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THE RELATIVE EFFICIENCY OF MECHANICAL AND POINT DETONATING FUZES FOR ANTIAIRCRAFT SHELL, A REVIEW OF PAPERS ON THE SUBJECT

by

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Abstract

The estimated relative efficiencies of mechanical and point detonating fuzes for A.A. shell obtained from various sources are compared. It appears that for combating small bombers the mechanical fuze should be more efficient if radio height finders are used, especially for the larger calibers. For combating very large bombers, the point detonating fuze seems to have an advantage. Such a fuze should have a delay of about .0005 sec. and should have a self destroying feature. The fuze should be used to arm a relatively small caliber shell such as a 3". To attack high flying bombers the 3" shell should be fired from a high velocity gun.

Attention has again been directed to the question of the relative efficiency of mechanical and point detonating or contact fuzes by a recent memorandum from M.A. Tuve of the N.D.R.C. to the Chief of Ordnance enclosing memoranda on this subject, especially two memoranda by D. M. Dennison and H. R. Crane dated Nov. 11th and Dec. 5, 1941 respectively. This subject had previously been discussed in the following British and American reports.

R.A.E. Report No. D.I./81, "The chances of hitting an aerial target (Siskin III and Blenheim Bomber) by antiaircraft fire," by Stevens, Hollingdale and Price.

B.R.L. Report No. 132, "The Probability of Hitting Various Parts of an Airplane as Dependent on the Fragmentation Characteristics of the Projectile," by R. H. Kent.

B.R.L. Report No. 155, "The Probability of Disabling an Airplane" by R. H. Kent.

For convenience, the memoranda of Dennison and Crane will be designated N.D.R.C., the British report will be designated by R.A.E. and B.R.L. reports Nos. 132 and 155 by B.R.L.

As might be expected from the diversity of methods, assumptions and types of target, different estimates of the relative efficiency of the mechanical and contact fuzes are obtained by the various authors of the memoranda and reports mentioned. These are summarized in Table I for an airplane in level flight.

Of course the calculated crash ratios depend very much on the nature of the assumptions made in the calculations. The data taken as bases for the calculations of the various reports are given in Table II.

TABLE I

Estimates of the Ratio of Crashes Produced by Contact Fuzes to those Produced by Mechanical Fuzes

Source	Caliber of Proj.	Approx. Slant Range ft.	Type of Height Finder	Type of Target Airplane	Armor Protect. for Pilot and Bomber	Crash Ratio
R.A.E.	3.7"	15,000	Radio	Blenheim Bomber	None	.7
N.D.R.C.	5"	15,000	Radio	Four Engined Bomber	None	3.8
N.D.R.C.	5"	15,000	Visual	Four Engined Bomber	None	4.8
N.D.R.C.	5"	25,000	Radio	Four Engined Bomber	None	3.8
N.D.R.C.	5"	25,000	Visual	Four Engined Bomber	None	5.3
B.R.L.	105 mm	15,000	Radio	Navy Type Bomber*	None	.25
B.R.L.	105 mm	15,000	Visual	Navy Type Bomber	None	.4
B.R.L.	105 mm	30,000	Radio	Navy Type Bomber	None	.4
B.R.L.	105 mm	30,000	Visual	Navy Type Bomber	None	1.6
B.R.L.	105 mm	15,000	Radio	Navy Type Bomber	Complete	.7
B.R.L.	105 mm	15,000	Visual	Navy Type Bomber	Complete	1.1
B.R.L.	105 mm	30,000	Radio	Navy Type Bomber	Complete	1.1
B.R.L.	105 mm	30,000	Visual	Navy Type Bomber	Complete	4.4

* The estimate of the probability of a crash due to fragments is based on the Navy bomber. The estimate of the probability of a direct hit assumes a much larger bomber. With the larger bomber, the probability of destruction by fragments is doubtless considerably smaller than the probability of destruction of the Navy bomber by fragments.

TABLE II

COMPARISON OF ASSUMPTIONS

A. Assumed Errors along Line of Sight, Mechanical Fuze.

Source	Caliber	Altitude ft.	Fuze Error sec.	Position Error Opt. ft.	Position Error Radio ft.	Trial Shot Error ft.	Resultant Error Opt. Height Finder	Resultant Error Radio Height Finder
R.A.E.	3.7"	10,000*		-	140			200
N.D.R.C.	5"	15,000	.07	520	100	67	540**	170**
N.D.R.C.	5"	25,000	.17	1450	100	95	1460**	210**
B.R.L.	105 mm	15,000	.06†	230	100†	75†	260	160†
B.R.L.	105 mm	30,000	.11†	930	100†	100†	940	240†

* For an angle of elevation of 45°, the slant range will be therefore about 15,000 ft.

