50X1-HUM

COMPUTATIONS IN PRESENT-DAY ACTUAL PROBLEMS OF SHOOTING DOWN AIRCRAFT BY HEAVY A A ARTILLERY (FLAK)

Summary:

Six projects, established between November 1944 and January 1945, deal with the probability of bringing down aircraft by heavy anti-aircraft guns and, especially, with a comparison between the shells with time fuzes and shells with percussion fuzes.

The first project evaluates expenditure of ammunition versus number of aircraft shot down. It covers the firing of 700,000 rounds and represents the actual probability of shooting down of aircraft with HE-shells eqipped with time fuzes, the only type of ammunition used so far. 12

The remaining works consider qualitatively and quantitativly the probability of shooting down aircraft with time shells (that is, with time fuzes) and percussion shells (that is, with percussion fuzes). This data is not necessarily mathematically exact. As distinguished from past detailed calculations, they are designed to be understood by laymen.

The report does not deal with incendiary fragmentation shells, a topic treated in detail by Dr. Voss.

Table of Contents:

50X1-HUM

V. Does the firing of shells with percussion fuses necessitate a change of AA firing tactics?

VI. The effect of the errors in range measurement and calibration upon the firing of shells with percussion fuzes.

Research Department of the Air Ministry and C.i.C. Air Force
Prof. Dr. Braunbek, Goettingen, 10 March 1945.

I. Evaluation of statistical data on expenditure of ammunition and number of aircraft shot down by heavy anti-aircraft artillery

1. The statistical material used here was collected from the combat activities of the 3rd, 4th and 7th anti-aircraft artillery divisions (Hamburg, Duisburg, Cologne) for the periods ~~from~~ July 1943 to Oct. 1944, April to Oct~~ober~~ 1944, Sept~~ember~~ 1943 to Oct~~ober~~ 1944.

2. The material deals only with actions in which all or most of the targets were at altitudes below 7000 meters. *)

3. Ammunition expended in barrage firing was not included, except for the 7th Division, where a subdivision could not be carried out.

4. The entire material tabulated here covers approximately 495,000 rounds of 8.8 cm, 158,000 rounds of 10.5 cm, and 49,000 rounds of 12.8 cm HE-shells, i.e. a total of 702,000 rounds, which accounted for 239 aircraft.

5. The detailed tabulation of rounds per aircraft shot down is as follows:

Unit	Number of rounds			total	a/c shot down	No. of rounds per a/c shot down
	8.8 cm	10.5 cm	12.8 cm			
3rd AAA Div. (Group Hamburg N. only)	41,500	7,300	3,600	52,400	26	2,020
4 AAA Div.	224,000	73,000	30,000	327,000	132	2,480
7 AAA Div. (incl. barrages)	230,000	78,000	15,000	323,000	81	4,000
Total	495,000	158,000	49,000	702,000	239	2,940

*) This limitation was introduced, because the material was to provide data of comparison between the 8.8 cm incendiary fragmentation shell and all other types of ammunition. The 8.8 cm incendiary fragmentation shell is effective only to elevations of 7,000 meters. Most of the actions took place at those altitudes used for this study.

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6. When the tabulation is limited to artillery activity during large-scale daylight raids, the result is as follows:

Unit	Number of rounds 8.8 cm	10.5 cm	12.8 cm	Total	a/c shot down	Number of rounds per a/c shot down
3rd AAA Div. (Group Hamburg N. only)	10,200	2,600	none	12,800	12	1,070
4th AAA Div.	51,500	26,000	8,000	85,500	57	1,500
7th AAA Div. (incl. barrages)	55,000	25,000	6,000	86,000	21	4,100
Total	117,000	54,000	14,000	185,000	90	2.050

7. When the tabulation is limited to purely optical firing, the result is as follows:

Unit	Number of rounds 8.8 cm	10.5 cm	12.8 cm	total	a/c shot down	Number of rounds per a/c shot down
3rd AAA Div. (Group Hamburg North only)	8,500	2,200	300	11,000	9	1,220
4th AAA Div.	10, 800	3,600	1,100	15,500	18	860
7th AAA Div.	7,100	4,600	1,700	13,400	9	1,490
Total	26,400	10,400	3,100	39,900	36	1,100

8. Only the total rounds expended ~~were~~ are tabulated so far, regardless of how many of them ~~were~~ are of 8.8 cm, 10.5 cm, or 12.8 cm caliber. An attempt may be made, however, to reduce the 10.5 and 12.8 cm shells to 8.8's by assuming the ratio of their effectiveness as 1:3:5.

The effects of the shells, when taken only on the basis of their bursting effect, are approximately in a ratio of 1:2:3; but since the heavier guns are slightly more accurate, the ratio 1:3:5 seems more appropriate.

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In respect to quantity, the three calibers appear in total expenditure of rounds in a ratio of 10:3:1.

Thus, in respect to effect, their ratio must be 10: 3x3: 5x1 = 10: 9 : 5, or nearly 2 : 2 : 1.

