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REPORT No. 989

JULY 1956

Ordnance Developments To Increase Accuracy Of Artillery Fire

R. H. KENT

L. E. SIMON

DEPARTMENT OF THE ARMY PROJECT No. 5B0305005
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0230

BALLISTIC RESEARCH LABORATORIES



ABERDEEN PROVING GROUND, MARYLAND

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RHKent/LESimon/plg
Aberdeen Proving Ground, Md.
July 1956

ORDNANCE DEVELOPMENTS TO INCREASE ACCURACY OF ARTILLERY FIRE

ABSTRACT

The meanings of accuracy and precision are defined and contrasted. The difficulties imposed on the designers of ammunition in achieving precision are pointed out. They consist, first, of the requirement of lethality involving a large percentage of bursting charge with a consequent increase in dispersion; second, the requirement of a small weight of gun and carriage which involves the designing of intrinsically long shell. Nevertheless, the Ordnance Corps has designed shell so effectively that tests show the dispersion due to exterior ballistic sources is smaller than that due to interior ballistic sources. To reduce the interior ballistic causes of dispersion and yet keep a large size of lot, the Ordnance Corps has recently adopted the Grand Lot procedure in which several ordinary lots are combined into one lot and a blending procedure of the powder charges is carried out so efficiently that there is no significant difference in mean muzzle velocity between the various sub-lots. One remaining difficulty is the sudden variation of the wind, especially in unobserved fire. A procedure is pointed out for obtaining the ballistic range and cross winds in a short time.

I consider it an honor that this opportunity has been given me to discuss with the Artillery School what Ordnance is doing to improve the accuracy of guns.

In what follows, I shall explain what we understand by accuracy, contrasting it with precision. I shall explain that the limits imposed by the requirement of lethality and by the limitation on the weight of gun and carriage make it difficult to obtain the desired accuracy. I shall explain the exterior and interior ballistic causes of dispersion and how they are affected by the requirements mentioned. Then I shall give a brief account of the manufacture of the grand lot of 105mm ammunition which was used in Korea. I shall conclude by saying something about what this grand lot does to enable you to get accurately predicted fire.

There is nothing that makes an artilleryman more proud of his gun or weapon than accuracy. There is hardly anything that will do more to improve the morale of an artillery outfit than to have a weapon with sufficient accuracy that the fire may be delivered exactly on the desired spot.

I hope that we in Ordnance are fully conscious of the importance of accuracy and that we never lose sight of one of the most important missions of the Ordnance and that is to supply the Field Forces with accurate weapons. However, in addition to accuracy, important as it is, there are other characteristics which the Field Forces insist their weapons should have. One is lethality or effectiveness at the target and the other is lightness of gun and carriage. As a result of the requirements for lethality, the Ordnance has to make shell with thin walls which are inherently less precise than the thick-walled shell. As a result of the requirement that the weight of the gun and carriage must be kept to a minimum, which imposes a restriction on muzzle velocity, the Ordnance is compelled to design and make very long shell for them to have a small air resistance. Otherwise, in order to obtain the desired range, the weight of the gun and carriage would have to be considerably augmented.

1. Accuracy vs. Precision

Precision is the reciprocal of the dispersion about the mean point of impact. We may say that it is a reciprocal of the probable error in range or the probable error in deflection. Accuracy implies precision plus absence of bias. Accurate fire has not only small dispersion but the center of impact is close to the target. The slide that you are now looking at explains fairly well the meaning of what the statisticians call precision as contrasted with accuracy, although the two words are frequently used synonymously even by statisticians. You see that the precision of these rounds is fairly high; the probable error in range is about 1/4 of a per cent. On the other hand, the center of impact is not very close to the target, so the fire could hardly be called accurate although it is fairly precise.

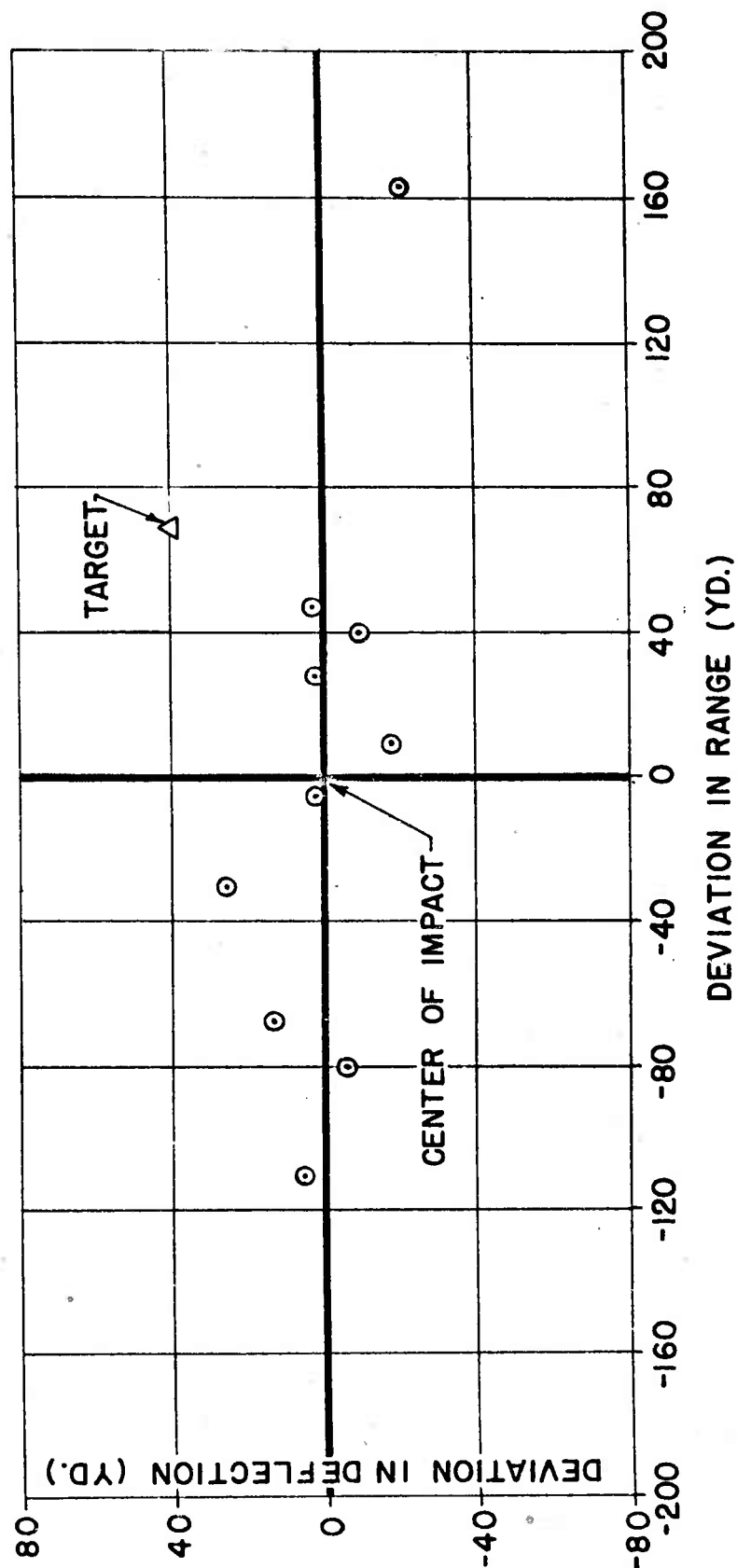
There are several reasons why the center of impact is usually not very close to the target. Suppose a target is attacked with a new lot of ammunition. It will have a different mean muzzle velocity than the lot last used and the difference is not known and hence cannot be included as a velocity correction. Then the lot of shell may have a different average finish and this will cause a change in the air resistance. Even if the ammunition is of the same lot, the wind may have changed since the last meteorological message. The slide that I am now showing illustrates this. It is a plot of the deflections of the 155mm Gun GPF vs. the time. You can see from the plot how great a variation in the deflection resulted from the change in cross-wind of 9 miles an hour that occurred in 40 minutes from 12:45 to 1:25 p.m. It happens that the deflection is a very good and accurate way of measuring the ballistic cross-wind.

