come to the same level—*i. e.*, supposing their line of elevation were alike originally.

The following particulars, and the diagram on page 130 (Fig. 16), will show how two bullets of the same bore, fired with the same charge of powder, vary in trajectory. The calculations were originally published in the *Field* on the occasion of a trial of Messrs. Holland's rifles in 1879.

The spherical ball and the Express bullet were both of ·577 bore, and both shot with 6 drams of powder. The long bullet (648 grs.), which was of more than double the weight of the spherical ball (287 grs.), had rather over 1600 ft.-sec. muzzle velocity, and the spherical ball had about 300ft. higher initial speed, yet, owing to their difference in loss of speed from air resistance, the time of the two bullets for 100 yards was almost the same, and the drop from the line of projection about 7½ inches in each.

The extent of drop of the respective bullets at eight equi-distant points in the 100 yards range will be seen by the following table, where the measurements are gi
the second decimal, or hundredth part of an inch
that the variations from stage to stage may be rea

FALL OF ·577 ELONGATED AND SPHERICAL BULLETS

	12½yds.	25yds.	37½yds.	50yds	62½yds.	75y
Elongated ..	0·11in.	0·43in.	0·96in.	1·74in.	2·78in.	4·[illegible]
Spherical ...	0·07	0·32	0·77	1·46	2·45	[illegible]
Difference...	0·04	0·11	0·19	0·28	0·33	[illegible]

The drop of the elongated bullet, ow
speed, is at first greater than that of
the difference increases till beyond
the turning point in the trajector
occurring at about 52 yards, and
about four yards further on; and
begun to drop from the culminat
while the round ball has not yet

between them goes on increasing until the latter has passed its turning point. Subsequently the spherical ball is the slower of the two, and its drop increases accordingly, thereby reducing the difference step by step till they become even just before completing the 100 yards range, and the sphere is consequently a fraction lower than the other at the full distance. Beyond this point the spherical ball would lose ground more and more rapidly, and at 200 yards it would have dropped 49 inches below the line of projection, whereas the elongated bullet would only have dropped about 35 inches.

Supposing, then, that rifles were sighted for a fall of $7\frac{1}{2}$ inches in 100 yards with each of the bullets, the difference in the heights of their trajectories would accord with the difference of drop at various points, as indicated in the foregoing table; and the spherical ball would have the higher trajectory up to nearly 100 yards, where it would dron below, as will be seen by the following figures:

OF TRAJECTORY OF ·577 SPHERICAL AND ELONGATED BULLETS IN 100 YARDS.

yds.	25yds.	37½yds.	50yds.	62½yds.	75yds	87½yds.	100yds.
in.	1·56in.	2·05in.	2·29in.	2·24in.	1·86in.	1·08in.	—0·14in.
	1·45	1·86	2·01	1·91	1·57	0·90	—0·07
	0·11	0·19	0·28	0·33	0·29	0·18	—0·07

…00 yards, as the spherical drops 14 inches …ated bullet, the same angle of elevation …both; and if two rifles were sighted to …fference of fall, the trajectory of the …0 inches at its highest point, whereas …ll the height would be very nearly … (Fig. 16, p. 130) will represent …he two bullets, *a c* being the … projectile, and *a c′* that of the … with the same elevation (line *a b*), the spherical ball, by reason of its higher velocity, is uppermost for about 100 yards, when, having lost its superiority of speed, and the time of flight having been equalised, its trajectory dips below that of the elongated bullet, which henceforth keeps the highest position. By the time it has gone about 170 yards, the spherical ball has dropped down below the line of sight (*a c*); and at the end of the 200 yards range it is about 14 inches lower than the elongated bullet. If the spherical ball were required to strike an object at 200 yards, the line of elevation would have to be raised 14 inches, and in that case the straight dotted line *a c′* would become the line of sight, and the distance between this and the curve *a c′* would be the height of trajectory.

Trajectories of Express Rifles.

There may be said to be two very distinct types of rifles made for elongated bullets, viz., those for long heavy projectiles, with low muzzle-velocity, and those for comparatively short and light bullets with high initial speed—the f. having low trajectories at long ranges, and the la trajectories at sporting distances. The last-ment be subdivided into two or three varieties, accor bullet is more or less light or hollow and powder more or less heavy. Where to dra what is or is not an "Express" rifle is a which opinions differ; but without attem what ought to be the nomenclature, same name has been applied to weapo ably in weight of bullet, initial spee

In the examples already given (p velocity and energy of various Expn siderable difficulty in making a co in consequence of their varying in length of barrel, and proportion endeavour will therefore here be made to put the various bores on an equal footing, by giving the weights of bullets which would have equal trajectories supposing that they had equal muzzle-velocities.

It is a not uncommon belief that the bullets of small-bore Express rifles have a flatter trajectory than those of large diameter; but, under equal conditions, the reverse of this is the case. It is only when the small bullets are *longer* than large ones that their trajectory is lower. When large and small are alike as to length, their trajectory is the same with equal initial velocity; and when there is equality in the proportion of length to diameter of bullet, the large bore has the advantage as to flatness of trajectory, supposing, as before, that they start with the same speed.

Let us take, by way of example, the Martini-Henry bullet, which is ·450in. in diameter, and 1·21in. (or a trifle more than 2⅔ diameters) in length. If bullets of other bores were made exactly proportionate with the Martini-Henry, their

.and weight would be as shown in the following table, and

sponding charge of powder required would be as here

osing the same proportion of powder were used:

OPORTIONS OF LENGTH TO CALIBRE OF BULLET.

Length of Bullet.	Weight of Bullet.	Corresponding Weight of Powder
0·97 inch	246 grains	42 grains.
1·02 ,,	282 ,,	50 ,,
1·05 ,,	337 ,,	60 ,,
3 ,,	390 ,,	69 ,,
,,	**480** ,,	**85** ,,
,,	658 ,,	117 ,,
[illegible]	1012 ,,	180 ,,

ties being equal, the larger the bore

trajectory, as the weight of the

pidly than the surface opposed to

osphere, and there is consequently

In the next table, however, the bullets are supposed to be equal in length; hence the area of resistance grows in the same proportion as the increase of weight. With equal initial velocity, the trajectory throughout is therefore the same, as they all lose speed at the same rate. Here it will be seen that, being all of the same length as the Martini-Henry bullet (nearly 1¼ inch), the small-bores would have to be lengthened beyond their proportion to calibre, in order to maintain an equally flat trajectory. Accordingly, their weight is increased beyond what is stated in the previous table; whereas those of larger bore are correspondingly diminished in length and in weight. This will be made more obvious if, instead of giving the length as equal in inch measurement, it is given in the number of diameters.

BULLETS OF EQUAL LENGTH BUT DIFFERENT CALIBRE.

Diameter of Bore.	Length of Bullet.	Weight of Bullet.	Corresponding Weight of Powder.
·360 inch	3·36 diameters	307 grains	56 grains.
·380 "	3·18 "	342 "	61
·400 "	3·02 "	379 "	67
·420 "	2·88 "	418 "	7
·450 "	**2·69** "	**480** "	
·500 "	2·42 "	593 "	
·577 "	2·11 "	789 "	

It is not very probable, however, that s
use small-bores with such very long bulle
would prefer to use less lead in proport
to get higher velocities. It may be a
see what bullets of different bore
those of ·450 of various weights.

The bullets in the next table woul
with like muzzle-velocities. In each
are taken as the type from which
and they are accordingly printed in
It may possibly be said that nobc

sporting purposes, such heavy projectiles as many of these. The last line of the table, however, is inserted for the sake of comparison with the Martini; and the rest have their ccunterparts in rifles already made for sporting purposes, although some may not have come into general use. Thus, with reference to the heavy projectiles in the last line but one, where a 440gr. bullet of ·450 calibre is taken as the type, the ·400 bullet is here given as 348 grains, and, by turning back to page 16, it will be seen that Sir H. Halford mentions a ·400-bore rifle with 350gr. bullet as "the pleasantest and best rifle for deer." Further on in the same line of the present table, the weight of the ·577 bullet may seem enormous, but it does not very much exceed that used with Messrs. Holland's heavy rifle (M), which appears in the last line of the tables of Express rifles given on pp. 101 and 110.

WEIGHT OF BULLETS OF DIFFERENT CALIBRE HAVING SAME TRAJECTORIES WITH EQUAL VELOCITY.

e.	·380 bore.	·400 bore.	·420 bore.	**·450** bore.	·500 bore.	·577 bore.
	Grains.	Grains.	Grains.	Grains.	Grains.	Grains.
	185	205	226	**260**	321	427
	200	221	244	**280**	346	460
	14	237	261	**300**	370	493
		261	287	**330**	407	543
		284	314	**360**	444	592
		316	348	**400**	494	658
		348	383	**440**	543	723
		379	418	**480**	593	789.

same dimensions do not, however, have
ecause some persons are content to
of powder than others. Let us see,
erence in speed and drop of the fore-
h different initial velocities.
e light projectiles corresponding in
et of ·450 calibre; and, as there is
iation in the powder-charges and in

uzzle-velocity with light bullets than with those of a heavier character, it would be hardly satisfactory to take only one speed as a basis of comparison. It may be as well, therefore, to take 2000, 1900, and 1800 feet per second.

BULLETS OF SAME TYPE AS 260 GRS., ·450 BORE.

2000 FT.-SEC. MUZZLE VELOCITY.			1900 FT.-SEC. MUZZLE VELOCITY.		1800 FT.-SEC. MUZZLE VELOCITY.	
Range.	Remaining Velocity	Drop of Bullet.	Remaining Velocity	Drop of Bullet.	Remaining Velocity.	Drop of Bullet.
Yards.	Ft per sec.	Ft. in	Ft per sec	Ft. in	Ft per sec	Ft in.
50	1787	0 1·22	1696	0 1·47	1604	0 1·51
100	1592	0 5·48	1508	0 6·1	1423	0 6·8
150	1413	1 1·9	1338	1 3·5	1266	1 5·3
200	1257	2 4·1	1195	2 7·2	1137	2 10·9
250	1130	4 1·7	1081	4 7·3	1040	5 1·3
300	1036	6 8·8	1006	7 5	977	8 2
350	974	10 2	948	11 2	922	12 2
400	919	14 8	896	16 0	873	17 4
450	870	20 4	849	22 0	828	23 9
500	826	27 3	807	29 4	788	31 7
Charge: 1 powder to about 1 8 lead			1 powder to about 2 2 lead.		1 powder to about 2·5 lead.	

An endeavour is made to give an idea of the charge of powder likely to produce the velocity stated at the head the table; but this must only be considered as approxin for all rifles will not give exactly corresponding results, when the conditions are apparently alike. Large bore will probably give rather higher results than small bor the same proportion of powder, and ' greater velocity than short ones assumed to be of equal length, viz

The question now arises, how f velocity and drop affect the traje difference in the position of the b different velocities were fired f

From the foregoing

range of 100 yards, a difference of 100 ft.-sec. muzzle-veloc. would make nearly three-quarters of an inch difference c drop; in 150 yards there would be about double this difference; in 200 yards more than four times as much; and so on. Consequently, if the rifle were sighted for, say, 150 yards, with a charge of powder giving 1900 ft.-sec. velocity, and were shot with a charge giving 2000, the bullet would strike about an inch and a half too high; or it would be nearly two inches too low if shot with a smaller charge, giving 1800 ft.-sec. velocity. If, however, the alteration of the charge produces a difference of "jump" in the rifle—as it certainly does in some cases—that cannot be estimated in this calculation. The amount of "drop" would not be affected by the jump, but the up and down position of the bullet on the target would be changed according to the extent of this muzzle disturbance, which would vary with the rifle.

Another mode of comparison may be made by means of independent trajectories, calculated from the drop of the respective bullets with their different velocities. These will now be given for every 50 yards from 100 up to 500 yards. It is not supposed, however, that sights for the whole of these ances would be applied to any one rifle; but, as different may be sighted for different distances, the table may more useful than if the ranges were taken more widely It will be seen that the trajectories for the three es at each range are grouped together, and the 0 shows for which the rifle is supposed to be 00 yards range, where the final ace in the page. The greatest also given in the last column, readily estimated in cases where g., in the 150 yards range. The ctory in this case occurs at about range the greatest height about 300 yards with this bullet, and at less with heavier bullets ; but there is no great difference between the height at the half-range and at the culminating point.

HEIGHT OF TRAJECTORIES OF BULLETS OF 260GR. TYPE IN RANGES FROM 100 TO 500 YARDS.

Full Range and Muzzle Velocity	Height of Bullet at points in the Range, 50 yards apart.									Greatest Height of Trajectory.
	50yds.	100yds.	150yds.	200yds.	250yds.	300yds.	350yds.	400yds.	450yds.	
Ft.-sec.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft in.	Ft. in.	Ft. in.
100										
2000	0 1·5	0	...	...	...	...	...	...	...	0 1·6
1900	0 1·6	0	...	...	...	...	. .	...	...	0 1·7
1800	0 1·9	0	...	...	...	...	...	. .	...	0 1·9
150										
2000	0 3·4	0 3·8	0	...	...	...	...	...	...	0 4·1
1900	0 3·8	0 4·3	0	...	...	..	...	...	...	0 4·5
1800	0 4·3	0 4·8	0	...	...	..	...	...	. .	0 5
200										
2000	0 5·8	0 8·6	0 7·1	0	..	...	..	..	...	0 8·7
1900	0 6·4	0 9·5	0 7·9	0	...	...	...	...	...	0 9·7
1800	0 7·2	0 10·6	0 8·8	0	...	..	...	...	...	0 10·8
250										
2000	0 9	1 2	1 4	1 0	0	..	...	...	...	1 4
1900	0 10	1 4	1 6	1 1	0	...	...	...	...	1 6
1800	0 11	1 6	1 7	1 3	0	...	...	...	...	1 7
300										
2000	1 0	1 10	2 2	2 2	1 6	0	...	...	...	2 2
1900	1 2	2 0	2 5	2 4	1 7	0	...	...	...	2 5
1800	1 4	2 2	2 8	2 6	1 8	0	...	...	..	2 8
350										
2000	1 4	2 5	3 3	3 6	3 2	2 0	0	...	...	3 6
1900	1 6	2 8	3 6	3 9	3 4	2 2	0	...	...	3 [illegible]
1800	1 7	2 11	3 9	4 1	3 7	2 4	0	...	...	4
400										
2000	1 10	3 3	4 4	5 0	5 0	4 4	2 8	0	...	
1900	1 11	3 6	4 8	5 5	5 4	4 7	2 10	0		
1800	2 1	3 9	5 1	5 10	5 9	[illegible]				
450										
2000	2 3	4 2	5 8	6 9	7 [illegible]					
1900	2 4	4 5	6 1	7 2	7 [illegible]					
1800	2 6	4 9	6 6	7 8	8					
500										
2000	2 8	5 0	7 0	8 7	9 [illegible]					
1900	2 10	5 4	7 6	9 1	10 [illegible]					
1800	3 1	5 9	8 0	10 7	10 [illegible]					

BULLETS OF SAME TYPE AS 280GRS., ·450 BORE.

1900 FT.-SEC. MUZZLE VELOCITY.			1800 FT.-SEC. MUZZLE VELOCITY.		
Range.	Remaining Velocity.	Drop of Bullet.	Range.	Remaining Velocity.	Drop of Bullet.
Yards.	Ft. per sec.	Ft. in.	Yards.	Ft. per sec.	Ft. in.
50	1710	0 1·34	50	1617	0 1·5
100	1534	0 6·2	100	1448	0 6·7
150	1372	1 3	150	1297	1 5
200	1233	2 6	200	1171	2 10
250	1118	4 5	250	1069	4 11
300	1034	7 1	300	1003	7 10
350	976	10 8	350	949	11 8
400	925	15 2	400	900	16 7
450	878	20 10	450	856	22 7
500	837	27 9	500	816	30 0
Charge: 1 powder to about 2·3 lead.			Charge: 1 powder to about 2·6 lead.		

It would be tedious to go through the various types of ullets with the same amount of fullness as is done on the previous two pages; and the figures there given show that, within moderate limits of change of velocity and alteration in weight of bullet, the variations of drop and differences in trajectory are comparatively small, and the divergences can be uessed at within a little when you have the weights, velocity, id drop of other bullets to take as standards to judge by. ccordingly, the "remaining velocities" and "drop" will, the majority of cases, be calculated only from two muzzle ities; but in two other instances, the three velocities eights of trajectories will be given, for the purpose mparison.

these tables may be turned to iave two rifles of ·400 and ·500 wish to form an idea of what vould have at different ranges. our ·400 rifle weighs, say, he ·500 about 440 gra-

Looking at the table on page 142, we find that our ·400 bullet is similar in type to the ·450 of 280 grains, and that our ·500 bullet is much about the same as the ·450 of 360 grains. Hence we take as our means of comparison, in the former case, the table opposite, and for the 500-bore we refer to the table of 360gr. type given on page 150.

If we know, from chronograph results, or from the process of calculation hereafter described, what is about the muzzle velocity of the respective rifles, we may find that they come within a moderate difference from one or other of the muzzle velocities given at the head of the table we have to use, and accordingly we choose that which is nearest; or supposing that, in the case of the ·400 bullet, we know that its muzzle velocity is about 1850 ft.-sec., we may take the medium between 1900 and 1800, and see at a glance that at, say, 200 yards, the remaining velocity would be about 1200 ft.-sec., and the drop about 2ft. 8in.; and so on with other distances. If we do not know what the muzzle velocity is, we may yet perhaps be able to form an approximate notion by reference to the charge of powder. The ·400 bullet of 220 grains is shot with, say, 3¼ or 3½ drams of powder. Referring to the table on page 99, we see that the former charge is equal to about 89grs., and the latter to about 96grs.; and dividing the grains of lead by the grains of powder, we find that 3¼drs. would give the proportion of about 1 to 2·5, and 3½drs. of about 1 to 2·3; so it may be assumed that the muzzle velocity of the former would be rather over 1800 ft.-sec., and of the latter about 1900 ft.-sec.

One thing, however, it will not be safe to assume, viz., that if we alter the charge from 3¼drs. to 3½drs., or *vice versâ*, and thus raise or diminish the velocity by 100 or any other number of feet per second, the difference on the target will be only the number of inches shown in these tables. Such would be the case if all conditions remained exactly the same except the mere alteration of speed; and such, indeed, is the effect when, as the chronograph shows, there are variations of muzzle-velocity with exactly the same charges. But when we alter the quantity of powder, the conditions of explosion are also changed; a different degree of "jump" is set up in the barrel, and the effect of this change of jump does not run on the same lines as the effect of simple alteration of speed. Thus, referring to the next table, we find that, in 100 yards, there is less than one inch difference of drop produced by 100 ft.-sec. change of initial speed, but that at 500 yards the difference is nearly $2\frac{1}{2}$ feet. There might be a difference in jump such as would just compensate for the difference of drop at one range, but would have by no means the same effect at the other; for such a change of jump as would produce 30 inches difference in 500 yards would make 6 inches difference at 100 yards, and, as the gravity drop makes only about 1 inch difference in the latter range, the bullet would be 5 inches above or below the expected position on the target, and the marksman might be puzzled to account for it.

BULLETS OF SAME TYPE AS 300 GRS., ·450 BORE.

1900 FT.-SEC. MUZZLE VELOCITY.				1800 FT.-SEC. MUZZLE VELOCITY			1700 FT.-SEC. MUZZLE VELOCITY		
Range.	Remaining Velocity	Drop of Bullet		Remaining Velocity	Drop of Bullet		Remaining Velocity.	Drop of Bullet.	
Yards.	Ft. per sec.	Ft	in.	Ft per sec	Ft	in	Ft per sec.	Ft.	in.
50	1722	0	1·32	1629	0	1·49	1536	0	1·7
100	1556	0	5·9	1470	0	6·8	1384	0	7·4
150	1403	1	2·7	1325	1	4·4	1252	1	7
200	1267	2	5	1202	2	9	1141	3	1
250	1154	4	3	1100	4	9	1053	5	3
300	1062	9	3	1027	7	6	995	8	4
350	1002	10	2	973	11	2	945	12	4
400	951	14	6	926	15	10	900	17	4
450	906	19	11	882	21	7	859	23	6
500	864	26	5	843	28	7	822	31	0
Charge: 1 powder to about 2·3 lead.				1 powder to about 2·5 lead.			1 powder to about 3 lead.		

Height of Trajectories of Bullets of 300gr. Type, in Ranges 100 to 500 Yards.

Full Range and Muzzle Velocity	Height of Bullet at points in the Range, 50 yards apart. 50yds.	100yds	150yds	200yds	250yds	300yds.	350yds	400yds.	450yds,	Greatest Height of Trajectory.
Ft-sec.	Ft. in.	Ft. in	Ft. in.	Ft. in.	Ft. in	Ft. in	Ft. in.	Ft. in	Ft in	Ft. in.
100										
1900	0 1·6	0	...	.	.	...	...	..	...	0 1·[illegible]
1800	0 1·9	0	..	.		...	..	. .	.	0 1·[illegible]
1700	0 2·0	0	..	...	..	...	...	..	...	0 2·[illegible]
150										
1900	0 3·6	0 3·9	0	..	.	...	...	.	...	0 4·[illegible]
1800	0 4·0	0 4·2	0	.	..	.	...	.	..	0 4·[illegible]
1700	0 4·5	0 4·9	0	.	..	...	.	. .	...	0 5·2
200										
1900	0 6·0	0 8·7	0 7·2	0			..	.	..	0 8·8
1800	0 6·7	0 9·6	0 8·1	0	.	.	.	..	..	0 9·7
1700	0 7·5	0 10·9	0 9	0		.	. .	..	..	0 11·0
250										
1900	0 9	1 2	1 4	1 0	0	.	...	...	...	1 4
1800	0 10	1 4	1 6	1 1	0		.	...	...	1 6
1700	0 11	1 6	1 8	1 2	0	.	...	..	...	1 8
300										
1900	1 0	1 9	2 2	2 1	1 5	0	..	..	...	2 2
1800	1 1	1 11	2 5	2 4	1 7	0	...	.	...	2 5
1700	1 3	2 2	2 7	2 6	1 8	0	...		...	2 7
350										
1900	1 4	2 5	3 2	3 5	3 0	1 11	0	...	...	3 5
1800	1 6	2 8	3 5	3 8	3 3	2 1	0	...	...	3 8
1700	1 7	2 11	3 9	4 0	3 6	2 3	0	.	...	4 0
400										
1900	1 8	3 2	4 2	4 10	4 10	4 1	2 6	0	...	4 11
1800	1 10	3 5	4 6	5 2	5 2	4 4	2 8	0	...	5 3
1700	2 3	3 9	4 11	5 7	5 7	4 8	2 10	0	...	5 8
450										
1900	2 1	3 11	5 5	6 5	6 10	6 6	5 4	3 3	0	6 10
1800	2 3	4 3	5 10	6 11	7 3	6 11	5 7	3 4	0	7 3
1700	2 6	4 7	6 3	7 5	7 9	7 4	6 0	3 6	0	7 9
500										
1900	2 6	4 10	6 8	8 2	9 0	9 1	8 4	6 8	3 10	9 1
1800	2 9	5 2	7 2	8 9	9 7	9 8	8 10	7 0	4 1	9 8
1700	3 0	5 7	7 9	9 4	10 2	10 3	9 4	7 5	4 4	10 3

By comparing with page 145, we see that an increase of 40 grains gives in long ranges nearly the same trajectory as 260gr. bullet with 200 ft.-sec. more velocity.

