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The Long Range Guns*

EXTRACTS FROM A LECTURE DELIVERED AT THE ROYAL ARTILLERY INSTITUTE
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MAJOR J. MAITLAND-ADDISON: General Stokes, Ladies and Gentlemen. We read that the German Long Range Gun has been aptly nick-named by the French "la Grosse Berthe." Two other appelations which I am told are used, one of which is very appropriate even if the other is a little more expressive, are "La Princesse Lointaine," after one of Rostand's plays, and "L'Imbécile." Our gallant French Ally would thus appear to be contemptuously indifferent towards the attentions of this monster weapon—the "Super Gun."

However, a marked advance has been made in artillery—for a projectile has been thrown a distance four times greater than has ever been previously attained. It is my purpose to explain in as simple a manner as I can, the various factors which coöperate towards this achievement—and further to point out that there is nothing about this gun which differs, except in degree, from the ordinary gun—that is to say, no new discovery has been made which, *per se*, has enabled the enemy to affect what he has just accomplished in this respect.

On the 23rd March—Palm Sunday—the Parisians were much astonished by a bombardment of Paris, which lasted throughout the day. At first it was thought that bombs were being dropped from enemy aeroplanes—but this idea was soon

*My acknowledgments are due to Captains L. Benke, and F. Hunt, of the Ordnance College, for their assistance in the calculations entailed, and in the preparation of the plates.

dismissed, for none were to be seen, although the bombardment continued. The conclusion was then arrived at, that such a range as the distance between the German front and Paris had been obtained by a powerful gun, but only by the projectile itself becoming a gun at some point of its trajectory, and ejecting a secondary shell to complete the great distance of 75 miles.

This, and many other quaint ideas were hazarded one after another, to be eventually dispelled by the more technical experts, who gave the real reasons which lead up to such a feat.

It must be remembered that in 1915, the Germans caused us no little surprise by firing shells into Dunkirk from Dixmude—a distance of 20 miles—and since then a considerable amount of long range firing has been carried on at the Front. But in 1918, the unprecedented range of 75 miles is an accomplished fact. This is only in keeping with the progress that has been made in artillery during the war. War makes for progress—and I will leave it to my audience to surmise what will be the extreme distance to which shell may possibly be projected in 1921, assuming the rate of increase to be, at least, uniform.

My lecture is what may be called pseudo-scientific-popular, because, although I mean it to be popular, it must be to a certain extent scientific; otherwise, I should have some difficulty in explaining the factors which conduce towards firing shells to such great distances.

I have divided it into the various subheads, which would appear to me to form the logical sequence of the subject.

THE AIR RESISTANCE TO PROJECTILES (FIG. 1.)

I must first introduce to you some conceptions of what an important factor the air resistance is to projectiles in retarding their motion. We all know something about the atmosphere and its resistance to motion, but I think that few of us have more than a very cursory knowledge of how resisting it is to projectiles moving at high velocities. There may be a few here who have at some time or another been whirled round the

