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MEMORANDUM REPORT NO. 2035

A GRAPHICAL FIRING TABLE MODEL AND A COMPARISON OF THE ACCURACY OF THREE UTILIZATION SCHEMES

by

James A. Matts
Donald H. McCoy

April 1970

U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

36

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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RDT&E Project No. 1T562603A287

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MEMORANDUM REPORT NO. 2035

JAMatts/DHMcCoy/eaw
Aberdeen Proving Ground, Md.
April 1970

A GRAPHICAL FIRING TABLE MODEL
AND
A COMPARISON OF THE ACCURACY OF THREE UTILIZATION SCHEMES

ABSTRACT

This report presents a mathematical description of a graphical firing table and discusses three different schemes for using the table in the solution of artillery fire problems. A comparison of the effectiveness of the three schemes is made on the basis of the accuracy of the solutions obtained.

TABLE OF CONTENTS

I. THE GRAPHICAL FIRING TABLE

A graphical firing table (GFT) is an instrument closely resembling a slide rule (Figure 1) that is used by the U. S. artilleryman to make a fast, manual computation of the aiming data necessary to hit a target range under nonstandard conditions.

The principal scale printed on the body of the GFT is that of range. Using a set of standard conditions for "met" and materiel, a one-to-one relationship is established between range and elevation, range and fuze setting, range and drift, etc. and transferred to the GFT. Consequently, knowing the linear distance along the range scale to any range "x" will automatically give the distance to all aiming data corresponding to that "x" under standard conditions (Figure 2).

One of the two key relationships needed to describe the GFT then is a function relating the linear distance, s_x, to range "x." The required function is

$$s_x = [(\log x - \log x_m)/(\log x_M - \log x_m)]. s_T, \quad (1)$$

where x_M = maximum range on GFT, x_m = minimum range on GFT, and s_T = total length of range scale (generally $s_T = 1$). In the case of a charged weapon, x_M and x_m change from charge to charge. The reason the range scale is printed according to a logarithmic rule is to simplify the computation of the corrections, as will be shown in Section II.

In the utilization of the GFT, a line representative of the elevation necessary to hit a target under nonstandard conditions must be drawn on the cursor. This "adjusted elevation gageline" prescribes the standard elevation corresponding to the adjusted range, x_A, found by the equation

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$$x_A = x_T + \Delta x_T = x_T + \Delta x/x|_{x_T} \cdot x_T, \qquad (2)$$

where x_T = target range, Δx_T = total range correction to x_T to correct for nonstandard conditions, and $\Delta x/x|_{x_T}$ = percentage change in x_T due to nonstandard conditions (Range K).*

The elevation gageline is drawn in a manner such that the distance between it and the manufacturer's hairline, Δs_{x_T}, corresponds to the total range correction, Δx_T, needed to compensate for nonstandard conditions (Figure 3).

Therefore, a second key relationship required to express the functioning of the GFT is one which relates Δx_T and Δs_{x_T}, as shown below:

$$\Delta s_{x_T} = [s_T/(\log x_M - \log x_m)] \cdot \log(\Delta x/x|_{x_T} + 1), \qquad (3)$$

or

$$\Delta x_T = \Delta x/x|_{x_T} \cdot x_T = \left\{10^{[(\log x_M - \log x_m) \cdot \Delta s_{x_T}/s_T]} - 1\right\} \cdot x_T. \qquad (4)$$

From equations (1) and (3), it is found that the linear distance to the adjusted range, and therefore the adjusted elevation, is

---

*By replacing Range K with Fuze K, the equations appearing in this section and the next will apply to the problem of determining the time gageline. Fuze K is defined as the difference between a given range "x" and the range which under standard conditions has the same time of flight required to hit "x" under the nonstandard conditions divided by "x".

All adjusted aiming data on a GFT can be found by using the elevation gageline and time gageline. For details, see FM6-40.

$$s_{x_A} = s_{x_T} + \Delta s_{x_T} = (\log x_T - \log x_m) \cdot S_T / (\log x_M - \log x_m) + [s_T \cdot \log (\Delta x/x|_{x_T} + 1)] / (\log x_M - \log x_m). \quad (5)$$

One final observation should be made and that is that any straight line drawn on the cursor of the GFT can be written as a linear function of s_x as follows:

$$\Delta s_x = m s_x + b, \quad (6)$$

where "m" and "b" are the slope and the intercept, respectively, of the elevation gageline and will be determined in Section II.

In summary, the mathematical model for a GFT consists of equation (1) which locates each piece of aiming data on the body of the GFT, and equation (5) which locates the "adjusted aiming data." The auxiliary equation (6) will be helpful in the discussion of the GFT schemes in the section that follows.

II. THREE GFT SCHEMES

The artilleryman usually computes the percentage change in range due to nonstandard conditions, $\Delta x/x$, at only one range, say x_R. In reality, the value of $\Delta x/x$ varies with range and the three schemes to be discussed differ in the assumptions that they make concerning how $\Delta x/x$ varies.

A. Constant Range K (Scheme A)

For Scheme A, it is assumed that $\Delta x/x|_{x_R}$ is valid at all ranges; that is, the variation from range to range is 0. Therefore, Δs_{x_T} must be a constant, implying that m = 0 and b = Δs_{x_R} in equation (6) where

$$\Delta s_{x_R} = [S_T \cdot \log (\Delta x/x|_{x_R} + 1)] / (\log x_M - \log x_m). \quad (7)$$

To use the GFT, a line is drawn on the cursor parallel to the manufacturer's hairline at a distance determined by equation (7). If the range scale were not printed according to a logarithmic rule, Δs_{x_T} would not be a constant and the constant Range K Scheme would not be as simple to apply. In fact, this is the very reason that the logarithmic scale was chosen.

B. Average Slope (Scheme B)

In Scheme B, $\Delta x/x$ is assumed to follow an average rate of change. To approximate this rate, an average $\Delta x/x$ was theoretically determined from 50 nonstandard trajectories at each of five ranges($x_1 . . . x_5$).

