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NAVWEPS REPORT 7541
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THE EFFECTIVENESS OF CLUSTER WEAPONS AGAINST SQUARE AREA TARGETS

By

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ABSTRACT. This report contains the results of a parametric study on the effectiveness of cluster weapons against "area" targets, where an "area" target consists of a large number of units distributed over an area (e.g., a battalion of troops in the field).

The effects of number of bomblets, delivery error, ammunition dispersion, and warhead effectiveness are considered. The results of the study are presented in handbook form so that one may quickly determine the effectiveness of any proposed cluster weapon, once specific values have been assigned to the above parameters.

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FOREWORD

The Weapons Planning Group is engaged in an analysis of conventional free-fall ordnance with a view to making recommendations for the development of new weapons for use in limited war. One of the more frustrating features of such a process is the fact that the necessary information on warhead effectiveness changes with time. This often necessitates a re-evaluation of the weapons under consideration. In an effort to render less inconvenient such re-evaluations and to provide a means of expediting feasibility studies, a parametric study of the effectiveness of cluster weapons has been undertaken. The first results of this study, dealing with the effectiveness of cluster weapons against unitary targets, were presented in NAVORD Report 7019. The present report contains further results of the study.

The report has been reviewed for technical adequacy by Donald Kusterer and Robert S. Gardner.

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INTRODUCTION

In an effort to assist in the rapid determination of the effectiveness of proposed and existing weapons, a parametric study has been made of such weapon effectiveness. The results of the first part of this study, concerning weapons to be employed against unitary targets, are presented in Ref. 1. Further results of the study, dealing with the effectiveness of cluster weapons against square area targets, are presented herein in graphical and tabular form.

The parameters which were varied in making the study are number of bomblets or warheads per cluster weapon, delivery error[1], ammunition dispersion, radius of effect of each warhead, and an effectiveness factor[2] for each warhead.

The targets under consideration in this report are "area" targets as opposed to "unitary" targets. A "unitary" target is a target such as a tank or a ship which may be regarded as a unit for purposes of tactical warfare. The "area" target consists of a large number of units distributed over an area. The results presented in this report are based on the assumption that this area is square in form.

The results of studies on problems similar to the one treated here are found in Ref. 2 and 3. The basic assumptions found in Ref. 2 are significantly different from the basic assumptions of the study reported herein; hence, the results of the present study and those of Ref. 2 are not directly comparable. In Ref. 3, the basic assumptions are such that a comparison may be made with some of the results of the present study. The comparison appears in the third section of this report.

METHOD OF CALCULATION

It is desired to determine the fraction T of a two-dimensional target which may be expected to be destroyed by a cluster of bomblets. The following assumptions are made:

---

[1] The expression "delivery error" as used in this report includes all errors in the system resulting in the displacement of the projected impact point of the unseparated cluster from its aimpoint. Specifically, the effects of aim or fire-control error and the dispersion of the cluster weapon as a whole are included in the delivery error.

[2] The meaning of the term "effectiveness factor" as used in this report is explained in the section on the method of calculation.

1. The target is a square with its sides parallel to the axes of a Cartesian coordinate system.
2. The projected impact point of the cluster is normally distributed about its aimpoint, due to delivery error.
3. The bomblets are normally distributed about the projected impact point, due to ammunition dispersion.
4. The delivery error is independent of the ammunition dispersion.
5. Each bomblet is uniformly effective throughout a square region centered on the impact point of the bomblet.

Since it is desired to take account of cumulative damage which might result from several bomblets impacting in proximity to one another, a Monte Carlo method of evaluation is used. The method involves the use of random normal numbers in repeated evaluations of the weapon, the process being continued until the expected error in the estimate of weapon effectiveness is satisfactorily small.

The target is defined so that it lies within a "playing field" which is a 100- x 100-unit square. The location of any lattice point in this square is specified by an ordered pair of positive integers which represent the coordinates of the point in a Cartesian coordinate system.

Four quantities are required to characterize the target: the coordinates of the lower left corner, the length of the sides, and a unit value. For instance, if the sides of the target are 3 units in length with a unit value of 10, each square unit in the target will have a "value" of 10 so that the total "value" of the target is 90. It is considered that each square unit of a target is centered on a lattice point of the "playing field" and its value is concentrated there. That is, if a target is defined with lower left corner at (2, 6) and lengths of sides one unit each, only the point (2, 6) of the "playing field" will be considered to be occupied by the target.

If a lattice point of the "playing field" is included in the target, the point is said to be a target point and the unit value of the target is assigned to the point. The total value of the target is seen to be the sum of the values of the target points. The fraction T of this total value which is expected to be destroyed by the cluster weapon is determined by the calculation procedure.

Two quantities are required to characterize the effectiveness of each bomblet: the effectiveness distance R and the effectiveness factor E. The values of these quantities are the same for all bomblets in a given weapon. The square area of effectiveness of a bomblet (which will henceforth be named the impact area of the bomblet) includes those lattice points which lie within an x-distance of R from the impact point and which also lie within a y-distance of R from the impact point. The impact point will always be a lattice point. For instance, if R=1, the impact area of each bomblet consists of the nine lattice points centered on the impact point of that bomblet (three rows of three points each).

The effectiveness of an individual bomblet is accounted for in the following way. If a point of the impact area of a bomblet coincides with a target point, the value of the target point is multiplied by the effectiveness factor E ($E \leq 1$), the product is added to a tally of target value destroyed, and the value of the target point is reduced by the value of the product. If the resulting value is less than 0.5, the target point is given the value zero (at which time it loses its status as a target point).

Let us assume that a target has been defined and the characteristics of the bomblets (impact area, effectiveness, dispersion), as well as the number of bomblets in the weapon, the aim point of the weapon[3], and the delivery errors have been determined. The effectiveness of the weapon against the target is determined as follows.

Two random normal numbers, r_1 and r_2, are selected from a list of random normal numbers with unit standard deviation and zero mean[4]. Then the coordinates a_x and a_y of the actual aimpoint for the weapon are given by

$$\begin{aligned} a_x &= A_x + r_1 \cdot \sigma_{F_x} \\ a_y &= A_y + r_2 \cdot \sigma_{F_y}, \end{aligned} \qquad (1)$$

where A_x and A_y are the coordinates of the intended aimpoint of the weapon, and σ_{F_x} and σ_{F_y} are the standard deviations of the delivery error in the x- and y-directions. Note that a_x and a_y are not necessarily integers.

Now two more random normal numbers, r_3 and r_4, are generated, and the coordinates I_{1_x} and I_{1_y} of the actual impact point of the first bomblet are given by:

$$\begin{aligned} I_{1_x} &= (a_x + r_3 \cdot \sigma_{R_x}) \text{ rounded} \\ I_{1_y} &= (a_y + r_4 \cdot \sigma_{R_y}) \text{ rounded}, \end{aligned} \qquad (2)$$

where I_{1_x} and I_{1_y} have been rounded to integers; a_x and a_y are the quantities determined by Eq. 1, and σ_{R_x} and σ_{R_y} are the standard deviations of the ammunition (bomblets) in the x- and y-directions.

---

[3] For the calculations of this report, the aimpoint of the weapon was chosen to be the center of the target.

[4] If this method is programmed for a digital computer, subroutines are available which generate random normal numbers with the desired characteristics.

Once I_{1_x} and I_{1_y} have been determined, the impact area for the first bomblet is compared with the target area to determine whether the impact area of this bomblet includes any target points. If any target points are so included, the value destroyed is accounted for as described previously and the target is modified by appropriately reducing the value of these target points.

The actual impact point of the second bomblet is now determined in a similar manner, account is taken of any damage the second bomblet does to the target, and the process is repeated until all bomblets have been accounted for. For the ith bomblet, equations analogous to Eq. 2 yield

$$\begin{aligned} I_{i_x} &= (a_x + r_j \cdot \sigma_{R_x}) \text{ rounded} \\ I_{i_y} &= (a_y + r_k \cdot \sigma_{R_y}) \text{ rounded,} \end{aligned} \qquad (3)$$

where r_j and r_k are two random normal numbers. Note that for each bomblet the same values of a_x and a_y are used.

When all bomblets have been accounted for, the accumulated value destroyed is divided by the original total target value and the result is the first element in the set of evaluations of the weapon against the target. The target is now redefined in its original state and the process begins again with the selection of another actual aimpoint for the weapon (Eq. 1). After many repetitious of the procedure, the final answer T is taken as the average of the results of the several trials.

In order to determine the point at which to stop the process and give an estimate of the error in the final result, the quantity $\sigma_{\bar{a}}$, where $\bar{a}$ is the average value of the elements of $\{a\}$, is determined for set $\{a\}$ of results of the trials. When $\sigma_{\bar{a}}$ becomes less than a specified value, the process is stopped and we then have a probability of about 0.95 that the correct result T satisfies $|T - \bar{a}| \leq 2\sigma_{\bar{a}}$. It is known that

$$\sigma_{\bar{a}} = \frac{\sigma_a}{\sqrt{n}} = \frac{\sqrt{\sum_i (a_i - \bar{a})^2}}{n} . \qquad (4)$$

Equation (4) may be used to evaluate $\sigma_{\bar{a}}$.

If the number of bomblets per cluster weapon is at all sizable, it is apparent that the above procedure is too tedious for hand computation. However, the problem is suitable for programming on a high-speed digital computer, and this has been done: an IBM 709 program to carry out the computation procedure has been written. A complete description of this program will be found in Ref. 4. The program was used to compute the estimates of weapon effectiveness which are presented in this report.

COMPARISON WITH ANOTHER METHOD

As mentioned earlier, some work of a similar nature to that presented in this report is described in Ref. 3. The assumptions of Ref. 3 are somewhat different from those of this report, and the method used there is analytic in nature rather than being a Monte Carlo method. However, it is possible to compare some results of the two methods, and this section contains the comparison.

The principal difference between the assumptions of this report and those of Ref. 3 is that no differentiation is made in Ref. 3 between delivery errors and ammunition dispersion. The average fraction of a square target which is covered at least once by up to 10 individually-dropped bombs (each having a square impact area) is calculated in Ref. 3. Since these bombs are not dropped in a cluster, there is no need in Ref. 3 to assume a separate delivery error.

The results of this report which are comparable to data in Ref. 3 are those for which $\sigma_F = 0$, $N = 10$ and $E = 1$. It is assumed both in this report and in Ref. 3 that $\sigma_{R_x} = \sigma_{R_y}$. Table 1 contains estimates of weapon effectiveness from both Ref. 3 and this report. The impact areas of the bomblets range from the target area to .0156 (one sixty-fourth) of the target area. The quantity A_E in Table 1 is the impact area of the bomblet divided by the target area. The quantity σ_R is expressed in units of target widths. It is the common value of σ_{R_x} and σ_{R_y}. The somewhat unusual values of σ_R arise as a result of the method of tabulation of the results in Ref. 3.

TABLE 1. Expected Fraction of Target Destroyed 10 Bomblets

σ_R \ A_E	.0156	.0625	.25	1.0
0	.0156	.0625	.25	1.0
.053	.0628[a] .062	.1509 .163	.4201 .445	.9999 1.0
.106	.1059 .102	.2511 .256	.5972 .640	.9997 1.0
.212	.1329 .131	.3930 .377	.7960 .807	.9990 1.0
.425	.0863 .091	.3007 .309	.7494 .756	.9937 .998
.850	.0303 -	.1158 -	.3884 .410	.8583 .879

[a] The upper number of each pair is from Ref. 3 and the lower number is from this report.

It is seen from an inspection of Table 1 that the agreement between the two methods is quite good. In most cases the difference between the results is less than 0.01, and the few cases where the difference is greater are partly due to artistic license in drawing the curves of this report. The maximum discrepancy is 0.04.

ASSUMPTIONS AND PROGRAM DESCRIPTION

In making the calculations for this report, several assumptions were made in addition to those listed in the description of the method of calculation. For completeness, all major assumptions and conditions are listed below. These assumptions were made:

1. The target is a square with its sides parallel to the axes of a Cartesian coordinate system.
2. The aimpoint of the weapon is the center of the target.
3. The projected impact point of the cluster is normally distributed about its aimpoint, due to delivery error.
4. The bomblets are normally distributed about the projected impact point, due to ammunition dispersion.
5. The delivery error is independent of the ammunition dispersion.
6. Each bomblet is uniformly effective throughout a square region centered on the impact point of the bomblet.
7. $\frac{\sigma_{\bar{F}_y}}{\sigma_{\bar{F}_x}} = \frac{\sigma_{\bar{R}_y}}{\sigma_{\bar{R}_x}} = 1$
8. All target points have an initial unit value of 10.

Since assumption 7 indicates that $\sigma_{\bar{F}_y} = \sigma_{\bar{F}_x}$ and $\sigma_{R_y} = \sigma_{R_x}$, it will not be necessary to distinguish between the two directions when delivery errors and ammunition dispersion are discussed. Therefore, the symbols σ_F and σ_R will henceforth be used when reference is made to delivery errors and ammunition dispersion.

Assumption 8 increases the sensitivity of the method for cases in which $E < 1$.

The following parameters were varied in making this study: σ_F, σ_R, N, R, and E. The unit for σ_F, σ_R, and R is target length.

Due to the way in which R is defined, the area of effectiveness of a bomblet, A_E, is given by

$$A_E = (2R + 1)^2. \qquad (5)$$

In making the calculations for this report, values of R were chosen such that A_E assumed values of one sixty-fourth, one sixteenth, one fourth, and one target area. The decimal expansions of these values appear in

Table 2 below.

Table 2 contains the values of σ_F, N, A_E, and E (bomblet effectiveness factor) which were used in the calculations.

TABLE 2. Values of σ_F, N, A_E, and E Used in the Study

Parameter		Values
E		0.5, 1
N		1, 10, 50, 100
σ_F	(Target lengths)	0, 0.25, 0.5, 1, 2, 4
A_E	(Target areas)	0.015, 0.06, 0.25, 1

For calculations involving a given value[5] of σ_F, several values of σ_R were chosen in the range $0 < \sigma_R < 3\sigma_F$. In this way the variation of T with σ_R was determined. It was assumed that the ammunition dispersion is easier to control than the delivery error, and when optimized values of T are discussed, the optimization is with respect to σ_R. That is, when the data are crossplotted in Appendixes C and D, the maximum value of T from each curve in Appendix A is used for the crossplotting.

USE OF THE DATA

Appendix A contains the basic data of the study. The results for N=1 were obtained by an analytical method and are tabulated. The results for the other values of N are presented in graphical form. Each graph of Appendix A contains several curves of fraction of target destroyed T vs. ammunition dispersion σ_R. The various curves were obtained by use of different values of A_E and E for fixed values of σ_F and N. Results are not given for all values of A_E, since in some cases the delivery error was so large and/or N was so small that the smaller values of A_E gave negligible results.

Using the method of optimization outlined in the last section (i.e., choosing a value of σ_R such that T is maximum for a given curve), the maximum values of fraction of target destroyed are tabulated in Appendix B. These maximum values of T are plotted against N in Appendix C to show the effect of number of bomblets, and they are plotted against σ_F in Appendix D to show the effect of delivery error.

Elementary Examples

Since several parameters are involved in the calculations, it is clear that the simplest evaluations to make will be those for which the parameters of interest coincide with values of those parameters used in

5 For the calculations in which $\sigma_F = 0$, the values of σ_R were chosen in the range $0 < \sigma_R < 2$ target lengths.

the calculations. For instance, if one is interested in determining T for a weapon containing 50 bomblets against a 100-x 100-ft target where σ_F=50 ft, σ_R=50 ft, A_E=.25, and E=.5, he proceeds as follows. Since the target is 100 ft wide and the units for σ_F and σ_R are target widths W, σ_F=.5W, and σ_R=.5W in this case. The data for N=50 and σ_F=.5W are found in Fig. A9. Using the dashed curves of this figure for E=.5 and the second from the highest of these (keyed with a square) for A_E=.25, we find that T=0.70 when σ_R=.5W. Incidentally, it happens that σ_R=.5W gives the greatest value of T for this particular curve. In other words, σ_R=.5W is the optimum value of σ_R for N=50, σ_F=.5W, A_E=.25, and E=.5.

If it can be assumed that the optimum value of σ_R can be achieved for a given weapon, it is no more difficult to evaluate T when either N or σ_F (but not both) deviates from a value for which calculations were made. In this case, Appendix C or D may be used. For example, if N=40 in the previous example and the values of the other parameters are the same, we use Fig. C3 (σ_F=.5W) to get T_o=0.65 from the dashed curve keyed with a square[6]. If σ_F=75 ft (.75W) and N=50, Fig. D3 (N=50) gives T_o=0.55.

Interpolation

In the previous examples, not much more complexity is introduced by allowing E to assume an intermediate value and using the following parabolic interpolation formula:

$$T = (4m - n)E + (2n - 4m)E^2, \qquad (6)$$

where m and n represent values of T when E=0.5 and 1, respectively, and the values of all other parameters are fixed. It is seen from Eq. 6 that T=m when E=0.5 and T=n when E=1, so that the curve whose graph is Eq. 6 passes through the points for which calculations have been made[7].