Thus, 40% of the aircraft shot down were accounted for by 8.8 cm guns, 40% by 10.5 cm guns, and 20% by 12.8 cm guns.

9. With these "reduced numbers of rounds fired", we obtain the following "reduced number of rounds per a/c shot down", i.e. the number of rounds required to bring down one aircraft expressed in terms of 8.8 cm shells:

Unit	Over-all	Large-scale daylight raids only	Optical firing only
3rd AAA Div.	3,130	1,500	1,850
4th AAA Div.	4,490	2,980	1,500
7th AAA Div. (incl.barrages)	6,650	7,600	3,260
Total	5,080	3,860	2,030

(Example: The 52,400 rounds fired by the 3rd AAA Division, when reduced to 8.8 cm (41,500 + 3X 7,300 + 5 x 3,600) give 81,400 rounds, i.e. they correspond in their effect to 81,400 rounds of 8.8 cm shells. The reduced number of rounds per a/c shot down is thus 81,400 : 26 = 3,130).

10. ~~As~~ for the total average of all the above material, we can thus compute per a/c shot down:

approximately 5,000 rounds of 8.8 cm caliber

or (1/3) approx. 1,700 rounds of 10.5 cm caliber

or (1/5) approx. 1,000 rounds of 12.8 cm caliber;

and for optical firing:

approx. 2,000 rounds of 8.8 cm caliber

or (1/3) approx. 700 rounds of 10.5 cm caliber

or (1/5) approx. 400 rounds of 12.8 cm caliber.

If we use the ratio 1 ; 2 : 3 which is definitely too unfavorable for the heavier caliber guns, in order to obtain a check for the asumed 1:3:5 ratio for the effectiveness of the 8.8 cm, 10.5 cm, and 12.8 cm shells, the figures above for the rounds per a/c shot down will be changed to:

Total average: approx. 4,000 rounds of 8.8 cm caliber
or (1/2) approx. 2,000 rounds of 10.5 cm caliber
or (1/3) approx. 1,300 rounds of 12.8 cm caliber.

For optical firing:

approx. 1,600 rounds of 8.8 cm caliber
or (1/2) approx. 800 rounds of 10.5 cm caliber
or (1/3) approx. 500 rounds of 12.8 cm caliber.

Thus, a change in the ratio of effectiveness does not alter the figures very much.

II. Investigation of the advantages in artillery tactics by concentrating the fire of heavy anti-aircraft artillery on one target.

1. General.

The question to be investigated here is the following: To what extent can the probability of destroying the enemy be increased by having a number of heavy anti-aircraft guns concentrate their fire on just one enemy, instead of having the same number of guns fire the same number of rounds against several targets (possibly at different times)?

In other words, the question is whether or not the probability of shooting down an aircraft per number of rounds depends on the absolute number of rounds fired at one single target, and if so, to what extent the probability depends upon it.

It is of some importance in answering this question, whether the concentrated fire is carried out by the coordination of several batteries into one large battery, or by the equipping of one battery with an above-normal number of guns. In the first case, groups of normal numbers of bursting points will be statistically distributed along the flight path of the target, while in the second case there will be groups of greater numbers of bursting points, so that the probability of the simultaneous effect of several bursts on the target is increased.

It is even more important for the formulation of the answer to the above question to determine just how aircraft are shot down, by direct hits, by blast effect, or by fragmentation, or, what share these three effects have in the destructions of air-craft accomplished. We know very little about this. The considerations are therefore to be carried out for two extreme cases:

Case A: Aircraft shot down exclusively by direct hits:

This case would occur when firing shells with percussion fuzes. However, even when firing shells with time fuzes, direct hits may account for a considerable share of the aircraft destroyed.

Case B: Aircraft are shot down entirely by fragmentation effect, possibly also by blast at shorter distances:

For this case, the lethal radius can be given for any type of shell. Aircraft within this radius of the bursting point will generally be brought down. For the 8.8 cm HE shell this lethal radius is 7 meters. However, when the shell is fired at four-engine bombers, the radius is probably less, because of the low vulnerability of these aircraft.

2. Effect of concentrated fire

As long as the effect of only one single shell on the target is considered, concentration of fire can have no effect on the probability of the shell's

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hitting the target. Each shell has a definite probability of hitting, and this probability is quite independent of that of the other shells. For the total probability of hitting of a greater number of shells it is of no importance whether they are fired simultaneously on one target, at short time intervals on one target, over a longer period on one target, or on any number of targets.

A difference between these cases will show up only if two or more shells all share in the destruction of an aircraft. The frequency of the case of two or more shells all contributing to the bringing down of an aircraft is not in a simple proportion to the number of rounds fired on one target, but increases with the square or a higher power of that figure.

Strict distinctions must be made between the effect in cases A and B.

