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CHAPTER VI

THE RELATIVE EFFECTIVENESS OF HE BOMBS

1. Object of Bombing. In determining the size of bombs to be used against a target, the mission to be accomplished by the attack is one of the factors to be considered in choosing the weapon. In strategic bombing, the object is to do the maximum damage to a given target taking into consideration the maximum vulnerability of the latter and the requirements of operations.

2. Effective Damage. A selected target will present some installations at which the attack should be directed in order to most effectively damage the entire target with a minimum of operational requirements. To accomplish this, it is necessary to measure the vulnerable areas and compute the mean area of effectiveness. The vulnerability of installations within the computed area will determine the size of the weapon to be used.

3. Weapons Vs Targets. In selecting a bomb for a given target it is not advisable to refer to a weapon as a large or small bomb. A bomb of given size may be considered as a large bomb when used against a light or delicate type target, where the same bomb would be considered relatively small when directed at a target of highly resistant construction.

4. Explosive Weight per Area to Achieve Desired Results. To determine the explosive weight per area to achieve the desired results, it must first be determined whether total destruction to the buildings and machines is necessary, or whether temporary stoppage of production is sufficient to accomplish the prescribed mission.

5. Computation of Mean Areas of Effectiveness. The great majority of data previously available on the MAE's of American and British HE bombs ~~has been~~ were obtained by interpretation of aerial photographs. In the present report the data used is based entirely upon the ground surveys made by the PDD, USSBS, of structures on the continent of Europe. For buildings, only structural damage, as opposed to superficial damage, is considered. Structural damage is here defined to be damage to load-bearing members. Only damage caused directly by the earth shock, blast, or fragmentation effects of HE bombs is considered; fire damage, where the fire is initiated by the HE bomb, has been excluded.

6. All structures have been grouped into the following types:

a. Single story structures.

(1) Masonry load-bearing wall types. Roofs flat or pitched - steel or timber.

(2) Light factory, steel or wood framed. North-light or pitched roofs.

(3) Heavy steel-framed buildings or those containing runways supporting heavy cranes..

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(4) Hangar and aircraft-assembly types of buildings - steel, timber or reinforced concrete framed roofs.

(5) Factory reinforced concrete framed or reinforced concrete shell kinds. Roofs flat, north-light or pitched.

(6) Small buildings of light construction.

b. Multi-story.

(1) Masonry load-bearing wall or composite construction.

(2) Steel framed.

(3) Concrete framed or flat slab.

7. In the analysis of machine tool damage, all machine tools of the type: lathes, grinders, millers, etc. have been grouped without distinction, and only for this type of tool has an MAE been calculated.

8. In selecting the data used in this report attention has been confined to structures that fitted into the above classification. Such targets as sub-pens, air-raid shelters, bridges, and marshalling yards were not included. Structures in which the damage was due to both HE effects and fire (either from (1) HE, (2) IB's)were eliminated, as were those in which HE bombs of two or more types fell in the same structure, unless it was possible to segregate the damage caused by each type. Also eliminated, naturally, were those cases in which the type of bomb or the number of bombs was undeterminable. In a few cases buildings were so completely destroyed that it was impossible to determine their structural classes, these were also omitted.

9. Machine tools were not included unless information on the location of undamaged machines was obtainable as well as on damaged machines. For machine tools the calculations are in terms of machines destroyed or heavily damaged. Heavy damage covers those cases in which repairs involved the replacement of major parts and could not be made to the machine at the plant where it was used.

10. The mean area of effectiveness of HE bombs in causing structural damage to the various classes of buildings has been estimated by two methods. For a discussion of various methods of estimating MAE's see REN 406 "Methods of estimating the Mean Area of Effectiveness of HE weapons against buildings, machine tools, and similar targets", by R.B. Fisher, Ministry of Home Security, Research and Experiments Division, RE 8 - Joint Anglo- American Division. For the first method, the binomial, the following data were obtained for each type of bomb and structure:

B_i - plan area of building $_i$

G_i - plan area of structural damage (zero cases included)

n_i - the number of bombs in building i.

Then the MAE was estimated by solving for M in:

$$\sum_i G_i = \sum_i B_i \left(1 - \left[1 - \frac{m}{B_i}\right]^{n_i}\right)$$

11. This is the method used in "Direct-Hit Effects of US 500-lb. GP bombs on European industrial buildings - structural HE damage" AN-23 Group, Monthly Report EWT -2f (OSRD - 5045f) "Effects of Weapons on Targets", Vol 2, 5 May 1945. As in that paper, the MAE so calculated is a "direct-hit effect" only, and in using it the following criteria, in addition to those previously stated, were used in selecting data.

a. The building was hit by at least one HE bomb.

b. The damage did not extend beyond this particular building.

12. The second way used to estimate the MAE's of structural damage was the concentric annulus method. In this method concentric circles are drawn around the bombs and the area of building in each (say the jth) annulus, (B_{ij}), and the area of structural damage in each annulus, (G_{ij}), are measured. Then, if aj is the area of the jth annulus, the MAE was estimated by

$$MAE = \sum_j a_j \frac{\sum_i G_{ij}}{\sum_i B_{ij}}$$

13. Actually two MAE's were computed by this method, one (M_1) for bombs which were direct hits and a second (M_2) for bombs which were near misses. They were then combined according to the probability of securing a near miss or direct hit under random attack, given that the target area was hit, on an average building as follows:

$$MAE = M_1 \frac{\sum_i B_i}{\sum_i A_i} + M_2 \left(1 - \frac{\sum B_i}{\sum A_i}\right)$$

14. Here A_i is the plan area of building B_i plus a near miss margin. Let P_i be the perimeter of building B_i and m the width of the margin, then A_i was calculated from:

$$A_i = B_i + P_i m + \pi m^2$$

In using this method only "isolated" bombs, whose effects could be segregated from those of other direct hits or near misses to the same structure could be used.