To illustrate the use of Eq. 6, let us consider the second of the above examples. We found that T_o=0.65 when N=40, σ_F=0.5W, A_E=.25, and E=.5. Let us find T_o when E=.7 and the values of the other parameters are the same (except that the optimum value of σ_R may be slightly different due to the change in E). We consult Fig. C3 again and find that T_o=0.82 when E=1 (solid curve keyed with a square). Hence, we have m=0.65 and n=0.82 for this application of Eq. 6, and our interpolation

[6] The notation T_o denotes optimization with respect to σ_R.

[7] It has, of course, not been established that Eq. 6 represents the proper curve for interpolation. However, use of this curve appears to the author to yield more realistic results than would be the case if linear interpolation were used.

formula for this example is

$$T_o = \left[4(0.65) - 0.82\right] E + \left[2(0.82) - 4(0.65)\right] E^2$$
$$= 1.78E - 0.96E^2. \qquad (7)$$

Substituting E=0.7 into Eq. 7, we find that T_o=0.78 when E=0.7.

If it is desired to interpolate on area of effectiveness A_E, the situation becomes more complicated. Perhaps the best procedure would be to evaluate T (or T_o) for all values of A_E available in this report and sketch a graph of T (or T_o) versus A_E. Then the interpolation can be made by reading the graph for the appropriate value of A_E.

Graphical interpolation is somewhat laborious. If a numerical method of interpolation on A_E is desired, perhaps the simplest and best is linear interpolation. The principal region in which such a method is inaccurate is the region between A_E=0.25 and A_E=1, and any errors in this region will be on the conservative side. Therefore, if the results of this report are to be used for preliminary estimates of weapon effectiveness, linear interpolation on A_E should not introduce catastrophic errors.

Let us compare the results of a graphical interpolation on A_E with the results of a linear interpolation on the same parameter. We shall take E=1, N=40, σ_F=0.5W, σ_R its optimum value, and we shall find T_o for A_E=0.5. From Fig. C3 we find that T_o=0.18 when A_E=0.015, T_o=0.46 when A_E=0.062, T_o=0.82 when A_E=0.25, and T_o=0.99 when A_E=1. If we plot these points, we find that T_o=0.94 when A_E=0.5. If we use linear interpolation on A_E we get T_o=0.88 when A_E=0.5. If instead of doing a linear interpolation on A_E we do it on $\sqrt{A_E}$ (the length of a side of the square area of effectiveness), we get T_o=0.89 when $\sqrt{A_E} = \sqrt{0.5} = 0.7$. This latter result is in slightly better agreement with the result obtained graphically.

If intermediate values must be used for all parameters, the interpolation problem becomes quite formidable. We conclude this section of the report with example in which we evaluate T_o for E=0.7, A_E=0.5, N=40, and σ_F=0.75. One way of proceeding is as follows. Taking E=0.5, we evaluate T_o for the four values of A_E of this report when N=40 and σ_F= 0.5W. We use Fig. C3 and get:

T_o	A_E	E	σ_F	N
0.11	0.015	0.5	0.5W	40
0.28	0.062	0.5	0.5W	40
0.65	0.25	0.5	0.5W	40
0.90	1.00	0.5	0.5W	40

We now repeat the process for σ_F=W and the same values for the other parameters (Fig. C4):

T_o	A_E	E	σ_F	N
0.04	0.015	0.5	W	40
0.13	0.062	0.5	W	40
0.37	0.25	0.5	W	40
0.69	1.00	0.5	W	40

If we examine the curves of Fig. D3 (for N=50), we see that linear approximations to the curves are satisfactory in the range $0.5 \leq \sigma_F \leq 1$. Therefore we perform linear interpolations on the data tabulated above to evaluate T_o at $\sigma_F = 0.75W$:

T_o	A_E	E	σ_F	N
0.08	0.015	0.5	0.75W	40
0.21	0.062	0.5	0.75W	40
0.51	0.25	0.5	0.75W	40
0.80	1.00	0.5	0.75W	40

We are now ready to plot T_o vs. A_E to evaluate T_o when A_E=0.5. The result[8] is T_o =0.67.

In order to interpolate on E, it will be necessary to begin again using E=1. By use of Fig. C3 we have

T_o	A_E	E	σ_F	N
0.18	0.015	1.0	0.5W	40
0.46	0.062	1.0	0.5W	40
0.82	0.25	1.0	0.5W	40
0.99	1.00	1.0	0.5W	40

Then we get from Fig. C4

T_o	A_E	E	σ_F	N
0.09	0.015	1.0	W	40
0.22	0.062	1.0	W	40
0.48	0.25	1.0	W	40
0.87	1.00	1.0	W	40

We again do linear interpolations on σ_F to obtain

T_o	A_E	E	σ_F	N
0.14	0.015	1.0	0.75W	40
0.34	0.062	1.0	0.75W	40
0.65	0.25	1.0	0.75W	40
0.93	1.00	1.0	0.75W	40

[8] If linear interpolation on $\sqrt{A_E}$ were used instead of plotting the graph, it would not have been necessary to evaluate T_o for A_E=0.01 and A_E=0.06. The result of the linear interpolation would be T_o=0.63 when $\sqrt{A_E}$=0.7.

Another plot is made of T_o vs A_E to evaluate T_o when A_E=0.5. This time the result is T_o=0.81.

We are now ready to interpolate on E, using Eq. 6. Having T_o=0.67 when E=0.5 and T_o=0.81 when E=1.0, we see that m=0.67 and n=0.81. Therefore Eq. 6 yields

$$T_o=[4(0.67) - 0.81]\ E + [2(0.81) - 4\ (0.67)]\ E^2 = 1.87E - 1.06E^2. \quad (8)$$

Substituting E=0.7 into Eq. 8, we reach the final result of T_o=0.78 when E=0.7, A_E=0.5, N=40, and σ_F=0.75. By a separate calculation, the correct answer for this example was found to be T_o=0.75.

CONCLUSION

The results of a parametric study to determine the effectiveness of cluster weapons against square area targets have been presented and discussed in this report. The method of calculation of the fraction of target destroyed has been described and examples have been given to illustrate the use of the material. The applicability of the data presented in this report is quite general, since the quantities involved in the computations are dimensionless and independent of any assumptions regarding specific targets or warheads.

Appendix A

BASIC DATA

TABLE A1. Expected Fraction of Target Covered by One Bomb

σ/W \ A_E	1.0	0.25	0.0625	0.0156
0.25	0.6400	0.2100	0.0569	0.0156
0.50	0.3700	0.1075	0.0288	0.0072
1.00	0.1350	0.0360	0.0090	0.0023
2.00	0.0380	0.0098	0.0024	0.0006
4.00	0.0100	0.0025	0.0006	0.0002

It should be noted that the quantity tabulated above is fraction of target covered. If it is desired to evaluate the fraction of target destroyed by a particular bomb, the numbers in the table should be multiplied by the effectiveness factor E of the bomb.

Since only one bomb is involved, the delivery error σ_F and the ammunition dispersion σ_R need not be distinguished, and an overall error σ will suffice. The relation

$$\sigma^2 = \sigma_F^2 + \sigma_R^2$$

is the proper way to combine σ_F and σ_R in this case.

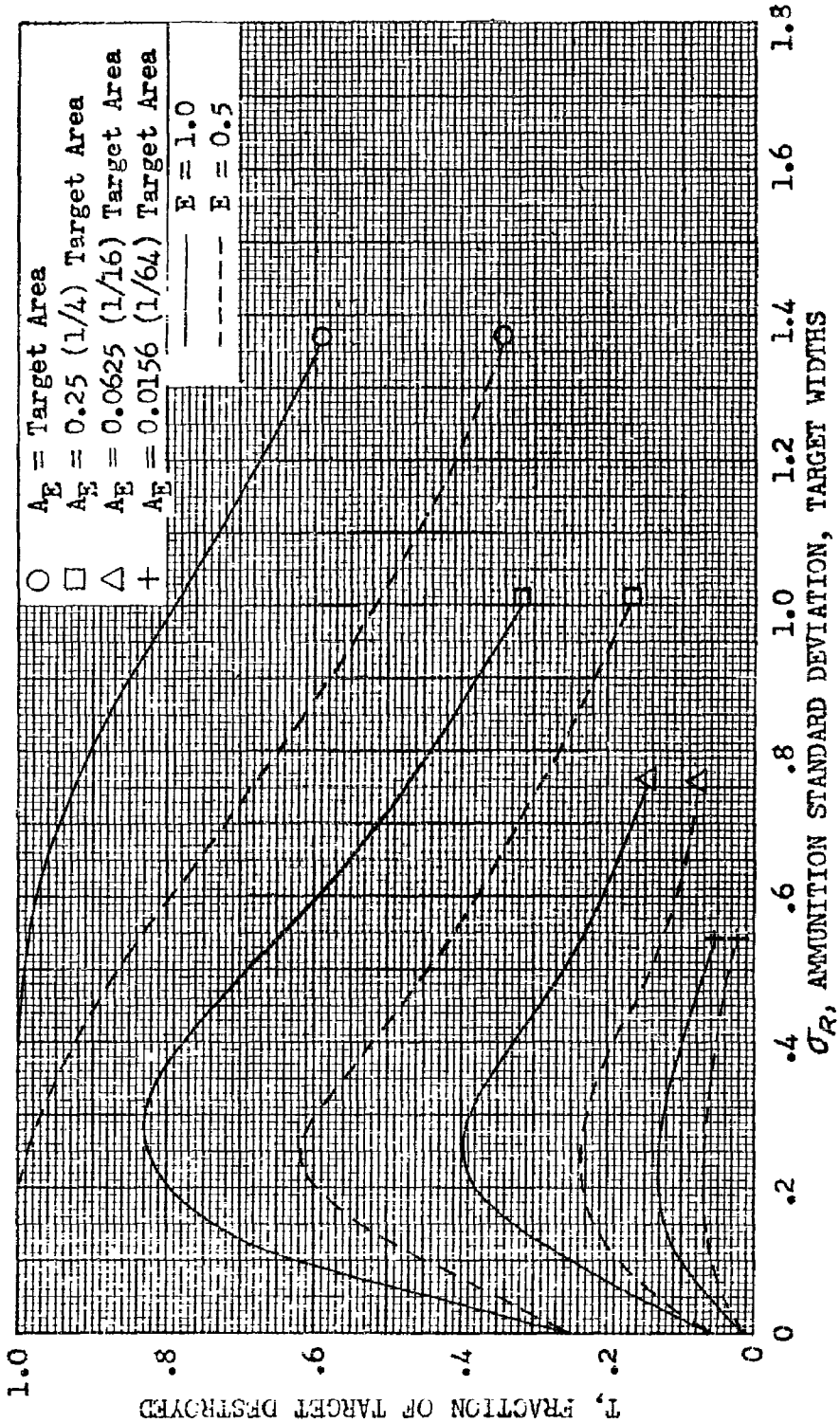

FIG. A1. Fraction of Target Destroyed vs. Ammunition Dispersion.
$\sigma_F = 0$, N=10

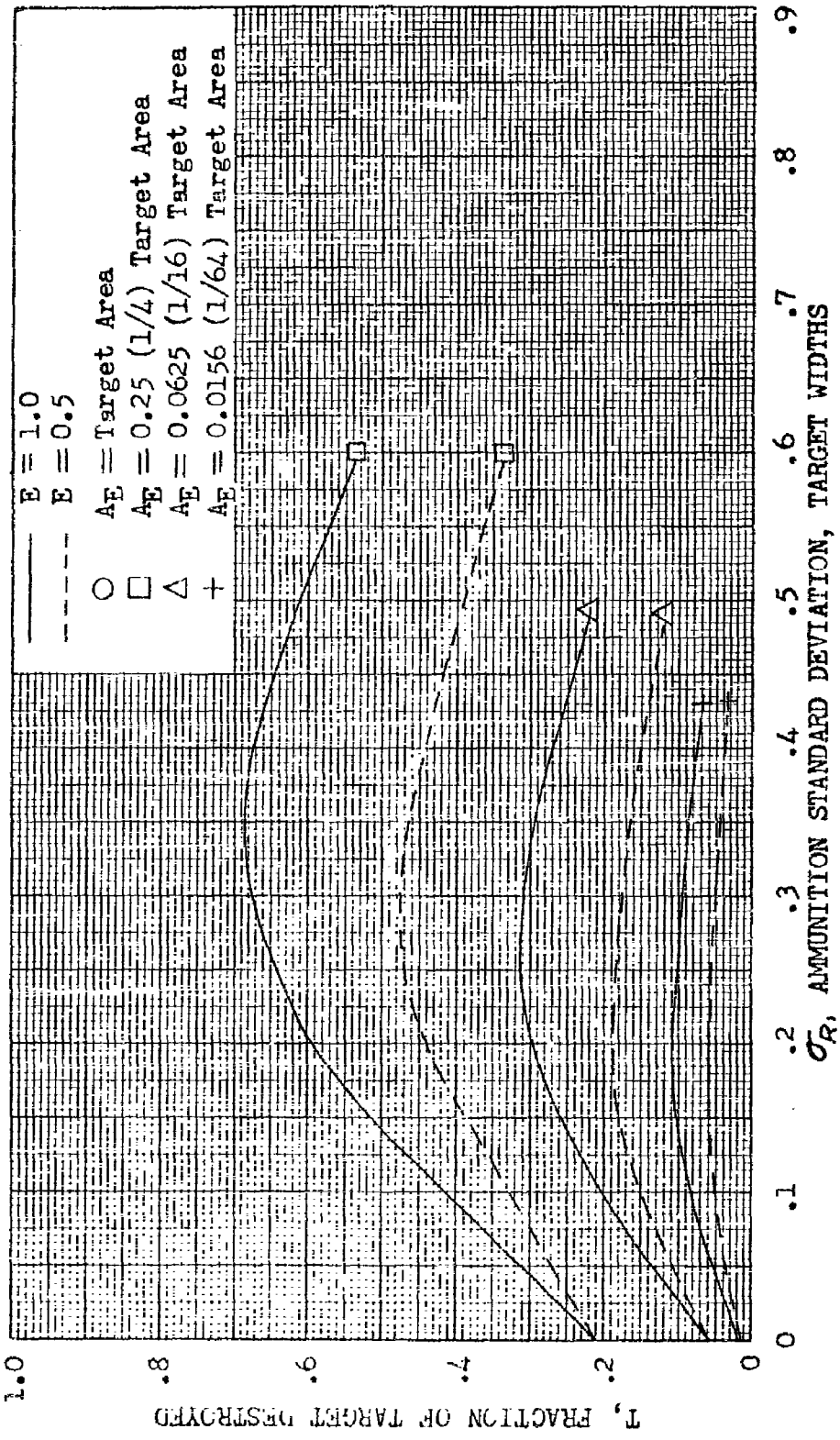

FIG. A2. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = 0.25W$, N = 10

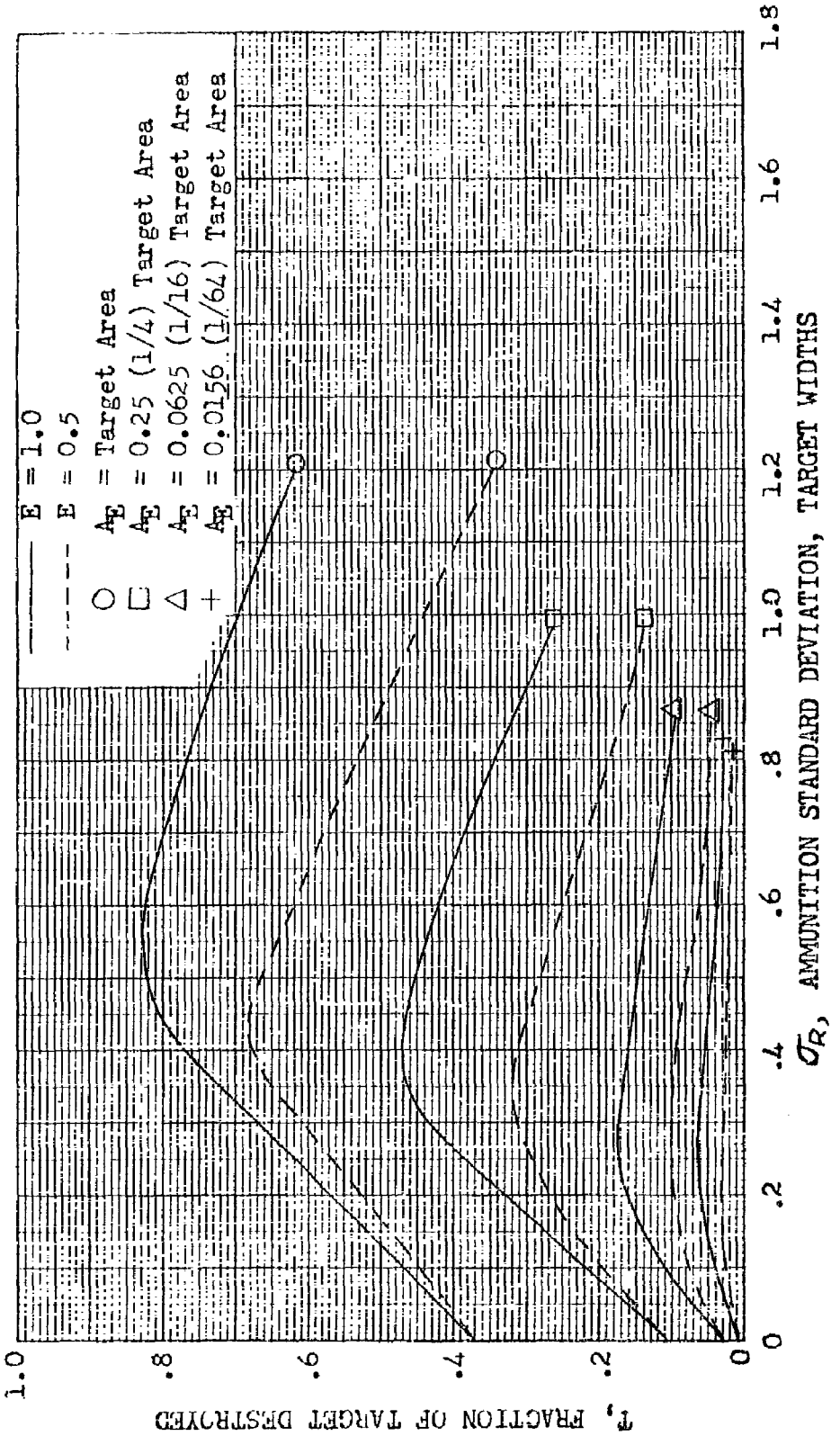

FIG. A3. Fraction of Target Destroyed vs. Ammunition Dispersion.
$\sigma_F = 0.5W$, N = 10