3. Effect of concentrated fire on case A:

In the case of a direct hit, at least when firing shells with percussion fuzes, one shell will definitely destroy the target. Thus the combined effect of several shells (simultaneous direct hits or direct hits at short intervals by several shells) will mean no improvement. Just the contrary is the case, since one direct hit has already destroyed the target, the other shells are wasted, while, had they been fired at another target, they might have brought down another aircraft - assuming another direct hit on that target.

In case A, therefore, the concentration of fire reduces the probability per shell of shooting down an aircraft.

In order to estimate by how much the probability is reduced, the probability of a direct hit on a single aircraft must be estimated. For a four-engine bomber, flying alone, and under normal aiming conditions, it should be around 1/1000. Thus, the probability of obtaining at least one direct hit with N rounds is:

$$W = 1 - e^{-N/1000} = N/1000 - \tfrac{1}{2}(N/1000)^2 \quad \ldots$$

The term with $(N/1000)^2$ represents the reduction of the probability per shell of shooting down an aircraft due to two direct hits, whose frequency is a function of $(N/1000)^2$. Triple and multiple direct hits need not be considered, since their probability is extremely slight.

For the frequency of double direct hits the only figure of importance is the number of rounds N fired within a short period, let us say 10 seconds, at one aircraft, since if the rounds are fired within a longer period, the first direct hit has already caused the aircraft to crash so that it can no longer receive a second hit. Even in the case of very heavy concentration of anti-aircraft guns and in the case of using one fire control set for many guns, N will be 100 rounds at the most during this short period of time.

Thus: $W = 1/10 - 1/200 \quad \ldots \quad 1/10\ (1 - 0.05)$

The reduction of the probability of bringing down an aircraft by concentrated fire because of double direct hits is thus maximally 5%, but in reality it is probably much lower and therefore of no practical importance.

4. Effect of concentrated fire on case B:

In case B, that of fragmentation effect, the situation is somewhat more complicated. Here, too, the effect of concentrated fire can occur only, of course, if two or more rounds contribute to the bringing down of an aircraft; viz. if the fragments hitting the aircraft simultaneously or in succession cause it to crash, while it would have remained in flight had it been hit by the fragments of only one shell.

Let R_1 be the normal "lethal radius" of an anti-aircraft shell, i.e. the radius of a sphere around the center of the aircraft, within which (after averaging the different directions of the fragments) a burst will destroy the aircraft. There is also a second radius R_2, within which two shells will bring down an aircraft. If the two bursts are simultaneous, R_2 will be slightly greater than in the case of the two shells exploding in succession, but R_2 will be larger than R_1 in any case. Triple and multiple hits are so rare that they need not be considered.

For estimating the order of magnitude of R_2 it seems appropriate to require that there be as many fragments from two shells at the extreme limit of R_2 as there are at the extreme limit of R_1 from one shell. Since the density of fragments per unit of space decreases with the square of the distance from the bursting point, the formula will be:

$$R_2 = R_1 \cdot \sqrt{2}$$

In the case of the 8.8 cm HE shell, R_2 will be 10 meters when R_1 is 7 meters.

The probability of obtaining at least one burst within ~~the~~ a sphere of radius R_1 and volume V_1, when firing N rounds, is:

$$W_1 = 1 - e^{-CNV_1} = CNV_1 - \tfrac{1}{2}(CNV_1)^2,$$

C being a proportionality factor whose magnitude is of no importance for the problem discussed below.

The probability of obtaining at least two bursts within the additional volume V_2, located between the spheres with radii R_1 and R_2, is in the first approximation:

$$W_2 \doteq \tfrac{1}{2}(CNV_2)^2$$

The total increased probability of shooting down an aircraft by the combined effect of two shells is thus:

$$W = W_1 + W_2 \approx CNV_1 + \tfrac{1}{2} C^2 N^2 (V_2^2 - V_1^2) =$$

$$WN + \tfrac{1}{2}(V_2^2/V_1^2 - 1)\, W^2N^2 =$$

$$WN \left[1 + \tfrac{1}{2}(V_2^2/V_1^2 - 1)\, WN\right]$$

where $W = CV_1$ is the probability of bringing down an aircraft per shell without considering the effect of two bursts.

With $R_2 = R_1\sqrt{2}$ we obtain:

$$V_2 = V_1 \, (2\sqrt{2} - 1) = 1.83 \, V_1$$

$$\frac{1}{2} \, (V_2^2/V_1^2 - 1) = 1.17$$

If we set W = 1/5000, a figure which should be close to the actual conditions for the probability of bringing down an aircraft per 8.8 cm HE shell (cf. Chapter I), we obtain the following increase in the probability of bringing down an aircraft due to concentration of fire for various numbers of rounds N fired:

N	w/WN	Increase
small	1.00	0%
100	1.02	2%
200	1.05	5%
500	1.12	12%

Example: Two large batteries of 3x6 = 18 guns each fire 14 salvos each on the same target. Then N is 2x18 x 14 = 504. The probability increase is 12% over the case in which the rounds are fired at a large number of targets.

