the last century, guns from 6 to 7 feet in length were used to project stones, case shot, &c. from besieged places: the shortness of these guns and the largeness of their calibre generally adapted to a shot of 24 lbs. gave rise to the idea of the howitzer; the proportions of which vary among different nations, according to the several uses for which they are intended. The longest howitzers I ever saw were 6 diameters of the muzzle in length of bore, with a cylindrical chamber capable of containing 1 lb. 10 oz. of powder: the bore of the shortest was 4 diameters of the muzzle in length, with a cylindric chamber containing 1 lb. of powder. The long ones were used in the imperial army which Prince Eugene of Savoy commanded against the Turks, and the shells fired from them are said to have caused great destruction and dismay among the Ottoman cavalry. On the other hand, the predilection for this species of ordnance was much abated at the battle of *Guastalla*, fought on the 19th of September 1734; where our cavalry of the left wing was neither disordered nor hurt by the shower of shells fired by the enemy, but made several charges with great effect. As the Ottoman cavalry generally charge in an irregular, desultory manner, they present a much larger object than our cavalry drawn up two or three deep with close files; being therefore very much exposed, the explosion of the shells will be more destructive among them, than in the regular movements and dispositions practised by us. Whatever may be the reason of this difference, we will only consider the physical effects of projectiles

tiles impelled from a howitzer 6 diameters of the muzzle in length of bore, and compare them with those of the 8 pr. (183), in order to ascertain the disorder that each of these pieces can severally produce among a body of troops: leaving it to others to discuss the moral effects resulting from the use of howitzer shells, which have by many authors been supposed to be very great: a disquisition totally foreign to our purpose, as the absolute consequences can neither be calculated nor depended on; for it has happened more than once, that troops, which had at the beginning of an engagement been thrown into disorder by the fire of artillery, have at length recovered themselves so far as to despise the former object of their fear, on finding that their apprehensions had greatly magnified the effects of these seemingly terrific machines.

216. *A shell is fired from a howitzer with a view of destroying the enemy both by its shock, and explosion on bursting:* its greatest effects are when, having enfiladed a body of troops and being quite spent in striking men or other objects, it bursts in the midst of those that remain. To convey a just idea of the comparison we propose drawing; let the howitzer be equal in length of bore to an 8 pr. of common length, and let them both be loaded with $3\frac{1}{4}$ lb. of powder: the elastic fluid on quitting the chamber of the howitzer dilates towards the chace, and exerts against the shell less pressure, than the same quantity of fluid generated in the gun exerts against the shot; consequently its initial velocity is less. As a howitzer 6 diameters of the muzzle in length of bore is only half as long as an 8 pr. and as the largest charge for throwing a shell 16 lbs. in weight is 1 lb. 10 oz. of powder (215), this projectile must have a much less initial velocity than an 8 lb. shot impelled by $3\frac{1}{4}$ lbs of powder, with the wads well rammed. The initial velocity and the specific gravity of the shell being less than those of the shot, the air's resistance will be greater; and consequently its penetrations into the same butt will be less.

217. There are two methods of ascertaining the effects of howitzer shells: the first is, by firing against a butt at different elevations and distances, and comparing the penetrations of the shell with those of a shot fired from an 8 pr. The result will express the proportion between the effects of the two projectiles, though the hole made by the howitzer shell will be much larger than that made by the shot: but the
velocity

velocity with which the shell impinges on the butt and its specific gravity being less than those of the shot, the penetrations, provided the butt be of a proper consistence, will be less than would result from the formula $fS = Du^2$ (182).

The second method, is to find the initial velocity of the shell fired at different elevations (167.)

As the difference between the elevations and the corresponding velocities will be greater in the shell than in the shot; it will be necessary, after having ascertained the initial velocity and the value of r = the resistance of the air, to find the remaining velocity = V and substitute its value in the formula Du^2 , in order to obtain the penetrations of the shell supposing it to be solid: but as its weight is less than the specific gravity of a sphere of solid iron of the same diameter, the expression Du^2 must be diminished in the ratio of its actual weight to its weight when solid; which will then nearly give the absolute penetration to be compared with that of the shot.