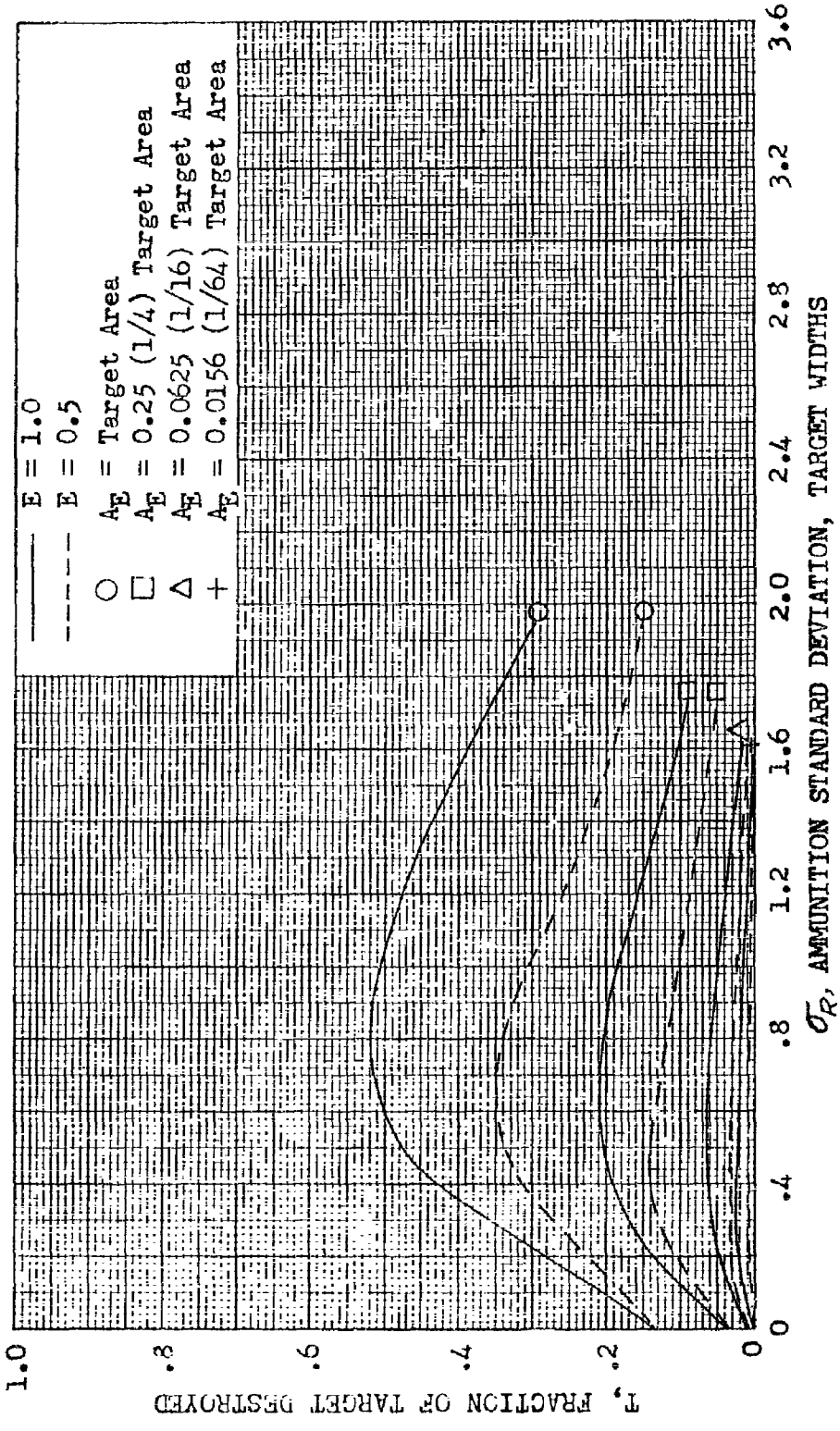

FIG. A4. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = W$, N = 10

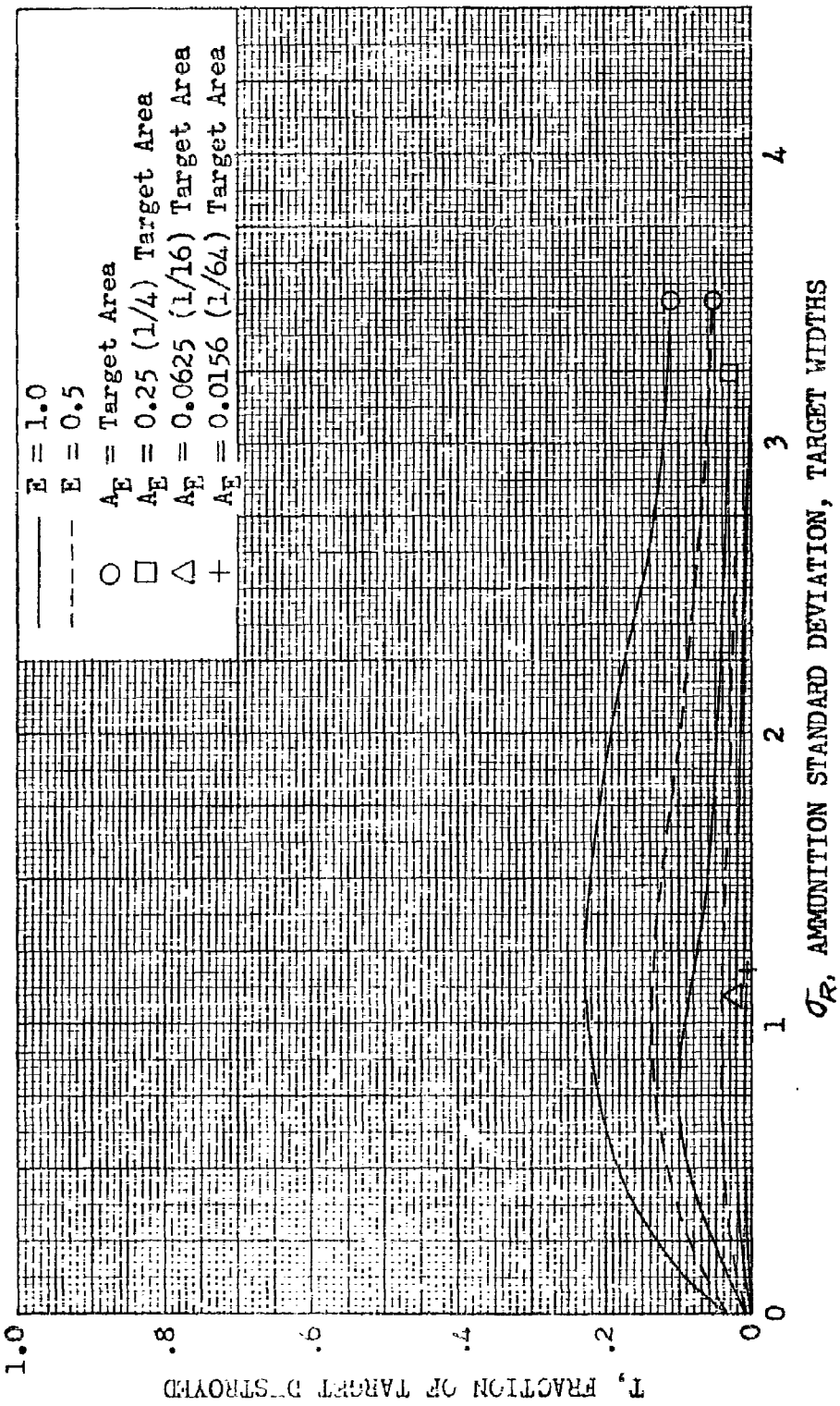

FIG. A5. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = 2W$, N = 10

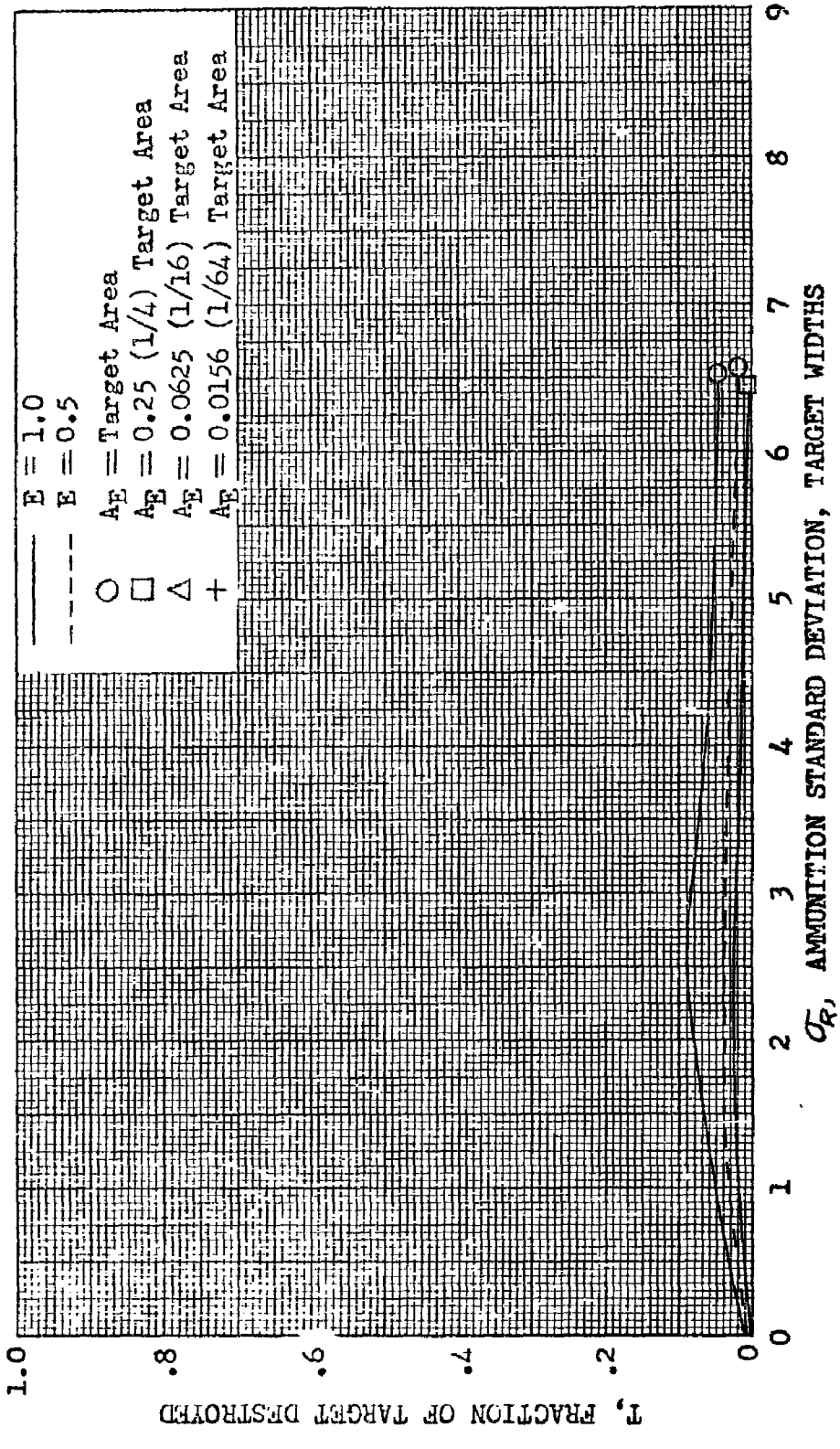

FIG. A6. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = 4W$, N = 10

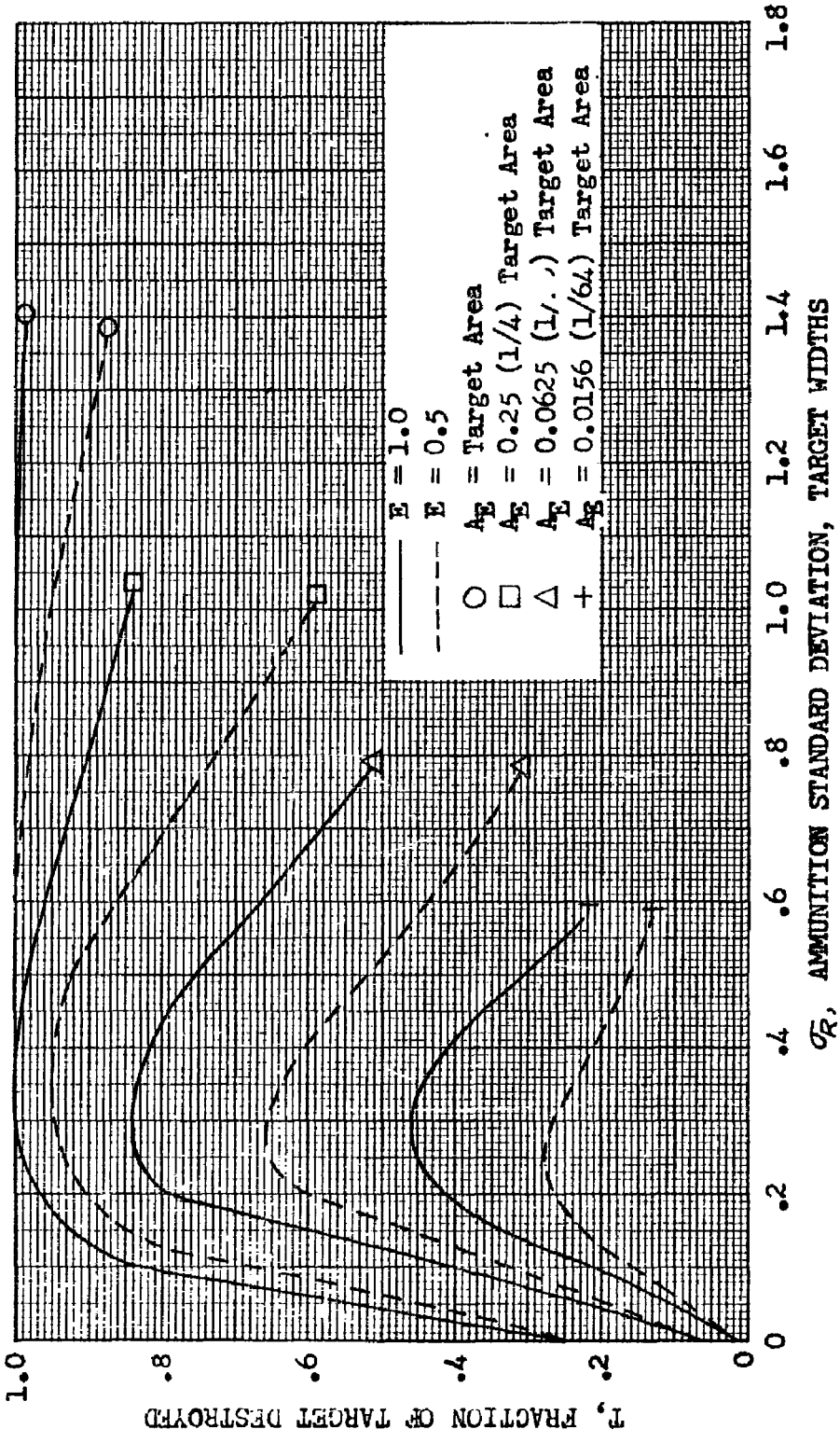

FIG. A7. Fraction of Target Destroyed vs. Ammunition Dispersion.
$\sigma_F = 0$, N = 50