15. For purposes of computation only in the above formula on multi-storied buildings the "plan area of structural damage" was taken to be the sum of the area of structural damage to each floor plus the area of structural damage to the roof divided by the number of floors.

16. In the case of the very large British bombs the assumption of random attack does not seem to hold, and for such bombs only the concentric annulus method was used to give values of M_o and M_2.

17. Near misses were taken to be all bombs within fixed distances from the building under consideration, i.e. within the margin, regardless of whether the bomb hit in the open or in another building. The width of this miss margin for various weight HE bombs (regardless of type) was as follows:

100-lb.) 250-lb.)	15 ft.	2000-lb.	45 ft.	12,000-lb.	200 ft.
		4000-lb.	75 ft.		
500-lb.) 1000-lb.)	30 ft.	8000-lb.	150 ft.		

18. For machine tools, the concentric annulus method was used, except that, in place of areas, the total number of machines and the number of machines seriously damaged or destroyed in each annulus was counted. Free-hand curves were fitted to the data to get estimates of empty rings. Also, in the annulus method it is necessary to fix maximum distance at which a direct hit is considered to cause structural damage. These were taken to be:

100-lb.) 250-lb.)	60 ft.	2000-lb.	150 ft.	12000-lb.	200 ft.
		4000-lb.	150 ft.		
500-lb.) 1000-lb.)	90 ft.	8000-lb.	150 ft.		

19. Included in Tables 13, 14, 15 and 16 is data on dwelling types at two area targets -- Pirmasens and Krefeld. This data is taken directly from the two EDD reports 30 and 21 respectively, on those targets. In both the Pirmasens and Krefeld reports, the buildings are mainly typical German urban dwellings. The typical house was about two and one-half to three stories, brick wall bearing with tile roof on wood battens or sheathing.

HE BOMB DAMAGE DATA

Grouping of Structural Types for Secregation of Data.

Single-Story Structures.

1/a. Masonry load wall bearing types.
Roofs flat or pitched - steel or timber.

1/b. Light factory, steel or wood framed.
North-light or pitched roofs.

1/c. Heavy steel framed buildings or those containing runways supporting heavy cranes.

1/d. Hangar and aircraft assembly types of buildings - steel, timber or R/C framed roofs.

1/e. Factory R/C framed or R/C shell kinds.
Roofs flat, north lighted or pitched.

1/f. Miscellaneous.

Multi-story.

M/a. Masonry load wall bearing or composite construction.

M/b. Steel framed

M/c. Concrete framed or flat slab.

TABLE 10

MEAN AREA OF EFFECTIVENESS OF HE BOMBS
(Sq. Ft. per Bomb)

Direct hit effects, structural damage only.
Fire and mixed HE and fire cases omitted.

	Type of Structure	Size of Bomb 250-lb. GP	500-lb. GP	1000-lb. GP.	4000-lb. HC
1/a	MAE		6200	6200	
	No. Bombs		32	14	
	No. Bldgs.		13	9	
1/b	MAE		4800		
	No. Bombs		48		
	No. Bldgs.		21		
1/c	MAE		3100	3700	11000
	No. Bombs		11	19	4
	No. Bldgs.		6	12	4
1/d	MAE		10700 (spreading collapse)		
	No. Bombs		51		
	No. Bldgs.		10		
1/c	MAE	3900	2700	4700	
	No. Bombs	6	21	6	
	No. Bldgs.	4	4	4	
1/f	MAE		3000		
	No. Bombs		25		
	No. Bldgs.		21		
M/b	MAE			1700	
	No. Bombs			7	
	No. Bldgs.			5	
M/c	MAE		1900		
	No. Bombs		6		
	No. Bldgs.		4		

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TABLE 11

MEAN AREA OF EFFECTIVENESS OF HE BOMBS
(Sq. Ft. per Bomb)

Annulus method, structural damage only.
Fire and mixed HE and fire cases omitted.

	Type of Structure	Size of Bomb 500-lb. GP	1000-lb. GP	12000-lb. HC.
Direct Hits				
	1a	4668	5561	
	1b	3890	12178	
	1c	1868	7040	
Near Misses				
	1a	781	--	--
	1b	2080	--	--
	1c	--	--	57,000
Weighted Mean				
	1a	2950		
	1b	2940		

TABLE 12

MEAN AREA OF EFFECTIVENESS OF HE BOMBS

MACHINE TOOLS DESTROYED OR SEVERELY DAMAGED

500-lb. GP
Estimated MAE: 3,300 sq. ft. per bomb

	Distance from Bomb (ft.)				
	0-25	25-50	50-75	75-100	100-125
Number Destroyed or Severely Damaged	20	20	3	1	3
Total No. Tools	45	170	181	91	46