If each of the six batteries participating in the action were firing at a different target, 6 x 14 = 84 rounds would be fired at each target, which still means a probability increase of about 2% over the case of each gun firing on a different target.

The concentration of the fire of six batteries on one single target thus, with the large number of 14 salvos fired by each battery, means an increase of the probability of shooting down the aircraft of 12 - 2 = 10% over the case of the six batteries firing at six different targets.

III. Probability of hits by heavy anti-aircraft artillery in firing on formations.

1. In firing on close-flying formations, the probability of shooting

down an aircraft is increased considerably over the probability in firing on single aircraft, since not only the target aircraft itself but also those flying next to it may suffer a hit, due to the scattering of the bursting points of shells with time fuzes and the scattering of the trajectories in firing shells with percussion fuzes.

2. The increase factor f which appears as the increase in the probability of shooting down an aircraft in firing on formations over the case of firing on a single aircraft under the same conditions, is the greater:

a) the more aircraft in the formation

b) the closer the formation

c) the greater the scattering of the bursting points, or trajectories.

Point c) should not give the impression that the maximum scatter is favorable in firing on formations. The probability of shooting down an aircraft decreases as the scatter increases, even when firing on formations, although it does not decrease as fast as in the case of firing on single aircraft, so that the factor f, the ratio between the two probabilities which are decreasing at different rates, will increase.

3. In order to get an idea of the increase of the probability of shooting down an aircraft when firing on formations, i.e. to get an idea of the magnitude of factor f, this factor will be computed for various conditions.

4. By "formation" we understand the normal American bomber formation, as described by the Intelligence Service, it consists of one bomber group made up of three squadrons of 12 aircraft each. Each squadron extends about 120 m in the direction of flight, 160 m in width, and a maximum vertical depth of 80 m. The aircraft flying next to each other are 20 m apart in forward direction and lateral direction, and staggered by 10 m in altitude, thus at an oblique distance of 30 m from each other. The high-altitude squadron and the low-altitude squadron fly in the same formation as the lead squadron, their lead aircraft flying about 240 m behind the lead aircraft of the

lead squadron and 360 m to the right or to the left, and approximately 200 m higher or lower.

This entire bomber group consists of 36 aircraft; when projected upon the horizontal plane, it forms a triangle 360 m long in the direction of flight and 880 m laterally wide.

The center of gravity S_1 of the lead squadron lies on the rectilinear flight path of the lead aircraft, 80 m behind it. No aircraft of the formation occupies this position. The nearest aircraft in the formation is 28 m distant from this spot.

The center of gravity S_2 of the entire group is 240 m behind the lead aircraft. This point, too, is unoccupied, the nearest aircraft being 127 m distant. (Cf. Fig. 1)

5. The probability increase f for this type of formation is computed for three cases:

I. a) Firing from directly ahead

b) Firing from the side

c) Firing from below.

(The shielding of individual aircraft by others in the formation has not been considered, since this can be counteracted by slight changes of the angle)

Furthermore for the three cases:

II. a) Using lead aircraft Sp as future position of target.

b) Using squadron center of gravity S_1 as future position of target.

c) Using group center of gravity S_2 as future position of target.

Furthermore, for:

III a) Firing with time fuzes.

b) Firing with percussion fuzes.

Furthermore, for:

IV. a) Optical ranging

Assumption: Scattering is rotational-symmetrical about the direction of fire; longitudinal scatter is 2½ times the lateral scatter; and there is 50% (180 m) deviation between the center of gravity of the formation and the future position at the moment of burst (50% longitudinal scatter ± 130 m, 50% lateral scatter ± 52 m).

b) Electrical ranging:

Assumption: Spherical scatter with 50% deviation (300 m) between bursting point and future position at moment of burst (sic).

In firing with percussion fuzes the lateral scatter given in IVa and IVb is used for computations, although these figures do not quite correspond to the actual ones.

6. The increase factor for all combinations of cases enumerated in 5 is shown in the following Table 1:

Time fuze				Percussion fuze			
from:	front	side	below		front	side	below
optical lead a/c	9.1	7.0	6.7	optical	9.8	7.2	6.7
optical S_1	9.5	9.5	8.6	"	9.8	9.8	8.6
optical S_2	6.6	1.8	1.3	"	9.8	2.5	1.3
elec. lead a/c	11.3	11.3	11.3	electric	14.4	14.9	12.0
elec. S_1	12.7	12.7	12.7	"	14.4	18.6	13.6
elec. S_2	10.5	10.5	10.5	"	14.4	21.5	12.2

Table 1 shows the following:

a) The increase factor f for formations, as compared for single aircraft, is quite considerable, if the formation flies close. It is approximately 10 and may go as high as 20.

b) Due to the greater scatter, the increase factor is higher with electrical than with optical ranging.

c) Aiming on the center of the lead squadron (S_1), although this spot is not occupied by an aircraft, generally brings somewhat better results than aiming on the lead aircraft, while the aiming on the center of the entire bomber group (S_2) is usually much more unfavorable.

d) The direction of fire usually does not have a great or homogeneous effect on the magnitude of f. In optical ranging, the increase factors are greatest in firing from a frontal direction, and lowest in firing from below. In firing on S_2 considerable increase factors occur only when the fire comes from a frontal direction.