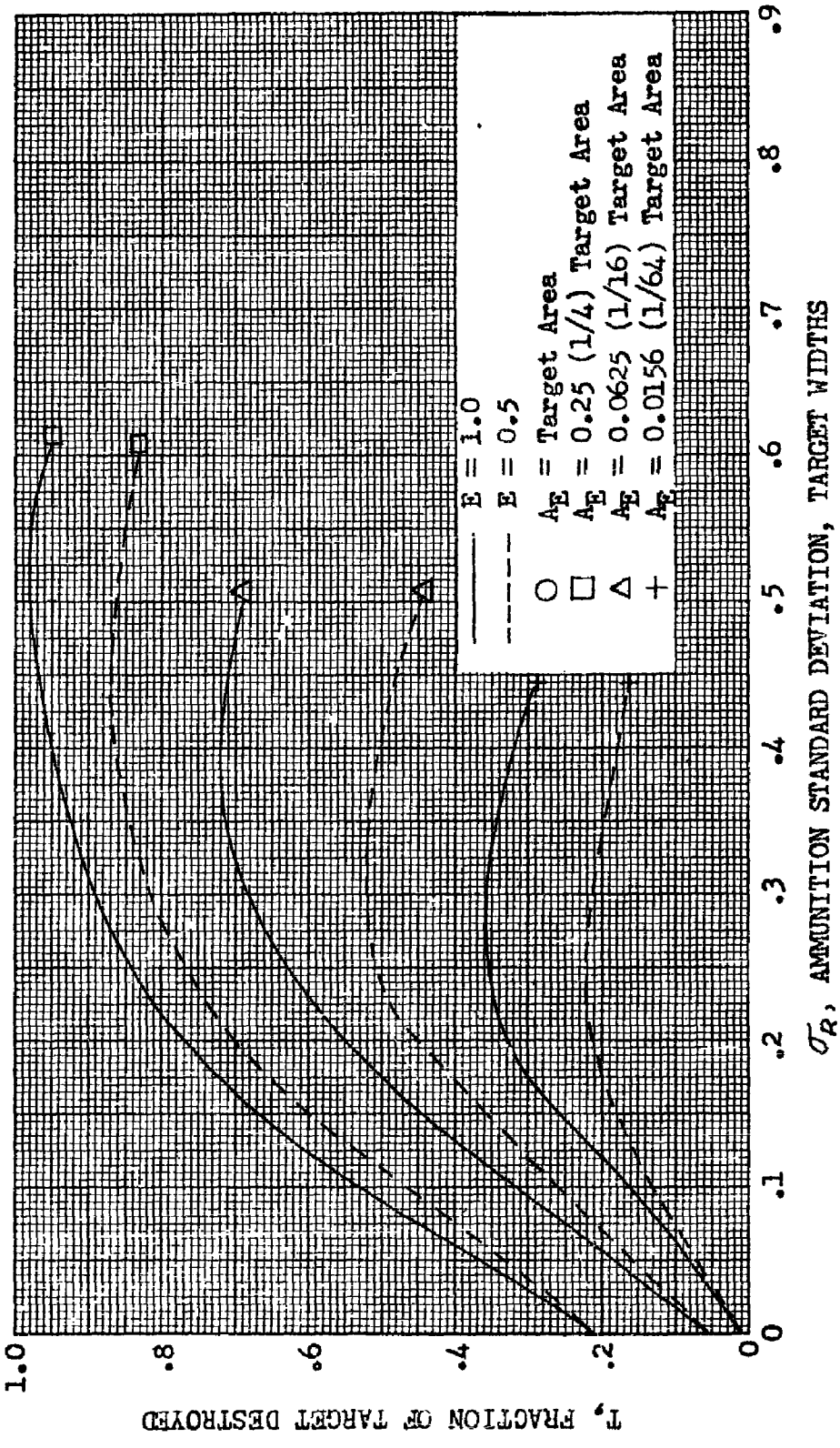

FIG. A8. Fraction of Target Destroyed vs. Ammunition Dispersion.
$\sigma_F = 0.25W$, N = 50