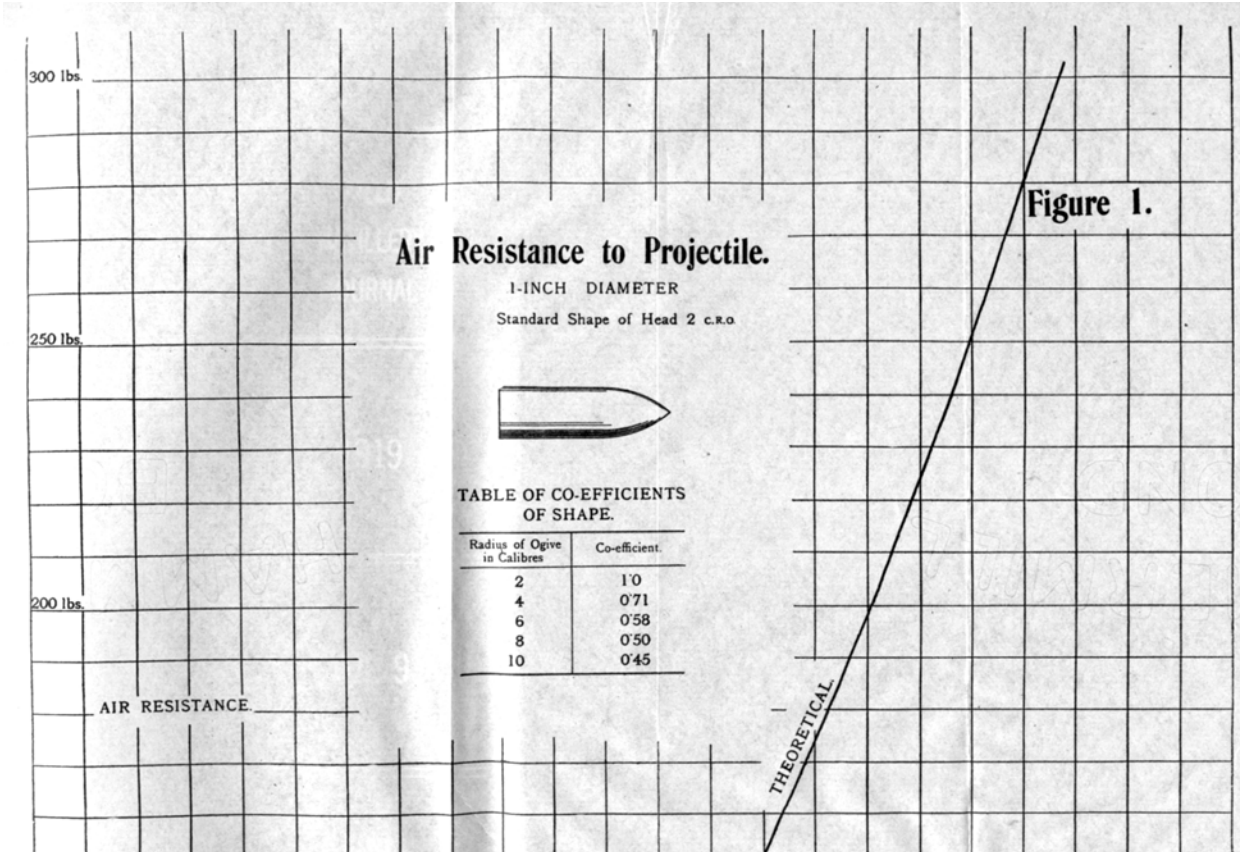


Figure 1.

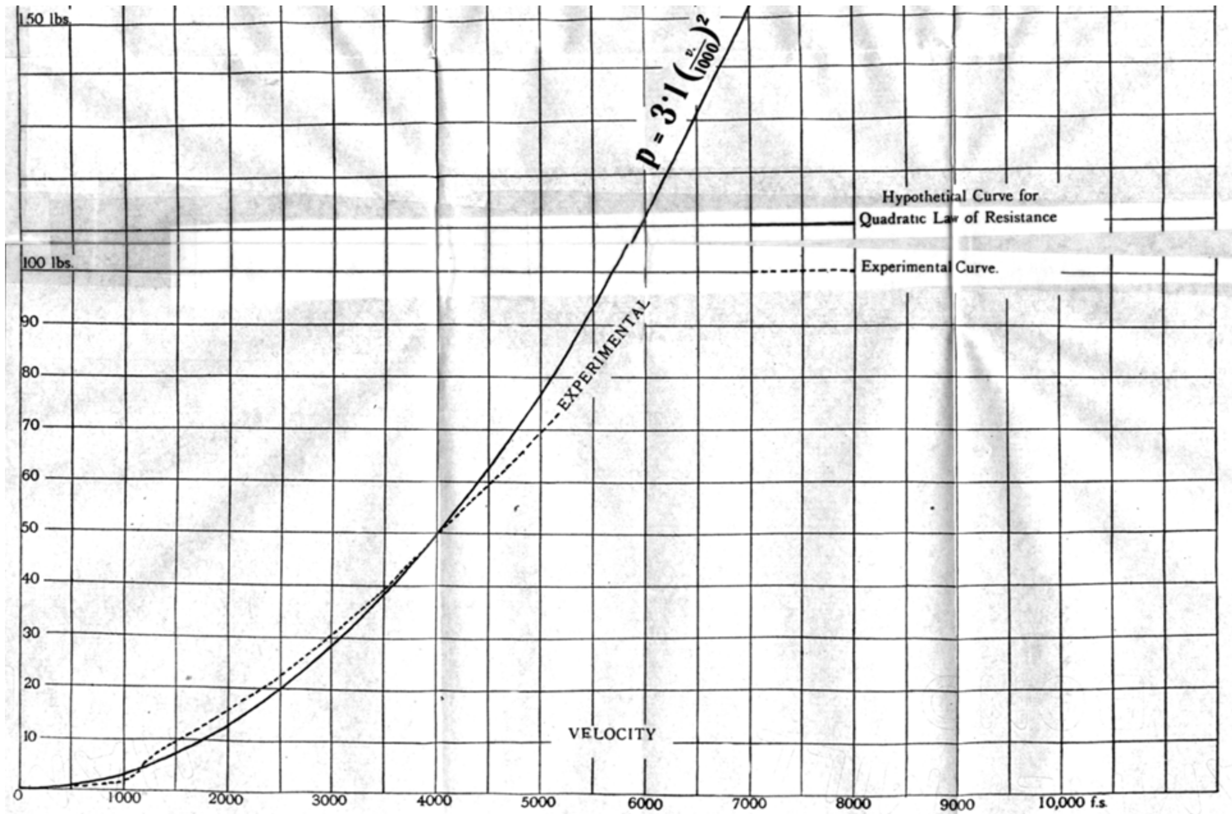
Air Resistance to Projectile.

1-INCH DIAMETER

Standard Shape of Head 2 C.R.O.

TABLE OF CO-EFFICIENTS OF SHAPE.

Radius of Ogive in Calibres	Co-efficient.
2	1·0
4	0·71
6	0·58
8	0·50
10	0·45


150 lbs.
100 lbs.
90
80
70
60
50
40
30
20
10
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000 f.s.
VELOCITY
EXPERIMENTAL
$p = 3{\cdot}1\left(\frac{v}{1000}\right)^2$
Hypothetical Curve for
Quadratic Law of Resistance
Experimental Curve.

Brookland's Motor Track at speeds approaching to, but probably under, 100 miles per hour, and who consequently will have gained some experience of the pressure of the air as they rushed through it; and we know that racing cars are in some cases stream-lined in order to diminish the air resistance.