Using these five values for $\Delta x/x$, it is possible to find an optimum slope, m, for equation (6) by minimizing the error function,

$$F(m,b) = \sum_{i=1}^{5} \left\{ \Delta x/x|_{x_i} - \left[10^{[(\log x_M - \log x_m).(ms_{x_i}+b)/s_T]} - 1 \right] \right\}^2 ,$$

employing a nonlinear least squares technique.

To utilize this scheme, the artilleryman computes $\Delta x/x|_{x_R}$, i.e., the Range K at a registration range x_R. This fixes the value Δs_{x_R} at s_{x_R} and so $b = \Delta s_{x_R} - ms_{x_R}$ where "m" is the optimum slope found above. Therefore, Δs_x is established for each range and, as can be seen from equation (4), $\Delta x/x$ is also determined. To assist the artilleryman in drawing a straight line on the cursor so that Δs_x will actually take on the desired values, a Range K line is printed on the GFT with the required slope (Figure 1).

C. Two-Point Scheme (Scheme C)

With this scheme, it is assumed that the true values of $\Delta x/x$ are known at two ranges, x_2 and x_4. Then Δs_{x_2} and

Δs_{x_4} are also known and a straight line is drawn on the cursor connecting these two points. Thus the slope becomes

$$m = (\Delta s_{x_4} - \Delta s_{x_2})/(s_{x_4} - s_{x_2}),$$

and the value of "b" is fixed by equation (6) as

$$b = \Delta s_{x_i} - m s_{x_i},$$

where i = 2 or 4.

III. TEST CONDITIONS

The accuracy with which each of the three GFT schemes can predict the adjusted elevation was determined for the following weapon/charge combinations, using the nonstandard conditions listed in Tables Ia, Ib, and Ic.

Weapon	Charge
105mm How., M108	1 - 7
155mm How., M109	1G - 5G, 3W - 8
175mm Gun, M107	1 - 3

IV. ACCURACY COMPUTATIONS

Five ranges, corresponding to elevations between 100 and 600 mils, were chosen for each weapon/charge combination. The <u>true</u> value of Range K at each of these ranges for each set of nonstandard conditions was found in the following manner:

$$\text{Range K} = \Delta x_{ij}/x_i;\ i = 1, \ldots, 5 \text{ and } j = 1, \ldots, 50,$$

where Δx_{ij} = the difference between x_i and the range achieved under standard conditions using the elevation required to hit x_i under j^{th} set of nonstandard conditions.

A number of cases could not be computed because the predicted range exceeded the maximum range for the particular charge involved.

The Range K values predicted by each scheme were computed as shown below:

Scheme A

For the j^{th} set of nonstandard conditions, the Range K at the fourth range (registration range), $\Delta x_{4j}/x_4$ was considered true for all ranges within a weapon/charge combination.

Scheme B

For the j^{th} set of nonstandard conditions, the Range K at the i^{th} range was computed using the rule

$$\Delta x_{ij}/x_i = 10^{[(\log x_M - \log x_m) \cdot \Delta s_{x_{ij}}/s_T]} - 1,$$

where $\Delta s_{x_{ij}} = ms_{x_i} + b_j$, m = optimum slope for the weapon/charge combination, and $b_j = \Delta s_{x_{4j}} - ms_{x_4}$, and $\Delta s_{x_{4j}}$ is computed using equation (3) with

$$\Delta x/x|_{x_T} = \Delta x_{4j}/x_4.$$

Scheme C

Two ranges, x_2 and x_4, of each weapon/charge combination were chosen as registration ranges. Therefore, for the j^{th} set of nonstandard conditions the Range K at the i^{th} range is

$$\Delta x_{ij}/x_i = 10^{[(\log x_M - \log x_m) \cdot \Delta s_{x_{ij}}/s_T]} - 1,$$

where

$$\Delta s_{x_{ij}} = m_j s_{x_i} + b_j,$$

$$m_j = (\Delta s_{x_{4j}} - \Delta s_{x_{2j}})/(s_{x_4} - s_{x_2}),$$

$$b_i = \Delta S_{x_{2j}} - m_i S_{x_2}.$$

V. COMPARISON OF ACCURACY RESULTS

To compare the accuracy of the assumptions made by each of the three schemes, the errors in the predicted Range K's were converted to range errors by computing the difference between the true Range K and a predicted Range K at each range for each set of nonstandard conditions and multiplying this difference by the range being considered. For example, if the true Range K for the second set of nonstandard conditions was +5% at 10,000 meters and one of the three predicted values was +3% at this range, the error in range would be (-.02) X 10,000 or -200 meters.

For all weapon/charge combinations, the mean and standard deviation of the range errors were computed at the chosen ranges to reveal, as a function of range, the average range error and standard deviation caused by the various sets of nonstandard conditions. Computed values are listed in Tables IIa and IIb.

The means and standard deviations were then statistically combined with the probable errors in range described below[1]. This converted the range errors into a corresponding decrease in the percent of rounds falling within plus and minus one and two probable errors. If there were no errors, 50% of all rounds would fall within plus and minus one probable error and 82.3% within plus and minus two probable errors. A probable error of 0.3% of range was used to describe the round to round dispersion about the target range and a normal distribution of rounds about these ranges

[1]The statistical methods employed may be found in Introduction to the Theory of Statistics, A. Mood and F. Graybill.

was assumed.

These percents found for all weapon/charge/range combinations are listed in Tables IIIa and IIIb.

VI. SUMMARY AND CONCLUSION

A. Summary

Weapon	Summary of Results					
	The percent of rounds falling within plus and minus					
	One probable error			Two probable errors		
	For a probable error equal to 0.3% of range					
	Graphical Firing Table Scheme					
	A	B	C	A	B	C
105mm	38.95	41.59	49.03	67.95	71.64	81.24
155mm	38.37	41.39	48.66	67.01	71.30	80.79
175mm	28.23	32.60	46.86	50.36	57.69	78.52
	35.18	38.53	48.18	61.71	66.88	80.18

NOTE: If there were no errors involved, 50% of all rounds would fall within ± one probable error and 82.3% within ± two probable errors.