1000-lb. GP
Estimated MAE: 17,000 sq. ft. per bomb

	Distance from Bomb (ft.)					
	0-25	25-50	50-75	75-100	100-125	125-150
Number Destroyed or Severely Damaged	9	21	11	12	6	1
Total No. Tools	9	37	33	62	45	12

12000-lb. HC
Estimated MAE: 37,000 sq. ft. per bomb

	Distance from Bomb (ft.)									
	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250
Number Destroyed or Severely Damaged	--	30	25	--	--	1	2	3	2	1
Total No. Tools	--	31	28	1	--	33	59	51	57	23

20. Comment on Tables 13 and 14 of Krefeld Report (PDD 21)

a. In the heading of Table 13 the "E" is for estimated, the "R" for reliable.

b. In Table 14 the estimated bomb density per acre to cause 50% damage to 90% of the buildings (col.10) was obtained by simple proportion from cols. 8 and 9.

21. Comment on Tables 15 and 16 of Pirmasens Report (PDD 30)

a. The MAE's were calculated from:

$$F = 1 - e^{-MD}$$

Where F = fraction damage
M = MAE
D = density of bombing

b. The damage categories are:

A: Complete destruction of the building to rubble.

B: Damage requiring demolition, cannot be inhabited or repaired, but possibly retaining a roof and standing walls.

C: Considerable structural damage, but may be made habitable in its present state or by means of repairs.

D: Superficial damage involves stripping of roofing and glass breakage but no important structural damage.

c. The unit numbers (col. 1) refer to areas of 1/4 sq. km. formed by putting a 1/2 km. grid over the city plan. On the edge of the city, the area may be somewhat less than 1/4 sq. km.

22. Variability of Amount of Structural Damage

a. In order to present some indication of the variability of the structural damage caused by the pure HE effects of direct hits the structural damage caused in each building was plotted against the expected damage for eight building-bomb categories. The expected damage was computed from:

$$\text{Expected damage} = B\left[1 - \left(1 - \frac{M}{B}\right)^{n}\right]$$

b. If the building was smaller than the MAE, the expected damage was taken to be the building area. In considering these plots it should be remembered that any structural damage caused by near misses to the structure is included, as well, as the damage caused by the direct hits.

WT/AREA TO ACHIEVE DESIRED RESULTS

23. Strategic bombing experience has demonstrated that an industrial building ceases to be productively useful when one third of its area has sustained structural damage.

a. Complete destruction is therefore not required. A building that has sustained severe structural damage requires more time to raze and rebuild than one that has been totally destroyed.

b. For industrial targets the primary objective is loss in production and not destruction of buildings.

24. In order to determine the weight of an attack necessary to cause a desired loss in production over a period of time the following factors must be taken into consideration:

a. The size of the target area.

b. The installations vital to production.

c. The vulnerability of vital installations to bombing.

d. The relative effectiveness of weapons.

e. The current bombing accuracy.

Other considerations are:

f. Was the target a secondary target?

g. What is the recuperability of target?

h. What quantities of spare machines and tools are on hand?

i. What is the aircraft bomb capacity?

j. Probable weather at target.

k. Necessary bombing altitudes.

l. The range of aircraft being used.

m. The available blind bombing techniques.

n. The nature and importance of the area surrounding the target.

o. The number aircraft of given types available.

p. The available stocks of bombs and fuzes.

q. The strength and location of enemy defences.

r. The priority of the target.

From the foregoing considerations it is evident that bomb and fuze selection and bomb density must be determined for each individual target on its own merits if it is to be attacked effectively.

25. Table 17 lists in acres per ton the amount of structural damage that may be expected from a given weapon against a type structure. Due to the wide variation in structural types at the targets and the many operational factors involved no recommendations are made as to the weight of attacks. The tabulation is limited to structures and weapons investigated by the U. S. Strategic Bombing Survey.

Revise.

TABLE 17

Type Structure	Weapon: Bomb Sizes	Weapon: Type	Fuzing	Structural Damage Acres/Ton
1/a. Masonry load wall bearing types. Roofs flat or pitched - steel or timber.	500 lb	GP	0.01	0.33
	500 lb	GP	0.025	0.28
	1000 lb	GP	0.025	0.14
	1000 lb	MC(Br)	0.025	0.52
1/b. Light factory, steel or wood framed, North-light or pitched roofs.	500 lb	GP	0.01	0.33
	500 lb	GP	0.025	0.20
	1000 lb	GP	0.01	0.05
	1000 lb	GP	0.025	0.27
1/c. Heavy steel framed buildings or those containing runways supporting heavy cranes.	1000 lb	MC	0.01	0.23
	1000 lb	MC	0.025	0.16
1/d. Hangar and aircraft assembly types of buildings - steel, timber, or R/C roofs.	500 lb	GP	0.025	0.45
	500 lb	GP	0.01	0.33
1/e. Factory R/C framed or R/C shell kinds, roofs flat, north lighted or pitched.	500 lb	GP	0.01	0.18
	1000 lb	GP	0.025	0.71
	1000 lb	MC(Br.)	Non-delay	0.15
	1000 lb	MC(Br.)	0.025	0.17
1/f. Miscellaneous	500 lb	GP	0.01	0.17
	500 lb	GP	0.025	0.18
	1000 lb	MC(Br.)	Non-delay	0.17
	1000 lb	MC(Br.)	0.025	0.30
M/b. Steel framed	500 lb	GP	0.025	0.09
	1000 lb	GP	0.01	0.15

26. Type Bomb used strategically. The following list of bombs and fuzes were used by the Eighth Air Force. Other bombs were used, but as a matter of supply were used in small quantity:

Size in lbs.	Type	Series
100	GP	AN-M30
150	GP	T-1
250	GP	AN-M57
300	GP	M-31
500	GP	AN-M43, AN-M64
600	GP	M-32
1000	GP	AN-M44, AN-65
2000	GP	AN-M34, AN-M66
4500	Special	
500	SAP	AN-M58
1000	SAP	AN-M59
1600	AP	AN-MKI
20	Frag.	AN-M41
90	Frag.	M-82
260	Frag.	AN-M81

Tail Fuzes.