BULLETS OF SAME TYPE AS 330GRS., ·450 BORE.

1800 FT.-SEC. MUZZLE VELOCITY.				1700 FT.-SEC. MUZZLE VELOCITY.			
Range.	Remaining Velocity.	Drop of Bullet.		Range.	Remaining Velocity.	Drop of Bullet.	
Yards.	Ft. per sec.	Ft.	in.	Yards.	Ft. per sec.	Ft.	in.
50	1645	0	1·5	50	1550	0	1·7
100	1498	0	6·5	100	1411	0	7·3
150	1363	1	4	150	1286	1	6
200	1244	2	7	200	1179	2	11
250	1144	4	6	250	1089	5	1
300	1062	7	2	300	1025	7	11
350	1007	10	7	350	977	11	8
400	960	14	11	400	933	16	5
450	917	20	4	450	892	22	3
500	878	26	10	500	855	29	3
Charge: 1 powder to about 2 8 lead				Charge· 1 powder to about 3 lead.			

Taking each of these, and comparing them with the same muzzle velocity in the type of bullet above or below it in weight, we find the differences are not so wide apart but that approximate estimates may be formed of other bullets intermediate in weight, as the variations may be only a few feet in velocity or a few inches in drop.

BULLETS OF SAME TYPE AS 360 GRS., ·450 BORE.

1800 FT.-SEC. MUZZLE VELOCITY.				1700 FT.-SEC. MUZZLE VELOCITY.			1600 FT.-SEC. MUZZLE VELOCITY.		
Range.	Remaining Velocity.	Drop of Bullet.		Remaining Velocity.	Drop of Bullet		Remaining Velocity.	Drop of Bullet	
Yards.	Ft per sec	Ft.	in.	Ft per sec.	Ft.	in.	Ft per sec.	Ft.	in
50	1657	0	1·46	1563	0	1·55	1468	0	1·86
100	1522	0	6·36	1433	0	7·15	1347	0	8·1
150	1395	1	5·4	1315	1	5·6	1240	1	7·9
200	1282	2	6·5	1212	2	10	1148	3	2·6
250	1184	4	4	1124	4	10	1070	5	5·5
300	1100	6	10	1052	7	7	1017	8	5·6
350	1036	10	1	1004	11	2	973	12	5
400	991	14	2	961	15	8	933	17	3
450	949	19	3	922	21	2	896	23	2
500	911	25	5	886	28	9	862	30	3
Charge: 1 powder to about 2·5 lead.				1 powder to about 3 lead.			1 powder to about 4 lead.		

HEIGHT OF TRAJECTORIES OF BULLETS OF 360GR. TYPE, FROM 100 TO 500 YARDS.

Full Range and Muzzle Velocity	Height of Bullet at points in Range, 50 yards apart.									Greatest Height of Trajectory.
	50yds.	100yds	150yds.	200yds.	250yds.	300yds.	350yds.	400yds.	450yds.	
Ft.-sec.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in	Ft in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.
100										
1800	0 1·7	0	..	.	..	...	...	..	...	0 1·8
1700	0 2	0	. .	...	...	...	...	...	...	0 2·1
1600	0 2·2	0	...	...	...	. .	..	..	...	0 2·3
150										
1800	0 3·8	0 4·1	0	...	...	...	...	...	...	0 4·6
1700	0 4·3	0 4·6	0	...	...	. .	...	...	...	0 5·0
1600	0 4·8	0 5·2	0	..	...	...	..	...	...	0 5·6
200										
1800	0 6·1	0 8·9	0 7·2	0	...	...	...	...	...	0 9.1
1700	0 6·9	0 9·9	0 8·0	0	..	. .	...	...	...	0 10·1
1600	0 7·8	0 11·2	0 9·0	0	...	...	...	...	...	0 11.4
250										
1800	0 8·9	1 2·4	1 3·5	0 11·1	0	...	...	...	...	1 4
1700	0 10	1 4·1	1 5·4	1 0·4	0	...	...	..	...	1 6
1600	0 11·3	1 6·0	1 7·6	1 1·8	0	...	...	..	...	1 8
300										
1800	1 0	1 9	2 1	2 0	1 4	0	..	...	...	2 2
1700	1 2	1 11	2 4	2 3	1 6	0	...	...	...	2 5
1600	1 3	2 2	2 7	2 5	1 7	0	..	...	...	2 8
350										
1800	1 4	2 4	3 0	3 3	2 9	1 10	0	...	...	3 4
1700	1 6	2 7	3 4	3 6	3 2	2 0	0	...	...	3 7
1600	1 7	2 10	3 7	3 10	3 5	2 2	0	...	...	3 11
400										
1800	1 8	3 0	4 0	4 7	4 7	3 10	2 4	0	...	4 7
1700	1 10	3 4	4 5	5 0	4 11	4 2	2 6	0	...	5 0
1600	2 0	3 8	4 10	5 5	5 4	4 5	2 8	0	...	5 5
450										
1800	2 0	3 9	5 1	6 0	6 5	6 1	4 11	2 11	0	6 5
1700	2 3	4 1	5 7	6 7	6 10	6 6	5 3	3 2	0	6 10
1600	2 5	4 6	6 1	7 1	7 5	6 11	5 7	3 5	0	7 5
500										
1800	2 5	4 7	6 3	7 7	8 4	8 5	7 8	6 1	3 7	8 5
1700	2 8	4 11	6 10	8 3	9 0	9 1	8 3	6 6	3 10	9 1
1600	2 10	5 4	7 5	8 10	9 7	9 8	8 9	6 10	4 1	9 8

Weight again tells; and we find that, when the range is long, the 360gr. bullet gives much the same trajectory with 1600 ft.-sec. muzzle velocity as the 260gr. bullet (page 145) gives with 400ft. more speed; while, at short ranges, the effect is much about the same as 200ft. difference of initial speed. The 300 gr.-bullet (page 149), as might be expected, gives medium results; the long-range trajectories being very similar to those of 260grs. and 360grs. having 200ft. higher or lower speed, and the short ranges having about half that difference.

BULLETS OF SAME TYPE AS 400GRS., ·450 BORE.

1600 FT.-SEC. MUZZLE VELOCITY.			1500 FT.-SEC. MUZZLE VELOCITY.		
Range.	Remaining Velocity.	Drop of Bullet.	Range.	Remaining Velocity.	Drop of Bullet.
Yards.	Ft. per sec.	Ft. in.	Yards.	Ft. per sec.	Ft. in.
50	1481	0 1·84	50	1387	0 2·09
100	1370	0 7·9	100	1286	0 9·1
150	1270	1 7	150	1196	1 10
200	1183	3 1	200	1118	3 6
250	1107	5 3	250	1054	5 11
300	1046	8 1	300	1010	9 1
350	1003	11 10	350	971	13 2
400	965	16 5	400	935	18 2
450	929	21 11	450	896	25 3
500	896	28 6	500	870	31 4
Charge: 1 powder to about 4 of lead.			Charge: 1 powder to about 4·5 of lead.		

BULLETS OF SAME TYPE AS 440GRS., ·450 BORE.

1500 FT.-SEC. MUZZLE VELOCITY.			1400 FT.-SEC. MUZZLE VELOCITY.		
Range.	Remaining Velocity.	Drop of Bullet.	Range.	Remaining Velocity.	Drop of Bullet.
Yards.	Ft. per sec.	Ft. in.	Yards.	Ft. per sec.	Ft. in.
50	1397	0 2·08	50	1306	0 2·4
100	1303	0 8·9	100	1222	0 10·2
150	1219	1 9·5	150	1147	2 1
200	1145	3 5	200	1083	3 11
250	1081	5 9	250	1034	6 6
300	1033	8 9	300	996	9 10
350	995	12 8	350	962	14 1
400	961	17 5	400	929	19 3
450	928	23 2	450	899	25 6
500	898	29 11	500	870	32 10
Charge: 1 powder to about 4·5 of lead.			Charge: 1 powder to about 5 of lead.		

BULLETS OF SAME TYPE AS MARTINI-HENRY, 480GRS., ·450 BORE.

1400 FT.-SEC MUZZLE VELOCITY			1350 FT.-SEC MUZZLE VELOCITY.		1300 FT.-SEC MUZZLE VELOCITY	
Range	Remaining Velocity	Drop of Bullet	Remaining Velocity	Drop of Bullet.	Remaining Velocity	Drop of Bullet
Yards	Ft per sec.	Ft. in	Ft per sec	Ft. in.	Ft per sec	Ft. in.
100	1235	0 10·1	1195	0 10·8	1153	0 11·9
200	1103	3 9	1072	4 1	1045	4 4
300	1015	9 7	996	10 2	976	10 10
400	950	18 9	934	19 8	917	20 7
500	894	31 9	879	33 3	864	35 0
600	844	49 3	831	51 7	817	54 1
700	799	72 0	787	75 2	775	78 5
800	757	100 9	746	104 10	735	109 2
900	718	136 3	708	141 6	697	147 4
1000	683	179 3	672	186 0	661	193 5
Charge. 1 powder to about 5·3 lead			1 powder to about 5·6 lead		·1 powder to about 6 lead.	

These tables, as before observed, represent merely the natural drop from gravitation in accordance with the time taken by the bullet to traverse each particular range. This is all that can be accounted for on the theoretical side of the question. On the practical side, there are other matters which the maker of the rifle must necessarily take into consideration, or he would produce but a very sorry result. He has to meet the peculiar "jump" of each weapon; and the *apparent* drop for which he regulates the rifle may therefore be more or less than the *real* drop indicated by the tables. These calculations, however, are not intended to be mere theoretical curiosities. It is hoped that they may prove of some practical service to the maker, as well as the user, of the rifle, by enabling them to meet this condition of things. A comparison of the results actually obtained at the target with the amount of natural drop shown in the tables, will give an idea, when different charges are used, of how much of the difference of position of the bullets is due to jump, and how much to the altered velocity of the bullet.

The Calculation of Trajectories.

The trajectory of a bullet may be calculated either from the amount of its drop in a given distance, or from its muzzle velocity; and if the latter be known, the former may be estimated, and *vice versâ*—always supposing that the diameter and weight, as well as the shape of the projectile, have been ascertained.

If a chronograph is available, that, of course, is an authoritative means of getting the bullet's velocity; and the method afterwards described is only a substitute for obtaining approximate results, where a proper instrument cannot be obtained. The chronograph does not, however, directly tell the speed with which the shot leaves the muzzle; it merely records the amount of time taken to traverse a given distance, and shows the *mean* velocity for such distance. Thus, if we know what fraction of a second of time was taken by the bullet in passing from the muzzle of the gun to a screen placed 20 yards distant, and we divide the 20 yards, or 60 feet, by this fraction, we ascertain the velocity in feet per second. But, inasmuch as the bullet loses speed in the 20 yards, from its encounter with the atmosphere, the chronograph record neither shows the velocity with which the bullet left the gun nor that with which it struck the screen; it gives, in fact, the average velocity, and this is equivalent to the actual speed of the bullet at the mean distance of 10 yards. Perhaps, however, it would be more strictly correct to say that the mean velocity of the full range very closely approximates to the actual speed at half-range; but the divergence from strict accuracy is so small that it may be disregarded in short ranges. If the resistance of the atmosphere varied exactly in accordance with the cube of the velocity, the average speed at one distance would exactly represent the real velocity at half that distance; but, inasmuch as the ratio varies somewhat, being less than the cube when the velocity either rises much above or falls much below 1100 feet per second, there is a consequent amount of variation, which tells most with very light projectiles, at high velocities, in long ranges; but even with these the difference is comparatively trifling, and, for all practical purposes, it may be left out of consideration.

We will suppose, however, in the first place, that the muzzle velocity is known, and that we wish to find out what would be the "remaining velocity" of the projectile at any given distance. Having done this, we can easily reverse the process, and ascertain the muzzle velocity from the mean time.

But we can do nothing without the tables invented by Professor Bashforth, and some of these, which apply to elongated projectiles with ogival heads, are accordingly quoted in the ensuing pages. It would be beyond the scope of this book to enter into a description of the manner in which these tables were framed. Anyone wishing for particulars on this subject must be referred to Mr. Bashforth's volume and supplement, or to the Government blue books containing his reports to the War Office. The tables given over leaf are copied from the "Final Report" mentioned below. The titles of these books and reports are as follows:

"A Mathematical Treatise on the Motion of Projectiles, founded chiefly on the Results of Experiments made with the Author's Chronograph." By Francis Bashforth, B D, Professor of Applied Mathematics to the Advanced Class of Royal Artillery Officers, Woolwich. London: Asher & Co, 17, Bedford-street, Covent-garden. 1873.

"Supplement to a Mathematical Treatise on the Motion of Projectiles." By Francis Bashforth, &c. London Asher & Co. 1881.

"*Reports on Experiments made with the Bashforth Chronograph to* Determine the Resistance of the Air to the Motion of Projectiles." 1865–1870. London: W. Clowes & Sons, and other booksellers.

"Final Report on Experiments made with the Bashforth Chronograph to Determine the Resistance of the Air to Elongated Projectiles." 1878–80. London: W. Clowes & Sons, &c.

A General Table of Values of $\frac{d^2}{w}t$ for Ogival-headed Shot.

v	0	1	2	3	4	5	6	7	8	9	Diff.
f.s.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	+
10	75·399	77·111	78·790	80·437	82·052	83·636	85·190	86·715	88·212	89·682	1·584
11	91·125	92·542	93·934	95·301	96·644	97·964	99·261	*00·536	*01·789	*03·021	1·320
12	1 04·232	05·423	06·595	07·748	08·883	09·999	11·097	12·178	13·243	14·291	1·116
13	1 15·323	16·339	17·340	18·326	19·297	20·254	21·196	22·124	23·039	23·941	·957
14	24·830	25·706	26·570	27·422	28·262	29·091	29·908	30·714	31·509	32·294	·829
15	33·068	33·832	34·586	35 331	36·066	36·792	37·508	38·215	38·913	39·602	·726
16	1 40·283	40·955	41·618	42·273	42·920	43·559	44·190	44·813	45·42[illegible]	46·038	·639
17	46·640	47·235	47·823	48·404	48 978	49·546	50·107	50·662	51·21[illegible]	51·754	·568
18	52·291	52·822	53·347	53 867	54·381	54·890	55·393	55·890	56·38[illegible]	56·869	·509
19	1 57·351	57·828	58·300	58·767	59·229	59·686	60·138	60·586	61·029	61·468	·457
20	61·902	62·332	62·758	63·180	63·598	64·012	64·422	64·828	65·230	65·628	·414
21	66·022	66·412	66·798	67·181	67·560	67·936	68·308	68·676	69·041	69·403	·376
22	1 69·762	70·118	70·470	70·819	71 165	71·508	71·848	72·185	72·519	72·850	·343
23	73·179	73·505	73·828	74·148	74 465	74·780	75·092	75·401	75·708	76·012	·315
24	76·314	76·613	76·909	77·203	77·494	77·783	78·070	78 354	78·636	78·916	·289
25	1 79·194	79·470	79·743	80·014	80·283	80·550	80·815	81·078	81·339	81·598	·267
26	81·855	82·110	82·363	82·614	82·863	83·110	83·355	83·598	83·839	84·079	·247
27	84·317	84·553	84·787	85·020	85·251	85·481	85 709	85·935	86·160	86·382	·230
28	1 86·604	86·824	87·042	87·259	87·474	87 688	87 900	88 111	88 320	88·528	·214
29	88·734	88·939	89·143	89·345	89 546	89·745	89·943	90 140	90·335	90·529	·199
30	90·721	90·912	91·102	91·291	91·478	91·664	91·849	92·033	92·216	92·397	·186
31	1 92·577	92·756	92·934	93·111	93·287	93·461	93·634	93·806	93·971	94·147	·174
32	94·316	94·484	94·651	94·817	94·982	95·146	95·309	95·471	95·632	95·792	·164
33	95·951	96·109	96·266	96·422	96·577	96·731	96·884	97·036	97·187	97·338	·154
34	1 97·488	97·637	97·785	97·932	98 078	98·223	98·367	98·510	98·652	98·794	·145
35	98·935	99·075	99·214	99 352	99·490	99·627	99·763	99·898	*00·032	*00·166	·137
36	2 00·299	00·431	00·562	00 692	00 822	00·951	01·079	01·206	01 333	01·459	·129
37	2 01·585	01·710	01·834	01·957	02·080	02·202	02·323	02·443	02 563	02 682	·122
38	02·801	02 919	03·036	03·152	03·268	03·383	03·497	03 610	03·723	03·835	·115
39	03·947	04·058	04·168	04·278	04·387	04·496	04·604	04 711	04·818	04·924	·109
40	20 5·0299	5·1349	5·2393	5·3432	5·4466	5·5494	5 6517	5·7534	5·8546	5·9553	·1028
41	6·0554	6·1550	6·2540	6 3525	6·4505	6·5480	6·6450	6 7414	6·8373	6·9327	·0975
42	7·0276	7·1220	7·2159	7·3093	7·4022	7·4947	7·5867	7·6782	7·7693	7·8599	·0925
43	20 7·9501	8·0398	8·1291	8·2179	8·3063	8·3942	8·4817	8·5687	8·6553	8·7415	·0879
44	8·8272	8·9125	8 9974	9·0819	9·1660	9·2497	9 3330	9·4159	9·4984	9·5805	·0837
45	9·6622	9·7435	9·82[illegible]4	9·9050	9·9852	*0·0651	*0·1446	*0·2237	*0·3025	*0·3809	·0799
46	21 0·4590	0·5367	0·6140	0·6910	0·7677	0 8440	0·9200	0·9956	1·0709	1·1459	·0763
47	1·2205	1·2948	1·3687	1·4423	1·5156	1·5886	1·6613	1·7336	1·8056	1·8773	·0730
48	1·9487	2·0198	2·0906	2·1611	2·2313	2 3012	2·3708	2 4401	2·5091	2·5779	·0699
49	21 2·6464	2·7146	2·7825	2·8501	2·9174	2·9845	3·0513	3·1178	3·1841	2·2501	·0671
50	3·3159	3·3814	3·4466	3·5116	3·5763	3·6608	3·7050	3·7689	3·8326	3·8960	·0645
51	3·9592	4·0221	4·0848	4·1472	4·2094	4·2713	4·3330	4·3944	4·4556	4·5165	·0619
52	21 4·5772	4·6377	4·6979	4·7579	4·8177	4·8773	4·9367	4·9958	5·0547	5·1134	·0596
53	5·1719	5·2302	5·2882	5·3460	5·4036	5·4610	5·5182	5·5752	5·6320	5·6986	·0574
54	5·7450	5·8012	5·8572	5·9130	5·9686	6·0240	6·0792	6·1342	6·1890	6·2436	·0554
55	21 6·2980	6·3522	6·4062	6·4600	6·5136	6·5670	6·6202	6·6732	6·7260	6·7786	·0534
56	6·8311	6 8834	6·9355	6·9874	7·0391	7·0907	7·1421	7·1933	7·2444	7·2958	·0516
57	7·3460	7·3965	7·4469	7·4971	7·5471	7·5970	7·6467	7·6962	7·7456	7·7948	·0499
58	21 7·8438	7·8928	7·9417	7·9904	8·0389	8·0873	8·1356	8·1837	8·2316	8·2793	·0488
59	8·3271	8·3746	8·4220	8·4692	8·5163	8·5632	8·6100	8·6566	8·7031	8·7494	·0468
60	8·7957	8·8417	8·8877	8·9334	8·9791	9·0246	9·0700	9·1152	9·1603	9·2052	·0454
61	21 9·2501	9·2947	9·3393	9·3837	9·4280	9·4721	9·5161	9·5600	9·6037	9·6473	·0441
62	9·6908	9·7341	9·7773	9·8204	9·8633	9·9062	9·9489	9·9914	*0·0338	*0·0761	·0428
63	22 0·1183	0·1604	0·2023	0·2441	0·2858	0·3273	0·3687	0·4100	0·4512	0·4922	·0415
64	22 0·5832	0·5740	0·6147	0·6552	0·6957	0·7360	0·7762	0·8163	0·8563	0·8962	·0403
65	0·9859	0·9755	1·0151	1·0544	1·0937	1·1328	1·1718	1·2107	1·2495	1·2881	·0391
66	1·3267	1·3651	1·4034	1·4416	1·4797	1·5177	1·5555	1·5983	1·6309	1·6684	·0379