B. Conclusion

This study indicates that Scheme C provides a better representation of the variation of Range K with range than does either Scheme A or B. As a result, it produces more accurate adjusted data for a GFT and permits wider transfer limits. Although Schemes A and B are both easier to apply, since only one Range K value is required, it is recommended that whenever time permits Scheme C should be employed.

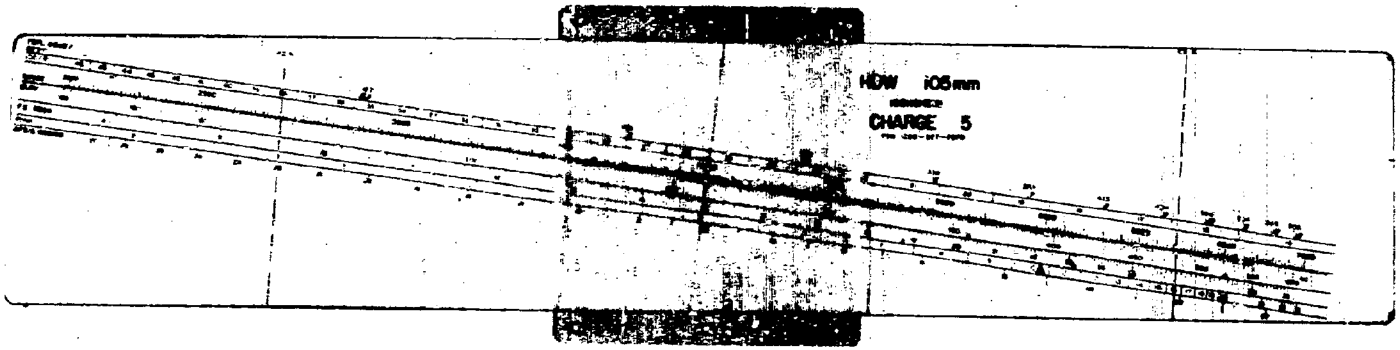

Figure 1. A Graphical Firing Table

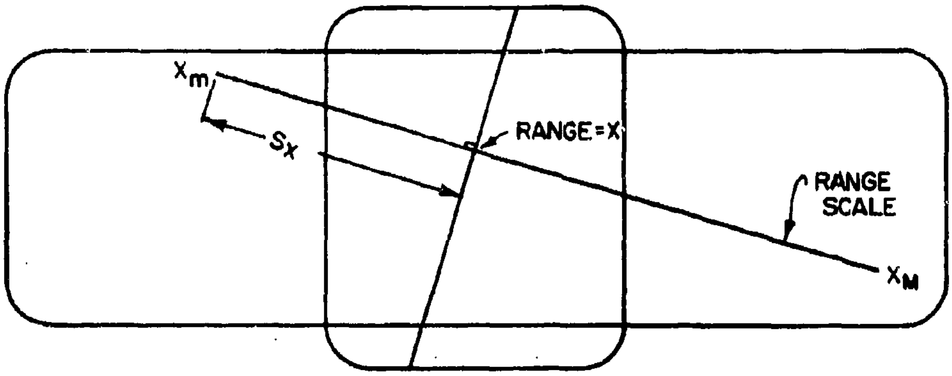

Figure 2

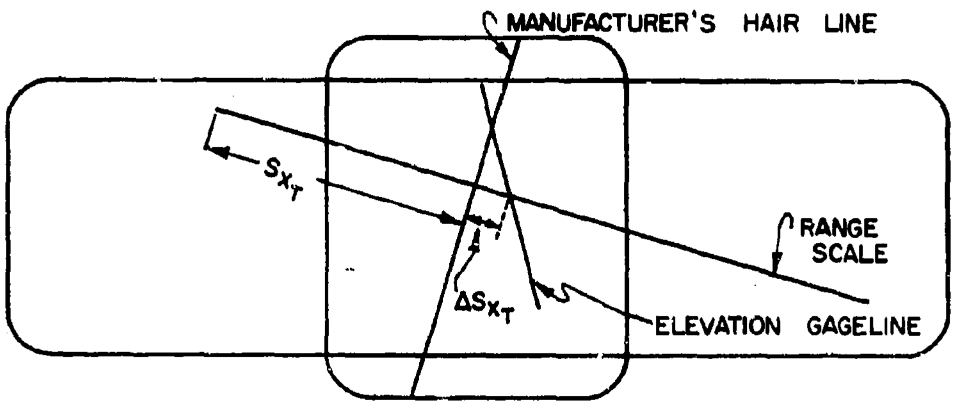

Figure 3

Table Ia. Nonstandard Conditions for 105mm How., M108

NO.	DENSITY	TEMPERATURE	RANGE WIND KNOTS	MUZZLE VELOCITY VARIATION M/S
1	97.1	99.8	- 0.3	-0.35
2	107.3	99.1	- 2.3	-0.06
3	88.2	103.1	- 8.7	-0.34
4	110.1	104.6	-16.6	-0.48
5	92.0	96.9	10.6	-0.07
6	95.7	98.7	0.2	-0.01
7	100.0	107.2	-13.3	-0.09
8	92.5	99.6	14.1	-0.30
9	94.9	101.5	8.8	-0.31
10	94.8	98.1	2.2	-0.01
11	99.7	101.9	9.3	-0.04
12	99.8	99.4	-18.0	-0.24
13	91.4	103.2	0.5	-0.06
14	101.9	95.8	19.6	-0.17
15	87.3	98.9	- 6.1	-0.47
16	98.0	97.7	3.2	-0.43
17	78.7	107.2	9.8	-0.24
18	88.3	99.8	- 2.8	-0.05
19	102.9	104.7	-11.3	-0.10
20	89.9	100.8	- 0.5	-0.16
21	94.0	103.1	8.0	-0.47
22	105.6	102.1	21.5	-0.11
23	95.0	96.0	1.4	-0.34
24	84.0	99.8	0.3	-0.25
25	97.2	106.6	- 2.4	-0.31
26	90.8	95.1	18.3	-0.03
27	86.4	101.2	-12.5	-0.36
28	97.4	106.3	- 8.2	-0.21
29	88.4	102.0	9.6	-0.02
30	83.9	103.4	6.6	-0.44
31	97.3	97.1	24.0	-0.48
32	95.9	95.6	- 1.2	-0.08
33	98.9	99.6	6.3	-0.29
34	90.7	99.7	21.1	-0.13
35	98.9	103.1	2.8	-0.06
36	99.6	98.9	19.2	-0.11
37	94.5	99.6	-16.6	-0.42
38	88.3	99.6	9.2	-0.20
39	97.0	102.3	2.1	-0.02
40	88.3	100.6	3.1	-0.25
41	95.1	100.6	0.5	-0.31
42	96.7	94.1	- 6.8	-0.07
43	88.8	101.2	1.2	-0.08
44	93.5	100.8	-11.0	-0.45
45	98.1	101.4	0.8	-0.36
46	87.3	101.2	-11.2	-0.04
47	91.4	99.8	7.4	-0.06
48	92.3	103.2	24.8	-0.35
49	94.6	95.3	7.4	-0.04
50	88.7	100.3	-17.2	-0.29

Table Ib. Nonstandard Conditions for 155mm How., M109

NO.	DENSITY	TEMPERATURE	RANGE WIND KNOTS	MUZZLE VELOCITY VARIATION M/S
1	97.1	99.8	- 0.3	-1.26
2	107.3	99.1	- 2.3	-0.10
3	88.2	103.1	- 8.7	-1.27
4	110.1	104.6	-16.6	-2.12
5	92.0	96.9	10.6	-0.12
6	95.7	98.7	0.2	0.00
7	100.0	107.2	-13.3	-0.20
8	92.5	99.6	14.1	-0.99
9	94.9	101.5	8.8	-1.04
10	94.8	98.1	2.2	0.00