Also when travelling on the Paris Lyons et Méditerranée Railway to the South of France, many will have observed that the locomotives are fitted with "wind cutters" for the same purpose. The natural inference to be deduced is that, even at velocities of 100 miles per hour or under, the air offers such a great resistance that it is desirable to take advantage of such means as can be devised to reduce it, even if the reduction effected be small. Now these velocities are comparatively low ones. The projectile of to-day moves at high velocities. To illustrate the difference, the projectiles at present being fired from the German Long Range Gun commence their flight at about 1 mile per second, or 3600 miles per hour. Fig. 1 represents a hypothetical curve of the air resistance to what is termed the "Unit Projectile" of "Standard Shape"—that is, a projectile of 1-inch diameter with an ogival head of 2 calibres radius—for velocities up to 10,000 feet per second, or about 2 miles per second. This curve is based on what is called a "quadratic law" of resistance—that is to say, the resistance increasing as the square of the velocity.

Alongside it the dotted line represents our experimental knowledge of the air resistance to the same projectile. As you can see, this does not, at present, extend beyond velocities of 4000 feet per second. The two curves agree at two points only, and until we have experimented at higher velocities, thereby extending the knowledge that we possess, it is necessary, for the purpose of calculating these long-range trajectories of the future, to make use of a hypothetical curve similar to that illustrated, working on the principle that such a law is in conformity with the ways in which nature presents itself to us in other respects—these are well known to the scientific world. An examination of the curve shows that for the "unit" projectile moving at 4000 f.s. the air resistance is about 50 pounds—or nearly 50 times the weight of the projectile, which is normally about 1 pound; for a velocity of 800 f.s. this resistance is increased to about 200 pounds, and so on.

To ascertain the resistance to any other projectile of different diameter and shape, we have to multiply the figures shown on the curve by the square of its diameter and by a suitable coefficient of shape.

Thus for a 10-inch shell of standard shape of head moving at 4000 f.s. the resistance is 5000 pounds, or only ten times the weight of the shell. If we give the shell a much more pointed head—that is to say, strike the curve of the head with a radius of, say 8 calibres—the resistance at the same velocity now becomes 2500 pounds, so that it has been reduced by 50 per cent. A table of such coefficients of shape is inset in Fig. 1. This pointing of the head corresponds to the "wind cutter" on the locomotive, and at such high velocities as projectiles move at it is mainly the shape of the head that is important.

DIMINUTION OF ATMOSPHERIC DENSITY AS THE ALTITUDE ABOVE THE EARTH'S SURFACE INCREASES

If the density of the air were uniform throughout, implying a total height of about 30,000 feet, the resistance to projectiles about which I have just been speaking would always be so great that such super-ranges as are now being obtained would be beyond all our efforts, even for very high velocities of projection. But it is a fact that the density diminishes very rapidly with the altitude above the ground and consequently the resistance offered by the air becomes so reduced that as the projectile ascends its motion becomes less and less affected, and so in the extreme case such as we are considering, it tends to travel as if in a vacuum.

At the ground the density is proportional to the pressure exerted by the weight of a vertical column of air reaching to the upper limit, which is equivalent to the weight of a column of mercury 30 inches in height, the pressure being about 15 pounds to the inch—and the density is then about 534 grains to the cubic foot, or a little more than the fourteenth part of a pound avoirdupois. If we assume that the atmosphere expands upwards according to what is known as the Adiabatic Law, which allows for the diminution of temperature with altitude, we should arrive at the conclusion that it terminates somewhat abruptly at a height of 17 miles. On the other hand, assuming that the expansion follows an Isothermal Law—that is, expands at a uniform temperature—we are led to the consideration of an atmosphere of infinite height. But we are practically certain that there is a very much rarefied atmosphere at heights of 50 miles and more, as indicated by meteorites glowing redhot owing to the resistance to their motion—their velocity being very considerable. Equally well, our "physical" knowledge tells us that the height cannot be infinite. The present view is that the expansion follows the first law in the lower strata and tends towards the second in the higher and more rarefied region. Both laws do not differ much in the estimated density of the air up to a height of 30,000 feet or about 6 miles—moreover, up to this point theory has been largely confirmed by experiment. The air is then getting so rarefied that, as far as a projectile of reasonably high ballistic efficiency is concerned, it is not very material as to which of the two above-mentioned laws is nearer the reality.

I have followed the Isothermal Law in my calculations, as it does not favor the estimated range. On this law the density at 20,000 feet is about one-half its value at the ground, one-quarter at 40,000 feet, one-ninth at 60,000 feet, one-eighteenth at 80,000 feet, and at 100,000 feet or about 20 miles it is only one-thirty-sixth—so that at such a height each cubic foot should contain about 15 grains only of air, as compared with 534 grains at the ground.

This is illustrated in Fig. 3 by the shaded column. You will now appreciate how very much the resistance is diminished at such great heights. It is this diminution of density in the upper regions of the atmosphere which alone allows the projectile to travel unimpeded, thus giving such a great range as 75 miles.