v	0	1	2	3	4	5	6	7	8	9	Diff.
f.s.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	+
10	1066	1238	1409	1578	1745	1910	2074	2236	2397	2557	166
11	2715	2871	3026	3180	3333	3484	3633	3782	3929	4075	151
12	4220	4363	4506	4647	4787	4926	5064	5200	5336	5471	139
13	5604	5737	5866	5999	6129	6257	6385	6511	6637	6762	129
14	6886	7009	7132	7253	7373	7493	7612	7730	7847	7964	120
15	8079	8194	8309	8422	8535	8647	8758	8868	8972	9087	112
16	9196	9304	9411	9517	9623	9728	9833	9937	10040	10142	105
17	10244	10346	10447	10546	10645	10743	10841	10939	11037	11134	98
18	11230	11326	11421	11516	11610	11704	11797	11890	11982	12074	94
19	12165	12256	12346	12436	12525	12614	12703	12791	12878	12966	89
20	13052	13139	13224	13310	13395	13480	13564	13648	13731	13814	85
21	13896	13979	14060	14142	14223	14303	14384	14463	14543	14622	81
22	14701	14779	14857	14935	15013	15090	15167	15244	15319	15395	77
23	15470	15545	15620	15694	15768	15842	15916	15989	16061	16134	74
24	16206	16278	16350	16421	16492	16563	16633	16703	16773	16843	71
25	1 6912·1	6981·2	7050·0	7118·5	7186·7	7254·7	7322·4	7389·8	7457·0	7523·9	68·0
26	7590·6	7657·0	7723·2	7789·1	7854·7	7920·1	7985·3	8050·2	8114·8	8179·3	65·4
27	8243·5	8307·5	8371·2	8434·7	8498·0	8561·0	8623·9	8686·4	8748·8	8810·9	63·0
28	1 8872·8	8934·5	8996·0	9057·2	9118·3	9179·1	9239·7	9300·1	9360·3	9420·3	60·8
29	9480·0	9539·6	9598·9	9658·1	9717·0	9775·8	9834·3	9892·6	9950·8	*0008·7	58·7
30	2 0066·5	0124·0	0181·4	0238·5	0295·5	0352·3	0409·0	0465·4	0521·7	0577·7	56·8
31	2 0633·6	0689·3	0744·8	0800·1	0855·3	0910·2	0965·0	1019·6	1074·0	1128·3	55·0
32	1182·4	1236·3	1290·0	1343·5	1396·9	1450·2	1503·2	1556·1	1608·8	1661·4	53·2
33	1713·8	1766·0	1818·1	1870·0	1921·7	1973·3	2024·7	2076·0	2127·1	2178·1	51·6
34	2 2228·9	2279·6	2330·0	2380·4	2430·6	2480·6	2530·5	2580·2	2629·7	2679·1	50·0
35	2728·4	2777·5	2826·4	2875·2	2923·8	2972·3	3020·7	3068·8	3116·9	3164·7	48·5
36	3212·5	3260·1	3307·5	3354·8	3402·0	3449·0	3495·9	3542·6	3589·2	3635·6	47·0
37	2 3682·0	3728·1	3774·2	3820·0	3865·8	3911·4	3956·9	4002·2	4047·4	4092·5	45·6
38	4137·4	4182·2	4226·8	4271·4	4315·7	4360·0	4404·1	4448·1	4491·9	4535·7	44·3
39	4579·2	4622·7	4666·0	4709·2	4752·3	4795·2	4838·1	4880·8	4923·3	4965·7	42·9
40	2 5008·0	5050·2	5092·3	5134·2	5176·0	5217·6	5259·2	5300·6	5341·9	5383·0	41·7
41	5424·0	5464·9	5505·7	5546·4	5586·9	5627·3	5667·6	5707·8	5747·8	5787·8	40·4
42	5827·6	5867·3	5906·9	5946·4	5985·8	6025·0	6064·2	6103·3	6142·2	6181·0	39·3
43	2 6219·8	6258·4	6296·9	6335·3	6373·6	6411·8	6449·9	6487·9	6525·8	6563·6	38·2
44	6601·3	6638·9	6676·4	6713·7	6751·0	6788·2	6825·3	6862·3	6899·3	6936·1	37·2
45	6972·8	7009·4	7046·0	7082·4	7118·8	7155·0	7191·2	7227·3	7263·3	7299·2	36·3
46	2 7335·1	7370·8	7406·5	7442·1	7477·6	7513·0	7548·3	7583·6	7618·8	7653·9	35·4
47	7688·9	7723·8	7758·7	7793·5	7828·2	7862·8	7897·3	7931·8	7966·2	8000·5	34·6
48	8034·7	8068·9	8103·0	8137·0	8170·9	8204·8	8238·6	8272·3	8305·9	8339·5	33·9
49	2 8373·0	8406·5	8439·8	8473·1	8506·4	8539·5	8572·6	8605·6	8638·6	8671·5	33·2
50	8704·3	8737·1	8769·8	8802·4	8835·0	8867·5	8900·0	8932·3	8964·7	8996·9	32·5
51	9029·1	9061·2	9093·2	9125·2	9157·1	9189·0	9220·8	9252·5	9284·2	9315·8	31·9
52	2 9347·3	9378·8	9410·3	9441·6	9472·9	9504·2	9535·4	9566·5	9597·6	9628·7	31·3
53	9659·6	9690·6	9721·4	9752·2	9783·0	9813·7	9844·3	9874·9	9905·4	9935·9	30·7
54	9966·3	9996·7	*0027·0	*0057·3	*0087·5	*0117·7	*0147·8	*0177·8	*0207·8	*0237·8	30·2
55	3 0267·6	0297·5	0327·3	0357·0	0386·7	0416·3	0445·9	0475·4	0504·9	0534·3	29·6
56	0563·6	0592·9	0622·2	0651·4	0680·6	0709·7	0738·7	0767·7	0796·7	0825·6	29·1
57	0854·5	0883·3	0912·1	0940·9	0969·6	0998·2	1026·8	1055·4	1083·9	1112·4	28·6
58	3 1140·8	1169·2	1197·6	1226·0	1254·3	1282·5	1310·8	1339·0	1367·1	1395·2	28·3
59	1423·3	1451·3	1479·3	1507·3	1535·2	1563·0	1590·9	1618·7	1646·4	1674·2	27·9
60	1701·8	1729·5	1757·1	1784·6	1812·2	1839·6	1867·1	1894·5	1921·9	1949·2	27·5
61	3 1976·5	2003·7	2031·0	2058·1	2085·3	2112·4	2139·4	2166·4	2193·4	2220·4	27·1
62	2247·3	2274·2	2301·0	2327·8	2354·5	2381·3	2407·9	2434·6	2461·2	2487·7	26·7
63	2514·3	2540·8	2567·2	2593·6	2620·0	2646·3	2672·6	2698·9	2725·1	2751·3	26·3
64	3 2777·5	2803·6	2829·7	2855·7	2881·7	2907·7	2933·7	2959·6	2985·4	3011·2	26·0
65	3037·0	3062·8	3088·5	3114·2	3139·8	3165·4	3191·0	3216·5	3242·0	3267·4	25·6
66	3292·8	3318·2	3343·5	3368·8	3394·1	3419·3	3444·5	3469·6	3494·7	3519·8	25·2

 A General Table of Values of $\frac{d^2}{w}t$ for Ogival-headed Shot:

v	0	1	2	3	4	5	6	7	8	9	Diff.
f.s.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	+
67	22 1·7059	1·7432	1·7804	1·8175	1·8545	1·8914	1·9281	1·9648	2·0014	2·0378	·0368
68	2·0742	2·1105	2·1466	2·1827	2·2186	2·2545	2·2902	2·3259	2·3614	2·3969	·0358
69	2·4322	2·4675	2·5027	2·5377	2·5727	2·6076	2·6424	2·6771	2·7117	2·7462	·0348
70	22 2·7806	2·8150	2·8492	2·8833	2·9174	2·9513	2·9852	3·0189	3·0526	3·0862	·0339
71	3·1196	3·1530	3·1863	3·2195	3·2526	3·2856	3·3185	3·3513	3·3840	3·4167	·0330
72	3·4492	3·4816	3·5140	3·5462	3·5784	3·6105	3·6424	3·6743	3·7061	3·7378	·0320
73	22 3·7694	3·8009	3·8323	3·8636	3·8949	3·9260	3·9571	3·9881	4·0189	4·0497	·0311
74	4·0804	4·1110	4·1416	4·1720	4·2024	4·2326	4·2628	4·2929	4·3230	4·3529	·0302
75	4·3828	4·4125	4·4422	4·4719	4·5014	4·5308	4·5602	4·5895	4·6187	4·6478	·0294
76	22 4·6769	4·7058	4·7347	4·7635	4·7922	4·8208	4·84[illegible]3	4·8777	4·9060	4·9343	·0286
77	4·9624	4·9905	5·0185	5·0464	5·0742	5·1020	5·1296	5·1572	5·1847	5·2121	·0277
78	5·2394	5·2666	5·2937	5·3208	5·3478	5·3747	5·4015	5·4282	5·4549	5·4814	·0268
79	22 5·5079	5·5343	5·5606	5·5869	5·6130	5·6391	5·6652	5·6911	5·7170	5·7428	·0261
80	5·7685	5·7941	5·8197	5·8452	5·8706	5·8959	5·9212	5·9463	5·9714	5·9965	·0253
81	6·0214	6·0463	6·0711	6·0959	6·1205	6·1451	6·1696	6·1941	6·2184	6·2427	·0245
82	22 6·2669	6·2910	6·3151	6·3390	6·3629	6·3867	6·4104	6·4340	6·4576	6·4810	·0237
83	6·5044	6·5277	6·5509	6·5740	6·5971	6·6201	6·6430	6·6658	6·6885	6·7111	·0229
84	6·7337	6·7562	6·7786	6·8009	6·8232	6·8454	6·8675	6·8895	6·9114	6·9333	·0221
85	22 6·9551	6·9768	6·9984	7·0200	7·0415	7·0629	7·0842	7·1055	7·1267	7·1478	·0214
86	7·1688	7·1898	7·2107	7·2315	7·2522	7·2729	7·2935	7·3140	7·3345	7·3549	·0206
87	7·3752	7·3954	7·4156	7·4357	7·4558	7·4757	7·4956	7·5155	7·5353	7·5550	0199
88	22 7·5746	7·5942	7·6137	7·6332	7·6526	7·6719	7·6912	7·7104	7·7295	7·7486	·0193
89	7·7677	7·7866	7·8055	7·8244	7·8431	7·8618	7·8805	7·8991	7·9176	7·9360	·0187
90	7·9544	7·9727	7·9909	8·0091	8·0272	8·0452	8·0632	8·0812	8·0990	8·1168	·0180
91	22 8·1346	8·1523	8·1699	8·1875	8·2050	8·2225	8·2399	8·2573	8·2746	8·2918	·0174
92	8·3090	8·3261	8·3432	8·3602	8·3772	8·3941	8·4109	8·4277	8·4445	8·4611	·0169
93	8·4778	8·4943	8·5109	8·5273	8·5437	8·5601	8·5764	8·5927	8·6089	8·6250	·0163
94	22 8·6411	8·6572	8·6732	8·6892	8·7051	8·7209	8·7367	8·7525	8·7682	8·7838	·0158
95	8·7994	8·8150	8·8305	8·8459	8·8613	8·8767	8·8920	8·9073	8·9225	8·9376	·0153
96	8·9528	8·9678	8·9828	8·9978	9·0128	9·0276	9·0425	9·0573	9·0720	9·0867	·0149
97	22 9·1014	9·1160	9·1306	9·1451	9·1595	9·1740	9·1884	9·2027	9·2170	9·2312	·0144
98	9·2454	9·2596	9·2737	9·2878	9·3018	9·3158	9·3298	9·3437	9·3575	9·3713	·0140
99	9·3851	9·3989	9·4126	9·4262	9·4398	9·4534	9·4670	9·4805	9·4939	9·5073	·0136
100	22 9·5207	9·5340	9·5473	9·5606	9·5738	9·5869	9·6001	9·6132	9·6262	9·6392	·0132
101	9·6522	9·6651	9·6780	9·6908	9·7036	9·7164	9·7291	9·7418	9·7544	9·7670	·0127
102	9·7796	9·7921	9·8046	9·8170	9·8294	9.8417	9·8540	9·8662	9·8783	9·8904	·0123
103	22 9·9024	9·9144	9·9262	9·9380	9·9496	9·9612	9·9727	9·9841	9·9954	*0·0066	·0115
104	23 0·0177	0·0287	0·0396	0·0504	0·0610	0·0716	0·0820	0·0923	0·1025	0·1126	·0105
105	0·1226	0·1325	0·1423	0·1520	0·1615	0·1710	0·1804	0·1897	0·1988	0·2079	·0094
106	23 0·2170	0·2259	0·2347	0·2435	0·2522	0·2609	0·2694	0·2780	0·2864	0·2948	·0086
107	0·3031	0·3114	0·3196	0·3278	0·3359	0·3439	0·3520	0·3599	0·3678	0·3757	·0080
108	0·3835	0·3913	0·3990	0·4067	0·4143	0·4219	0·4295	0·4370	0·4445	0·4519	·0076
109	23 0·4593	0·4667	0·4740	0·4813	0·4885	0·4958	0·5030	0·5101	0·5172	0·5243	·0072
110	0·5314	0·5381	0·5454	0·5524	0·5593	0·5662	0·5731	0·5800	0·5868	0·5936	·0069
111	0·6004	0·6071	0·6139	0·6206	0·6272	0·6339	0·6405	0·6471	0·6537	0·6603	·0066
112	23 0·6668	0·6733	0·6798	0·6863	0·6928	0·6992	0·7056	0·7120	0·7184	0·7248	·0064
113	0·7311	0·7374	0·7437	0·7500	0·7563	0·7625	0·7688	0·7750	0·7812	0·7874	·0062
114	0·7936	0·7997	0·8059	0·8120	0·8181	0·8242	0·8303	0·8364	0·8424	0·8484	·0061
115	23 0·8545	0·8605	0·8665	0·8726	0·8787	0·8847	0·8906	0·8965	0·9024	0·9083	·0059
116	0·9142	0·9200	0·9259	0·9317	0·9375	0·9433	0·9490	0·9548	0·9605	0·9663	·0058
117	0·9720	0·9777	0·9833	0·9890	0·9947	1·0003	1·0059	1·0115	1·0171	1·0227	·0056
118	23 1·0283	1·0338	1·0394	1·0449	1·0504	1·0559	1·0614	1·0669	1·0723	1·0778	·0055
119	1·0832	1·0886	1·0940	1·0994	1·1048	1·1101	1·1154	1·1208	1·1261	1·1314	·0054
120	1·1367	1·1420	1·1473	1·1525	1·1578	1·1630	1·1682	1·1734	1·1786	1·1838	·0052
121	23 1·1889	1·1941	1·1992	1·2043	1·2095	1·2146	1·2196	1·2247	1·2298	1·2348	·0051
122	1·2399	1·2449	1·2499	1·2549	1·2599	1·2649	1·2698	1·2748	1·2797	1·2847	·0050
123	1·2896	1·2945	1·2994	1·3043	1·3091	1·3140	1·3188	1·3237	1·3285	1·3333	0049

v	0	1	2	3	4	5	6	7	8	9	Diff.
f.s.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	+
67	3 3544·8	3569·8	3594·8	3619·8	3644.7	3669 5	3694·3	3719·1	3743·9	3768·6	24·8
68	3793·3	3818 0	3842·6	3867·2	3891·7	3916·2	3940·7	3965·2	3989·6	4014·0	24·5
69	4038·4	4062·7	4087·0	4111·3	4135·6	4159·8	4184·0	4208·1	4232·2	4256·3	24·2
70	3 4280·4	4304·5	4328·5	4352·4	4376·4	4400·3	4424·1	4448·0	4471·8	4495·5	23·9
71	4519·3	4543·0	4566·6	4590 2	4613·8	4637·4	4660·9	4684·4	4707·8	4731·3	23·5
72	4754·7	4777·9	4801·3	4824·6	4847·9	4871·1	4894·2	4917·4	4940·5	4963·6	23·2
73	3 4986·6	5009·6	5032·6	5055·5	5078 4	5101·3	5124 1	5146·9	5169·6	5192·4	22·8
74	5215·1	5237·7	5260·3	5282·9	5305·5	5328·0	5350 5	5373·0	5395·4	5417·8	22·5
75	5440·2	5462·5	5484·8	5507·1	5529·3	5551·5	5573·7	5595·8	5617 9	5640·0	22·2
76	3 5662·1	5684·1	5706·0	5728·0	5749·9	5771·7	5793·5	5815·3	5837·0	5858·7	21·8
77	5880·4	5902·0	5923·6	5945·1	5966·6	5988·1	6009·5	6030·9	6052·2	6073·6	21·5
78	6094·8	6116·1	6137·3	6158·4	6179·6	6200·7	6221·7	6242·7	6263·7	6284·6	21·1
79	3 6305·5	6326·4	6347·2	6368·0	6388·8	6409·5	6430·2	6450·8	6471·4	6492·0	20·7
80	6512·6	6533·1	6553·6	6574·0	6594·4	6614·8	6635·1	6655·4	6675·7	6695·9	20·4
81	6716·1	6736·3	6756·4	6776·5	6796 5	6816·5	6836·5	6856·4	6876·3	6896·1	20·0
82	3 6916·0	6935·7	6955·5	6975 1	6994 8	7014·4	7033·9	7053·4	7072·9	7092·3	19·6
83	7111·7	7131·0	7150 3	7169·6	7188·8	7207·9	7227·1	7246·1	7265·2	7284·1	19·1
84	7303·1	7322·0	7340·8	7359·6	7378·4	7397·1	7415·8	7434·4	7453·0	7471·5	18·7
85	3 7490·0	7508·5	7526·9	7545·3	7563·6	7581 8	7600·0	7618·2	7636·3	7654·4	18·2
86	7672·4	7690 5	7708·4	7726 4	7744 2	7762 0	7779·9	7797·6	7815·4	7833·0	17·8
87	7850·6	7868·2	7885·8	7903·3	7920·8	7938·2	7955·6	7973·0	7990·3	8007·6	17·4
88	3 8024·8	8042·0	8059·2	8076·3	8093 4	8110·4	8127·4	8144·4	8161·3	8178·2	17·0
89	8195·0	8211·9	8228 6	8245·4	8262 1	8278 7	8295·4	8312·0	8328·5	8345·0	16·6
90	8361·5	8377·9	8394 3	8410 7	8427·0	8443 3	8459·6	8475 8	8492·0	8508·2	16·3
91	3 8524·3	8540·4	8556·4	8572·4	8588·4	8604·3	8620 3	8636·1	8652·0	8667·8	15·9
92	8683·5	8699·3	8715 0	8730 7	8746 3	8761 9	8777 5	8793·0	8808·5	8824·0	15·6
93	8839 4	8854·8	8870 2	8885·5	8900 8	8916·1	8931·3	8946·5	8961·7	8976·8	15·3
94	3 8991·9	9007·0	9022·0	9037·0	9052·9	9066·9	9081·9	9096·7	9111·6	9126·4	15·0
95	9141 2	9156·0	9170 7	9185·4	9200·1	9214 7	9229·3	9243·9	9258·4	9272·9	14·6
96	9287·4	9301·9	9316·3	9330·7	9345·0	9359 4	9373 7	9387·9	9402·2	9416·4	14·3
97	3 9430·6	9444·7	9458 9	9473·0	9487·0	9501·1	9515 1	9529·1	9543·0	9557·0	14·0
98	9570·8	9584·7	9598·6	9612 4	9626 1	9639 9	9653·6	9667 3	9681·0	9694·6	13·7
99	9708·3	9721 9	9735 4	9749·0	9762 5	9775·9	9789·4	9802·8	9816·2	9829·6	13·5
100	3 9842·9	9856·3	9869 6	9882·9	9896·1	9909·3	9922·5	9935·7	9948 8	9961·9	13·2
101	9975·0	9988 1	*0001 1	*0014·1	*0027·1	*0040 0	*0052 9	*0065·8	*0078 7	*0091·5	12·9
102	4 0104·3	0117 1	0129·8	0142 5	0155·2	0167·8	0180·4	0192·9	0205·4	0217·8	12·6
103	4 0230·1	0242 4	0254·6	0266·8	0278·8	0290·8	0302·7	0314·5	0326·2	0337·8	11·9
104	0349·4	0360 8	0372 2	0383·4	0394·5	0405·6	0416 5	0427·3	0438·[illegible]	0448·7	11·0
105	0459·2	0469·6	0479·9	0490·0	0500·1	0510·1	0520·0	0529·8	0539·5	0549 2	9·9
106	4 0558·7	0568·2	0577·6	0586·9	0596·2	0605 4	0614·5	0623·6	0632·6	0641·6	9·2
107	0650 5	0659·3	0668 1	0676·9	0685·6	0694·2	0702·8	0711·4	0719·9	0728·4	8·6
108	0736 8	0745·2	0753·6	0761·9	0770·2	0778·4	0786·6	0794·8	0802·9	0811·0	8·2
109	4 0819·0	0827·1	0835·0	0843·0	0850 9	0858 9	0866·7	0874·6	0882·4	0890·2	7·9
110	0897·9	0905·7	0913·4	0921·1	0928·7	0936·4	0944·0	0951·5	0959·1	0966·6	7·6
111	0974·2	0981·6	0989·1	0996·6	1004·0	1011·4	1018·8	1026·2	1033·5	1040·9	7·4
112	4 1048·2	1055·5	1062·8	1070·0	1077·3	1084·5	1091·7	1099·0	1106·1	1113·3	7·2
113	1120·5	1127·6	1134·8	1141·9	1149·0	1156·1	1163 2	1170·2	1177·3	1184·4	7·1
114	1191·4	1198·4	1205·4	1212·4	1219 4	1226·4	1233·3	1240·3	1247·2	1254·1	6·9
115	4 1261·0	1267·9	1274·8	1281 7	1288·6	1295·4	1302·3	1309·1	1315·9	1322·7	6·8
116	1329·5	1336·8	1343·1	1349·8	1356·6	1363·3	1370·0	1376·7	1383·4	1390·1	6·7
117	1396·8	1403·5	1410·1	1416·8	1423·4	1430·0	1436·6	1443·2	1449·8	1456·4	6·6
118	4 1462·9	1469·5	1476·0	1482·6	1489·1	1495·6	1502·1	1508·6	1515·1	1521·5	6·5
119	1528·0	1534·4	1540·9	1547·3	1553·7	1560·1	1566·5	1572·9	1579·2	1585·6	6·4
120	1591·9	1598·3	1604·6	1610·9	1617·2	1623·5	1629·8	1636·1	1642·3	1648·6	6·3
121	4 1654·8	1661·1	1667·3	1673·[illegible]	1679·7	1685·9	1692·1	1698·2	1704·4	1710·5	6·2
122	1716·7	1722·8	1728·9	1735·0	1741·1	1747·2	1753·3	1759·4	1765·4	1771·5	6·1
123	1777·5	1783·6	1789·6	1795·6	1801·6	1807·6	1813·6	1819·6	1825·6	1831·5	6·0