218. These experiments having been made with a $5\frac{1}{2}$ inch howitzer and $r = 12$ for the resistance of the air to a 32 lb. shot, the remaining velocities of the shell fired with proper elevation to strike the butt at the different distances are inserted in the following table, and also the corresponding relative penetrations, supposing the shell to be solid and the butt easily penetrable.

			Relative penetrations.
The velocity with which the shell impinges.			
	<i>Yards.</i>	<i>Feet.</i>	
Shell fired close to the butt		472	$5\frac{1}{2} \times 472^2$
At the distance of 340	340	364	$5\frac{1}{2} \times 364^2$
At the distance of 680	680	286	$5\frac{1}{2} \times 286^2$

The weight of the howitzer shell being to a solid sphere of iron of the same diameter as 7 to 10, the above penetrations will be reduced to $\frac{7}{10}$ and will be as follows:

	<i>Yards.</i>		Relative penetrations,
Shell fired close to the butt			2359
At the distance of 340	340	—	1404
At the distance of 680	680	—	869

On

On comparing these penetrations with those of the 8 lb. shot (183) the number of men in file that the shell can pass through from the different distances will be found in round numbers.

	<i>Yards.</i>	Number of men destroyed by a shell.	
Fired close to them	—	—	5
At the distance of	340	—	3
At the distance of	680	—	2

219. To derive from the howitzer shell the fullest effects, it should burst in the midst of a body of troops, and its power of movement be quite exhausted in passing through the obstacles it meets with before it bursts.

To determine the effects of the splinters, let some howitzer shells burst in the midst of a number of dead animals and their effects be carefully observed. The result in general will prove that the splinters of a shell will not pass through the thickest parts of a man's body; and if it burst in the midst of a number of men, not more than four of those nearest to it will be wounded: by adding to the possible effects of the shock (218) those of the splinters, we shall ascertain how many men can be killed or wounded by a howitzer shell.

Number of men killed or wounded.

	<i>Yards:</i>	By the shock alone.	By the shock and splinters.
Fired close to them	—	5	— 9
At the distance of	340	3	— 7
At the distance of	680	2	— 6

The number of men wounded and disabled will be greater, if the least resisting parts of the body be struck; as was remarked in the case of cannon shot.

220. On comparing the effects of a shell and shot (197), it is apparent that in respect to the shocks alone, not only common 8 prs. but even short guns fired with the least charge are more destructive than the howitzer; and that the only advantage the latter has over them is when the shell bursts at 680 yards. A howitzer shell fired against the front of an army will seldom range 680 yards; and even then it is mere chance, if it burst in the midst of a body of men: should not this happen, or should it by accident break against a stone

a stone, or the fuze be extinguished by falling into soft ground, its effects will by no means equal the effects of the shot.

221. The remarks on the penetrations of shells compared to shot will precisely apply to the length of their respective ricochets. That the first graze of the shell and shot may be at the same distance, the howitzer must be more elevated than the gun; the shell consequently will not so easily reach its destination, the angle of incidence being less acute its force will be more deadened by the fall, and its ricochets shorter and fewer.

222. To ascertain the effects of a howitzer loaded with case shot equal in weight to the shell, it suffices to remark that the initial velocity of each ball is equal to the initial velocity of the shell (207): which being found by experiment, and a round of case shot fired at the same angle of elevation, the penetrations of the balls may be easily determined (205). Suppose the balls be projected from different distances, then on comparing the relative penetrations with those in the preceding table (205), or with others produced by velocities less than 1450 feet, it will give the ratio between the effects of case shot fired from a howitzer and a gun. The initial velocity of a shell fired horizontally or nearly so, is about 474 feet; the following will be the penetrations of the case shot.

Weight of balls. oz.		Very near the butt.		At the distance of 170 yards.
6½	—	803	—	138
3½	—	640	—	59
1	—	444	—	6

On comparing this with the former table (205), the penetrations of balls projected from a howitzer placed close to the butt, are to those of balls of equal diameter impelled from of a gun with an initial velocity of 1450 feet; as 803:7580; or as 10:94 nearly: and at the distance of 170 yards, as 138:4624; or as 1:33 nearly.

