OEG

Study 264

Analysis of Test Data for Comparison of Various Anti-Aircraft Fire Control Systems

Prepared by
Operations Evaluation Group
Office of the Chief of Naval Operations

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OPERATIONS EVALUATION GROUP STUDY
No. 264

ANALYSIS OF TEST DATA FOR COMPARISON OF VARIOUS ANTI-AIRCRAFT FIRE CONTROL SYSTEMS

OEG Studies summarize the results of current analyses. While they represent the views of OEG at the time of issue, they are for information only, and they do not necessarily reflect the official opinion of the Chief of Naval Operations.

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ANALYSIS OF TEST DATA FOR COMPARISON OF VARIOUS ANTI-AIRCRAFT FIRE CONTROL SYSTEMS

References:
(a) TF69/S71 Serial 015, "CTF69 Test P-5, Tests of Performance of 5"/38 Control Systems Mark 51 Director (40 mm ballistics), Mark 52 Director, Mark 57, Mark 63, Mark 37 Directors." 23 July '45, Confidential.
(b) ComOpDevFor/S71 Serial 83, "CTF69 Test P-5 (Revised)". 23 Jan '46, Confidential.
(c) TF69/S71/S74 Serial 87, "CTF69 Exercise Z-6, AA Practice "K" (Kamikaze) Rev. A)" 25 Aug '45, Restricted.

Enclosures:
(A) OEG Study #248, "Mathematical Background for Evaluation of AA Firing Tests". 2 Jan '46, Confidential.
(B) OEG Study #262, "Method for Testing Reliability of AA Gunfire Data." 25 Feb '46, Restricted.

A. Introduction

1. The tests described in references (a) and (b) were designed "to compare and evaluate, through shipboard firing at maneuvering drone targets, existing, modified or new AA fire control systems as to ability to produce hits, tracking performance, and suitability for fleet use of the operational and maintenance characteristics incorporated in the system". The present Study is a report based on the analysis of data obtained during the execution of these tests.

B. The P-5 Test Method

1. This test is fully described in reference (b). Briefly, it consisted in firing 5"/38 V.T. fuzed non-fragmenting ammunition, from batteries under control of various Fire Control systems, at actively maneuvering TD2C drone targets.

2. Four types of target approach runs were used: -

G-at: glider-like runs directed at the firing ship, (the K-1 type of run described in reference (b));

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G-ahead: glider-like runs directed toward an imaginary ship 750 to 1000 yards ahead of the firing ship, (the K-2 runs of reference (b));

T-at: torpedo-like runs directed at the firing ship, (V-1 runs of reference (b)); and

T-ahead: torpedo-like runs directed toward an imaginary ship 750 to 1000 yards ahead of the firing ship, (the V-2 runs of reference (b)).

The four types of runs were used in the testing of each type of Fire Control System. They were repeated until preliminary analysis of the data showed some evidence of adequate sampling.

3. The several Fire Control Systems under trial were operated in accordance with established doctrine. Except where noted, tracking was exclusively under full optical control. In the systems which include radar equipment, radar was used for range only. No arbitrary spots were applied to correct for target maneuver or errors in the systems.

4. Observers were stationed in various parts of the firing ship to report the results of gunfire. The number of premature bursts of 5"/38 VT fuzed ammunition as well as the number of presumably target-triggered (hit) bursts was recorded. All shoots were photographed by an Atlantic Fleet Camera Party, using the two or three camera method, as a check on the observers' reports.

5. Reports submitted by the firing ship included the number and type of run, the type of Fire Control used, the number of guns firing, the rate of fire, the lot number and normality of the ammunition, the number of rounds fired, the present ranges of open and cease fire, the number of seconds spent by the target in each 500 yard range band (present range), the number of prematures, the number of hits and present range of each hit, as well as much such additional data as wind, state of sea, etc.

C. The Fire Control Systems Tested

1. Seven systems were subjected to the tests discussed above.

a) Mark 37 - 1 System

Director	- Mark 37 Mod
Computer	- Mark 1
Radar	- Mark 12 Mod 2
	Mark 22 Mod 0

b) Mark 37 - 8 System
   Director - Mark 37 Mod
   Computer - Mark 8
   Radar - Mark 12 Mod 2
   Mark 22 Mod 0

c) Mark 51 - 5" System
   Director - Mark 51 Mod 3
   Gun Sight - Mark 15 Mod 3 (5" ballistics)
   Radar - none

d) Mark 51 - HMG System
   Director - Mark 51 Mod 3
   Gun Sight - Mark 15 Mod 11 (40 m.m. HMG ballistics)
   Radar - none

e) Mark 52 System
   Director - Mark 52 Mod 3
   Gun Sight - Mark 15 Mod 3 (5"ballistics)
   Computer - Mark 13
   Radar - Mark 26 Mod 3

f) Mark 63 System
   Director - Mark 51 Mod 6
   Gun Sight - Mark 15 Mod 12 (40 mm HMG ballistics)
   Radar - Mark 28 Mod 2

g) Mark 57 System
   Director - Mark 57 Mod 1
   Computer - Mark 17 Mod 1
   Mark 15 Mod 1
   Radar - Mark 29 Mod 2 (until Dec '45)
   Mark 34 Mod 10(Dec '45 on)

D. Ships Concerned in the Test

1. These tests were conducted aboard the U.S.S. WYOMING (AG-17) during the period 27 July 1945 to 8 February 1946, in the waters of Casco Bay, Maine, and the offshore region of the Norfolk to Cape May areas. The data obtained by this ship forms the main body of the material which will be analyzed in this Study.

2. A number of other ships participated in these tests, but the data collected by them will be used only for purposes of support and comparison. The following is a partial list of these supporting ships:

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USS BREMERTON,	CA - 130
USS BUCKLEY,	DD - 808
USS TUCKER,	DD - 875
USS LEARY,	DD - 879
USS TWEEDY,	DE - 532
USS MCDOUGAL,	AG - 126

E. Observations

1. Number of Runs - The WYOMING conducted 262 firing runs against TD2C Drone targets. Two hundred and thirty-three of these runs (89%) furnished sufficiently reliable statistical data to warrant their inclusion in this analysis. The distribution of these runs among the various Fire Control systems investigated and the corresponding ammunition expenditures are given in Table I. The larger number of rounds per run shown for the 37-1 and 37-8 Systems reflects the fact that most of the firing with these systems was done with four, rather than two, barrels.

Table I. Distribution of Firing Runs Among the Various Fire Control Systems.

System		37-1	37-8	52	57	63	51 HMG	51-5"	51-5" *	51-HMG #	Total
No. of runs	T-at	10	9	7	7	6	6	8	2	4	59
	G-at	15	12	7	6	6	8	5	6	3	68
	T-ah	10	7	7	6	7	6	6	1	2	52
	G-ah	8	6	6	6	5	6	8	5	4	54
	Tot.	43	34	27	25	24	26	27	14	13	233
Total No. Rounds		2903	2007	859	731	634	451	523	281	169	8558
Rds/Run		67.5	59.0	31.8	29.2	26.4	17.3	19.4	20.1	13.0	36.7

* Using Fixed Range Setting of 2000 yds.
# Using Fixed Line of Sight (No lead angle)

2. Reasons for Discarding Runs - Of the 29 firing runs which had to be discarded only twelve could be classed as due to equipment casualty: one was a radar failure associated with the Mark 52 Fire Control System, two were mount casualties and the remaining nine were eliminated because the Mark 37-8 System was found to have been 15 minutes off in train after completion of the runs. Eleven runs could not be used because smoke obscured observation of hits or because one or more items had been omitted from the required data. A summary of runs discarded is given in Table II.

Table II. Causes for Eliminating Certain Firing Runs From the Analysis

Cause	Director System	No. of Runs Discarded
Inadequate data	Several	11
Director casualty	37-8	9
Mount casualty	37-1	2
Radar casualty	52	1
Poor drone maneuver	Several	4
Personnel failure	57	2

3. Record of Runs Made by Supporting Ships - The record of runs and ammunition expenditures by supporting ships was kept only for those instances in which the data was such that it could be used for comparing performance of any given Fire Control System among the several ships concerned. These details are given in Table III.

Table III. Distribution of Firing Runs Among the Various Supporting Ships

Ship		System 51		52		63		37-1		Total	
		Runs	Rds	Runs	Rds	Runs	Rds	Runs	Rds	Runs	Rds
BREMERTON	CA-130	1	21					18	525	19	546
BUCKLEY	DD-808	7	147			9	197	11	563	27	907
TUCKER	DD-875	2	31					14	575	16	606
LEARY	DD-879							8	398	8	398
TWEEDY	DD-532			8	143					8	143
MCDOUGAL	AG-126							9	486	9	486
	Total	10	199	8	143	9	197	60	2547	87	3086

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4. Record of Ammunition Normality - All 5"/38 VT fuzed non-fragmenting ammunition used was subjected to the V.T. Fuze performance tests in accordance with Bureau of Ordnance doctrine. When firing from a specific lot of ammunition had to be extended over a protracted period of time the performance tests were repeated. The record of such ammunition used in the runs available for statistical analysis is given in Table IV. It should be noted that in general the percentage of prematures observed in practice is nearly always less than the average shown in the tests of a given lot.

Table IV. Record of Ammunition Performance

Mark & Mod.	Lot Number	Amount used	Observed Prematures Number	Observed Prematures Percent	% Prematures Scored in Test
53 -	2195	558	46	8.2	7.0
53 -	2386	740	32	4.3	6.0
53 -	2171	439	24	5.5	12.0
53 -	2173	1794	180	10.0	24.0
53 -	2253	1707	101	5.9	14.0
53 -	2255	1582	115	7.3	6.0
53 - 6	2283	1822	100	5.5	7.0
53 - 6	2279	1120	81	7.2	6.0
53 - 6	2303	934	62	6.6	9.3
53 - 6	2351	399	56	14.0	20.0
Totals	(10)	11095	797	aver. 7.2	aver. 11.1

These totals do not include ammunition used in tests or in training firings at sleeve and TDD targets.

5. TD2C Drone Performance - While it was not always possible to obtain the same degree of weaving and jinking in consecutive runs, there was a high degree of similarity in the over-all relative amount of maneuvering of drones among the various Fire Control systems and among the four types of runs for a given system.

There was considerable fluctuation in the speed attained by the drone both during the approach run and from run to run. The average speed of the drone in glider-like approaches was 150 knots, while the average speed in torpedo-like runs was

130 knots. This difference is considered statistically significant. There was no significant difference between runs made at the ship and those made at an imaginary ship 750 to 1000 yards ahead of the firing ship.

6. Rate of Fire - The average rate of fire established by the WYOMING during 218 observed runs was 16.3 rounds per gun per minute. This rate varied from 7 to 26 r.p.g.p.m. with a standard deviation of 3.6 r.p.g.p.m. This average rate of fire was slightly more than 17 in the period preceding the last few weeks of firing. A frequency distribution plot illustrating this fluctuation is presented in Figure 1.

There was no significant difference in average rate of fire between the various Fire Control systems, between torpedo-like and glider-like runs, or between the runs directed toward and ahead of the firing ship.

7. Observation of V.T. Bursts - There was far better agreement between groups of observers reporting apparent target-triggered V.T. bursts (TTB's) than there was between the report of those observers and that established by photoanalysis. A good many T.T.B's were missed by the photographers because of smoke interference, vibration and shock which throws either the target or the burst out of the field of one camera, and other causes. It is considered that well trained teams of observers constitute the best available means of scoring results. Nevertheless, photo-analysis is often extremely valuable in supporting observer results in questionable cases.

A series of nearly 300 bursts in which the error in range, as determined by photo-triangulation, did not exceed 100 yards has been examined. The average radial error of these bursts is 37 feet. A histogram showing the frequency distribution of these radial errors is given in Figure 2. A plot of these bursts in a plane through the target perpendicular to the trajectory is given in Figure 3. These data are summarized in Table V.

Table V. Distribution of V.T. Bursts Whose Range Error As Determined by Photo-triangulation Does Not Exceed 100 Yards

Radial Error in feet	Elevation Error +	−	0	Total	Normal Distribution $\sigma = 30$ feet
0 - 20	19	32	8	59	56
20 - 40	62	52	4	118	110
40 - 60	29	35	0	64	77
60 - 80	13	16	1	30	30
80 - 100	1	5	0	6	7
over 100	2	2	0	4	1
Total	126	142	13	281	281
Percent	45	51	4	100	

It should be noted that 96.5% of these recorded bursts have a radial error of less than 80 feet. More bursts were obtained below the target than above it, this trend being reversed in one interval - the interval which contains the most bursts. In the right hand column of Table V are listed the expected number of bursts in each 20 ft. interval if the bursts were normally distributed about the target with a standard deviation of 30 feet.

In spite of the fact that phototriangulation methods for determining error in range yield values which are accurate only to within ± 50 yards, a frequency distribution of range errors for these V.T. bursts is given in Figure 4. The mean absolute error in range is 21.6 yards, and 97.2% of the bursts were within 80 yards of the target.

This photoanalysis data therefore strongly supports the original assumption that any V.T. burst with a range error not exceeding 100 yards and a radial error not exceeding 80 feet would be considered a target-triggered burst (T.T.B.).

F. Analysis of WYOMING Data

1. Method - The measure of effectiveness which is to be used in this analysis for estimating the performance of a particular Fire Control system is based on the number of hits obtained per effective round fired at the target. The methods employed

in analyzing the test data are given in detail in enclosures (A) and (B). The procedure, briefly, involves the following steps:

a) Conversion, by graphical means, of present ranges of open and cease fire to advanced ranges.

b) Calculation of the number of effective rounds fired into each 500 yard range interval from the data on open and cease fire ranges, normality of ammunition, time spent by the target in each range interval and, except where otherwise indicated, a rate of fire assumed to be uniform throughout the run.

c) Summation of these calculated figures for each Fire Control System by type of run, and computation of the number of target-triggered bursts (T.T.B.'s) per effective round for each 500 yard range interval.

d) Computation of the expected number of T.T.B.'s in each 500 yard range interval with a standard rate of fire, speed of target and normality of ammunition, so that various Fire Control systems may be compared.

e) Calculation of probabilities either of obtaining at least one hit on a TD2C or of splashing a target with guns under a given Fire Control system.

2. Number of Target-triggered Bursts (T.T.B.'s) per Run per Barrel - In the 188 standard firing runs conducted during this test an average of approximately one TTB per run per barrel was obtained. This number varied from 0 to 4 with a considerable amount of scatter for all Fire Control systems. A frequency distribution table illustrating this fluctuation is given in Figure 5. There was no significant difference in the average number of T.T.B.'s per run per barrel obtained with the various Fire Control systems, or between torpedo-like and glider-like runs. There was, however, a significant difference in the average number of T.T.B.'s scored in runs made at the ship and at an imaginary ship 750 to 1000 yards ahead of the firing ship, approximately twice as many T.T.B.'s per run per barrel being scored on "at" as on "ahead" runs.

3. Number of Target-triggered Bursts (TTB's) per Effective Round Fired in Each 500 Yard Range Interval - The average number of TTB's per effective round fired in each 500 yard range interval for the various fire control systems is given in Table VI. The results are plotted in Figure 6 after combining data for similar systems.

Table VI. Number of Target-triggered Bursts Per Effective Round Fired in Each 500 yard Range Interval.

Range in 100's of yards	Fire Control System							
	37-1	37-8	52	57	63	51-HMG	51-5"	Average
5 - 10	.058	.050	.243	.225	.382	.274	.291	.218
10 - 15	.205	.125	.144	.250	.257	.296	.262	.220
15 - 20	.088	.148	.192	.152	.187	.068	.229	.152
20 - 25	.083	.127	.056	.143	.256	.150	.142	.129
25 - 30	.066	.054	.013	.114	.068	.085	.039	.063
30 - 35	.049	.058	.000	.016	.056	.122	.161	.066
35 - 40	.010	.013	.000	.068	.018	.400	.047	.079
40 - 45	.030	.050	.051	.043	.040		.000	.036
45 - 50	.010	.000	.000	.027	.072		.000	.018
50 - 55	.043	.000	.000	.000	.000		.000	.007
55 - 60	.012	.010	.000	.000	.000		.000	.004
60 - 65	.000	.018	.000	.000				.004
65 - 70	.000	.033	.092					.031
70 - 75	.000	.000						.000
75 - 80	.020	.000						.010
80 - 85	.000	.000						.000
85 - 90	.000	.000						.000
90 - 95	.000							.000

In Spite of the lower performance of the two Mark 37 Fire Control systems in the range interval 500 - 1000 yards, it can be seen in the above table and in Figure 6 that the average number of T.T.B.'s per effective round fired in each range interval in general decreases rapidly with increasing range. Usually, less than one percent of the effective rounds fired at ranges beyond 5000 yards were triggered by the maneuvering TD2C drone, and none were so triggered at ranges in excess of 8000 yards.

4. <u>Probability of Scoring at Least One Target-triggered Burst (TTB) on a Maneuvering TD2C Drone with one Barrel Fire</u> - This measure of effectiveness has been calculated for each Fire Control system according to type of target approach

(at and ahead runs) and overall performance (all runs combined). These calculations were extended to each of the four types of run made with each Fire Control system but since no statistically significant differences could be established with such small samples the individual results are omitted from this Study. The results of the other calculations are presented in Figures 7 to 25.

Each of the above figures shows the curve of accumulated probability of scoring at least one T.T.B. on an approaching and actively maneuvering TD2C drone target, with one barrel firing under the control of a particular Fire Control system and under the following conditions:

Rate of Fire: 17 rds/bbl/min.

Ammunition
Type : 5"/38 V.T. fuzed
Normality : 0.75

Target Speed
"T" Runs : 130 knots
"G" Runs : 150 knots

The degree of statistical reliability for each point on a curve is indicated by a vertical line extending above and below the point. The average advanced range of open fire is given at the beginning of each curve.

Certain similarities and differences between Fire Control systems and between types of target approaches become evident in a study of these curves. A few of these are indicated in the following notes:

a) The Mark 37-1 System (Figures 7 and 8) - The curve of accumulated probability (all runs) rises at a fairly uniform rate to a range of around 1500 yards after which the rate drops off fairly rapidly. When runs made at the ship are compared with runs made ahead of the firing ship, the accumulated probabilities show a marked and statistically significant difference throughout the firing range.

b) The Mark 37-8 System (Figures 9 and 10) - The curve of accumulated probability (all runs) shows a general resemblance to that of the Mark 37-1 System. There is no consistently significant difference in the accumulated probability curves for at and ahead runs.

c) The Mark 57 System (Figures 11 and 12) - The curve of accumulated probability (all runs) rises at an almost constant rate. The change in rate at the shorter range, as shown in the Mark 37 systems, is not apparent here. The curves for at and ahead runs are almost identical.

d) The Mark 63 System (Figures 13 & 14) - The curve of accumulated probability (all runs) follows very closely that of the Mark 57 system. There is no consistently significant difference in the curves for at and ahead runs.

e) The Mark 52 System (Figures 15 & 16) - The steep rise shown here in the curve of accumulated probability (all runs) reflects the high score in T.T.B's per effective round obtained with this system at ranges less than 2000 yards compared with the very low score at ranges greater than 2000 yards. There is a statistically significant difference in the at and ahead run curves of probability, but this should be interpreted with considerable caution. The low score on ahead runs is due entirely to the poor performance of this system on "T ahead" runs: a total of only 4 T.T.B.'s having occurred out of 188 effective rounds fired in these six runs.

f) The Mark 51-HMG System (Figures 17 & 18) - The curve of accumulated probability (all runs) rises steeply and with almost no change of slope. When the curves for at and ahead runs are compared there is a statistically significant difference between them but only at ranges of less than 1500 yards.

g) The Mark 51-5" System (Figures 19 & 20) - The curve of accumulated probability (all runs) resembles that of the Mark 51-HMG system but there is a slight flattening in the slope at ranges less than 1300 yards approximately. There is no statistically significant difference between the curves for at and ahead runs.

h) Mark 51-5" System Using a Pre-set Fixed Range of 2000 yards - (Figure 21) The curve of accumulated probability (all runs) for this special data is presented in Figure 21. There were too few target-triggered bursts on ahead runs to warrant statistical comparison of at and ahead runs.

i) Comparison of Fire Control System Performance - On the basis of the above analysis a series of preliminary conclusions on the comparative performance of the various Fire Control Systems can be reached. These will be discussed in terms of performance on all runs combined and of performance on runs made at and ahead of the firing ship.

i(1) Overall Performance (Figures 22 and 23, all runs combined) - There is no consistent, statistically significant difference in the performance of the Fire Control systems Marks 57, 63, 51-5" and 51-HMG in the control of 5"38 V.T. fuzed non-fragmenting ammunition fire at actively maneuvering TD2C drone targets other than that of the maximum range at which target triggered bursts (T.T.B.'s) first occur, (Figure 22).
There is no statistically significant difference in the performance of Mark 37-1 and Mark 37-8 Systems nor in the performance of these two systems when compared with the performance of the systems Marks 57, 63, 51-5" and 51-HMG at ranges of 2000 or more yards. At shorter ranges than this the two Mark 37 systems show a less efficient performance than that of the other systems named and the difference is statistically significant. The performance of the Mark 52 system at ranges greater than 1500 yards is significantly inferior to that of any other system, but its capacity to score T.T.B's at shorter ranges is quite high. (Figure 23).
When a fixed range of 2000 yards is pre-set into the Mark 51-5" the record of performance of this system is reduced to approximately one-half (Figure 22). No T.T.B.'s were scored with the Mark 51-HMG system in the 13 runs during which it was operated with a fixed line of sight (no lead angle).

i(2) Performance on "At" Runs (Figure 24) - There is no significant difference between all the Fire Control systems tested in their performance against a TD2C drone making its approach directly at the firing ship.

i(3) Performance on "Ahead" Runs (Figure 25) - In their performance against TD2C drones making their approach at an imaginary ship 750-1000 yards ahead of the firing ship, the Fire Control systems tested fall into three general groups. The highest type of performance occurs with the Marks 51-5",57, 63, and 37-8 systems, and there is no significant difference between them. The Mark 51-HMG does less well at ranges under 2000 yards. Performance on these runs is least good with the Mark 37-1 and Mark 52 and the difference between these systems and the others tested is significant at ranges of 2500 yards or less.

5. The Probability of Splashing a Typical Operational Target With One Barrel Firing -

a) The previous comparison of fire control systems was based upon the probability of obtaining at least one T.T.B. on the maneuvering TD2C drone target with one barrel firing at the rate of 17 rounds per minute. Another comparison is that based upon the probability of splashing a typical operational target with one barrel firing. Although the results obtained with this method of comparison may not differ from the results obtained with the previous method in sense, differences among the various fire control systems should be more apparent.

In order to convert T.T.B.'s on the drone into lethal bursts on an operational target, it is necessary to assume some value for α, the probability that a T.T.B. on the drone will be a lethal burst on the operational target. In comparing the performances of various fire control systems any reasonable value of α may be used, the resulting comparison being valid for the particular target vulnerability characterized by this value of α. Since it is generally believed that on the average three or four target-triggered bursts were required to splash a typical operational target in World War II, a value of $\alpha = 0.25$ will be used in making this comparison.

The value $\alpha = 0.25$ checks well with the values of α derived in Appendix A of enclosure (A) from measured values of the burst area and the lethal area of the 55 lb. VT-fuzed projectile against an operational target, at ranges of 3000 yards or less and for a shooting error of the magnitude to be expected with a maneuvering target. Although it is shown in enclosure (A) that α may be expected to vary with range, little error will be introduced by assuming a constant value of α since most of the T.T.B.'s were scored at 3000 yards or less. Although more T.T.B.'s are to be expected against an operational target than against the drone target, most of these additional bursts will occur at large distances from the target and hence will contribute little to the lethal area.

b) Using $\alpha = 0.25$ and target speeds equal to the speeds of the drone targets used in the tests, the probability that an operational target will be splashed before it reaches a given range from the firing ship by the gunfire from one barrel firing at a standard rate as controlled by various fire control systems was computed. The results are presented in Figures 26, 27, and 28. As was to be expected, the rankings of the various fire control systems remain unaltered but the relative differences are larger. As α decreases, the ratio of two probabilities of splashing approaches the corresponding ratio of the expected numbers of target-triggered bursts presented below.

c) The results presented in part 4 above may be interpreted as the probability of splashing the target with 4 barrels firing if $\alpha = 0.25$.

6. <u>Expected Number of T.T.B.'s with One-Gun Fire.</u>-

a) The probabilities presented in parts 4 and 5 above were computed from the formula

$$P = 1 - e^{-H}$$

If H is the expected number of T.T.B.'s, then P is the probability of scoring at least one T.T.B. If H is the expected number of lethal bursts, P is the probability of splashing the target. A comparison of fire control systems in terms of the exponent H is of interest and for many purposes is more informative than the previous comparisons. For example, if the expected number of T.T.B.'s with one system is twice that with a second system, twice as many barrels must be controlled by the second system as by the first system to obtain the same probability of splashing the target.

b) The expected number of T.T.B.'s with one barrel firing is plotted in Figures 29 and 30 for the various fire control systems. As before, the results are cumulative, that is, the value shown for a given range is the expected number of T.T.B.'s by the time the target has approached to that range. Although the differences between fire control systems appear larger here than in the corresponding probabilities presented in part 4, the remarks made in part 4 concerning the statistical reliability of the differences still apply.