v	0	1	2	3	4	5	6	7	8	9	Diff.
f.s.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	+
124	23 1·3381	1·3429	1·3477	1·3524	1·3572	1·3619	1·3667	1·3714	1·3761	1·3808	·0047
125	1·3855	1·3902	1·3948	1·3995	1·4041	1·4088	1·4134	1·4180	1·4226	1·4272	·0046
126	1·4318	1·4364	1·4410	1.4455	1·4501	1·4546	1·4591	1·4636	1·4681	1·4726	·0045
127	23 1·4771	1·4816	1·4860	1·4905	1·4949	1·4993	1·5038	1·5082	1·5126	1·5170	·0044
128	1·5214	1·5257	1·5301	1·5345	1·5388	1·5431	1·5475	1·5518	1·5561	1·5604	·0043
129	1·5647	1·5690	1·5732	1·5775	1·5818	1·5860	1·5902	1·5945	1·5987	1·6029	·0042
130	23 1·6071	1·6113	1·6155	1·6196	1·6238	1·6280	1·6321	1·6362	1·6404	1·6445	·0042
131	1·6486	1·6527	1·6568	1·6609	1·6650	1·6690	1·6731	1·6772	1·6812	1·6852	·0041
132	1·6893	1·6933	1·6973	1·7013	1·7053	1·7093	1·7133	1·7173	1·7212	1·7252	·0040
133	23 1·7291	1·7331	1·7370	1·7410	1·7449	1·7488	1·7527	1·7566	1·7605	1·7644	·0039
134	1·7682	1·7721	1·7760	1·7798	1·7837	1·7875	1·7913	1·7952	1·7990	1·8028	·0038
135	1·8066	1·8104	1·8142	1·8179	1·8217	1·8255	1·8292	1·8330	1·8367	1·8405	·0038
136	23 1·8442	1·8479	1·8517	1·8554	1·8591	1·8628	1·8665	1·8702	1·8738	1·8775	·0037
137	1·8812	1·8848	1·8885	1·8921	1·8958	1·8994	1·9030	1·9067	1·9103	1·9139	·0036
138	1·9175	1·9211	1·9247	1·9282	1·9318	1·9354	1·9390	1·9425	1·9461	1·9496	·0036
139	23 1·9532	1·9567	1·9602	1·9638	1·9673	1·9708	1·9743	1·9778	1·9813	1·9848	·0035
140	1·9883	1·9918	1·9952	1·9987	2·0022	2·0056	2·0091	2·0125	2·0160	2·0194	·0035
141	2·0228	2·0263	2·0297	2·0331	2·0365	2·0399	2·0433	2·0467	2·0501	2·0535	·0034
142	23 2·0569	2·0602	2·0636	2·0670	2·0703	2·0737	2·0770	2·0804	2·0837	2·0870	·0034
143	2·0904	2·0937	2·0970	2·1003	2·1036	2·1069	2·1102	2·1135	2·1168	2·1201	·0033
144	2·1234	2·1267	2·1299	2·1332	2·1364	2·1397	2·1430	2·1462	2·1494	2·1527	·0033
145	23 2·1559	2·1591	2·1624	2·1656	2·1688	2·1720	2·1752	2·1784	2·1816	2·1848	·0032
146	2·1880	2·1912	2·1944	2·1975	2·2007	2·2039	2·2071	2·2102	2·2134	2·2165	·0032
147	2·2197	2·2228	2·2260	2·2291	2·2322	2·2354	2·2385	2·2416	2·2447	2·2478	·0031
148	23 2·2509	2·2540	2·2571	2·2602	2·2633	2·2664	2·2695	2·2726	2·2757	2·2787	·0031
149	2·2818	2·2849	2·2879	2·2910	2·2940	2·2971	2·3001	2·3032	2·3062	2·3093	·0030
150	2·3123	2·3153	2·3183	2·3214	2·3244	2·3274	2·3304	2·3334	2·3364	2·3394	·0030
151	23 2·3424	2·3454	2·3484	2·3514	2·3543	2·3573	2·3603	2·3633	2·3662	2·3692	·0030
152	2·3722	2·3751	2·3781	2·3810	2·3840	2·3869	2·3899	2·3928	2·3958	2·3987	·0029
153	2·4016	2·4046	2·4075	2·4104	2·4133	2·4162	2·4192	2·4221	2·4250	2·4279	·0029
154	23 2·4308	2·4337	2·4366	2·4395	2·4424	2·4453	2·4481	2·4510	2·4539	2·4568	·0029
155	2·4597	2·4625	2·4654	2·4683	2·4711	2·4740	2·4768	2·4797	2·4825	2·4854	·0029
156	2·4882	2·4911	2·4939	2·4967	2·4996	2·5024	2·5052	2·5080	2·5108	2·5137	·0028
157	23 2·5165	2·5193	2·5221	2·5249	2·5277	2·5305	2·5333	2·5361	2·5389	2·5416	·0028
158	2·5444	2·5472	2·5500	2·5528	2·5555	2·5583	2·5611	2·5638	2·5666	2·5693	·0028
159	2·5721	2·5748	2·5776	2·5803	2·5831	2·5858	2·5885	2·5913	2·5940	2·5967	·0027
160	23 2·5994	2·6022	2·6049	2·6076	2·6103	2·6130	2·6157	2·6184	2·6211	2·6238	·0027
161	2·6265	2·6292	2·6319	2·6346	2·6373	2·6400	2·6426	2·6453	2·6480	2·6506	·0027
162	2·6533	2·6560	2·6586	2·6613	2·6640	2·6666	2·6693	2·6719	2·6745	2·6772	·0026
163	23 2·6798	2·6825	2·6851	2·6877	2·6903	2·6930	2·6956	2·6982	2·7008	2·7034	·0026
164	2·7061	2·7087	2·7113	2·7139	2·7165	2·7191	2·7217	2·7243	2·7268	2·7294	·0026
165	2·7320	2·7346	2·7372	2·7398	2·7423	2·7449	2·7475	2·7500	2·7526	2·7552	·0026
166	23 2·7577	2·7603	2·7628	2·7654	2·7679	2·7705	2·7730	2·7756	2·7781	2·7806	·0025
167	2·7832	2·7857	2·7882	2·7908	2·7933	2·7958	2·7983	2·8008	2·8034	2·8059	·0025
168	2·8084	2·8109	2·8134	2·8159	2·8184	2·8209	2·8234	2·8258	2·8283	2·8308	·0025
169	23 2·8333	2·8358	2·8383	2·8407	2·8432	2·8457	2·8481	2·8506	2·8531	2·8555	·0025
170	2·8580	2·8604	2·8629	2·8653	2·8678	2·8702	2·8726	2·8751	2·8775	2·8799	·0024
171	2·8824	2·8848	2·8872	2·8896	2·8921	2·8945	2·8969	2·8993	2·9017	2·9041	·0024
172	23 2·9065	2·9089	2·9113	2·9137	2·9161	2·9185	2·9209	2·9233	2·9257	2·9281	·0024
173	2·9304	2·9328	2·9352	2·9376	2·9399	2·9423	2·9447	2·9470	2·9494	2·9518	·0024
174	2·9541	2·9565	2·9588	2·9612	2·9635	2·9659	2·9682	2·9705	2·9729	2·9752	·0023
175	23 2·9776	2·9799	2·9822	2·9845	2·9869	2·9892	2·9915	2·9938	2·9961	2·9985	·0023
176	3·0008	3·0031	3·0054	3·0077	3·0100	3·0123	3·0146	3·0169	3·0192	3·0215	·0023
177	3·0237	3·0260	3·0283	3·0306	3·0329	3·0351	3·0374	3·0397	3·0420	3·0442	·0023
178	23 3·0465	3·0488	3·0510	3·0533	3·0555	3·0578	3·0600	3·0623	3·0645	3·0668	·0023
179	3·0690	3·0713	3·0735	3·0757	3·0780	3·0802	3·0824	3·0847	3·0869	3·0891	·0022
180	3·0913	3·0935	3·0958	3·0980	3·1002	3·1024	3·1045	3·1068	3·1090	3·1112	·0022

v	0	1	2	3	4	5	6	7	8	9	Diff.
f.s.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	+
124	4 1837·5	1843·4	1849·4	1855·3	1861.2	1867·1	1873·0	1878·9	1884·8	1890·6	5·9
125	1896·5	1902·3	1908·2	1914·0	1919·8	1925·6	1931·5	1937·3	1943·0	1948·8	5·8
126	1954·6	1960 4	1966·1	1971·9	1977·6	1983·3	1989·0	1994·8	2000·5	2006·2	5·7
127	4 2011·8	2017·5	2023·2	2028·9	2034·5	2040·2	2045·8	2051·4	2057·0	2062·7	5·6
128	2068·3	2073·9	2079·5	2085·0	2090·6	2096·2	2101·8	2107·3	2112·9	2118·4	5·6
129	2123·9	2129·4	2135·0	2140·5	2146·0	2151·5	2157·0	2162·4	2167·9	2173·4	5·5
130	4 2178·8	2184·3	2189·7	2195·1	2200·6	2206·0	2211·4	2216·8	2222·2	2227·6	5·4
131	2233·0	2238·4	2243·7	2249·1	2254·5	2259·8	2265·1	2270·5	2275·8	2281·1	5·3
132	2286·4	2291·8	2297·1	2302·4	2307·6	2312·9	2318·2	2323·5	2328·7	2334·0	5·3
133	4 2339·2	2344·5	2349·7	2355·0	2360·2	2365·4	2370·6	2375·8	2381·0	2386·2	5·2
134	2391·4	2396·6	2401·8	2406·9	2412·1	2417·3	2422·4	2427·6	2432·7	2437·8	5·2
135	2443·0	2448·1	2453·2	2458·3	2463·4	2468·5	2473·6	2478·7	2483·8	2488·9	5·1
136	4 2493·9	2499·0	2504·1	2509·1	2514·2	2519·2	2524·3	2529 3	2534·3	2539·4	5·0
137	2544·4	2549·4	2554 4	2559 4	2564·4	2569·4	2574·4	2579·4	2584·3	2589·3	5·0
138	2594·3	2599 2	2604·2	2609·1	2614·1	2619·0	2624·0	2628·9	2633·8	2638·8	4·9
139	4 2643·7	2648·6	2653·5	2658·4	2663·3	2668·2	2673·1	2678·0	2682·9	2687·8	4·9
140	2692·6	2697·5	2702·4	2707·2	2712·1	2717·0	2721·8	2726·7	2731·5	2736·3	4·9
141	2741·2	2746·0	2750·8	2755·7	2760·5	2765·3	2770·1	2774·9	2779·7	2784·5	4·8
142	4 2789·3	2794·1	2798·9	2803·7	2808·5	2813·2	2818·0	2822·8	2827·5	2832·3	4·8
143	2837·1	2841·8	2846·6	2851·3	2856·0	2860·8	2865·5	2870·2	2875·0	2879·7	4·7
144	2884·4	2889 1	2893·8	2898·6	2903·3	2908·0	2912·7	2917·4	2922·1	2926·7	4·7
145	4 2931·4	2936 1	2940·8	2945·5	2950·1	2954·8	2959·5	2964·1	2968·8	2973·5	4·7
146	2978·1	2982·8	2987·4	2992·1	2996·7	3001·3	3006·0	3010·6	3015·2	3019·9	4·6
147	3024·5	3029·1	3033 7	3038·4	3043·0	3047·6	3052·2	3056·8	3061·4	3066·0	4·6
148	4 3070·6	3075·2	3079·8	3084·4	3089·0	3093·5	3098·1	3102·7	3107·3	3111·8	4·6
149	3116·4	3121 0	3125 6	3130·1	3134·7	3139·2	3143·8	3148·3	3152·9	3157·4	4·6
150	3162·0	3166·5	3171·0	3175·6	3180·1	3184·6	3189·2	3193·7	3198·2	3202·7	4·5
151	4 3207·2	3211·8	3216·3	3220·8	3225 3	3229 8	3234 3	3238 8	3243·3	3247·8	4·5
152	3252·3	3256 8	3261·3	3265·8	3270·3	3274·8	3279·3	3283·8	3288·3	3292·8	4·5
153	3297·2	3301·7	3306 2	3310·6	3315·1	3319·6	3324·1	3328·5	3333·0	3337·5	4·5
154	4 3342·0	3346 4	3350·9	3355·3	3359·8	3364 3	3368·7	3373·2	3377·6	3382·1	4·5
155	3386·5	3391·0	3395·4	3399·9	3404·3	3408·7	3413·2	3417 6	3422·0	3426·5	4·4
156	3430·9	3435·3	3439·8	3444 2	3448·6	3453·0	3457·4	3461·9	3466 3	3470·7	4·4
157	4 3475·1	3479·5	3483·9	3488·3	3492·7	3497·1	3501·5	3505·9	3510·3	3514·7	4·4
158	3519·1	3523·5	3527·9	3532·3	3536·7	3541·1	3545·4	3549·8	3554 2	3558·6	4·4
159	3563·0	3567·3	3571·7	3576·1	3580·4	3584·8	3589·1	3593·5	3597·9	3602·2	4·4
160	4 3606·6	3610·9	3615·3	3619·6	3624·0	3628·3	3632·6	3637·0	3641·3	3645·7	4·3
161	3650·0	3654·3	3658·7	3663·0	3667·3	3671·6	3676·0	3680 3	3684·6	3688·9	4·3
162	3693·3	3697·6	3701·9	3706·1	3710·5	3714·8	3719·1	3723·4	3727·7	3782·0	4·3
163	4 3736·3	3740·6	3744·9	3749·2	3753·5	3757·8	3762·1	3766·4	3770·6	3774·9	4·3
164	8779·2	3783·5	3787·8	3792·0	3796·3	3800·6	3804·9	3809·1	3813·4	3817·6	4·3
165	3821·9	3826·2	3830·4	3834·7	3838·9	3843·2	3847·4	3851·7	3855·9	3860·2	4·3
166	4 3864·4	3868·7	3872·9	3877·2	3881·4	3885·6	3889·9	3894·1	3898·3	3902·5	4·2
167	3906·8	3911·0	3915·2	3919·5	3923·7	3927·9	3932·1	3936·3	3940·5	3944·7	4·2
168	3949·0	3953·2	3957·4	3961·6	3965·8	3970·0	3974·2	3978·4	3982·6	3986·7	4·2
169	4 3990·9	3995·1	3999·3	4003·5	4007·7	4011·9	4016·0	4020·2	4024·4	4028·6	4·2
170	4032·7	4036·9	4041·1	4045·2	4049·4	4053·6	4057·7	4061·9	4066·0	4070·2	4·2
171	4074·3	4078·5	4082·6	4086·8	4090·9	4095·1	4099·2	4103·3	4107·5	4111·6	4·1
172	4 4115·7	4119·9	4124·0	4128·1	4132 3	4136·4	4140·5	4144·6	4148·7	4152·9	4·1
173	4157·0	4161·1	4165·2	4169·3	4173·4	4177·5	4181·6	4185·7	4189·8	4193·9	4·1
174	4198·0	4202·1	4206 2	4210·3	4214·4	4218·5	4222·6	4226·7	4230·8	4284·8	4·1
175	4 4238·9	4243·0	4247·1	4251·2	4255·3	4259·3	4263·4	4267·5	4271·5	4275·6	4·1
176	4279·6	4283·7	4287·8	4291·8	4295·9	4300·0	4304·0	4308·0	4312·1	4316·1	4·1
177	4320·2	4324·2	4328·3	4332·3	4336·4	4340·4	4344·4	4348·5	4352·5	4356·5	4·0
178	4 4360·5	4364·6	4368·6	4372·6	4376·6	4380·7	4384·7	4388·7	4392·7	4396·7	4·0
179	4400·7	4404·7	4408·8	4412·8	4416·8	4420·8	4424·8	4428·8	4432·8	4436·8	4·0
180	4440·8	4444·7	4448·7	4452·7	4456·7	4460·7	4464·7	4468·7	4472·6	4476·6	4·0

v	0	1	2	3	4	5	6	7	8	9	Diff.
f.s.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	+
181	23 3·1134	3·1156	3·1178	3·1200	3·1222	3·1244	3·1266	3·1287	3·1309	3·1331	·0022
182	3·1353	3·1375	3·1396	3·1418	3·1440	3·1461	3·1483	3·1505	3·1527	3·1548	·0022
183	3·1569	3·1591	3·1613	3·1634	3·1656	3·1677	3·1698	3·1720	3·1741	3·1763	·0021
184	23 3·1784	3·1805	3·1827	3·1848	3·1869	3·1891	3·1912	3·1933	3·1954	3·1975	·0021
185	3·1997	3·2018	3·2039	3·2060	3·2081	3·2102	3·2123	3·2144	3·2165	3·2186	·0021
186	3·2207	3·2228	3·2249	3·2270	3·2291	3·2312	3·2333	3·2353	3·2374	3·2395	·0021
187	23 3·2416	3·2437	3·2457	3·2478	3·2499	3·2520	3·2540	3·2561	3·2582	3·2602	·0021
188	3·2623	3·2643	3·2664	3·2685	3·2705	3·2726	3·2746	3·2767	3·278[illegible]	3·2808	·0021
189	3·2828	3·2848	3·2869	3·2889	3·2909	3·2930	3·2950	3·2970	3·299[illegible]	3·3011	·0020
190	23 3·3031	3·3051	3·3072	3·3092	3·3112	3·3132	3·3152	3·3172	3·3192	3·3212	·0020
191	3·3233	3·3253	3·3273	3·3293	3·3313	3·3333	3·3353	3·3372	3·3392	3·3412	·0020
192	3·3432	3·3452	3·3472	3·3492	3·3511	3·3531	3·3551	3·3571	3·3590	3·3610	·0020
193	23 3·3630	3·3649	3·3669	3·3689	3·3708	3·3728	3·3747	3·3767	3·3786	3·3806	·0020
194	3·3825	3·3845	3·3864	3·3884	3·3903	3·3922	3·3942	3·3961	3·3980	3·4000	·0019
195	3·4019	3·4038	3·4057	3·4077	3·4096	3·4115	3·4134	3·4153	3·4172	3·4192	·0019
196	23 3·4211	3·4230	3·4249	3·4268	3·4287	3·4306	3·4325	3·4344	3·4362	3·4381	·0019
197	3·4400	3·4419	3·4438	3·4457	3·4476	3·4494	3·4513	3·4532	3·4550	3·4569	·0019
198	3·4588	3·4606	3·4625	3·4644	3·4662	3·4681	3·4699	3·4718	3·4736	3·4755	·0019
199	23 3·4773	3·4791	3·4810	3·4828	3·4846	3·4865	3·4883	3·4901	3·4920	3·4938	·0018
200	3·4956	3·4974	3·4992	3·5010	3·5028	3·5047	3·5065	3·5083	3·5101	3·5119	·0018
201	3·5137	3·5155	3·5172	3·5190	3·5208	3·5226	3·5244	3·5262	3·5280	3·5297	·0018
202	23 3·5315	3·5333	3·5351	3·5368	3·5386	3·5404	3·5421	3·5439	3·5456	3·5474	·0018
203	3·5492	3·5509	3·5527	3·5544	3·5561	3·5579	3·5596	3·5614	3·5631	3·5648	·0017
204	3·5666	3·5683	3·5700	3·5717	3·5735	3·5752	3·5769	3·5786	3·5803	3·5820	·0017
205	23 3·5837	3·5854	3·5871	3·5888	3·5905	3·5922	3·5939	3·5956	3·5973	3·5990	·0017
206	3·6007	3·6024	3·6040	3·6057	3·6074	3·6091	3·6107	3·6124	3·6141	3·6157	·0017
207	3·6174	3·6191	3·6207	3·6224	3·6240	3·6257	3·6273	3·6290	3·6306	3·6323	·0016
208	23 3·6339	3·6355	3·6372	3·6388	3·6404	3·6420	3·6437	3·6453	3·6469	3·6485	·0016
209	3·6502	3·6518	3·6534	3·6550	3·6566	3·6582	3·6598	3·6614	3·6630	3·6646	·0016
210	3·6662	3·6678	3·6694	3·6710	3·6726	3·6741	3·6757	3·6773	3·6789	3·6805	·0016
211	23 3·6820	3·6836	3·6852	3·6867	3·6883	3·6899	3·6914	3·6930	3·6946	3·6961	·0016
212	3·6977	3·6992	3·7008	3·7023	3·7039	3·7054	3·7070	3·7085	3·7100	3·7116	·0015
213	3·7131	3·7146	3·7162	3·7177	3·7192	3·7207	3·7223	3·7238	3·7253	3·7268	·0015
214	23 3·7283	3·7298	3·7313	3·7329	3·7344	3·7359	3·7374	3·7389	3·7404	3·7419	·0015
215	3·7434	3·7448	3·7463	3·7478	3·7493	3·7508	3·7523	3·7538	3·7552	3·7567	·0015
216	3·7582	3·7597	3·7612	3·7626	3·7641	3·7656	3·7670	3·7685	3·7700	3·7714	·0015
217	23 3·7729	3·7743	3·7758	3·7772	3·7787	3·7801	3·7816	3·7830	3·7845	3·7859	·0014
218	3·7874	3·7888	3·7902	3·7917	3·7931	3·7945	3·7960	3·7974	3·7988	3·8002	·0014
219	3·8016	3·8031	3·8045	3·8059	3·8073	3·8087	3·8101	3·8115	3·8129	3·8144	·0014
220	23 3·8158	3·8172	3·8186	3·8200	3·8214	3·8227	3·8241	3·8255	3·8269	3·8283	·0014
221	3·8297	3·8311	3·8325	3·8338	3·8352	3·8366	3·8380	3·8394	3·8407	3·8421	·0014
222	3·8435	3·8448	3·8462	3·8476	3·8489	3·8503	3·8517	3·8530	3·8544	3·8557	·0014
223	23 3·8571	3·8584	3·8598	3·8611	3·8625	3·8638	3·8651	3·8665	3·8678	3·8692	·0013
224	3·8705	3·8718	3·8732	3·8745	3·8758	3·8772	3·8785	3·8798	3·8811	3·8824	·0013
225	3·8838	3·8851	3·8864	3·8877	3·8890	3·8903	3·8916	3·8930	3·8943	3·8956	·0013
226	23 3·8969	3·8982	3·8995	3·9008	3·9021	3·9034	3·9047	3·9059	3·9072	3·9085	·0013
227	3·9098	3·9111	3·9124	3·9137	3·9150	3·9162	3·9175	3·9188	3·9201	3·9214	·0013
228	3·9226	3·9239	3·9252	3·9264	3·9277	3·9290	3·9303	3·9315	3·9328	3·9341	·0013
229	23 3·9353	3·9366	3·9378	3·9391	3·9404	3·9416	3·9429	3·9441	3·9454	3·9467	·0013
230	3·9479	3·9492	3·9504	3·9517	3·9529	3·9542	3·9554	3·9567	3·9579	3·9592	·0013
231	3·9604	3·9617	3·9629	3·9642	3·9654	3·9667	3·9679	3·9692	3·9704	3·9716	·0012
232	23 3·9729	3·9741	3·9754	3·9766	3·9779	3·9791	3·9803	3·9816	3·9828	3·9841	·0012
233	3·9853	3·9866	3·9878	3·9890	3·9903	3·9915	3·9927	3·9940	3·9952	3·9965	·0012
234	3·9977	3·9989	4·0002	4·0014	4·0026	4·0039	4·0051	4·0063	4·0076	4·0088	·0012
235	23 4·0100	4·0113	4·0125	4·0137	4·0150	4·0162	4·0174	4·0186	4·0199	4·0211	·0012
236	4·0223	4·0236	4·0248	4·0260	4·0272	4·0284	4·0297	4·0309	4·0321	4·0334	·0012
237	4·0346	4·0358	4·0370	4·0383	4·0395	4·0407	4·0419	4·0431	4·0444	4·0456	·0012