223. But as the howitzer contains three times as many balls of the same diameter as the 8 pr. and 6 times as many as the 4 pr. this difference should be likewise estimated. To this end, the relative situation of the troops against which they are fired must be considered.

Suppose a howitzer and an 8 pr. to be on the same plane
with

with the enemy and equally distant from them; the number of men in the first rank struck by the case shot from the howitzer and by that from the gun will be in the ratio of the bases of the two cones, that is less than 3 : 1; each man struck by the howitzer, will be touched by more balls than one: but when the enemy is drawn up in very deep order, the case shot from the gun will make more havock, as from the greater velocity, it will pierce a whole file; and the greater the distance, the more will its effects exceed those of the howitzer, on account of its greater remaining velocity = V . To make the comparison clearer, suppose circumstances the most advantageous to the howitzer; viz. that at 170 yards, it strikes triple the number of men; under this supposition, its greatest effects will be to those of the gun as $3 \times 138 : 4642 :: 1 : 11$.

224. Again, if the enemy be drawn up on a rising ground in form of an amphitheatre, and so near that each ball may strike one man; the effects of the howitzer will be to the 8 pr. as 8 : 1 and to the 4 pr. as 6 : 1: but if three rounds of case shot be put at once into the 8 pr. it will regain its superiority, the number of balls being then equal, and the initial velocity of those projected from the gun, being greater by $\frac{1450}{3}$ (200) than of those projected from the howitzer; they will range farther and do more execution: the 8 pr. is therefore to be preferred. It was shewn in the former part of this work, that there is no danger of the gun bursting, if 3 cases be fired at the same time; and this has been fully confirmed by experience. On comparing a howitzer 6 diameters of the muzzle in length of bore, and a common 4 pr. charged with 1 lb. 10 oz. of powder; the latter, except when the enemy is very near and drawn up on an amphitheatre of hills, will be more destructive than the former. If the length of the howitzer be curtailed, the difference will be still greater.

225. In constructing howitzers, that from the great size of the chambers may project shells with a greater initial velocity and from the increased diameter contain larger shells, the preceding reflections should be had in view: the carriage and the wheels, for instance, should be made strong enough to resist the greatest efforts of a large quantity of powder. But when the shell is projected with twice the initial velocity supposed in the course of this comparison, the howitzer will yet be inferior to the 8 pr.

226. There

226. There are particular cases however, where the howitzer may be very useful, as in the attack of posts where the enemy is perfectly covered from cannon shot: the shells from the curve line that they describe may then be of excellent service; or, in the attack of towns or villages, where large quantities of straw, hay, faggots, or other combustible materials are deposited. Some pieces of port fire composition may be put into the shell, which on bursting will communicate the flame to every thing around: by these means, towns and magazines may be easily set on fire.

227. The howitzer may in the following cases be useful in the attack and defence of places.

1. In a fortified town, when the casemates or caponieres are too narrow to admit guns of the common length; howitzers are then preferable to short guns of cylindric bore, as the explosion of guns of large calibre soon destroy the embrasures.

2. To prevent as much as possible the inconveniences arising from the smoke in casemates and caponieres, and yet be able to project case shot with the greatest initial velocity; the howitzers may be lengthened if there be sufficient room; this will in some measure bring back the *pierrier* guns formerly in use.

3. In the attack of places, some howitzers may be planted on the batteries designed to fire à ricochet, to enfilade the covert way and its branches: essential service will be derived from this mode of using them; since beside the destruction they may cause among the besieged, they soon silence the fire of the infantry, and cover the workmen in carrying on the approaches.

C H A P VII.

OF SHELLS PROJECTED FROM MORTARS.

228. **T**HIRTEEN and 10 inch mortars are much used in sieges: 15 inch mortars are now generally disused; as from their great weight when properly reinforced, and the size of their chambers, they were very difficult to work on the batteries: when the thicknesses of metal are diminished and the chambers reduced in size, their ranges are so much shortened, that the shells do not fall with more force than those

those projected from 13 inch mortars; they are moreover very cumbersome and heavy.