11	99.7	101.9	9.3	-0.05
12	99.8	99.4	-18.0	-0.70
13	91.4	103.2	0.5	-0.09
14	101.9	95.8	19.6	-0.47
15	87.3	98.9	- 6.1	-2.04
16	98.0	97.7	3.2	-1.76
17	78.7	107.2	9.8	-0.71
18	88.3	99.8	- 2.8	-0.05
19	102.9	104.7	-11.3	-0.24
20	89.9	100.8	- 0.5	-0.42
21	94.0	103.1	8.0	-2.03
22	105.6	102.1	21.5	-0.28
23	95.0	96.0	1.4	-1.18
24	84.0	99.8	0.3	-0.76
25	97.2	106.6	- 2.4	-1.05
26	90.8	95.1	18.3	-0.02
27	86.4	101.2	-12.5	-1.31
28	97.4	106.3	- 8.2	-0.59
29	88.4	102.0	9.6	-0.01
30	83.9	103.4	6.6	-1.83
31	97.3	97.1	24.0	-2.08
32	95.9	95.6	- 1.2	-0.16
33	98.9	99.6	6.3	-0.92
34	90.7	99.7	21.1	-0.32
35	98.9	103.1	2.8	-0.10
36	99.6	98.9	19.2	-0.27
37	94.5	99.6	-16.6	-1.71
38	88.3	99.6	9.2	-0.58
39	97.0	102.3	2.1	-0.01
40	88.3	100.6	3.1	-0.78
41	95.1	100.6	0.5	-1.03
42	96.7	94.1	- 6.8	-0.14
43	88.8	101.2	1.2	-0.16
44	93.5	100.8	-11.0	-1.92
45	98.1	101.4	0.8	-1.33
46	87.3	101.2	-11.2	-0.05
47	91.4	99.8	7.4	-0.09
48	92.3	103.2	24.8	-1.28
49	94.6	95.3	7.4	-0.04
50	88.7	100.3	-17.2	-0.96

Table Ic. Nonstandard Conditions for 175mm Gun, M107

NO.	DENSITY	TEMPERATURE	RANGE WIND KNOTS	MUZZLE VELOCITY VARIATION M/S
1	97.1	99.8	- 0.3	-16.8
2	107.3	99.1	- 2.3	- 0.1
3	88.2	103.1	- 8.7	-16.3
4	110.1	104.6	-16.6	-19.4
5	92.0	96.9	10.6	- 0.1
6	95.[illegible]	98.7	0.2	- 0.0
7	100.0	107.2	-13.3	- 0.3
8	92.5	99.6	14.1	-11.6
9	94.9	101.5	8.8	-12.3
10	94.8	98.1	2.2	- 0.0
11	99.7	101.9	9.3	- 0.1
12	99.8	99.4	-18.0	- 7.5
13	91.4	103.2	0.5	- 0.1
14	101.9	95.8	19.6	- 3.3
15	87.3	98.9	- 6.1	-19.1
16	98.0	97.7	3.2	-17.9
17	78.7	107.2	9.8	- 7.6
18	88.3	99.8	- 2.8	- 0.1
19	102.9	104.7	-11.3	- 0.6
20	89.9	100.8	- 0.5	- 2.3
21	94.0	103.1	8.0	-19.1
22	105.6	102.1	21.5	- 0.9
23	95.0	96.0	1.4	-16.0
24	84.0	99.8	0.3	- 8.4
25	97.2	106.6	- 2.4	-12.4
26	90.8	95.1	18.3	- 0.0
27	86.4	101.2	-12.5	-17.2
28	97.4	106.3	- 8.2	- 5.6
29	88.4	102.0	9.6	- 0.0
30	83.9	103.4	6.6	-18.2
31	97.3	97.1	24.0	-19.3
32	95.9	95.6	- 1.2	- 0.1
33	98.9	99.6	6.3	-10.7
34	90.7	99.7	21.1	- 1.1
35	98.9	103.1	2.8	- 0.1
36	99.6	98.9	19.2	- 0.8
37	94.5	99.6	-16.6	-17.7
38	88.3	99.6	9.2	- 5.3
39	97.0	102.3	2.1	- 0.0
40	88.3	100.6	3.1	- 8.6
41	95.1	100.6	0.5	-12.2
42	96.7	94.1	- 6.8	- 0.1
43	88.8	101.2	1.2	- 0.1
44	93.5	100.8	-11.0	-18.6
45	98.1	101.4	0.8	-17.3
46	87.3	101.2	-11.2	- 0.1
47	91.4	99.8	7.4	- 0.1
48	92.3	103.2	24.8	-16.9
49	94.6	95.3	7.4	- 0.1
50	88.7	100.3	-17.2	-11.2