Series	Bomb Used In.
AN-M100	100, 250-lb. GP and 260-lb. Frag.
AN-M101	500-lb. GP & SAP
AN-M102	1000, 2000-lb. GP
M-106	All GP Bombs
M-123	100, 250-lb. GP
M-124	500-lb. GP & SAP
M-125	1000-lb. GP and SAP, 200-lb. GP
MK-223	500-lb. GP MK12, 1000-lb. GP MK13

Nose Fuzes.

AN-M103	All GP Bombs
AN-M109	20-lb. AN-M41 Frag.
AN-M110	20-lb. AN-M41 Frag.
AN-M126	100-lb. Chem. Bomb
MK 221	500-lb. GP MK12, 1000-GP MK13

The following pistols and fuzes were used by the RAF:

Tail Pistols.

No.	Bomb Used In
28	GP, MC, and AP Bombs
37	GP, MC, SAP & AP Bombs
53	" " " " " "
54	" " " " " "

Tail Fuzes

No.	Bomb Used In.
30	250 and 500-lb. SAP
37	2000-lb. SAP

Nose Pistols

27	250, 500, 1000, 1900, 4000-lb. GP all HC and MC
42	250, 500, 1000, 1900, 4000-lb. GP all HC and MC
44	" " " " " "
55	" " " " " "
45	All U.S. GP Bombs.
52	" " " "

Side pocket pistol

47	4000-lb. GP and HC 2000-lb. HC

The following list of bombs were used strategically by the RAF:

Size(lbs.)	Type
250	GP
500	GP
1000	"
1900	"
4000	"
250	MC
500	"
1000	"
4000	"
12000	"
22000	"
2000	HC
4000	"
8000	"
12000	"
22000	"
250	SAP
500	"
2000	AP

27. Figure 22 shows the tonnage of bombs dropped by the first four (4) months of each year. Note the change from heavier bombs to lighter bombs. **Figure** 23 shows the number and types of fuzes used in the first four (4) months of 1945. Information for later periods **is** not available. It will be noted from the chart that there is an excess of expenditures of tail fuzes over nose fuzes; this resulted

from not fuzing 100-lb. and 250-lb. bombs with nose fuzes. Table 18 shows the number of HE and Frag. bombs dropped by the Eighth Air Force, by type and in what month.

28. Fuzing. The fuzing of bombs is the most important part of any bombing operation for if the correct fuze is not used or does not function be it/due to mechanical or human error, the attack may be completely without effect. The fuze is the initiating part of a bomb and delicate in the sense that many things may go wrong with any fuze so as to render it inoperative. If a fuze does not function the filler of the bomb will not receive the necessary shock to cause detonation and the bombs become a dud, which would cause only relatively little damage.

29. Two types of fuzes are to be considered when they are to be used in bombs. Nose fuzes and those which fit in the tail of a bomb are the only normal ones used in American demolition bombs. Usually a bomb is armed with two fuzes, one in the nose and the other in the tail. One fuze is referred to as a secondary fuze when two are used and can be considered as insurance to make sure that detonation of the bomb will occur. When two fuzes are used, the one in the nose usually is considered the primary fuze and therefore considered as the one which will cause detonation of the bomb. The nose fuze in this case is set to cause detonation of the bomb at point where the tactical situation demands or where the effect of detonation should give the desired results. In case the nose fuze does not function the tail fuze should function by causing the bomb to detonate. If the tail fuze is being used solely as a secondary fuze it is fuzed with the same delay period as the nose fuze or may have a slightly longer delay, but in no case should the period be shorter or the whole purpose of the delay is ruined and the bomb will go off prematurely and not have reached the predetermined position to cause the desired results.

30. In some cases only tail fuzes are used to initiate and cause detonation of the bomb. Outstanding example of the use of tail fuzes exclusively is the arming of an armor piercing bomb. These bombs are more streamlined and constructed with thicker cases in order to withstand the tendency for case failure as it penetrates into the target. The nose of an armor piercing bomb is more pointed and heavily constructed to enable penetration and perforation. If a nose fuze were to be put in such a bomb the nose construction would be weakened to such an extent that during penetration the case would have greater possibility of failure and a nose fuze would detonate instantaneously destroying the effectiveness of the bomb, or it would be damaged to such an extent as to probably fail to function; this latter is the most likely of the two results. Tail fuzes are used by themselves in semi armor piercing bombs also and for the same reasons that they are used solely in armor piercing bombs. In some cases a tail fuze will be the only arming device for a general purpose bomb as they may be used for deep penetration if the material to be attacked will not offer high resistance. In these cases a nose plug is used to cover the nose fuze cavity. Another use of a tail fuze only in a general purpose bomb is when machinery inside a factory is to be

the target. By fuzing such a bomb in the tail only, fragments are normally scattered in a downward flat conical pattern since the explosion is initiated at the top or rear of the bomb.