229. The principal advantages to be derived from shells may be reduced to the three following;

1. In sieges, to dismount the enemy's artillery and bombard cities.

2. To set fire to and overthrow works, and produce havock and disorder among troops.

3. To break through the vaulted roofs of barracks, magazines, casemates, caponieres and other military edifices, that have not been constructed with sufficient strength to resist the shock.

Ten inch mortars are generally adequate to these purposes; hence on principles of œconomy, 13 inch mortars are seldom used, unless the distance be too great for the smaller mortars: their figure being the same, their longest ranges are nearly in the ratio of 4:5. Of shells of the same construction, the largest are undoubtedly the best for setting fire to buildings, especially when some pieces of port fire composition are put into them: the splinters are more destructive to works and buildings than to men, and the harsher the quality of metal of which the shell is cast, the greater number of pieces it will burst into.

Shells made of a very tenacious iron are best adapted for penetrating the vaulted roofs of barracks, magazines, &c. that on coming in contact with a hard body, they may not break before they explode: by diminishing the interior cavity of the shell, the force of the shock and its resistance to the explosion are much increased.

230. Our ancestors, in establishing the proportions of shells, conceived that the thickest part should be opposite to the fuse; that from its superior weight, it might always come first to the ground, and in striking against hard bodies be less liable to break. Hence they supposed also, that the shell, though buried in the earth, would always burst, since the fuse would remain uppermost; but experience has proved that these effects do not always take place, owing to the rotatory motion of the shell; the force of which overcoming the preponderance of the heavy part or bottom, makes it fall on every side indiscriminately; and when it enters a close compact soil which stops any communication between the fuse and the external air, the fire is soon smothered and extinguished. When the fuse is not driven far enough into the

the shell, it frequently happens that the shell beginning to turn before it quits the mortar, the head of the fuse strikes against the muzzle, and breaks off; thus, if the fire has not penetrated beyond the eye of the shell, it may reach the object but will not burst.

231. The difference in the form and size of the chambers, the various purposes for which they are used, and the different qualities and modifications of powder render it necessary to alter the charges and elevations of mortars.

In the largest mortars, the initial velocity of a shell increases in proportion to the charge; hence to obtain the greatest initial velocity, the chamber should be filled with the strongest powder, a tampion of wood placed immediately over it, and both the tampion and shell surrounded with sifted earth well rammed; that from the increase of resistance, the inflammation of the powder may be more instantaneous, and the fluid more abundant and elastic. An increase of elevation also adds to the initial velocity, even with equal charges; since from the greater resistance opposed to the explosion in this position of the mortar, the fluid generated in the chamber acquires, before the shell begins to move, greater density.

The same effects do not take place in musquets, though fired at different elevations (Treatise on Powder).

To prove that the initial velocity of a shell is modified by the elevation; fire the same mortar with two equal charges, but at different elevations; for instance, at 70° and 20° : the shell will range much farther at 70° than at 20° ; though, from the theory of projectiles, fired *in vacuo*, the ranges should be equal; and fired in the open air, the second should be the longest. By varying the charge of powder in the same mortar, it has been found, that there is a particular elevation which with each charge gives a longer range than can be obtained from the same charge at any other elevation; wherefore mortars should not be fixed in their beds at a certain elevation, as from the theory of projectiles many have imagined should be the case. The elevations that give the longest ranges, differ very sensibly in two mortars of different calibres, but of similar proportions, charged with a quantity of powder proportionate to the weight of their respective shells, and the size of their chambers.

232. It is evident, therefore, that a knowledge of the various circumstances that conduce to the effectual use of mortars

mortars, must be founded on theory, and derived from science (142, 231); consequently the generality of bombardiers are very ill-qualified for this service: but from the small number of officers, there being frequently a necessity during a siege, of leaving the direction of mortar batteries to the bombardiers, a particular form of instruction has been expressly made out for their use, calculated for unscientific men, that they may be enabled to do their duty with propriety and effect. For this purpose the use of shells is reduced to two principal cases; (229) the first consists in dismounting the enemy's artillery, destroying buildings, setting fire to and overturning works, and causing disorder among troops: the second, in breaking through casemates that have not been properly constructed.