THE BALLISTIC EFFICIENCY OF A PROJECTILE

I must now mention an important feature in connection with projectiles—that is, their "ballistic efficiency," or what we call in Gunnery their "ballistic coefficient." If it were not for the atmosphere, a ping-pong ball would travel as far as the heaviest projectile, given the same initial velocity. But in an atmosphere this statement is far from the truth. A ping-pong ball would soon come to rest, and this is because it has poor ballistic efficiency—therefore no power to force a path for itself through the air on account of its bad shape and light weight for its size.

The modern elongated projectile, with its long tapering head, has great ballistic efficiency, because of its good shape and heavy weight for any given diameter.

Then, if we give it a sufficient initial velocity, and project it from a gun at a high angle of elevation, it will reach the upper strata of the atmosphere—and as the air becomes rarefied, so in proportion does the ballistic efficiency increase. For any given calibre of well-designed projectile, there is a certain height above the ground at which point the effect of the air resistance becomes negligible and the ballistic efficiency for all practical purposes infinite. The projectile will then travel in the parabolic curve first pointed out by Galileo about 1610. This is what is happening in the case of the German Long Range Gun, and throughout the major portion of the trajectory, the projectile is describing this path as an actuality for the first time.

One rather curious fact concerning the shape of the head of projectiles—important factor as it is, it has been generally neglected by all the artilleries of the world up to within the last 10 or 12 years, although the advantage of the long pointed head had been indicated from mathematical consideration with very fair accuracy many years previously.

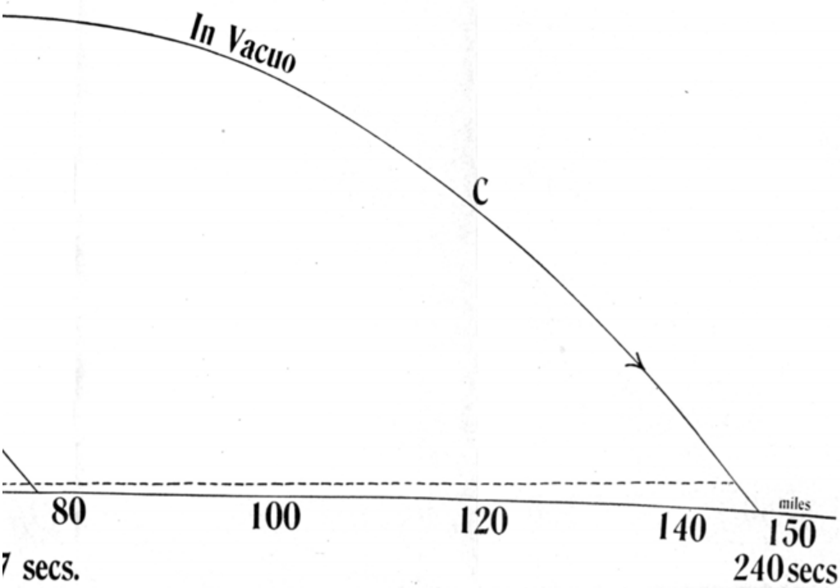
. of Trajectories.

Figure 2.

-	-	- 20 miles	-	-	1915.
-	-	- 70 miles	-	-	1918.

sistance) - 145 miles

10. $^{v}_{4}$(/) = 50°



COMPARISON OF LONG RANGE TRAJECTORIES (FIG. 2)

Fig. 2 represents the comparison of the 20-mile trajectory of 1915 with the 75 miles of 1918 of the latest Long Range Gun, also the limiting trajectory *in vacuo,* for the same velocity, and for the same angle of projection, as for the 75-mile trajectory. These two factors I have estimated to be 5000 feet per second and 50º. From what we learned about it at the time, the 20-mile trajectory from Dixmude to Dunkirk was accomplished with a large naval gun and with a much lower velocity than 5000 f.s. The ballistic efficiency of the projectiles at present fired into Paris is about 10 units, which is somewhat high for such a small calibre of gun as 210 mm. or 8.28 inches.* By employing guns for which the projectiles could have a greater ballistic efficiency, then with the same velocity ranges of more than 100 miles could be obtained. Proceeding in this way we could, for the same initial velocity, get nearer to the limiting trajectory of 146 miles—but never quite up to it. But by increasing both velocity and ballistic efficiency greater ranges than this even are obtainable.

Such a velocity as 5000 feet per second has not, to my knowledge, ever been obtained before. The greatest I know of is that of 4000 f.s. from a small gun at Shoeburyness in 1904, when the Ordnance Committee were redetermining the air resistance to projectiles. The late Sir Andrew Noble—some 30 to 40 years ago—obtained velocities of about 3200 f.s. out of a 6-inch gun, but this figure does not even compare with the high velocity of the German Gun. We therefore see how great is the advance that has recently been made in this respect.

THE TRAJECTORY OF THE LONG RANGE GUN (FIG. 3)

In Fig. 3 are shown the details of the trajectory for a range of 76 miles, which is slightly in excess of that from the Forêt de St. Gobain to Paris. The angle of projection has been taken at 50º, but more correctly I think it should be about 54º for this particular gun. The angle for maximum range—which is

* See additional data at end of article. (EDITOR.)

45° in vacuo—is greater in the case of these long-range guns, which have to force projectiles into the upper rarefied strata of the atmosphere. It varies according to the initial velocity and ballistic efficiency of the projectile, and tends to return to 45° as these two factors increase in magnitude—the principle involved being that it is necessary to get the projectile into the more rarefied region by the shortest path, and further, that the flight in this region should commence at about 45°.