2. The Importance of Minimizing the Drag

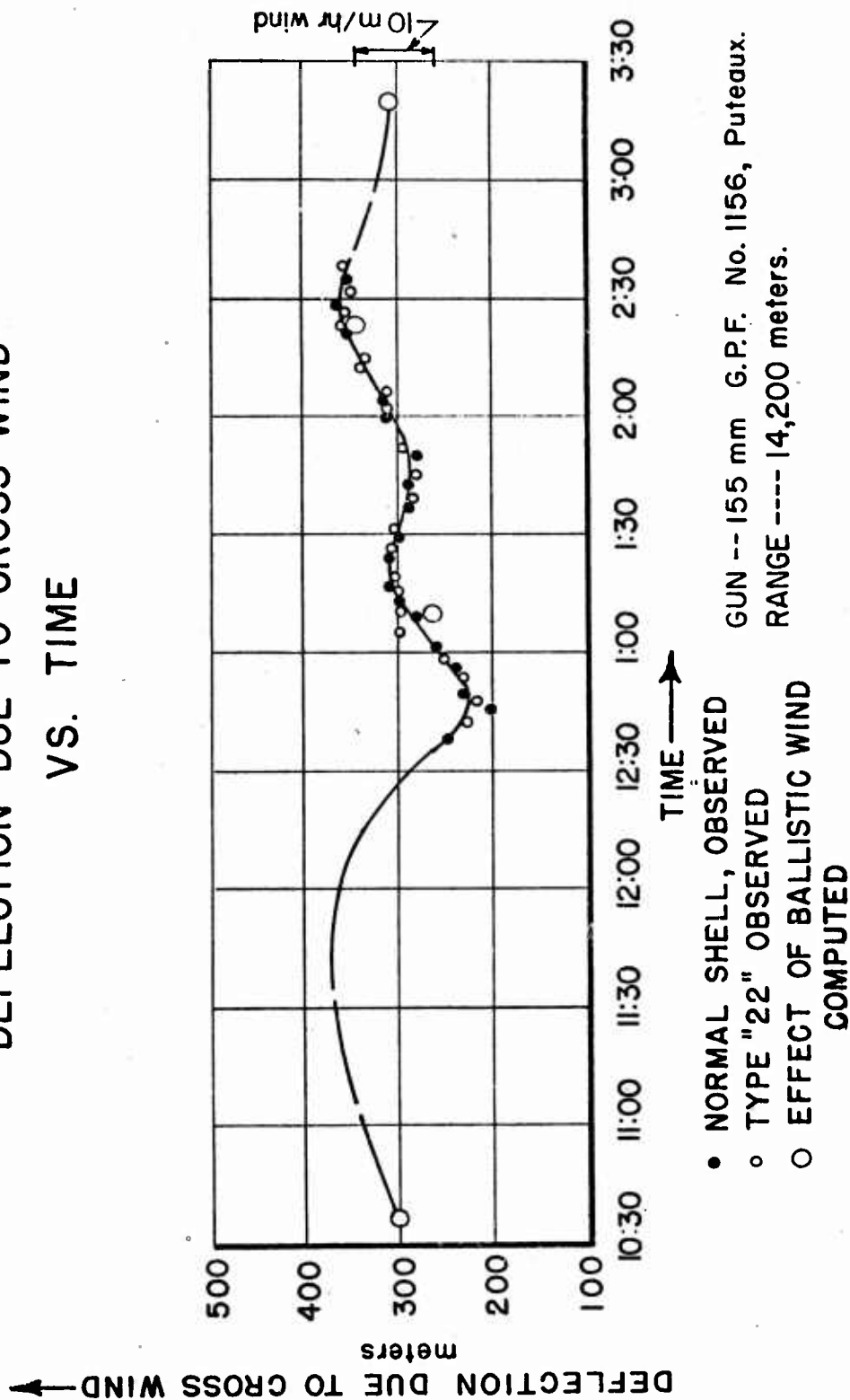
The range of an artillery shell depends on the muzzle velocity and the ballistic coefficient as shown in the slide. You will note how greatly the range depends upon the ballistic coefficient. The ballistic coefficient is defined by $C = \frac{m}{id^2}$, where