31. Some fuzes may be set at many and varying degrees of delay while others are preset for a single operating time only. The most common of settings or delays are instantaneous, non-delay, 0.025, 0.01 and 0.1 of a second. The "instantaneous" fuze setting pertains only to nose fuzes while the most rapid acting tail fuzes are called 'non-delay'. These non-delay fuzes are slightly slower than the instantaneous nose fuzes in the lapsed time between initiation and detonation but for practical purposes it is considered that when using such a fuze the bomb will detonate at the same instant that it hits the target. Actually the elapsed time that it takes these fuzes to function is 0.0008 seconds for an instantaneous fuze while a non-delay fuze takes 0.0056 seconds to function and actuate the bomb. Other fuzes with a longer delay period of from 4 to 5 or 8 to 15 seconds are obtainable and they also use a burning powder train as the delay element. In order to change from a 4 to 5 second delay to one of 8 to 15 seconds does not require a new or different fuze to be used, as interchangeable primary detonators are available to effect this variation in functioning time. This is a simple and speedy operation to change the delay period of the fuze.

32. Some fuzes, which are referred to as long delay fuzes make use of chemicals and their action, to produce the required delay. By using such a fuze it is possible to delay detonation of a bomb for 1,2, 6, 12, 24, 36, 72 or 144 hours or if delays in minutes are needed another series of fuzes can be used which will give a delay period of anywhere from 6 to 80 minutes. The chemical action of these fuzes basically consists of a liquid dissolving a series of discs, which permits a cocked firing pin to be released. All long delay fuzes are of the anti-removal type to prevent defuzing of the bomb by enemy personnel. This prevents the fuze being removed from the bomb once it is armed since any attempt to unscrew the fuze from the cavity in the bomb will actuate the fuze.

33. Still another type of fuze which is capable of a variety of delay settings is one which is controlled by a clockwork mechanical mechanism. With these fuzes delays from 5 to 92 seconds are available, depending upon the pre-selected setting. A time scale on the nose section of the fuze body is set by rotating the nose piece of the fuze until the desired setting is opposite the pointer. Also it is possible to adjust this scale to the nearest .1 of a second.

MALFUNCTIONS OF BOMBS

34. Percentages of Malfunctions. The accompanying chart (Table 19) is a compilation of data from twenty (20) USSBS targets, giving percentages of unexploded bombs and low order detonations on each, as well as an overall figure.

a. Unexploded Bombs (UXB's) An examination of the chart shows a variation of 0% to 18.5% UXB's per target, and an overall percentage of 5.6%. In many cases these percentages depend on the accuracy of records at the target, since UXB's were removed in most cases, before the USSBS teams arrived.

b. Low Order Detonations (LO's). Low order detonations (LO's) are reported on only one (1) target considered in this report. The percentage in this one case was 3%. The absence of reports of LO's on the other targets considered is believed to be due to the failure of the personnel interrogated from the target to either recognize or report LO's.

35. Causes of Malfunctions.

a. UXB's. The tables accompanying this report are prepared from the records of the Bomb Disposal Division, Ordnance Service, Theater Service Forces, European Theater, and record reasons for UXB's studied up to 3 May 1945.

TABLE 19

PERCENTAGES OF MALFUNCTIONS

TARGET	No. Bomb Hits	No of UXB's	No. of LO's	% UXB's	% LO's
Muehlenbau Industrie AG, Brunswick	190	14	0	7.4	0
Mitteldeutsch, Taucha	443	9	0	2.1	0
Junkers Flugzeug Motorenwerke, Mockau	223	2	0	.9	0
Bayerische Motorenwerke, Duerrendorf	82	1	0	1.2	0
Ernst Leitz Co., Wetzler	27	5	0	18.5	0
Bldgs with Airfield used by Erla	70	2	0	2.9	0
Automotive Plant, Volkswagenwerk, Fallersleben	883	84	0	9.5	0
Henschel-Sohn, Kassel	673	36	20	5.4	3
Aircraft Plant, Erla, Mockau	134	3	0	2.2	0
Erla Heiterblik	234	4	0	1.7	0
Daimler-Benz, Gaggenau	240	8	0	3.3	0
Auto Union, Ziegmar Werke	22	1	0	4.5	0
Auto Union AG, Horsch, Zwickau	547	11	0	2.0	0
Adam Opel, Russelsheim	211	23	0	11.0	0
Daimler-Benz, Unterturkheim	225	5	0	2.2	0
Friedriech Krupp, Magdeburg	1046	94	0	9.0	0
Bayerische Motorenwerke, Eisenach	89	0	0	0	0
Zeiss Co, Jena	64	7	0	11.0	0
Gustloff-Werke, Weimar	275	20	0	7.3	0
Blohm & Voss	1001	46	0	4.6	0
TOTAL	6679	375	20	5.6	0.3

From Table 19 it is apparent that the most common known reason for UXB's is the failure of the fuzes to arm, even though safety pins and arming wires have been removed. This would appear to indicate a fault in the fuze arming mechanism. However, it must be remembered that altitude of attack is a consideration in the choice of fuzing, and that low altitude attacks with fuzes requiring a long arming time may result in UXB's because impact occurs before arming is complete.

b. Low Order Detonations. No data was available on the reasons for low order detonations (LO's) of American bombs. However, experience of ordnance officers of the survey lead to the following conclusions:

(1) The majority ~~of LO's are~~ the result of failure of the bomb casing on impact, such that the compression necessary for normal detonation was not possible.