G. Analysis of Data Contributed by Supporting Ships

1. Limitations - The information submitted by ships other than the WYOMING was necessarily less exact and less complete than could be provided by the more experienced gunnery and photography staff of the larger ship. A fair portion of the shooting was done without photographic recording and the number of runs made by each ship for the various fire control systems was, of course, quite limited. Within the above limitations the data does furnish some interesting comparisons, but because the statistical sample is small the results of analysis should be treated only as indications, as trends or as tendencies.

2. Comparative Performance of the Mark 37-1 Fire Control System - Figure 31 shows the curves of accumulated probabilities of scoring at least one T.T.B. on a maneuvering TD2C drone for each supporting ship and for the all-run performance of this system on the WYOMING. The number of runs made by each ship is given below the name of that ship. The run-to-run variation and the smaller number of runs for any given system makes the exact placement of the probability curve far more difficult than is the case with the WYOMING runs. Some of the differences in performance of various ships is nevertheless significant. The BREMERTON's Mark 37-1 performed very well at ranges of 3000 yards or less, while that of the LEARY and the MCDOUGAL was decidedly inferior to the WYOMING's at very short ranges. Performance of this system on the BUCKLEY was distinctly poor throughout its range of operation. The TUCKER, whose data presented the least amount of run-to-run variation, has a Mark 37 probability curve most nearly resembling that of the WYOMING. The curve for the WYOMING is close to the average for all ships.

3. Performance of the Mark 52 Fire Control System on the TWEEDY - The curve of accumulated probability of scoring at least one T.T.B. with the Mark 52 Fire Control system aboard the TWEEDY is based on only 8 runs all of the G-at type, (Figure 32). This is undoubtedly a very small sample upon which to base an estimate of overall performance, but it is very different from that obtained for the WYOMING's Mark 52 either in all-runs combined or on G-at runs only. This tends to support the previous warning about the need for caution in interpreting the results obtained with the Mark 52 System on the WYOMING.

4. Performance of the Mark 63 Fire Control System on the BUCKLEY (Figure 33) - In contrast to the results shown in Figure 32 for the Mark 52 system, the performance of the Mark 63 system on another ship, the BUCKLEY, is decidedly inferior to that obtained with a similar system on the WYOMING. A comparison between the performances of the Mark 52 and Mark 37-1 systems aboard the BUCKLEY (Figures 31 and 33) shows no statistically significant difference between the two systems. The record of performance of this equipment on the Buckley, therefore, seems to invite comparison not of systems but of installation, of method or of personnel performance.

5. Performance of the Mark 51 Fire Control System - Several ships furnished data on the performance of this system in controlling fire against TD2C drones but the number of runs for any one ship is so small and the run to run variation so large that significant comparisons cannot be made even on pooled data.

6. Conclusions - The most significant conclusion which can be based on this analysis of Supporting Ship data is that there is a large amount of variation in the performance of a given type of Fire Control system on different ships. Therefore, if valid comparisons are to be made in the performance of a given system on different ships the runs must be repeated until the results become consistent and homogeneous. It would appear as corollary to this that if the performance of a new system is to be determined aboard any ship it should be compared with the performance of an established system aboard that ship, and the amount of data required will depend upon the variation from run to run for each of the two systems being tried. A great wealth of very reliable data has been gathered aboard the WYOMING by constant

repetition of runs. If the performance of a given system is to be used as a standard for comparison by other ships it should likewise be based on adequate data.

H. Analysis of WYOMING Data in Terms of Changes in Variables.

1. Typical AA Fire Control System - It is of interest to estimate the effect to be expected upon the probability of splashing a target of changes in various factors, such as the number of barrels or the target speed. Instead of making such analyses for each fire control system, the analyses are made for a typical AA fire control system. The performance of this typical system is taken as the average performance of the Mark 57 and Mark 63 Systems aboard the WYOMING. The number of T.T.B.'s per effective round for this average system is plotted in Figure 34, and is seen to be greater in general than the corresponding values for the average of all systems aboard the WYOMING shown in Figure 6.

2. Variables Considered - The variables considered are the following:

- a) Overall rate of fire.
  - (i) Number of barrels
  - (ii) Rate of fire per barrel
- b) Target Characteristics
  - (i) Speed
  - (ii) Vulnerability

The effect of changes in the above factors can be estimated from the theory of enclosure (A). Another factor which might be considered is the initial velocity of the projectile. The effect of a change in this quantity is difficult to estimate and will not be included here; it will be the subject of a later study.

3. Overall Rate of Fire. - The effect to be expected upon the probability of splashing a target of a change in the number of barrels or in the rate of fire per barrel or both depends upon the resulting change in the overall rate of fire. Thus, doubling the number of barrels will have the same effect upon the probability of splashing as doubling the rate of fire per barrel.

The probability of splashing a maneuvering target traveling at the average speed of the TD2C drone if the probability is 0.25 that a T.T.B. on the drone is a lethal burst on the target is shown in Figure 35 for various numbers of barrels firing. It is assumed that each barrel is firing ammunition of 0.75 normality at a rate of 17 rounds per minute.

The results shown in Figure 35 have been computed for a target velocity which is low compared with the velocities which are to be expected in the future or even the velocities which are possible now. The probability of splashing a maneuvering target, of the same vulnerability as before but flying at 500 knots, is shown in Figure 36 for various overall effective rates of fire. The overall effective rate of fire is the overall rate of fire multiplied by the ammunition normality. The rates used in Figure 36 are equivalent to 4, 8, and 12 barrels firing ammunition of 0.75 normality at a rate of 17 rounds per minute per barrel. The assumption upon which the computation is based is discussed below.

4. <u>Target Velocity and Vulnerability</u>. The results shown in Figure 36 for a target velocity of 500 knots have been computed upon the assumption that the number of T.T.B.'s per effective round is independent of target velocity; that is, it has been assumed that an increase in target velocity decreases the number of rounds which can be fired into each range interval but has no effect upon the accuracy of fire. This assumption is discussed in enclosure (A) where it is pointed out that the assumption is supported by operational data. If the amount of possible evasion is limited by the amount of acceleration which the pilot or the airframe can withstand, the error due to evasion will be independent of target velocity. The tracking errors would be expected to increase with an increase in target velocity. However, since the error due to evasion probably is much larger than any other error for a maneuvering target, the probabilities of splashing obtained from this assumption should be reasonably correct, although somewhat large.

It should be pointed out here that it has been assumed also that the guns can follow the gun orders at all target velocities. This latter assumption may not be valid, especially at short and intermediate ranges when the target is flying a passing course at a high velocity. Thus, the probabilities presented in Figure 36 may be much too large at ranges less than 3000 yards for a passing course.

The effect of target velocity upon the probability of splashing also is presented in Figure 37 along with the effect of target vulnerability. The curves were drawn for a target velocity of 300 knots and values of α equal to 0.4, 0.2, and 0.1, showing the effect of decreasing the target vulnerability. The top curve, which was drawn for v = 300 knots and α = 0.4, is approximately the same curve which would have been obtained for v = 150 knots and α = 0.2. Similarly, the bottom curve is approximately correct for v = 600 knots and α = 0.2. Then, with α = 0.2 the effect of target velocity is shown by these curves.

5. Limitations. The material presented in this section is somewhat conjectural but is based upon reasonable assumptions. However, it should be viewed only as an indication of the expected performance of one of the later anti-aircraft fire control systems when operated by adequately trained personnel using radar ranging and optical tracking under good visibility conditions.

I. Conclusions.

1. Partial conclusions have been given at various places throughout the report. These conclusions are summarized here.

2. The following conclusions concerning the performances of various fire control systems in controlling 5"38 guns firing V.T. fuzed ammunition against an actively maneuvering TD2C drone target have been reached:

a) Overall Performance - There is no consistent, statistically significant difference in the performance of the Fire Control Systems Marks 57, 63, 51-5" and 51-HMG other than that of the maximum range at which T.T.B.'s first occur. There is no statistically significant difference in the performance of Mark 37-1 and Mark 37-8 Systems nor in the performance of these two systems when compared with the performance of the systems Marks 57, 63, 51-5" and 51-HMG at ranges of 2000 or more yards. At shorter ranges than this the two Mark 37 systems show a less efficient performance than that of the other systems named and the difference is statistically significant. The performance of the Mark 52 system at ranges greater than 1500 yards is significantly inferior to that of any other system, but its capacity to score TTB's at shorter ranges is quite high. When a fixed range of 2000 yards is pre-set into the Mark 51-5" the performance of this system is markedly inferior to its performance when operated with variable range setting.

b) Performance on "At" Runs - There is no significant difference between all the fire control systems tested in their performance against a TD2C drone making its approach directly at the firing ship.

c) Performance on "Ahead" Runs - In their performance against TD2C drones making their approach at an imaginary ship 750-1000 yards ahead of the firing ship, the fire control systems tested fall into three general groups. The highest type of performance occurs with the Marks 51-5", 57, 63, and 37-8 systems, and there is no significant difference between them. The Mark 51-HMG does less well at ranges under 2000 yards. Performance on these runs is least good with the Mark 37-1 and Mark 52 and the difference between these systems and the others tested is significant at ranges of 2500 yards or less.

d) Performance on Supporting Ships - The data from supporting ships was erratic. The amount of variation of the performance of a given type of fire control system on different ships was much greater than the amount of variation of the performance of the various fire control systems aboard the WYOMING.

3. Other conclusions are as follows:

a) There was no significant dependence of the rate of fire per barrel upon the fire control system, the course of the target, or the type of run. However, the run-to-run variation was large.

b) The use of trained observers stationed in various parts of the firing ship, plus the supporting evidence of photographs, is an accurate means of recording data. The cameras sometimes missed bursts or the target, but proved valuable in settling questionable cases.

Submitted by:
G. R. Pomerat sam.
G. R. POMERAT
OEG
J. M. Dobbie dam.
J. M. DOBBIE
OEG

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OFFICE OF THE CHIEF OF NAVAL OPERATIONS
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Op-34H8-vt
(SC)S71-3

1 October 1946

Serial: 0765P34

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From: Chief of Naval Operations.
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Cont… rcraft Fire.

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Addendum To OEG Study No.264

Subject: Effectiveness of Director Mark 52 in Controlling 5"/38 Antiaircraft Fire.

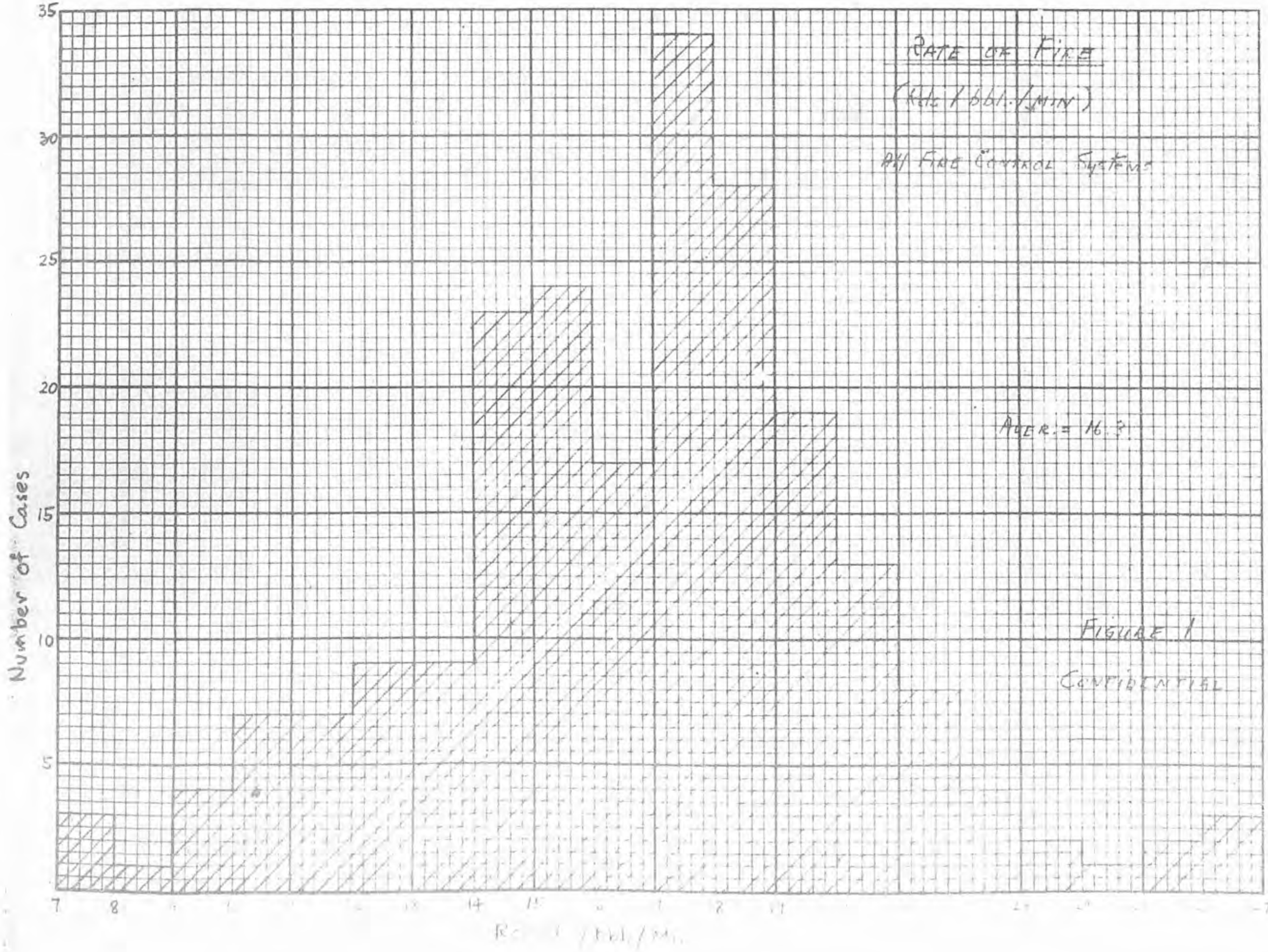
Reference: (a) OEG Study No. 264, "Analysis of Test Data for Comparison of Various Antiaircraft Fire Control Systems", Confidential, dated 2 April 1946.
(b) ComOpDevFor Confidential File S71-3 Serial 0251, "Effectiveness of Director Mark 52 in Controlling 5"/38 Antiaircraft Fire", dated 27 July 1946.

1. In reference (a) the Director Mark 52 was reported to be the least effective system of the various systems tested by OpDevFor controlling 5"/38 fire. The differences between the effectiveness of the Director Mark 52 and that of the Directors Mark 51 and Mark 63 were difficult to explain. After reference (a) had been issued the reason for the poor performance of the Director Mark 52 was found and reported in reference (b).

2. Almost two-thirds of the runs with the Director Mark 52 were made with the Gunsight Mark 15 Mod. 3 Serial 993 after a casualty to the Gunsight Mark 15 Mod. 15 Serial 5290. All Gunsights Mark 15 Mods. 2 and 3 were defective and are to be corrected by ORDALTS 2260 and 2359. However, neither of these ordalts had been applied to the sight used in the tests before the tests were conducted. When the test data are separated according to the sight used, the performance of the Director Mark 52 with the Mod. 15 sight is better than that with the Mod. 3 sight by a factor of at least two.

3. The results reported in reference (a) for the Director Mark 52 should be disregarded. The results of further tests with this director using a Gunsight Mark 15 Mod. 15 will be issued by ComOpDevFor in the third and successive partial reports on Project Op/S60/S71-3.

J. M. DOBBIE,
Operations Evaluation Group.



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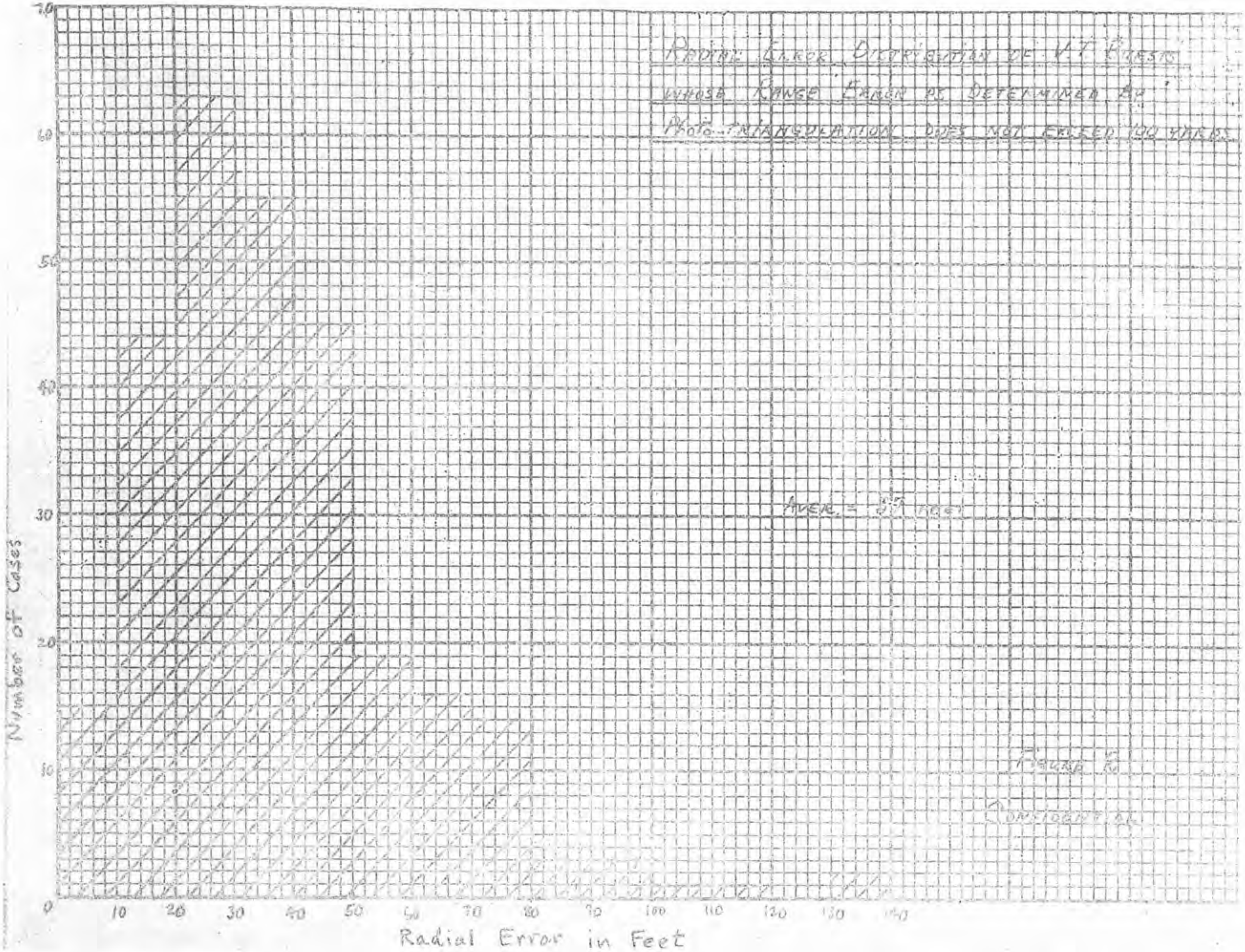

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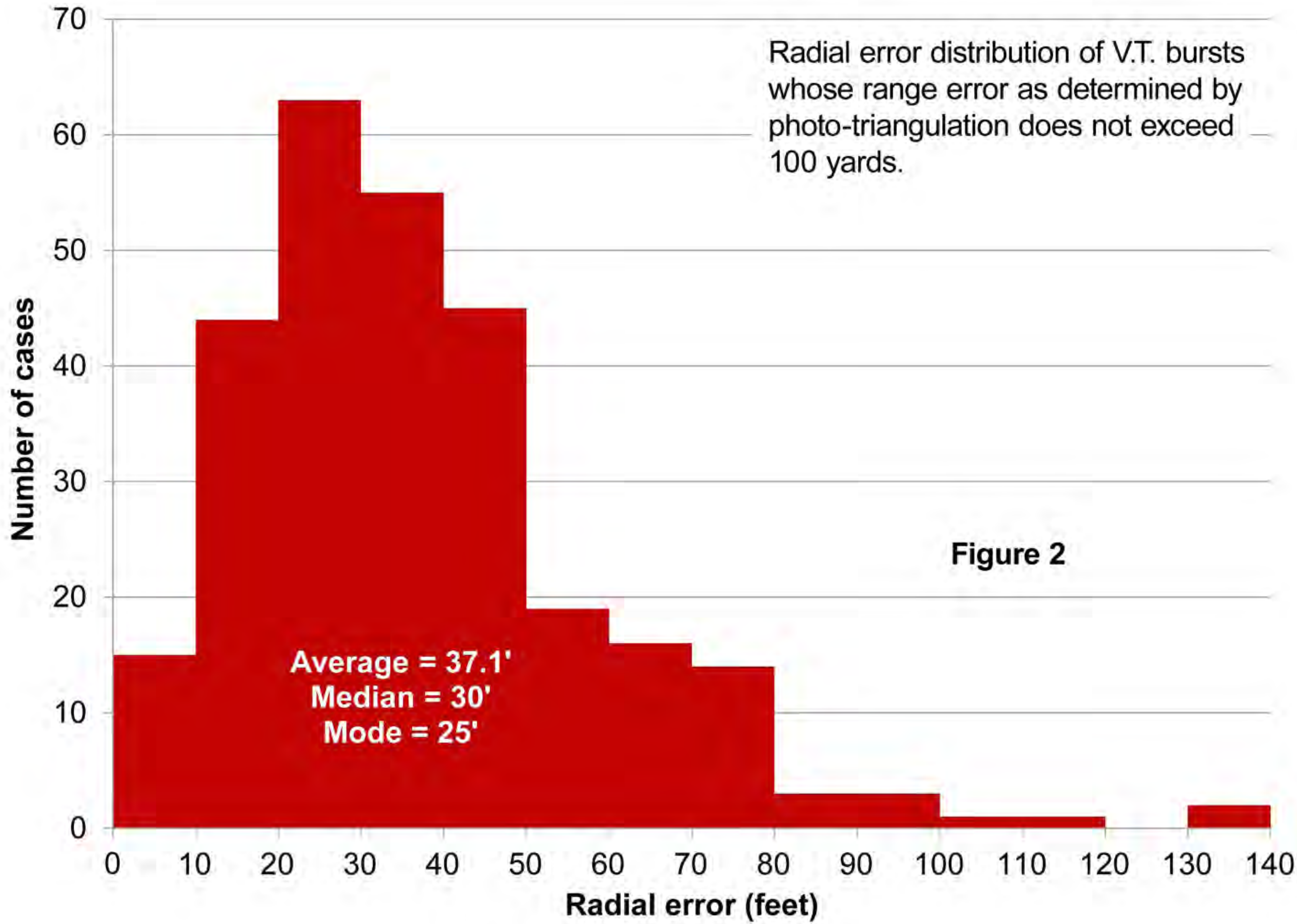
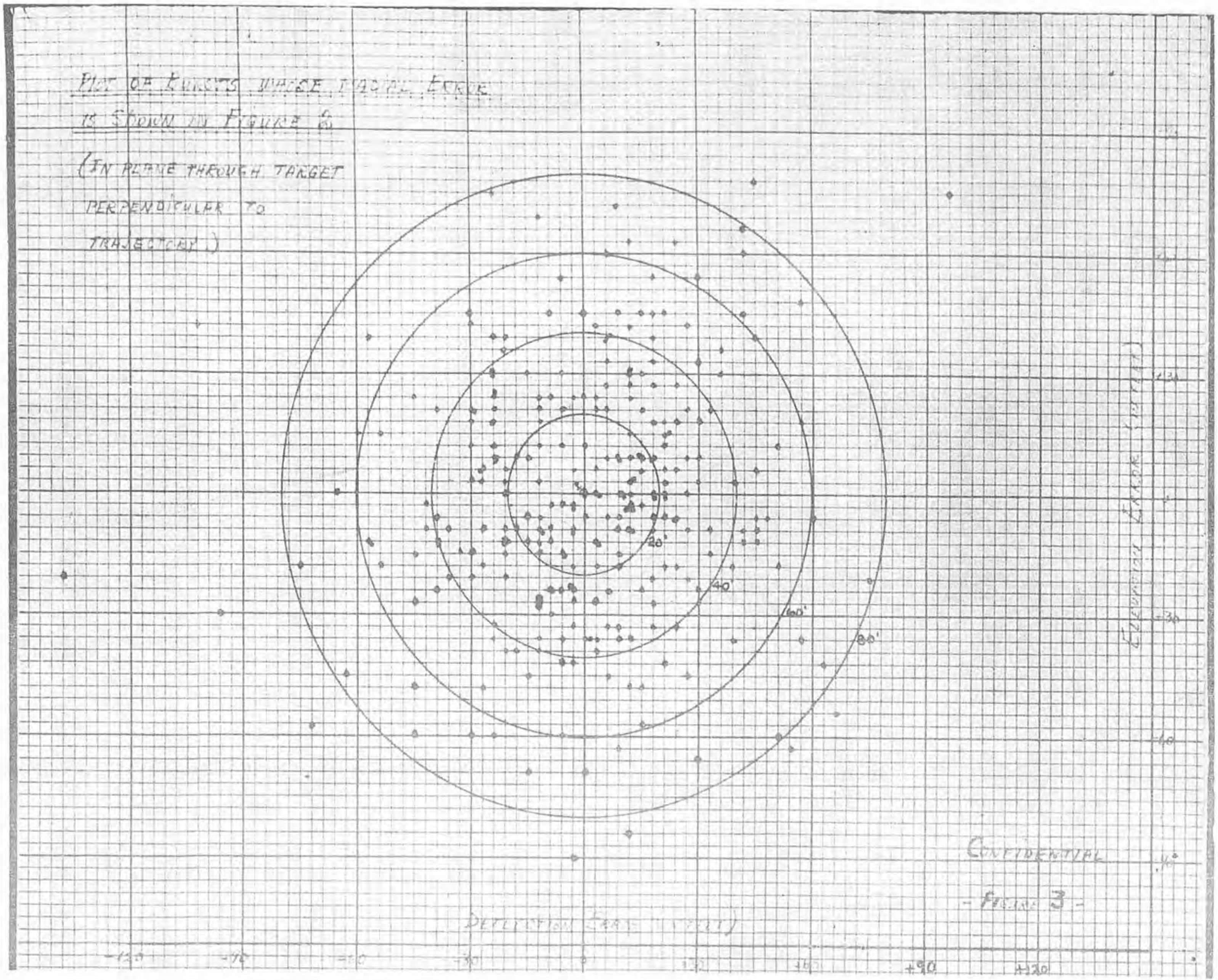