† These results are not given in B.R.L. Report 155 but are assumed here for calculating the resultant error with the radio fuze and correcting slightly the previous results for the mechanical fuze.

** These N.D.R.C. results are as revised by the writer since the original ones assumed that an error in dead time would cause an error with a crossing course.

B. Assumed Fragmentation Characteristics.

Source	Caliber of Shell	Thickness of Wood Penetrated	No. of Effective Fragments near Burst	Alt. of Burst	Average Effective Range of Fragments yds.
R.A.E.	3.7"	1.5"	900	-	75*
		2.5"	900	-	38
		3.5"	860	-	21
		6.5"	300	-	11
N.D.R.C.	5"	-	No estimate**	-	60*
B.R.L.	105 mm	-	980	15,000	100
				30,000	170

* Neither the R.A.E. nor the N.D.R.C. seem to make allowance for the dependence of range of fragment on air density as is done in B.R.L.

** Instead of assuming a number of fragments, N.D.R.C. assumes that if the center of the airplane is in the sidespray at a distance of 37 ft. from the burst, the probability of a crash is .60.

C. Assumptions Concerning Vulnerability of Component Parts of Target Airplane to Fragments.

	Components	Sectional area ft^2	Minimum size effective fragment (oz.)	Minimum penetration of wood (in.)	Chance that a hit will cause (i) immediate crash	(ii) failure of attack	(iii) failure to return home
R.A.E.	Engines and oil tanks	22.5	0.25	3.5	0	0.10	0.60
	Bombs and releases	25.8	0.25	6.5	0.80	0.80	0.80
	Pilot and bomb aiming instruments	29.5	0.04	1.5	0.15	0.30	0.50
	Petrol tanks	14.8	0.10	2.5	0.10 (fire risk)	0.10	0.70
	Gunner and control wires to tail unit	12.9	0.04	1.5	0.20 (controls)	0.30	0.50
	Spars of tail plane and controls	5.3	0.50	2.5	0.30	0.50	0.50

	Part of Airplane	Area yd^2	Probability that a hit by a fragment will cause: a. Immediate crash	b. Immediate crash or delayed crash
B.R.L.	Engine	.79	.097	.222
	Lubricating system	.27	.037	.370
	Fuel supply system	1.30	.034	.212
	Engine control	.073	.100	.175
	Engine bearers	.25	.091	.455
	Pilot	.40	.524	.571
	Surface controls	.60	.136	.227

Note: In estimating the probability of a crash with mechanical fuzes no allowance is made by B.R.L. for the effect of a shell which bursts above, having previously pierced the structure of the airplane. N.D.R.C. and apparently R.A.E. take this into account.

N.D.R.C.

In the memorandum dated November 11th, the assumption is made that the airplane will be destroyed if the burst lies directly below some part of the airplane and within 20 ft. of it. A certain additional probability of causing damage is attributed to bursts not directly below but within 20 ft. of the edge of the surface of the airplane. In the memorandum dated Dec. 5th, this is justified on the assumption that if the airplane lies within the side spray and center is 37 ft. from the burst, the probability of destruction is .60.. For greater distances it is assumed, (1) that the probability of destruction is proportional to $N^{3/2}$ or (2) that the probability is proportional to N^2 where N is the number of fragments hitting the airplane. The N^2 law could be justified on the assumption that the vulnerable components are in pairs and that both components of a pair have to be hit for the airplane to be destroyed.

D. Comparison of Plan Areas of Targets.

	Assumed Area ft^2
R.A.E.	625
N.D.R.C.	989
B.R.L.	1350*

* This area is much greater than that of the Navy bomber for which the estimate of vulnerability to fragments is based. In an airplane of this size in all probability two engines or two pilots would have to be incapacitated to cause a crash.