(2) Some ~~LO's are~~ caused by defects in the firing train of the fuze.

(3) Incomplete or improper filling of the bomb or filling with faulty explosive.

TABLE 20

The reasons for UXB's are tabulated as follows:

DS - Dropped safe. Arming wires and/or Safety Pins still in place.

FA - Failure to Arm. No arming wires or safety pins, but the arming operation was not complete.

MF - Mechanical Failure. Arming was complete, but the explosive train was not initiated.

CP - Crashed Plane. Bombs removed unarmed from crashed planes.

UK - Unknown. Reason for UXBs indeterminate, either because the bomb was detonated in place by disposal personnel, or because time did not permit complete examination.

Size of Bomb	No. of Bombs Considered	Cause of UXB				
		DS	FA	MF	UK	CP
20 lbs.	201	1	12		189	
23 lbs.	11				10	
100 lbs.	106		26	1	63	16
250 lbs.	174		20	3	125	26
260 lbs.	50				25	25
500 lbs.	562	20	111	56	349	26
1000 lbs.	191	3	29	3	135	21
2000 lbs.	18		3	1	14	
Total	1313	24	201	64	910	114

TABLE 21

DETAILED MALFUCTIONS BY TYPE BOMB

100-lb. GP BOMBS

NOSE	TAIL	DS	FA	MF	UK	CP
103		--	17	--	36	12
108		--	2	1	1	--
126		--	2	--	1	--
126A2		--	--	--	1	--
103	100	--	--	--	1	--
103	100A1	--	5	--	--	--
103	100A2	--	--	--	3	--
103	101A2	--	--	--	1	--
103	102A1	--	--	--	1	--
103	102A2	--	--	--	7	--
	100	--	--	--	1	--
	100A1	--	--	--	1	--
	100A2	--	--	--	1	4
	102	--	--	--	1	--
	102A2	--	--	--	7	--

250-lb. GP BOMBS

NOSE	TAIL	DS	FA	MF	UK	CP
103		--	15	1	37	--
103	100	--	2	--	2	--
103	100A1	--	--	--	25	--
103	100A2	--	1	--	10	14
103	101	--	--	--	2	--
103	101A2	--	--	--	2	--
	100A1	--	2	--	3	--
	100A2	--	--	--	10	12
	101A1	--	--	--	2	--
	101A2	--	--	--	1	--
	102A2	--	--	--	1	--
	112	--	--	--	2	--
	112A1	--	--	2	--	--
	113	--	--	--	24	--
	114	--	--	--	3	--

500-lb. GP BOMBS

NOSE	TAIL	DS	FA	MF	UK	CP
103		2	17	6	25	--
103	100	--	--	--	2	--
103	100A1	--	--	--	2	--
103	100A2	1	--	--	2	--
103	101	--	--	--	2	--
103	101A1	1	1	--	8	--
103	101A2	8	38	9	18	6
103	102	1	--	--	95	13
103	102A1	1	2	--	2	--
103	102A2	2	5	--	7	--
103	113	--	--	1	12	2
103	113A1	--	--	--	4	2
	100	--	--	--	1	--
	100A2	--	1	--	1	--
	101	--	3	--	1	--
	101A1	--	--	--	3	--
	101A2	--	4	5	6	--
	102A2	--	--	1	31	1
	106	--	--	1	15	--
	112A1	--	--	--	4	--
	113	--	25	13	1	--
	113A1	2	2	19	44	2
	113A2	--	3	--	46	--
	114	--	--	--	10	--
	114A1	--	--	1	9	--
	124	2	--	--	--	--

1000-lb. GP BOMBS

NOSE	TAIL	DS	FA	MF	UK	CP
	103	--	--	--	15	--
	101A2	--	--	--	1	--
	102	--	--	--	2	--
	102A1	--	--	--	1	--
	102A2	--	6	3	29	10
	112	--	1	--	--	--
	113	--	--	--	1	--
	114	--	3	--	6	--
	114A1	--	--	--	5	2
103	101A2	--	2	--	5	--
103	102	--	2	--	13	--
103	102A1	1	7	--	17	1
103	102A2	2	8	--	40	8

2000-lb. GP BOMBS

NOSE	TAIL	DS	FA	MF	UK	CP
	102A1	--	--	--	1	--
	102A2	--	3	--	1	--
103		--	--	--	6	1
103	102	--	--	--	1	--
103	102A2	--	--	1	5	--

20-lb. FRAG BOMBS

NOSE	TAIL	DS	FA	MF	UK	CP
104		--	--	--	3	--
110		--	12	--	135	--
110A1		--	--	--	50	--
120		--	--	--	1	--

23-lb. FRAG BOMBS

NOSE	TAIL	DS	FA	MF	UK	CP
104		--	--	--	2	--
109		--	--	--	1	--
110		1	--	--	1	--
110A1		--	--	--	1	--
120		--	--	--	5	--

260-lb. FRAG BOMBS

NOSE	TAIL	DS	FA	MF	UK	CP
-	100A2	--	--	--	2	--
103		--	--	--	10	--
103	100A1	--	--	--	11	25
103	100A2	--	--	--	2	--

DIFFICULTIES OF BOMB IDENTIFICATION AT TARGET

36. Methods of Identifying Bombs.

a. The attack data contained in the Target Folders assembled for each target to be surveyed contained the following information:

(1) Attacking Force.