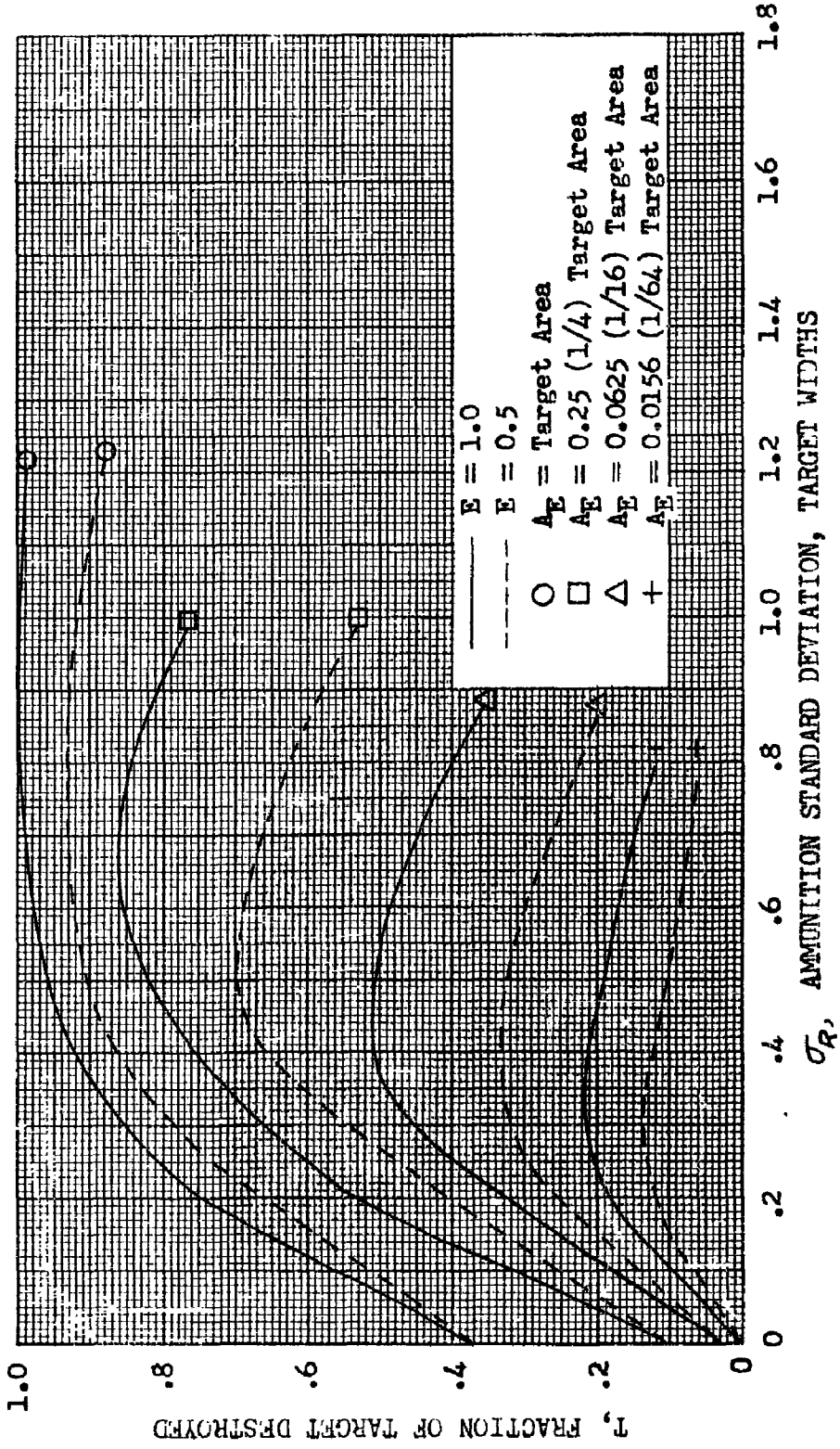

FIG. A9. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = 0.5W$, N = 50

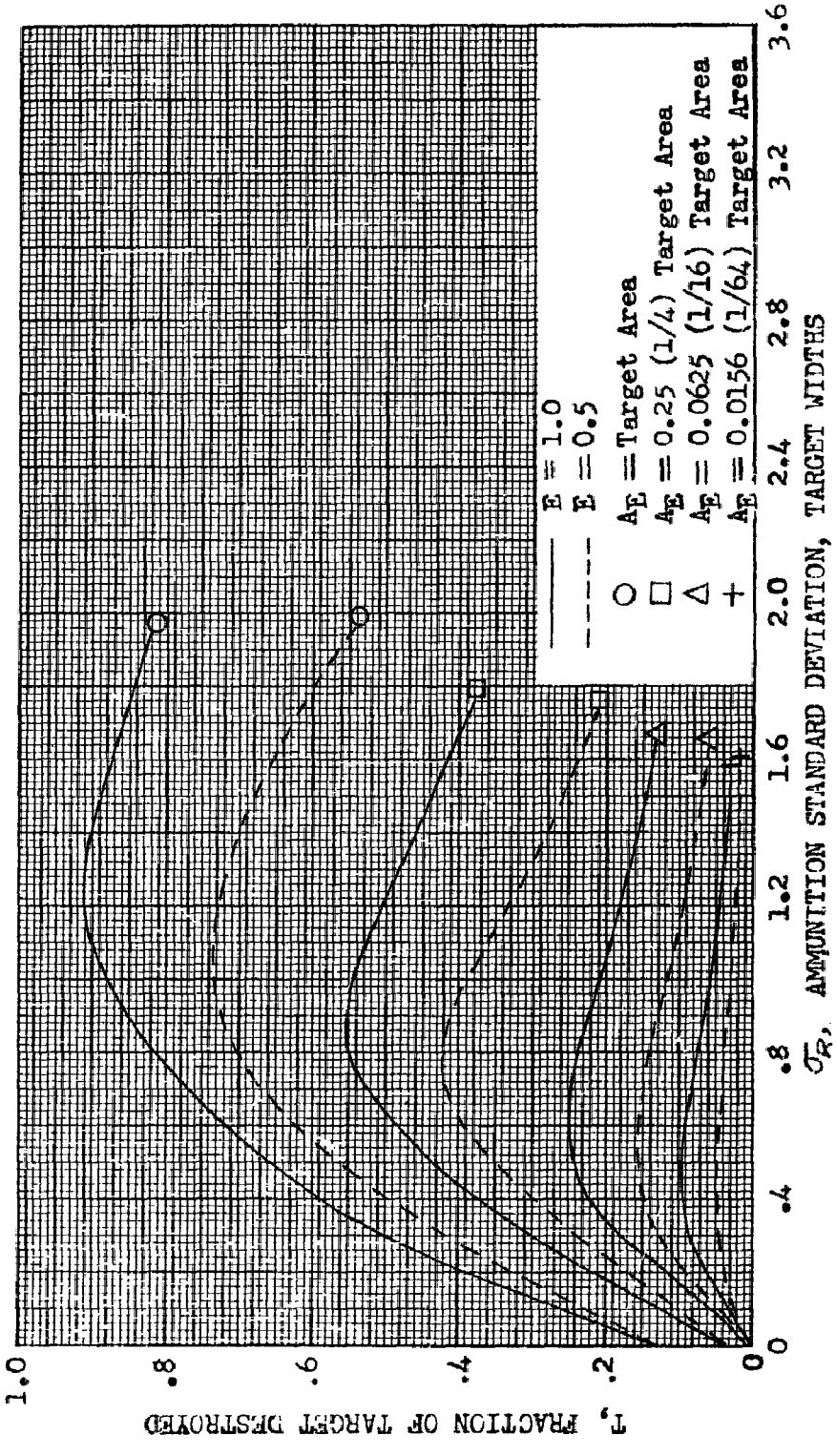

FIG. A10. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = W$, N = 50

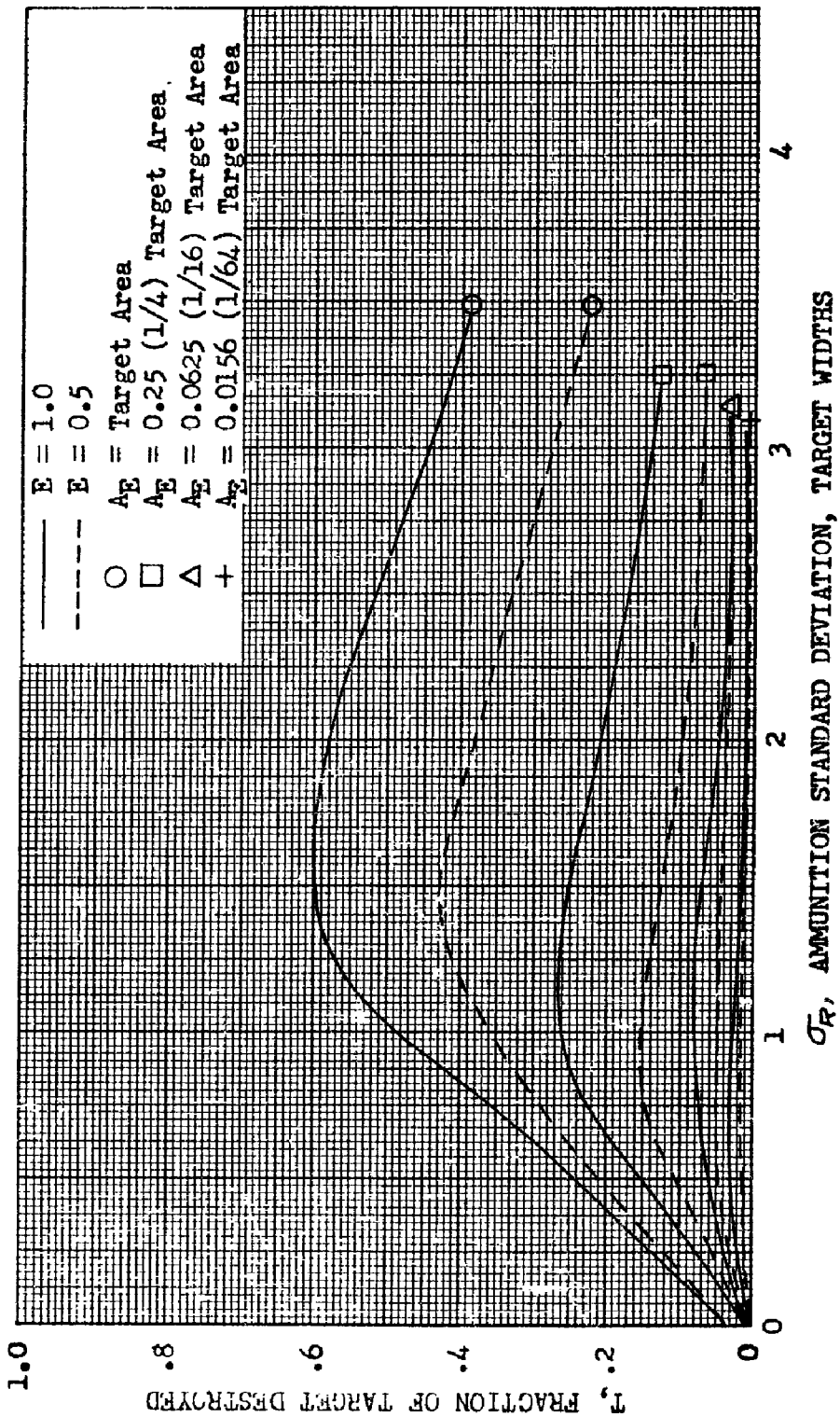

FIG. A11. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = 2W$, N = 50

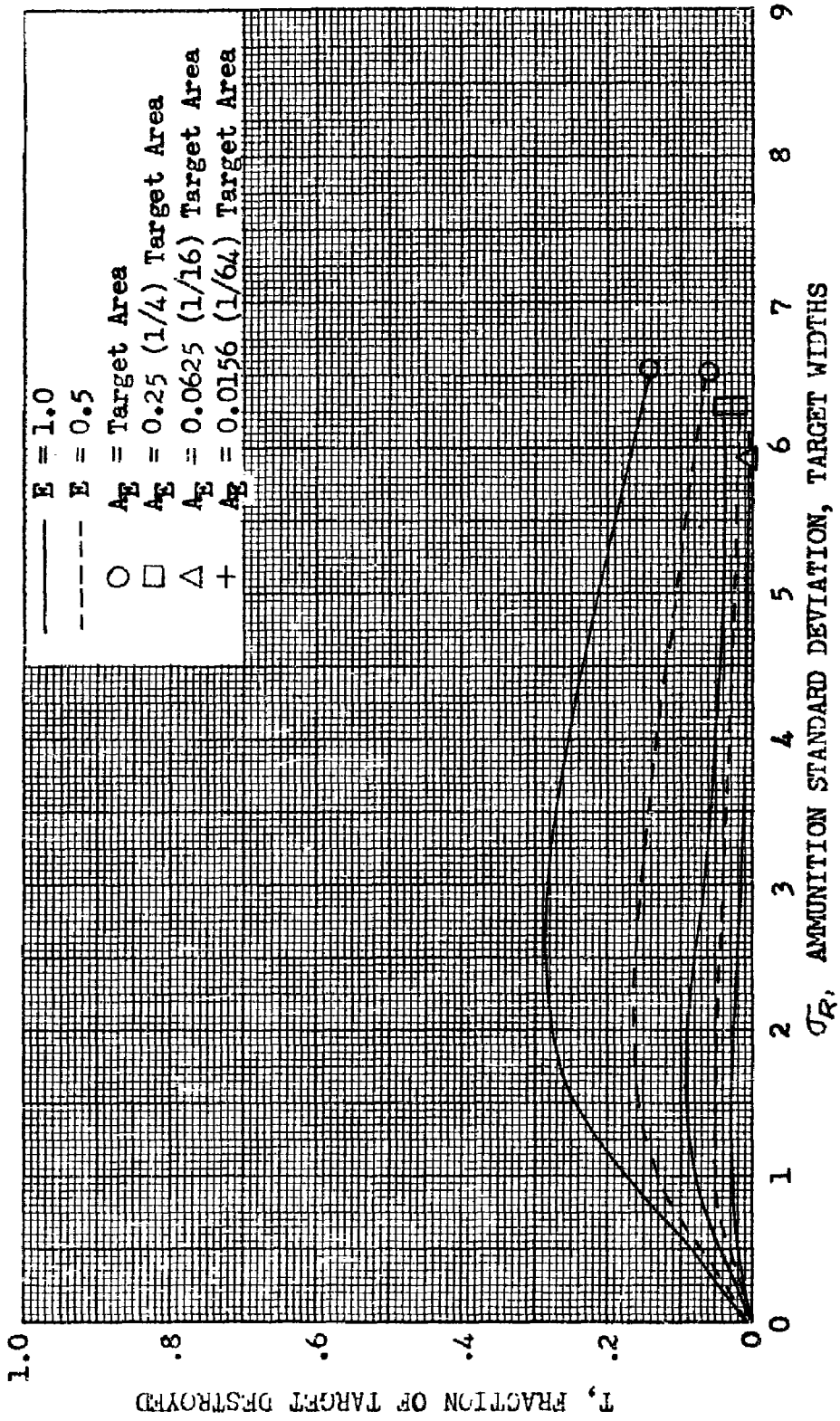

FIG. A12. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = 4W$, N = 50

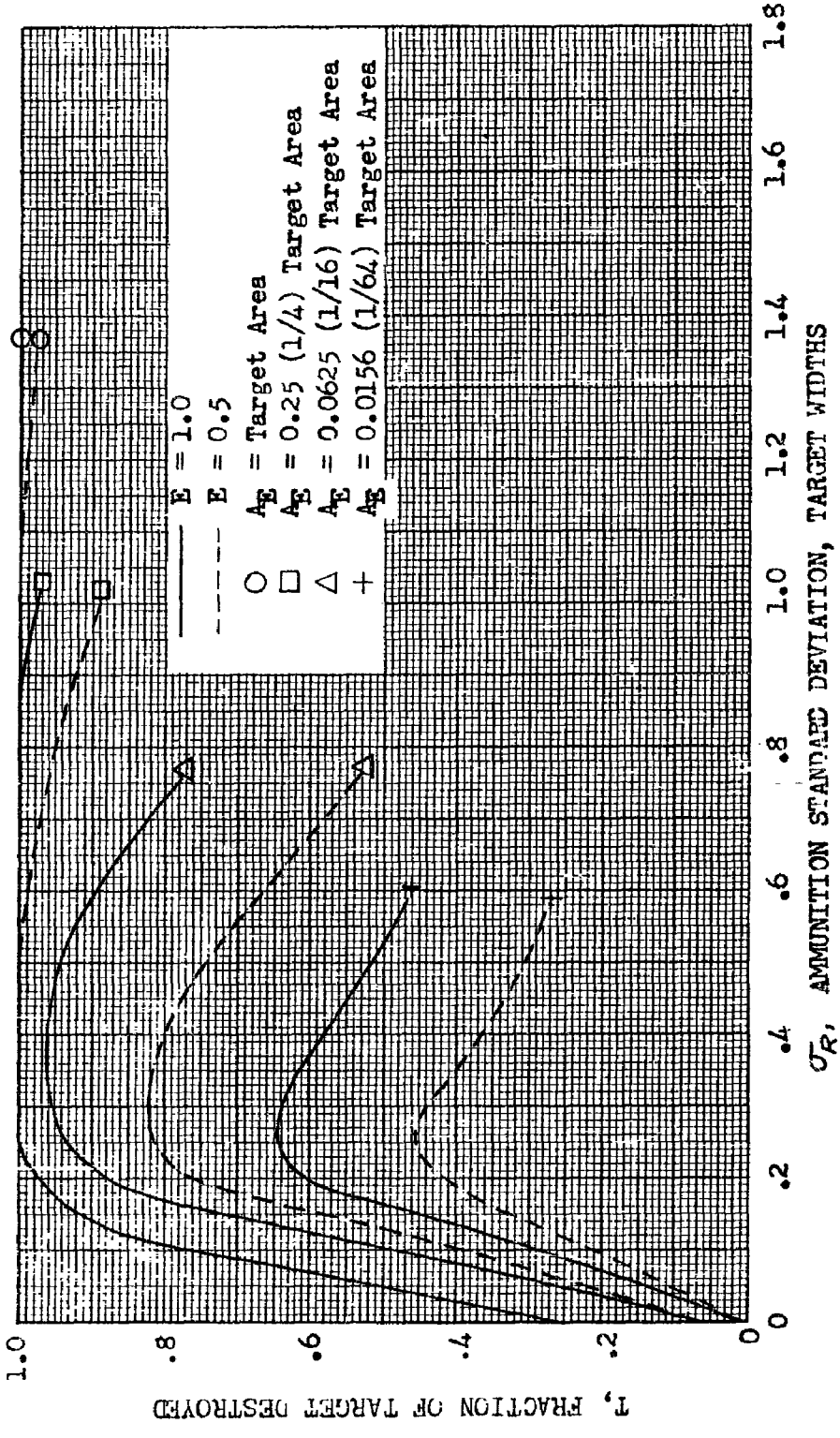

FIG. A13. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = 0$, N = 100

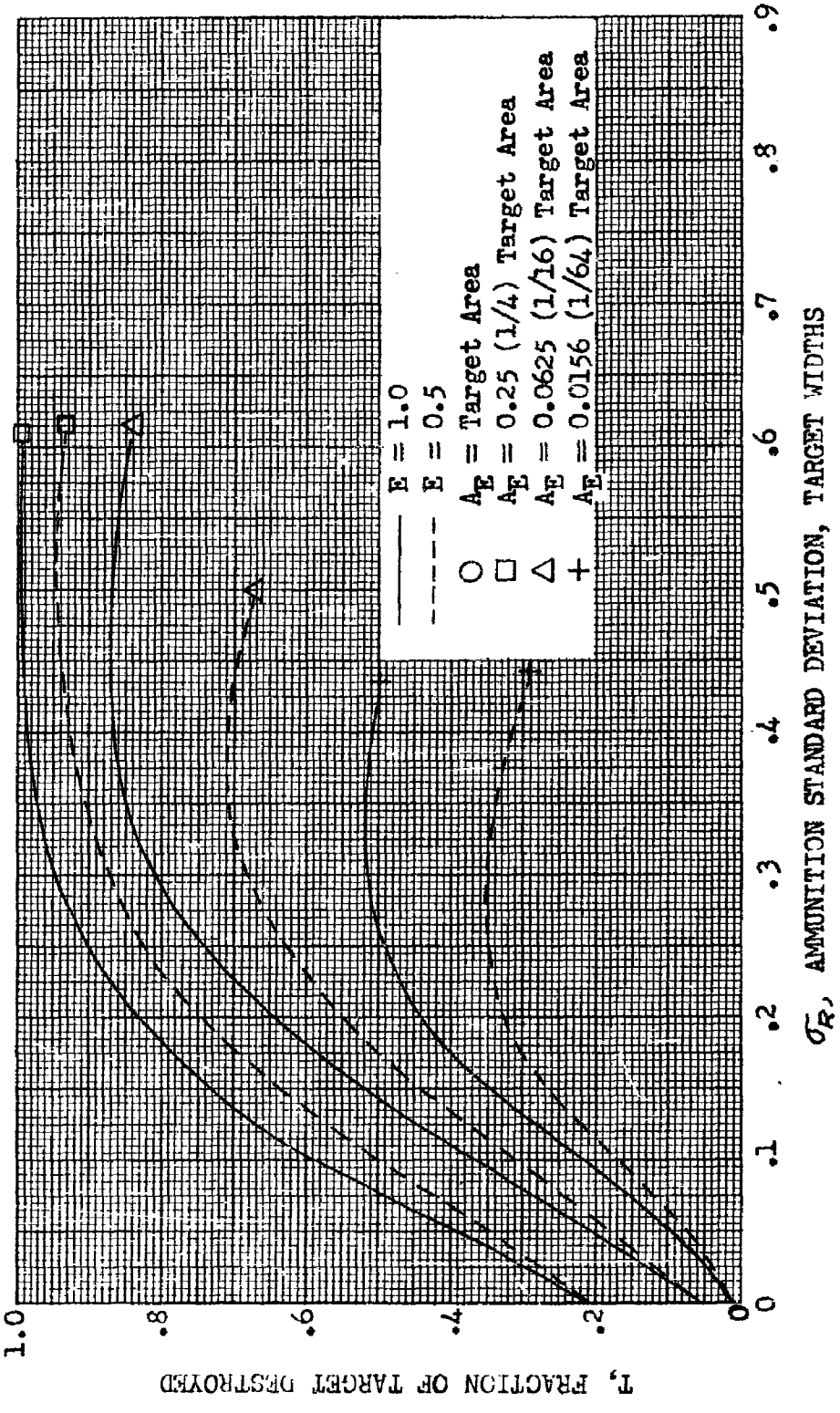

FIG. A14. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = 0.25W$, N = 100

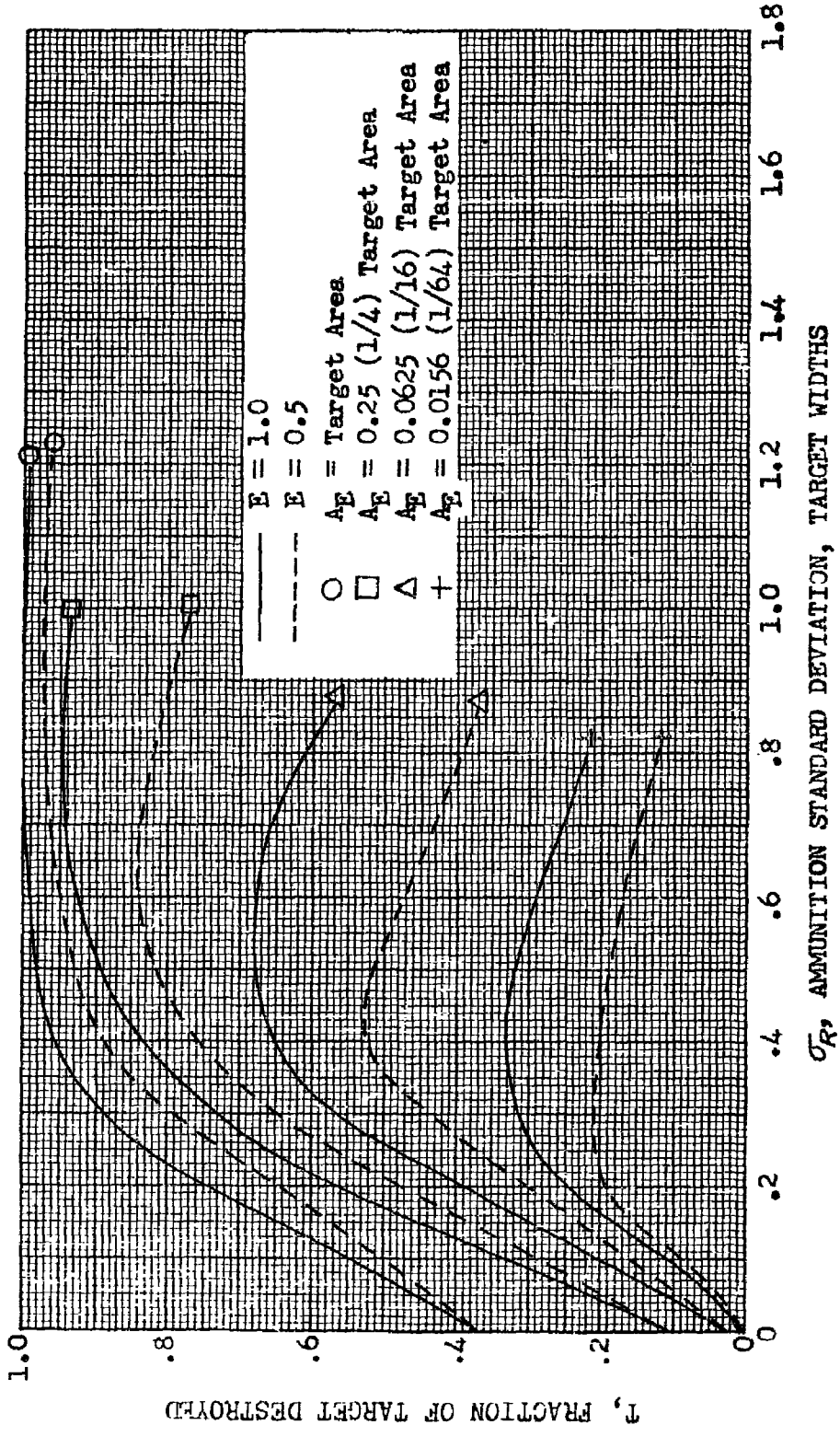

FIG. A15. Fraction of Target Destroyed vs. Ammunition Dispersion.
$\sigma_F = 0.5W$, $N = 100$

