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LXI. On the penetration of balls into uniform resisting substances

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applicable to the land-service, arranged upon the plan of Sir Home Popham's for the naval service, will be necessary.

When a tent or any other object is fixed upon as a centre-point, it is then generally unnecessary to use the double ball

When stations are taken *below the horizon*, the white sides of the balls are to be turned to your correspondent, and it is advantageous to have the men in white or fatigue dresses.

When stations are taken *above the horizon*, the black sides are to be turned towards your correspondent, and then it is advantageous to have the men in uniform.

I am, sir,

Your obedient servant,

Surry Institution,
Nov. 6, 1810.

KNIGHT SPENCER.

LXI. *On the Penetration of Balls into uniform resisting Substances.* By W. MOORE, Esq.

To Mr. Tillock.

SIR, **S**HOULD the following paper on the destruction of an enemy's vessel at sea by artillery be thought deserving a place in your excellent Magazine, you are at liberty to make use of it accordingly.

I am, sir,

Your most obedient servant,

Royal Military Academy,
Woolwich, November 10, 1810.

W. MOORE.

LEMMA I.

If two spheres of different diameters and different specific gravities impinge perpendicularly on two uniform resisting fixed obstacles, and penetrate into them; the forces which retard the progress of the spheres will be as the absolute resisting forces or strengths of the fibres of the substances directly, and the diameters and specific gravities of the spheres inversely.

Let R and r denote the absolute resisting forces of the two substances; F and f the retarding forces; D , d the diameters of the spheres; Q , q their quantities of matter, and N , n their respective specific quantities. Then the whole resistances to the spheres, being by mechanics proportional to the quantities of motion destroyed in a given time, will be as the absolute resisting forces of the sub-

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stances and quantities of resisting surfaces jointly; or as the resisting forces of the substances and squares of the diameters of the impinging spheres: that is, $\frac{M}{m} = \frac{R}{r} \times \frac{D^2}{d^2}$,

But in general $\frac{M}{m} = \frac{F}{f} \times \frac{Q}{q}$: therefore equating these two values of the whole resisting forces, we obtain $\frac{F}{f} \times \frac{Q}{q} = \frac{R}{r} \times \frac{D^2}{d^2}$, and $\frac{F}{f} = \frac{R}{r} \times \frac{D^2}{d^2} \times \frac{q}{Q}$: and since $\frac{q}{Q} = \frac{d^3}{D^3} \times \frac{n}{N}$, it is $\frac{F}{f} = \frac{R}{r} \times \frac{D^2}{d^2} \times \frac{d^3}{D^3} \times \frac{n}{N} = \frac{R}{r} \times \frac{d}{D} \times \frac{n}{N}$: that is, the forces retarding spheres penetrating uniform resisting substances are as the absolute strengths of the fibres of the substances directly, and the diameters and specific gravities of the spheres inversely.

LEMMA II.

The whole spaces or depths to which spheres impinging on different resisting substances penetrate; are as the squares of the initial velocities, the diameters and specific gravities of the spheres directly, and the absolute strengths of the resisting substances inversely; or, $\frac{S}{s} = \frac{V^2}{v^2} \times \frac{D}{d} \times \frac{N}{n} \times \frac{r}{R}$.

For by mechanics we have $\frac{S}{s} = \frac{V^2}{v^2} \times \frac{f}{F}$; and by the preceding lemma $\frac{f}{F} = \frac{r}{R} \times \frac{D}{d} \times \frac{N}{n}$, which substituted in the above it becomes $\frac{S}{s} = \frac{V^2}{v^2} \times \frac{D}{d} \times \frac{N}{n} \times \frac{r}{R}$.

These being premised, I now proceed to resolve the following most important

PROBLEM:

To find a general formula which shall express the quantity of charge for any given piece of ordnance to produce the greatest destruction possible to an enemy's ship at sea; it being supposed of oak substance of given thickness, and at a distance not affecting the initial velocity of the shot.