v	0	1	2	3	4	5	6	7	8	9	Diff.
f.s.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	+
181	4 4480·6	4484·6	4488·5	4492·5	4496·5	4500·5	4504·4	4508·4	4512·4	4516·3	4·0
182	4520·3	4524·2	4528·2	4532·2	4536·1	4540·1	4544·0	4548·0	4551·9	4555·9	4·0
183	4559·8	4563·7	4567·7	4571·6	4575·6	4579·5	4583·4	4587·4	4591·3	4595·2	3·9
184	4 4599·2	4603·1	4607·0	4610·9	4614·9	4618·8	4622·7	4626·6	4630·5	4634·4	3·9
185	4638·4	4642·3	4646·2	4650·1	4654·0	4657·9	4661·8	4665·7	4669·6	4673·5	3·9
186	4677·4	4681·3	4685·2	4689·1	4693·0	4696·9	4700·8	4704·6	4708·5	4712·4	3·9
187	4 4716·3	4720·2	4724·1	4727·9	4731·8	4735·7	4739·6	4743·4	4747·3	4751·2	3·9
188	4755·0	4758·9	4762·8	4766·7	4770·5	4774·4	4778·2	4782·1	4786·0	4789·8	3·9
189	4793·7	4797·5	4801·4	4805·2	4809·1	4812·9	4816·8	4820·6	4824·5	4828·3	3·8
190	4 4832·2	4836·0	4839·8	4843·7	4847·5	4851·4	4855·2	4859·0	4862·8	4866·7	3·8
191	4870·5	4874·3	4878·1	4882·0	4885·8	4889·6	4893·4	4897·3	4901·1	4904·9	3·8
192	4908·7	4912·5	4916·3	4920·1	4923·9	4927·7	4931·5	4935·3	4939·1	4942·9	3·8
193	4 4946·7	4950·5	4954·3	4958·1	4961·9	4965·7	4969·4	4973·2	4977·0	4980·7	3·8
194	4984·5	4988·3	4992·1	4995·8	4999·6	5003·4	5007·1	5010·9	5014·7	5018·4	3·8
195	5022·2	5025·9	5029·7	5033·4	5037·2	5040·9	5044·7	5048·4	5052·1	5055·9	3·7
196	4 5059·6	5063·4	5067·1	5070·8	5074·6	5078·3	5082·0	5085·7	5089·4	5093·1	3·7
197	5096·9	5100·6	5104·3	5108·0	5111·7	5115·4	5119·1	5122·8	5126·5	5130·2	3·7
198	5133·9	5137·5	5141·2	5144·9	5148·6	5152·3	5156·0	5159·6	5163·3	5166·9	3·7
199	4 5170·6	5174·3	5177·9	5181·6	5185·2	5188·9	5192·5	5196·2	5199·8	5203·4	3·6
200	5207·1	5210·7	5214·3	5218·0	5221·6	5225·2	5228·8	5232·5	5236·1	5239·7	3·6
201	5243·3	5246·9	5250·5	5254·1	5257·7	5261·3	5264·9	5268·5	5272·1	5275·7	3·6
202	4 5279·2	5282·8	5286·4	5290·0	5293·6	5297·2	6300·7	5304·3	5307·8	5311·4	3·6
203	5314·9	5318·5	5322·0	5325·6	5329·1	5332·7	5336·2	5339·7	5343·3	5346·8	3·5
204	5350·3	5353·8	5357·3	5360·9	5364·4	5367·9	5371·4	5374·9	5378·4	5381·9	3·5
205	4 5385·4	5388·9	5392·4	5395·9	5399·4	5402·9	5406·3	5409·8	5413·3	5416·7	3·5
206	5420·2	5423·7	5427·1	5430·6	5434·1	5437·5	5441·0	5444·4	5447·8	5451·3	3·5
207	5454·7	5458·1	5461·6	5465·0	5468·4	5471·9	5475·3	5478·7	5482·1	5485·5	3·4
208	4 5488·9	5492·3	5495·7	5499·1	5502·5	5505·9	5509·3	5512·7	5516·1	5519·4	3·4
209	5522·8	5526·2	5529·6	5532·9	5536·3	5539·7	5543·0	5546·4	5549·7	5553·1	3·4
210	5556·4	5559·8	5563·1	5566·4	5569·8	5573·1	5576·5	5579·8	5583·1	5586·4	3·3
211	4 5589·7	5593·0	5596·4	5599·7	5603·0	5606·3	5609·6	5612·9	5616·2	5619·5	3·3
212	5922·8	5626·1	5629·3	5632·6	5635·9	5639·2	5642·5	5645·7	5649·0	5652·3	3·3
213	5655·5	5658·8	5662·0	5665·3	5668·6	5671·8	5675·1	5678·3	5681·5	5684·8	3·2
214	4 5688·0	5691·2	5694·5	5697·7	5700·9	5704·2	5707·4	5710·6	5713·8	5717·0	3·2
215	5720·2	5723·4	5726·6	5729·9	5733·1	5736·3	5739·5	5742·6	5745·8	5749·0	3·2
216	5752·2	5755·4	5758·6	5761·8	5764·9	5768·1	5771·3	5774·4	5777·6	5780·8	3·2
217	4 5783·9	5787·1	5790·2	5793·4	5796·6	5799·7	5802·9	5806·0	5809·1	5812·2	3·1
218	5815·4	5818·5	5821·6	5824·8	5827·9	5831·0	5834·1	5837·3	5840·4	5843·5	3·1
219	5846·6	5849·7	5852·8	5855·9	5859·0	5862·1	5865·2	5868·3	5871·4	5874·4	3·1
220	4 5877·5	5880·6	5883·7	5886·8	5889·9	5893·0	5896·0	5899·1	5902·1	5905·2	3·1
221	5808·3	5911·3	5914·4	5917·4	5920·5	5923·6	5926·6	5929·6	5932·7	5935·7	3·0
222	5938·7	5941·8	5944·8	5947·8	5950·9	5953·9	5956·9	5959·9	5963·0	5966·0	3·0
223	4 5969·0	5972·0	5975·0	5978·0	5981·0	5984·0	5987·0	5990·0	5993·0	5996·0	3·0
224	5999·0	6002·0	6004·9	6007·9	6010·9	6013·9	6016·9	6019·8	6022·8	6025·8	3·0
225	6028·7	6031·7	6034·6	6037·6	6040·5	6043·5	6046·5	6049·4	6052·4	6055·3	3·0
226	4 6058·3	6061·2	6064·1	6067·1	6070·0	6072·9	6075·9	6078·8	6081·7	6084·7	2·9
227	6087·6	6090·5	6093·4	6096·3	6099·3	6102·2	6105·1	6108·0	6110·9	6113·8	2·9
228	6116·7	6119·6	6122·5	6125·4	6128·3	6131·2	6134·1	6137·0	6139·9	6142·8	2·9
229	4 6145·7	6148·6	6151·5	6154·4	6157·3	6160·2	6163·1	6166·0	6168·8	6171·7	2·9
230	6174·6	6177·5	6180·4	6183·3	6186·2	6189·1	6191·9	6194·8	6197·7	6200·6	2·9
231	6203·5	6206·4	6209·3	6212·1	6215·0	6217·9	6220·8	6223·7	6226·6	6229·5	2·9
232	4 6232·3	6235·2	6238·1	6241·0	6243·9	6246·8	6249·7	6252·6	6255·4	6258·3	2·9
233	6261·2	6264·1	6267·0	6269·9	6272·8	6275·7	6278·6	6281·5	6284·3	6287·2	2·9
234	6290·1	6293·0	6295·9	6298·8	6301·7	6304·6	6307·5	6310·4	6313·3	6316·2	2·9
235	4 6319·0	6322·0	6324·9	6327·7	6330·6	6333·5	6336·4	6339·3	6342·2	6345·1	2·9
236	6348·0	6350·9	6353·8	6356·7	6359·6	6362·5	6365·4	6368·3	6371·2	6374·1	2·9
237	6377·0	6379·9	6382·8	6385·7	6388·6	6391·5	6394·4	6397·3	6400·2	6403·1	2·9

v	0	1	2	3	4	5	6	7	8	9	Diff.
f.s.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	secs.	+
238	23 4·0468	4·0480	4·0492	4·0505	4·0517	4·0529	4·0541	4·0553	4·0566	4·0578	·0012
239	4·0590	4·0602	4·0614	4·0626	4·0639	4·0651	4·0663	4·0675	4·0687	4·0699	·0012
240	4·0711	4·0724	4·0736	4.0748	4·0760	4·0772	4·0784	4·0796	4·0809	4·0821	·0012
241	23 4·0833	4·0845	4·0857	4·0869	4·0881	4·0893	4·0905	4·0917	4·0930	4·0942	·0012
242	4·0954	4·0966	4·0978	4·0990	4·1002	4·1014	4·1026	4·1038	4 1050	4·1062	·0012
243	4·1074	4·1087	4·1099	4·1111	4·1123	4·1135	4·1147	4·1159	4·1171	4·1183	·0012
244	23 4·1195	4·1207	4·1219	4·1231	4·1243	4·1255	4·1267	4·1279	4·1291	4·1303	·0012
245	4·1315	4·1327	4·1339	4·1351	4·1363	4·1375	4·1387	4·1399	4·1411	4·1423	·0012
246	4·1435	4·1447	4·1459	4·1471	4 1483	4·1495	4·1506	4·1518	4·1530	4·1542	·0012
247	23 4·1554	4·1566	4·1578	4·1590	4·1602	4·1614	4·1626	4·1638	4·1649	4 1661	·0012
248	4·1673	4·1685	4·1697	4·1709	4·1721	4 1733	4 1744	4·1756	4·1768	4·1780	·0012
249	4·1792	4·1804	4·1815	4 1827	4·1839	4·1851	4·1863	4 1874	4·1886	4·1898	·0012
250	23 4·1910	4·1922	4·1933	4·1945	4·1957	4 1969	4·1980	4 1992	4·2004	4·2015	·0012
251	4·2027	4·2039	4·2051	4·2062	4·2074	4·2086	4·2097	4·2109	4·212'	4·2132	0012
252	4·2144	4·2156	4·2167	4·2179	4·2190	4·2202	4·2214	4·2225	4·2237	4·2248	·0012
253	23 4·2260	4·2272	4·2283	4·2295	4·2306	4·2318	4·2329	4·2341	4·2352	4·2364	·0012
254	4·2375	4·2387	4·2398	4·2410	4·2421	4·2433	4 2444	4·2455	4·2467	4·2478	·0011
255	4·2490	4·2501	4·2513	4·2524	4·2535	4·2547	4·2558	4·2569	4·2581	4·2592	·0011
256	23 4·2603	4·2615	4·2626	4·2637	4·2648	4·2660	4·2671	4·2682	4·2693	4·2705	·0011
257	4·2716	4·2727	4·2738	4·2749	4 2760	4·2772	4·2783	4·2794	4 2805	4·2816	·0011
258	4·2827	4·2838	4·2849	4·2860	4·2871	4 2882	4 2893	4·2904	4·2915	4 2926	·0011
259	23 4·2937	4·2948	4·2959	4·2970	4·2981	4·2992	4·3003	4·3014	4 3025	4·3036	·0011
260	4·3046	4·3057	4·3068	4·3079	4·3090	4·3101	4·3111	4·3122	4·3133	4·3144	·0011
261	4·3154	4·3165	4·3176	4·3187	4 3197	4·3208	4·3219	4·3229	4·3240	4·3250	0011
262	23 4·3261	4·3272	4·3282	4·3293	4·3303	4·3314	4·3325	4·3335	4·3346	4·3356	·0011
263	4·3367	4·3377	4·3388	4·3398	4 3409	4·3419	4 3429	4·3440	4·3450	4·3461	·0010
264	4·3471	4·3482	4·3492	4·3502	4·3513	4 3523	4 3533	4 3544	4·3554	4·3564	·0010
265	23 4·3574	4·3585	4·3595	4·3605	4·3615	4·3626	4·3636	4·3646	4·3656	4·3667	·0010
266	4·3677	4·3687	4·3697	4·3707	4·3717	4·3728	4·3738	4·3748	4·3758	4·3768	·0010
267	4·3778	4·3788	4·3798	4 3808	4·3818	4·3828	4·3838	4·3848	4·3858	4·3868	·0010
268	23 4·3878	4·3888	4·3898	4·3908	4·3918	4·3928	4·3938	4·3948	4·3958	4·3968	·0010
269	4·3977	4·3987	4·3997	4·4007	4·4017	4·4027	4·4036	4·4046	4·4056	4·4066	·0010
270	4·4075	4·4085	4·4095	4·4105	4·4114	4·4124	4·4134	4·4143	4·4153	4·4163	·0010
271	23 4·4172	4·4182	4·4192	4·4201	4 4211	4·4220	4·4230	4·4240	4·4249	4·4259	·0010
272	4·4268	4·4278	4·4287	4·4297	4·4307	4·4316	4·4326	4·4335	4·4344	4·4354	·0010
273	4·4363	4·4373	4·4382	4·4392	4·4401	4·4411	4·4420	4·4429	4·4439	4·4448	·0009
274	23 4·4457	4·4467	4·4476	4·4485	4·4495	4·4504	4·4513	4·4523	4·4532	4·4541	·0009
275	4·4551	4·4560	4·4569	4·4578	4·4587	4·4597	4·4606	4·4615	4·4624	4·4633	·0009
276	4·4643	4·4652	4·4661	4·4670	4·4679	4·4688	4·4697	4·4706	4·4715	4·4725	·0009
277	23 4·4734	4·4743	4·4752	4·4761	4·4770	4·4779	4·4788	4·4797	4·4806	4·4815	·0009
278	4·4824	4·4833	4·4842	4·4850	4·4859	4·4868	4·4877	4·4886	4·4895	4·4904	·0009
279	4·4913	4·4922	4·4930	4·4939	4·4948	4·4957	4·4966	4·4975	4·4988	4·4992	·0009
280	23 4·5001	4 5010	4·5018	4·5027	4·5036	4·5045	4·5053	4·5062	4·5071	4·5080	·0009
281	4·5088	4·5097	4·5105	4·5114	4·5123	4 5131	4·5140	4·5148	4·5157	4·5166	·0009
282	4·5174	4·5183	4·5191	4·5200	4·5208	4·5217	4·5226	4·5234	4·5243	4·5251	·0009
283	23 4·5260	4·5268	4·5277	4·5285	4·5293	4·5302	4·5310	4·5319	4·5327	4·5336	·0008
284	4·5344	4·5352	4·5361	4·5369	4·5378	4·5386	4·5394	4·5403	4·5411	4·5419	·0008
285	4·5427	4·5436	4·5444	4·5452	4·5461	4·5469	4·5477	4·5485	4·5494	4·5502	·0008
286	23 4·5510	4·5518	4·5527	4·5535	4·5543	4·5551	4·5559	4·5567	4·5576	4·5584	·0008
287	4·5592	4·5600	4·5608	4·5616	4·5624	4·5632	4·5641	4·5648	4·5657	4·5665	·0008
288	4·5673	4·5681	4·5689	4·5697	4·5705	4·5713	4·5721	4·5729	4·5737	4·5745	·0008
289	23 4·5753	4·5761	4·5769	4·5777	4·5785	4·5793	4·5800	4·5808	4·5816	4·5824	·0008
290	4·5832										

v	0	1	2	3	4	5	6	7	8	9	Diff.
f.s.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	+
238	4 6406·0	6408·9	6411·8	6414·8	6417·7	6420·6	6423·5	6426·4	6429·3	6432·2	2·9
239	6435·1	6438·0	6440·9	6443·8	6446·8	6449·7	6452·6	6455·5	6458·4	6461·3	2·9
240	6464·2	6467·1	6470·1	6473·0	6475·9	6478·8	6481·7	6484·6	6487·6	6490·5	2·9
241	4 6493·4	6496·3	6499·2	6502·2	6505·1	6508·0	6510·9	6513·8	6516·8	6519·7	2·9
242	6522·6	6525·6	6528·5	6531·4	6534·3	6537·3	6540·2	6543·1	6546·1	6549·0	2·9
243	6551·9	6554·9	6557·8	6560·7	6563·7	6566·6	6569·5	6572·5	6575·4	6578·3	2·9
244	4 6581·3	6584·2	6587·2	6590·1	6593·0	6596·0	6598·9	6601·8	6604·8	6607·7	2·9
245	6610·6	6613·6	6616·5	6619·5	6622·4	6625·3	6628·3	6631·2	6634·2	6637·1	2·9
246	6640·1	6643·0	6645·9	6648·9	6651·8	6654·8	6657·7	6660·6	6663·6	6666·5	2·9
247	4 6669·5	6672·4	6675·4	6678·3	6681·3	6684·2	6687·2	6690·1	6693·0	6696·0	2·9
248	6698·9	6701·9	6704·8	6707·8	6710·7	6713·7	6716·6	6719·6	6722·5	6725·5	2·9
249	6728·4	6731·3	6734·3	6737·2	6740·2	6743·1	6746·1	6749·0	6752·0	6754·9	2·9
250	4 6757·8	6760·7	6763·7	6766·7	6769·6	6772·6	6775·5	6778·4	6781·4	6784·3	2·9
251	6787·3	6790·2	6795·1	6796·1	6799·0	6802·0	6804·9	6807·8	6810·8	6813·7	2·9
252	6816·6	6819·6	6822·5	6825·4	6828·4	6831·3	6834·2	6887·1	6840·1	6843·0	2·9
253	4 6845·9	6848·8	6851·8	6854·7	6857·6	6860·5	6863·5	6866·4	6869·3	6872·2	2·9
254	6875·1	6878·1	6881·0	6883·9	6886·8	6889·7	6892·6	6895·6	6898·5	6901·4	2·9
255	6904·3	6907·2	6910·1	6913·0	6915·9	6918·8	6921·7	6924·6	6927·5	6930·4	2·9
256	4 6933·3	6936·2	6939·1	6942·0	6944·9	6947·8	6950·6	6953·5	6956·4	6959·3	2·9
257	6962·2	6965·0	6967·9	6970·8	6973·7	6976·5	6979·4	6982·3	6985·1	6988·0	2·9
258	6990·9	6993·7	6996·6	6999·4	7002·3	7005·1	7008·0	7010·8	7013·7	7016·5	2·9
259	4 7019·4	7022·2	7025·0	7027·9	7030·7	7033·5	7036·4	7039·2	7042·0	7044·8	2·8
260	7047·7	7050·5	7053·3	7056·1	7058·9	7061·7	7064·5	7067·4	7070·2	7073·0	2·8
261	7075·8	7078·6	7081·4	7084·2	7087·0	7089·7	7092·5	7095·3	7098·1	7100·9	2·8
262	4 7103·7	7106·5	7109·2	7112·0	7114·8	7117·6	7120·3	7123·1	7125·9	7128·6	2·8
263	7131·4	7134·2	7136·9	7139·7	7142·4	7145·2	7147·9	7150·7	7153·4	7156·2	2·8
264	7158·9	7161·7	7164·4	7167·1	7169·9	7172·6	7175·4	7178·1	7180·8	7183·5	2·7
265	4 7186·3	7189·0	7191·7	7294·4	7197·1	7199·9	7202·6	7205·3	7208·0	7210·7	2·7
266	7213·4	7216·1	7218·8	2221·5	7224·2	7226·9	7229·6	7232·3	7235·0	7237·7	2·7
267	7240·4	7243·1	7245·8	7248·5	7251·2	7253·8	7256·5	7259·2	7261·9	7264·5	2·7
268	4 7267·2	7269·9	7272·5	7275·2	7277·9	7280·5	7283·2	7285·9	7288·5	7291·2	2·7
269	7293·8	7296·5	7299·1	7301·8	7304·4	7307·1	7309·7	7312·3	7315·0	7317·6	2·6
270	7320·2	7322·9	7325·5	7328·1	7330·8	7333·4	7336·0	7338·6	7341·2	7343·9	2·6
271	4 7346·5	7349·1	7351·7	7354·3	7356·9	7359·5	7362·1	7364·7	7367·3	7369·9	2·6
272	7372·5	7375·1	7377·7	7380·3	7382·9	7385·5	7388·1	7390·7	7393·3	7395·8	2·6
273	7398·4	7401·0	7403·6	7406·2	7408·7	7411·3	7413·9	7416·4	7419·0	7421·6	2·6
274	4 7424·1	7426·7	7429·3	7431·8	7434·4	7436·9	7439·5	7442·0	7444·6	7447·1	2·6
275	7449·7	7452·2	7454·8	7457·3	7459·8	7462·4	7464·9	7467·4	7470·0	7472·5	2·5
276	7475·0	7477·5	7480·1	7482·6	7485·1	7487·6	7490·1	7492·7	7495·2	7497·7	2·5
277	4 7500·2	7502·7	7505·2	7507·7	7510·2	7512·7	7515·2	7517·7	7520·2	7522·7	2·5
278	7525·2	7527·7	7530·1	7532·6	7535·1	7537·6	7540·1	7542·6	7545·0	7547·5	2·5
279	7550·0	7552·4	7554·9	7557·4	7559·9	7562·3	7564·8	7567·2	7569·7	7572·2	2·5
280	4 7574·6	7577·1	7579·5	7582·0	7584·4	7586·8	7589·3	7591·7	7594·2	7596·6	2·4
281	7599·0	7601·5	7603·9	7606·4	7608·8	7611·2	7613·6	7616·1	7618·5	7620·9	2·4
282	7623·3	7625·7	7628·2	7630·6	7633·0	7635·4	7637·8	7640·2	7642·6	7645·0	2·4
283	4 7647·4	7649·8	7652·2	7654·6	7657·0	7659·4	7661·8	7664·2	7666·6	7669·0	2·4
284	7671·3	7673·7	7676·1	7678·5	7680·9	7683·3	7685·6	7688·0	7690·4	7692·7	2·4
285	7695·1	7697·5	7699·8	7702·2	7704·6	7706·9	7709·3	7711·6	7714·0	7716·4	2·4
286	4 7718·7	7721·1	7723·4	7725·8	7728·1	7730·4	7732·8	7735·1	7737·5	7739·8	2·3
287	7742·1	7744·5	7746·8	7749·1	7751·5	7753·8	7756·1	7758·4	7760·8	7763·1	2·3
288	7765·4	7767·7	7770·0	7772·4	7774·7	7777·0	7779·3	7781·6	7783·9	7786·2	2·3
289	4 7788·5	7790·8	7793·1	7795·4	7797·7	7800·0	7802·3	7804·6	7806·9	7809·2	2·3
290	7811·5										

TRAJECTORIES CALCULATED FROM CHRONOGRAPH VELOCITIES.