Radial error distribution of V.T. bursts whose range error as determined by photo-triangulation does not exceed 100 yards.
Figure 2
Average = 37.1'
Median = 30'
Mode = 25'
Number of cases
0
10
20
30
40
50
60
70
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
Radial error (feet)



PLOT OF BURSTS WHOSE RADIAL ERROR
IS SHOWN IN FIGURE 2
(IN PLANE THROUGH TARGET
PERPENDICULAR TO
TRAJECTORY)
20'
40'
60'
80'
+90
+120
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- FIGURE 3 -

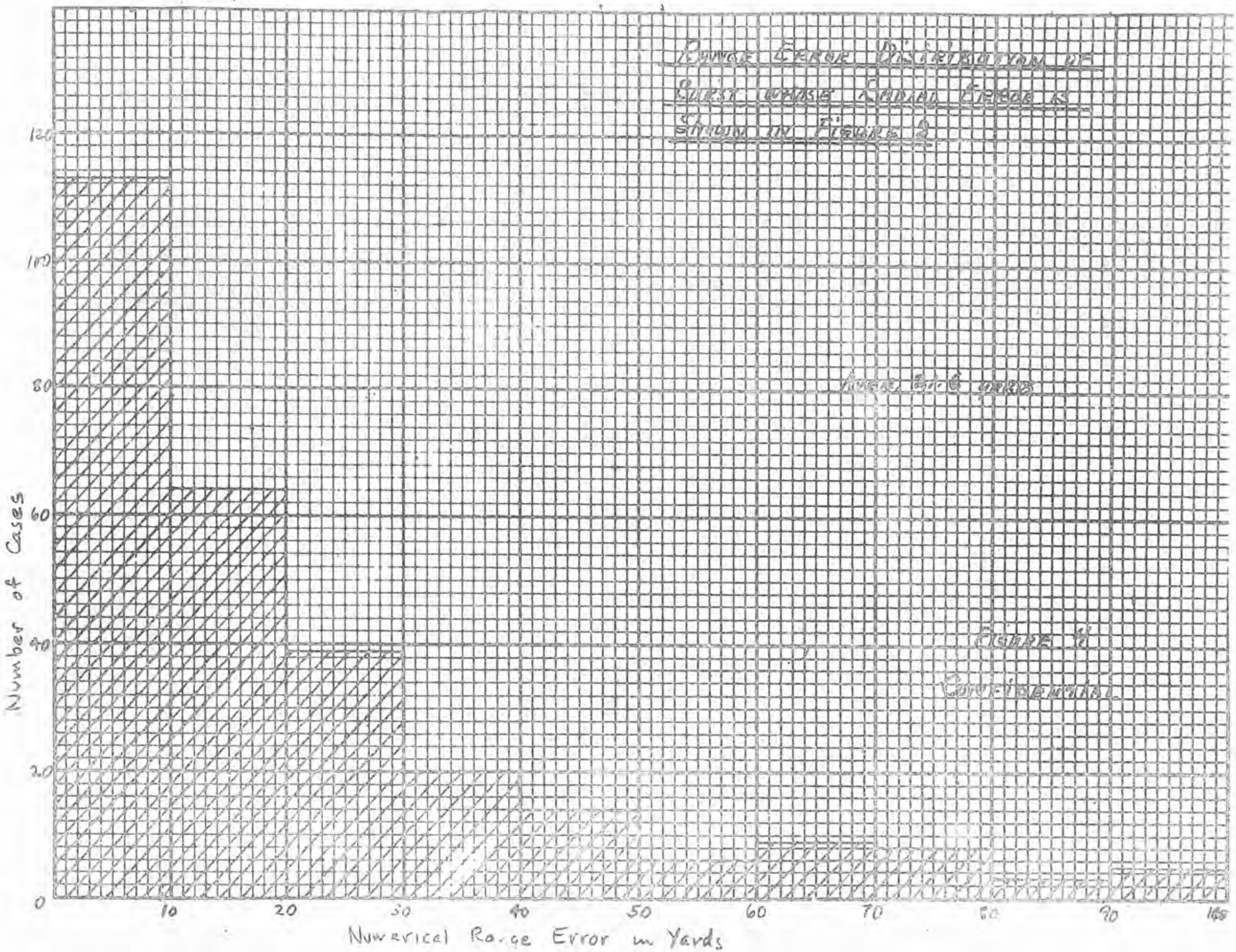

Figure 4

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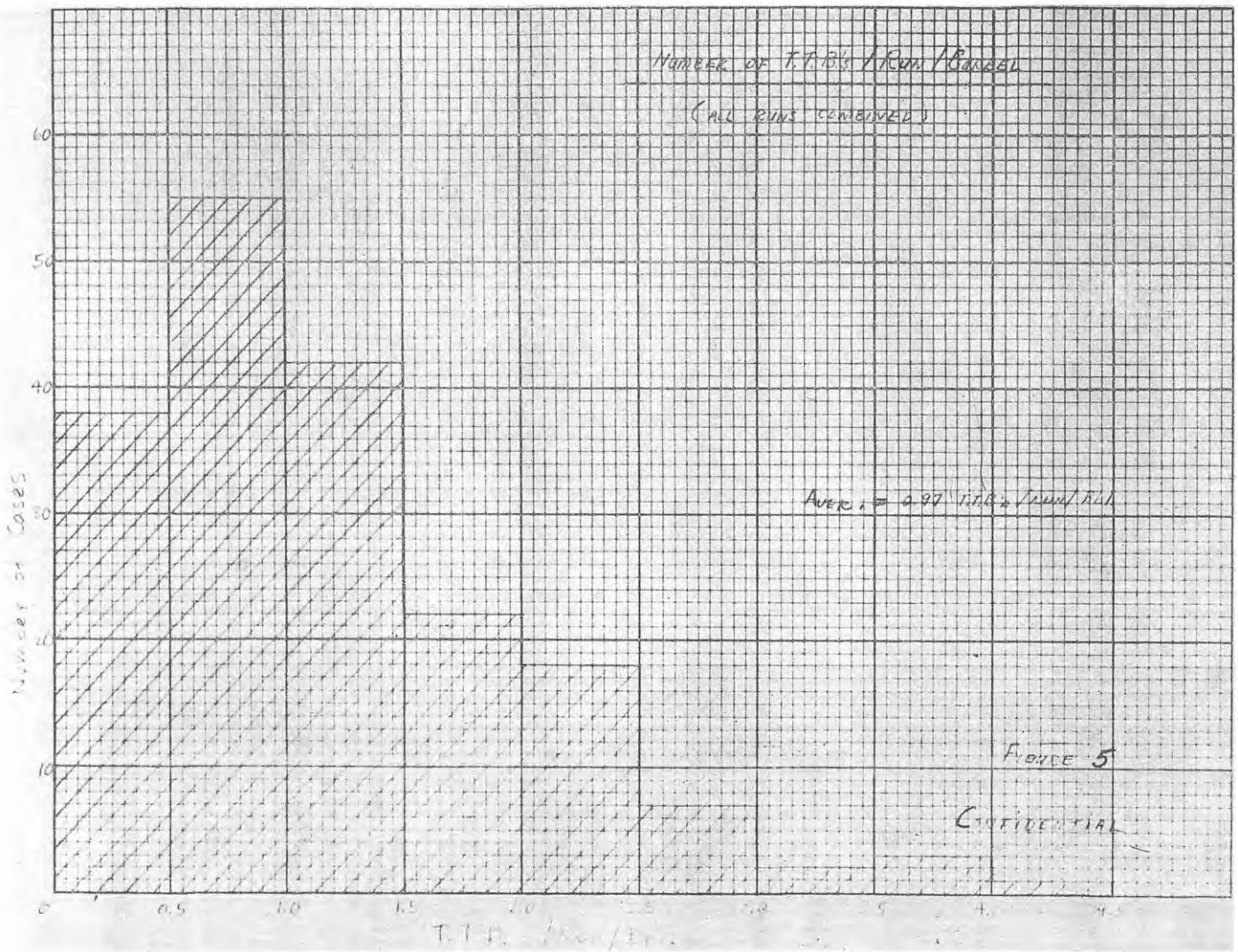
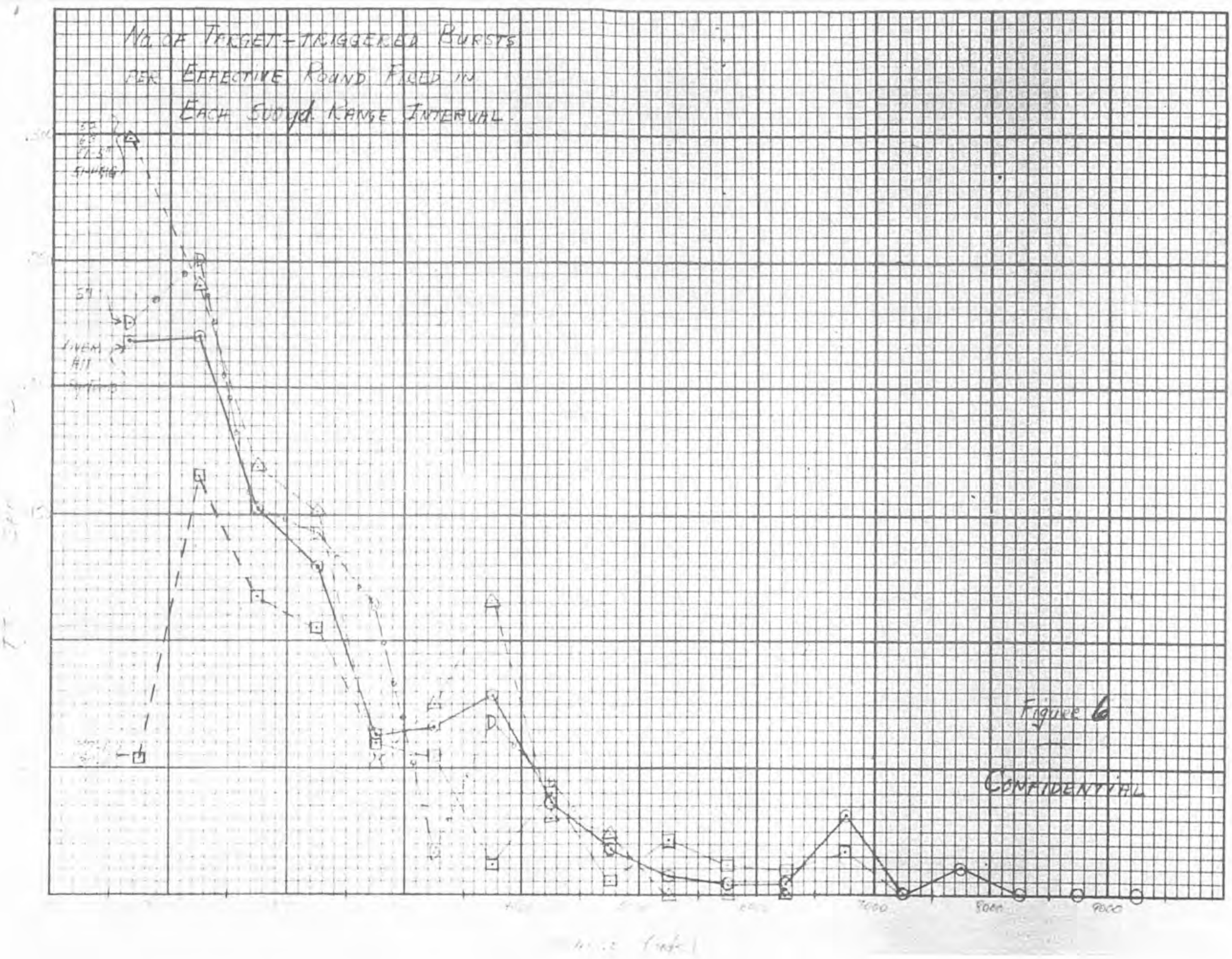

NUMBER OF T.T.B.'s /RUN /BARREL
(ALL RUNS COMBINED)
AVER. = 0.97
60
50
40
30
20
10
0
0.5
1.0
1.5
2.0
2.5
3.0
4.0
4.5
FIGURE 5



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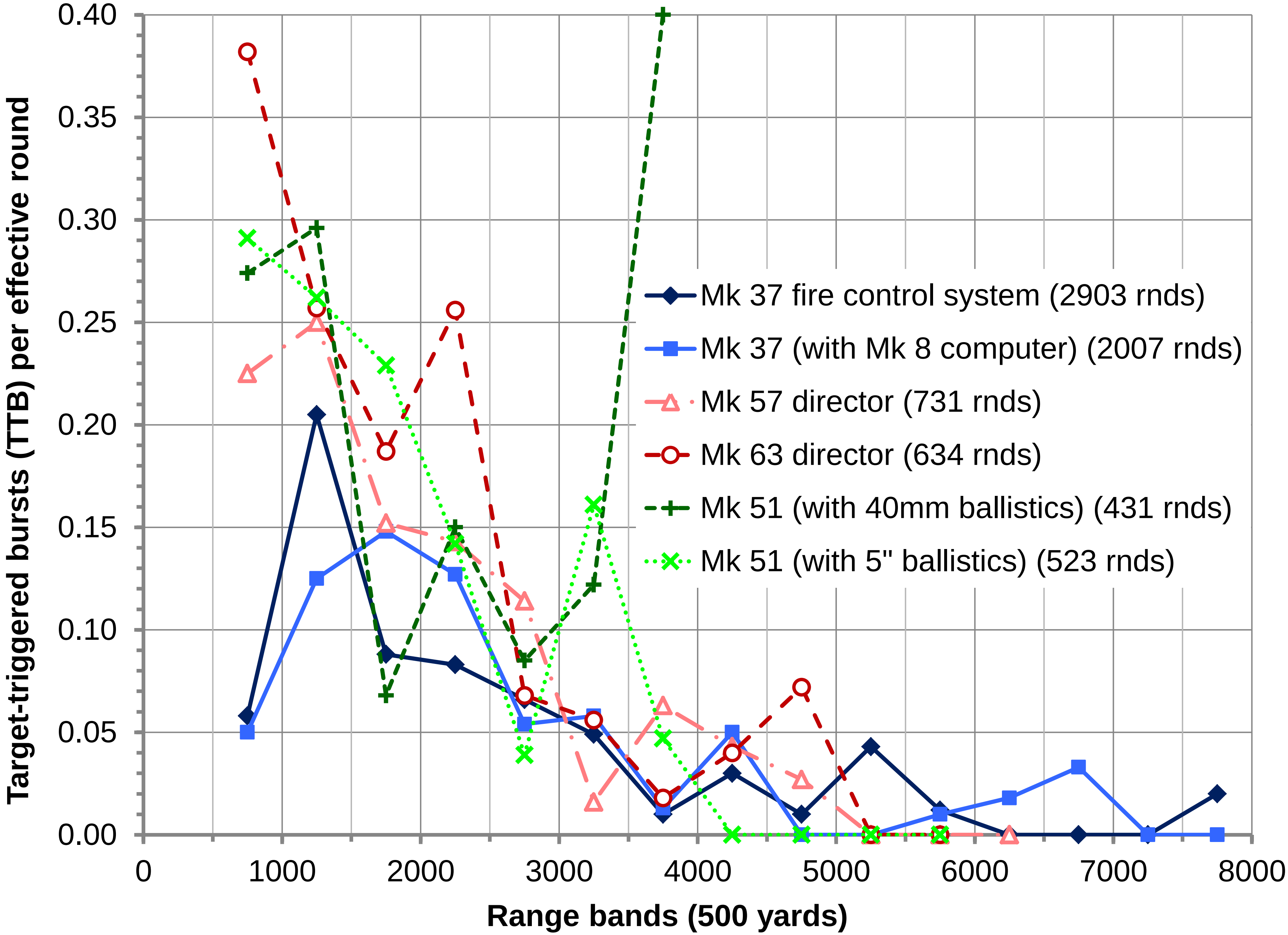
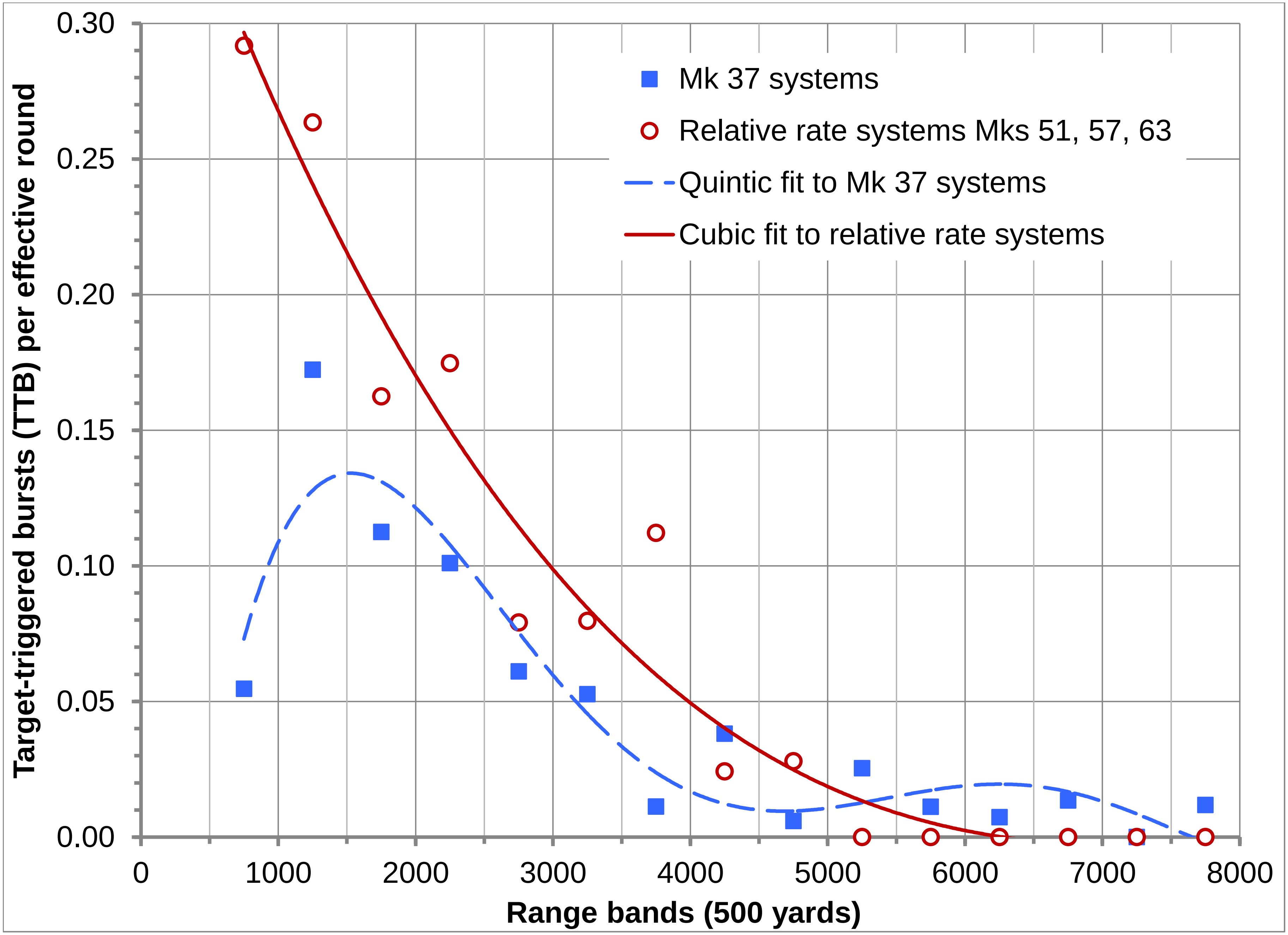
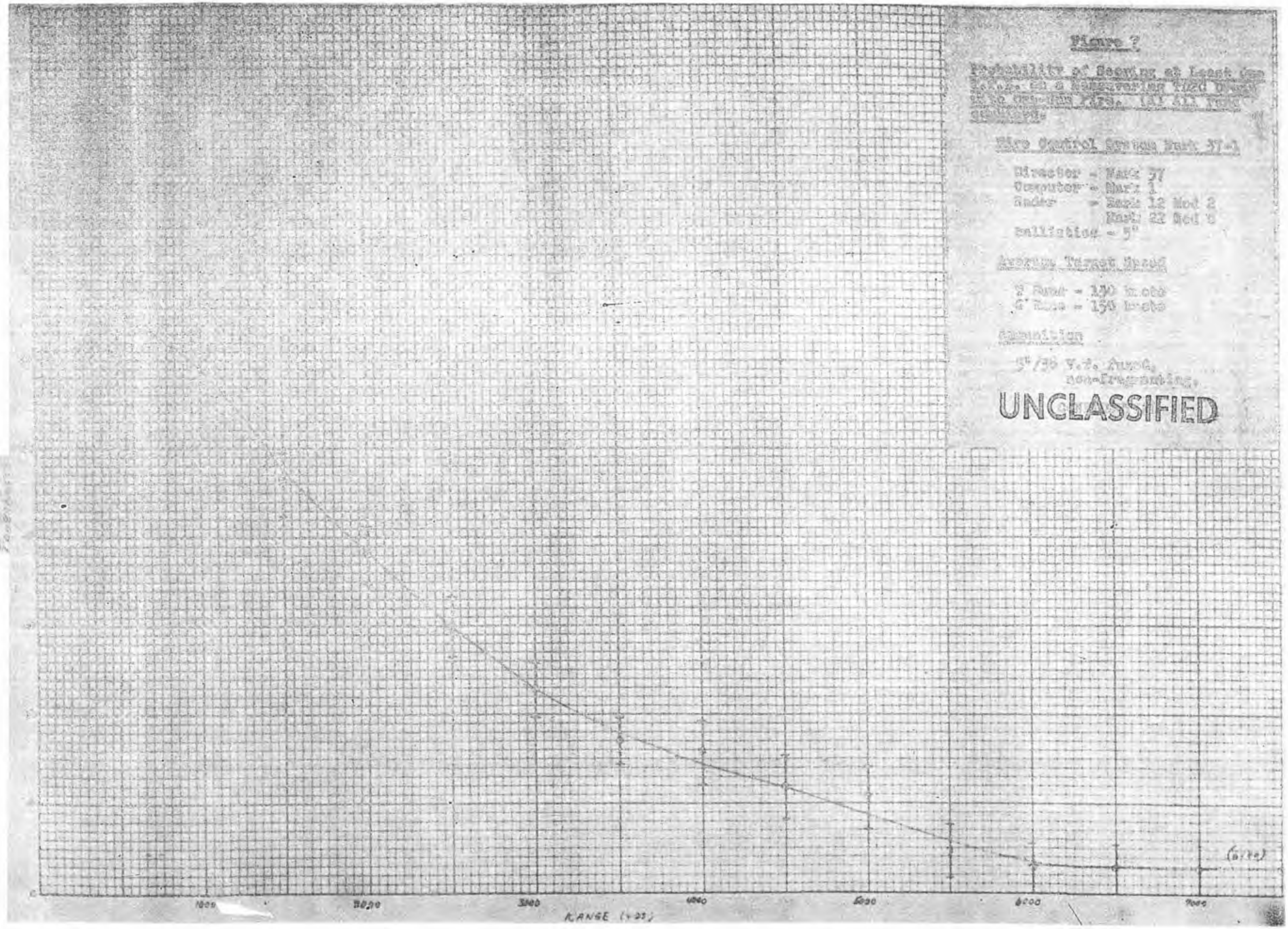


0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Target-triggered bursts (TTB) per effective round
0
1000
2000
3000
4000
5000
6000
7000
8000
Range bands (500 yards)
Mk 37 fire control system (2903 rnds)
Mk 37 (with Mk 8 computer) (2007 rnds)
Mk 57 director (731 rnds)
Mk 63 director (634 rnds)
Mk 51 (with 40mm ballistics) (431 rnds)
Mk 51 (with 5" ballistics) (523 rnds)



0.30
0.25
0.20
0.15
0.10
0.05
0.00
Target-triggered bursts (TTB) per effective round
0
1000
2000
3000
4000
5000
6000
7000
8000
Range bands (500 yards)
Mk 37 systems
Relative rate systems Mks 51, 57, 63
Quintic fit to Mk 37 systems
Cubic fit to relative rate systems



Director - Mark 37
Computer - Mark 1
Ballistics - 5"
Ammunition
UNCLASSIFIED
1000
2000
3000
4000
5000
6000
7000
RANGE (yds)