In electrical ranging, in firing with time fuzes, f is completely independent of the direction of the fire, since the scatter has been assumed to be spherical, while the highest values in firing with percussion fuzes are obtained in firing from a lateral direction.

e) The increase factors are nearly the same for firing with percussion fuzes as they are for firing with time fuzes. The f-values for percussion fuzes fired from a frontal and especially from a lateral direction are higher than for time fuzes, when electrical ranging is used.

f) The fact that the f-values are partially higher than 12 shows immediately that aircraft flying in the two rear squadrons may contribute to the high values of these figures (which may also apply to figures below 12).

Due to the slight scattering, the values for optical ranging can be attributed almost entirely to the aircraft of the lead squadron. The other squadrons contribute most in the firing of shells with percussion fuzes from a lateral direction, aiming at the center of the formation S_2. In this case, the total value of 2.5 is composed of a factor of 1.7 for the lead squadron, and 0.4 each for the two other squadrons.

In electrical ranging, the situation is different, with the contributions of the two rear squadrons to the total value being much higher. E. g., in the firing of shells with percussion fuzes from a lateral direction, the values are made up as follows:

	Lead sqdrn.	High-alt. sqdrn.	Low-alt. sqdrn.	Total value
Lead a/c	10.9	2.0	2.0	14.9
Center of lead sqdrn.	11.6	3.5	3.5	18.6
Center of group	8.3	6.6	6.6	21.5

This means the following: During firing on the lead aircraft of the lead squadron, the 24 aircraft of the low-altitude and high-altitude squadrons which are approximately 500 m distant are still as likely to be hit as four aircraft flying exactly at the point of the future position.

7. If the formation is more spread out, the increase factors f are greatly reduced. This is shown in Table 2 for the firing of shells with time fuzes with electrical ranging. The f-values here are given under the condition that all distances within the formation have been increased n times, with maintenance of the general shape of the formation. For n = 1, the values previously given will hold.

Table 2

n	Lead a/c	Center of lead sqdrn.	Center of group
1	11.3	12.7	10.5
2	7.7	9.5	2.6
3	5.5	7.2	0.6
4	4.3	5.1	0.1
6	3.0	2.5	0.0

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4	4.3	5.1	0.1
6	3.0	2.5	0.0

At any rate, with electrical ranging (the decrease is much greater with optical ranging), a formation flying with its aircraft six times as far apart as the normal formation (minimum distance between two aircraft now 170 m) still offers a probability of bringing down an aircraft three times that of shooting down a single aircraft.

8. Up to now we have been dealing exclusively with the increase factors f of the probability of shooting down an aircraft. We shall now, as the conclusion of this chapter, cite the probabilities ~~themselves~~, (with reservations), applicable ~~applying~~ when ~~to~~ firing at the center of the lead squadron.

These figures are given with reservations, because other assumptions have to be introduced, and because, as has already been pointed out in section 5, IV of this chapter, the scattering conditions for time fuzes and percussion fuzes, on which this compilation is based, are not exactly alike, so that the shells with percussion fuzes in this table are represented in too favorable a light over shells with time fuzes.

The other assumptions which have to be made are the following:

For time fuzes: Lethal area for bursts about the aircraft (8.8 cm HE shell):

3,000 cu.m.

For percussion fuzes: Target area of the aircraft (B-17):

from the front: 30 sq. m

from the side : 60 sq. m

from below : 200 sq. m

The reciprocal values of the probability of shooting down an aircraft, i.e. the number of 8.8 cm shells required to bring down an ~~aircraft,~~ are shown in Table 3.

Table 3

Number of rounds required per aircraft shot down

			Single aircraft	Aircraft in formation
Time fuze	elec. ranging		38,500	3,000
	opt.	front	6,200	650
		side	6,200	650
		below	6,200	720
Percussion fuze	Elec. ranging	front	8,000	550
		side	4,000	215
		below	1,200	88
	opt. ranging	front	1,200	120
		side	620	64
		below	190	22

The figures from the statistics of aircraft actually shot down by 8.8 cm HE shells with time fuzes are about 5,000 rounds per aircraft destroyed in the overall average and 2,000 rounds per aircraft destroyed for optical ranging. These figures fit into the above table quite well, since they should lie between the figures for single aircraft and those for close-formations.

IV. Summary of the reasons for the superiority of shells with percussion fuzes over shells with time fuzes fired by heavy anti-aircraft artillery, (in particular 8.8 cm guns).