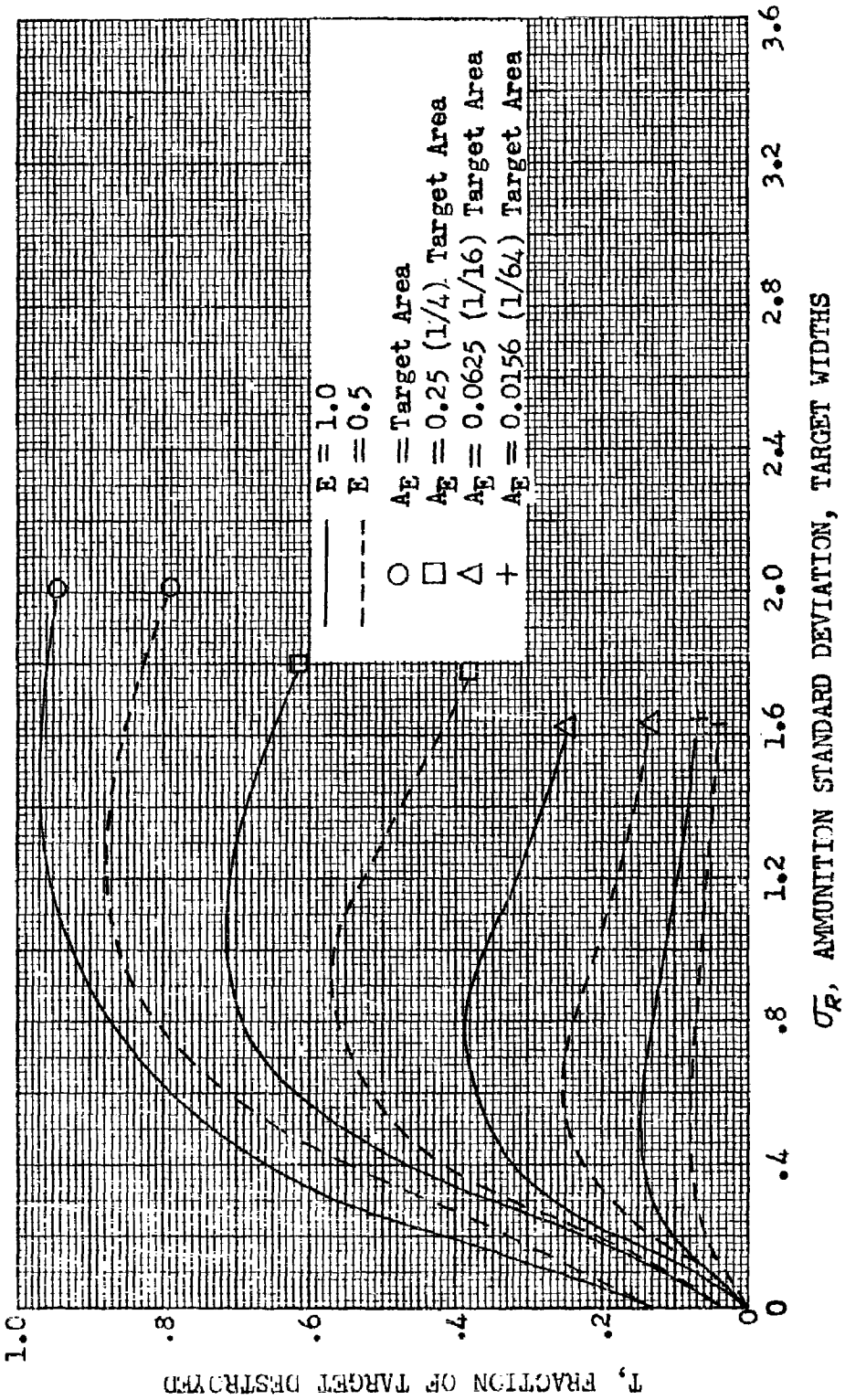

FIG. A16. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = W$, N = 100

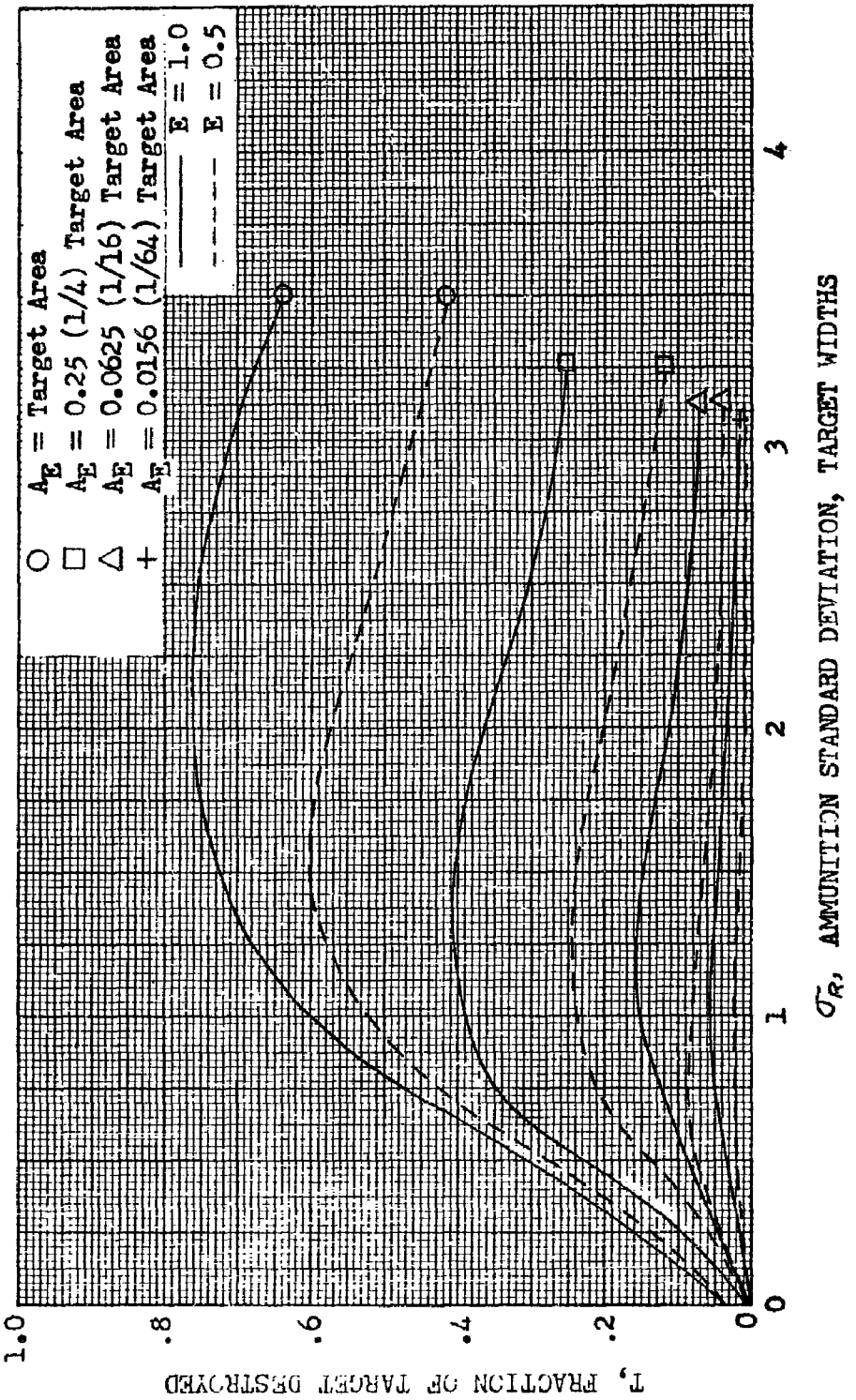

FIG. A17. Fraction of Target Destroyed vs. Ammunition Dispersion.
$\sigma_F = 2W$, N = 100

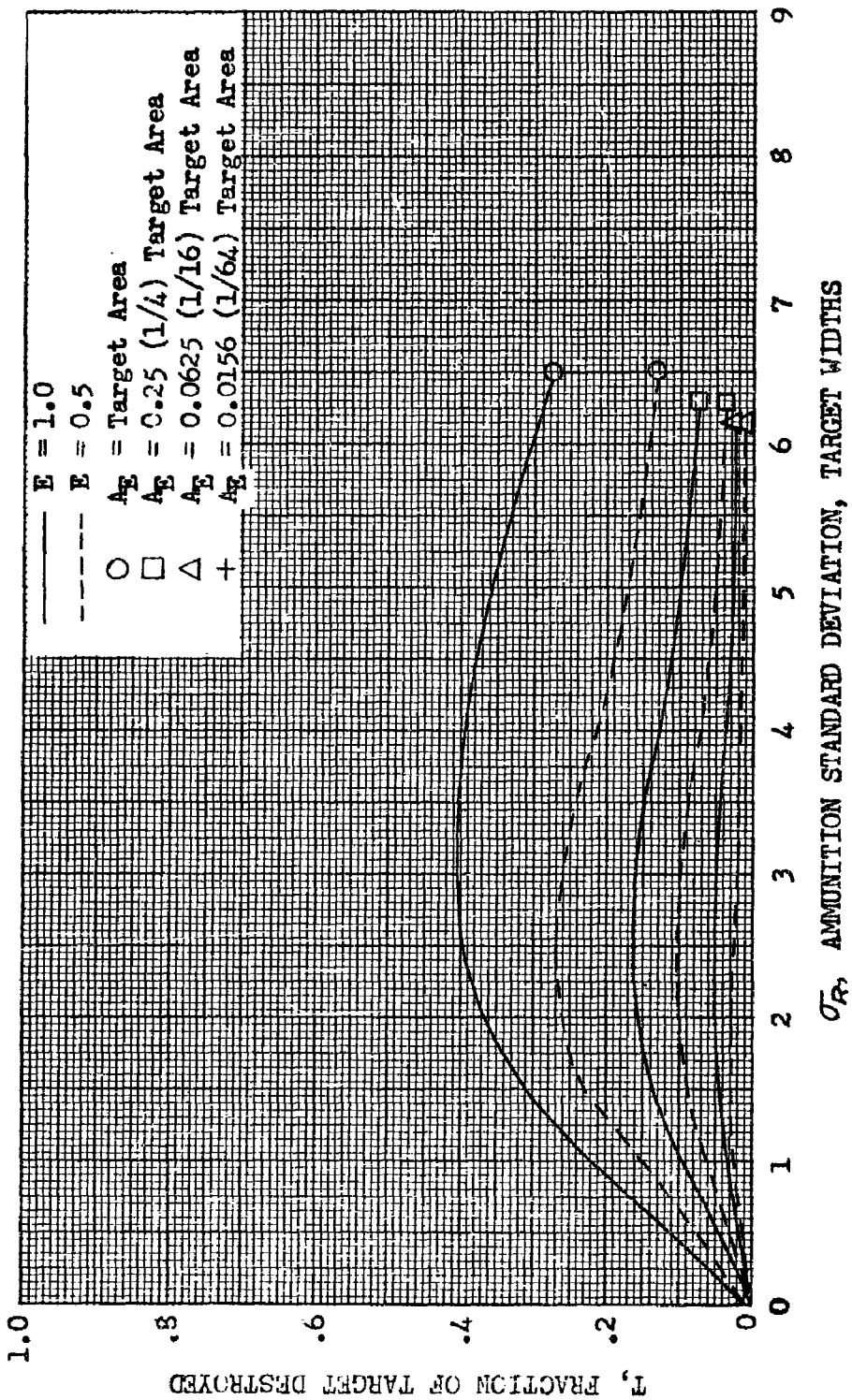

FIG. A18. Fraction of Target Destroyed vs. Ammunition Dispersion. $\sigma_F = 4W$, N = 100

Appendix B

OPTIMIZATION OF BOMBLET DISPERSION

TABLE B1. Optimum Values of Fraction of Target Destroyed

E=0.5

N=10

σ_F \ A_E	1.00	0.25	0.0625	0.0156
0	1.00	0.62	0.24	0.07
0.25	0.86*	0.48	0.19	0.06
0.50	0.68	0.32	0.10	0.03
1.00	0.35	0.14	0.03	0.01
2.00	0.14	0.04	0.02*	0.00*
4.00	0.04	0.01*	0.00*	0.00*

N=50

0	1.00	0.95	0.66	0.28
0.25	0.97*	0.87	0.52	0.22
0.50	0.93	0.70	0.33	0.14
1.00	0.74	0.42	0.16	0.05
2.00	0.43	0.15	0.05	0.02
4.00	0.17	0.05	0.01*	0.00*

N=100

0	1.00	1.00	0.82	0.46
0.25	0.99*	0.95	0.71	0.35
0.50	0.98	0.84	0.53	0.21
1.00	0.88	0.57	0.26	0.08
2.00	0.60	0.25	0.09	0.02
4.00	0.27	0.10	0.03	0.01*

Values marked by an asterisk (*) were determined by interpolation or extrapolation. The quantity σ_F is expressed in units of target widths. The "optimum values of fraction of target destroyed" are the values of T for which σ_R is optimized as described in the report.

TABLE B2. Optimum Values of Fraction of Target Destroyed

E=1.0
N=10

σ_F \ AE	1.00	0.25	0.0625	0.0156
0	1.00	0.83	0.40	0.13
0.25	0.93*	0.69	0.31	0.11
0.50	0.83	0.47	0.17	0.06
1.00	0.52	0.21	0.07	0.03
2.00	0.23	0.10	0.02	0.01
4.00	0.09	0.03	0.01*	0.00*

N=50

0	1.00	1.00	0.84	0.46
0.25	1.00*	0.98	0.72	0.36
0.50	1.00	0.86	0.51	0.22
1.00	0.91	0.55	0.25	0.10
2.00	0.60	0.27	0.08	0.03
4.00	0.29	0.09	0.03	0.01*

N=100

0	1.00	1.00	0.96	0.65
0.25	1.00*	1.00	0.87	0.52
0.50	1.00	0.95	0.68	0.33
1.00	0.97	0.71	0.39	0.15
2.00	0.76	0.41	0.16	0.06
4.00	0.40	0.16	0.05	0.02*

Values marked by an asterisk (*) were determined by interpolation or extrapolation. The quantity σ_F is expressed in units of target widths.