Before we can make any progress whatever, we must know the diameter and weight of the bullet. In all our Express rifles, we have the diameter ready to hand, the calibre being given in thousandths of an inch, as ·450, ·500, &c.; and the weight of the bullet is usually stated in grains. Having these particulars we proceed as follows:

We first square the diameter of the bullet, and then divide by its weight, so as to obtain a factor or co-efficient of air-resistance, which is the basis of every calculation with this bullet, and which, in writings on the subject, is commonly designated as its $\frac{d^2}{w}$. In the foregoing pages, the tables on the left-hand, headed by this symbol followed by the letter *t*, apply to calculations of *time*; those on the left-hand pages, with an *s* after the symbol, apply to calculations of *space* or distance.

Let us suppose—to take an easy example—that the diameter is ·500 and that the bullet weighs 500 grains. We get the square of ·500 by multiplying it by itself; and, omitting the superfluous cyphers, the result is ·25. We have now to divide this by the weight; and, as the tables which have afterwards to be worked from are based on the weight of the projectile "in pounds," the number of grains in our bullet has to be reduced to the fraction of a pound. With 500 grains, we see at once that it is $\frac{1}{14}$th of a pound of 7000 grains; and, as the process of dividing by this fraction is the same as multiplying by 14, we should readily obtain the required result. Generally, however, the number of grains does not divide so easily, and the simplest method, in most cases, is to multiply by 7000 and divide by the number of grains in the bullet. This is, of course, merely the same as dividing by the fraction of a pound, which in our case is

$\frac{500}{7000}$, or $\frac{1}{14}$; and in many instances this method is more simple than that of ascertaining the corresponding decimal fraction, which for the 500 grain bullet would be ·07142857lb.

The division of the square of the diameter by the weight of our bullet will be seen to give 3·5 as the result; and if we want to know the remaining velocity of this bullet at any range—say, 100 yards—we must multiply the 3·5 by 300 (the number of feet in that range), which gives 1050 as the product. And now we are in a position to make use of the tables.

Supposing we know from the chronograph that the muzzle velocity of our bullet is 1685 feet per second, we refer to the table of "Space" (page 161), and in the line beginning 168, and the column headed 5, we find that 43970 is the number corresponding with 1685 velocity. We take this number, subtract therefrom the 1050 previously obtained for 100 yards, and the remainder is 42920. Referring again to the same table, we find that the nearest number to 42920 is in the line beginning with 144, and that, without resorting to fractions, the remaining velocity would be represented by 1448, or by 1447·6 if you wish to be more exact.

Having now obtained the "remaining velocity," you may desire to ascertain the time of flight or amount of drop of the bullet in the same distance; and for this purpose it is necessary to refer to the opposite page relative to "Time." You take from this, in similar fashion to the table previously used, the number corresponding to 1685 velocity, which is 232·8209; subtract therefrom the number corresponding to 1448, which would be 232 1494; and the remainder (·6715), divided by the 3·5 previously mentioned as the factor of air-resistance, gives you the fraction of a second (·191857) in which the bullet traversed the 100 yards range.

To ascertain the "drop," this fraction of a second has to be squared, which gives ·036809, and multiplied by 193 inches (or 193·145, if you wish to be very particular), as the gravity drop for 1 second, and this shows our bullet drop in 100 yards to be a trifle over 7·1 inches. There is a table in Mr. Bashforth's book from which the drop of the bullet can be read off by inspection, when you know the time; and it is very useful indeed for long ranges, where the drop is stated in feet; but for the short ranges required for sporting purposes, where the fractions of a second are very small, and the measurement must be given in inches, I prefer to calculate from the number 193·145, as if you take the fraction of a foot from the table and turn it into inches, any little divergency in the last figure of the decimal is multiplied 12 times in this process, and thus makes the differences between successive ranges appear out of proportion.

Calculation of Drop from Muzzle Velocity.

The above long description may be briefly summarised in figures, with the aid of the ordinary arithmetical signs for multiplication, division, &c., the same dimensions, weight of bullet, velocity, &c., being given as before.

$500 \times \cdot 500 = \cdot 25$, square of diameter of bullet;
$\cdot 25 \times 7000$ grs. $= 1750$;
$1750 \div 500$ grs. $= 3\cdot 5$, factor of air-resistance, or $\frac{d^2}{w}$

We now have recourse to Bashforth's tables as follows—selecting the "space number" from the right-hand page, and the "time number" from that on the left:

	Space Number		Time Number
1685 ft.-sec. velocity	43970	1685 ft.-sec. velocity	232 8209
$- 3\cdot 5 \times 300$ feet	1050		
	42920 =	Remaining velocity 1448 ft.-sec. =	232·1494
			·6715

$\cdot 6715 \div 3\cdot 5 = \cdot 191857$ sec. (Time of flight)
$\cdot 191857 \times \cdot 191857 = \cdot 036809$ square of Time.
$\cdot 036809 \times 193$ in. $= 7\cdot 1$ in. drop of bullet.

These calculations are, of course, much more rapidly made by logarithms than by ordinary arithmetic; and the process is so easily acquired, that it is well worth the while of anyone, not already acquainted with the process, to learn it before he indulges much in work of this kind.

It may also be as well to mention here that, if "drop" calculations for comparative purposes are about to be made, it may save time in the end to be very exact in estimating the "remaining velocity" to fractions of a foot. The time calculation is based on this remaining velocity; and any slight inaccuracy is considerably magnified by the squaring of the time, and will thus make a very noticeable difference in long ranges. The young beginner may therefore be greatly puzzled by irregularities of increase in drop at different ranges, and, fancying that his calculations are wrong, may work and re-work his figures to trace the error, whereas the inaccuracy may, after all, be only due to allowance not having been made for a fraction of a foot in the velocity.

CALCULATION OF MUZZLE VELOCITY FROM TIME OR DROP.

If, now, you wish to ascertain the muzzle velocity from the mean velocity obtained by the chronograph, the above process, or a part of it, has to be reversed. Supposing that the mean velocity in 20 yards has been ascertained, that would, as recently stated, be the actual velocity at half-distance, or 10 yards. The factor of air-resistance, 3·5 (if the bullet were the one just mentioned), would have to be multiplied by the half-distance in feet (30), and the product *added* to the "Space" number taken from the right-hand table. This will give the number corresponding to the velocity at the muzzle, which is 30 feet from the point where the velocity is known.

If the amount of drop is known, and you wish to ascertain the muzzle velocity, it may be worked out by a further application of the reverse process just described. Taking the previous figures, by way of example, with 7·1in. drop of bullet, we proceed as follows:

7·1in. drop ÷ 193in. = ·036809 square of time;
Extract square root of ·036809 = ·191857 sec., Time of flight;
300 feet ÷ ·191857sec. = 1564 mean velocity in 100 yards;
Mean velocity in 100 yards = actual velocity at 50 yards.

Actual velocity, 1564 = 43448·6 in Space table;
add 150 feet × 3·5 = 525 0
and the remainder, 43973·6 = 1686 velocity in Space table.

The result here is only 1 foot different from the muzzle velocity previously mentioned, and that difference would have been less had fractions been resorted to, as the mean velocity was rather over 1563½ feet per second.

CALCULATION OF TRAJECTORY WITHOUT A CHRONOGRAPH.

Few persons have a chronograph at their service, but many may like to carry out experiments within their means for the purpose of estimating the trajectories of their rifles or ascertaining the muzzle velocity. It is not to be expected that the results to be obtained by the methods now about to be described can be more than approximate, but the experiments, if carefully carried out, will often give a closer approximation than might be expected.

Col. Davidson, the inventor of the telescopic sight for rifles, in commenting, in the *Field*, on the recent rifle trial at Putney, thus described the method he adopts for ascertaining the trajectory and drop of bullets:

"Every gunmaker should be prepared to tell his customer what is the trajectory of the rifle he sells. Everyone has not the means of making such trials as you record. I have been in the habit of adopting a more simple method. Using my telescopic sight, and taking the line which represents no elevation at all (that is, the prolongation of the axis of barrel), I aim with that line at a spot the size of a shilling at the different distances from 25 to 200 yards; and, measuring from the centre of each group of shots, I note the fall of the bullet below the line of the axis of the piece. To lay down the trajectory, I have only to draw a line representing the prolongation of the axis, and mark off in that line the distances from 25 to 200 yards, and then lay off the drop of the bullet from each of these distances, when a curved line, connecting these points, will give the trajectory. Of course, for convenience, I use a different scale for the distances and for the drop."

From a line subtending the curve made as Col. Davidson describes, the height of the trajectory at different points could doubtless be ascertained with a very close approximation to accuracy; but I doubt whether measurement from the zero line, or line of no elevation, can be relied on to give a correct representation of the *actual* drop of the bullet in all cases; for the apparent drop and the actual drop are not necessarily the same. I am led to this remark by Col. Davidson having stated, in the course of his letter, that the drop of a rifle he tried he had found to be about 10 inches at 150 yards. A drop of 10 inches under the action of gravity is accomplished in less than a quarter of a second (·2275 sec.); and it will be seen, on dividing 450 feet by this time, that a bullet having so small a drop in 150 yards must have a *mean* velocity of over 1970 feet a second. To produce so high a mean velocity for that distance, the initial velocity of the bullet would have to be somewhere about 2600 feet per second. I conclude, therefore, that the apparent drop in Col. Davidson's bullet measured some inches less than the true drop—probably owing to a certain amount of "jump" in the rifle when fired. If, however, there be such a "jump" or other irregularity in the shooting as produces any material difference between the apparent and the real drop of the bullet, a clue to the fact may be found by taking the known height of the trajectory at mid-range, and multiplying it by 4, which will give approximately the drop at full range; so that, if any great difference is found to exist, it may be assumed that there is something wrong in the measurement of the apparent drop, although the curve of the trajectory itself may be right. It may be as well, moreover, instead of taking a single measurement from the centre of the group of shots, to go to the additional trouble of measuring every shot separately, and calculating the average; otherwise one might possibly have half a dozen bullets at different distances from the zero line, and only get the mean of the two extremes instead of the average of the entire group.

Another simple method of ascertaining trajectories is to fire a series of shots with the same sight at different distances in the following fashion. Let us suppose that half-a-dozen shots are fired from a sandbag or rest at 150 yards, and measurement made of the distance of each shot above or below a cross-line in the centre of the bullseye; the same is done with a similar half-dozen shots, 25 yards nearer, using the same sight, and aiming again at the centre of the bullseye; at 100, 75, 50, and 25 yards (or any other equal intervals that are convenient) the process is repeated, and measurements are taken. A straight line is drawn on a sheet of paper, and divided into equal distances to correspond with the divisions of the range, and at each division is plotted down the average measurement of the six shots above or below the line, as the case may be. When the whole are laid down, another straight line may be drawn from that part of the first line which corresponds with the position of the muzzle of the rifle, to the point which marks the average position of the six shots at 150 yards, and, if the rifle has been shot with equal accuracy at each distance, a curve drawn through the various points marked down in the range will represent the trajectory, and measurements from the base-line to the curve will give the height at any point. By measuring the height of the trajectory at a point a little beyond mid-distance (say 80 yards) and multiplying this height by 4, you get the total amount of drop in 150 yards; and from the drop you may, as recently pointed out, ascertain the time of flight, the mean velocity, and ultimately the muzzle velocity.

THE VERTEX OR CULMINATING POINT OF THE TRAJECTORY.

This occurs a little beyond mid-range, at about half the time of flight; and, taking 150 yards as a convenient range for Express rifles, 80 yards may, for all practical purposes, be assumed to representing the highest point of the trajectory; though with very light bullets and great speed the turning point would really be somewhat beyond 80 yards, and with heavy bullets and lower velocity it would be rather under that distance. Thus, a 360gr. bullet of ·450 bore, with 1600ft. muzzle velocity; would be at its highest about 79½ yards; whereas a 260gr. bullet, with 2000ft. initial velocity, would not reach its vertex till about 81 yards.

This, however, is on the supposition that the trajectory is calculated from a line produced from the axis of the barrel, without any allowance for the height of the front sight; but, if taken from the line of aim, the height of the front sight above the axis of the bore has to be allowed for, and this would vary in different rifles, according to the size of the bullet, the thickness of the barrel, and the height of the sight itself, and whether it were placed on the top of single-barrel, or on the rib of a double. Taking, however, half an inch as a convenient height of sight for our purpose, that would make a difference of a quarter of an inch at mid-range, and more or less as it was under or over 75 yards.

As the angle of elevation compensates for the bullet's drop throughout the whole range, it may be said to represent the average drop. During the first half of the time, when the speed is greatest, the bullet drops at a less rate than the angle rises; in the second half, the reverse is the case; and about midway, where there is an average of speed, the rise of angle and drop of bullet are brought into correspondence, and, for a few yards, the rise and fall so nearly counteract each other that recourse must be had to thousandths of an inch in order to mark the turning point. This will be seen by the following calculations of the respective heights of bullets of 260 and 360grs., with muzzle velocities of 2000ft. per second for the former and 1600 for the latter, so as to make a rather wide contrast:

HEIGHTS OF 150 YARDS TRAJECTORY BEYOND MID-RANGE, WITH NO ALLOWANCE FOR SIGHT.

260 GR. BULLET, WITH 2000 FT.-SEC. MUZZLE VELOCITY		360 GR. BULLET WITH 1600 FT.-SEC. MUZZLE VELOCITY	
At 75 yards	4·059 inches.	At 75 yards	5·590 inches.
76 ,,	4·067 ,,	76 ,,	5·596 ,,
77 ,,	4·074 ,,	77 ,,	5·600 ,,
78 ,,	4·078 ,,	78 ,,	5·604 ,,
79 ,,	4·082 ,,	79 ,,	5·608 ,,
80 ,,	4·083 ,,	80 ,,	5·609 ,,
81 ,,	4·084 ,,	81 ,,	5·606 ,,
82 ,,	4·085 ,,	82 ,,	5·602 ,,
83 ,,	4·082 ,,	83 ,,	5·597 ,,

SAME, WITH HALF-INCH ALLOWANCE FOR SIGHT.

At 79 yards	3·844 inches.	At 77 yards	5·357 inches.
80 ,,	3·849 ,,	78 ,,	5·365 ,,
81 ,,	3·853 ,,	79 ,,	5·372 ,,
82 ,,	3·857 ,,	80 ,,	5·376 ,,
83 ,,	3·859 ,,	81 ,,	5·376 ,,
84 ,,	3·858 ,,	82 ,,	5·376 ,,
85 ,,	3·855 ,,	83 ,,	5·373 ,,

On comparing the first division of the table with the second it will be seen that, in the latter, the turning point appears to be removed a yard or two further on; and, with the slow bullet, the change is so gradual that even thousandths of an inch are not small enough to indicate the differences. This arises from the fact that, whereas the line of elevation increases in height with length of range, the allowance for sight diminishes; and thus another counteracting influence joins in with the diminishing velocity of the bullet, and gives almost absolute flatness for several yards. This is very convenient for amateurs who wish to calculate the height of trajectory and the velocity of their rifles, as, by taking such a point as 80 yards in a range of 150, there is little fear of the velocity or weight of the bullet making any material difference; for, although, strictly speaking, the various bullets may have different culminating points, no ordinary mode of measurement would tell the variation in height of the same bullet if taken a yard or two earlier or later.

One method of calculating the height of trajectories from times ascertained by the chronograph is to take the time at any given point (say, 50 yards), and multiply by the difference between the time at 50 and the time of the full range (say, 150 yards); and the product, multiplied by the drop per second, is taken as the height of the trajectory at 50 yards, or whatever the selected distance may be. I confess, however, I prefer to subtract the drop from the height of angle, although it may be a more cumbersome process; for the former makes the trajectory appear somewhat too low. To show the effect, I will illustrate it by reference to the foregoing table. The highest point of the trajectory would, by this method, be at the point exactly corresponding with half-time of the full range. If we take this half time, and square it, we get one-fourth, and multiplying this by the gravity drop per second, we find the highest point of the trajectory given is exactly one-fourth of the drop in the full range. But, if we look at the angle of elevation, we see that at mid-range (not mid-time) its height is just one-half of the total drop; whereas the time being less than half, the drop up to that point is less than a quarter. If we subtract from the height of angle at half-distance the amount of drop in that distance, the result is that we find the position of the bullet to be higher than the "highest point of the range" as calculated by the method alluded to. This appears to arise from the fact that the line of angle representing the elevation of the gun is a line of mean velocity, whereas, the base line of the angle is a line of variable velocity, and consequently the points of time on the two lines do not coincide. Calculated by the method in question, the greatest height of trajectory, as based on half-time, would be, for the 260grs. bullet 3·48in., and for the 360grs. bullet 4·97in. Accordingly the results would not accord satisfactorily with the foregoing table, nor with calculations worked out on the basis now to be described.

Mode of Calculating Velocity from Bullet Marks on Target.

Express rifles are commonly sighted for 150 yards, and this range will therefore be very suitable for the experiment. Mark a horizontal line on a target or sheet of paper, and, having measured a distance of 80 yards from this target, fire half a dozen shots, aiming at the line, with the rifle sighted for 150 yards.

Measure each shot separately, from the centre of the bullet-mark to the centre of the horizontal line, and calculate the average of the whole. If the shooting be pretty even, Express bullets, according to their weight and velocity, should average from about 4in. to 5½in. above the horizontal line on the target, and this will represent the height of the trajectory above the line of aim. Military bullets would be considerably higher.

To the height thus obtained, add $\frac{8}{15}$ths of the height of the sight from the centre of the bore, and you obtain the height of trajectory without sight allowance. Multiply this by the square of 15 (or 225) and divide by the square of 8 (or 64) and you obtain the same result as dividing by the square of $\frac{80}{150}$, which represents the proportionate part of the range. This gives you the total bullet-drop in 150 yards. Very nearly the same result is obtained by merely multiplying by $3\frac{1}{2}$, as dividing by the square of $\frac{80}{150}$ is similar in effect to multiplying by 3·516.

Take the total drop in inches and fractions, divide by 193·145 (the number of inches fall by force of gravity in one second), and the square root of the quotient gives the time of flight of the bullet for 150 yards—a fraction of a second.

Divide 450 feet (150 yards) by this fraction of a second, and the mean velocity is ascertained. The mean velocity for 150 yards is also the actual speed of the bullet at half the distance, or 75 yards.

Then, having ascertained the factor of resistance, or $\frac{d}{w}$ of the bullet (by squaring diameter, dividing by grains of weight, and multiplying by 7000 to turn it into pounds or fractions of a pound), multiply the 225 feet (or 75 yards) by this factor of resistance, and you obtain a number which, added to a "Space number" in Bashforth's table corresponding to the velocity at half-distance, will give a second number which, on again referring to Bashforth's table, will show the muzzle velocity.

At the time of the recent *Field* trial of rifles at Putney I endeavoured, by this method, to ascertain the approximate velocities from the bullet marks on the paper screens; but, as the rifles were fired from a machine rest, and they were levelled from the bore, there was no need to make any allowance for height of sight. Having ascertained from the screens the average height of the bullet-marks of four rifles, I worked out the estimated velocities. Two of these were only 1 ft.-sec. each different from the velocities obtained by the chronograph; the other two were fully 50 ft.-sec. out. The getting so very close in two instances I take to be a mere "fluke;" but in the other two I consider the difference would have been less, except for some divergences of the bullets arising from their contact with previous paper screens.

Now, it must be admitted that the above-mentioned process of multiplying and squaring fractions is rather troublesome; and so is that of finding out the distance of the highest point of the trajectory from the muzzle of the gun. But very similar results may be obtained by a simpler empirical process, which may be thus described:—

To find the *distance* of the highest point of trajectory, multiply the length of range by the fraction ·52, if the range is 100 yards, and add ·01 to the fraction for every additional 50 yards.

To find the *height* of the trajectory at this highest point, multiply the drop in the full range by the fraction ·28, if the range is 100 yards, and add ·01 to the fraction for every additional 50 yards.