Table IIa. Mean Range Errors Caused by the Various Sets of Nonstandard Conditions

WPN/CHG	RANGE METERS	MEAN RANGE ERROR METERS			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
	1000	-3.41	0.11	0.84	50
	1600	-3.68	-0.62	0.00	50
105MM 1	2200	-2.59	-0.78	-0.41	50
	2800	0.00	0.00	0.00	50
	3400	4.45	2.19	1.74	50
	1000	-3.84	0.47	1.05	50
	1700	-4.40	-0.51	0.00	50
2	2400	-3.15	-0.81	-0.51	50
	3100	0.00	0.00	0.00	50
	3800	5.40	2.46	2.08	50
	1500	-6.32	0.08	1.36	50
	2300	-6.49	-1.07	0.00	50
3	3100	-4.42	-1.25	-0.63	50
	3900	0.00	0.00	0.00	50
	4700	7.29	3.38	2.62	50
	1500	-7.63	0.13	1.67	50
	2500	-8.26	-1.36	0.00	50
4	3500	-5.72	-1.59	-0.78	50
	4500	0.00	0.00	0.00	50
	5500	9.26	4.08	3.09	50
	2000	-13.28	0.70	2.39	50
	3400	-14.09	-1.48	0.00	50
5	4800	-9.51	-1.94	-1.06	50
	6200	0.00	0.00	0.00	50
	7600	14.98	5.46	4.37	50
	2500	-17.24	0.69	1.56	50
	4000	-16.27	-0.70	0.00	50
6	5500	-10.71	-1.50	-1.10	50
	7000	0.00	0.00	0.00	50
	9000	23.29	7.61	7.00	50
	3500	-24.12	-0.22	-3.07	50
	5300	-17.58	2.49	0.00	50
7	7100	-11.57	0.14	-1.35	50
	8900	0.00	0.00	0.00	50
	10700	20.25	5.89	7.78	50

Table IIb. Standard Deviations Caused by the Various Sets of Nonstandard Conditions

WPN/CHG	RANGE METERS	STANDARD DEVIATION METERS			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
	1000	4.02	4.04	1.03	50
	1600	4.38	4.40	0.00	50
105MM 1	2200	3.12	3.13	0.53	50
	2800	0.00	0.00	0.00	50
	3400	5.74	5.76	2.55	50
	1000	4.45	4.48	1.25	50
	1700	5.13	5.16	0.00	50
2	2400	3.71	3.73	0.63	50
	3100	0.00	0.00	0.00	50
	3800	6.67	6.69	2.82	50
	1500	7.28	7.33	1.61	50
	2300	7.52	7.57	0.00	50
3	3100	5.18	5.20	0.77	50
	3900	0.00	0.00	0.00	50
	4700	8.97	9.00	3.58	50
	1500	8.70	8.77	1.94	50
	2500	9.46	9.52	0.00	50
4	3500	6.57	6.61	0.95	50
	4500	0.00	0.00	0.00	50
	5500	10.90	10.94	3.91	50
	2000	14.46	14.68	3.73	50
	3400	15.00	15.17	0.00	50
5	4800	10.29	10.38	1.89	50
	6200	0.00	0.00	0.00	50
	7600	17.74	17.82	8.49	50
	2500	27.71	28.13	5.10	50
	4000	22.92	23.29	0.00	50
6	5500	13.32	13.54	2.90	50
	7000	0.00	0.00	0.00	50
	9000	27.03	27.31	18.14	50
	3500	40.95	41.46	3.71	50
	5300	35.65	36.06	0.00	50
7	7100	20.42	20.68	3.06	50
	8900	0.00	0.00	0.00	50
	10700	28.39	28.76	16.21	50

Table IIa. Mean Range Errors Caused by the Various Sets of Nonstandard Conditions (Continued)

WPN/CHG	RANGE METERS	MEAN RANGE ERROR METERS			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
	1000	-3.10	0.34	0.71	50
	1600	-3.31	-0.32	0.00	50
155MM 1G	2200	-2.28	-0.51	-0.32	50
	2800	0.00	0.00	0.00	50
	3400	3.63	1.43	1.20	50
	1500	-5.91	0.66	1.22	50
	2300	-6.03	-0.47	0.00	50
2G	3100	-4.08	-0.82	-0.55	50
	3900	0.00	0.00	0.00	50
	4700	6.53	2.52	2.19	50
	1500	-6.96	0.75	1.66	50
	2500	-7.67	-0.80	0.00	50
3G	3500	-5.33	-1.22	-0.75	50
	4500	0.00	0.00	0.00	50
	5500	8.47	3.32	2.73	50
	2000	-12.23	1.33	2.99	50
	3400	-13.69	-1.46	0.00	50
4G	4800	-9.56	-2.22	-1.35	50
	6200	0.00	0.00	0.00	50
	7600	15.49	6.25	5.18	50
	2500	-19.80	0.92	1.82	50
	4200	-19.29	-0.75	0.00	50
5G	5900	-12.70	-1.59	-1.16	50
	7600	0.00	0.00	0.00	50
	9300	18.36	4.43	3.93	50
	2000	-8.92	0.89	1.69	50
	3000	-8.85	-0.65	0.00	50
3W	4000	-5.87	-1.10	-0.72	50
	5000	0.00	0.00	0.00	50
	6000	8.99	3.15	2.70	50
	2000	-12.94	0.97	3.40	50
	3500	-14.96	-2.19	0.00	50
4W	5000	-10.57	-2.85	-1.54	50
	6500	0.00	0.00	0.00	50
	7500	10.75	4.45	3.39	50