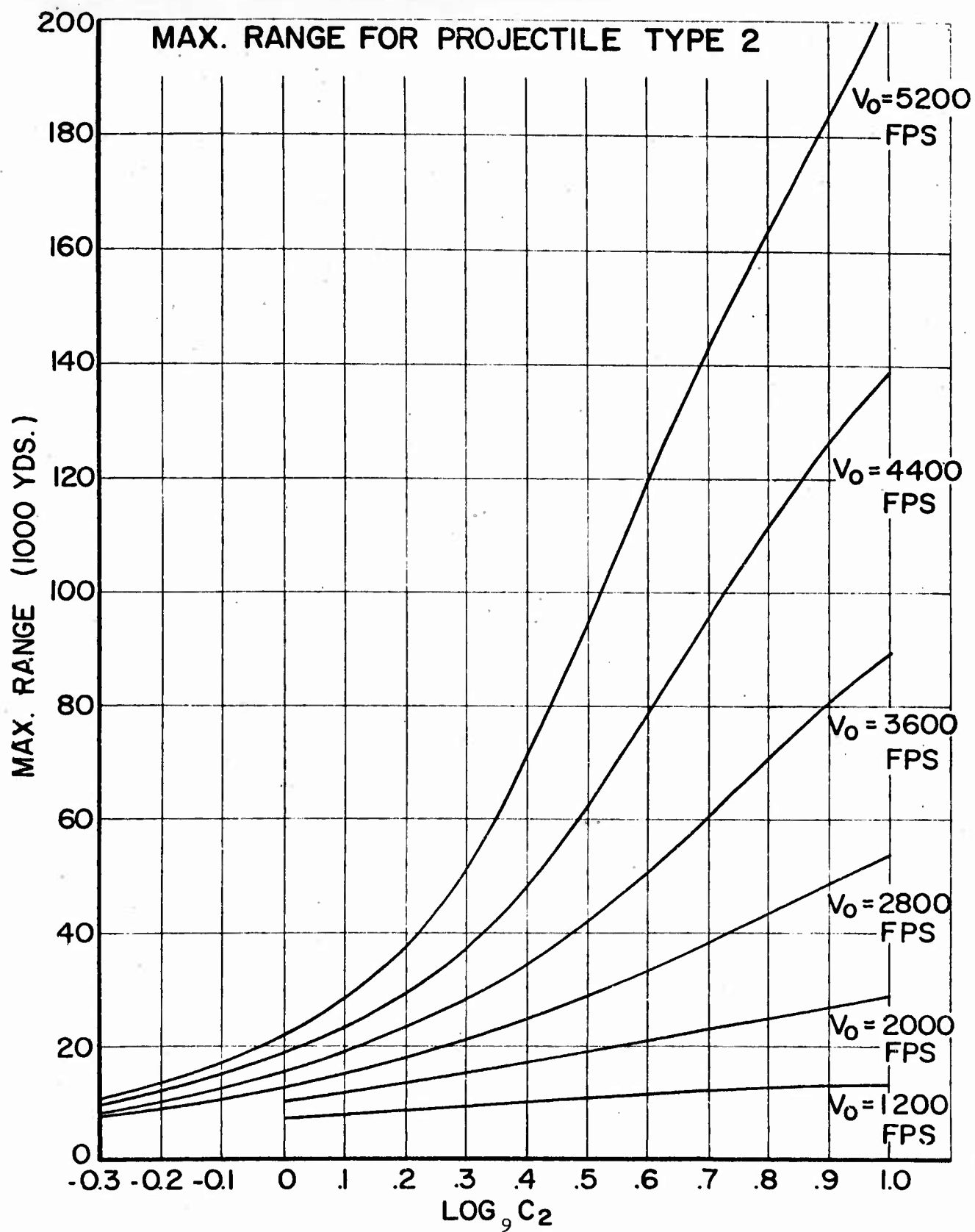
DEVIATION IN RANGE AND DEFLECTION FROM CENTER OF IMPACT

PROBABLE ERROR IN RANGE - 50 YD.
PROBABLE ERROR IN DEFLECTION - 10 YD.



DEFLECTION DUE TO CROSS WIND VS. TIME





m is the mass (weight) of the shell in pounds,
 d the diameter in inches, and
 i the ratio of the drag coefficient
 K_D to that of a standard shape (you multiply K_D by the density of
the air by d^2 and the square of the velocity to get the drag
or air resistance of the shell).

If the caliber, d , is specified, e.g., the 110mm (4.331 in.) and if the weight is approximately determined by the caliber and the lethality, then the ballistic coefficient for a shell for a given caliber and lethality is inversely proportional to the drag coefficient, K_D . The drag coefficient, K_D , is in general smaller, the greater the length of the ogive and the greater the length of the boattail, in other words, the more streamlined the shell.

As may be seen on the last slide, to increase the range, you should either increase the ballistic coefficient or the muzzle velocity or both. One might question why you should not attain greater range by augmenting the muzzle velocity and not doing anything about the ballistic coefficient. The reason is that it has been found, by experience, that the weight of the gun and carriage is approximately proportional to the muzzle energy of the projectile. Hence, if you double the muzzle velocity, other things being equal, you quadruple the weight of the gun and carriage. On the other hand, if you attain the greater range by increasing the ballistic coefficient by reducing the drag, then you do not penalize yourself by introducing unmanageable weights of the gun and carriage.

If one obtains the greater range by lengthening the ogive and the boattail, one augments the difficulty of stabilizing the projectile. When a shell leaves the muzzle of a gun, it usually wobbles a bit and as a rule, for a shell that is practical, the amplitude of this wobbling diminishes until the shell goes to sleep on the trajectory. However, the greater the length of the ogive and the boattail, the greater the difficulty in stabilizing the shell, the more difficult it is, in a sense, to get the shell to sleep on its trajectory. As long as this wobbling persists, extra resistance is produced which tends to reduce the velocity of the shell as compared to what it would be if there were no wobble. This is known as the yaw drag. One of the main jobs, if not the main job, of the Exterior Ballistics Laboratory, Ballistic Research Laboratories, is to investigate the possible designs of shell in

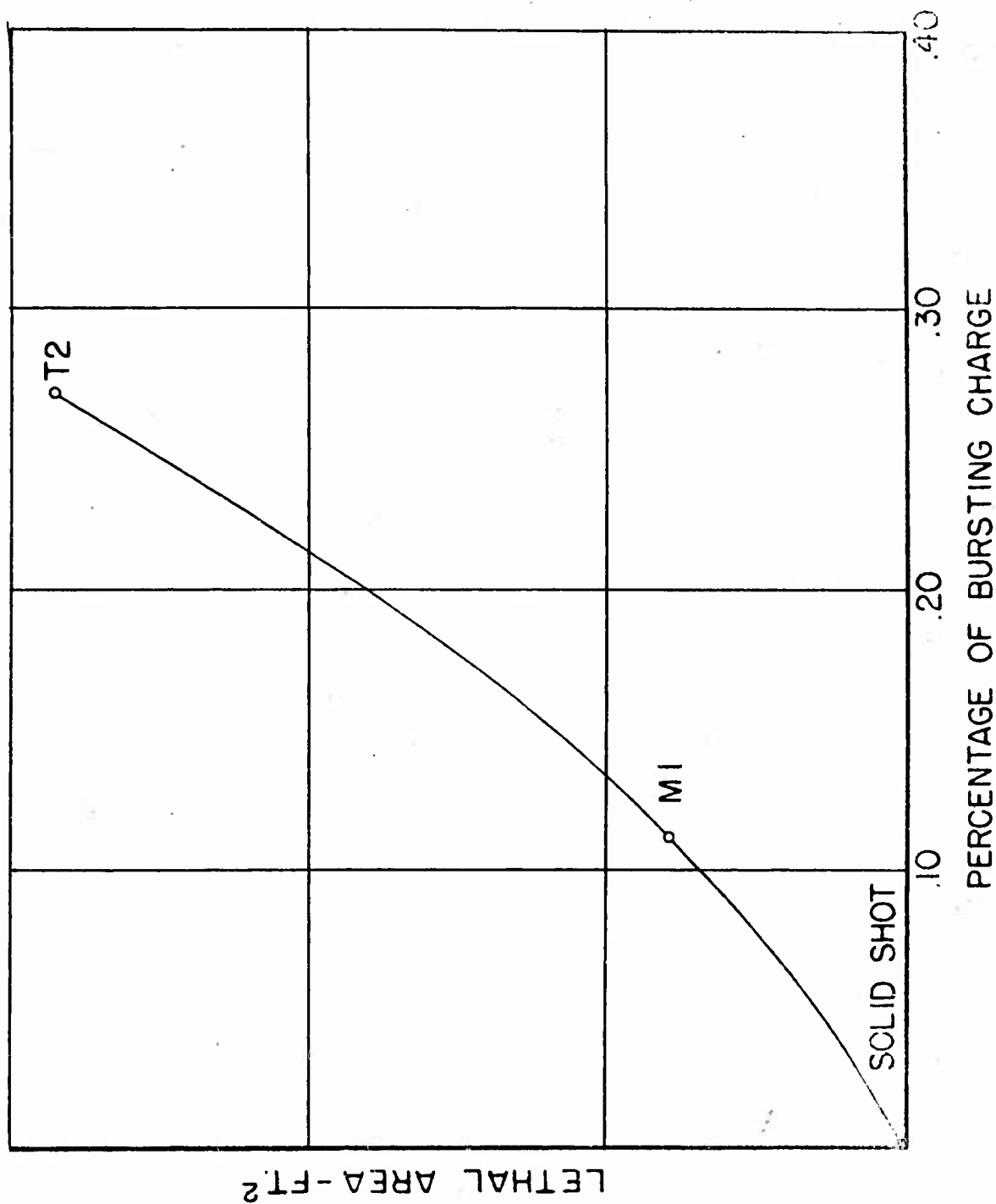
order to determine which types of shell will go to sleep on their trajectories soonest and so minimize the drop in velocity caused by the wobble. This drop in velocity, induced by initial yaw, is really equivalent to a change in muzzle velocity. Variations in it produce dispersion in velocity and hence dispersion in range. As a rule, the dispersion in velocity caused by the initial wobble is not very large, say, a few ft/sec, but if one is striving to minimize the probable error in range, it is important.