(2) Date of Attack.

(3) Unit.

(4) Primary, Secondary, or Target of Opportunity.

(5) Aiming point.

(6) Number of aircraft dispatched.

(7) Type of Aircraft.

(8) Number of bombs dispatched.

(9) Type of bombs dispatched.

(10) Fuzing.

(11) Altitude of release.

(12) Type of bombing i.e Visual or by instruments.

(13) Time over target.

b. Fragments of the bomb case available at the target provide an additional source for the identification of bombs.

(1) Limitations of this method as a means of positive identification

(a) Bombs may have been employed against the target having the same side wall thickness, e.g. 1000-lb.MC (Br.)

(b) Possibility that fragment recovered may have been from bomb detonating in vicinity of incident

c. Craters.

(1) Crater sizes normally vary with

(a) Size of bomb

(b) Fuzing

(c) Nature of material being displaced

(d) Altitude of release (due to striking velocity.)

(2) Craters provide a good means of identification in incidents involving near misses as well as direct hits. It was often possible to identify a bomb scoring a direct hit on a structure by means of crater measurement of bombs in the same stick falling outside the building

d. UXB's

(1) Unexploded bombs in a target area provided positive identification.

e. Low Order Detonations

(1) In incidents where low order detonations occurred recovery of large sections of the bomb case provided identification.

f. Fins

(1) Every bomb employs a fin assembly which differs from that of every other bomb in three characteristics:

(a) Width

(b) Length

(c) Weight.

(2) When a fin assembly could be recovered in such a condition that it was possible to determine the width, length or weight, identification was possible.

g. Strike Attack Reports.

(1) S.A. reports showing bomb falls upon a target area often made possible the isolation of the bomb pattern of one attack from another. When a different weapon was employed it was possible to accurately identify the weapon causing damage in various parts of the target area providing not too great an overlap occured.

h. The amount of damage was not a valid criterion in determing bomb size In targets involving similar size bombs i.e. 500-lb GP (B.T.)., 500-lb MC. 500-lb. GP (US), 1000-lb GP (US), and 1000-lb MC it was impossible to determine bomb size from amount of damage. The position of detonatio was the determining factor in determining the type and amount of damage.

37. Methods of Identifying Fuzes.

a. Point of Detonation in Buildings

(1) The position of the point of detonation within buildings is a direct clue to the fuzing. Assuming that the roof structure was capable of initiating the fuze and that the bomb was released at the altitudes flown by heavy bombers the following general observations made by ordnance officers are applicable.

(a) Instantaneous fuzing. Bomb detonated on roof or after partial penetration.

(b) Non-delay. Bomb usually detonated just underneath roof structure or initating point.

(c) 0.01 Second Delay. Bomb detonated approximately 10 ft. below initiating point.

(d) 0.025 Second Delay. Bomb detonated approximately 25 ft. below initiating point.

(e) 0.1 Second Delay. In single story structures bomb cratered in floor. In multi-story structures bomb detonated after penetration of two or more stories. Extent of penetration being dependent upon nature of structural material.

(f) Long Delay. Bomb came to rest in multi-storied structures or penetrated ground forming a crater or camouflet upon detonation.

(2) The fragmentation pattern and centers of heaviest damage indicated the position of detonation in incidents involving bombs that detonated without forming a crater.

(3) Low altitudes of release usually resulted in a relatively low striking velocity or an angle of penetration considerably off the vertical.

b. Type of Crater

(1) Bombs fuzed instantaneous, non-delay, or 0.01 second tail delay normally produced shallow, clean swept craters with thin widespread debris. Floor of crater might be seen and floor and walls blackened.

(2) Bombs fuzed 0.025 second delay produced craters with a definite lip. Shear platform was usually visible. The debris extended in tongues for a distance about three times the crater diameter.

(3) Bombs fuzed 0.1 second delay formed craters with a pronounced lip and well filled with debris. Crater walls appeared vertical at the top and there was no pronounced shoulder. Debris spread was heavy but limited in extent.

38. Difficulties from conflicting Attack Data.

a. The main sources of information for attack data in order of importance were:

(1) Statistical Control Daily Summary of Operations

(2) Ordnance Expenditure Reports

(3) Intops Summary

(4) Tactical Mission Reports

(5) Photo Interpretation strike Attack Analysis Report.

b. In many instances these three sources of information were not in agreement as to bomb loads carried and fuzings rmployed.

39. Overlapping damage.

a. With the exception of the rare target against which only one or two weapons had been employed great difficulty was experienced in weapon identification due to the overlapping damage. This was especially true of targets which were high on the priority lists of the US 8th AF and RAF Bomber Command.

b. Causes of overlapping damage

(1) Large number of attacks.

(2) Heavy concentration of bombs.

c. Besides difficulties in weapon identification it was also difficult to isolate damage caused by a given number of bombs. This was quite predominant at targets which were hit with the large HC type bombs.