As previously stated, the initial velocity is 5000 f.s. or just short of 1 mile per second. The projectile rises to a height of 12½ miles in 25 seconds—the inclination of the trajectory changing from 50° to 41°—the horizontal advance being also about 12½ miles. At this point the air density, as indicated by the shaded column, has diminished to about 1/10 of its value at the ground, and the ballistic efficiency of the projectile, which is 10 units at the ground, has, *vice versa*, been increased 10 times—that is to say, it is now 100 units. From this point the projectile practically ignores such slight air resistance as there may be in the region above it, and its motion becomes a parabolic to a point at the same level on the descending branch, the horizontal distance to which is about 65 miles from the gun. Thus 52½ miles or about 70 per cent. of the whole trajectory lies in what may be termed the Parabolic Region of Flight. The projectile passes through the vertex at a height of 23.9 miles, the horizontal distance to the vertex being about 39 miles, or just over one-half the range.

I might mention that in 1862 two celebrated and intrepid aeronauts, Coxswell and Glaisher, ascended in a balloon from Wolverhampton to a height of about 37,000 feet or 7 miles—the greatest known height ever reached by man—and narrowly escaped with their lives on this occasion. To Glaisher we owe much of our knowledge of the physical characteristics of the atmosphere, and his tables have been in use in the "Artillery" for many years. An aeroplane has never been higher than 4 miles, and Mount Everest, the highest point on the earth, has an altitude of 5½ miles, so that these comparisons will enable you to appreciate the great height attained by the projectile.

On the descending branch, the velocity, which is reduced to 2267 f.s. at the vertex, commences to increase rapidly, attaining its maximum of 3088 f.s. at 7½ miles from the ground, and at about 6 miles from the point of arrival. It then diminishes owing to the rapidly increasing air density, and the projectile finally reaches its destination at a velocity of 2626 f.s.—about 2½ times, the rate at which sound travels; there is, therefore, no possibility of any one hearing it coming, even for the fraction of a second. It will be seen, therefore, that in determining the trajectory, the air resistance has to be taken into account at the two ends only. To quote Sir George Greenhill, F.R.S., so long associated with the Royal Artillery in his capacity as Professor of Artillery and Mathematics at the Ordnance College, Woolwich, the trajectory may be considered as being on two stilts, and it is on these stilts that we have to give careful attention to the exactitude of our calculations. The angle of arrival on a tangent to the earth through the gun is about 54° 40′, which is only a little greater than the angle of departure—and allowing for the earth's curvature, which is considerable over a 76-mile trajectory, another 1° 6′ has to be deducted from this figure, so that actually it is about 53° 34′.

Subsidiary Problems in Connection With the Trajectory

There are several subsidiary problems which I will briefly mention. Some of these—hitherto negligible—now assume importance in these long-range trajectories.

Earth's Curvature.—You will have noticed, for instance, in Fig. 3 that account has been taken of the earth's curvature, which in this case adds ½ mile to the range. This correction is now very much of account, as it varies as the square of the range.

Diminution of Gravity with Altitude.—For a trajectory of the height in question; that is, 24 miles, the acceleration due to gravity at the vertex is diminished about 1 per cent. This would have to be allowed for in calculation were it not that an almost exact compensation is provided by ignoring another effect, namely, the convergence of the "parallels of gravity" towards the earth's centre.

Earth's Rotation.—This is also responsible for a correction to either the direction of the shooting—or to the range—or to both—according as the direction of the fire is from Pole to Pole—parallel to the Equator—inclined to both—also this correction is dependent on the latitude at which the firing is being carried out.

I have estimated that unless such a correction be applied in the case of the gun firing into Paris—the direction of fire being about southwest and the latitude 50º—there would be an excess of about 700 yards of range and a deviation to the right of the line of fire of about 400 yards.

Drift.—As artillerymen, we know what "Drift" is, but I will just mention that it is the deviation to the right from the vertical plane of departure due to the right-handed rotation of the projectile. I have not attempted to calculate how much this drift is, because it is a matter of great difficulty, and the result arrived at would be uncertain, but I will say this much about it: I think it is much less than a gunner might be predisposed to imagine, for the reason that 70 per cent. of the trajectory is accomplished practically in a vacuum where there is no appreciable atmosphere to cause it—and such "drift" as there may be is due to the comparatively small curvature of the trajectory in the two "stilts." If I were asked to hazard a guess as to its "How much," I would say that I think that it would be less than 1 mile of deviation in 100 miles of range. However, this is guesswork, and it is really a matter of experiment to ascertain its magnitude.

Accuracy of the Gun.—A small error in the elevation for maximum range would not appreciably affect the range, so that a little "jump" or "whip" of the gun is of no great importance.

But a varying error in the muzzle velocity from round to round, if it be large, vitally militates against the accuracy—and there is just a possibility that it may be difficult to maintain a constant M.V. in such a gun. For example, 100 f.s. or 2 per cent. change in M.V. alters the range in this case by over three miles.

Wind Effect.—Here again I have not made any estimate, but arguing on the same lines as for the "drift," I do not think it should be very great.

I will now pass on to some considerations of the projectile and the gun.