3. The Importance of Lethality

In 1951, the Army Field Forces requested the Ballistic Research Laboratories to recommend a family of field artillery. For the light howitzer, the Field Forces stated that the requirements in order of relative priority were: projectile effect, accuracy, mobility, howitzer characteristics, and range. We interpret projectile effect to mean lethality. Since these requirements came from Field Forces, it appeared that primary consideration should be given to projectile effect or lethality. In general, for a shell to be lethal, it has to have a large percentage of bursting charge.

I will show you a slide of some shell of a particular caliber, which I shall call solid shot, M1, and T2, giving lethality as a function of percentage of bursting charge. From this slide, it is clear that, in order to get great lethality, you need, above all, a large bursting charge. The reasons why you need a large bursting charge are: (1) the greater the bursting charge, the greater is the velocity of the fragments of the shell, and (2) the smaller the fragments, hence the greater the total number of fragments. It happens that the incapacitation effect of a fragment is very strongly related to the velocity and much less closely related to the fragment weight. In view of the fact that the shell walls must not be too thin in order to provide the necessary strength to resist setback in the gun, it appears that, within practical design limits, the greater the bursting charge, the greater the lethality of the shell.

LETHAL AREA vs. PERCENTAGE BURSTING CHARGE



4. The Causes of Dispersion

Dispersion is due to (1) exterior ballistic causes, and (2) interior ballistic causes.

a. Exterior ballistic causes - (1) variations in initial yaw and (2) variations in roughness.

(1) Effects of variations in initial yaw

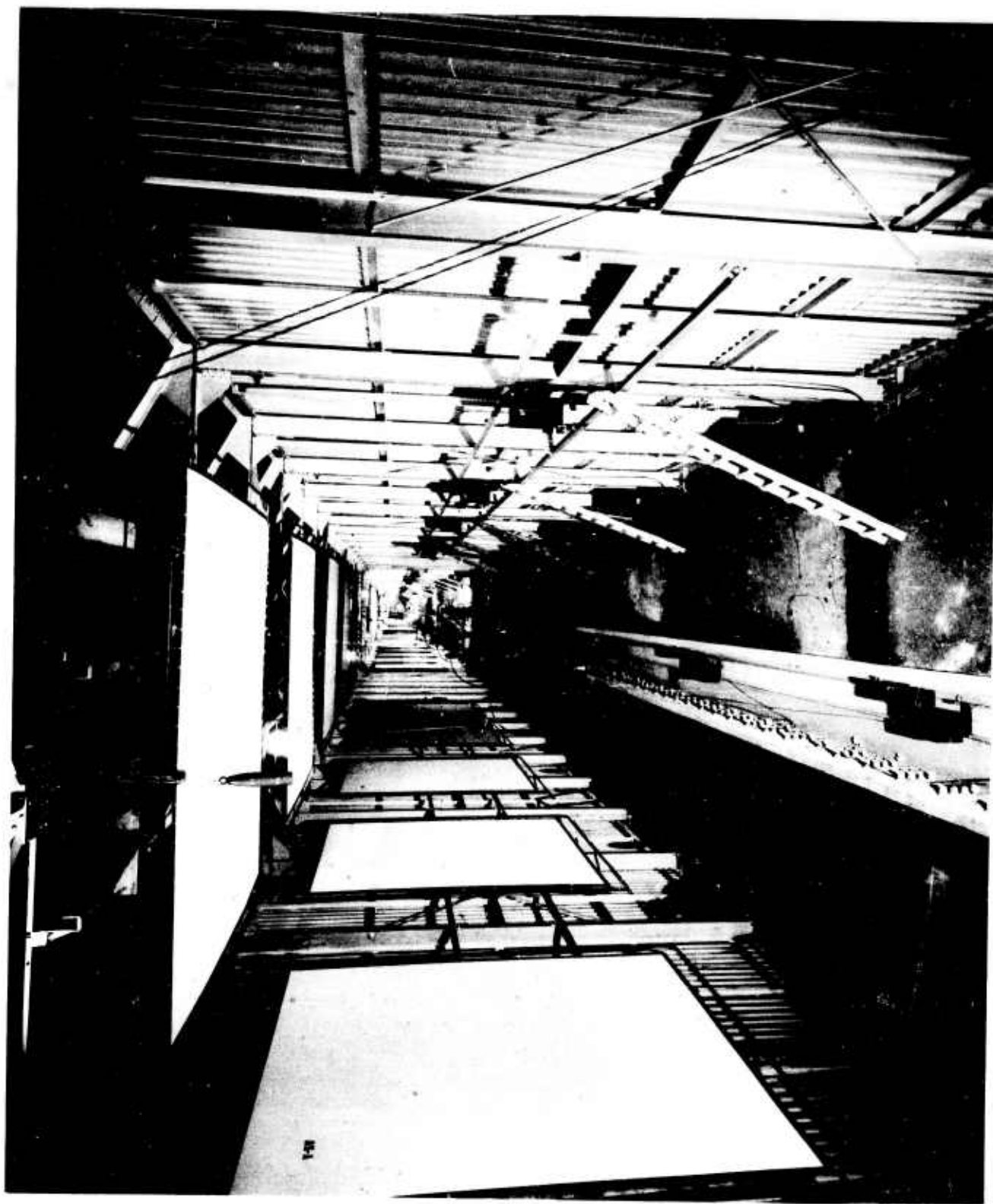
One of the exterior ballistic causes of dispersion is the initial wobble of the shell mentioned above. This wobble has two effects: (1) it increases the drag of the shell as long as it persists and thus produces an apparent or effective muzzle velocity reduction. Variation in the velocity reduction gives an effective muzzle velocity dispersion: (2) The forces acting upon the shell, mainly the lift force, change the direction of the trajectory of the shell, hence, it does not agree with what the direction would have been if there had been no wobble. This change in direction is referred to as the jump due to bore clearance and is really an effective jump which, for certain purposes, should be included with the jump due to other causes.