The respective multiples will thus be as follows:

	Greatest Height of Trajectory.	
Length of Range.	Multiple of Distance.	Multiple of Drop.
100 yards	·52	·28
150 "	·53	·29
200 "	·54	·30
250 "	·55	·31
300 "	·56	·32
350 "	·57	·33
400 "	·58	·34
450 "	·59	·35
500 "	·60	·36

These will apply approximately to all express rifles; but light bullets with very high velocities are slightly under-estimated at short ranges and over-estimated at long ranges, and *vice versâ* with heavy bullets and low velocities. Thus, taking 150 yards as the range, and multiplying it by ·53, we get 79·5 yards as the highest point of trajectory. This would be nearly true of the 360gr. bullet with 1600 ft.-sec. muzzle velocity, but rather short for the 260gr. bullet with

2000ft. velocity. We can meet extreme cases, however (if thought necessary), by taking the next point higher or lower; for, if we multiply 150 by ·54 instead of ·53, we get 81, which is just about the highest point of the 260gr. trajectory with 2000 ft.-sec. initial speed.

In similar fashion, if we know that the drop of the 360gr. bullet, with 1600 ft.-sec. muzzle velocity, is 38 inches in 200 yards, we multiply 38 by ·30 and get 11·4in. as the greatest height of trajectory; and this is sufficiently correct. In 500 yards, the result would be too high.

EFFECT OF TEMPERATURE AND MOISTURE.

Hitherto all that has been said about the resistance of the atmosphere has had reference to the effect produced when the air is of the normal weight, or when there is a fall in the barometer alone taken into account. Professor Bashforth's tables, lately given, are calculated on the supposition that the weight of a cubic foot of air is 534·22 grains, which is the weight of dry air at a temperature of 62° F., under a pressure of 30 inches of mercury. When the barometer rises above or falls below 30″, the weight of the air is increased or diminished, and the weight is further affected by the amount of moisture. If one takes into consideration nothing more than the rise or fall in the barometer (as may be done with the ordinary run of mild English weather), the co-efficient of resistance (or $\frac{d^2}{w}$) need only be multiplied by the height of the barometer, and divided by 30, and the rest of the calculation be worked on this basis. If, however, you wish to take temperature and moisture also into account, then it is necessary to ascertain the weight of a cubic foot of the air in which the experiment is carried on, and for that purpose recourse must be had to meteorological tables, such as Mr. Glaisher's, if strict accuracy is required; but a close approximation may be obtained by means of the table here given, which will suffice for all practical purposes, and render unnecessary the reprinting of longer tables and giving an explanation of their mode of use. This table, and the remarks appended thereto, are taken from a very interesting article, by Lieut. E. L. Zalinski, of the United States Army, which appeared in an American journal, *Forest and Stream*, of June 21, 1883, a copy of which was sent me by a friend:

TABLE OF WEIGHTS OF AIR, PER CUBIC FOOT, AT DIFFERENT TEMPERATURES, THE BAROMETER BEING AT A HEIGHT OF THIRTY INCHES AND MOISTURE AT $66\frac{2}{3}$ PER CENT. OF SATURATION.

Temperature.	Weight per cubic feet of air in grains	Mean change of weight for each $\frac{1}{10}$ inch change in height of Barometer	Mean change of weight for each degree of temperature	Mean decrease of weight with humidity at saturation (=100).
		Grains.	Grains	Grains
−30°	647			
−20°	633	2·1	1·4	
−10°	619	2·1	1·4	0·10
0°	605	2·0	1·4	0·20
10°	592	2·0	1·3	0·35
20°	579	1·9	1·3	0·53
30°	567	1·9	1·2	0·76
40°	555	1·8	1·2	1·03
50°	544	1·8	1·2	1·42
60°	532	1·8	1·2	1·96
70°	521	1·7	1·2	2·66
80°	509	1·7	1·2	3·60
90°	497	1·7	1·2	4·83
100°	485	1·6	1·2	6·50
110°	473	1·6	1·2	8·32

"It is seen from the above that an average change of 15·5° of temperature is equivalent to one inch height of barometer. At or near sea-level the changes of barometer rarely exceed two-tenths (0·2) of an inch from a mean height of 30in., producing a variation of less than four grains of weight per cubic foot. It is apparent that the probable limits of changes of barometer affect the weight of air so slightly that it may ordinarily be considered as at a height of 30in., or, better, at the average height of any firing locality.

Temperature, however, varying considerably as it may within a single day's firing, and ranging at different seasons from below zero to more than 100° above, effects marked changes in the weight of air, and may not be neglected. It is seen that the weight decreases with rise of temperature.

At Ft. Keogh, Montana, the temperature ranged from —27° in February, 1882, to 109° in August, 1882, a variation of 136°, giving a difference of weight of air of 161grs. per cubic foot.

Moisture reduces weight of air by its elastic force, but the extreme variations produced by this are so inconsiderable, compared with the changes produced by temperature, that ordinarily no great error will result if the weight of the air is taken for a condition of $66\frac{2}{3}$ per cent. for saturation. It will be seen this element decreases the weight most at the higher temperatures."

Fortunately, in these islands we do not run to such extremes as 109° in summer and 27° below zero in winter; and therefore we shall not require to make allowance for temperature and moisture to the full extent mentioned in the above table. As this table is calculated for an amount of moisture equal to two-thirds (or $66\frac{2}{3}$ per cent.) of saturation, and our temperatures do not usually go to great extremes, we will leave moisture out of consideration, and merely pay attention to the barometer and thermometer. Supposing, then, that the barometer stands at 29″ instead of 30″, and the thermometer is at 55°, we find that at 50° the weight of the air is 544 grains; for the other five degrees we deduct five times 1·2, as shown in the fourth column, which reduces the weight to 538; and as the barometer is 1 inch below 30, we deduct also ten times 1·8, as shown in the third column, and consequently get 520 grains as the weight per cubic foot of air. Bashforth's tables are calculated on the basis of 534·22 grains per cubic foot; and, to allow for the difference in weight, the number obtained as the $\frac{d^2}{w}$ of the bullet has to be multiplied by 520 and divided by 534·22, and the result used as the basis for calculation of the experiments carried out under this condition of the atmosphere.

Lieut. Zalinski's paper also contains a number of calculations on the effect of temperature on air-resistance, but as they apply almost exclusively to the American military rifle, it has not been thought necessary to quote them here. A second paper, in continuation of the subject, was announced, but I not know whether it has been published. Other articles, by various writers have, I understand, also appeared in American journals, touching on the same subject, but unfortunately I have not had an opportunity of perusing them. It seems certain, however, from the number of articles published, that our American cousins pay much more attention to such matters than do the sportsmen of these islands.

Trajectories of Large-bores.

The previous remarks have chiefly had reference to the trajectories of Express bullets. For the calculation of the trajectories of spherical balls the foregoing set of tables would be useless, as the amount of air-resistance with spherical shot is entirely different at all velocities. It would occupy too much space to insert here another set of tables similar in dimensions to those just given, and anyone who wishes to have recourse to them must therefore be referred either to Professor Bashforth's treatise, or to the blue-book containing his first report, already alluded to. But a few particulars, from notes relative to the large-bores at Messrs. Holland's trial in 1879, may be of interest, more especially as no chronograph velocities were taken with the large-bores shot at the *Field* trial of 1883.

In his book on the "Sporting Rifle," already alluded to on page 9, Capt. Forsyth gave the trajectory of a 14-bore rifle which had much pleased him. Its "point-blank range" with spherical ball was stated by the author to be about 60 yards with 3drs., 85 yards with 4drs., and 100 yards with 5drs.

The height of the trajectory at different points of the range was given as follows:

	25yds.	50yds.	75yds.	100yds.
14-bore	1in.	$2\frac{5}{8}$in.	$2\frac{3}{8}$in.	0

These measurements will serve as a basis for comparison with the trajectories of the rifles of 12-bore and upwards that were tried in the course of Messrs. Holland's experiments.

It may be as well, however, first to insert Capt. Forsyth's definition of "point-blank range." He says (the italics are his own): "I define the point-blank of the sporting rifle to be, *that distance up to which a shot may be taken at any object without allowing anything for the rise or fall of the projectile.* A rise or fall of 1 inch will not require any allowance to be made even in the finest shooting that ever occurs in actual sport; therefore, this amount of rise and fall will regulate the length of the point-blank range." A rise or fall of 1 inch would be equivalent to a rise of $1\frac{1}{2}$ inch above the line of sight at mid-range without allowing for fall.

Let us now take 100 yards as the range of Messrs. Holland's rifles, and supposing the 12-bore to be sighted for the largest charge (the bullet dropping 9 inches in 100 yards), the rise and fall of the bullets, with four different charges, was estimated as follows:

TRAJECTORIES OF 12-BORE RIFLE, SIGHTED FOR 9IN. FALL IN 100 YARDS.

	25yds.	50yds	75yds.	100yds.
4drs.	1·5in.	1·5in.	—0·7in.	—5·3in.
5drs.	1·7	2·0	0·6	—3 0
6drs.	1·8	2·4	1·6	—1·0
7drs.	1·9	2·6	2·1	0

With the same elevation, the bullet fired with the smallest charge falls below the line of aim before it has gone quite 75 yards, and, as the slowest bullet drops most in equal distances, the height of the trajectory is consequently less than with the faster bullets. If, however, the elevation be increased, so as to make each bullet strike on the line of aim at 100 yards, the trajectory is highest with the slowest bullet, as about one-fourth of the former drop below the line is now added to the height at the first point, half at the second, and three-quarters at the third; for example:

TRAJECTORIES OF 12-BORE RIFLE, ELEVATED FOR DIFFERENT CHARGES.

	25yds.	50yds.	75yds.	100yds.
4drs.	2·9in.	4·2in.	3·4in.	0
5drs.	2·4	3·5	2·8	0
6drs.	2·0	2·9	2·4	0
7drs.	1·8	2·6	2·1	0

The trajectory of Capt. Forsyth's rifle would thus be intermediate between the last two on the list, except as regards the 25 yards, which appears to be very low as compared with the figures just given; but these calculations of Messrs. Holland's trajectories were made from the axis of the bore, without any allowance for the height of the front sight; whereas Capt. Forsyth's trajectories were ascertained by measurements from shots fired at paper screens, aim being taken from the sight in the usual way. What was the height of the sight on Capt. Forsyth's rifle I do not know, but probably it was something more than half an inch above the axis of the bore. Taking it, however, at half an inch, this would lower the trajectory by $\frac{3}{8}$in. at 25 yards, $\frac{2}{8}$in. at 50 yards, and $\frac{1}{8}$in. at 75 yards. This would bring them much nearer together; and possibly some little further difference may have been caused by the bullet striking several paper screens in succession, as such appears to have been the case with the paper screens used at the Putney trials.

The trajectories of the larger rifles in Messrs. Holland's trial did not differ very greatly from that of the 12-bore with the largest charge, but were lowest with the heaviest bullets. Supposing in each case the bullet to strike on the line of aim at 100 yards, the following would be the trajectories.

TRAJECTORIES OF THE LARGE-BORES.

	25yds	50yds	75yds.	100yds.
10-bore, 8drs.	1·9in.	2·7in.	2·2in.	0
8-bore, 9drs. ...	2·0	2·9	2·3	0
Ditto, 10drs.	1·8 . .	2·5	2·1	0
4-bore, 14drs. ...	1·7	2·4	1·9	0

With regard to the "point-blank range," I think that, with spherical-ball rifles, the distance should not be much more than the bullet would travel in the fifth of a second. This would allow for a drop of about 8in., and the trajectory would be very similar to that of the 4-bore just given. Adopting this time limit, the "point-blank range" of the 12-bore rifle above mentioned would be about 75 yards with 4drs., 83 yards with 5drs., 90 yards with 6drs., and 95 yards with 7drs.; while the 10-bore and 8-bore (with 10drs.) would be about 93 yards, and the 4-bore about 97. With the Express rifle, however, as the bullet loses its velocity less rapidly, and the trajectory is consequently flatter, the time limit need not be so short.

In making use of the term "point-blank," in the foregoing remarks, I do so in consideration of the fact that it is commonly used by sportsmen, and in order to show in what sense it is employed by an acknowledged authority on sporting rifles. Capt. Forsyth's definition, however, is by no means of universal acceptation; and, indeed, no definition is generally accepted. It was stated in the daily press last year that a newly-invented rifle had a point-blank range of 900 yards! General Lefroy recommended, some years ago, that the use of the term should be abandoned; and such has been done of late in military books.

TRAJECTORY OF MATCH RIFLES.

As to match rifles, the following article, from a great authority on the subject, is so complete, that it is desirable to reprint it in full. It originally appeared in the New York *Spirit of the Times* of April 13, 1878.

TRAJECTORY OF THE MODERN MATCH RIFLE.

BY W. E. METFORD, C.E.

In treating of this very interesting branch of gunnery, the writer will not refer to any older views based on the spherical bullet, for air resistance with such a bullet is so heavy that practically long range was ever out of the question.

When the use of a solid bolt in the place of a short conoidal bullet, and about $2\frac{1}{4}$ diameters, was introduced, gunners began to get to ranges which naturally brought the question of trajectory prominently forward. Since then Sir Joseph Whitworth increased the length of the rifle bullet to nearly its present amount, and it appears that gunners have now arrived to a final proportion of diameter to length of about 1 to 3, with a weight of from 540 to 550 grains. With this proportion of bullet all the modern shooting is being performed; and it is with the trajectory of this bullet, therefore, that the writer will deal.

Before, however, entering into the trajectory of the present bullet, it may be as well to point out that, even with such trajectories as given by the old English Enfield musket, there was none of that very rapid sharpening of the curve of the trajectory which it has been the fashion of writers to pourtray in their books; for instance, the Enfield, when loaded with the cartridges best adapted to it, had its culminating point but just 50 yards beyond the half way for the 1000 yards, and the slopes of its falling into the target were, for the longer ranges, with the very best fresh cartridges, as follows:—

600 yds.,	1 foot in about	27	feet.	900 yds.,	1 foot in about	$13\frac{1}{2}$	feet.
700 ,,	1 ,,	$20\frac{1}{2}$	,,	1000 ,,	1 ,,	11	,,
800 ,,	1 ,,	$16\frac{1}{2}$	,,				

And its angles were, with such cartridges, as follows:—

100 yards, about	12′ 9″	600 yards, about	1° 40′ 3″
200 ,, ...	27′ 2″	700 ,, ...	2° 3′ 4″
300 ,, ...	42′ 9″	800 ,, ...	2° 29′ 0″
400 ,, ...	1° 0′ 2″	900 ,, ...	2° 57′ 2″
500 ,, ...	1° 19′ 2″	1000 ,, ...	3° 28′ 4″

and this trajectory was produced with a bluff, short wood-plugged bullet of 530 grains and 70 grains of powder, and having a computed initial speed of about 1160 feet per second.

The match rifle—which the writer takes to be the fullest expression of a first-rate modern long-range small arm—when charged with 90 grains of the English powder of Curtis and Harvey's No. 5 or No. 6,* will drive a 540 grains bullet at the rate of about 1400 feet per second out of its muzzle.

In treating of trajectory, it would appear to be the best way, first, to point out that, if there existed no air, the bullet, fired at any given angle from the horizontal would fall into the target at its initial or muzzle speed,† and the angle of the inclination of the fall in of the bullet on the target would be precisely equal to that of the inclination of the bullet's path in its issue from the rifle's muzzle; and, secondly, to point out that the curve of the bullet's path would be a parabola of which the apex would be the half-way point. Now, when the curve happens to be a very short piece of a very flat parabola, it may be held to be, for all practical purposes, equal to a short piece of a very large circle:‡ and, again, for curves where the height of the trajectory bears a small proportion to the length of the arc, it may be taken as sufficiently correct that the distance round the arc is equal to the length of the straight or eye line. For instance, the difference, as computed, is about a foot, with the flat curves of the modern rifles, for the 1000 yards range.

If the above positions be granted, then, where there is no air existing, we may use the problem of Euclid III. XX., which indirectly proves that equal portions of a circular curve will give angles equal to each other from any position on the curve itself. For example, to put the point into a practical form, let a man, on a piece of level ground, put up a theodolite (an instrument many readers will know is for setting off, and also for taking angles) exactly over a peg, and having set out, with the aid of assistants, a truly straight line for 1000 yards, at each 100 yards let him drive in a peg truly in the line. Let him then set off from this line any given angle, such as, say $8\frac{1}{2}'$, by the aid of the instrument, and get his assistants to measure out 100 yards alongside the

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* With the Hazard powder (American) about 106 grs. are required to attain this speed.

† In the ascent to its culminating point the bullet would lose speed, but this loss would be exactly balanced by the gain in the descent from this highest point of the trajectory. In cases such as the modern rifle's bullets give, this loss and gain may be, for the ranges in use, safely ignored. The writer will, throughout this article, assume the 1000 yards to be a true plane.

‡ In all that concerns the curves here treated of they would coincide within some fractions of an inch.

straight line already laid out; let a pole be ranged by the aid of the cross wires in the telescope of the theodolite at this 100 yards and left there (this would be a position about nine inches from the first peg on the straight line already set out); let the same thing be done again, that is, another $8\frac{1}{2}'$, or in toto $17'$ of angle, be set off, and another 100 yards measured and poled (this would be a position of $35\frac{1}{2}$ inches from the second peg on the straight line), and so proceed, adding the $8\frac{1}{2}'$ each time to the angle and putting up a pole, and so on to 1000 yards. The operator would then have set out a truly circular curve together with its tangent.

He would also find, if he measured, from the last pole on this curve in a straight line back to the theodolite, in fact on the chord of the arc, that the distance would be $999\frac{2}{3}$ yards, that is if the measurements were made throughout with such an unstretchable thing as a steel tape, and all very carefully indeed; and he would also have the natural curve that a match rifle bullet would make if the curve could be put in a horizontal position, and if the bullet had been projected *into a vacuum*. If this is the case, then the actual difference or angle between this and the actual curve is due to the air resistance retarding the speed of the bullet, and thus giving more time for gravity to act, and so coercing the bullet into making not only a coarser curve, but a curve rapidly altering its pitch. For instance, the writer finds, as already stated, that where the speed is 1400 feet per second, and where about $8\frac{1}{2}'$ of angle would in vacuo be the angle of elevation for 100 yards, and $8\frac{1}{2}' \times 10'$ would be the angle for 1000 yards, the radius of such a curve would be 20,222 yards, or $11\frac{1}{2}$ miles, whereas, as matters stand, the radius of any part of the actual curve would be:

At 50	yds. (or the mean between 0 yds. and 100 yds.), about	18,600 yds.
At 150	,,	16,000
At 250	,,	14,040
At 350	,,	12,510
At 450	,,	11,270
At 550	,,	10,260
At 650	,,	9,420
At 750	,,	8,700
At 850	,,	8,090
At 950	,,	7,560
At 1050	,,	7,090

Now, all this is to be easily computed from the actual angles as ascertained—first, by much shooting in good weather, and, secondly, by computing a table of angles which will fit fairly accurately the mean of such shooting, of which more further on.

The sights of the writer's rifles have ever been divided in terms of the great circle—that is, instead of putting on an arbitrary scale, where the angular value in rise, usually the hundredth of an inch, varied as the distance between the sights varied, a scale was put on of such a character that, whatever the distance between the sights might happen to be, the dividing of the scale should be such that, first, it should invariably give but one angular value, and, secondly, it should be that same angular value which has been universally recognised as the standard for all angle-taking instruments; thus the rifleman would be, in conversing about his sights, speaking a language universally accepted by scientific men.

Such a system involved, of course, giving up a simple value per inch, as, for example, the one-hundreth of an inch, or one inch, and also involved cutting the scales in a definite relation to the distance between the two sights, or what is called the radius. The reader will now perceive that his sights are in fact neither more nor less than a piece of an extremely large theodolite or angle-taking instrument,* and that he therefore is able to ascertain with it the actual angles of the projecting instrument to which it is attached—that is, the barrel.

It has been the custom for gunners to ascertain their trajectories by erecting screens, covered with tissue paper, at intervals along the track of the bullet. This method, available without much trouble for short ranges, becomes difficult with the larger ranges. It is open to objection, too, that the bullet, in passing through any substance, however thin, not only receives a check, but also is liable to the possibility of deflection. The first objection is the most important, and the time alone it takes makes it objectionable.

But why should any such trouble be thought necessary when, with the modern sights—actually a perfect bit of a very large theodolite—the entire path of the bullet can be calculated with the most perfect certainty and rapidity. Or, if a gunner dislikes figures, he may, as has been already pointed out, lay the entire curve out on a flat meadow, either with a good theodolite, or even with the rifle sights themselves, with the rifle laid horizontally

* The circles of all angle-taking instruments, as is well known, are divided into 360 degrees, and each degree into 60 minutes, which would give 21,600 minutes for the whole circle. The value is given in minutes, as, for small angles, it is sometimes preferred to have their values stated in minutes, instead of degrees and minutes. For instance, the 1000 yard angle can be expressed in degrees and minutes—thus, 2° 15′, or in minutes alone, 135′.

and rigidly fixed. He may do exactly as the writer has already pourtrayed, except that, instead of setting off $8\frac{1}{2}'$, he sets off the table at angles of his rifle. He will thus have his trajectory laid flat on the turf. He can ascertain the trajectory by actual measurement, for any range and at any part of the range. He can, if he has not 1000 yards of turf at hand, do it to say a half, third, or quarter scale, or even a tenth or twelfth scales, if only 100 yards are available, and multiply his values by twice, three, four, ten, or twelve times, as may be, to procure actual values; and with regard to, say, a twelfth scale, there is the convenience that the operator could lay out the entire curve in less than 100 yards; and, with his offset rod divided to inches and twelfths, he would be able, without much walking, to ascertain his values at once, substituting feet for inches.

If, however, a gunner desires to ascertain his trajectory heights by computation—and of course this is the most accurate and quickest method, for he will escape the chance of errors in setting the lines out (a process requiring care and skill)—he will proceed thus: Let it be supposed that the rifleman desires to ascertain the path the bullet makes for 1000 yards. The zero of the scale of his rear sights, divided to degrees and minutes of the great circle, has been ascertained to be correct, by shooting at, say, 12 yards,* with the Vernier at zero, and seeing that the bullet centre is just as much below the centre of the small dot he shoots at, as the eye line is above the axis of bore, plus the one-eighth of an inch which must be added for gravity pull acting during the time the bullet is travelling the 12 yards. Let his rifle, under this condition, be assumed to give the following angles:

100 yards	9′	600 yards	1° 09′ or 69′
200 „	19′	700 „	1° 24′ „ 84′
300 „	30′	800 „	1° 40′ „ 100′
400 „	42′	900 „	1° 57′ „ 117′
500 „	55′	1000 „	2° 15′ „ 135′

Now, when shooting at 1000 yards, the bore of the rifle, at the instant the bullet is passing the muzzle, will have to point at an angle of 2° 15′ (some persons prefer to omit the use of degrees, and record the angles in minutes only), or 135′ above the centre of the bull's-eye.