Table IIb. Standard Deviations Caused by the Various Sets of Nonstandard Conditions (Continued)

WPN/CHG	RANGE METERS	STANDARD DEVIATION METERS			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
	1000	3.43	3.45	0.82	50
	1600	3.69	3.71	0.00	50
155MM 1G	2200	2.57	2.58	0.39	50
	2800	0.00	0.00	0.00	50
	3400	4.26	4.28	1.56	50
	1500	6.48	6.52	1.42	50
	2300	6.68	6.72	0.00	50
2G	3100	4.58	4.61	0.67	50
	3900	0.00	0.00	0.00	50
	4700	7.91	7.94	3.15	50
	1500	7.44	7.50	1.85	50
	2500	8.27	8.32	0.00	50
3G	3500	5.81	5.84	0.87	50
	4500	0.00	0.00	0.00	50
	5500	9.65	9.69	3.49	50
	2000	12.50	12.64	3.05	50
	3400	13.98	14.10	0.00	50
4G	4800	9.84	9.91	1.45	50
	6200	0.00	0.00	0.00	50
	7600	17.07	17.16	6.66	50
	2500	25.68	26.12	8.12	50
	4200	21.95	22.33	0.00	50
5G	5900	13.80	14.00	4.16	50
	7600	0.00	0.00	0.00	50
	9300	21.88	22.05	13.86	50
	2000	9.58	9.66	1.90	50
	3000	9.58	9.65	0.00	50
3W	4000	6.44	6.48	0.87	50
	5000	0.00	0.00	0.00	50
	6000	10.40	10.45	3.63	50
	2000	13.53	13.68	3.50	50
	3500	15.43	15.56	0.00	50
4W	5000	10.93	11.01	1.63	50
	6500	0.00	0.00	0.00	50
	7500	11.53	11.60	3.99	50

Table IIa. Mean Range Errors Caused by the Various Sets of Nonstandard Conditions (Continued)

WPN/CHG	RANGE METERS	MEAN RANGE ERROR METERS			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
	2500	-18.22	1.04	1.31	50
	4000	-16.91	-0.18	0.00	50
155MM 5W	5500	-10.95	-1.05	-0.96	50
	7000	0.00	0.00	0.00	50
	9000	21.63	4.78	4.67	50
	3500	-30.75	4.29	-2.42	50
	5500	-24.21	5.86	0.00	50
6W	7500	-16.52	1.19	-2.30	50
	9500	0.00	0.00	0.00	50
	11500	29.63	8.15	11.47	49
	5000	-43.48	1.51	-12.79	50
	7000	-24.50	11.53	0.00	50
7W	9000	-11.29	9.24	2.64	50
	11000	0.00	0.00	0.09	50
	13500	31.55	0.80	9.81	50

Table IIb. Standard Deviations Caused by the Various Sets of Nonstandard Conditions (Continued)

WPN/CHG	RANGE METERS	STANDARD DEVIATION METERS			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
	2500	25.03	25.42	6.06	50
	4000	20.48	20.82	0.00	50
155MM 5W	5500	12.09	12.28	3.40	50
	7000	0.00	0.00	0.00	50
	9000	24.41	24.64	16.14	50
	3500	41.55	42.27	4.84	50
	5500	38.31	38.90	0.00	50
6W	7500	22.36	22.75	5.01	50
	9500	0.00	0.00	0.00	50
	11500	28.46	28.91	19.27	49
	5000	49.00	50.03	19.70	50
	7000	42.02	42.63	0.00	50
7W	9000	25.00	25.32	3.17	50
	11000	0.00	0.00	0.00	50
	13500	36.87	37.50	15.58	50

Table IIa. Mean Range Errors Caused by the Various Sets of Nonstandard Conditions (Continued)

WPN /CHG		RANGE METERS	MEAN RANGE ERROR METERS			NO. OF CASES
			GFT SCHEMES			
			A	B	C	
		4500	-77.70	3.68	-1.64	50
		7000	-64.55	4.73	0.00	50
175MH	1	9500	-34.29	6.35	3.49	50
		12000	0.00	0.00	0.00	50
		14000	31.11	-7.48	-4.63	49
		7500	-128.78	-7.40	9.24	50
		10500	-110.05	-12.98	0.00	50
	2	13500	-58.92	-3.66	3.60	50
		16500	0.00	0.00	0.00	50
		19500	31.45	-34.76	-43.20	50
		12000	-229.90	22.77	5.32	50
		17000	-188.19	15.08	0.00	50
	3	22000	-97.30	18.75	9.70	50
		27000	0.00	0.00	0.00	50
		30000	68.47	-10.88	-11.17	49

Table IIb. Standard Deviations Caused by the Various Sets of Nonstandard Conditions (Continued)

WPN /CHG	RANGE METERS	STANDARD DEVIATION METERS			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
175MM 1	4500	61.40	61.88	26.88	50
	7000	62.74	62.83	0.00	50
	9500	39.83	39.85	5.53	50
	12000	0.00	0.00	0.00	50
	14000	32.84	33.02	6.84	49
2	7500	106.62	109.77	14.95	50
	10500	86.08	88.55	0.00	50
	13500	44.31	45.53	15.97	50
	16500	0.00	0.00	0.00	50
	19500	59.04	59.28	64.64	50
3	12000	250.03	260.84	29.50	50
	17000	219.59	228.43	0.00	50
	22000	142.79	147.88	25.84	50
	27000	0.00	0.00	0.00	50
	30000	104.03	107.07	38.61	49