By Lemma 2, we have, generally, $\frac{V^2}{v^2} = \frac{S}{s} \times \frac{d}{D} \times \frac{n}{N} \times \frac{R}{r}$. Also the charges of powder vary as the squares of the velocity

velocity and weight of ball jointly*. Hence, since it has been determined from experiment that a charge of half a pound impelled a shot weighing one pound with a velocity of 1600 feet per second; we shall, considering V the velocity of any ball impinging on the side of the vessel, have for the expression of the charge impelling it through the

$$\text{space } S = \frac{SdnRv^2w}{2DsNr \times \frac{7}{1600^2}}.$$

Now to apply this in the present instance, it is first necessary that a case be known concerning the penetration of a given shot into oak. Such a case is presented at page 273 of Dr. Hutton's Robins's New Principles of Gunnery. It is there asserted that an 18-pounder cast-iron ball penetrated a block of well-seasoned oak, such as ships of war are generally built with, to the depth of $3\frac{1}{2}$ inches when fired with a velocity of 400 feet per second. Making, therefore, this the standard of comparison for all cases where the object is of oak substance, we shall have for the charge

$$\text{generally } \frac{400^2 \times .42}{2 \times 1600^2 \times \frac{7}{24}} \times \frac{SnRw}{DNr}; \text{ or, because the balls}$$

are of the same specific gravity, and the substance the same, or $R=r$, and $N=n$; it will be $\frac{400^2 \times .42}{2 \times 1600^2 \times \frac{7}{24}} \times$

$\frac{Sw}{D} = .045 \times \frac{Sw}{D}$; that is the charge varies as the space to be penetrated and weight of ball directly, and diameter of the ball inversely.

But the charge by the question being to produce the greatest effect possible in the destruction of the vessel; S in the above formula must always be put equal to the given thickness of its side *plus the radius of the ball*; since it is well ascertained that, for a shot to produce the most damage to any splintering object, such as oak; it must lose all its motion just as it quits the superior or further surface of it.

Hence the charge in question is $= .045 \times \frac{(\frac{1}{2}S + \frac{1}{2}D)w}{D}$. S

being the thickness of the side of the vessel, w the weight of the ball, and D its diameter.

We have supposed, that the resistance opposed to the ball's motion is uniform throughout the entire penetration;

* This law of variation of the charges does not exactly obtain in practice after a certain charge, on account of the definite lengths of the guns: but it is presumed the deviation from it, if known, would not materially affect our results.

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which is not strictly true; since that resistance depends partly on the quantity of the surface resisted, which continually varies until the ball has penetrated to the depth of its radius; when it continues uniform till it arrives at the further surface of the object; where the resistance again commences its variation. These deviations from uniformity are about sufficient to set against that of the law of variation of the charges before mentioned; the velocities from them falling somewhat short of the law there prescribed after a certain charge.

EXAMPLE I.

An enemy's ship is in sight; required the charge for the 42-pounder guns to destroy her as quickly and completely as possible when the ships have approached near to each other: the side of the enemy's vessel (a seventy-four) being $1\frac{3}{4}$ foot thick of oak timber.

The diameter of a 42 pounder of cast-iron being $=.557$ foot; we get $.045 \times \frac{(\dot{S} + \frac{1}{2}D)w}{D} = 6.88306\text{lbs. or } 6\text{lbs. } 14\text{ozs.}$ for the weight of the charge required.

TABLE

Containing the various charges for the 12-, 18-, 24-, 32-, 36- and 42-pounder guns, for producing the greatest effect in all cases of action: the substance or object being of oak materials, and its thickness together with the radius of the ball from 1 foot to that of 5 feet, regularly increasing by 1 in the inches.

Nature of Ordnance.	Thickness of the Side of the Vessel, plus the Radius of the Ball.			
	12 Inches.	13 Inches.	14 Inches.	15 Inches.
Pounder	lbs.	lbs.	lbs.	lbs.
12	1.439242	1.559178	1.679116	1.799052
18	1.928571	2.089285	2.249999	2.410714
24	2.336650	2.531371	2.726091	2.920813
32	2.830470	3.066343	3.302215	3.538088
36	3.061630	3.316766	3.571901	3.827038
42	3.393180	3.675949	3.958710	4.241475

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Nature of Ordnance.	Thickness of the Side of the Vessel, plus the Radius of the Ball.			
	16 Inches.	17 Inches.	18 Inches.	19 Inches.
Pounder	lbs.	lbs.	lbs.	lbs.
12	1·918987	2·838926	2·158863	2·278800
18	2·571428	2·732142	2·892856	3·053571
24	3·115533	3·310254	3·504975	3·699696
32	3·773960	4·009833	4·245705	4·481578
36	4·082173	4·337310	4·592445	4·847581
42	4·524240	4·806905	5·089770	5·372535

	20 Inches.	21 Inches.	22 Inches.	23 Inches.
	lbs.	lbs.	lbs.	lbs.
12	2·398737	2·518674	2·638612	2·758547
18	3·214285	3·374999	3·535714	3·696428
24	3·894417	4·089137	4·283859	4·478580
32	4·717350	4·953323	5·189195	5·425068
36	5·102717	5·357853	5·612988	5·868124
42	5·655300	5·938065	6·220830	6·670262