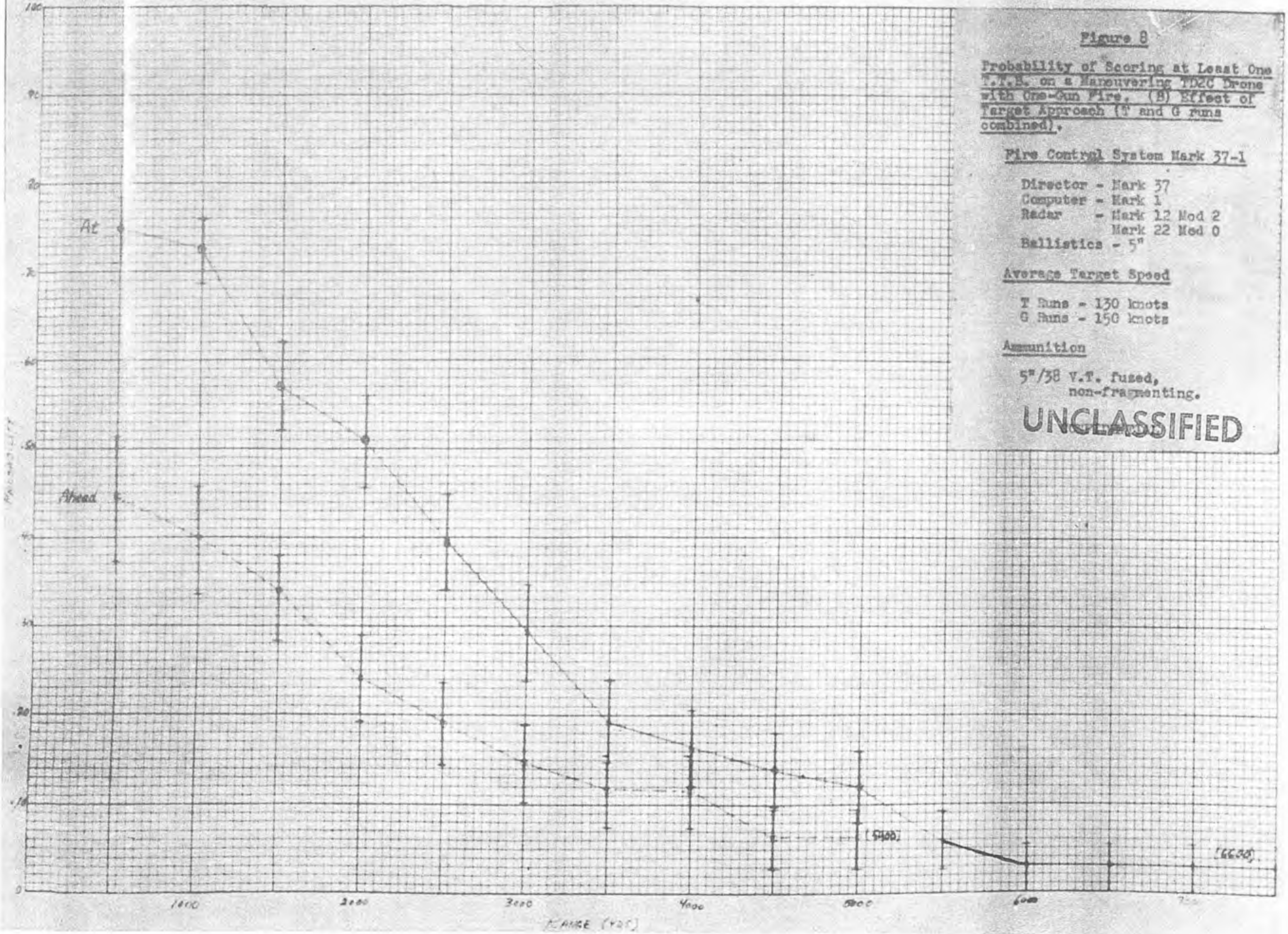


Figure 8

Probability of Scoring at Least One T.T.B. on a Maneuvering TD2C Drone with One-Gun Fire. (B) Effect of Target Approach (T and G runs combined).

Fire Control System Mark 37-1

Director - Mark 37
Computer - Mark 1
Radar - Mark 12 Mod 2
Mark 22 Mod 0
Ballistics - 5"

Average Target Speed

T Runs - 130 knots
G Runs - 150 knots

Ammunition

5"/38 V.T. fused, non-fragmenting.

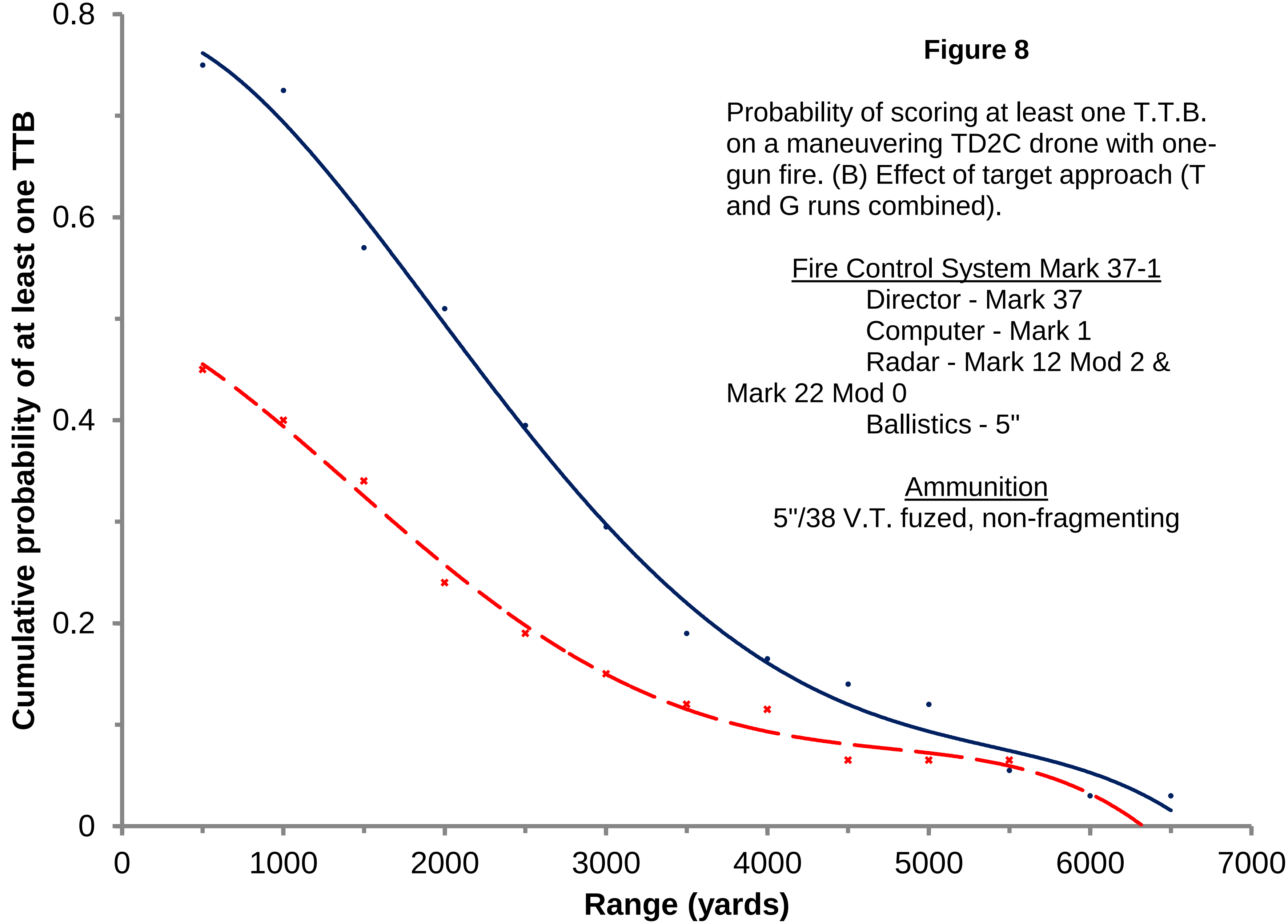
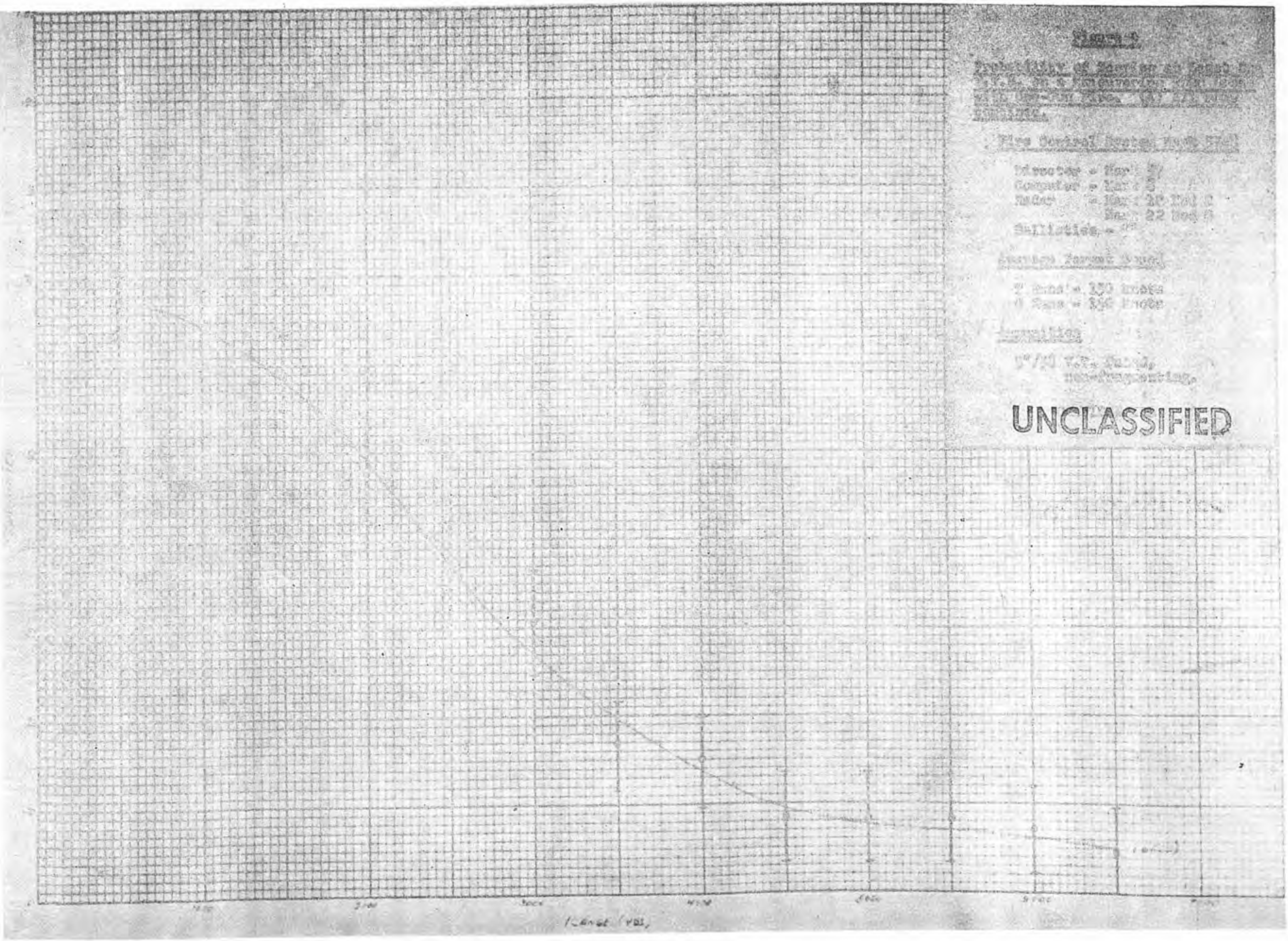


Figure 8
Probability of scoring at least one T.T.B. on a maneuvering TD2C drone with one-gun fire. (B) Effect of target approach (T and G runs combined).
Fire Control System Mark 37-1
Director - Mark 37
Computer - Mark 1
Radar - Mark 12 Mod 2 & Mark 22 Mod 0
Ballistics - 5"
Ammunition
5"/38 V.T. fuzed, non-fragmenting
Cumulative probability of at least one TTB
0.8
0.6
0.4
0.2
0
0
1000
2000
3000
4000
5000
6000
7000
Range (yards)



Fire Control System
Director
Computer
Radar
22 Mod
Ballistics
Average Target Speed
150 knots
Ammunition
non-fragmenting.
UNCLASSIFIED
Range (Yds)

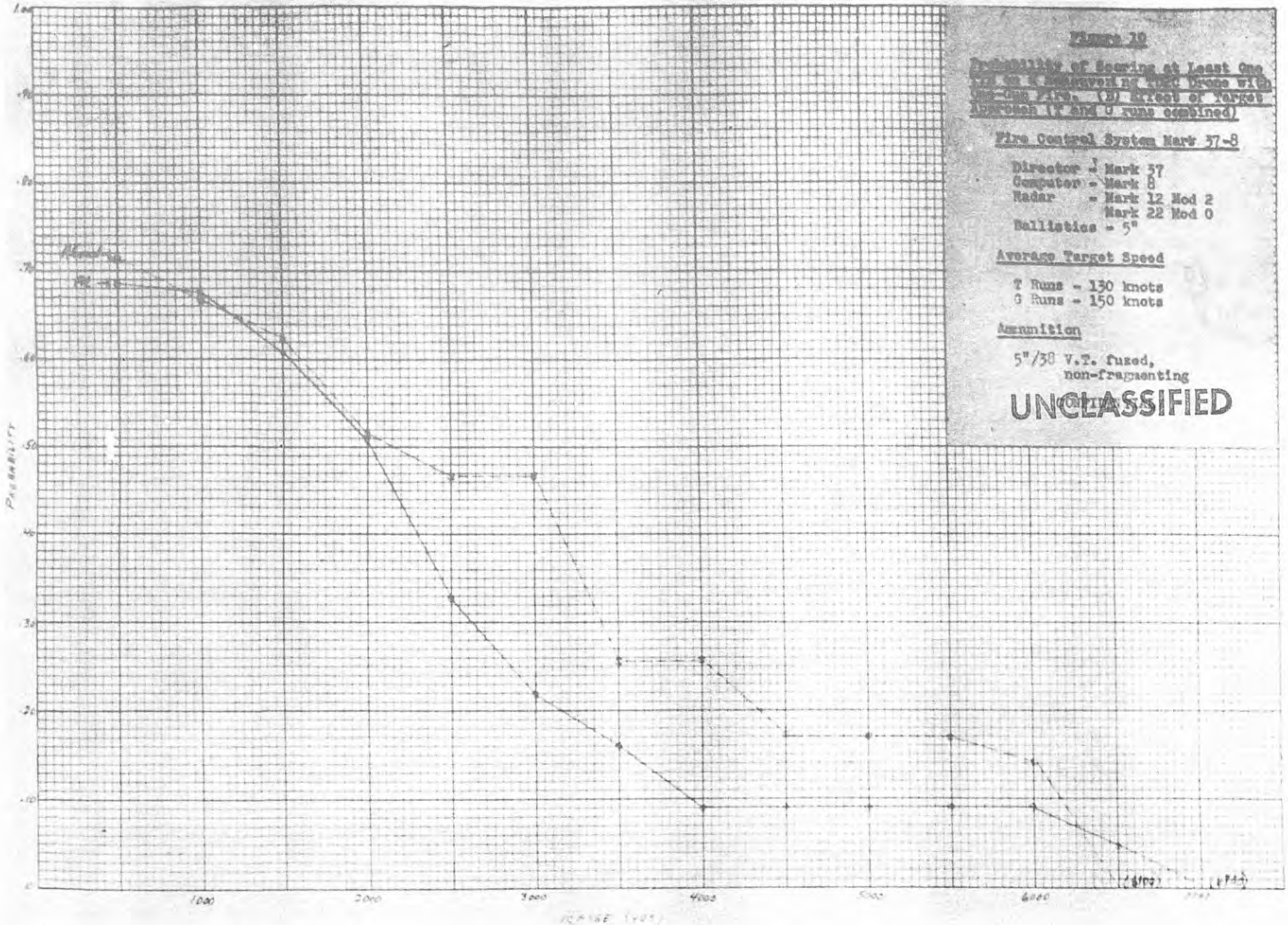
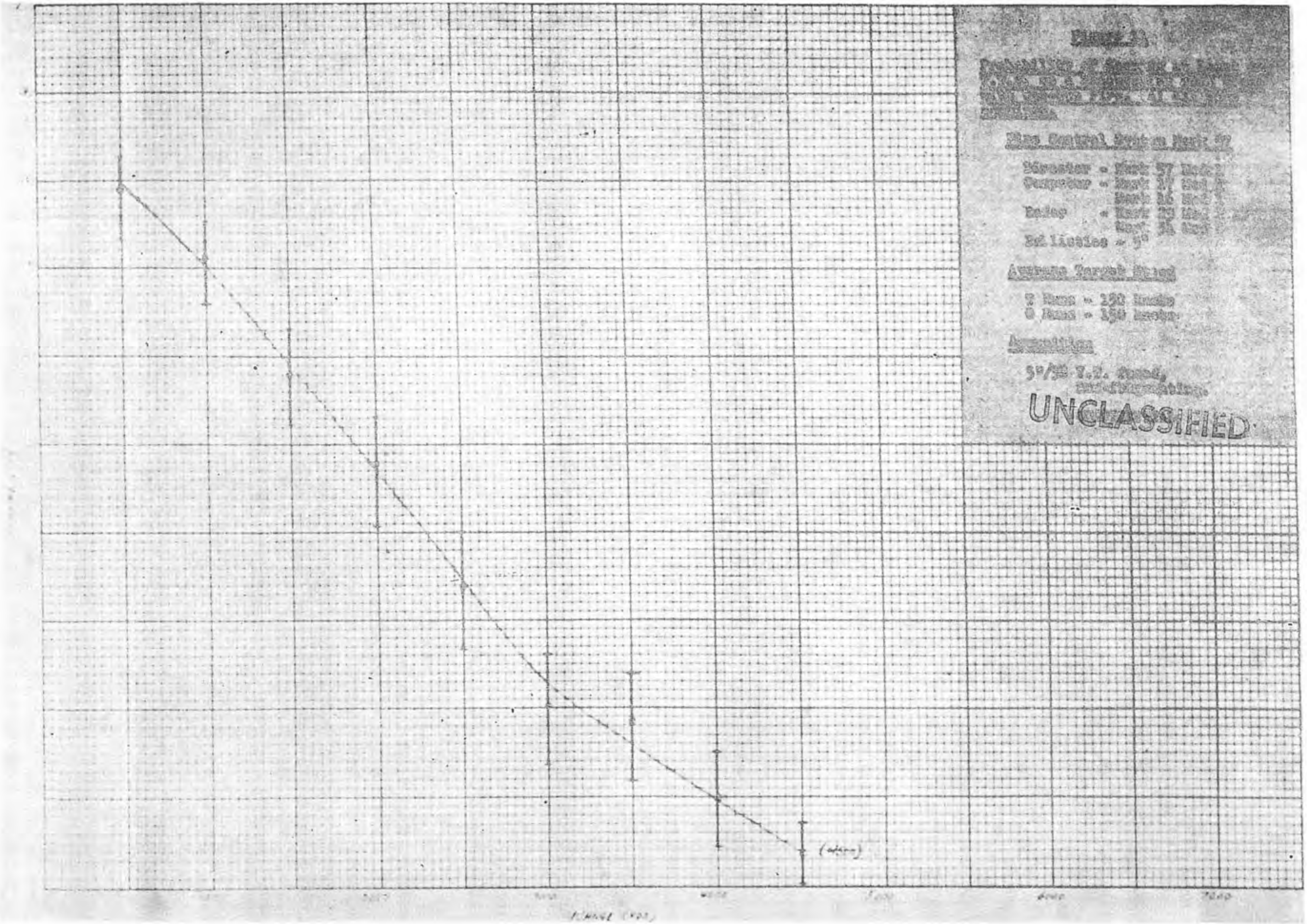


Figure 10

Probability of Scoring at Least One Hit on a Maneuvering TD2C Drone with One-Gun Fire. (B) Effect of Target Approach (T and [illegible] runs combined)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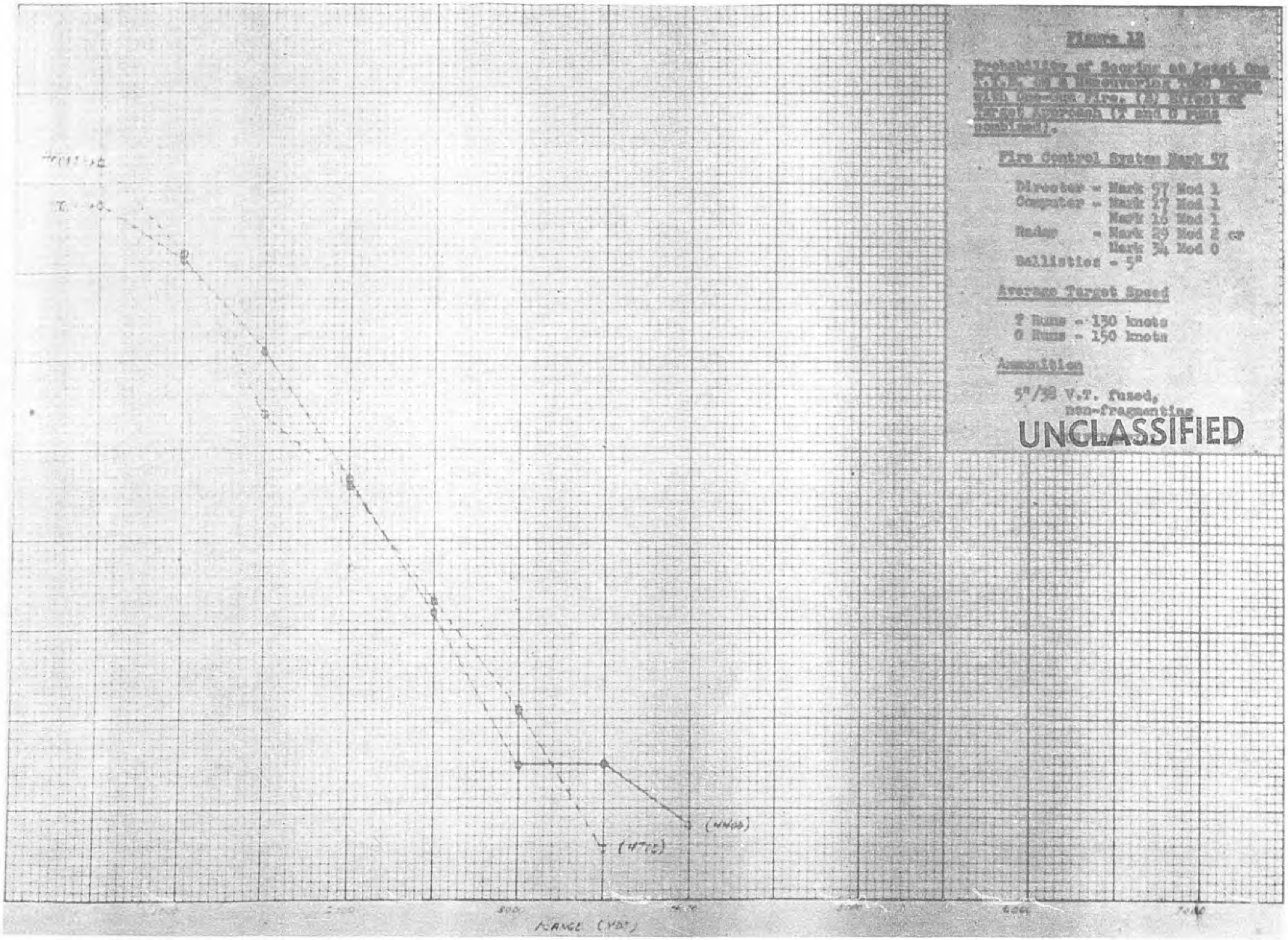

Figure 12

Probability of Scoring at Least One [illegible] on a Maneuvering [illegible] with One-Gun Fire. (2) Effect of Target Approach (T and G runs combined).