E. Comparison of Assumed Positions and Flights of Target Airplane.

	Position of Airplane with respect to gun	Type of Flight
R.A.E.	Line of sight about 45° from vertical	Level flight
N.D.R.C.	Directly overhead*	Level flight*
B.R.L.	Directly overhead	Level flight

* The N.D.R.C. also considers combat with a dive bomber which is much less favorable to the contact fuze than is combat with a bomber in level flight directly overhead.

Discussion of Data of Table II

A. The values for the resultant error along the line of sight with the radio height finder are substantially the same for the various reports. For the optical height finder, the resultant errors given by B.R.L. are considerably smaller than those calculated from the N.D.R.C. data.

In calculating the resultant errors, the N.D.R.C. have considered the error due to the error in dead time to be the product of the dead time error and the remaining velocity. This is obviously incorrect since on a crossing course, an error in dead time produces no resultant error along the line of sight. The director predicts the time of flight at the time the fuze is set. If the slant range remains constant the time of flight remains appreciably constant and no appreciable error is caused by dead time.

B. The R.A.E. data for the range of the fragments capable of penetrating 1.5" of wood are reasonably consistent with those of B.R.L. if allowance is made for air density. Since,as shown in Table II C, the R.A.E. assume that for damaging certain structures the fragment must be capable of penetrating 6.5" of wood, the average R.A.E. fragment range is considerably less than that of B.R.L. B.R.L. also assumes a somewhat greater number of fragments than does R.A.E. The greater number and greater range of fragments assumed by the B.R.L. are no doubt the main reasons why the R.A.E. crash ratio is higher than that of B.R.L.

While the N.D.R.C. make no estimate of the number of fragments, it appears that approximately 1000 would be required to produce a .60 probability of a crash at 37 ft. if the vulnerable components consist of two pairs and the projected area of each component of each pair is about 1 yd^2. The N.D.R.C. estimate of the range of the fragments on the ground seems plausible also.

C. Table II C brings out the radical difference between the assumption of R.A.E. and B.R.L. on the one hand and those of N.D.R.C. on the other so far as the vulnerability of the component parts of the target airplane is concerned. R.A.E. and B.R.L. assume that these parts are unconditionally vital, i.e., if the single component is destroyed the airplane will be destroyed while N.D.R.C. assumes that the parts are only conditionally vital, i.e., both components of a pair must be destroyed to cause the destruction of the airplane if the N^2 law holds. However, it appears that the assumptions of all three reports are appropriate to the type of airplane considered. R.A.E. and B.R.L. treat the attack by fragments of a relatively small single-engined bomber with a single pilot while N.D.R.C. contemplates a four engined 'flying fortress' with a large crew as a target.

R.A.E. assumes considerably greater areas for the components than does B.R.L. This serves to offset in part the greater number and range of fragments assumed by B.R.L.

D. The plan area assumed by R.A.E. is less than one-half as great as that assumed by B.R.L. for attack with an impact fuze. The smaller plan area produces a smaller probability of a direct hit. This also serves to offset the greater fragment ranges and numbers assumed by B.R.L.

The plan area assumed by N.D.R.C. is conservative for a modern four engined bomber. If the N.D.R.C. were to take the plan area of B.R.L. it would obtain a still more favorable crash ratio, i.e., the case for the contact fuze would appear to be still stronger.

E. The position of the airplane assumed by B.R.L. and N.D.R.C. is more favorable to the contact fuze than is that assumed by R.A.E. It should be pointed out that the contact fuze would be relatively ineffective against dive bombers.

Discussion of Net Results of Table I

The ratio of crashes produced by mechanical fuzes to those produced by contact fuzes (called 'crash ratios' for short) as deduced by the various reports are given in Table I. From the discussion it appears that the R.A.E. and B.R.L. estimates are reasonably consistent although perhaps the discrepancies have not been entirely accounted for. On the other hand, especially if we take the revised crash ratios, the N.D.R.C. estimates are much higher than those of R.A.E. and B.R.L. As brought out in Table II C, this is a result of assuming a target the component parts of which are only conditionally vital. On the whole then the crash ratios given by R.A.E. and B.R.L. seem appropriate to the attack of a small bomber while those of the N.D.R.C. are appropriate to the attack of a very large bomber. From this one infers that in attacking a small bomber, if the ranges are obtained by radio the use of a contact fuze is of doubtful advisability but that in attacking a large four engined bomber the contact fuze seems preferable to the mechanical fuze.