	24 Inches.	25 Inches.	26 Inches.	27 Inches.
	lbs.	lbs.	lbs.	lbs.
12	2·878484	2·998420	3·118358	3·238292
18	3·857142	4·017856	4·178570	4·339284
24	4·673300	4·868021	5·062741	5·257463
32	5·660940	5·896813	6·132685	6·368559
36	6·123260	6·378396	6·633531	6·888668
42	6·786360	7·069125	7·351890	7·634655

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Nature of Ordnance.	Thickness of the Side of the Vessel, plus the Radius of the Ball.			
	28 Inches.	29 Inches.	30 Inches.	31 Inches.
Pounder	lbs.	lbs.	lbs.	lbs.
12	3·358228	3·478164	3·598100	3·718036
18	4·521340	4·682054	4·842768	5·003482
24	5·452184	5·646905	5·841626	6·036347
32	6·504432	5·840305	7·076178	7·312051
36	7·143804	7·398940	7·654076	7·909212
42	7·917420	8·200185	8·482950	8·765715

	32 Inches.	33 Inches.	34 Inches.	35 Inches.
	lbs.	lbs.	lbs.	lbs.
12	3·837972	3·957908	4·077844	4·197780
18	5·164196	5·324910	5·485624	5·646338
24	6·231068	6·425789	6·620510	6·815231
32	7·547924	7·783797	8·019670	8·255543
36	8·164348	8·419484	8·674620	8·929756
42	9·048480	9·331245	9·614010	9·896775

	36 Inches.	37 Inches.	38 Inches.	39 Inches.
	lbs.	lbs.	lbs.	lbs.
12	4·317716	4·437652	4·557588	4·677524
18	5·807052	5·967766	6·128480	6·289194
24	7·009952	7·204673	7·399394	7·594115
32	8·491416	8·727289	8·963162	9·199035
36	9·184892	9·440028	9·695164	9·950300
42	10·179540	10·462305	10·745070	11·027835

Nature of Ordnance.	Thickness of the Side of the Vessel, plus the Radius of the Ball.			
	40 Inches.	41 Inches.	42 Inches.	43 Inches.
Pounder 12.	lbs. 4·797460	lbs. 4·917396	lbs. 5·037332	lbs. 5·157268
18	6·449908	6·610622	6·771336	6·932050
24	7·788836	7·983557	8·178278	8·372999
32	9·434908	9·670781	9·906654	10·142527
36	10·205436	10·460772	10·715708	10·970844
42	11·310600	11·593365	11·876130	12·158895

	44 Inches.	45 Inches.	46 Inches.	47 Inches.
12	lbs. 5·277204	lbs. 5·397140	lbs. 5·517076	lbs. 5·637012
18	7·092764	7·253478	7·414192	7·574906
24	8·507720	8·762441	8·957162	9·151883
32	10·378400	10·614273	10·850146	11·086019
36	11·225980	11·481116	11·730252	11·991338
42	12·441660	12·724425	13·007190	13·289955

	48 Inches.	49 Inches.	50 Inches.	51 Inches.
12	lbs. 5·756948	lbs. 5·876884	lbs. 5·996820	lbs. 6·116756
18	7·735620	7·896334	8·057048	8·217762
24	9·346604	9·541325	9·736046	9·930767
32	11·321892	11·557765	11·793638	12·029511
36	12·246524	12·501660	12·756796	13·011932
42	13·572720	13·855485	14·138250	14·421015

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Nature of Ordnance.	Thickness of the Side of the Vessel, plus the Radius of the Ball.		
	52 Inches.	53 Inches.	54 Inches.
Pounder 12	lbs. 6·236692	lbs 6·356628	lbs - 6·476554
18	8·378476	8·539190	8·699904
24	10·125488	10·320209	10·514930
32	12·265384	12·501257	12·737130
36	13·267068	13·522204	13·777340
42	14·703780	14·986545	15·269310

	55 Inches.	56 Inches.	57 Inches.
12	lbs. 6·596500	lbs. 6·716436	lbs. 6·836372
18	8·860618	9·021332	9·182046
24	10·709651	10·904372	11·099093
32	12·973003	13·208876	13·444749
36	14·032476	14·287612	14·542748
42	15·552070	15·834840	16·117605