233. It is sufficient in the first case (232) that the shells be projected with justness, without much regard to the force of the shock; this may be attained by observing the following instructions, which are within the comprehension of every man. The bombardiers should practise with 13 and 10 inch mortars of the common construction; afterwards with some of the same calibre, but with chambers of different dimensions, in order to convince them that a difference in the size of the chamber considerably affects the length of the range.

1. They should know the elevation that gives the longest range, when the chambers are filled; and also the best elevation and charge for firing from the batteries constructed in the first and second parallels, when the besieged town and the batteries are in the same plane.

2. They should be made to observe that a difference in the form of the chambers in mortars of the same calibre, induces a necessity of altering the elevation, and also affects the range; and that with the same mortar, the ranges diminish in proportion as the elevation is greater or less than that which gives the longest range.

3. They should be taught always to load the mortar in the same manner, when the same charge is used; since to negligence or mistake in this particular, may be attributed many of the varieties that occur in the lengths of ranges: and that with the same charge, the error that may tend to shorten the range, will not add much to the deflection of the shell.

4. As a difference in the quality of the powder, in the moisture and temperature of the atmosphere, considerably affects the ranges, they should be taught to make allowance for these circumstances, by elevating or depressing the mortars; by increasing or decreasing the charge.

5. They should fire at a butt with the degree of elevation that gives the longest range, and increase or diminish the charge till they strike the object: this will convince them that less irregularity ensues from altering the charge, than from altering the elevation; for the more the elevation deviates from that which gives the longest range, generally between 40° and 50° , the more irregular are the ranges.

6. When the object is to fire at troops or enfilade works, it is better to lay the mortars at small elevations, that the shells may not bury themselves.

7. When the plane of the mortar battery is below the plane of the object, it is much easier to project the shells with justness, than when they are both on the same, or the mortar on the higher plane.

234. The second case (232) viz. to break through casemated buildings, requires much theoretical knowledge in the officer charged with the execution of this piece of service, in order to determine the situation of the mortar, its proper charge and elevation; that the shell may impinge on the object with the greatest possible force. Suppose a shell projected from the point A, in the direction AP (Pl. 6, Fig. 22) has described a curve AFNBL of the fourth kind; in order to determine the force that the projectile has in each point of this curve, the direction and quantity of compound velocity at each point must be found. For this purpose it is necessary to have a scale of the spaces passed through in times of unequal movement (170, 172) from whence may be deduced the scale of corresponding velocities: then, to ascertain the direction and quantity of compound velocity at the point B, in the perpendicular line BP, make BE equal to the corresponding velocity at this point, of a movement BP unequally accelerated by gravity; draw EH parallel to AP, and equal to the velocity which at the same point B corresponds to the retarded movement of impulsion AP; then the right line HB will express the direction and quantity

tity of compound velocity, which the shell has at the point B (168).

235. From the construction (234) it appears;

1. That if the point F represent the vertex of a curve, FC will express the horizontal direction which the shell has at that point, and the quantity of compound velocity, which is less than the shell can have in any other point of the curve.

2. That the compound velocity at the point N increases in proportion to the distance of N from F: that the direction of the compound velocity forms a very acute angle with the horizon, when the point N is very near to F, is less acute in proportion as N is farther distant from F, and becomes a right angle when the shell has lost its movement of impulsion; which in practice is always greatly below the plane AB: the velocity of the projectile is then reduced to the unequally accelerated movement of gravity.

3. That the angle formed by the direction of the shell with the horizon, approaches nearer to a right angle, in proportion as the angle PAB is less acute: on the contrary, when the mortar is fired at a very small elevation, the angle formed by the direction of the shell and the horizon, can only become a right angle, in a point L far distant from the horizontal line BA.

236. The formula $mV \times \frac{a}{\text{whole sine}} = f$ (178) serves to

express the force of the shock of a shell against a plane, of which the inclination is given; the application of this formula will be rendered more familiar by the following remarks:

1. The force of the shell N increases, in proportion to its distance from the vertex F of the curve; since its compound velocity also increases (235, No. 2): the force of the shell at the point B being expressed by $mV = m \times BH$ is greater than its force at the point F, because BH is greater than CF.