Table IIIa. Percent of Rounds Falling Within One Probable Error

WPN/CHG	RANGE METERS	PERCENT OF ROUNDS FALLING WITHIN ONE PROBABLE ERROR (PROBABLE ERROR=.3% OF RANGE)			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
	1000	33.04	38.24	48.18	50
	1600	39.81	43.27	50.00	50
105MM 1	2200	46.65	47.82	49.90	50
	2800	50.00	50.00	50.00	50
	3400	45.63	46.78	49.13	50
	1000	30.84	36.44	47.33	50
	1700	38.12	42.19	50.00	50
2	2400	46.01	47.47	49.88	50
	3100	50.00	50.00	50.00	50
	3800	45.18	46.57	49.10	50
	1500	29.04	35.03	47.97	50
	2300	36.71	41.11	50.00	50
3	3100	45.40	47.05	49.89	50
	3900	50.00	50.00	50.00	50
	4700	44.42	46.00	49.06	50
	1500	25.34	31.71	47.08	50
	2500	33.91	39.01	50.00	50
4	3500	44.29	46.36	49.87	50
	4500	50.00	50.00	50.00	50
	5500	43.85	45.72	49.13	50
	2000	20.59	27.31	45.38	50
	3400	30.05	36.53	50.00	50
5	4800	42.52	45.46	49.78	50
	6200	50.00	50.00	50.00	50
	7600	42.00	44.52	48.37	50
	2500	16.85	19.58	45.69	50
	4000	27.66	31.77	50.00	50
6	5500	41.80	44.44	49.66	50
	7000	50.00	50.00	50.00	50
	9000	38.17	41.79	45.59	50
	3500	16.32	18.74	48.06	50
	5300	26.76	28.74	50.00	50
7	7100	41.11	42.74	49.76	50
	8900	50.00	50.00	50.00	50
	10700	41.22	43.41	47.19	50

Table IIIb. Percent of Rounds Falling Within Two Probable Errors

WPN/CHG	RANGE METERS	PERCENT OF ROUNDS FALLING WITHIN TWO PROBABLE ERROR (PROBABLE ERROR=.3% OF RANGE)			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
	1000	60.91	68.19	80.38	50
	1600	70.45	74.74	82.27	50
105MM 1	2200	78.72	79.99	82.17	50
	2800	82.27	82.27	82.27	50
	3400	77.57	78.84	81.37	50
	1000	57.53	65.68	79.47	50
	1700	68.21	73.41	82.27	50
2	2400	78.01	79.61	82.14	50
	3100	82.27	82.27	82.27	50
	3800	77.05	78.61	81.35	50
	1500	54.67	63.62	80.15	50
	2300	66.26	72.02	82.27	50
3	3100	77.31	79.15	82.15	50
	3900	82.27	82.27	82.27	50
	4700	76.17	77.96	81.30	50
	1500	48.52	58.60	79.19	50
	2500	62.23	69.24	82.27	50
4	3500	76.02	78.37	82.13	50
	4500	82.27	82.27	82.27	50
	5500	75.50	77.65	81.38	50
	2000	40.16	51.52	77.27	50
	3400	56.38	65.80	82.27	50
5	4800	73.92	77.34	82.04	50
	6200	82.27	82.27	82.27	50
	7600	73.24	76.25	80.57	50
	2500	33.00	38.00	77.62	50
	4000	52.25	58.70	82.27	50
6	5500	72.99	76.15	81.92	50
	7000	82.27	82.27	82.27	50
	9000	68.28	72.90	77.50	50
	3500	32.01	36.46	80.25	50
	5300	50.64	53.88	82.27	50
7	7100	72.05	74.09	82.02	50
	8900	82.27	82.27	82.27	50
	10700	72.24	74.91	79.30	50

Table IIIa. Percent of Rounds Falling Within One Probable Error (Continued)

WPN/CHG	RANGE METERS	PERCENT OF ROUNDS FALLING WITHIN ONE PROBABLE ERROR (PROBABLE ERROR=.3% OF RANGE)			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
155MM 1G	1000	35.40	40.53	48.76	50
	1600	41.78	45.00	50.00	50
	2200	47.53	48.52	49.94	50
	2800	50.00	50.00	50.00	50
	3400	47.27	48.20	49.64	50
2G	1500	30.83	36.95	48.38	50
	2300	38.34	42.68	50.00	50
	3100	46.17	47.70	49.92	50
	3900	50.00	50.00	50.00	50
	4700	45.46	46.90	49.29	50
3G	1500	27.70	34.51	47.24	50
	2500	35.84	41.02	50.00	50
	3500	45.18	47.12	49.88	50
	4500	50.00	50.00	50.00	50
	5500	44.88	46.62	49.31	50
4G	2000	22.49	30.11	45.60	50
	3400	30.97	37.74	50.00	50
	4800	42.75	45.76	49.82	50
	6200	50.00	50.00	50.00	50
	7600	42.06	44.70	48.71	50
5G	2500	16.55	20.83	41.07	50
	4200	27.40	33.48	50.00	50
	5900	41.44	44.76	49.43	50
	7600	50.00	50.00	50.00	50
	9300	41.93	44.65	47.59	50
3W	2000	28.47	35.15	48.32	50
	3000	36.50	41.50	50.00	50
	4000	45.46	47.31	49.91	50
	5000	50.00	50.00	50.00	50
	6000	45.05	46.76	49.39	50
4W	2000	21.30	28.64	44.44	50
	3500	29.67	36.50	50.00	50
	5000	41.99	45.18	49.78	50
	6500	50.00	50.00	50.00	30
	7500	45.73	47.26	49.48	50

Table IIIb. Percent of Rounds Falling Within Two Probable Errors
(Continued)