THE PROJECTILE (FIG. 4)

The shell presents features that are distinctly novel. In the first place it is built up, instead of being made as a whole; in this way manufacture and filling are much facilitated. Secondly, it is divided into two principal parts, entirely different in characteristics and functions. These are: (*a*) The body or shell proper; (*b*) the head.

The Body.—The walls of the shell are abnormally thick, tapering towards the front, where the danger of deformation due to "set back" diminishes. This is an indication that the pressure to which the gun is worked is in all probability greater than usual, but it also serves another purpose—one that is evident in the entire construction of the shell—and this I will refer to later. The function of the two copper bands AA is that of centering and steadying the shell in the bore and of effecting the gas seal. Since they take the rifling, they indirectly assist in rotating the shell, but this is not their "métier"; and to effect this the shell itself is rifled, which is a reversion to old practice. Rifled projectiles were used by ourselves many years ago, but the design was naturally more crude. The thrust of the rifling of the gun on the shell, in imparting the necessary rotation for stability of flight, is thereby much more evenly distributed along the shell, and failure to rotate, which might result if the two copper bands were alone called upon to do this work, is thus eliminated.

Assuming a maximum working pressure of 21 tons/in^2, the acceleration of the projectile at the point of maximum pressure is about 250,000 feet per second, which is enormous, and consequently the "set back" pressure is unduly high.

The diaphragm B increases the strength of the shell, and by dividing the bursting charge into two parts, lessens any risks there might be due to the "set back" of the explosive towards the base. It is understood that it is also called upon to support an additional "impact" fuze inside the shell, which tends to obviate all possibility of "blinds," and serves to ensure the bursting of the forward compartment. It appears to me that this last-mentioned function is its real "raison d'être." The screwed socket C also holds a base impact fuze.

The capacity for high explosive is small, and the burster would weigh about 33 pounds, or 10 per cent. of the weight of the shell. With such thick walls and a small burster, the projectile would break up into a few large pieces, the resulting damage in all probability being small.

The Head.—A curious feature, although not entirely novel, is a false head, which is screwed on to the body or shell proper. It is a comparatively thin-pointed steel dome, and I should say is struck with a radius of about 10 calibres. I have assumed such a radius in estimating the ballistic efficiency of the projectile. I am not aware if the head has been "reconstructed" from parts which may have been found, so that this value is hypothetical, although a reasonable one. The function of this head is to diminish the air pressure, as I have previously explained, but it also serves another purpose—that is, to throw the centre of pressure well forward of the centre of gravity—a principle which, given the requisite twist of rotation for stability, increases the steadiness of the projectile during flight. The analogy of the peg top and the teetotum serves us here. Given the requisite spin, the peg top in which the C.G. is situated high up, is much steadier and maintains its steadiness better than the teetotum in which the C.G. is low down near the point. The pressure on the head of the projectile when leaving the gun is about 1 ton, and the head must be strong enough to withstand this pressure. There is one more point which I might conveniently mention here—and that is this: In a vacuum, a rotated projectile would travel on its path in the same relative position to that at starting, and its axis would become more and more oblique to the trajectory. The presence of air resistance causes a rotated projectile to keep its point nearly in the trajectory. Hence, although the air must be very rarefied in the upper part of the trajectory which I have described, yet there must be sufficient resistance to keep the "yaw" within limits until on descending again into the denser strata the projectile becomes steadied, otherwise it would become quite unstable, the result being "blinds" and short ranging. This I believe not to be the actual case.

The rifling on the shell indicates a slope of 4° or a uniform rifling in the bore of 1 in 45 calibres. Such are the main features of the projectile.

THE GUN AND ITS MOUNTING

Now we know nothing of the type of gun the Germans are using, except its calibre; nor do we know how it is mounted for firing. But by employing another branch of artillery science called "Internal Ballistics" we are able to form a fairly accurate estimate of its length, charge, capacity, pressure, etc. The principles of gun construction can then be applied to determine a gun which will furnish the requisite strength, and we are then in a better position to deduce what type of mounting or carriage might be suitable and form a mental picture of the whole.

The Gun.—One or two of the illustrated journals have depicted in bold lines the gun on a railway mounting. An examination of these pictures shows clearly that they fail to represent with any degree of accuracy what the dimensions of a gun must be that can discharge a projectile with a velocity of one mile per second. I have, therefore, worked out the ballistics and dimensions of a gun which would be equal to doing this—represented graphically to scale in Fig. 5. I have assumed a maximum working pressure of 21 tons to the inch, which is some two to three tons more than a gun is usually worked to. Supposing that it were possible to maintain a constant pressure of this magnitude, all the way down the bore, it is a matter of very elementary dynamics to estimate that the length of the shot travel alone—that is, of the rifled portion of the bore—would be 50 feet. Now no one has yet invented a system by which a constant pressure can be maintained, and as the gases of the charge expand the pressure drops considerably towards the muzzle—down to less than one-half of the maximum. I have estimated, by the more elaborate methods of "Internal Ballistics," that for such a maximum pressure as I am considering, the shot travel must be 75 feet, the average pressure being 15 tons, and that at the muzzle about 8 to 10 tons to the inch. Add to this figure a minimum length of chamber of about 15 feet necessary to hold the very large charge of propellant required, and the total length of the gun comes to 90 feet, or about 130 calibres of length—a length in calibres not previously approached except by Sir Andrew Noble's experimental 6-inch gun of 100 calibres. The weight of a gun is dependent on design, besides considerations of the requisite strength—but following the usual methods laid down for gun construction, it would work out at about 80 tons for such a gun.