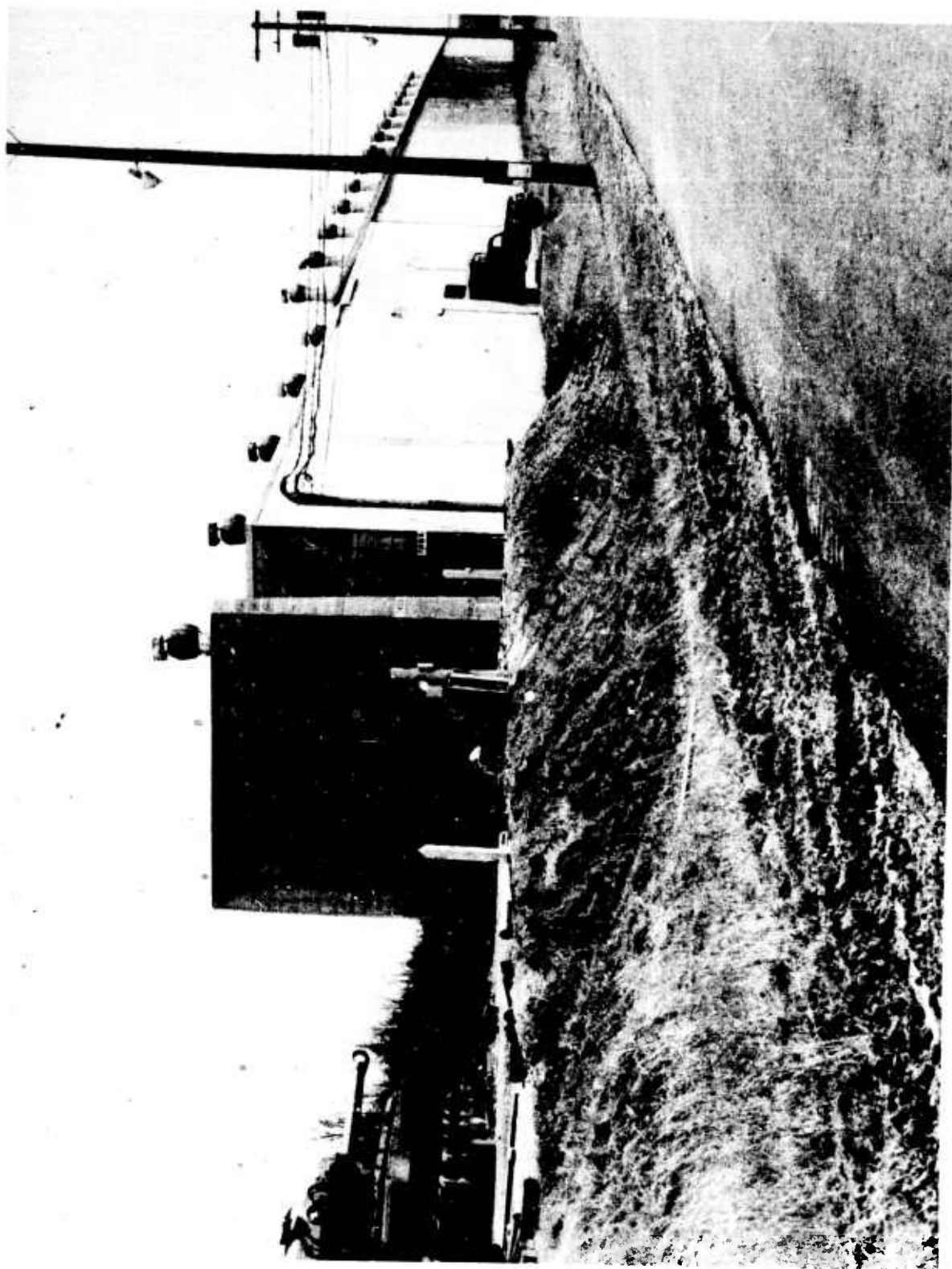
It has been pointed out above that the velocity-reducing effect of the wobble of the shell is caused by two factors: (1) the initial maximum yaw, and (2) the rate at which this initial yaw is damped. The damping of the yaw is a complicated phenomenon. It depends upon various aerodynamic moments and forces. Among the forces and moments are the lift force, the overturning moment, the yawing moment and the Magnus moment. It depends not only upon these aerodynamic forces but also upon the mass of the shell. Unfortunately, aerodynamics has not yet reached the state where these aerodynamic forces can be predicted accurately and one must make experiments which are time-consuming. The actual process of determining these aerodynamic forces consists of shooting shell through a well-instrumented range and observing the motion very carefully by photographic means and then inferring the forces and moments from the recorded motion of the shell.

I will show you pictures of the Transonic Range. It is one of the two exterior ballistic ranges at the Ballistic Research Laboratories, Aberdeen Proving Ground. It is equipped to record the motion of the shell photographically. The Transonic Range, some 800 ft. long, is used for fairly large shell from 2 to 8 inches in caliber and the smaller range, 300 ft. long, for smaller caliber shell.

I have mentioned before the importance of projectile effect or lethality, and that the greater the bursting charge, the greater the lethality of the shell. For a given caliber of shell, the greater the bursting charge, the thinner the walls must be. If the walls are thin, then you are likely to have the phenomenon of dynamic unbalance. You are all familiar with the fact that with high speed rotating machinery, it is necessary to balance the machinery both statically and dynamically by putting the center of gravity on the axis of rotation and making the principal axis of inertia coincide with the axis of rotation. Obviously, if you have a shell without any cavity at all, it will, in general, tend to be dynamically balanced, but if the cavity is large and the walls are thin, then the variations of the wall thickness as you turn the shell will introduce not only static but also dynamic unbalance.

Experiment shows that with dynamically unbalanced shell, the initial yaw is considerably greater than it is with dynamically balanced shell. The yaw due to unbalance is added vectorially to the yaw due to bore clearance. It follows, therefore, that the jump due to bore clearance and unbalance should be greater with thin-walled shell than with thick-walled shell. The slide I'm about to show gives an example of the comparative angular dispersion of thick-walled shell, such as armor-piercing shell, and of thin-walled shell, such as high explosive shell. Thus, the requirement for lethality means that the initial yaw of the lethal shell will be greater. This will produce not only a greater variation in jump but also a greater variation in velocity drop caused by yaw than would be the case with the thick-walled shell. This slide gives the dispersion in deflection vs. per cent bursting charge for a solid shot, and the two high explosive shell which I have called M1 and T2. From this curve, the amounts of dynamic unbalance for these shell can be calculated. From them, the velocity drops





due to initial yaw may also be computed. The results are given in the table which is shown on the next slide.

Average Velocity Drop Due to Initial Yaw
(ft/sec)

<u>Solid Shot</u>	<u>M1</u>	<u>T2</u>
0.2	1.1	5.0

Corresponding Probable Error in Velocity
(ft/sec)

0.1	1.0	4.4
-----	-----	-----

Corresponding Range Probable Errors

0.1 yd	7 yd	18 yd
--------	------	-------

In order to bring out more vividly the cost that you pay in range dispersion for high lethal area, I show you a slide, "Lethal Area & Range Probable Error vs. Percentage Bursting Charge".

The apparent or effective dispersion in muzzle velocity caused by variations in initial yaw may or may not be recorded as muzzle velocity dispersion, depending on where the solenoid coils or other measuring apparatus are placed with respect to the muzzle. If the velocity measuring apparatus is placed very close to the muzzle, the velocity variations caused by the variations in initial yaw will not be recorded as variations in muzzle velocity.