Fire Control System Mark 57

Director - Mark 57 Mod 1
Computer - Mark 17 Mod 1
Mark 16 Mod 1
Radar - Mark 29 Mod 2 or
Mark 34 Mod 0
Ballistics - 5"

Average Target Speed

T Runs - 130 knots
G Runs - 150 knots

Ammunition

5"/38 V.T. fused,
non-fragmenting

UNCLASSIFIED

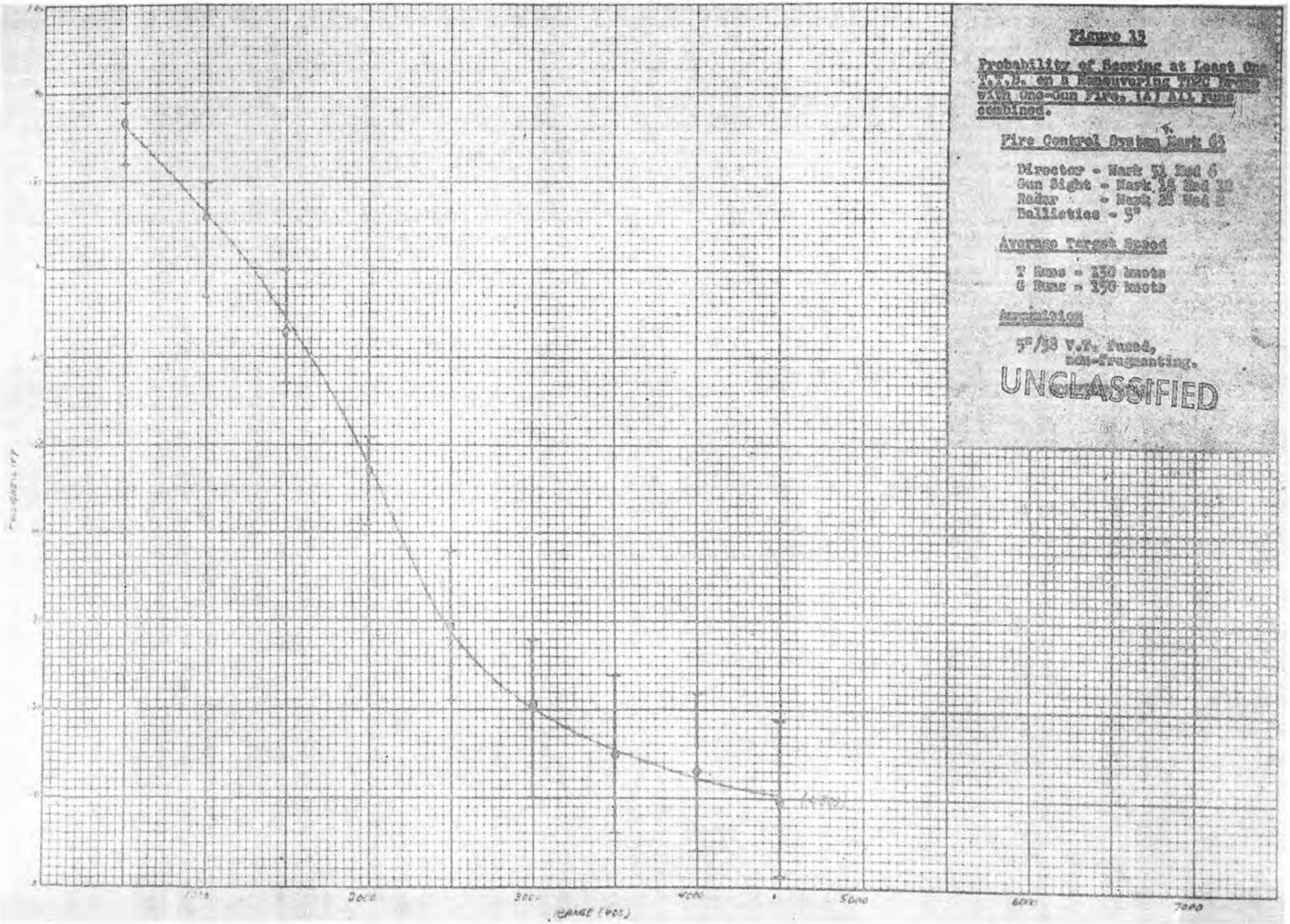

Figure 13

Probability of Scoring at Least One T.?.B. on a Maneuvering TBM Drone with One-Gun Fire, (A) All runs combined.

Fire Control System Mark 63

Director - Mark 51 Mod 6
Gun Sight - Mark 15 Mod 10
Radar - Mark 28 Mod 2
Ballistics - 5"

Average Target Speed

T Runs = 150 knots
G Runs = 190 knots

Ammunition

5"/38 V.T. fused,
non-fragmenting.

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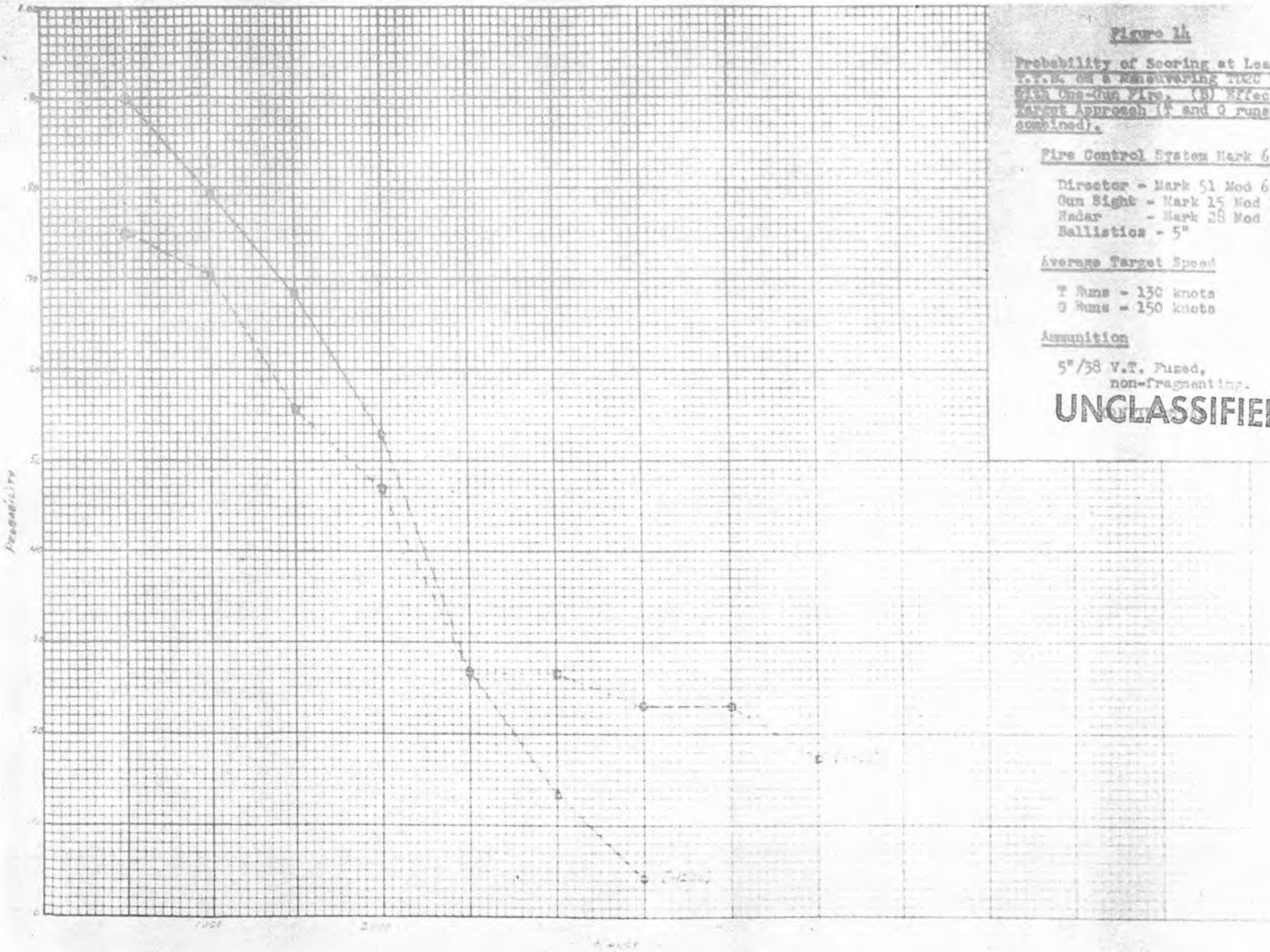


Figure 14

Probability of Scoring at Least One V.T.H. on a Maneuvering TD2C Drone With One-Gun Fire. (B) Effect of Target Approach (T and G runs combined).

Fire Control System Mark 63

Director - Mark 51 Mod 6
Gun Sight - Mark 15 Mod 12
Radar - Mark 28 Mod 2
Ballistics - 5"

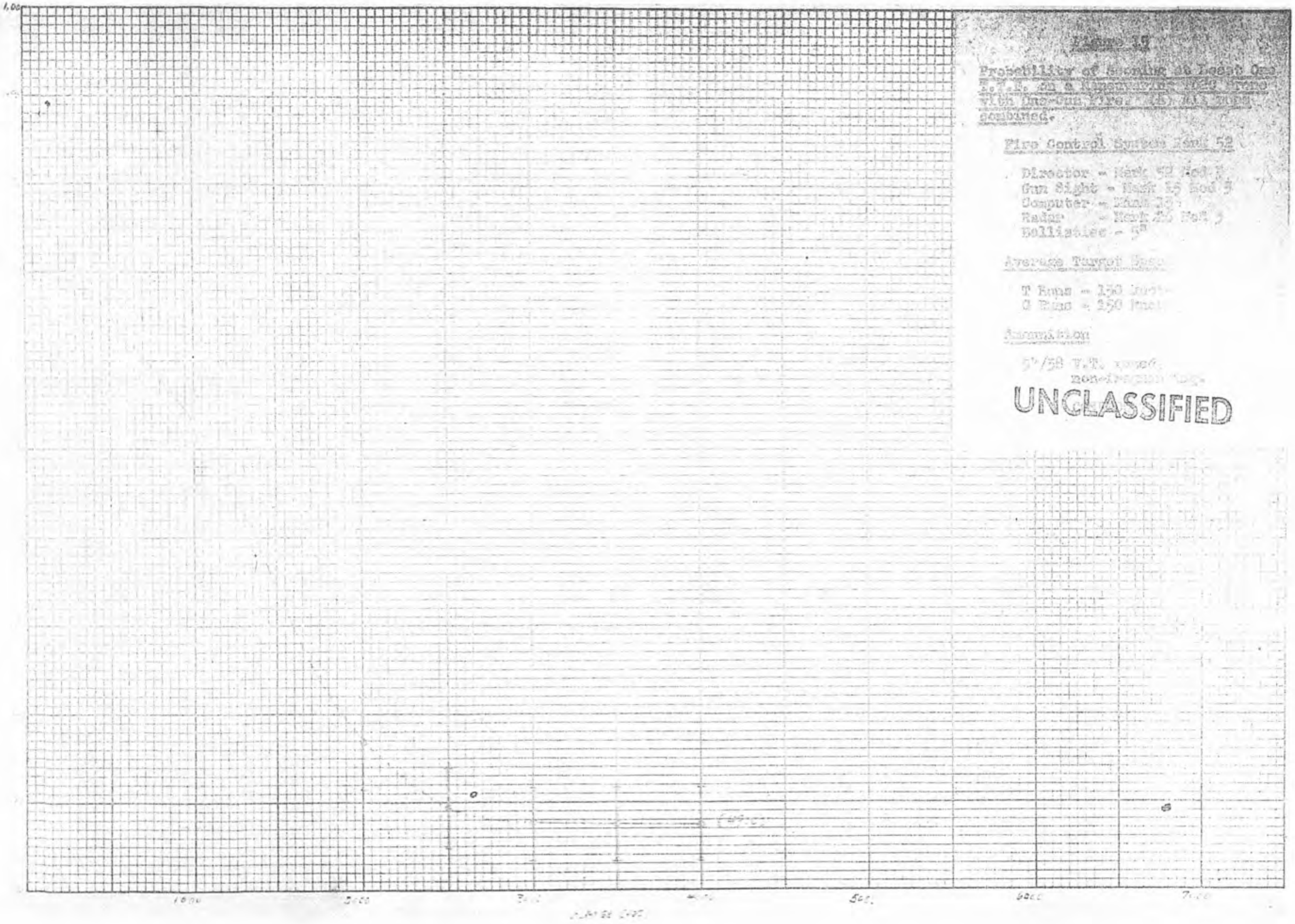
Average Target Speed

T Runs - 130 knots
G Runs - 150 knots

Ammunition

5"/38 V.T. Fused, non-fragmenting.

UNCLASSIFIED



1.00
Fire Control System Mark 52
Director
Gun Sight
Computer
Radar
Ballistics
Average Target
T Runs
G Runs
5"/38 V.T.
UNCLASSIFIED
1000
2000
5000
6000

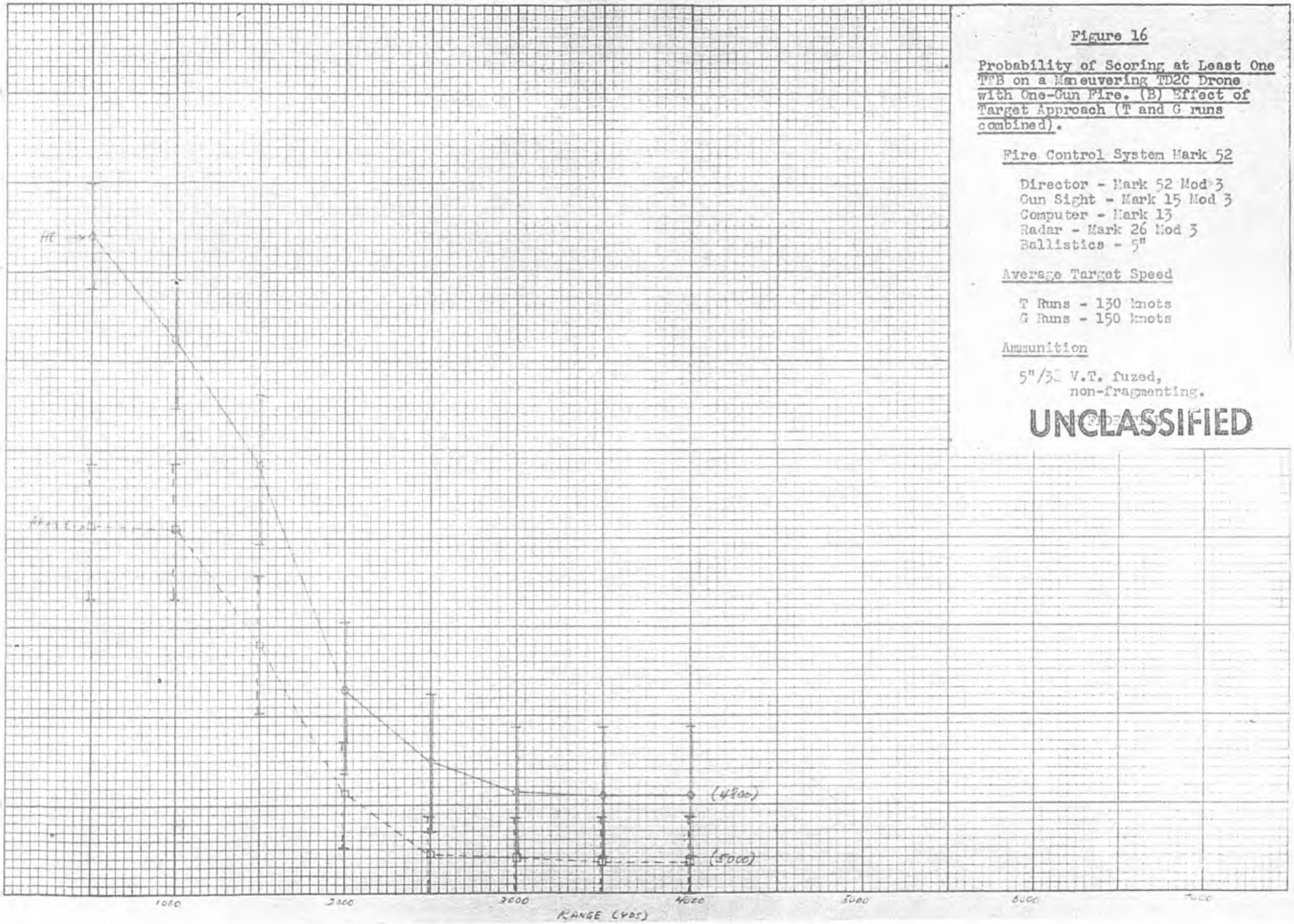


Figure 16

Probability of Scoring at Least One TTB on a Maneuvering TD2C Drone with One-Gun Fire. (B) Effect of Target Approach (T and G runs combined).

Fire Control System Mark 52

Director - Mark 52 Mod 3
Gun Sight - Mark 15 Mod 3
Computer - Mark 13
Radar - Mark 26 Mod 3
Ballistics - 5"

Average Target Speed

T Runs - 130 knots
G Runs - 150 knots

Ammunition

5"/38 V.T. fuzed, non-fragmenting.

UNCLASSIFIED

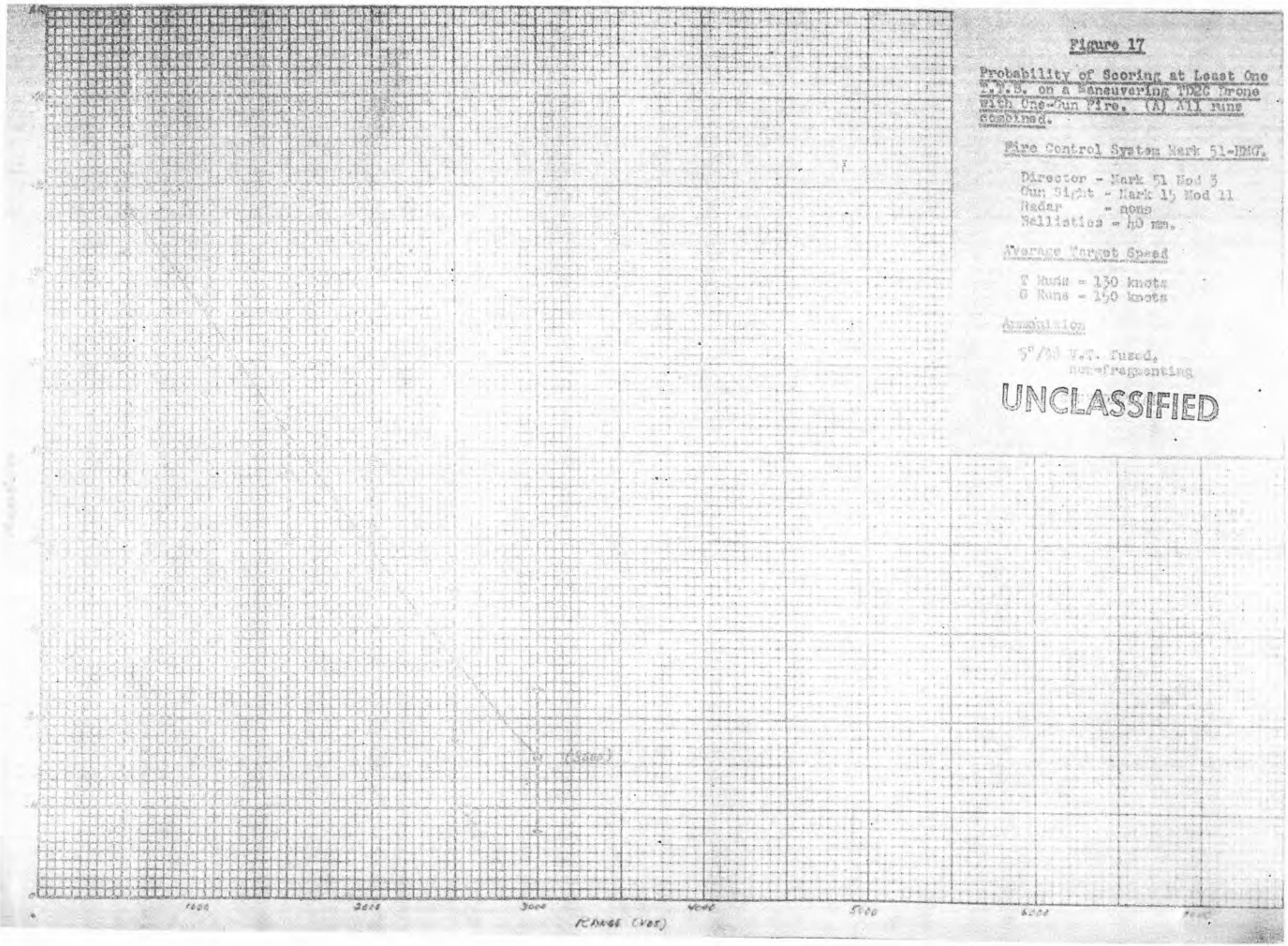


Figure 17

Probability of Scoring at Least One T.V.B. on a Maneuvering TD2C Drone with One-Gun Fire. (A) All runs combined.

Fire Control System Mark 51-IMG.

Director - Mark 51 Mod 3
Gun Sight - Mark 15 Mod 11
Radar - none
Ballistics - 40 mm.

Average Target Speed

T Runs = 130 knots
G Runs = 150 knots

Ammunition

5"/38 V.T. fused, non-fragmenting

UNCLASSIFIED

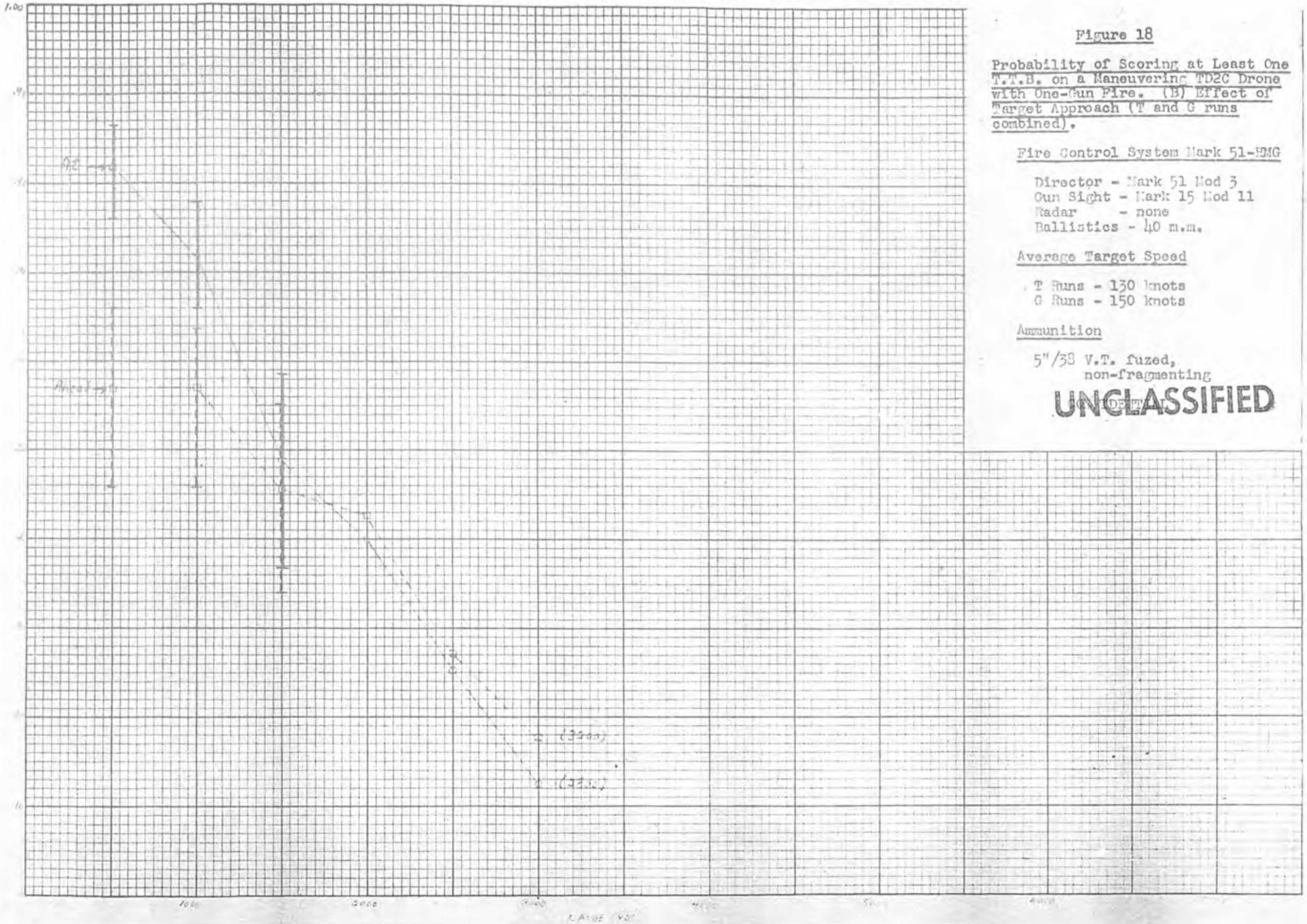


Figure 18

Probability of Scoring at Least One T.T.B. on a Maneuvering TD2C Drone with One-Gun Fire. (B) Effect of Target Approach (T and G runs combined).

Fire Control System Mark 51-HMG

Director - Mark 51 Mod 3
Gun Sight - Mark 15 Mod 11
Radar - none
Ballistics - 40 m.m.