This is the first position. Now let a case be assumed. Say it

* Twelve yards is a convenient distance, for reasons stated further on.

is required to compute the heights of the trajectory for every hundred yards along the whole range to 1000 yards, beginning at the position of the first 100 yards. On examining the table, it is clear that the bullet (neglecting the little difference already referred to, caused by the eye line and the bore line not being quite coincident), * had there been no gravity pull, would have kept along the 135′ line; but gravity has had time to pull the bullet down 9′ by the time it has got to the first 100 yards, therefore the bullet would actually pass below the 135′ line this 9′, or 126′ above the eye line. And because at *100* yards *1′* equals *0·0873* of one foot,† therefore 0·0873 × 126 ft., which equals 10·99 ft., is the height the bullet passes at 100 yards above the eye line.

To repeat the process, substituting the different distances along the ranges for the 100 yards :—

Yards.					Feet.		Times.		Feet.
200	135′	−	19′	×	0·0873	×	2	=	20·2
300	135′	−	30′	×	0·0873	×	3	=	28·1
400	135′	−	42′	×	0·0873	×	4	=	32·4
500	135′	−	55′	×	0·0873	×	5	=	34·9
600	135′	−	69′	×	0·0873	×	6	=	34·5
700	135′	−	84′	×	0·0873	×	7	=	31·1
800	135′	−	100′	×	0·0873	×	8	=	24·4
900	135′	−	117′	×	0·0873	×	9	=	14·1
1000	135′	−	135′	×	0·0873	×	10	=	0·0

* To be very accurate, to these angles should be added the angular value which the fact of the eye line being above the bore line demands. This would give for 100 yards 9′ + about 1′, for 200 yards, 19′ + ½′, and for 300 yards 30′ + ⅓′, and so on.

† Should the computer prefer the values to be in inches, he would have to substitute 1·0472in. for 0·0873ft., for the value of 1′ of angle at 100 yards. It has been already stated there are 21,600′ in the circle; the value of 1·0472in., or 0·0873ft. is, therefore, computed as follows: What is the value of 1′ of angle at 100 yards in actual measurement? There are 21,600′ in the circle, and the radius is 100 yards; all, therefore, that has to be done is to find the feet measurement of the circumference of *this circle, and divide by 21,600. The ratio of* circle and radius being 6·2832, these last figures of the ratio must be multiplied by *100. This equals 628·32* yards or *1884·96*ft., and is the length of the circle round; and 1884·96 ÷ 21,600′ = 0·08726ft. per 1′, &c., and if inches are preferred, then these last figures multiplied by 12 will give the value of 1′ *of* angle, or in inches 1·0472 nearly. Call it, when feet are required, 0·0873, and when inches are required 1·047. Of course, unless great accuracy is required, 0·087 and 1·05 will give close results.

For rough computation, 1in. for 1′ at 100 yards will be sufficiently near to give results. To be accurate 1in. equals 1′ at 95·49 yards. The same values can be computed with a table of sines. And here it is as well to bring to the recollection of those who are conversant with such tables that, for small arcs, say to 4°, it may be reckoned with perfect safety that the arcs can be practically taken as equal to either the chord, sine, or tangent.

Here the last column will represent the exact heights of the curve at every 100 yards along the range from the line of sights or eye line.*

Again, let it be required to find the highest point in the curve.

By inspecting the last column it will be seen at once that this point must be somewhere between 500 and 600 yards, and probably between 500 and 550 yards. It shall be assumed that 540 yards will be the place. Now the angle for 540 yards must be computed. At 500 yards it is 55′, and at 600 yards it is 69′, or a difference of 14′. It is not strictly correct to divide proportionately by the distance, but as it only involves an error of one-eighth of a minute at the half way, it may be done without fear. If this be done, the angle at 540 yards will be 60′ 6″, say 60′ 5″, which is really more correct. Thus, for 540 yards, 135′— 60′ 5″ × the 0·0873 × 5·4 times = 35·073 feet. The question now comes, is this the highest point; if not, which side of 540 yards is it? The thing, therefore, will be to try one side of 540. Let 535 yards be taken. For this distance 59′·9 will be the angle. Then for 535 yards it will be 135′— 59′·9 × 0·0873 × 5·35 times = 35·0758 feet.

Clearly this is a very small trifle higher than 35·073 feet, and thus the point is between 535 yards and 540 yards, and probably near enough for general purposes.† If it should be desired to determine it closer, each yard could be computed—actually the place is between 535 and 536 yards—thus the entire trajectory values, yard by yard, if necessary, can be computed from the sight elevations with an accuracy and a certainty far surpassing screen experiments, which are subject to the variations of each shot, as well as to the drawbacks already mentioned, and also with a freedom from the errors which will arise even with experienced users of the theodolite. The latter plan, it is true, places the whole affair, especially if it be done on a tenth, or some such scale, as it were before the eyes, at one single grasp; but, excepting this,

* It will easily be understood that if it be desired to compute the heights for any other trajectory, as, say, for 600 yards, all that is necessary will be to substitute for 135′ the 600 yards angle of 69′.

† To give an idea of the flatness of the curves, this short table is appended:

534 yards 35·07552	537 yards 35·07571	539 yards 35·07456
535 yards 35 07583	538 yards 35·07523	540 yards 35·07364
536 yards 35 07589		

From this it will be seen how many figures of decimals it requires to detect the exact point.

calculation is by far the better plan where very accurate values are required.*

With regard to the computations, it will be seen that simple arithmetic is sufficient to insure perfect results, and those who are conversant with that very simple thing, the slide rule, may get close enough results to serve every common purpose.

With regard to the table of angles and their method of construction, the first thing the writer has always done is to shoot his rifle at 12 yards (a mere convenience as regards the distance—the 1′ of angle at that distance is one-eighth of an inch, which all foot rules give.) He shoots at a row of dots, say five, first one shot, with the sight at a guess position—the sight not being divided. The shot ought to strike the difference between the axis of bore and the eye, or sight line, plus the drop by gravity, which is an eighth of an inch for twelve yards, when the speed is about 1400 feet per second. If it does not strike this much below the dot—and the chances are it will not—then the error between the place where the bullet should strike, and where it actually does, is measured in eighths; and as eighths are equal to minutes, the slide carrying the aperture is screwed up or down, as the case requires, the number of minutes wanted to make the bullet strike where it should—which can be done by compasses stepping off the amount from an already divided sight borrowed from a similar rifle. After a shot or two to verify, a pencil line is struck across, and the divisions and Vernier cut. The Vernier should have the power of shifting 10′ or more. The rifleman will verify the truth of the Vernier position, of course. With the sight so set, the rifleman shoots in all weathers at enough ranges along the 1000 yards to enable him to get the angles on which he may eventually base his tables. 200, 500, 800, 900, and 1000 yards would be enough. If possible, say ten shots at each range should be made in one day. Now, it is clear, from what has been said, that as the bullet flies along, the resistance of the air checks its speed, and, therefore, gives more and more time than if there was a vacuum for gravity to act. The curve must therefore get coarser and coarser, and the angle more full, for every hundred yards; and that

* Any man accustomed to make very accurate drawings could plot the curve; but it would be better to plot it from the calculated heights than to depend on even the very best protractor—the angles are too fine. A scale of 100 yards to the foot, using a 30 scale, would be found convenient.

fullness of angle will decrease in some definite way, and not sometimes faster and sometimes slower.

This increase, too, will depend for its value not only on the mass, but on the proportion of the diameter to the length of the bullet, &c., also on its speed.

Fortunately the increase of the angle for each 100 yards for the match rifle is so exceedingly nearly one minute of angle, that if a minute be taken to represent the air retardations no error of any possible moment will obtain.

All that remains to be done is to hit on some starting angular value, which, with the additional minute for extra value due to air resistance increasing the time gravity has to act, will fairly fit the mean of observation throughout.

Now this angle which is wanted may be really got at through the speed. The writer possesses a ballistic pendulum, and is able with it to ascertain this speed by the well known gravity formula (fall $= 193$ inches $\times$ time^2)* and reducing it to angular value. At the best speed it comes out that it is over 8′—call it 8′; and, as the retardation equals, the writer finds, all but 1′, this makes 9′.

And thus the scale is built as follows:—

Yards.		Diff.	Diff.	Yards.		Diff.	Diff.
0	0′	—	–	700	1° 24′	15′	1′
100	9′	9′	–	800	1° 40′	16′	1′
200	19′	10′	1′	900	1° 57′	17′	1′
300	30′	11′	1′	1000	2° 15′	18′	1′
400	42′	12′	1′	1100	2° 34′	19′	1′
500	55′	13′	1′	1200	2° 54′	20′	1′
600	1° 9′	14′	1′				

This scale, which may be called A., is, the writer finds, available for weather giving the flattest trajectory; but he also has scales B. and C. for weather not so favourable. There is, too, some slight difference in rifles, and in muzzle-loaders especially, when a large nipple-hole will let more gas escape than usual. Powder, again, varies a rifle.

* Fall equals 193 inches × square of time. Practically applied it would be so. Say 1420 feet per second initial speed of bullet, what is the fall due to gravity at 100 yards? 100 yards = 300 feet; then as 1420 feet is to 300 feet, so is 1 second of time to 0·2113 nearly seconds of time; that is, this bullet would, in vacuo, have passed over the 100 yards in 0·2113 seconds. ·2113 × ·2113 = ·04463, etc., and that multiplied by 193 = 8·614 inches, which at 100 yards will, at 1·047 inches to the minute, give 8·22 minutes.

They are as follows:

Yards.	A	Diff.	B	Diff.	C	Diff.
100	9′	—	9¼′	—	9½′	—
200	19′	10′	19½′	10¼′	20′	10½′
300	30′	11′	30¾′	11¼′	31½′	11½′
400	42′	12′	43′	12¼′	44′	12½′
500	55′	13′	56¼′	13¼′	57½′	13½′
600	1° 9′	14′	1° 10½′	14¼′	1° 12′	14½′
700	1° 24′	15′	1° 25¾′	15¼′	1° 27½′	15½′
800	1° 40′	16′	1° 42′	16¼′	1° 44′	16½′
900	1° 57′	17′	1° 59¼′	17¼′	2° 1½′	17½′
1000	2° 15′	18′	2° 17½′	18¼′	2° 20′	18½′
1100	2° 34′	19′	2° 36¾′	19¼′	2° 39½′	19½′
1200	2° 54′	20′	2° 57′	20¼′	3° 0′	20½′

The writer here points out that, in the construction of the scales B. and C., properly the value 1′ should alone be altered if it be the alteration of air resistance only which is the cause of the alteration of elevation for the same range; whereas he has kept to the 1′ and reckoned as if the initial speed alone had altered. But the fact is that, being desirous to keep to angles not involving endless decimals, he found he could assume an alteration† in the initial speed of a trifling amount, and still no error of any practical value for such ranges as are shot at would arise. In fact, the value of the 1′, slightly too favourable for B. and C., would balance, for these ranges, the error introduced into the speed.

There is a further item in this interesting branch of gunnery to be considered, and that is the loss of initial speed per 100 yards, due to air retardation.

There are difficulties attending the solving of this problem.

If, while the air offered resistance to the forward flight of the bullet, it offered none to its fall, the problem would be easy; but not only does it offer resistance, but this fact has been brought to light, that a body falling in undisturbed air will act differently from what it would in disturbed air.

A body falling, and having at the same time no forward movement, will, as it falls, pack the air under it, and so disturb before it actually gets to it, whereas a body, with a forward movement, such as a rifle bullet, will enter into new and therefore undisturbed air.

The writer's ballistic pendulum unfortunately has always been in a position not to be available for the actual values to be ascer-

* Scale A. is again entered, so that the difference may be seen without a back reference.

† Such an alteration of speed can, indeed, occur.

tained; he hopes, however, to be able to rearrange its position, and accomplish this, but he computes that, taking the A. table of angles as a basis, and about 1400 feet per second as the initial speed, as it in fact is, the loss of speed will be represented by the following table, as calculated from those angles. Nevertheless this must be said, that it is a computation alone, and on a certain assumption which involves a possibility of error.

The writer, therefore, only gives the table for what it is worth, for he has a strong belief, which it is hoped will be soon verified by actual ballistic experiments, that the loss is not so great as the table gives.

Distance	Velocity	Distance	Velocity*
0 yards,	1400 feet initial speed.	600 yards,	822 feet initial speed.
100 ,,	1255 ,,	700 ,,	769 ,,
200 ,,	1136 ,,	800 ,,	723 ,,
800 ,,	1037 ,,	900 ,,	682 ,,
400 ,,	954 ,,	1000 ,,	645 ,,
500 ,,	883 ,,	1100 ,,	611 ,,

There is a very apparent disagreement between two statements made in this paper, the one being that the highest part of the trajectory is not greatly over the half way, and the other that the speed at 1000 yards is not half the initial speed. One would be led to infer, from the great loss of speed, that the highest point would be more like at two-thirds of the range; but it happens that the falling of the bullet by gravity is also checked by the air resistance, and much more heavily than it would be if it fell with its nose pointing downward. In fact, it falls broadside, and thus is in its best attitude for the air resisting its gravity velocity—a fortunate event, for otherwise the trajectory would be far coarser than it now is.

As the position of the bullet opposing its broadside in its gravity fall to the air has been referred to, the writer takes the opportunity of pointing out that, though in vacuo the axis of the bullet would undoubtedly keep parallel to the initial line, in air the axis of the bullet most certainly keeps tangential to the trajectory curve, or so nearly so as to be considered tangential. This fact he has many years since ascertained by direct experiment, and this has since been verified by the Woolwich gunners, by examining the position of the six hundred pounder projectiles in their flight.

* In this table decimals have been omitted, and the nearest foot the calculations give, taken. The strings of decimals were interminable.

It is rather beside the present position of the loss of initial speed of the match bullet to give tables of the loss of such speed in other bullets, but it may exemplify the massiveness of the air resistance to introduce two tables, computed from actual pendulum experiments with Express bullets.

110 grains powder, Curtis & Harvey, 309 grains bullet, ·451 diameter.

Yards.	Initial Speed in Feet.
0	1913
25	1783
50	1673
75	1578
100	1474
125	1418
150	1347
175	1280
200	1217

110 grains powder, Curtis & Harvey, 366 grains bullet, ·451 diameter.

Yards.	Initial Speed in Feet.
0	1765
25	1674
50	1592
75	1518
100	1449
125	1384
150	1323
175	1276
200	1223

These bullets it will be at once seen are short in length, in fact they are, as already stated, for Express rifles: it exemplifies the undesirableness of carrying the Express system too far, and also illustrates the point now in treatment.

Appendix.

It may be interesting to those engaged in gunnery to examine the following table, which the writer has drawn up for his general guidance.

It gives for the two columns, the proportions of bullet and powder, and the third column the resulting initial speed.

It is found that these velocities are fairly sound for all usual small arm work, that is, for bores varying very largely, and of the usual length, and also for charges varying very largely. In the length case about eighty times the diameter of bore has been taken: where there is a shorter length a little loss of force will obtain, and *vice versâ*.

In fact, it is a very good general table for breech-loaders, and rather too favourable for muzzle loaders, say about 25 feet per second.

Lead.	Powder.	Velocity.
2	1	2260
2½	1	2000
3	1	1850
3½	1	1750
4	1	1670
4½	1	1600
5	1	1537
5½	1	1479
6	1	1425
6½	1	1374
7	1	1326
7½	1	1280
8	1	1236

There is a curious anomaly worth mentioning in relation to the zero of rifles. It is this, that if a thoroughly accurately-made pin-hole plug be entered into the breech end of any rifle, the construction of which permits the eye to see through the barrel, and also an aperture plug be entered at the muzzle; and if the rifle is then pointed, with its sights set to the zero, ascertained by shooting at the 12 yards, at any object, say at 100 yards off, and if then the line of bore be examined—it will be found that there is a very great difference between the two lines, instead of there being only about the inch the eye line is above the bore line.

It happens in all rifles, more or less, and in rifles with the long fore-end, such as military rifles, the removing the fore-end increases the amount considerably.

A rifle, however, having an *extremely* short barrel does not exhibit this anomaly. This peculiarity will develop vertically if the rifle be shot as usual, but horizontally if the rifle be fired horizontally.

The best way to develop this fact is to shoot at such a distance as not to mix up the gravity pull with it, say at 25 yards, when the fall is half an inch only.

The anomaly is no doubt due to the total mass of the rifle being non-coincident with the axis of the bore, and on the jerk of recoil being given (it is like a sharp blow to the rifle, as it happens in less than $\frac{1}{300}$th of a second), the rifle, instead of a true recoil, has imparted to it such a motion as eventually causes the muzzle to jerk up, but of which the first result is to set up a distinct bend of the barrel itself, actually forcing the muzzle *down below* its original line.

It happens that at just about this moment the bullet passes the muzzle, and so it strikes *lower* on the target than if there had been no such action. In fact, it is similar to the action of a fishing-rod, which, if watched while a "strike" is being made, will exhibit, some way three-quarters up, a neutral point, above which the rod will actually move the contrary way for a short time, before the rest of the rod drags this upper part back.

It is easy to comprehend this objection, that the barrel, especially of a match rifle, is too stiff to allow of this; but, first, it is the fact that such a barrel can be easily sprung, even with the two hands, a very eyeable amount out of truth (of course it goes back again), and that the jerk of the kick is in actual fact like the blow of a hammer.

With regard to the improvement of trajectories, the writer does not feel that much more can be done to improve them under the terms of the weights and charges used.

No doubt with a heavier rifle more may be done; for instance, the writer has 15lb. rifles requiring, for 500 yards, 45′; for 1000 yards, 1° 55′; for 1500 yards, 3° 25′; and for 2000 yards, 5° 17′; the initial speed being about 1565 feet per second, but this only because these rifles are "a little bit longer—a little bit broader—a little bit deeper"—than the usual match rifle, which requires about $6\frac{1}{4}$° at 2000 yards, and the weight of the bullet and powder in proportion.

But the trajectory of the match rifle as it stands is very small. Let the reader contemplate some of the older curves. The English Enfield musket of 1854, for 1000 yards, under its very best conditions, gave $3\frac{1}{2}$°, and with common cartridges $3\frac{1}{4}$°.

The writer's own angles, in 1852, at that range, were worse.

General Jacobs, whose name has been well known in relation to long ranges, was satisfied with very coarse angles; and, though the writer cannot at the moment of writing state what his angles were at 1000 yards, he has found it stated that one of Jacobs' rifles, of $14\frac{1}{2}$lb. weight, especially built for 2000 yards range, required 12° 30′ of elevation for that range, whereas, as has been just stated, even the 10lb. match rifle, with its usual charge, only requires about $6\frac{1}{4}$°. It is probable that the rifle above referred to as requiring 12° 30′ for 2000 yards, would demand over 4° for 1000 yards.

In conclusion it must be admitted that, in studying that branch of gunnery of which this paper treats, a very large field of interest is opened to the rifleman, which, while it cannot but make him a better marksman, must vastly increase his grasp of the subject, and his interest in its higher branches.

CHAPTER VII.

RECOIL.

THE recoil of the gun appears to me to consist of two distinct portions, although closely connected; and, for the sake of explicitness, they may be described as the *initial recoil* and the *kick*. The former is a process of gradual development, brief as is the period of action. Until a certain amount of force is generated there can be no movement whatever. As soon, however, as the shot begins to move forward, the gun (unless fixed) would move backward—slowly at first, but with gradually increasing speed as the shot increases in velocity.

On the shot reaching the muzzle, the circumstances undergo a marked change. The "initial recoil" had been gradually increasing as the shot moved faster and faster up the barrel, but now it receives a sudden additional impulse; for hitherto the backward pressure of the gas on the breech had been in great measure counterbalanced by its forward pressure on the projectile; but the counterpoise being lost as the shot leaves the barrel, the full force of the gas takes effect on the breech, and hence it is that the *kick* is so sensibly felt.

During the progress of the shot up the barrel the gas-pressure operating on the breech had not been wholly engaged in producing recoil, because other work had been going on which to some extent counteracted the tendency of the breech to move backward. Thus, breech and barrel virtually form one whole, the breech being no more able to retreat without the barrel than the barrel can run forward without the breech. The force of the gas, however, is exerted, so to speak, in an endeavour to move them in opposite directions; for when the shot is driven forward, it would, by reason of the friction, carry the barrel forward also, just as a tight-fitting mass of tow on a cleaning-rod, on being forced into the bore, will carry the barrel with it unless the latter is firmly held. Accordingly, the force of the powder-gases engaged in pushing back the breech of the gun is diminished in effect by so much of the forward pressure as, in the form of friction, is tending to drive the barrel forward.

Besides this friction, however, which has to be overcome, and the weight of the shot which has to be moved, a considerable proportion of the work to be done by the powder-gases is the expulsion of the column of air in the barrel, which, especially as the shot approaches the muzzle, must offer much more resistance than the shot itself.

When the shot reaches the muzzle of the gun, a sudden relief occurs at one end of the barrel while the gas pressure is still in action at the other. The compressed air is expelled from the barrel, and the frictional resistance and projectile are removed simultaneously; the pressure of the gases being thus exerted unchecked upon the breech, gives a strong additional impulse to the slow-growing initial recoil, and the movement of the gun culminates in the *kick*.

Equal muzzle velocity in shot may be produced by very different powders; and that which, by evolving its gases most rapidly, exerts greatest pressure at first, diminishes soonest in force as the shot moves up the barrel, and exerts least pressure when shot and gun part company. The quick-burning powder would thus give greater initial recoil and less kick. The initial pressure against the shoulder, being in the nature of a comparatively slow push, would in many cases probably have an effect similar to that produced by holding the gun with a very firm grip—the sensation of the kick would be