2. If the shell at the vertex F strike at right angles a vertical plane, it will impinge with all the force expressed by $mV = m \times CF$; since in this case, the quantity

a being equal to the whole sine, the expression $\frac{a}{\text{whole sine}}$

represents unity: on the contrary, if the shell at the point F meet a horizontal plane, $a=0$; in this case, there will be no shock, and the shell will roll upon the plane.

3. If the shell strike the point B in the plane Z y inclined to the horizon with a direct shock, its force will be to the force of a shock on the horizontal plane B Q, as the whole sine is to the right sine $=a$ of the angle of incidence H B Q: wherefore, if the shell instead of striking the horizontal plane B Q, strike the inclined plane I O, the force of the shock will be less; and will be in the proportion of the right sine of the angle of incidence H B I to the sine of the angle H B Q.

4. If two shells be projected from two mortars of different calibres, but of similar proportions, fired with the largest quantity of powder, and with the same degree of elevation; the largest shell will have the most force in the corresponding points of the curves, owing to its superior weight, and greater compound velocity (229); since it describes a larger curve.

5. If two shells of different diameters, fired as above, in corresponding points of their curves strike two objects in differently inclined planes, the shock of the least shell may exceed that of the largest; because the angle of incidence of the latter may be most acute.

237. To strike with a direct shock, and with great force, a superficies whose position is given (234); it is necessary:

1. To place the mortar so that the axis produced may cut the vertical plane of the object; and that the curve described by the shell, be at right angles to it at the point of impact.

2. To use the largest quantity of powder that the chamber of the mortar can contain.

3. To observe the relative position and figure of the given superficies, whether flat, or convex like the roof of a casemate; whether horizontal or inclined.

4. Thence to determine the distance that the mortar should be placed from the object and its proper elevation.

238. It is observed, that the curve described by shells does not always cut the vertical plane of the object, in the direction of the axis of the mortar, but deflects from it so as to describe a double curve. The solid sphere of bronze projected

projected from the *eprouvette-mortar*, when it reaches the vertex of the curve, deflects either to the right or left, though it be very dense, and its surface very smooth. The deflection of shells, whose specific gravity is less, and centre of gravity distant from the centre of the figure, and which from the ears and the head of the fuse present an uneven surface to the air is greater: the fuse, from the rotation of the shell round its axis, describes a kind of *piccoloide*.

This deflection does not much diminish the force of the shock on a flat, but on a convex superficies its effects are very considerable; for, however small the deflection may be to the right or left, the angle of incidence instead of being right, becomes very acute. This circumstance merits a more particular examination:

239. Suppose in the first place, that the superficies B to be impinged be flat and horizontal like the ramparts of fortresses, (Pl. 6, Fig. 22) under which are casemated barracks or magazines, covered with thick layers of earth well rammed: in order to break through these casemates, the mortar should be placed in Q very near to the point B, and laid at a very high elevation, as 75° or 85° , that the angle of incidence may be nearly a right angle. If the distance from B to Q be short, and the plane of the mortar much higher than B, the compound velocity of the shell will be greater, since the angle of incidence approaches nearer to a right angle, and the force of the shock will be greatly increased: the reverse will happen if the mortar be much lower than the object; infomuch, that if the shell on reaching the vertex of its curve, meet a horizontal plane, it will roll upon it without penetrating (236). This first supposition is the most favourable to the effect of shells, the vertical plane cutting the plane of the object at right angles; and the given superficies being generally of great extent, the mortar may be placed so, that the shell will always fall on it, in spite of any trifling irregularity in the length of the range.