The superiority of firing shells with percussion fuzes over firing shells with time fuzes in the probability of destroying aircraft has been computed for various assumptions and by different methods. All these methods show the same result: The probability of shooting down heavy bombers with 8.8 cm shells with percussion fuzes is a multiple of the probability attained with time fuzes.

This result seems quite surprising at first glance. We shall now give a short proof in a manner comprehensible also to non-mathematicians.

M Most people are emotionally averse to the idea of firing shells with percussion fuzes at aircraft, for the simple reason that they all feel that the chance of obtaining a direct hit on a target as small and as fast-moving as a high-flying aircraft is exceedingly slight.

Very few people, however, are aware of the fact that the chances of making a shell with a time fuze burst in the immediate vicinity of the target (an 8.8 cm shell has to burst within a distance of 5 to 6 meters from a four-engine bomber to bring it down) are still slighter. In this case not only is it necessary to hit a certain area whose size is increased only slightly by the margin of 5 to 6 m width, but also there must be coincidence of the bursting point and the target in the third dimension, in the direction of fire; this is the most unlikely effect to be achieved, because of the fact that it is here where the greatest scattering occurs, namely the longitudinal scattering, due mostly to errors in ranging, calibration, fuze scattering, and other errors in operating the fire control unit.

For a numerical example, let us take a shot with great angular height of the target, i.e. firing from below, for the sake of simplicity. If we now imagine that with this location of gun and aircraft (gun at zero point O, aircraft at target point or future position Z), many thousand rounds, independently aimed, are fired, the bursting points will form a scatter area around the aircraft, due to the ranging error and other errors which will be different in every case, which in optical firing will have the ellipsoidal shape shown in Figure 2 (AB), and which will be nearly spherical in case of electrical firing, due to the much greater scattering in a direction lateral to the trajectory. The scatter area is not closely defined, but the density of the bursting points, greatest in the immediate vicinity of the target, gradually decreases with greater distance from the target. For our considerations, however, we can assume it to be an area with definite limits and a constant density of bursting points in its interior, so that the total number of bursting points will be constant. The distance ZA or AB from the target to the definite border of the scatter area in the direction of fire must be of the order of magnitude of the mean longitudinal scatter, or, according to more exact calculations, 1.8 times the so-called 50% longitudinal scatter. The empirical value for optical firing, the 50% longitudinal scatter which contains all sources of error, is 100 to 150 m; for electrical firing the figure is sometimes higher. The distance ZA, or ZB, in Figure 2 thus is to be taken as 200 m for optical firing, and greater than that for electrical firing.

The aircraft is shot down, when time fuzes are employed, by the small fraction of bursts of the many thousands within the space AB, which is less than 6 m away from the aircraft, in the small vertically-shaded space in Figure 2 around the aircraft. The volume of this space is a measure of the number of bursts contained in its, and is thus a measure of the total probability of shooting down an aircraft with shells with time fuzes.

The area of a heavy bomber projected in the horizontal plane is about 200 sq. m. Since the vertically shaded area protrudes by 6 m, its area becomes greater, increasing, as has been determined, to about 800 sq. m. Its "thickness" is 2 x 6 = 12 m; thus its volume is approximately 10,000 cu. m. At that, this figure is certainly too high, since shells bursting 6 m from the wing tips will undoubtedly fail to destroy the aircraft.

If the shells are equpped with percussion fuzes instead of time fuzes, all trajectories passing through the point at which the aircraft is located, i.e. all trajectories within the cylindrical horizontally-shaded area in Figure 2, will bring down the aircraft. It is quite evident that this horizontally shaded area contains many more bursting points than the vertically shaded one, in the same ratio as it is larger.

Its cross-section is that of the aircraft, 200 sq. m; its longitudinal extent AB is 400 m in optical firing and still greater in electrical firing; its volume is thus 80,000 cu.m. That is 8 times the volume of the vertically shaded area.

In other words, when employing percussion fuzes, approximately 8 times as many shells will hit the aircraft as there are bursting points of shells with time fuzes in the vertically shaded area; or worded still differently, firing with percussion fuzes increases the probability of shooting down an aircraft 8 times. When firing with electrical ranging, the factor will be still higher than 8, since in that case the longitudinal scatter and thus the distance AB is much greater.

V. Does firing of shells with percussion fuzes necessitate a change in heavy anti-aircraft artillery tactics?

1. Differences of tactical importance between firing of shells with time fuzes and firing of shells with percussion fuzes:

In order to be able to answer the question whether firing with percussion fuzes would make changes in the operation of heavy anti-aircraft artillery desirable or necessary, those differences between firing with percussion fuzes and firing with time fuzes, which have a tactical effect, must be enumerated.

a) Firing with percussion fuzes will result in 6 to 10 times as many aircraft destroyed as firing with time fuzes, with the same number of rounds fired. Even a single battery firing shells with percussion fuzes is more effective than a large (consolidated) battery firing shells with time fuzes, as far as the probability of shooting down aircraft is concerned.

b) The psychological effect of the smoke puffs from bursting shells near the aircraft is absent, when percussion fuzes are used.

c) Firing with percussion fuzes cannot be detected from the aircraft, except by observing the muzzle flashes on the ground or by seeing another aircraft crash. This increases the importance of the moment of surprise.

d) In firing shells with percussion fuzes, concentrating the fire of several batteries on one target will not cause any additional effect in excess of the sum of the individual effects, while this may be the case to a slight extent when firing shells with time fuzes. (cf. II.)