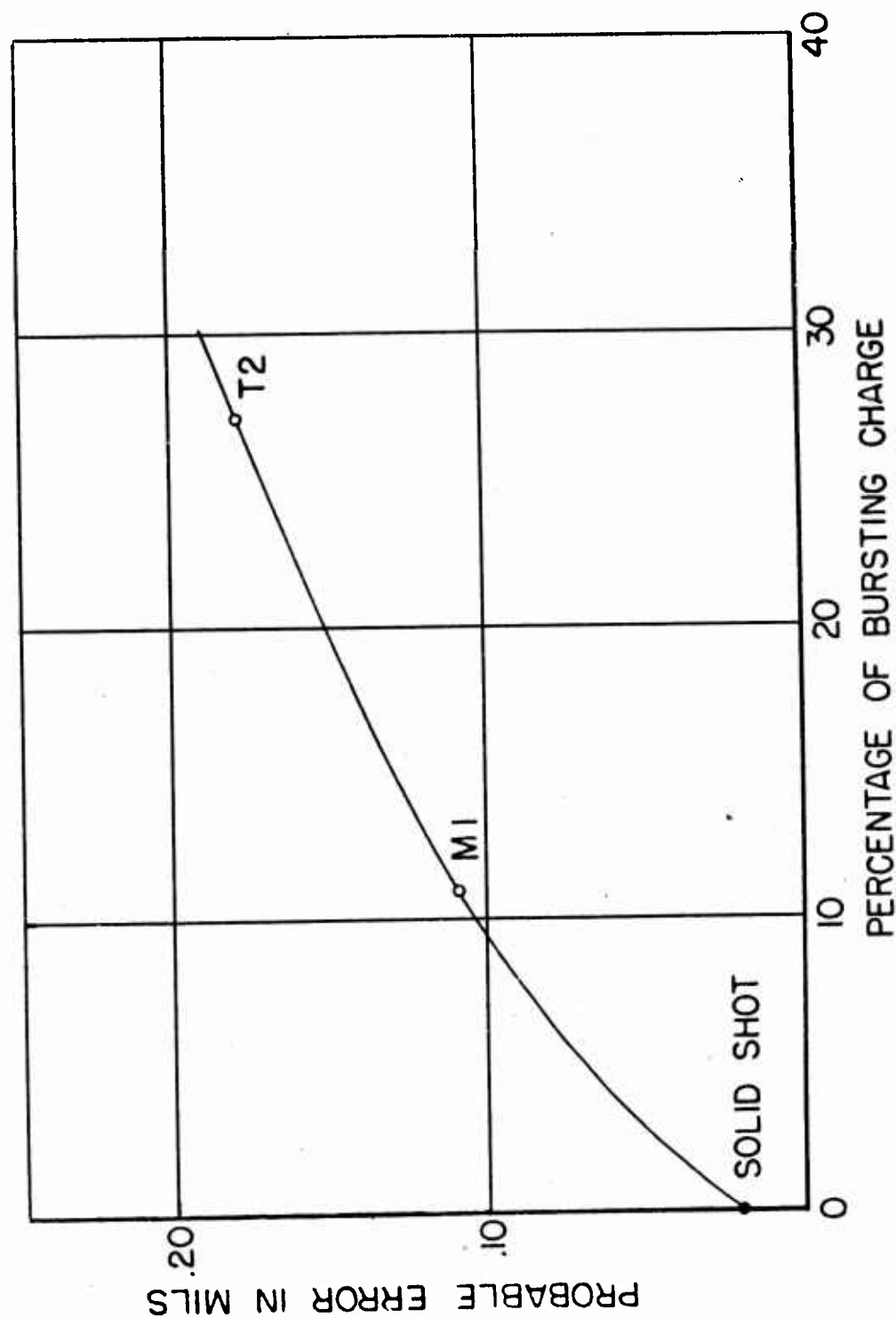
(2) Effects of variations in roughness

It was found out early in World War II that the roughness of the shell had a considerable effect on the range. I show you a slide giving the ranges of the 105mm shell M1 with varying types of surface finish.

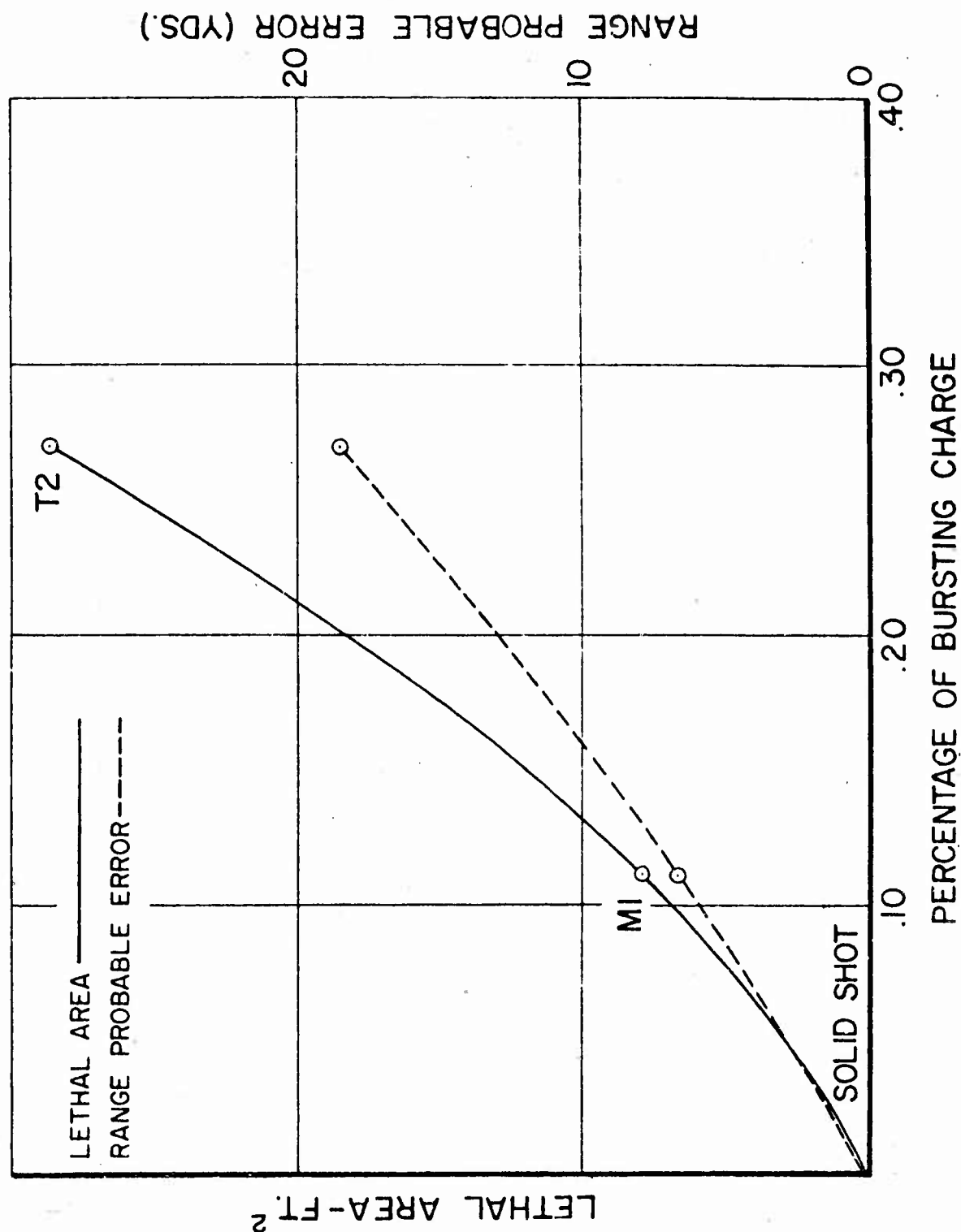
Range of 105mm Shell M1 with
Various Types of Surface Finish