In considering the relative merits of the two types of fuzes, one should not lose sight of the fact that bursts of shell armed with mechanical fuzes may cause a considerable damage to the target even when they fail to cause crashes from a single shot, while presumably if the shell armed with a contact fuze fails to destroy the target it will do no damage at all. In this connection it is worth while to quote the "Discussion of Results" of the R.A.E. report.

"8. DISCUSSION OF RESULTS

"The chances of hitting the aerial target for the various cases considered are exhibited in Tables 3, 5 and 6.

"In the case of the Siskin, the chances of a hit by a fragment as calculated in this report are appreciably higher than those calculated by Woolwich, and both indicate a marked superiority of the fragment over the direct impact shell. For the Blenheim, on the other hand, this superiority is less marked. The chance of a hit with a direct impact shell is about the same as that of causing an immediate crash with a fragmenting shell detonated by a powder fuze; the more accurate mechanical fuze produces an appreciable improvement. The fragment shell has the further advantage that it enables damage to be inflicted less catastrophic than that required to cause an immediate crash, but sufficient to prevent the attacker either carrying out his bombing programme or returning home. The chance of doing either of these is greater than that of making a direct hit by a shell.

"The Blenheim, owing to its larger size, has a greater chance than the Siskin of being damagingly hit by a fragment. The former is, however, the better protected, and the probability of inflicting serious damage is lower than in the case of the Siskin. The increasing invulnerability of modern bombers to shell fragments clearly strengthens the case for the direct impact shell.

"The results of this report only apply to the particular aiming errors here assumed. The direct hit chances are independent of range errors, but for both types of shell the probabilities of hitting are almost equally sensitive to changes in the deflection errors.

"The conclusions from this analysis are not inconsistent with those of Professor Blackett. His calculations indicate that percussion fuzing is superior for shells of 3" calibre, while time fuzing is preferable for 4.7" shells. The 3.7" shell occupies an intermediate position, and Professor Blackett's conclusions do not permit of prediction as to the relative merits of time and percussion fuzing for shells of this calibre."

The influence of caliber brought up by the R.A.E. is worth emphasizing. It was pointed out in B.R.L. that if a contact fuze is used the caliber could be reduced and this would be an additional argument in favor of the contact fuze. If a contact fuze is adopted it should be used first on the 3" shell. However, to augment the probability of hitting, a gun considerably more powerful than the 3" Gun M3 should be made to fire it.

Fuze Design

It has been tacitly assumed in the foregoing that a direct hit by any of the shell mentioned would cause the target to crash immediately. However, especially for the smaller shell, this result might not follow unless the fuze were suitably designed for the purpose. For example, according to B.R.L. Report No. 158, the delay of the M46 fuze is about .00027 sec. If the remaining velocity of a 3" or 90 mm shell were 1000 ft/sec, the shell would burst when only about 3" of the shell had penetrated the structure and practically all of the TNT would burst outside the structure. According to some results obtained by the Navy, the blast or concussion effects from a 3" shell would not do very serious damage under such circumstances. On the other hand if a delay of from .0005 sec to .00075 sec were obtained, most of the TNT would burst inside of the structure and would doubtless cause the airplane to crash. It follows that if the A.A. shell are to have a contact fuze, the fuze should be designed to have approximately a delay of .0005 sec or slightly greater.

If shell with contact fuzes are fired from Naval vessels possibly a self-destroying device may not be needed but certainly shell fired from army guns need a self-destroying device.

Conclusion

The question arises whether steps should be taken in the immediate future to fuze some of our 3" A.A. shell with a suitable contact fuze with the proper delay and with a self-destroying device. Whether this would be a wise procedure will depend upon the types of enemy bombers to be used in the future. If the enemy are going to use large numbers of very large bombers, it would seem desirable to fight them with A.A. shell armed with contact fuzes. On the other hand if the enemy are going to use small bombers for the most part the adoption of the contact fuze would be open to serious question.

In any event the United States should be prepared to combat efficiently large enemy bombers by A.A. fire when, and if, they appear. If a 3" shell armed with a suitable contact fuze is sufficient to destroy the enemy bomber, it is obviously uneconomical to fire shell of larger caliber such as 4.7" armed with contact fuzes. However, the 3" gun should have a muzzle velocity high enough to obtain times of flight approximately equal at combat ranges to those of the 4.7" projectiles.

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