40. Evidence Obliterated.

a. Evidence pertaining to amount of damage sustained and weapon identification disappeared rapidly at German targets for the following reasons:

(1) Rapid rate of reconstruction and repair

(2) Clearance

(3) Craters filled and resurfaced.

b. At many targets the only damage that could be surveyed was that caused by attacks occurring in the last few months before the capitulation of Germany, Evidence of damage from earlier attacks having been obliterated by the reasons stated in Paragraph a.

41. Absence of fragments

a. Rarely could fragments be found at a point of detonation of a non-cratering bomb which could definitely be attributed to the bomb.

b. It was usually possible to recover fragments from craters by digging.

42. Insufficient Attack Data.

a. When a target was a secondary target or a target of opportunity the subject attack was not always listed.

b. Lack of Information Regarding Fuzing

(1) Fuzings employed were not always listed. This was especially true of RAF data. Generally the only fuzings listed for RAF attacks were those in which special purpose bombs e.g. Tallboy, Grand Slam, were dropped.

43. Damage Other Than Shown in Attack Data

a. Damage at many targets was in excess of what would normally be expected from the weight of attacks listed. This was due to the following:

(1) Spillovers from adjacent industrial targets or area raids.

(2) Tactical missions concerning which very little information was available.

(3) Artillery Fire.

(4) Demolitions carried out by the Germans.

b. Damage not visible on air cover e.g. internal fires, machine tool damage.

ACCURACY OF DATA IN TARGET FOLDERS

44. General. Target folders were compiled by the G-2 Section of the U.S. Strategic Bombing Survey for each target to be visited by any of the field teams. All of the information available concerning the targets was thus assembled for the teams before they actually left for the target. The data usually originated from either one of two main sources:

a. Ground Intelligence Reports ----- the accuracy of which depended upon the reliability of the source.

b. Photo Intelligence Reports ----- which were subject to the discrepancies inherent in the method.

45. Data contained in Target Folders. There were numerous types of reports included in the various target folders. The number and variety of reports in any specific folder depended upon the importance of the target in the strategic bombing offensive. A complete list of the different types follows:

	Report	Description	Publ. by
a.		Target illustrations	
b.	B.S.	Photo Interpretation Report on V-1 weapon installations.	ACIU
c.	D	Industrial Report based on photo interpretation	ACIU
d.	F) F.S.)	Photo interpretation reports on railroad facilities in Germany and occupied countries	ACIU
e.	L	Photo interpretation report on A/C plants and A/F	ACIU
f.	K	Photo interpretation report on bomb damage.	ACIU
g.	K.N.	Negative damage report based on Photo Interpretation.	ACIU
h.	K.S.	Photo Interpretation on reconstruction and clearance.	ACIU
i.	S.A.	Damage report based on strike photos.	ACIU
j.	D.	Detailed Photo Interpretation Report on damage.	MAAF
k.	D.B.	Second phase Photo Interpretation report on Damage and Repairs.	MAAF

l.	D.P.	Photo Interpretation reports petroleum refineries	MAAF
m.	D.S.	Photo Interpretation on activity and repairs.	MAAF
n.	G.	General Photo Interpretation on bomb damage and activity.	MAAF
o.	H.I.	Photo Interpretation report on industrial activity and repairs.	MAAF
p.	H.C.	Photo Interpretation reports on communication.	MAAF
q.	RE/H (or RE/8)	Reports on damage and effects from air raids, based on Photo interpretation.	PR3
r.	RE/8 P	Preliminary damage assessments.	PR
s.	TVN	Notes on Target Vulnerability, its characteristics, and choice of bomb to be used against it.	PR
t.	E.U.U.	Reports giving aiming points and plan of targets.	
u.		Bombing Data.	
v.		Extracts from Intelligence Reports.	

46. Function. Target folders first demonstrated their usefulness in facilitating the selection of certain plants as adapted to Physical Damage Surveys. This having been done they were again of inestimable value when it came to briefing the Field Teams which were being sent out to study these targets. The information which they contained was used by the team not only in the briefing period but also during the actual survey at the target and in theprocess of writing up the reports.

47. Although the various ways in which this data was used cannot all be enumerated, a few ideas can be gained from the following:

a. They provided a general idea of the nature and extent of damage to be expected at the target along with the overall layout and arrangement of the factory buildings.

b. Strike photos showed where bomb hits occured which may have since been repaired or filled in. This was also useful in checking bomb plots prepared by German agencies.

c. Data giving size and fuzing of bombs dropped assisted in specifically identifying hits which otherwise might have been in doubt. This contributed to the accuracy of weapons effectiveness information.

48. Estimate of Accuracy. In general it may be said that the data contained in Target Folders was a close approximation of actual conditions as they were found at the target area. Although it is true that many discrepancies were found, these were usually on very specific details which were often of a minor importance. Whereas the general information concerning a plant was correct, it was sometimes found that the designation of the use of specific buildings was in error. There were also cases where buildings were included as a part of a certain company when they actually belonged to another and different firm adjacently located.

49. As far as damage assessment is concerned, the errors made in Photo Interpretation Reports were more often in error on the conservative side, actual damage being in excess of that reported. More detailed information about the accuracy and difficulties encountered with aerial photo interpretation is found in another section of this report. It should be noted that the information contained in Target Folders pertinent to the functions of the Physical Damage Division was mainly derived from this source.