Average Target Speed

T Runs - 130 knots
G Runs - 150 knots

Ammunition

5"/38 V.T. fuzed, non-fragmenting

UNCLASSIFIED

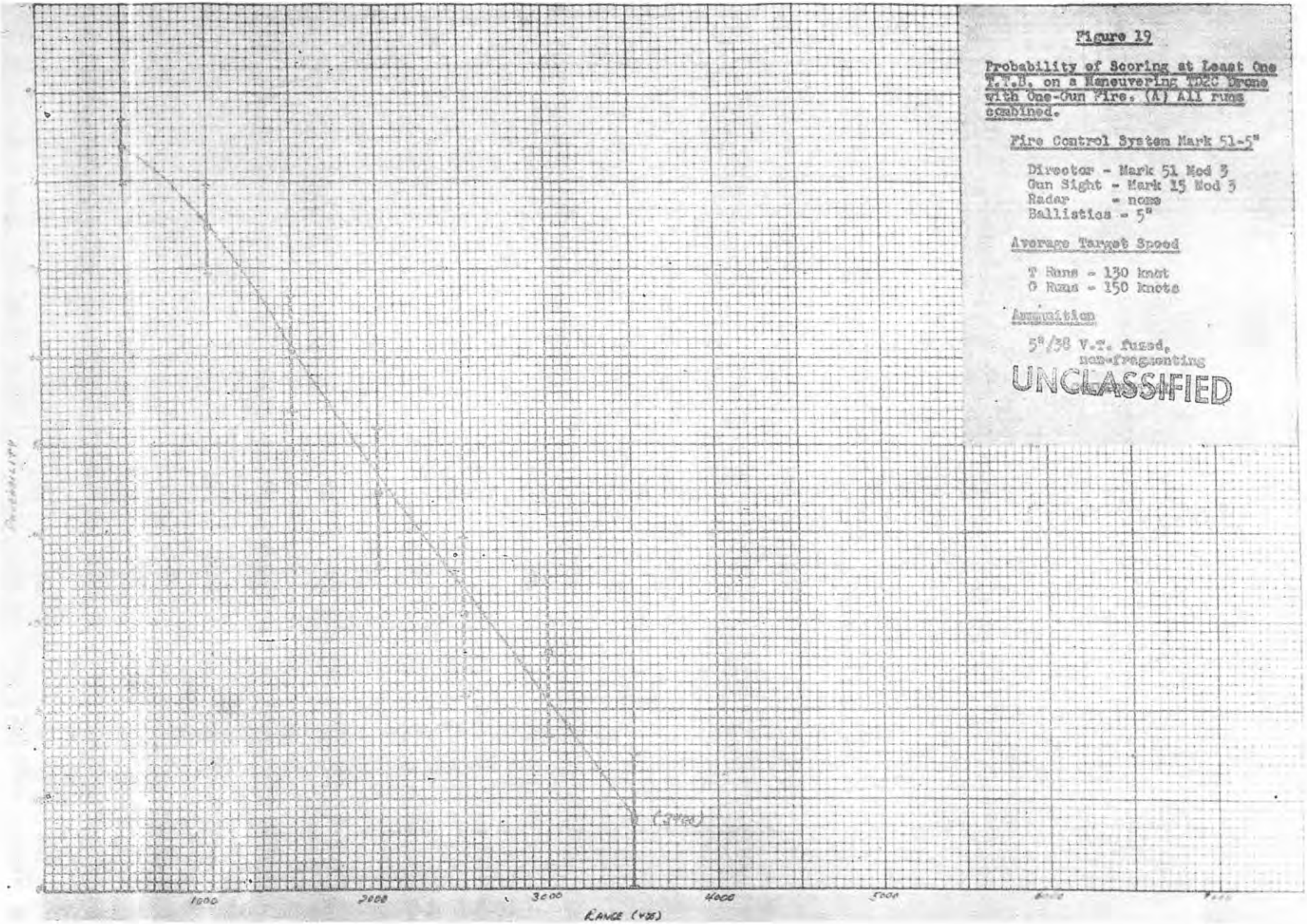


Figure 19

Probability of Scoring at Least One T.T.B. on a Maneuvering TD2C Drone with One-Gun Fire. (A) All runs combined.

Fire Control System Mark 51-5"

Director - Mark 51 Mod 3
Gun Sight - Mark 15 Mod 3
Radar - none
Ballistics - 5"

Average Target Speed

T Runs - 130 knot
G Runs - 150 knots

Ammunition

5"/38 V.T. fuzed, non-fragmenting

UNCLASSIFIED

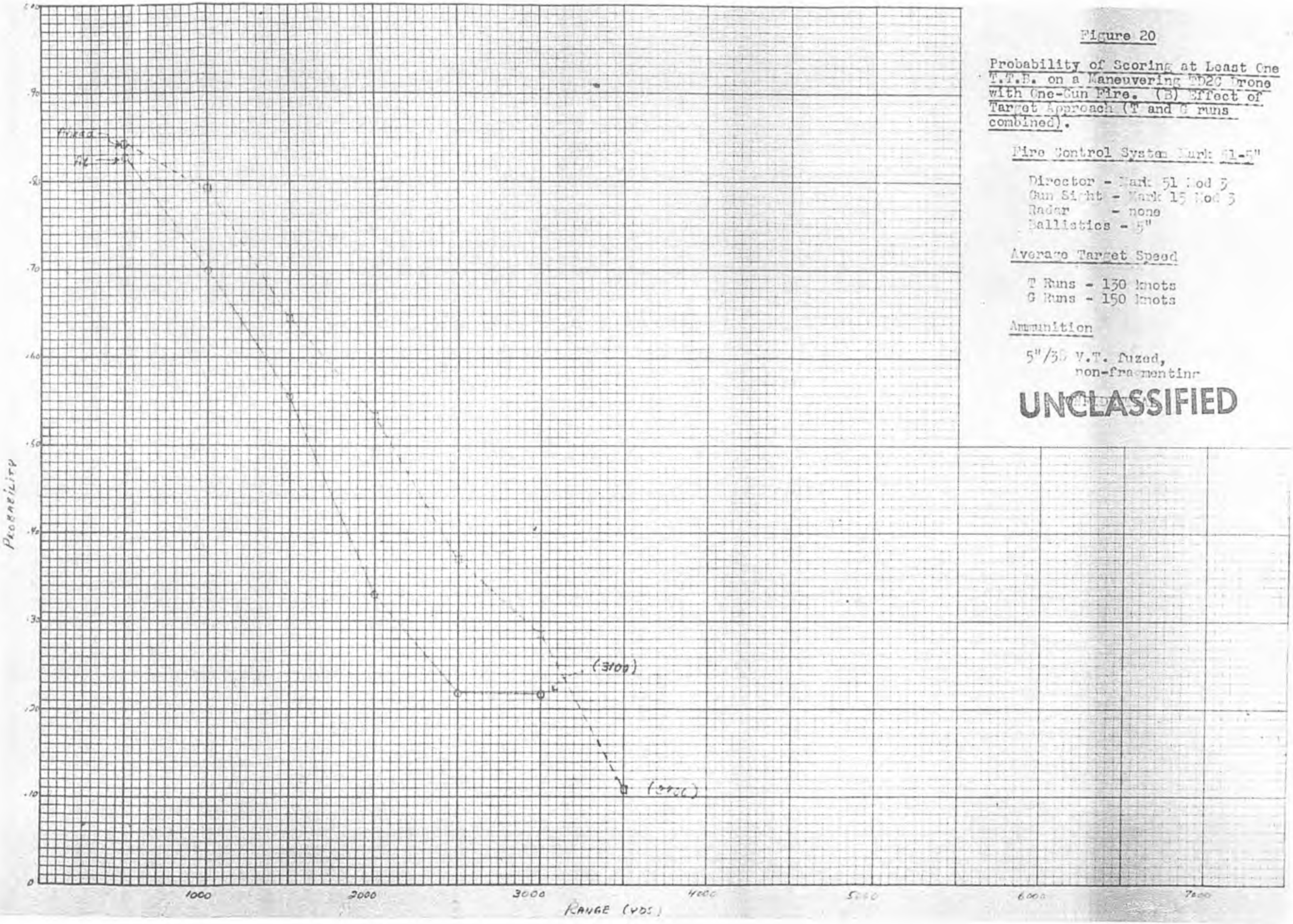


Figure 20

Probability of Scoring at Least One T.T.B. on a Maneuvering TD2C Drone with One-Gun Fire. (B) Effect of Target Approach (T and G runs combined).

Fire Control System Mark 51-5"

Director - Mark 51 Mod 3
Gun Sight - Mark 15 Mod 3
Radar - none
Ballistics - 5"

Average Target Speed

T Runs - 130 knots
G Runs - 150 knots

Ammunition

5"/38 V.T. fuzed, non-fragmenting

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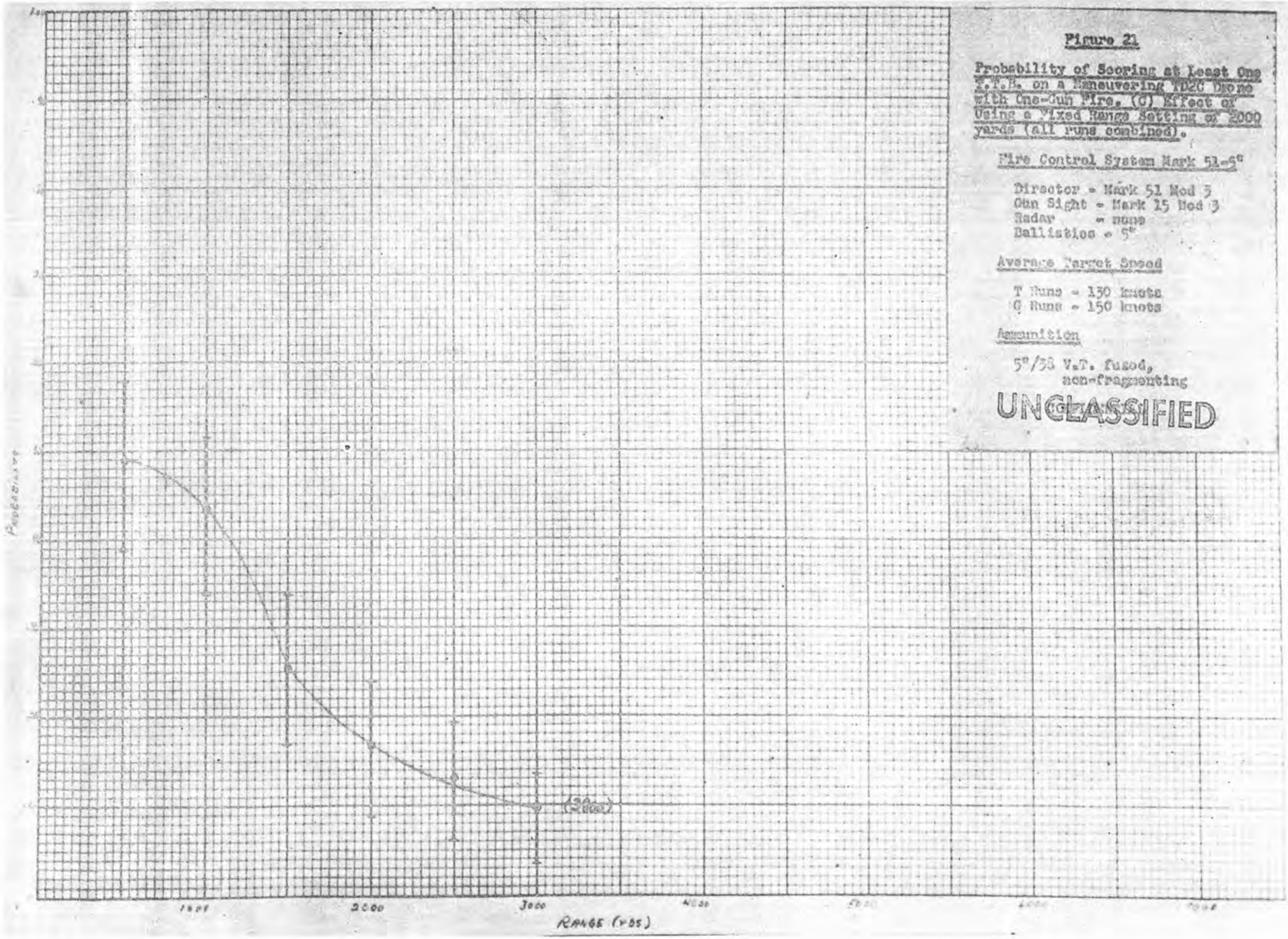

Figure 21

Probability of Scoring at Least One V.T.B. on a Maneuvering TD2C Drone with One-Gun Fire. (G) Effect of Using a Fixed Range Setting of 2000 yards (all runs combined).

Fire Control System Mark 51-5"

Director - Mark 51 Mod 3
Gun Sight - Mark 15 Mod 3
Radar - none
Ballistics - 5"

Average Target Speed

T Runs - 130 knots
G Runs - 150 knots

Ammunition

5"/38 V.T. fused,
non-fragmenting

UNCLASSIFIED

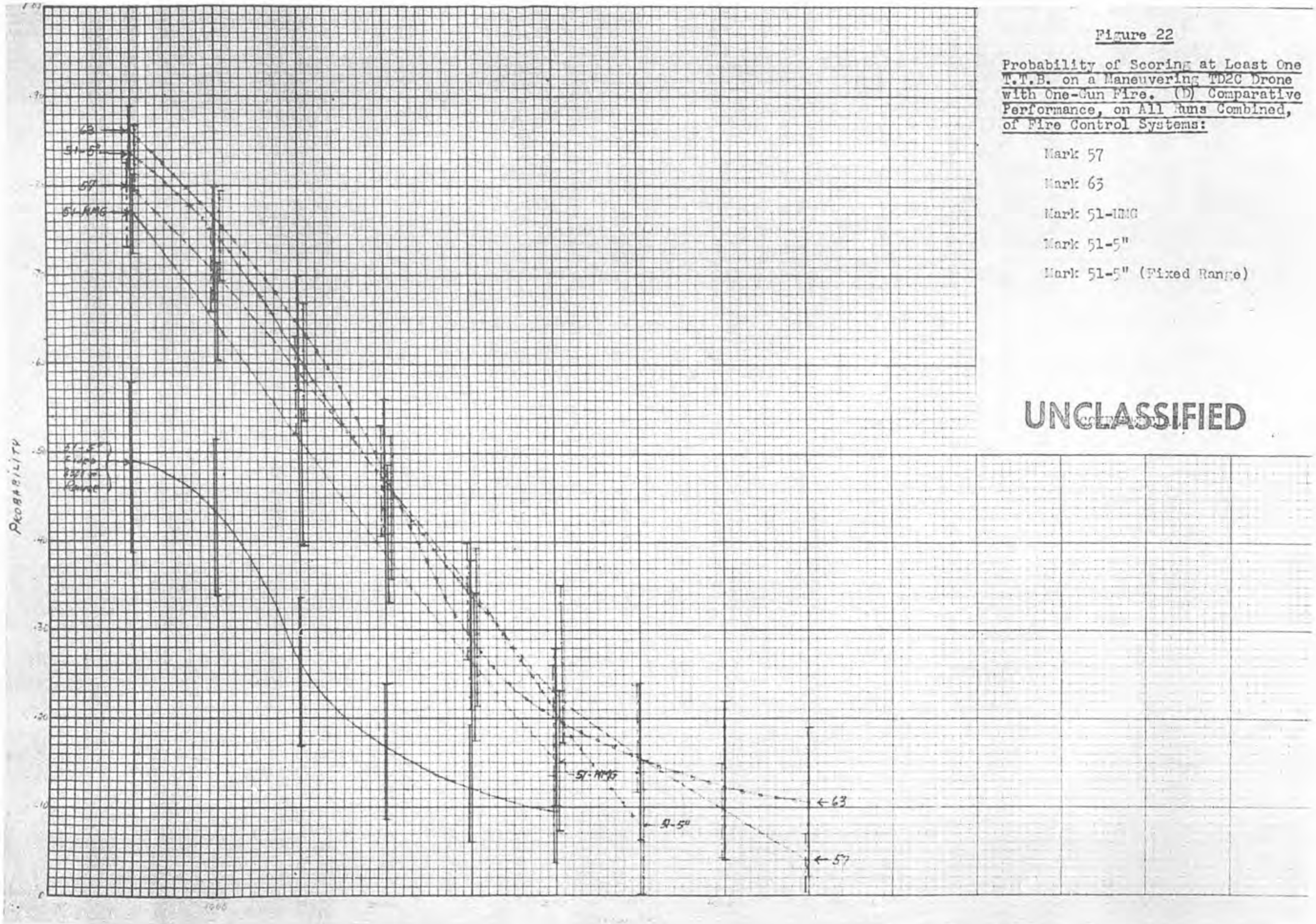

Figure 22

Probability of Scoring at Least One T.T.B. on a Maneuvering TD2C Drone with One-Gun Fire. (D) Comparative Performance, on All Runs Combined, of Fire Control Systems:

Mark 57

Mark 63

Mark 51-HMG

Mark 51-5"

Mark 51-5" (Fixed Range)

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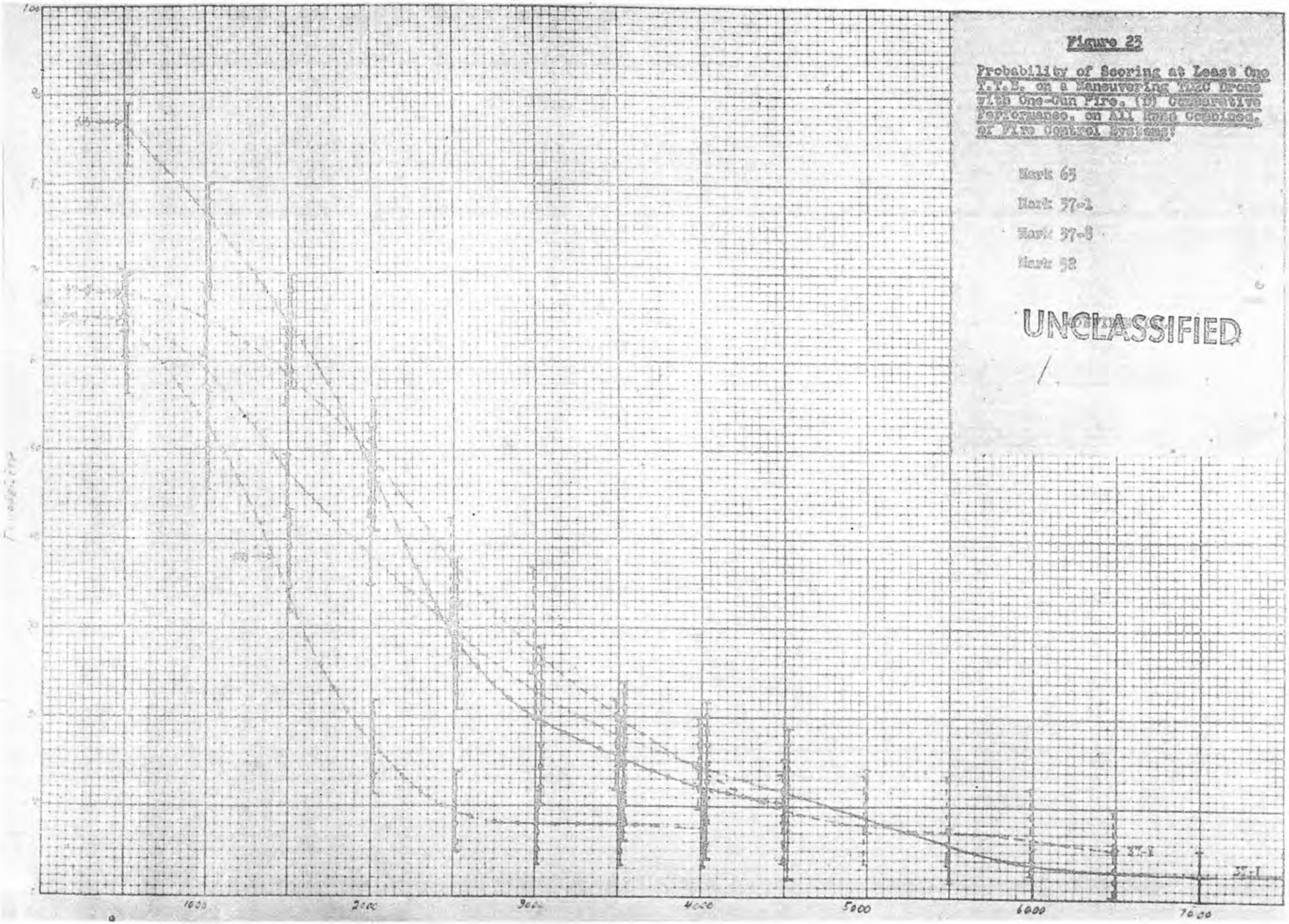

Figure 23

Probability of Scoring at Least One T.T.B. on a Maneuvering TD2C Drone with One-Gun Fire. (D) Comparative Performance, on All Runs Combined, of Fire Control Systems:

UNCLASSIFIED

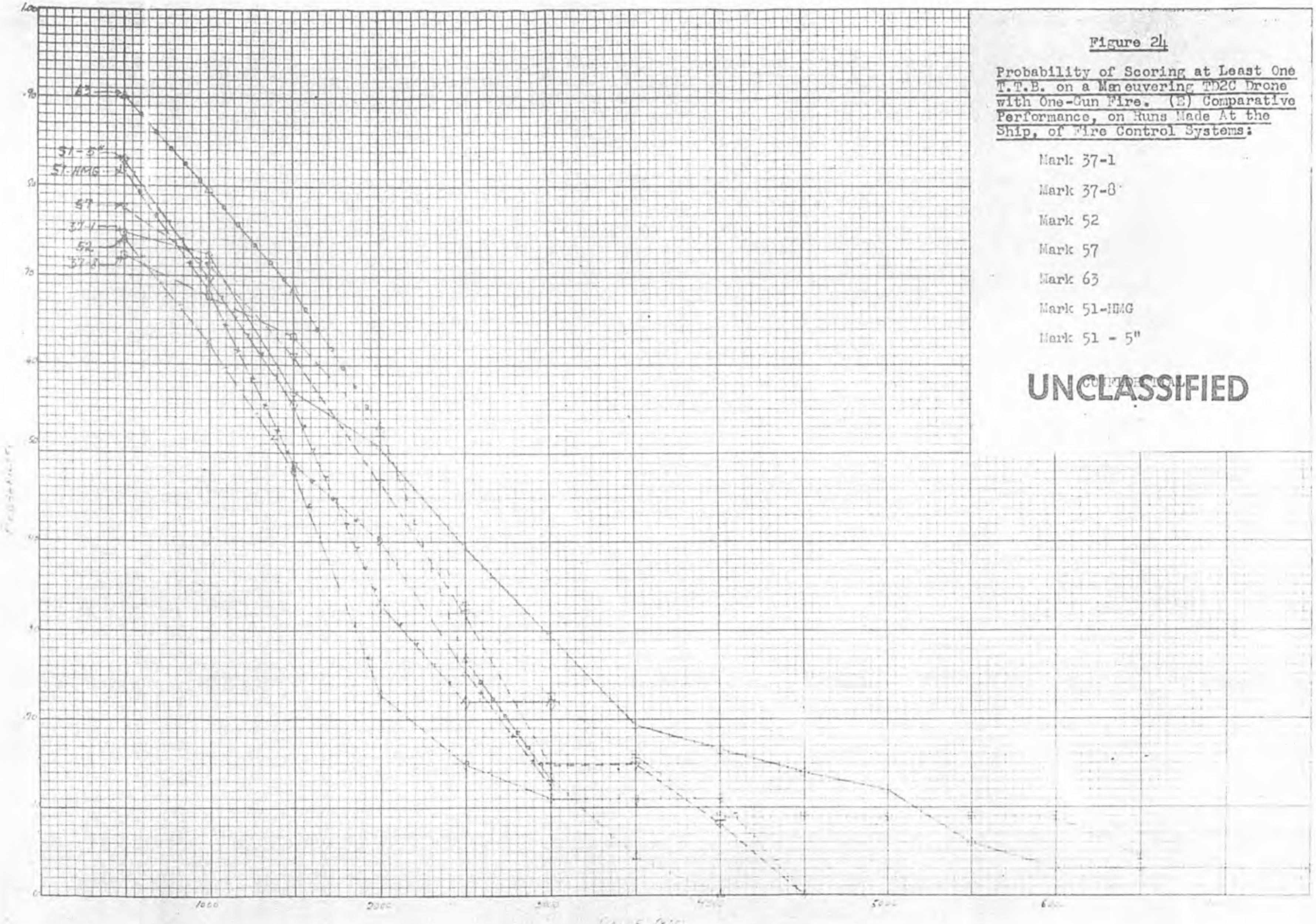

Figure 24

Probability of Scoring at Least One T.T.B. on a Maneuvering TD2C Drone with One-Gun Fire. (E) Comparative Performance, on Runs Made At the Ship, of Fire Control Systems:

Mark 37-1

Mark 37-8

Mark 52

Mark 57

Mark 63

Mark 51-HMG

Mark 51 - 5"