<u>Finish</u>	(Zone V) Corrected Range (yd.)
Unpolished, Unpainted	6902
Polished, Unpainted	7206
Unpolished, Painted	7015
Polished, Painted	7165

PROBABLE ERROR vs. PERCENTAGE BURSTING CHARGE



LETHAL AREA & RANGE PROBABLE ERROR vs. PERCENTAGE BURSTING CHARGE



From these results, it is clear that the surface finish has a considerable effect on the range of the shell. The type of flow of air depends on the surface finish. If the surface is smooth, then the flow is predominantly laminar, this means there is almost complete absence of turbulence. The skin friction effects in laminar flow are much less than those in turbulent flow.

There was a laminar flow airplane designed some years ago by the eminent British aerodynamicist and applied mathematician, Sydney Goldstein. The wings and all the surfaces of this airplane were kept in a highly polished condition. It was found that in order to prevent the finish being marred by insects squashed on the plane, they had to protect the wings and so forth until an altitude of 4,000 feet was reached. Then they could take off the wraps and let the plane fly without them.

In view of the effects mentioned, it would not be wise to have our shell highly polished because the laminar flow might be upset by squashed insects, thus producing great variations in the drag and the ballistic coefficient. So the proper arrangement is to have the shell of average, well-controlled roughness. While these rough shell have a greater drag than smooth shell, nevertheless, it is reproducible from round to round and the finish is not easily spoiled by handling.

b. Interior ballistic causes

The interior ballistic cause of dispersion in range is dispersion in muzzle velocity. However, the true interior ballistic dispersion in muzzle velocity should be distinguished from the effective dispersion in muzzle velocity caused by the variation in the initial yaw. This problem has three aspects. The first is related to the design of guns. The second is related to the design of ignition systems. The third arises from imperfect blending of the propellant.

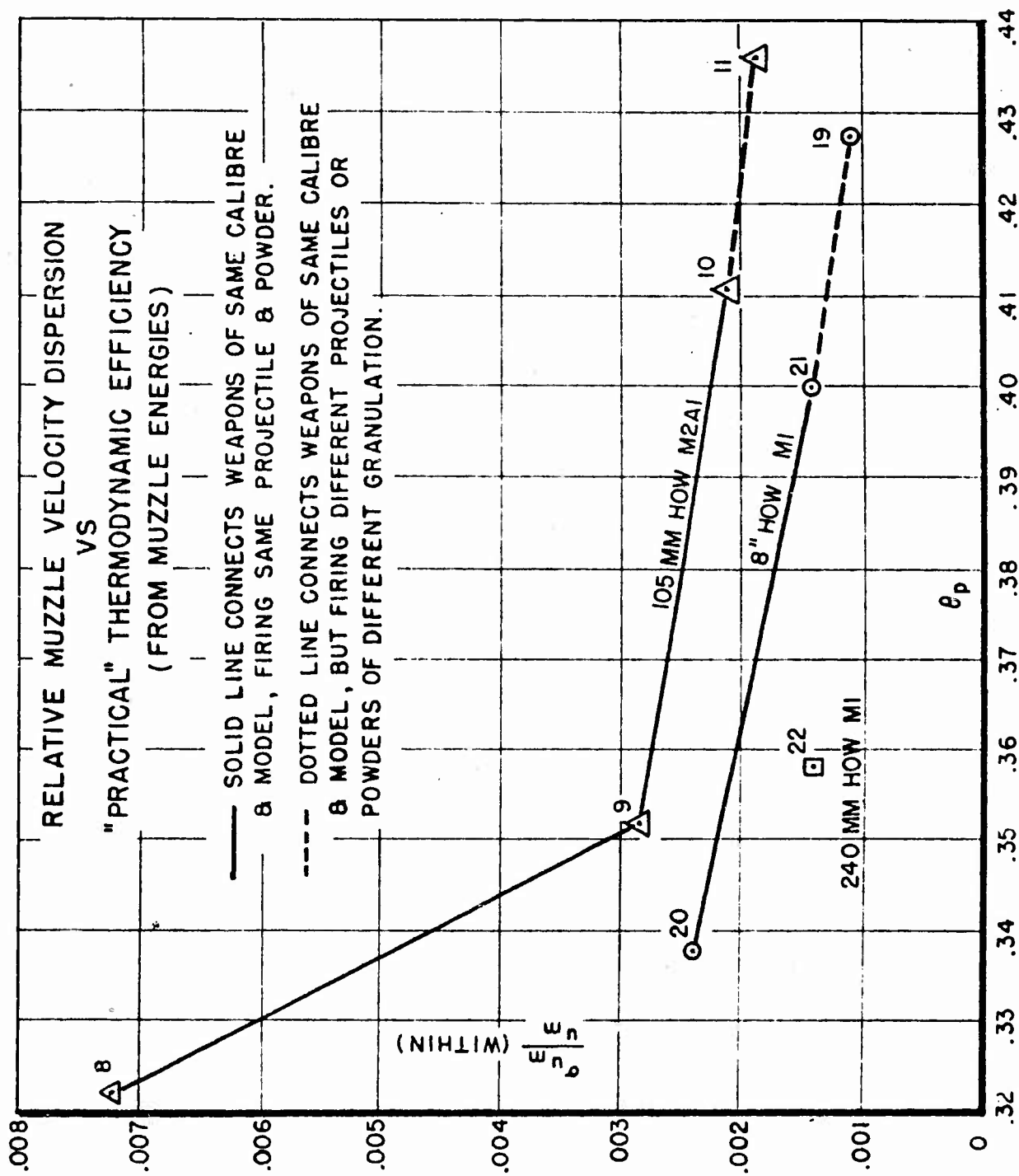
(1). Design of Gun

In general, it is easier to get muzzle velocity uniform in a gun designed especially for uniformity of muzzle velocity than in one that is not so designed. The main point of view in the designing of a gun to produce a small muzzle velocity dispersion is to have the propellant charge use up most of its chemical energy in imparting

kinetic energy to the projectile. Theoretically, if one could have a sufficiently long gun so that the temperature of the powder gas could be reduced to absolute zero and therefore would have no chemical energy remaining, then the kinetic energy of the projectile would be absolutely proportional to the weight of the powder charge, since no variation in burning from round to round would have any effect because all of the chemical energy of the propellant would be converted into kinetic energy of the projectile. I have prepared a slide to give some of the data we have obtained, related to this subject. The slide shows the relative muzzle velocity dispersion, that is, the dispersion in muzzle velocity divided by the muzzle velocity, plotted as a function of the thermodynamic efficiency of the gun. Thermodynamic efficiency denotes the ratio of the kinetic energy of the projectile to the chemical energy of the propelling charge. From the slide, we see that the weapons which have high thermodynamic efficiency are correlated with small relative muzzle velocity dispersions. However, guns having high thermodynamic efficiency will require a higher maximum pressure to impart to a given projectile as high a muzzle velocity as guns with smaller thermodynamic efficiency.