WPN/CHG	RANGE METERS	PERCENT OF ROUNDS FALLING WITHIN TWO PROBABLE ERROR (PROBABLE ERROR=.3% OF RANGE)			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
	1000	64.44	71.27	80.99	50
	1600	72.99	76.81	82.27	50
155MM 1G	2200	79.68	80.74	82.21	50
	2800	82.27	82.27	82.27	50
	3400	79.40	80.39	81.90	50
	1500	57.57	66.40	80.59	50
	2300	68.52	74.01	82.27	50
2G	3100	78.19	79.86	82.18	50
	3900	82.27	82.27	82.27	50
	4700	77.37	78.98	81.54	50
	1500	52.57	62.87	79.36	50
	2500	65.07	71.91	82.27	50
3G	3500	77.07	79.22	82.15	50
	4500	82.27	82.27	82.27	50
	5500	76.72	78.66	81.56	50
	2000	43.68	56.08	77.55	50
	3400	57.88	67.50	82.27	50
4G	4800	74.21	77.69	82.08	50
	6200	82.27	82.27	82.27	50
	7600	73.34	76.46	80.94	50
	2500	32.50	40.26	71.98	50
	4200	51.99	61.32	82.27	50
5G	5900	72.57	76.54	81.69	50
	7600	82.27	82.27	82.27	50
	9300	73.17	76.40	79.73	50
	2000	53.83	63.81	80.53	50
	3000	66.01	72.53	82.27	50
3W	4000	77.39	79.43	82.18	50
	5000	82.27	82.27	82.27	50
	6000	76.91	78.82	81.65	50
	2000	41.51	53.70	76.22	50
	3500	55.82	65.76	82.27	50
4W	5000	73.27	77.03	82.05	50
	6500	82.27	82.27	82.27	50
	7500	77.69	79.38	81.74	50

Table IIIa. Percent of Rounds Falling Within One Probable Error (Continued)

WPN/CHG	RANGE METERS	PERCENT OF ROUNDS FALLING WITHIN ONE PROBABLE ERROR (PROBABLE ERROR=.3% OF RANGE)			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
	2500	17.39	21.30	44.42	50
	4000	28.49	33.88	50.00	50
155MM 5W	5500	42.34	45.31	49.56	50
	7000	50.00	50.00	50.00	50
	9000	39.58	43.23	46.60	50
	3500	14.78	18.35	47.59	50
	5500	24.74	27.83	50.00	50
6W	7500	39.36	42.25	49.43	50
	9500	50.00	50.00	50.00	50
	11500	39.65	43.92	46.31	49
	5000	15.98	21.58	35.49	50
	7000	28.12	30.23	50.00	50
7W	9000	42.18	42.41	49.78	50
	11000	50.00	50.00	50.00	50
	13500	39.73	43.27	48.09	50

Table IIIb. Percent of Rounds Falling Within Two Probable Errors
(Continued)

WPN/CHG	RANGE METERS	PERCENT OF ROUNDS FALLING WITHIN TWO PROBABLE ERROR (PROBABLE ERROR=.3% OF RANGE)			NO. OF CASES
		GFT SCHEMES			
		A	B	C	
	2500	34.07	41.10	76.13	50
	4000	53.74	61.92	82.27	50
155MM 5W	5500	73.69	77.17	81.82	50
	7000	82.27	82.27	82.27	50
	9000	70.17	74.69	78.64	50
	3500	29.13	35.74	79.74	50
	5500	47.26	52.38	82.27	50
6W	7500	69.81	73.47	81.68	50
	9500	82.27	82.27	82.27	50
	11500	70.34	75.53	78.32	49
	5000	31.51	41.61	64.39	50
	7000	52.93	56.28	82.27	50
7W	9000	73.40	73.68	82.04	50
	11000	82.27	82.27	82.27	50
	13500	70.35	74.74	80.28	50

Table IIIa. Percent of Rounds Falling Within One Probable Error (Continued)

WPN /CHG		RANGE METERS	PERCENT OF ROUNDS FALLING WITHIN ONE PROBABLE ERROR (PROBABLE ERROR=.3% OF RANGE)			NO. OF CASES
			GFT SCHEMES			
			A	B	C	
175MM	1	4500	8.11	16.42	31.26	50
		7000	15.61	23.49	50.00	50
		9500	32.05	37.43	49.49	50
		12000	50.00	50.00	50.00	50
		14000	41.20	44.65	49.63	49
	2	7500	8.29	15.52	44.90	50
		10500	13.71	24.50	50.00	50
		13500	31.11	40.86	48.48	50
		16500	50.00	50.00	50.00	50
		19500	40.61	40.21	38.27	50
	3	12000	7.49	10.72	44.35	50
		17000	12.58	16.75	50.00	50
		22000	25.55	28.87	48.38	50
		27000	50.00	50.00	50.00	50
		30000	37.61	40.04	48.16	49

Table IIIb. Percent of Rounds Falling Within Two Probable Errors (Continued)

WPN /CHG		RANGE METERS	PERCENT OF ROUNDS FALLING WITHIN TWO PROBABLE ERROR (PROBABLE ERROR=.3% OF RANGE)			NO. OF CASES
			GFT SCHEMES			
			A	B	C	
		4500	16.37	32.15	57.90	50
		7000	30.97	44.99	82.27	50
175MM	1	9500	59.42	67.07	81.75	50
		12000	82.27	82.27	82.27	50
		14000	72.28	76.40	81.89	49
		7500	16.67	30.45	76.71	50
		10500	27.68	46.74	82.27	50
	2	13500	50.59	71.70	80.69	50
		16500	82.27	82.27	82.27	50
		19500	71.40	70.89	68.31	50
		12000	14.96	21.24	76.05	50
		17000	24.95	32.78	82.27	50
	3	22000	48.68	54.09	80.58	50
		27000	82.27	82.27	82.27	50
		30000	67.41	70.63	80.35	49

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13. ABSTRACT

This report presents a mathematical description of a graphical firing table and discusses three different schemes for using the table in solution of artillery fire problems. A comparison of the effectiveness of the three schemes is made on the basis of the accuracy of the solutions obtained.

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