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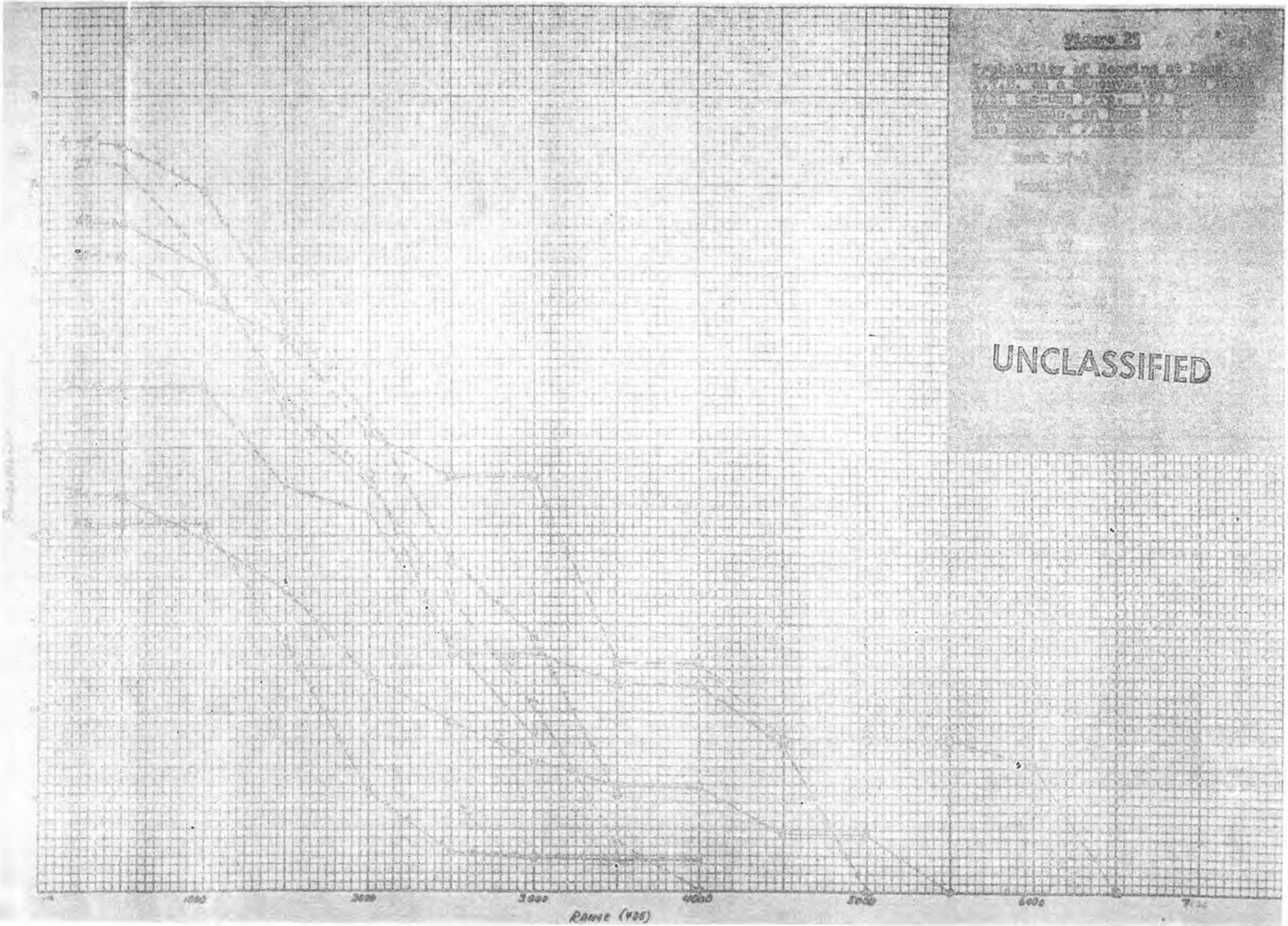
Figure 29

[illegible]



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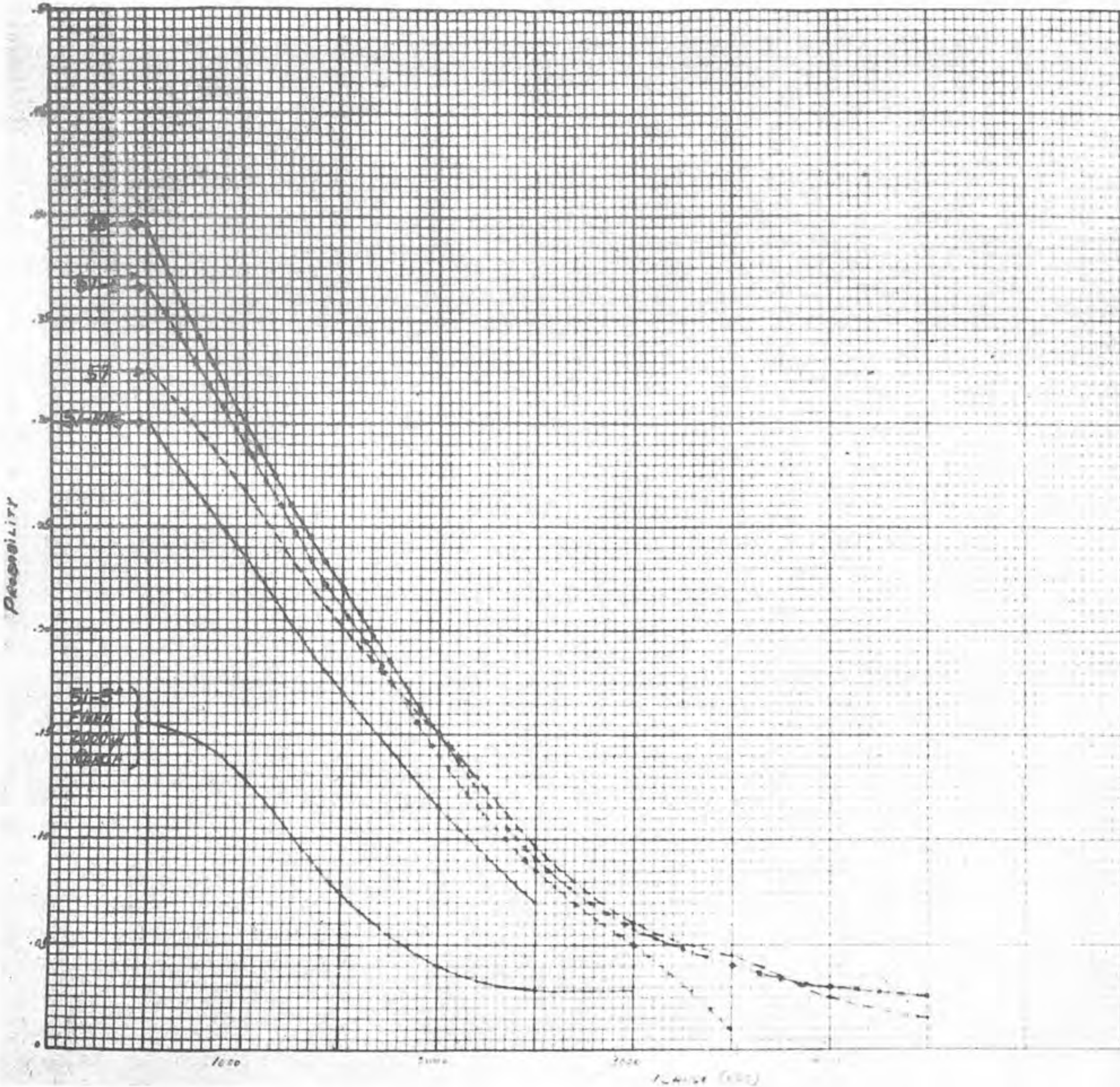


Figure [illegible]

Probability of Splashing a Maneuvering Target with [illegible] Fire. Target Speed [illegible] Knots. Vulnerability [illegible]. [illegible] Comparative Performance, on All Runs Combined, of Fire Control Systems:

Mark 57

Mark 63

Mark 51 - HMG

Mark 51 - 5"

Mark 51 - 5"(Fixed Range)

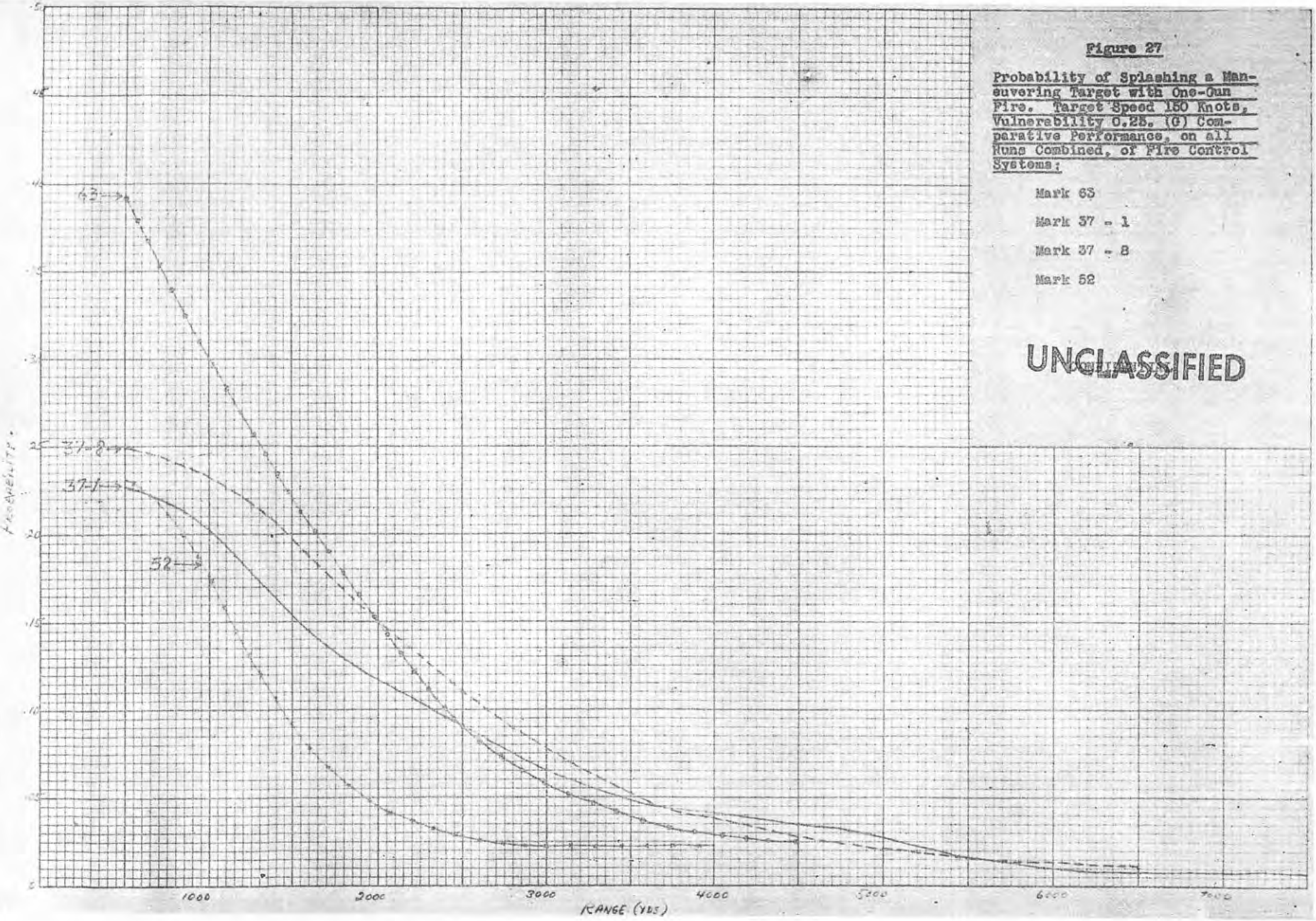


Figure 27

Probability of Splashing a Maneuvering Target with One-Gun Fire. Target Speed 150 Knots, Vulnerability 0.25. (G) Comparative Performance, on all Runs Combined, of Fire Control Systems:

Mark 63

Mark 37 - 1

Mark 37 - 8

Mark 52

UNCLASSIFIED

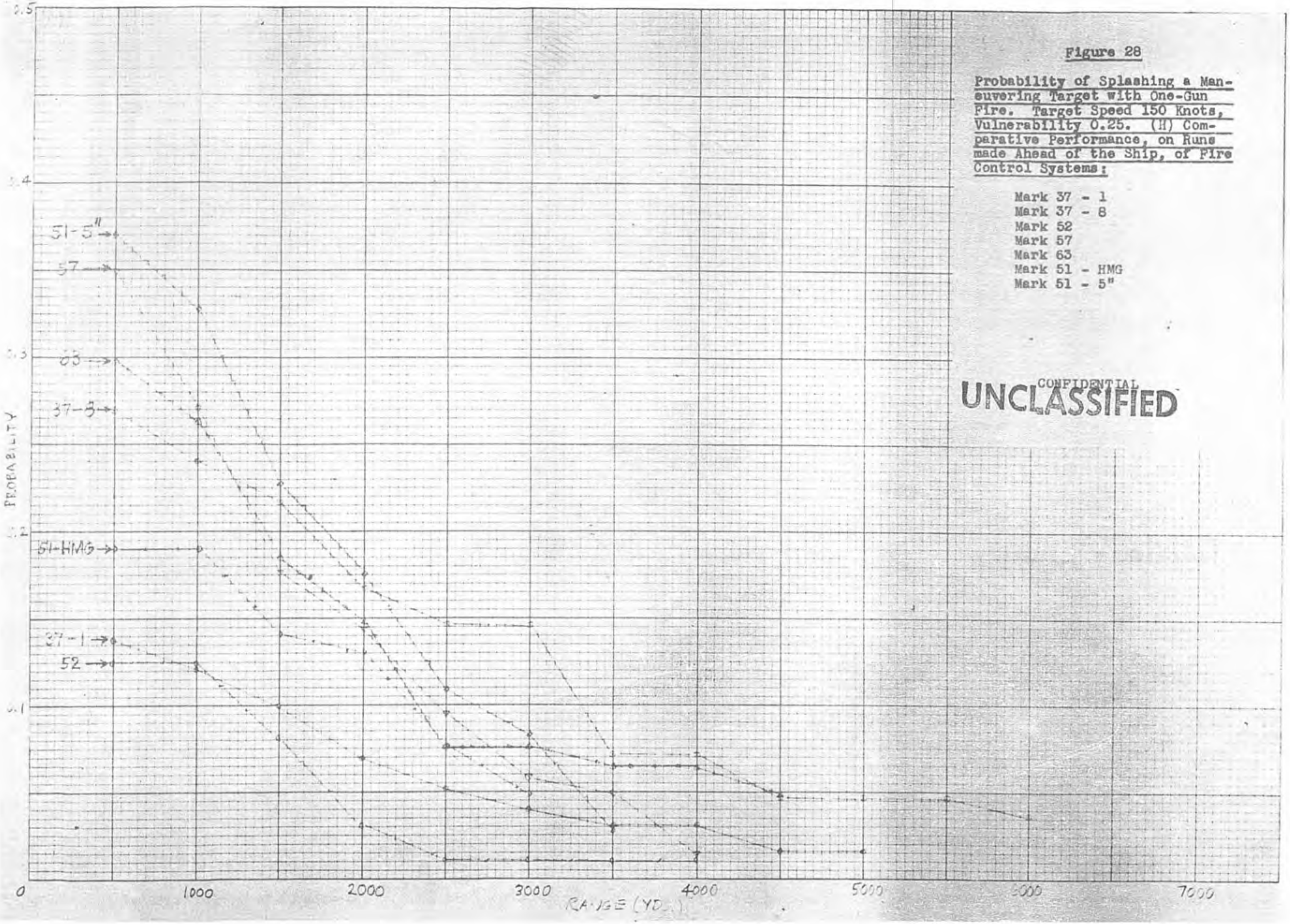
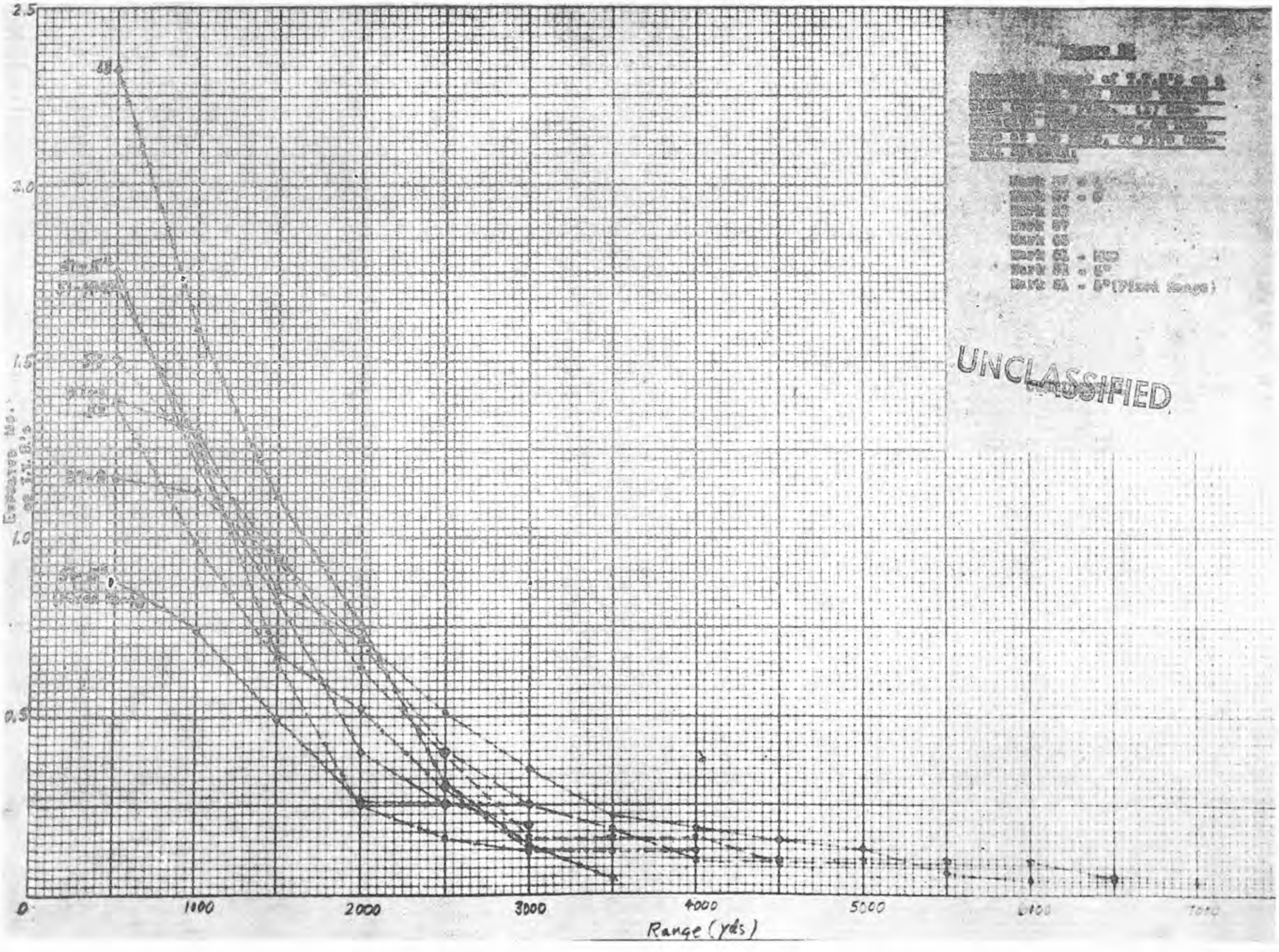


Figure 28

Probability of Splashing a Maneuvering Target with One-Gun Fire. Target Speed 150 Knots, Vulnerability 0.25. (H) Comparative Performance, on Runs made Ahead of the Ship, of Fire Control Systems:

Mark 37 - 1
Mark 37 - 8
Mark 52
Mark 57
Mark 63
Mark 51 - HMG
Mark 51 - 5"


2.5
2.0
1.5
1.0
0.5
0
1000
2000
3000
4000
5000
Range (yds)
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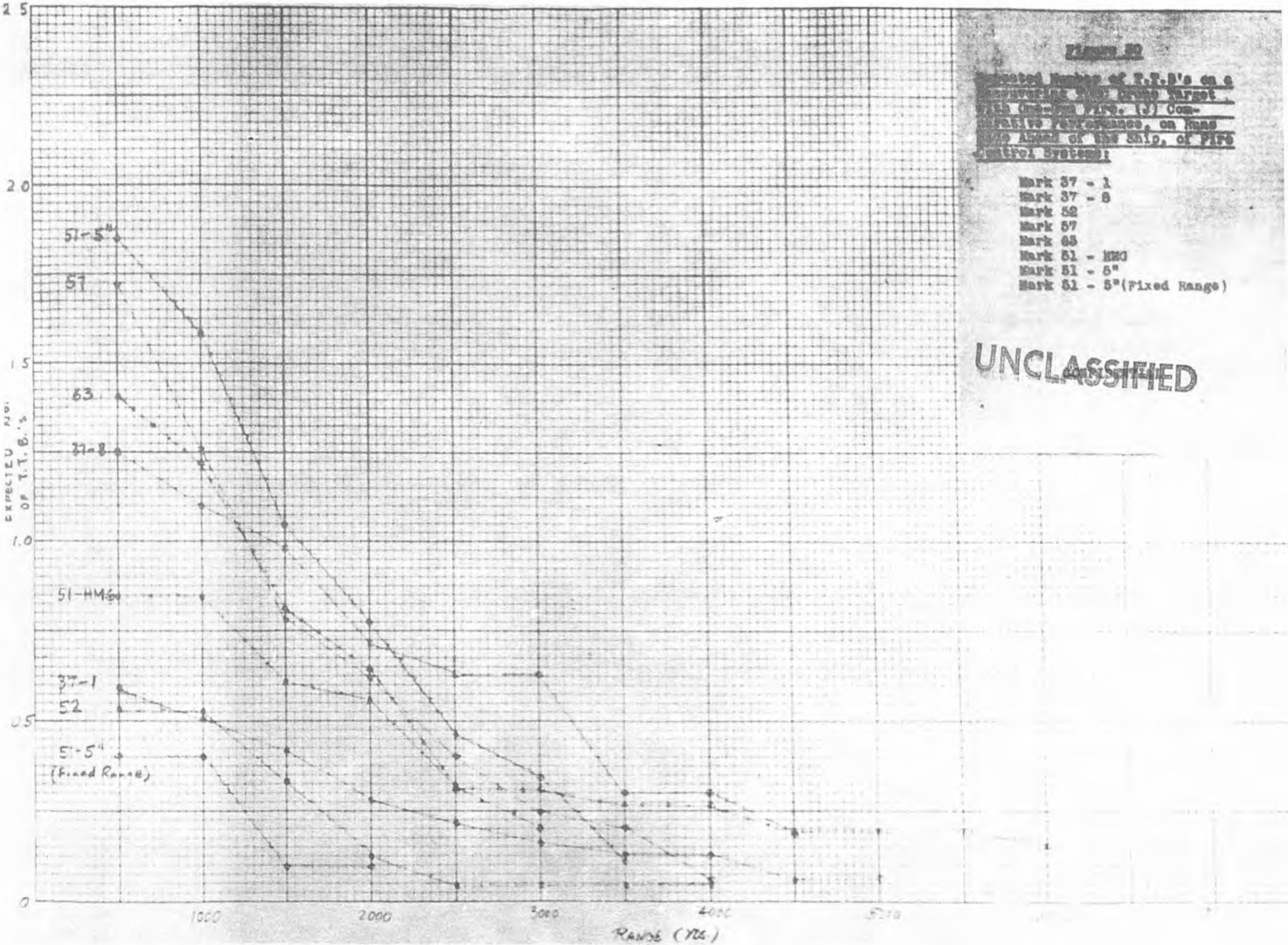

Figure 20

[illegible] Number of T.T.B's on a [illegible] Target with One-[illegible] Fire. (J) Comparative Performance, on Runs [illegible] Ahead of the Ship, of Fire Control Systems:

Mark 37 - 1
Mark 37 - 8
Mark 52
Mark 57
Mark 63
Mark 51 - HMG
Mark 51 - 5"
Mark 51 - 5"(Fixed Range)

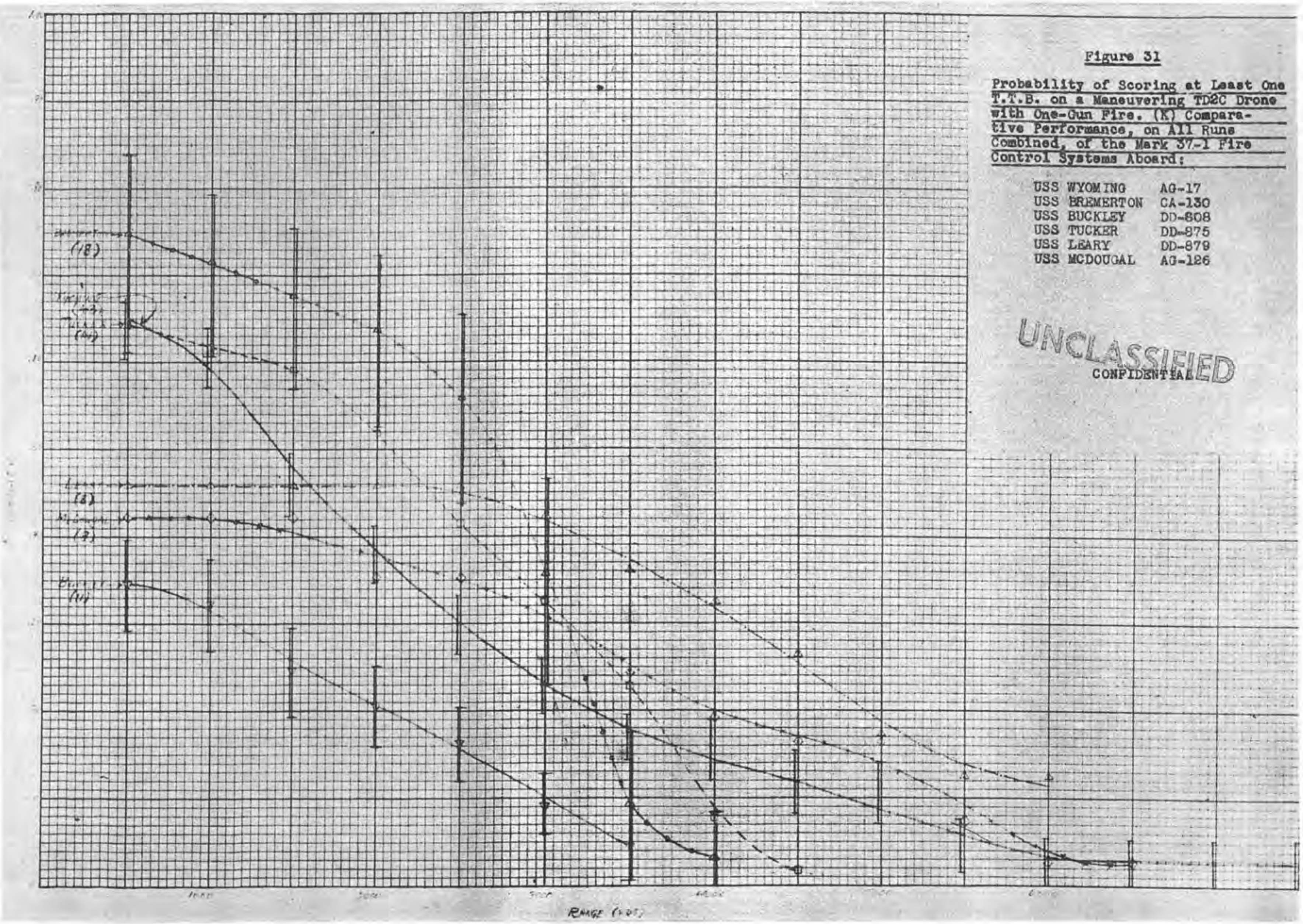

Figure 31

Probability of Scoring at Least One T.T.B. on a Maneuvering TD2C Drone with One-Gun Fire. (K) Comparative Performance, on All Runs Combined, of the Mark 37-1 Fire Control Systems Aboard:

USS WYOMING	AG-17
USS BREMERTON	CA-130
USS BUCKLEY	DD-808
USS TUCKER	DD-875
USS LEARY	DD-879
USS MCDOUGAL	AG-126

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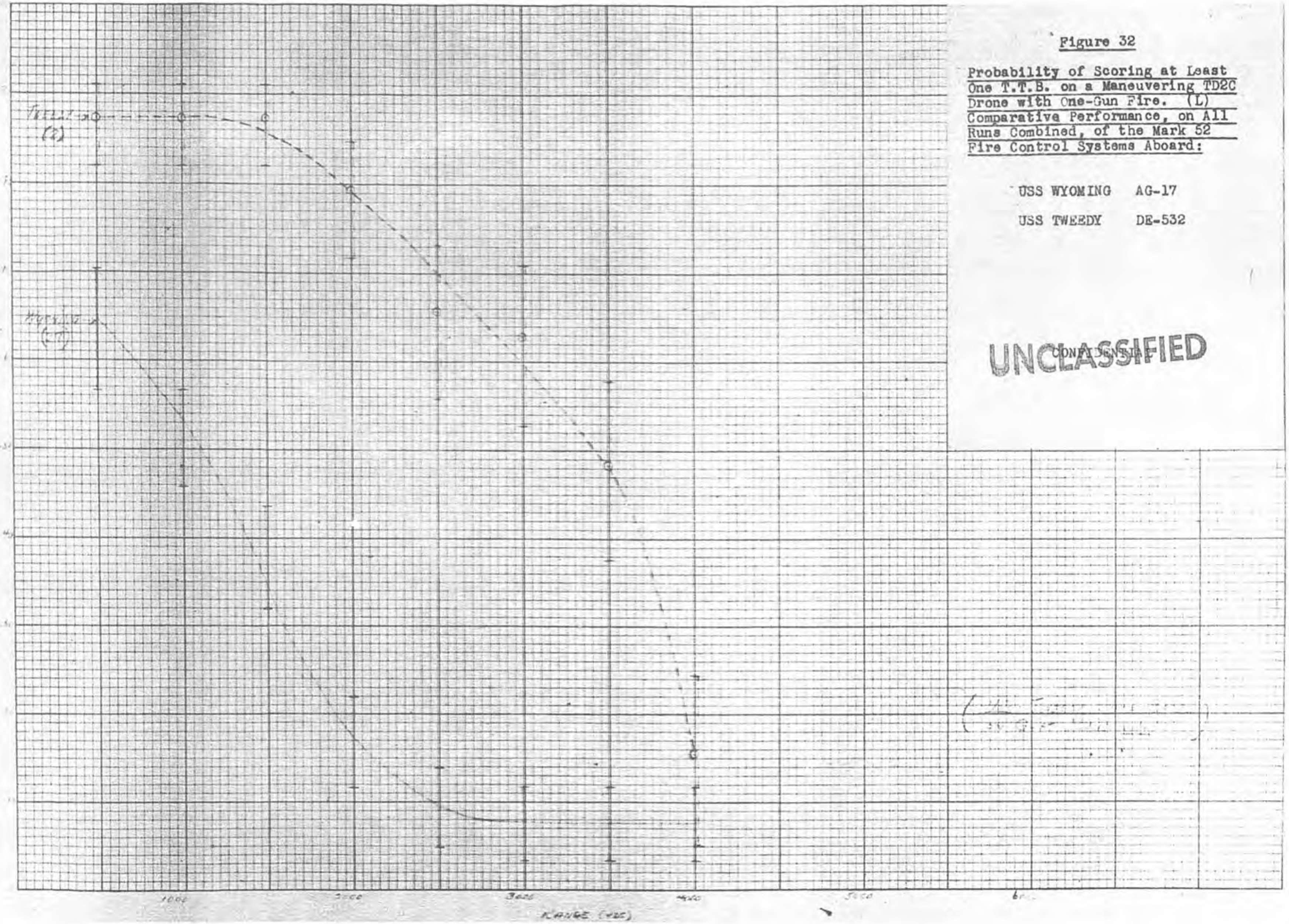

Figure 32

Probability of Scoring at Least One T.T.B. on a Maneuvering TD2C Drone with One-Gun Fire. (L) Comparative Performance, on All Runs Combined, of the Mark 52 Fire Control Systems Aboard:

USS WYOMING AG-17

USS TWEEDY DE-532

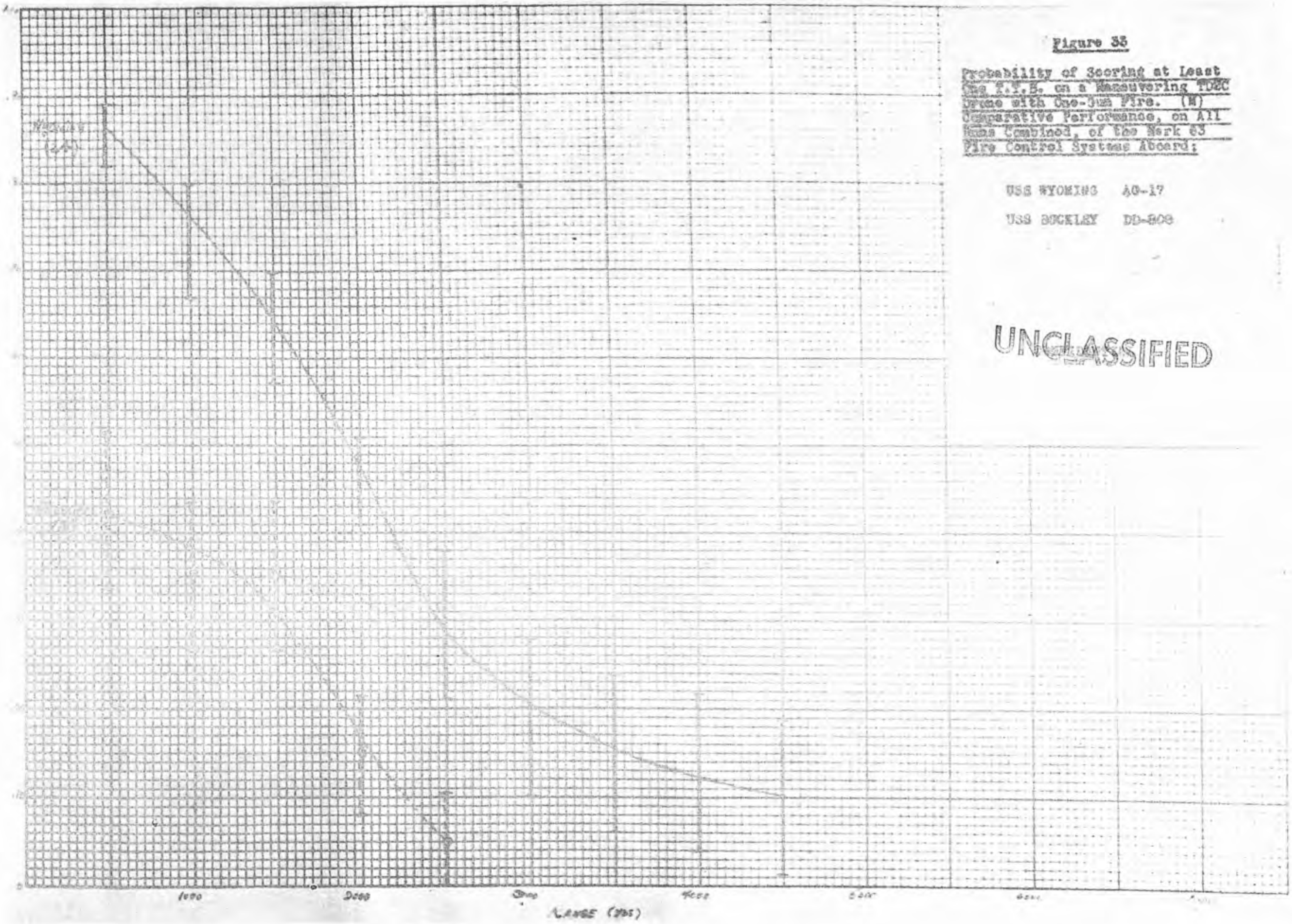

Figure 33

Probability of Scoring at Least One T.T.B. on a Maneuvering TDEC Drone with One-Gun Fire. (M) Comparative Performance, on All Guns Combined, of the Mark 63 Fire Control Systems Aboard:

USS WYOMING AG-17

USS BUCKLEY DD-808

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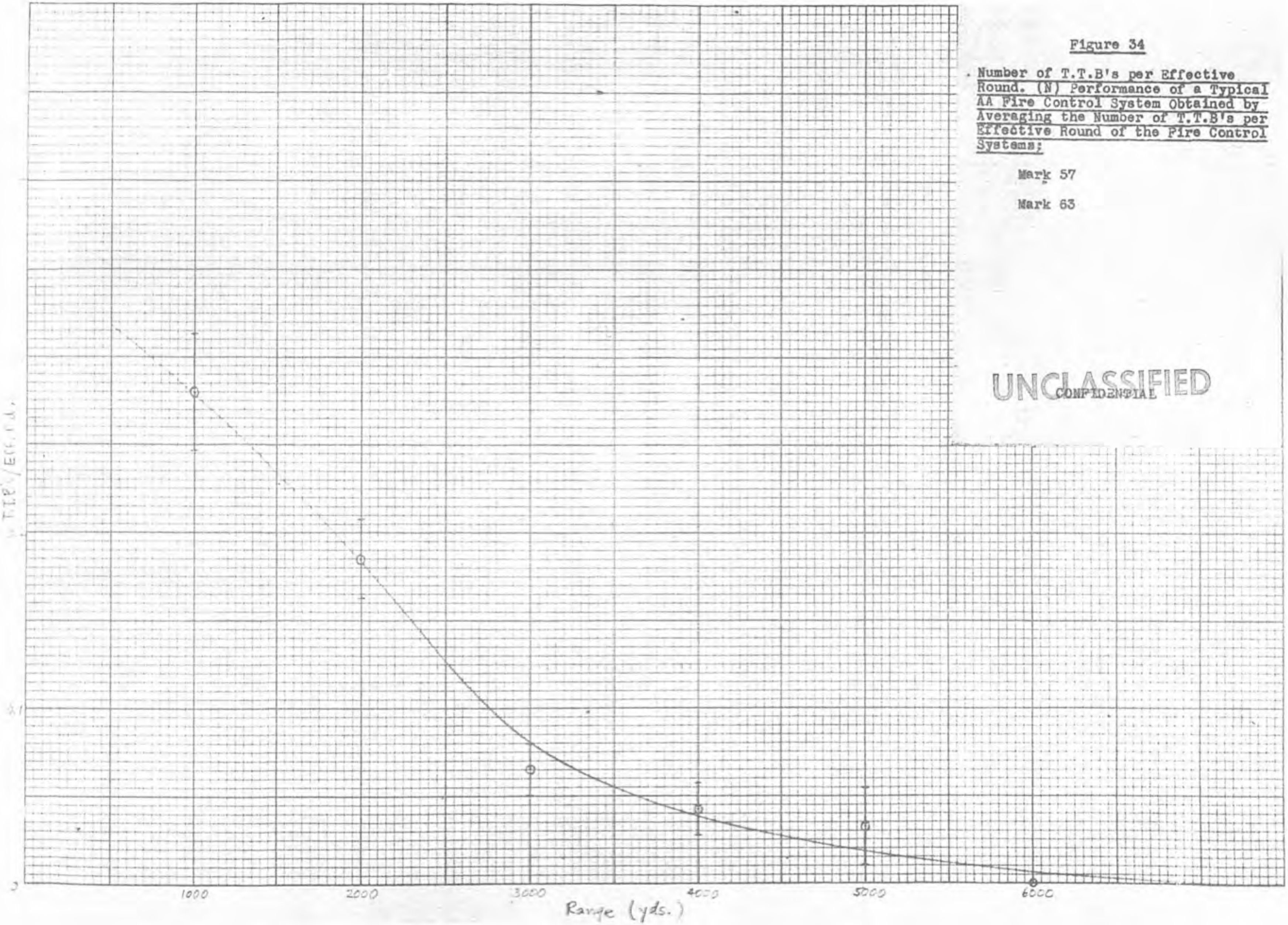
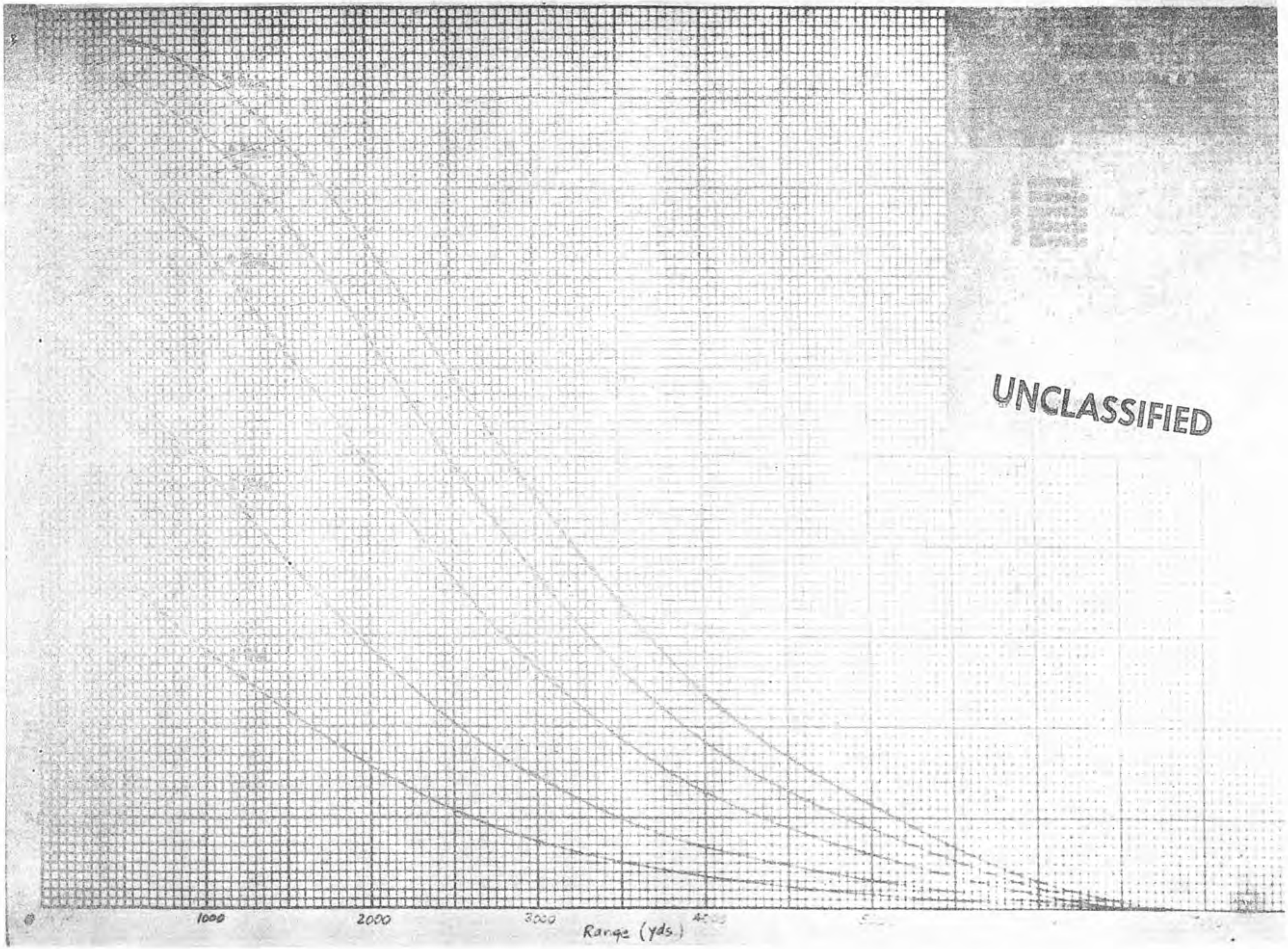


Figure 34

Number of T.T.B's per Effective Round. (N) Performance of a Typical AA Fire Control System Obtained by Averaging the Number of T.T.B's per Effective Round of the Fire Control Systems;

Mark 57

Mark 63



UNCLASSIFIED

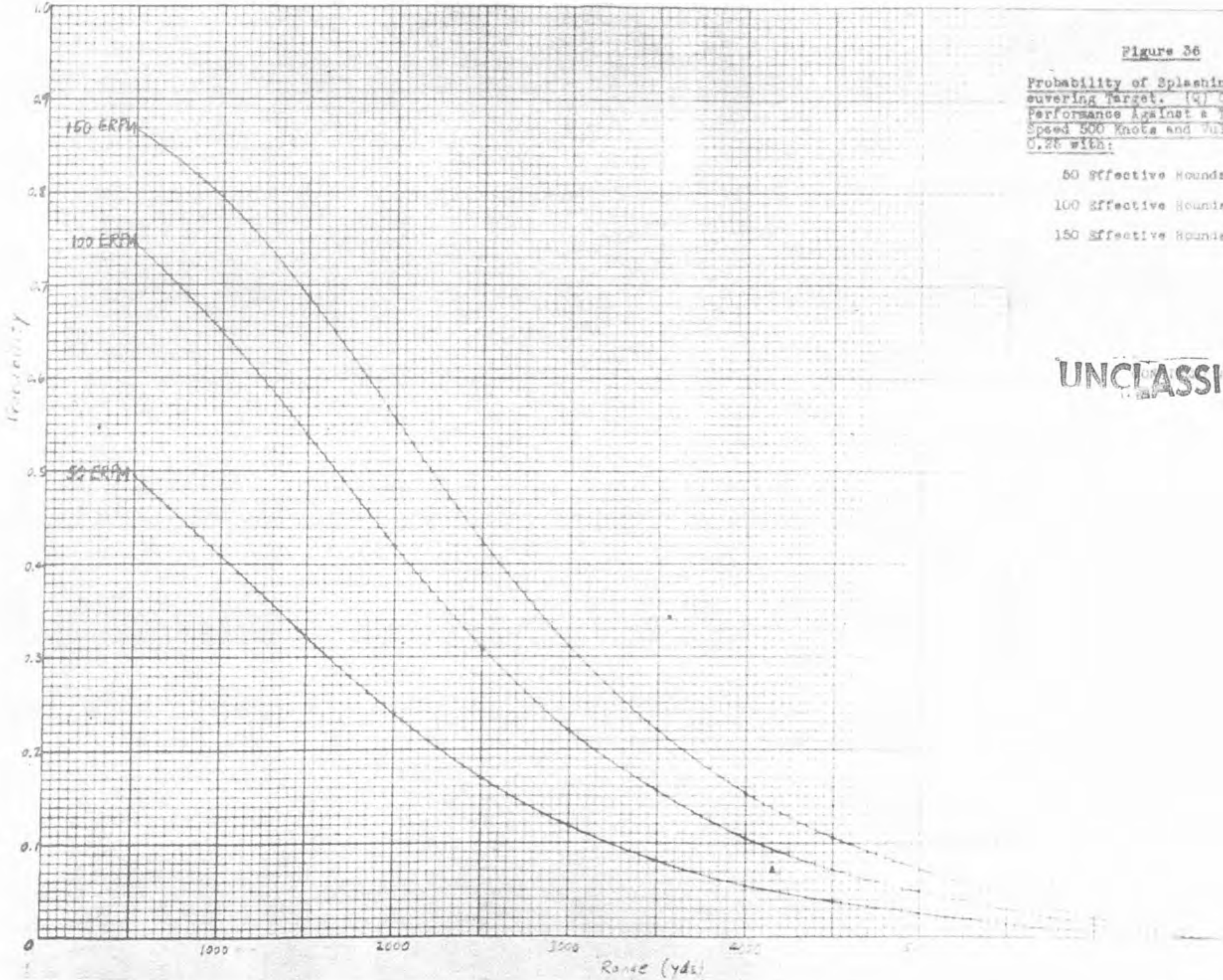


Figure 36

Probability of Splashing a Maneuvering Target. (U) Comparative Performance Against a Target of Speed 500 Knots and Vulnerability 0.25 with:

50 Effective Rounds per Min.

100 Effective Rounds per Min.

150 Effective Rounds per Min.

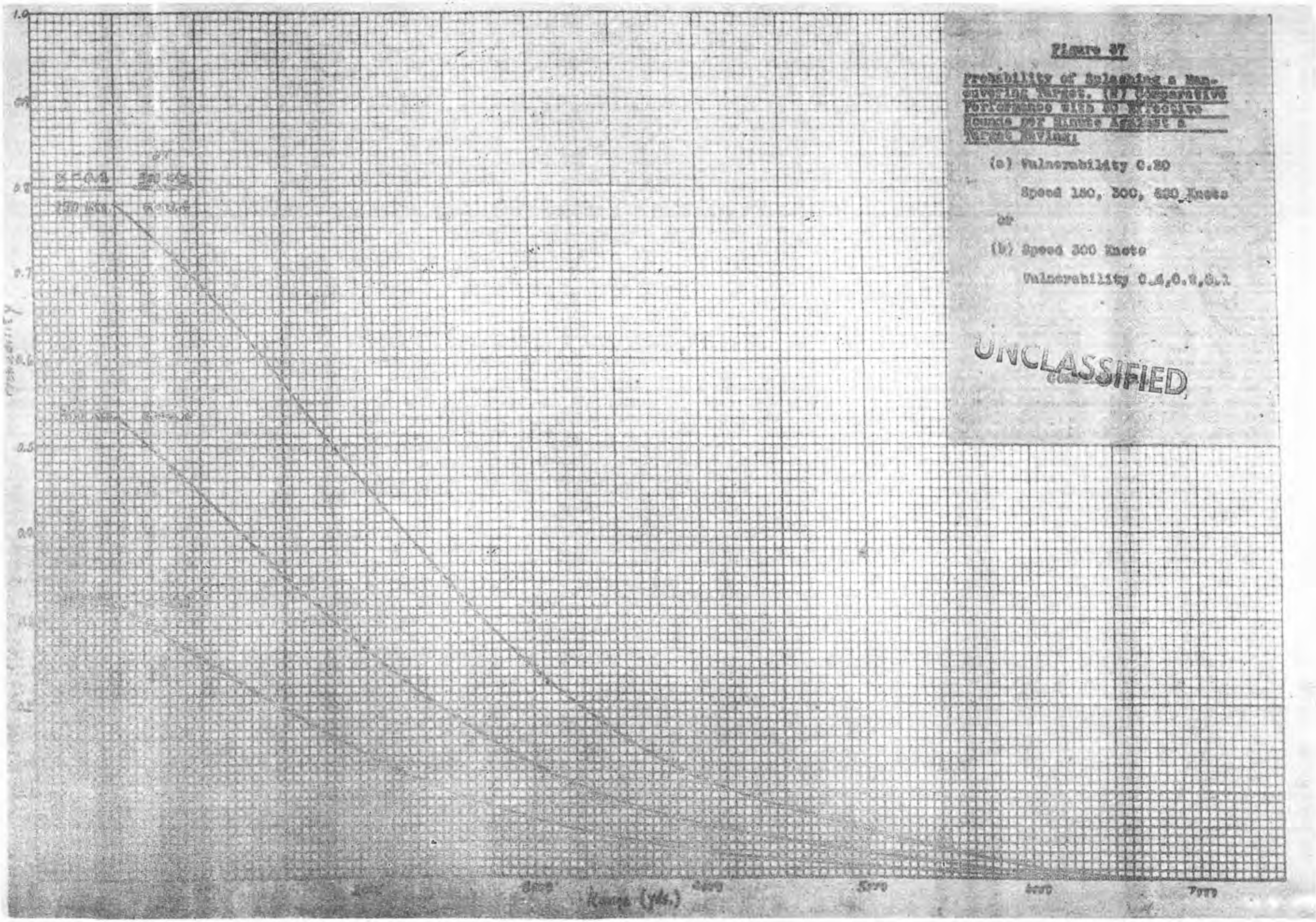


Figure 37

Probability of Splashing a Maneuvering Target. (B) Comparative Performance with 80 Effective Rounds per Minute Against a Target Moving:

(a) Vulnerability 0.80

Speed 180, 300, 600 Knots

or

(b) Speed 300 Knots

Vulnerability 0.4, 0.8, 0.1