Appendix C

EFFECT OF NUMBER OF BOMBLETS

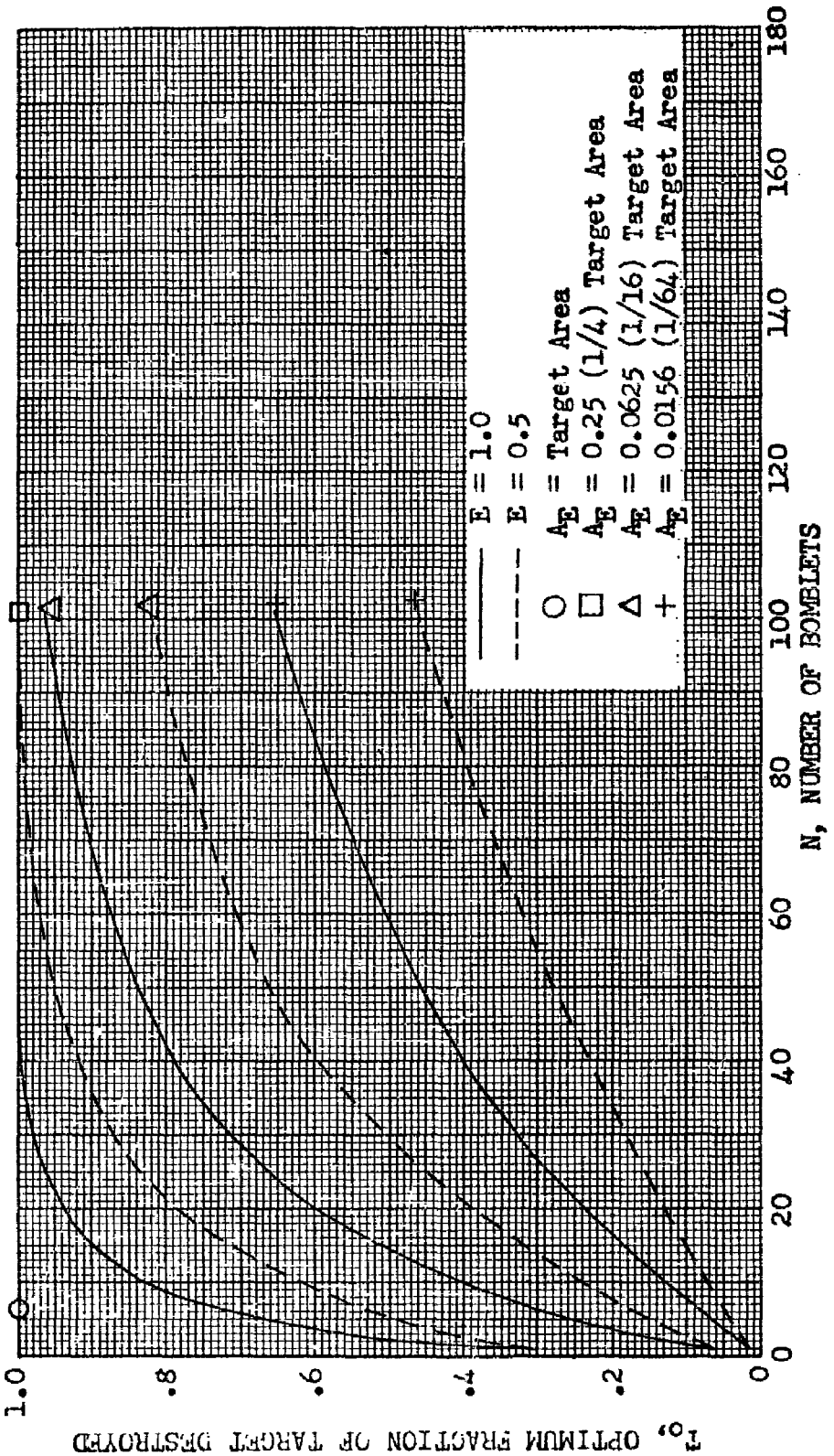

FIG. C1. Optimum Fraction Destroyed vs. Number of Bomblets. $\sigma_F = 0$

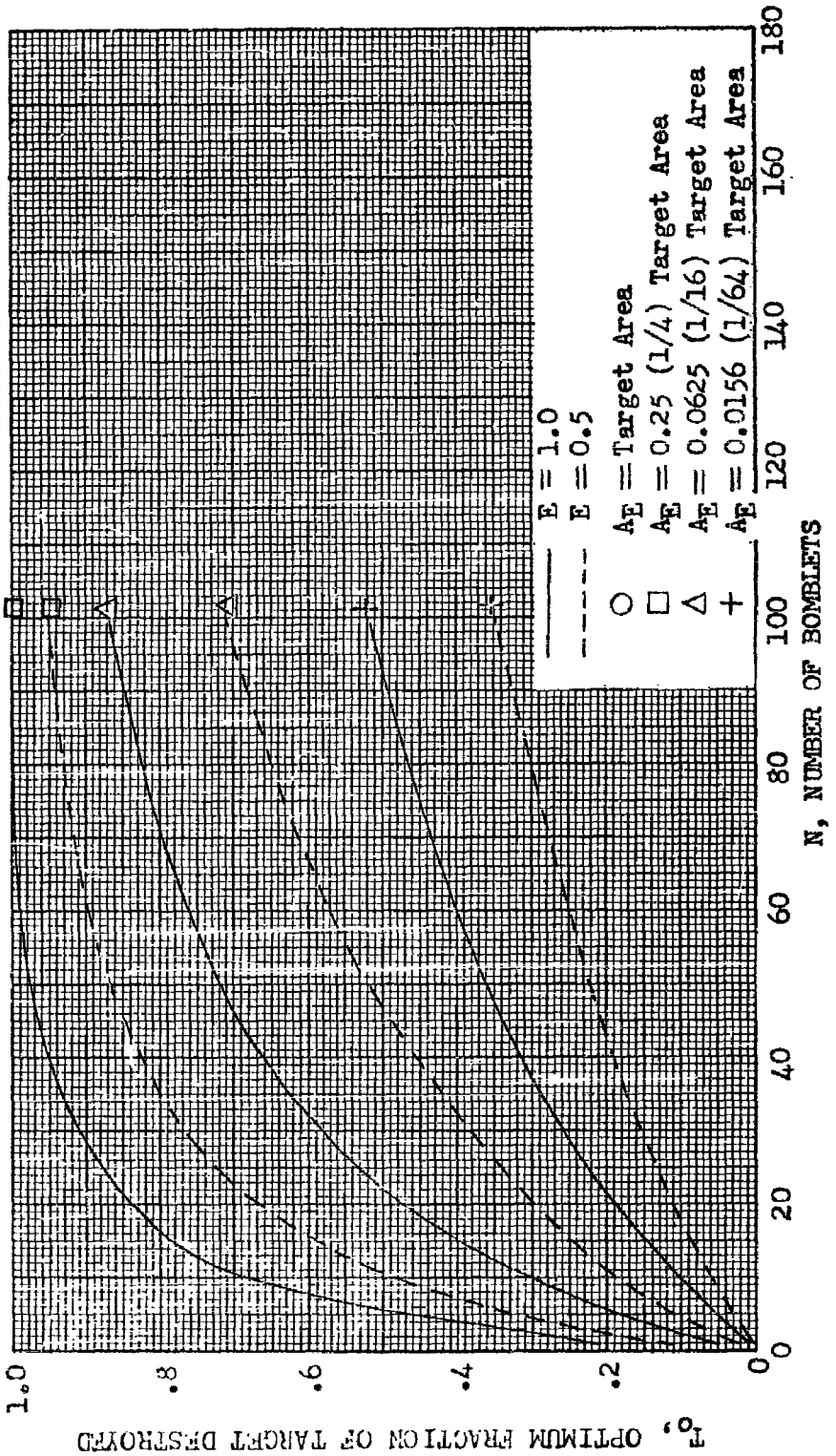

FIG. C2. Optimum Fraction Destroyed vs. Number of Bomblets. $\sigma_F = 0.25N$

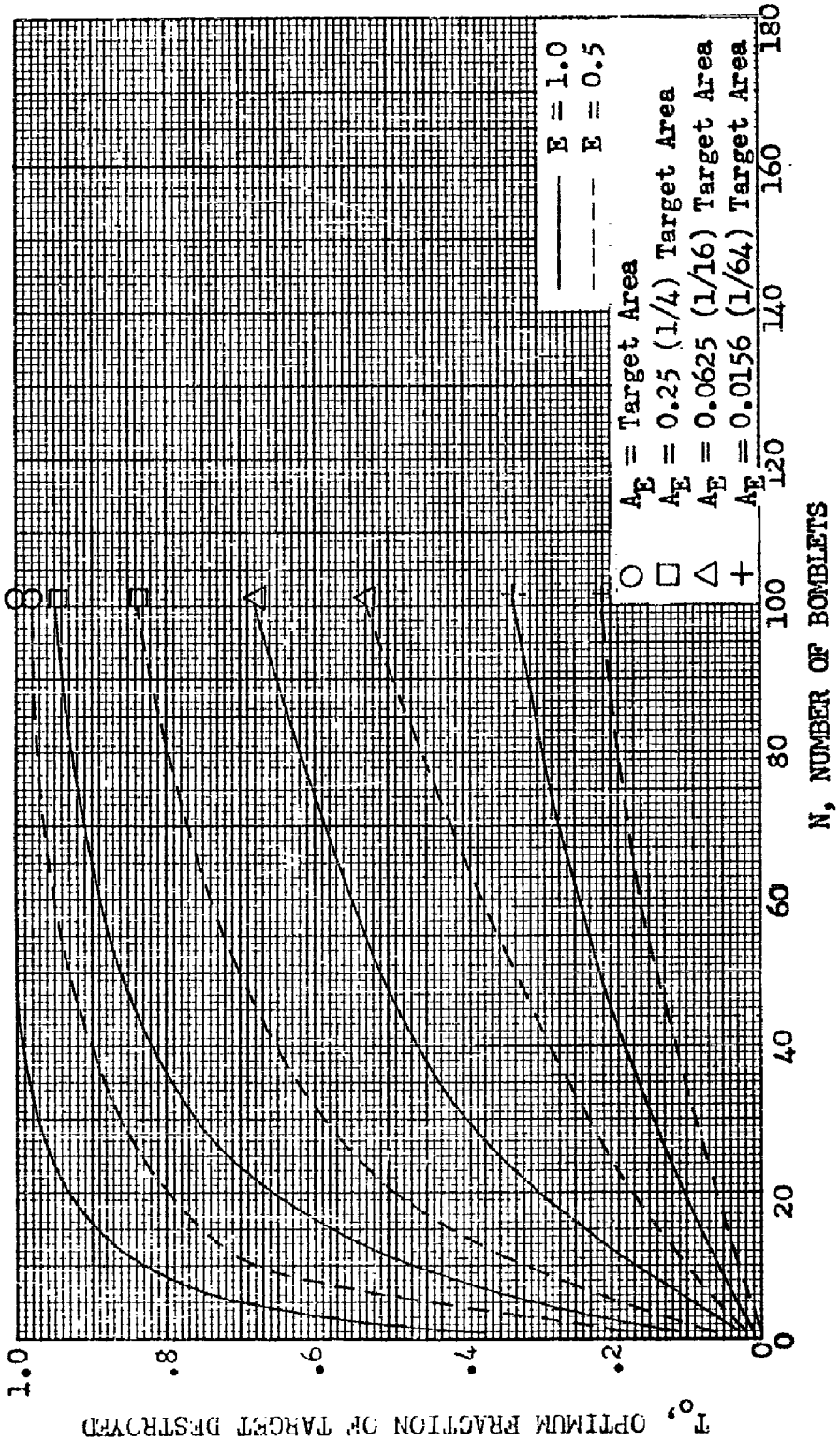

FIG. C3. Optimum Fraction Destroyed vs. Number of Bomblets.
$\sigma_F = 0.5W$

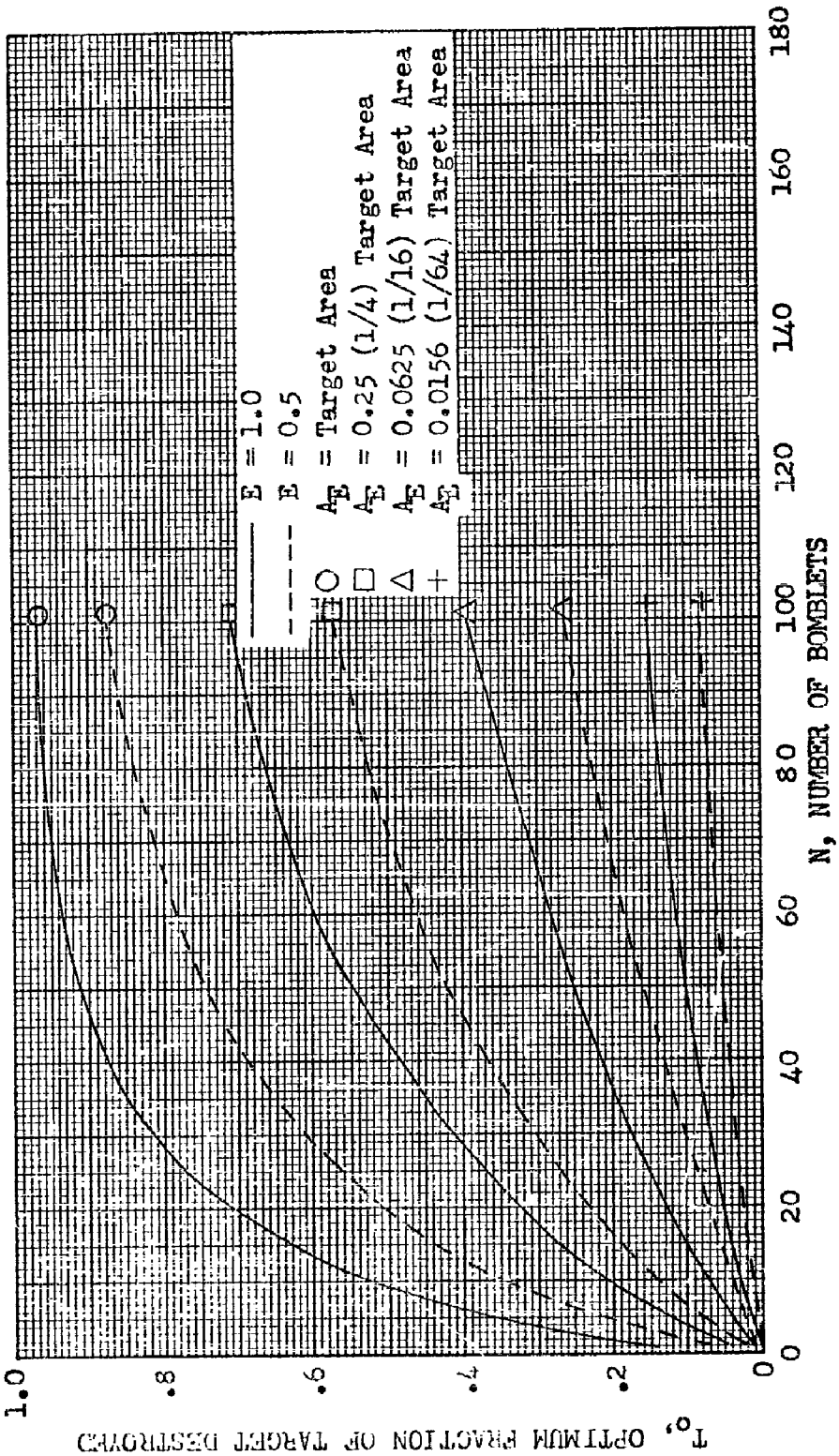

FIG. C4. Optimum Fraction Destroyed vs. Number of Bomblets. $\sigma_F = W$

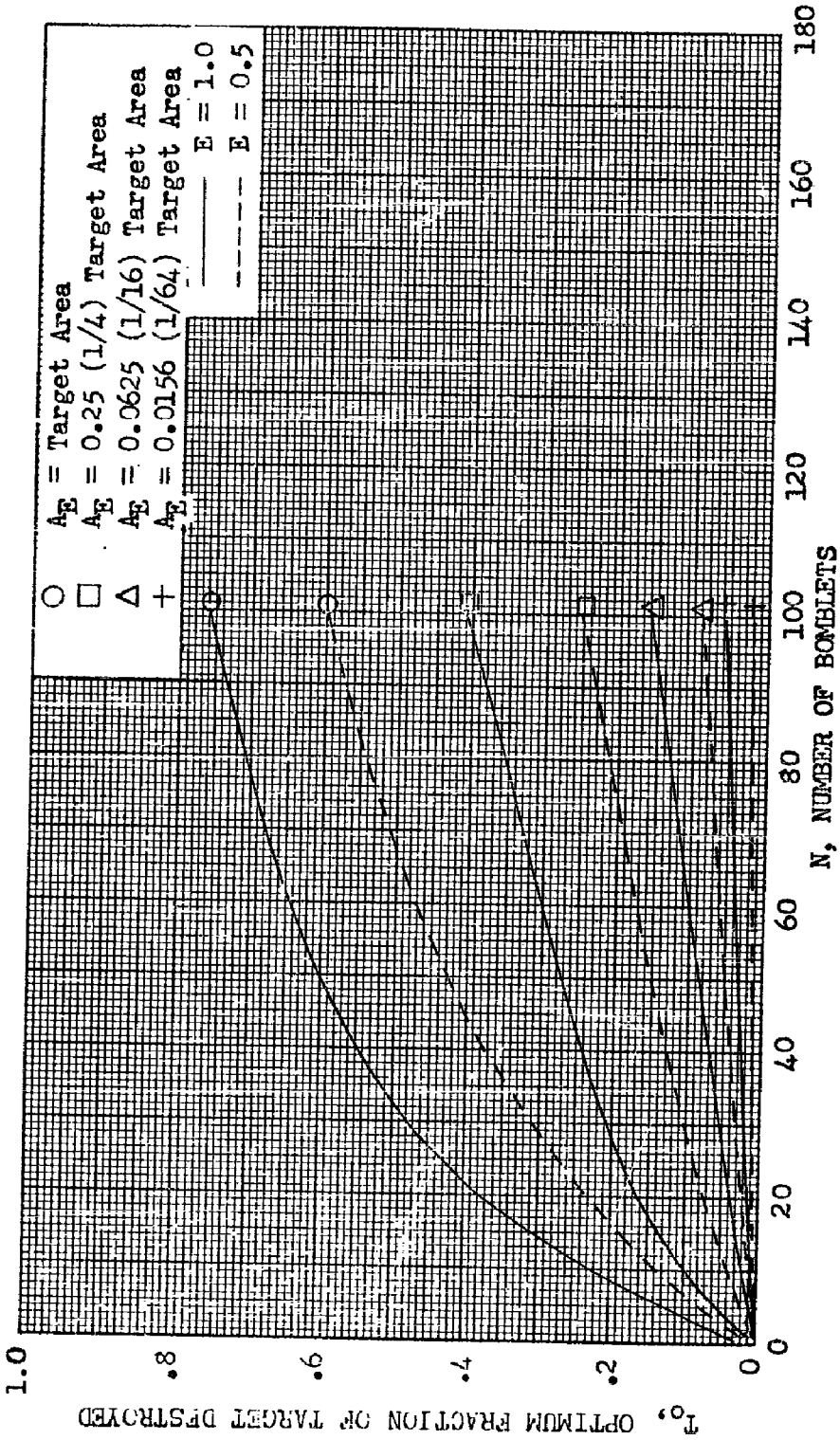

FIG. C5. Optimum Fraction Destroyed vs. Number of Bomblets. $\sigma_F = 2W$

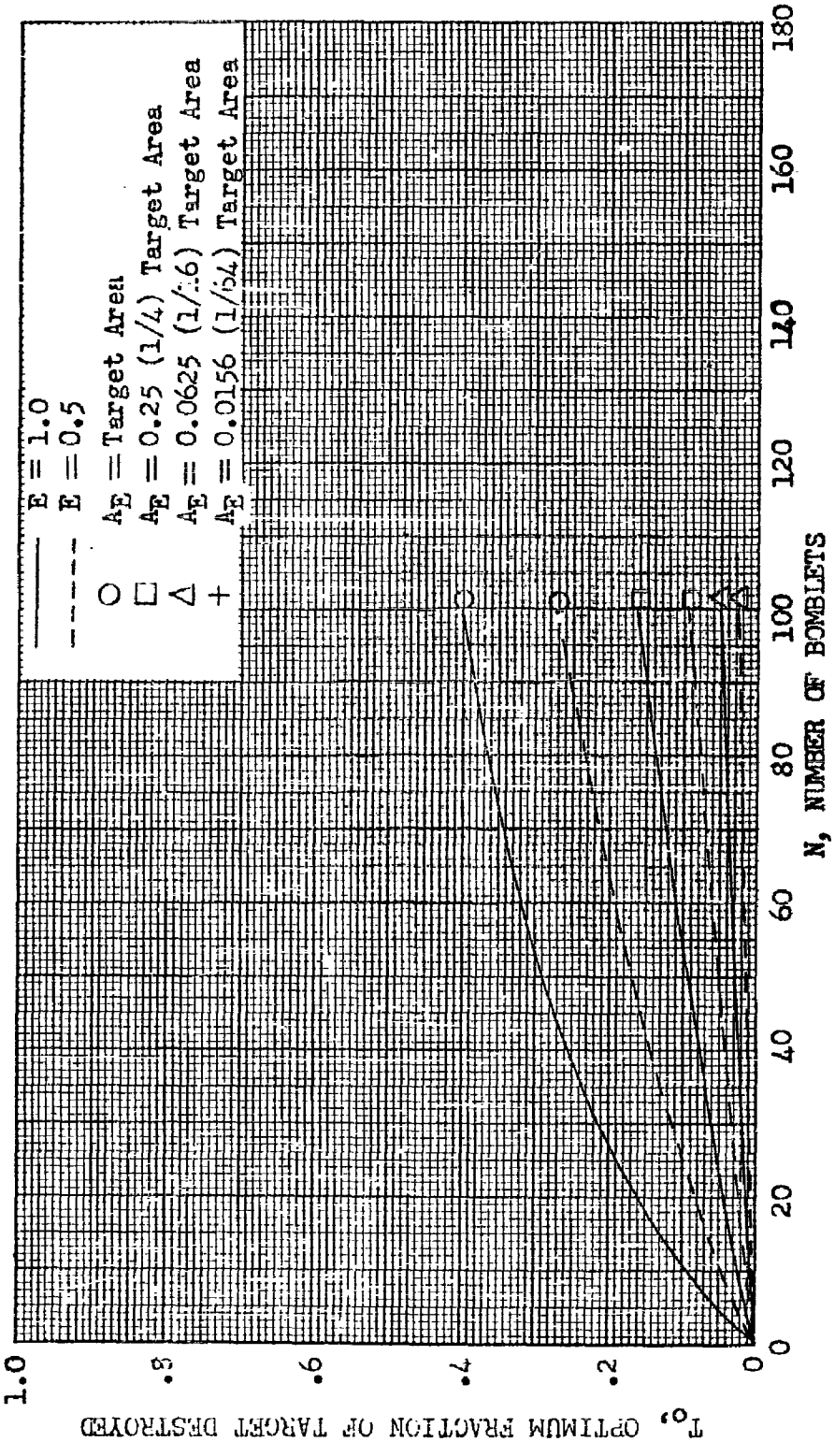

FIG. C6. Optimum Fraction Destroyed vs. Number of Bomblets.
$\sigma_F = 4W$

Appendix D

EFFECT OF DELIVERY ERROR

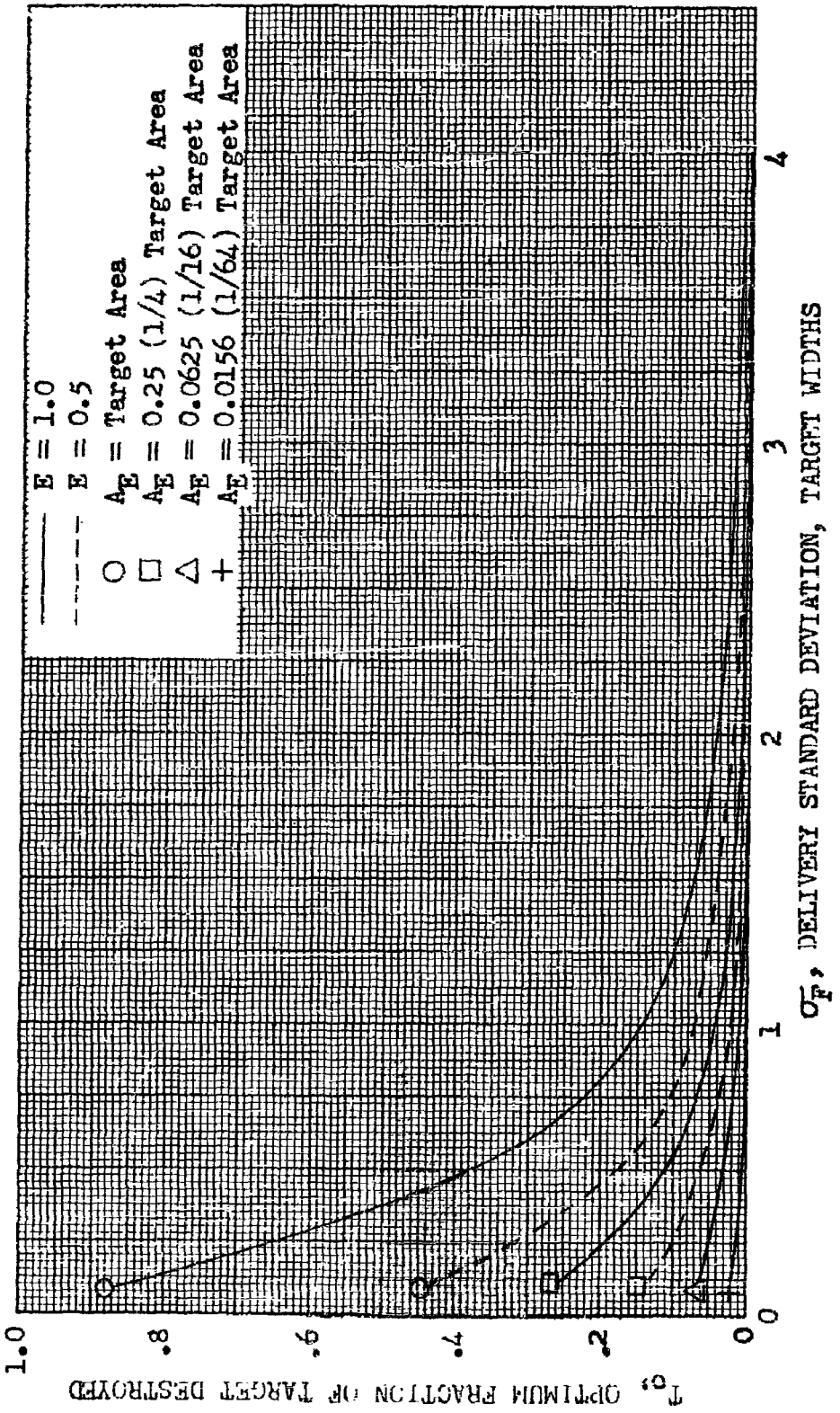

FIG. D1. Optimum Fraction Destroyed vs. Delivery Error.
N = 1

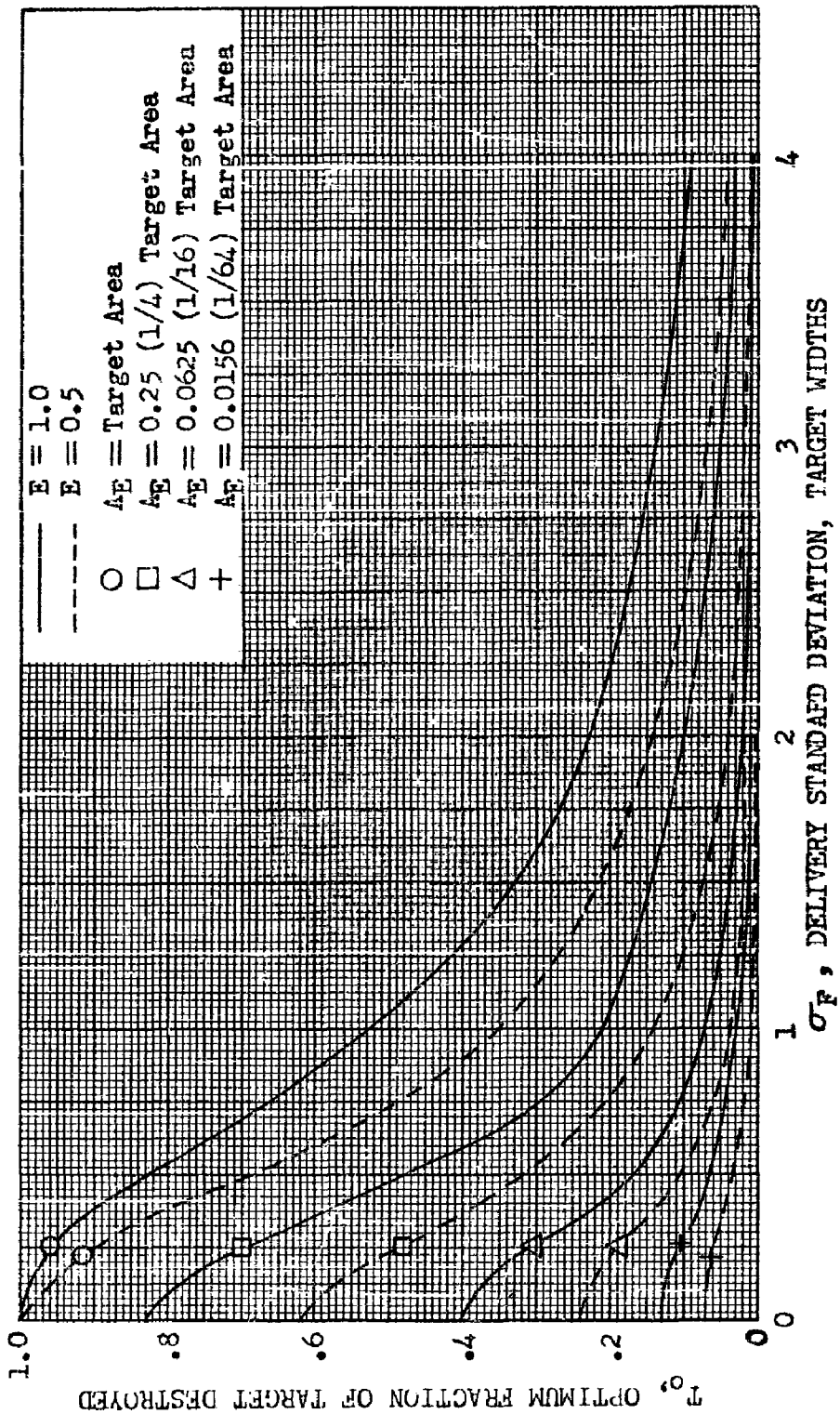

FIG. D2. Optimum Fraction Destroyed vs. Delivery Error.
N = 10

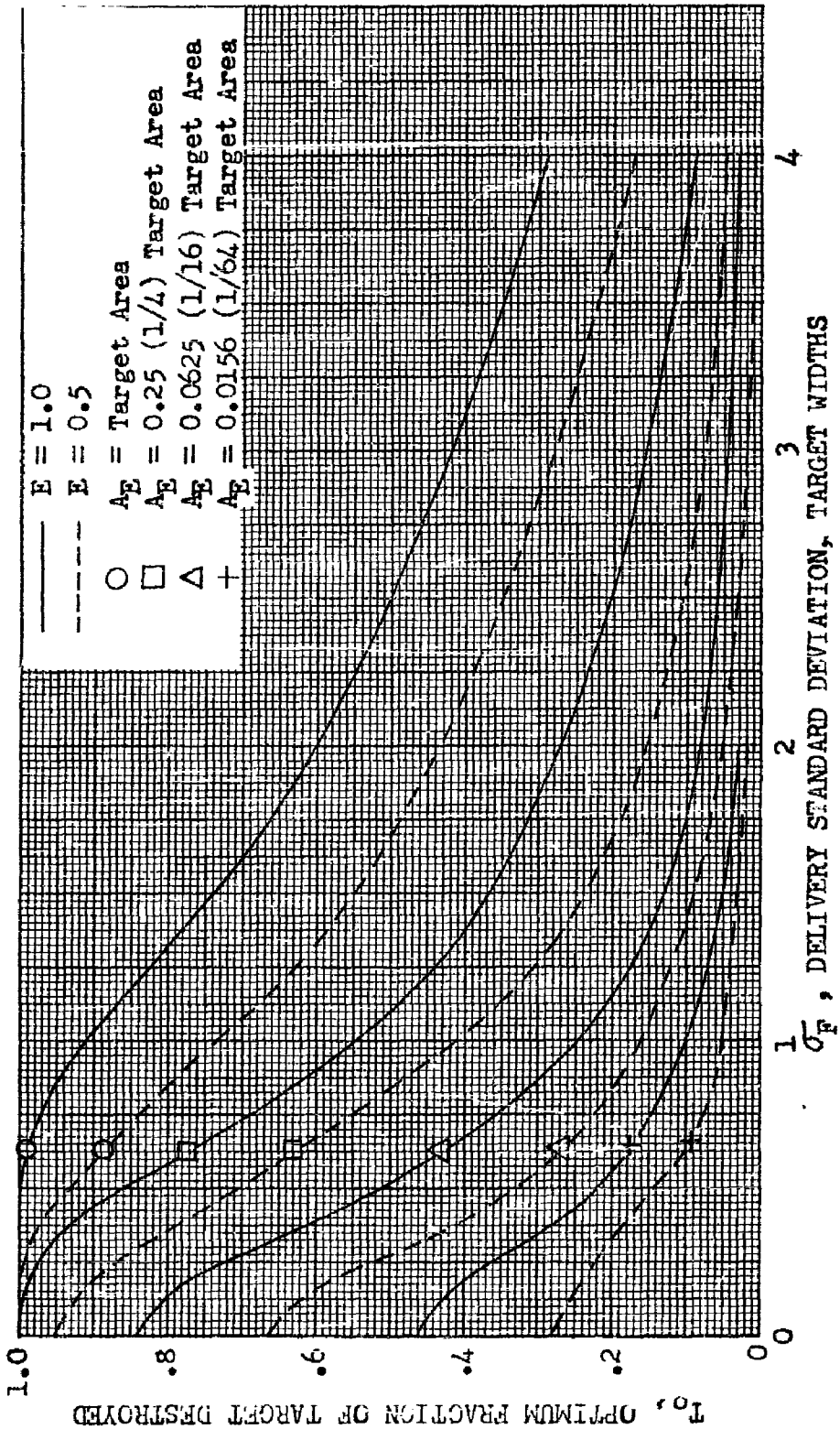

FIG. D3. Optimum Fraction Destroyed vs. Delivery Error.
N = 50

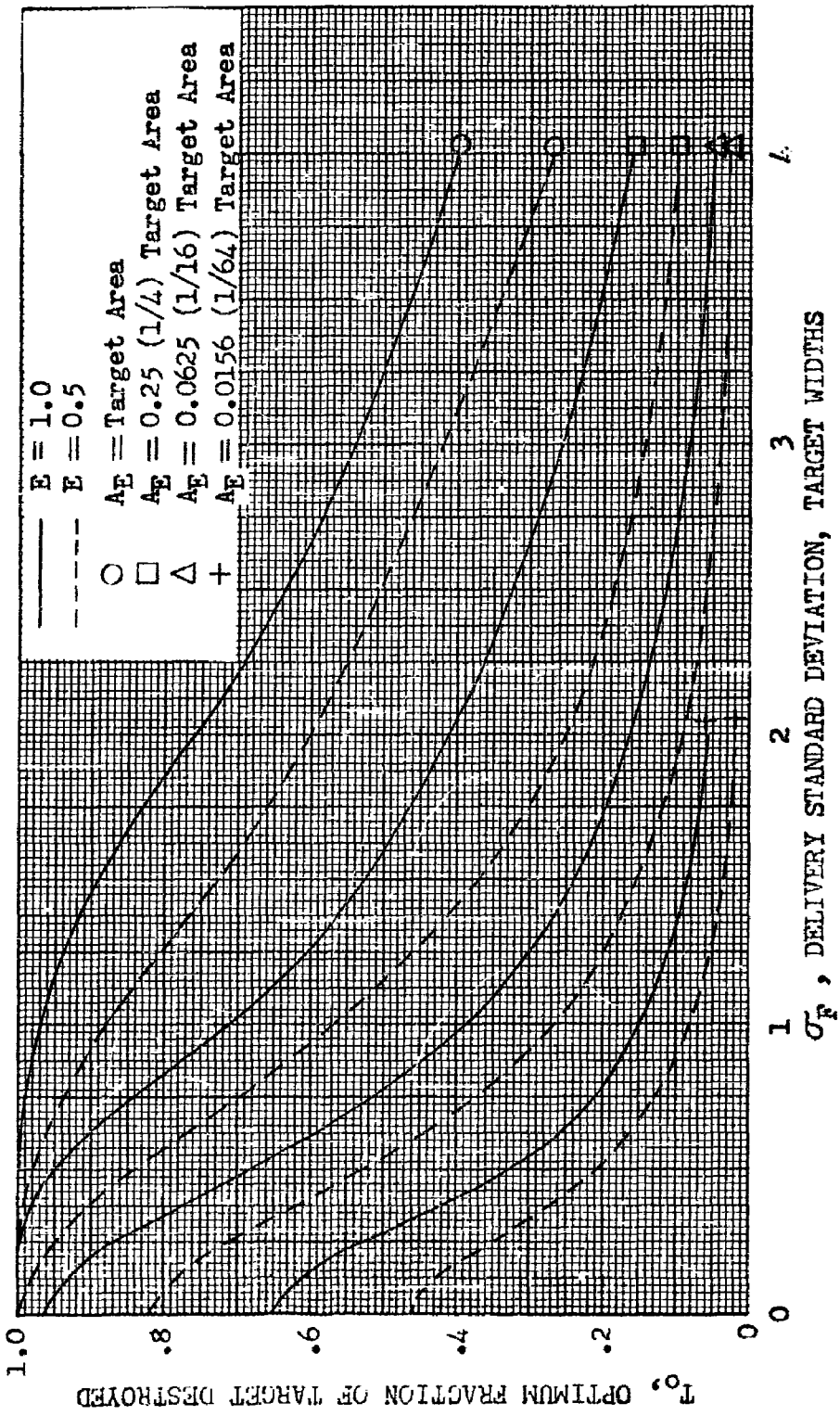

FIG. D4. Optimum Fraction Destroyed vs. Delivery Error.
N = 100

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3. Rand Corporation. Average Percent of Target Area Covered, by A. M. Mood. Santa Monica, Calif., RAND, 8 June 1950. (RAND RM 404). CONFIDENTIAL.

4. U.S. Naval Ordnance Test Station. A Method for Calculating the Effectiveness of Cluster Weapons Against Area Targets, by Eldon L. Dunn. China Lake, Calif., NOTS, 30 October 1959. (NOTS TN-122-6).

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ABSTRACT CARD

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The Effectiveness of Cluster Weapons Against Square Area Targets, by Eldon L. Dunn. China Lake, Calif., NOTS, 30 Mar 1961. 47 pp. (NAVWEPS Report 7641, NOTS TP 2655), UNCLASSIFIED.

ABSTRACT. This report contains the results of a parametric study on the effectiveness of cluster weapons against "area" targets, where an "area" target consists of a large number of units distributed over an area (e.g., a battalion of troops in the field).

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The effects of number of bomblets, delivery error, ammunition dispersion, and warhead effectiveness are considered. The results of the study are presented in handbook form so that one may quickly determine the effectiveness of any proposed cluster weapon, once specific values have been assigned to the above parameters.

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