The amount of propellant required is about 400 pounds, which is considerably in excess of the weight of the projectile, and if a cord propellant is used its diameter would be 0.6 inches. It is possible that some form of multitubular propellant may be employed by the Hun, which would tend more towards giving the constant pressure I have previously mentioned, and thereby slightly diminish the length of gun required, but this decrement would be very small. As regards the life of the gun, it has been said that such guns would be very soon worn out. I do not hold this view. With a working pressure very little above that normally used, the life of the inner tube should not be much short of the normal life of an ordinary gun of the same calibre, and I think it is quite possible that this particular calibre of gun may fire 600 to 700 rounds before requiring to be relined.

It has also been suggested the Hun may be using a big gun, lined up to a smaller calibre, to effect his purpose of shelling Paris. Such a measure would not give the ballistics for a 75-mile range—and I am inclined to the view that the gun has been specially constructed for the purpose. Manufacturing difficulties are to some extent increased; also special plant is required. These difficulties are not insuperable, as is evidenced, and although gun design has been very much standardized, it is quite possible that newer methods of construction will be evolved which will facilitate manufacture.

The Mounting.—I have pictured the gun as being mounted on a very ordinary type of standing carriage, erected over a deep excavation in the ground, for it is quite inconceivable that a gun of such length could be fired at the correct angle of elevation from any form of railway mounting or even from a long elevated bed of concrete, which has also been much discussed as being the only feasible arrangement.

The gun could be more easily transferred from its travelling position on railway trucks to this type of mounting. It is also practically certain that it has to be brought to the horizontal position for loading. It is not possible to say whether any arrangements exist for traversing. Having regard to the target at which the gun is being fired—also the range—very little traverse is required. One degree change in direction means a displacement of the point of impact of nearly one and a half miles right or left. At the same time, it would be feasible to arrange for a small degree of traverse, although possibly not an easy matter.

The Recoil.—The energy of recoil is greatly subnormal on account of the great weight of gun and recoiling parts relative to that of the shell. In this case the ratio is between 600 and 700 to 1 as compared with the more normal ratio of 120 to 1 in most guns. Therefore, the recoil arrangements do not call for any remarks.

THE ULTIMATE LIMIT OF VELOCITY (FIG. 6)

This illustration shows the effect of increasing the velocity up to what—for want of a better term—I call the "ultimate limit," which is to throw projectiles off the earth into space—such a feat as Jules Verne had in his mind when he wrote his book "De la Terre à la Lune." The requisite velocity is not so immeasurably higher than has already been achieved to-day. A velocity of a mile per second has been obtained. Assuming that some day we may be able to increase this to five miles per second (a velocity only five times greater), the projectile would then travel round the earth as a grazing satellite, completing its orbit between seventeen to eighteen times daily. And with a still higher velocity of about 7 miles a second, it would move off into space never to return. But it must not be presupposed that the dimensions of the gun are merely in simple proportion to the velocity it is required to produce. On the contrary, they increase as some power of the velocity. Nevertheless, it is a remarkable fact that such a velocity as one mile per second has been reached.

SUMMARY

To summarize what I have spoken about at some length, the factors which bring about such long ranges are—

High ballistic efficiency of projectile.

High velocity.

Velocity alone is useless without high ballistic efficiency of projectile, and the greater the calibre of gun we employ, the greater will this efficiency be. Given both requisites, the rapidly diminishing air density with altitude does the rest.

The employment of a long and heavy gun is inevitable.

As regards the pressure to which these guns should be worked, the higher the pressure the shorter the gun within limits. But to use much higher pressures than those at present is not very feasible or desirable.

CONCLUSION

In conclusion, I want particularly to emphasize the fact that there is nothing abnormal about this gun the Hun is using, because all the points I have drawn your attention to in connection with it are points that have been known to us for many years. "Punch" has said, "The gunnery experts of the Allies say that we could have built guns of this nature, if only we had thought of it. Well, we did not think of it, but we must now take the Long Range Gun seriously. It has come to take its place amongst all the other weapons that are being used in the Great War. I do not say for a moment that the employment of such a gun would win the war; far from it, but it fulfils a mission, as does each engine of war devised. And these have been manifold in the last four years.

It will probably have a rapid development in the future—say in the next 20 years: Peace or war, it must be considered.

From such data as I have given you, it is patent that for still bigger guns and higher velocities, the engineering difficulties of construction will go up by leaps and bounds—and we shall have, in all probability, to acclimatize ourselves to a radical change in the scale of gun building. As regards the question—"What useful purpose will such a gun serve?" my reply is—Quite apart from any policy that may dictate its employment as a weapon of war, we should be able to add quite a lot of valuable information to our scientific knowledge of artillery by building a gun of this nature and carefully experimenting with it. Progress demands that we must always be marching towards a further goal or higher limit, and in this respect artillery is no exception.

THE CHAIRMAN: Has any gentleman any question to ask the lecturer?

GENL. CLEEVE: Are there any data which have been found out from the French as to the fall of the projectiles in Paris?