240. Suppose in the second place, that the plane to be impinged, be yBZ , inclined to the horizon AB ; the mortar must then be removed so much the farther from B towards A, as the angle ABy is the greater; the axis of the mortar produced should pass through a vertical plane, supposed to cut YZ at right angles. The distance between the mortar and object, and the proper elevation for giving a

direct shock, must be determined from a knowledge of the two unequal movements that form the curve (170, 172); and the initial velocity produced at a certain elevation, known by previously firing a few rounds to ascertain the quality of the powder. But if the law of the two unequal movements cannot be obtained, the officer must have recourse to the treatise on curves, and their greatest amplitudes; in order to determine the distance AB, and the angle of elevation, taking notice that in general these inclined planes form with the horizon angles from 30° to 45° , and that the initial velocity of the shell increases in proportion to the greater elevation of the mortar: by properly combining these circumstances, he may, without removing the mortar a great way from the object, procure an oblique shock of greater force than the direct shock that could be obtained at a greater distance with a less initial velocity; since the greater the distance the less will be the elevation, and the less, of course, the initial velocity. Under this second supposition, deflections to the right or left do not much diminish the force of the shock, but a very small error in the amplitude is sufficient to prevent the shell from impinging on the object; since these planes, in the direction of the mortar, are of no great extent, and from their inclination, the shocks would become so oblique, that the end proposed could by no means be attained (236, No. 3).

241. Suppose in the third place, that the superficies be convex, as the roof of a casemate turned with a circular arch: the mortar should be placed as near to it as possible, that from the higher elevation, the shell may have a greater velocity; and in the direction of the keys of the arches, that notwithstanding any small variation in the amplitude, they may still be of service: the least deflection will be sufficient to render the shock, which should be direct, very oblique. Again, if the superficies be convex, in form of a dome, the slightest error in the direction or range will greatly diminish the force of the shock; since this superficies declines on every side from the perpendicular: wherefore, it is of all others the most difficult object to strike with a direct shock.

242. When the officer has determined the best situation for directing the mortars against the objects he proposes to bombard; he will inform the bombardiers of the proper elevation and quantity of powder, and point out every particular that can conduce to the better execution of the service:

vice : the bombardiers having been already trained at the school of practice (233) will be enabled to execute with precision and efficacy the order they receive.

243. In bombarding military edifices, the shells may fall on solid works of masonry, built upon arches, or on soft substances, as earth, &c. with which arches are frequently covered, to secure them from shells. When they fall on solid works of masonry, they tend by their shocks to penetrate and split the casemates, and by their explosion to overturn the counterforts, and shatter the walls.

Arches constructed on the principles laid down in the first and second books of Military Architecture, are capable of resisting the most violent shocks from 13 inch shells : their resistance increases when they are constructed of the best materials, in a climate favourable to their acquiring great tenacity ; and when they are contiguous to solid and immoveable bodies.

In buildings totally detached from others, or built on eminences, the counterforts should be so proportioned, as not only to resist the pressure of the vaulted roofs, but every shock to which they may be exposed from shells.

244. All the effect of a shell falling upon a solid work of masonry built on arches, is reduced, if the arch be well turned and made of choice materials, to a small excavation in the place where it falls : it even often happens that the shell breaks before it bursts, particularly when cast of brittle iron. But if the arch be not firmly supported, the counterforts not sufficiently solid ; or in insulated buildings not well proportioned to resist the shock, and the unnecessary thickness which masons generally give to the arches, under the idea of rendering them impenetrable ; the substances in too small a mass, as in detached powder magazines ; or the stone of of so elastic a nature, as considerably to increase the shock ; (Treatise on Moving Bodies) in all these cases the shells will produce the desired effects. A shell on penetrating a brick arch, makes a hole nearly circular, if the bricks be of a good quality : but if from the negligence or ignorance of the workmen, the materials be bad or badly worked up ; or if owing to the climate, they have not acquired a sufficient degree of tenacity, the shell, beside making a hole, will split and shatter the building.

245. Shells falling on arches covered with earth or other soft materials (243) bury themselves without doing any material

rial injury, if the earth has been properly prepared (Military Architecture). Arches of this kind will sustain no damage from 10 inch shells, nor will the building be much shattered if the counterforts are of proper dimensions: the only danger is that the explosion of the shell may carry off a part of the circumjacent earth; so that by a number of shells falling on the same spot, the top of the arch may be entirely uncovered, and, in the event, pierced through. Those that wish to enter more particularly into the construction of military edifices, to enable them to resist the force of shot or shells, may refer to the fifth book of Military Architecture, where the subject has been fully discussed.