2. Advantages and disadvantages of battery concentrations (single vs. consolidated battery).

The basic question of heavy anti-aircraft artillery tactics is whether the individual batteries should be spread out or whether they should be concentrated in the form of consolidated batteries (several batteries, each with its own fire control unit, concentrated in a small space, and all of them connected to one radar set). This question will now be discussed by enumerating the advantages and disadvantages of such concentration measures, with special consideration of the problem of firing shells with percussion fuzes.

The so-called "mammoth battery" (24 or more guns connected to one fire control set) shows such grave disadvantages in nearly every respect - in contrast to the normal consolidated battery - that we can omit it from our considerations.

A. Advantages of concentrations.

a) When the enemy comes within range of the anti-aircraft concentration, he can be attacked very effectively. This advantage holds for firing shells with both types of fuzes.

b) Sometimes concentration of fire on one single target will cause an increase in effect in excess of the sum of the individual effects (by combined fragmentation damage from several shells). This increased effect is slight in the case of firing with time fuzes, and totally absent in the case of firing with percussion fuzes.

c) The psychological effect of bunches of bursts is greater than the effect of the same number of bursts spread over a longer period of time. This advantage also applies only to time fuzes.

d) Saving of personnel. Applies equally for both types of fuzes.

e) Saving of equipment. Applies equally for both types of fuzes.

f) Better chances of training of personnel, because of the close proximity of all kinds of equipment. Applies equally for both types of fuzes.

g) Better chances of keeping foreign auxiliary personnel under surveillance. Applied equally to both types of fuzes.

B. Disadvantages of concentration.

a) Because of the greater concentration of personnel and equipment, the vulnerability to air attack of consolidated batteries is much greater than if the same number of batteries were distributed over a greater area. This disadvantage is not connected with the type of ammunition used, but it might become important in the case of percussion fuze ammunition, since the enemy might be compelled to increase his attacks on anti-aircraft artillery emplacements whose effectiveness has increased.

b) If concentrations are formed, the gaps between the concentrations will be that much bigger. As Intelligence reports show (cf. No. 28, 1944), the enemy is already trying to take advantage of this fact by using the gaps to penetrate without being attacked. This disadvantage holds for both types of fuzes. The greater effectiveness of firing shells with percussion fuzes might cause the enemy to increase his efforts to avoid flying over anti-aircraft artillery concentration points.

c) In the case of anti-aircraft artillery concentrations, it is easier for the enemy to determine where the fire is coming from. Since firing shells with percussion fuzes is difficult to detect, this disadvantage will be largely compensated for in that case.

3. Conclusions on tactics for firing shells with percussion fuzes

The enumeration in the preceding section shows that the advantages of concentration of batteries, in the case of firing shells with percussion fuzes, are less and the disadvantages greater than when employing time fuzes, so that the problem of firing with percussion fuzes involves the spreading out of concentrated batteries. Otherwise, number of the advantages and disadvantages described depend to a great extent on the tactics employed by the enemy, so that the question of consolidation vs. dispersal of batteries cannot be answered without considering the tactics of the enemy.

With the enemy tactics prevailing at the present time, the factors in favor of dispersal do not seem to be important enough to warrant a change in our anti-aircraft artillery tactics, especially when the circumstance is considered that every fundamental change of tactics means increased use of labor and material for reconstruction of gun emplacements.

However, it is quite conceivable that there will be a time in the future when the enemy will concentrate his air activity on anti-aircraft gun positions and will thereby force dispersal of the emplacements. Thus: Vulnerability against air attack is just about the only important reason for which such tactical changes might be carried out.

While maintaining our tactics of concentration of anti-aircraft artillery, it does seem practicable to close the gaps between these concentration points by single batteries which will afford single coverage of the gap, to prevent completely unopposed penetration by the enemy through these gaps, and also to utilize effectively the moment of unexpected and sometimes undetected fire, which is important when percussion fuzes are employed.

Otherwise, the tactical points for the improvement of the effectiveness of heavy anti-aircraft artillery are not nearly as decisive as the improvement of the guns and of the ammunition and the untiring and thorough efforts of training the personnel.

V. The effect of ~~the~~ errors in range measurement and calibration upon the firing of shells with percussion fuzes.

In the treatment of the problem of firing percussion fuze ammunition from heavy anti-aircraft guns, the idea has cropped up occasionally that the range measurement need not be as exact as when firing ammunition with time fuzes, and that errors in the calibration of the guns will not have much of an effect.