	58 Inches.	59 Inches.	60 Inches.
12	lbs. 6·956308	lbs. 7·076244	lbs. 7·196180
18	9·342760	9·503474	9·664188
24	11·293814	11·488535	11·683256
32	10·680622	13·916495	14·152368
36	14·797884	15·053028	15·308156
42	16·400370	16·683135	16·965900

In

In this Table the first column contains the nature of the ordnance, and the numbers in the other columns are their respective charges of gunpowder in pounds, when the thickness of the object to be destroyed is as specified at the top of the columns. If the thickness be given in inches, and parts of inches, take such parts of the difference between the charge for the given number of inches and the next greater; and add them to the charge first found for the given number of inches for the charge required.

The value of the decimal part of each will be had by multiplying it by 16, the number of ounces in a pound, and pointing off in the product from the right hand towards the left, as many places for decimals as are contained in the given decimal, and retaining the number on the left of the point for the ounces, increasing it by $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, or 1, when the first figure of the decimal is 2, 5, 7 or 8 respectively. This hint is merely given for those practitioners who may not be very conversant in decimals.

SCHOLIUM.

This question is not only of the utmost importance and practically useful in naval engagements, but in several instances also of military operations; as the bursting open gates of besieged cities with promptitude and effect, and breaking up all fortifications composed of wooden materials; especially those of a splintering nature, to which the above charges apply most correctly. In the case of a naval action where the object to be penetrated is of oak substance, the ball by having a small motion when it quits the ship's side tears and splinters it excessively, breaking away large pieces before it, which are not so easily supplied in the reparation: whereas on the other hand, if the shot had any considerable velocity when it quitted the side, the effect produced would be merely a hole, which would be stopped instantly by the mechanic employed for that purpose; and indeed in a great measure by the springiness of the wood itself; for I have seen in his majesty's dock-yard at Woolwich, captured vesse's having a number of shot-holes in them, almost entirely closed by the wood's own efforts; and that required nothing more than a small wooden peg or a piece of cork to stop them up perfectly: all the damage, therefore, the shot can do under such circumstances of swift celerity is merely killing those men who may chance to stand in the way of their motion.

If any object to be destroyed be so thick that it cannot be completely pierced by any common engine; or if it be
of

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of a very brittle nature, such as stone or brick, then that charge is to be used which will give the greatest velocity to the shot to produce the maximum effect. But in many cases of bombardment this charge is by no means to be preferred; for though the effect produced each individual time be greater, yet in any considerable time the whole effect would be less than that from a smaller charge oftener fired, on account of the extreme heat it would give to the engine after a few discharges; and in consequence of which greater time would be required for cooling the gun and preparing it for further service.

EXAMPLE II.

Required the charge for a 24-pounder shot to burst open the gates of a city with the greatest ease possible, the being of elm one foot thick.

Here the object to be penetrated being elm, the small

letters in the general formula $\frac{Sdv^2w}{2Ds \times 1600^3} \left(= \frac{(\dot{S} + \frac{1}{2}D)dv^2w}{2Ds \times 1600^3} \right)$: must be made to denote the several numbers of some experiment made in the penetration of this substance. Taking, therefore, the experiment of Dr. Hutton contained in the 5th problem of his elegant Exercises on Forces, we have $d = \frac{1}{6}$ ft. $v = 1500$, and $S = \frac{13}{12}$ ft.; also by the question

$S = 1$ ft. $D = .46$, and $w = 24$ lbs. therefore $\frac{(\dot{S} + \frac{1}{2}D)dv^2w}{2Ds \times 1600^3}$
 $= \frac{1.23 \times \frac{1}{6} \times 1500^2 \times 24}{2 \times .46 \times \frac{13}{12} \times 1600^3} = \frac{830.25}{191.36} = 4.33868$ lbs. or 4 lbs. 5½ ozs. nearly the weight of the charge required in this case.

Retaining the experiment of Dr. Hutton as a standard for all cases where the substance to be penetrated is of elm, we

shall have by reduction $\frac{(\dot{S} + \frac{1}{2}D)dv^2w}{2Ds \times 1600^3} = .0676 \times \frac{(\dot{S} + \frac{1}{2}D)w}{D}$: the charge for any piece the diameter of whose shot is D , and weight w ; S being the thickness of the object as before.

It is not unworthy of remark, that the gates of a besieged place, or any like things, might be effectually broken open by the gun itself, charged only with powder; by placing it close to the gates with its muzzle from them; the momentum of recoil being generally sufficient to force such objects completely.