(2) Faulty ignition system

Consider the other aspect. Suppose you have your gun already designed and you are trying to get the smallest muzzle velocity dispersion possible with the given gun. This is the problem of design of the ignition system which, in a case of fixed rounds, means the design of the primer. In the case of separate loading rounds, it means the design of the primer plus the design of the base or other charges. I can give you some examples of the influence of the design of the primer on the uniformity of velocity. The results are shown on the slide.



Muzzle Velocity Dispersion for Various Ignition Systems

<u>Gun</u>	<u>Primer</u>	<u>Weight of Charge (oz.)</u>	<u>Muzzle Velocity (fps)</u>	<u>Probable Error in Velocity (fps)</u>	<u>Range Effects (yd.)</u>
76mm	T48	90	3950	19.4	104
	T88	90.5		4.7	27
90mm	M58	141	2975	11.5	88
	T88E1	141	2975	7.6	60

Recently, in an attempt to develop a charge for a gun, it appeared they were having difficulty in reaching the desired muzzle velocity of 2900 fps. In fact, they had to stop firing well before the desired muzzle velocity was obtained. Violent pressure waves (I show you a slide of a pressure wave in a weapon that is now performing satisfactorily, the 8-inch howitzer) were obtained in the chamber and the muzzle velocity dispersion was very great. Then, with a new system of ignition, they were able to raise the muzzle velocity to 2914 fps, and reduce the probable error in muzzle velocity to less than 2 fps.

To make it easier to make suitable primers, the Interior Ballistics Laboratory (I show you a slide of its new building), Ballistic Research Laboratories, is developing a substitute for black powder. As far as I am aware, this will be the first practical substitute for black powder that has been proposed since the beginning of the Christian Era.

Black powder is used to set on fire the main charge of smokeless powder, just as kindling wood sets on fire the logs in our fireplaces. The black powder in turn is set on fire by the percussion element, just as kindling wood is set on fire by a match.

This substitute is currently made in laboratory sized lots by a process less tedious and dangerous than that by which black powder is manufactured. If this process can be expanded to full plant scale, and if the material successfully endures the required storage tests, then it is hoped that this substitute for black powder will facilitate the development of primers which will produce much greater accuracy in muzzle velocity than the old primers with black powder.

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(3) Imperfect blending of the propellant lot

No matter how carefully a propellant lot is manufactured there are unavoidable variations in the web thickness of the propellant and hence in the rate of burning because of unavoidable variation in the dies through which the propellant is extruded. In order to obtain a uniform velocity, it is necessary that the propellant be adequately blended. Various procedures are used in the blending of the propellant. For example, if you have the propellant in a big pile in a room, you shovel it into ten separate piles and you then blend the propellant by putting a small layer from pile 1 on the floor and then a layer from pile 2 and so on. This process is repeated until all the propellant from piles 1, 2, etc., has been reassembled in the central pile. In this way, one achieves a certain blending of the propellant.

When I was at Picatinny Arsenal in 1934, I performed an experiment for ascertaining whether the propellant was adequately blended. I colored various portions of the lot with different colors and then made experiments to determine how often the blending process should be repeated to get a reasonably uniform mixture of these variously colored grains. In making tests to determine whether these lots were adequately blended, I used quality control techniques which I shall later explain in the description of the large lot of 105mm ammunition. As a result of these experiments and the information derived from them we are confident that at the present time, using the procedures thus developed, our propellant lots are adequately blended. However, in the absence of adequate blending, of course, there will be variations in velocity as a result.

5. The Grand Lot of 105mm Ammunition

Prior to the invasion of Normandy in 1944, it was my job to sort out the 105mm ammunition which was to be used in the invasion, both with respect to muzzle velocity and to roughness. For this purpose, I had a small team that conducted firings on a field overlooking the Bristol Channel. The object was to group the 105mm ammunition into families of lots that would have fairly constant ballistic coefficients within the

lot and fairly constant muzzle velocity. Although I spent a great deal of time on this, and the selection was successful, the confusion after the invasion was such that the lots I recommended were not used to full advantage. One of the big disadvantages of having small lots, say, of 3000 rounds, is that when you stop using one lot and go to another one, the muzzle velocity changes and, in general, the roughness of shell changes and there is a resulting change in the ballistic coefficient. You have to readjust your fire if you change to another lot.

Ever since World War II, the problem of establishing a very large lot, called a grand lot, has been under study. Such grand lots were started during the war in Korea. The first grand lot had a total of 149,223 rounds with projectile sub-lots, primer lots and lots of other components so selected, and with powder blended within the grand lot so as to give uniformity in ballistic characteristics. The shell were of uniformly average roughness.

The slide I am going to show you gives some of the results of firings of this grand lot at Jefferson Proving Ground.

105mm Howitzer - Zone VII
Muzzle Velocity = 1550 ft./sec.
Elevation 4054

	A	B	A/B
Sub Lot	Observed Probable Error in Range	Estimated Probable Error in Range Due to Observed Probable Error in Velocity	
1	13.55	14.28	.949
2	15.10	16.47	.917
3	18.57	14.47	1.283
4	16.73	10.68	1.566
5	18.94	10.50	1.804
6	14.33	18.06	.793
7	13.81	15.67	.881
Grand Lot	15.86	14.56	1.089

You see the observed probable error in range and then in the next column, you see the estimated probable error in range due to the observed probable error in velocity. Both the range and the velocity were measured on each round. In the last column is given the ratio of the observed probable error

in range to the estimated probable error in range due to the observed probable error in velocity.

If the range were accurately measured (and as a rule it is) and if the velocity were also accurately measured, then the figures in the second column should be greater than the figures in the third column. The ratio should be greater than unity. In other words, there should be exterior ballistic dispersion including dispersion, from variations in finish as well as that due to muzzle velocity dispersion, which may be true interior ballistic muzzle velocity dispersion and apparent dispersion caused by variations in initial yaw. However, as a result of errors in measurement of velocity, the ratios are not always greater than one. It should be noticed, however, that the mean of the ratios is greater than unity but only slightly. This indicates that the exterior ballistic cause of dispersion, variation in the roughness of the shell, produces effects considerably smaller than interior ballistic causes of dispersion including that due to yaw. This means that the variation of roughness of the shell in this grand lot has been kept within acceptable bounds.

In making the grand lot of ammunition, strict attention was paid to the control of the quality (1) of the propellant (2) of the surface finish, and (3) of the weight of the shell. I shall explain what we mean by quality control in the following.

In actual operation, Quality Control involves three steps: (1) sampling, (2) posting the charts, and (3) hunting for trouble.

Sampling. Ordinarily the quality inspector takes small samples of the product (consisting of about 5 articles) in the order of production at arbitrary periods such as every half hour. As each sample is inspected for a quality characteristic such as length, two results are observed: the average value of the measures taken on the sample and the spread or range between the greatest value in the sample and the least.

Posting the Charts. Two charts are kept near the inspector: one for ranges and the other for averages. The two charts I refer to are combined on the slide you now see. The chart for ranges consists of a heavy horizontal

QUALITY CONTROL CHARTS