This attitude must be branded as quite wrong. The advantages of firing percussion fuze ammunition can be utilized only when the same care as before is taken in the determination of the range and the proper calibration.

We shall prove this point by giving a few numerical examples which show that, when using percussion fuze ammunition, errors in ranging and calibration will not have quite as great an effect as on the firing of time-fuze ammuntion, but that the effect will still be great enough to reduce the probability of hitting to a considerable extent.

a) General

While the effect of a ranging error (and also the effect of a calibration error) in the firing of time fuze ammunition will manifest itself directly by the burst being short or wide of the target, the effect on percussion fuze ammunition is indirect, but nevertheless just as annoying.

For instance, if the range is measured continuously too short, at the instant in which the shell reaches the future position determined by the short range measurement (this point would be the bursting point if time fuze ammunition were being used), the target will have moved on in the direction of fire

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the distance of the range error. Furthermore, because of the superelevation's being too small, the shell will pass below the path of the target; and because the target will have moved on while the shell is approaching the path of the target, it will also pass behind the target. If the range is measured too long, the error will have the opposite effect: the shell will go too high and pass in front of the target.

Fluctuating errors in range measurement also will cause the shell to fly in the wrong direction and at a wrong horizontal velocity, thus causing additional deviations. When firing percussion fuze ammunition, these deviations will not show up in the form of bursts wide of the target, but they will cause the shell to miss the target by a considerable distance.

Use of incorrect calibration has the same effect as a range error in the same continuous sence, too low a calibration having the same effect as a continuously short range measurement and too high a calibration acting like a continuously wide range measurement.

b) First numerical example:

Gun: 8.8 cm Flak 37, 8.8 cm HE shell with percussion fuze

Target: Horizontal path at altitude h = 7,000 meters, flies through e_{KW} = 5000 m at v_h = 150 m/sec.

Plane of position at instant of firing: Determined by e_k - 6000 m (e = 9220 m). Approaching target.

Range measurement error: 160 m short in direction of fire, making the "apparent" target fly a path which is by 160/9220 = 1.73% closer and lower than the actual target, with a horizontal velocity 1.73% lower than that of the actual target. (A constant error in seconds of angle would not result in an error in meters whose percentage is constant, i.e. it would not result in the appearing of a parallel "apparent" target path. The deviation from the parallel, however,

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is very slight.) On the 4 m R 40 with a magnification of 36, this range error corresponds to an error of 50 seconds of angle, thus to the error by a gunner who is at the borderline of being "good".

We assume all other errors to be zero, with firing table conditions prevailing.

At the instant when the shell arrives at the "apparent" target (which is ranged too short), the real target is still 160 m away. Shell and target continue their flight. After 0.5 seconds the shell will reach a point which is 75 m directly below the target path. At that moment, however, the target has already advanced 75 m toward the midpoint, and is 106 m away from the shell. Already shortly before, 0.37 seconds after its passing through the "apparent" target, the shell was at its minimum distance from the target, this distance being 98 m. (The lengthy calculations, carried out on the basis of the firing tables, have been omitted here.)

This ranging error, which would have caused the bursting point to be 160 m off the target in the case of time fuze ammunition, here causes the shell to pass the target at a distance of 98 m. Thus, the adverse effect of the ranging error is nearly as great in the case of percussion fuze ammunition as it is in the case of time fuze ammunition.

c) Second numerical example

Gun, target, and plane of position at instant of firing same as above.

Calibration error: 5 units too low.

All other errors are assumed to be zero; firing table conditions prevailing with the exception of the wrong calibration.

In the instant, at which the shell should have reached the target according to the lead calculation which is correct by the firing table conditions, it has only reached a point which is 105 m below the target and whose e_K is 75 m less than that of the target. At that instant, therefore, (when it would burst if it were equipped with a time fuze) it has a distance of 129 m from the target. After 0.40 seconds it reaches a point which is 68 m directly below the target path. The target has moved 60 m toward the midpoint in the meantime, so that the distance between shell and target is now 92 m. Already a short time previously, 0.32 seconds after it has passed through the point which would have been the bursting point had it been equipped with a time fuze, the shell passed through the point of its minimum distance of 86 m from the target.

The calibration error of 5 units would have caused the bursting point of a shell with a time fuze to be 129 m off the target, while in this case it causes the shell to go past the target at a distance of 86 m.

Figures:

Fig. 1: American bomber group formation (Page 35)

Legend: Flugrichtung: direction of flight

Fuhrungsangriffsgruppe: lead squadron

12 Maschinen: 12 aircraft

Tief-Angriffsgruppe: Low-level squadron

Hoch-Angriffsgruppe: High-level squadron

Quadrat: square

Jeder. bedeutet ein Flugzeug: Each dot represents one aircraft

S_1: Schwerp. d. Fuhrungsgruppe: S_1: Center of the lead sqdrn.

S_2: Schwerp. d ganzen Geschwaders: S_2: Center of the entire group.

Fig. 2. No titles or legend. (Page 36)

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