MAJOR MAITLAND-ADDISON: Yes, sir, but they are confidential. I can hardly say anything as regards the accuracy except this, that I see no reason to suspect that it need be anything less than normal. The trajectory lies three-fourths *in vacuo* and can be affected only by the atmosphere on the two stilts, namely the upward stilt and the downward stilt; and so proportionately a gun which will fire 75 to 100 miles will in all probability be more accurate than are the smaller guns we have been using. I do not see any reason why the whole 100 per cent. of rounds should not be placed in a distance of well under a mile at 100 miles.

GENL. CLEEVE: That is what I wanted to find out.

MAJOR MAITLAND-ADDISON: Yes, sir; that is purely a conception of course; it is difficult to say what the accuracy is without knowing more.

BRIG. GENL. PERCEVAL: Would there be any difficulty about a traverse in the mounting, do you think?

MAJOR MAITLAND-ADDISON: I cannot myself see, sir, why there should be any very great difficulty. The gun is nothing more than the normal weight for a big gun, possibly some 70 or 80 tons, but apparently all the "experts" that exist at the present moment say it is probable that this German gun is directed on fixed lines. I think we ourselves would probably design a mounting to permit a traverse.

COL. BETHELL: About the weight of the gun, we are told that it would be about 80 to 90 tons, relying only upon the necessary strength to prevent it from bursting. Now it seems rather doubtful whether a gun of that length would not be so whippy as to require a very considerable increase of weight to make it rigid; that is to say, the gun would have to be built primarily as a rigid girder and then, so to speak, have a hole made in it to make it into a gun. It would probably take the shape of a hollow tube built as a girder and enclosing the gun. Now if that were the case the 80 or 90 ton estimate of weight would be far below the reality, and I should like to know whether that point has been considered.

MAJOR MAITLAND-ADDISON: I have considered that point, sir. I really do not see that there is going to be any great "whip" in such a gun. A small amount of droop or whip is almost immaterial in such a problem as this long-range firing. Guns are very much more rigid than people would imagine them to be. If we take the normal 12-inch gun of 50 calibres in length there is not more than some seven or eight minutes of droop. There is a certain amount of whip, it is true, but I do not think those two factors would enter very largely into this gun. Of course, it would be possible to give it girder strength if necessary without vastly increasing its weight. The jacket, for example, of the gun might be made oval in shape with the thick part of the oval towards the top and the bottom, or it might be strutted to give it girder strength in the ordinary way that is done in bridge construction. But again, I see no great necessity for that. The gun I designed to show to you on the screen has a factor of safety of over 1½ and that is the usual factor of safety which we use in gun construction. Such a gun should be rigid enough.

AN OFFICER: Can you tell us how the shock of the recoil is taken up?

MAJOR MAITLAND-ADDISON: The shock of recoil could be taken up in the normal way. The recoil in this case would not be excessive, because the weight of the projectile is only 330 pounds for a gun of enormous weight; that is to say, a gun from 80 to 90 tons in weight. Therefore, nothing more than the ordinary recoil arrangements are required to absorb the recoil energy.

ADDITIONAL DATA ON LONG RANGE GUN

In connection with Major J. Maitland-Addison's lecture on the Long Range Gun, the following additional information has been received:

Up to date more than 100 shells calibre, 220 mm., have been fired. Each shell includes:

(*a*) A body proper, made of one piece, 500 mm. high, with 40 mm. base, and walls 40 mm. thick at the lower part and 25 mm. at the upper.

(*b*) A plug screwed on the body and bearing threads for screwing the dummy head of the shell.

(*c*) A diaphragm, 28 mm. thick, with 6 holes and, in the centre, a threaded opening 32 mm. diameter. This opening seems to be meant for a second fuze, which could be connected with first one by a tube containing the firing charge of H. E., which accounts for the very small number of non-bursts.

The base is provided with a screwed gaine and a fuze, which seems to be the regulation fuze for the 21-cm. marine shell.

The two relating bands are at 35 and 240 mm. from the base; one is 30 mm. wide, the other 25 mm.

Immediately above each rotating band, grooves have been made a swelled part of the body.

Depth of the grooves. .	2.5	in millimetres
Length	95 and 80	
Width	3	
Twist	4 degrees	

The upper rotating band seems to be provided with grooves to avoid the balloting of the projectile.

Weight	100 kgs.
H. E.	Tolite: 10-12 kgs.

Steel of the projectile: Great proportion of carbon with Ni and Cr.

Calculation gives:

M. V.	about 1700	m.
R. V.	about 700	m.
Maximum ordinate	38	km.
Time of flight	3	min.
Angle of departure	50	degrees
Angle of rail	60	degrees

The resistance of the air is reduced by using a high trajectory on account of the small density of the air in the high regions of the atmosphere. This question of the small density of air seems to be very important in ballistics when firing at long ranges. It is an obvious fact that it is easier to reach long ranges if the projectile travels during a great length of time in regions where the atmosphere delays or disturbs the projectile very little; the shell then travels almost as if it were *in vacuo*. If such is the case, it may be advisable to use an angle of departure a little greater than the angle which would correspond to the maximum range.

The rotation of the earth deviates the projectile a distance which may be 1 km. when the gun is fired from N.E. to S.W. at the latitude of Paris.

No information about the guns; they may be 280 mm. guns, brought to the calibre of 220, tubing them with tubes made of some special steel. The small twist of the grooves (4 degrees) shows that they are fired with a great M.V.