AD 866669

BRL MR 2027

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MEMORANDUM REPORT NO. 2027

A COMPARATIVE STUDY OF BALLISTIC METEOROLOGICAL SYSTEMS

by

James A. Matts
Donald H. McCoy

February 1970

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

37

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FEBRUARY 1970

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James A. Matts
Donald H. McCoy

Exterior Ballistics Laboratory

RDT&E Project No. 1T562603A287

ABERDEEN PROVING GROUND, MARYLAND

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JAMatts/DHMcCoy/ajb
Aberdeen Proving Ground, Md.
February 1970

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ABSTRACT

Two proposed ballistic meteorological correction systems are presented and discussed. A statistical treatment of theoretical data is given to indicate which system is less degrading to the accuracy of the artillery fire problem solution.

TABLE OF CONTENTS

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I. INTRODUCTION

During recent years, there has been much discussion among the member nations of NATO concerning the content and format of the ballistic meteorological message. Several proposals have been made regarding the choice of parameters to define the atmosphere in the met message. Two of the proposed systems are as follows:

A. Density Aloft - Temperature Aloft,

B. Ground Pressure - Temperature Aloft.

A discussion of these and the results of a study conducted for the purpose of theoretically determining which system offers the more accurate solution to an artillery fire problem are presented in the following pages.

II. EXPLANATION OF ATMOSPHERIC DESCRIPTORS

A. System A, Density Aloft - Temperature Aloft. For this system, the standard atmospheric density and temperature are given as functions of altitude and are exact for all standard firing table trajectories (Figure 1a). Perturbations in density and temperature (Figures 1b and 1c), which are used to compute unit range corrections, are introduced by using constant multiplicative factors to increase or decrease the standard values. In general, density and temperature are perturbed independently and the resultant atmospheres are physically inconsistent. Changes in density affect the drag of a projectile directly, while changes in temperature produce an affect only through a change in Mach number.

B. System B, Ground Pressure - Temperature Aloft. The standard atmospheric temperature, as in System A, is given as a function of altitude. Standard pressure is computed by the hydrostatic equation,

$$\frac{dP}{dy} = -k \frac{P(y)}{T(y)},$$

with standard ground pressure given as an initial condition. Standard atmospheric density is computed from the perfect gas law,

$$\rho(y) = k \frac{P(y)}{T(y)}.$$

A change in ground pressure produces a constant percent change in pressure aloft which in turn produces the same constant percent change in density aloft. Thus unit range corrections for ground pressure in this system are the same as those for density in the Density Aloft - Temperature Aloft System (Figures 2a and 2b).

Temperature perturbations are also introduced in the same manner as in System A. Using the perturbed temperature structure, and standard ground pressure, in both the hydrostatic equation and the perfect gas law, gives - one, a variation in pressure aloft which increases or decreases with altitude; and two, a change in density which varies with altitude. Figures 2c and 2d show the density and temperature perturbations which were used to compute unit range corrections for temperature.

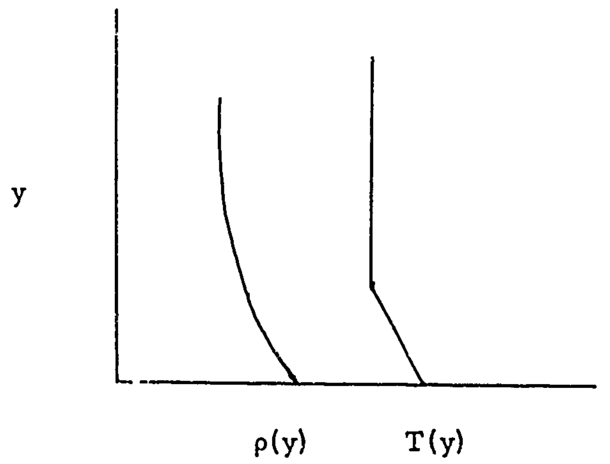

Figure 1a

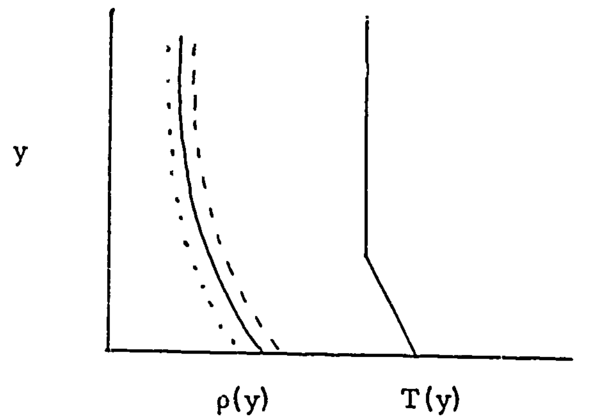

Figure 1b

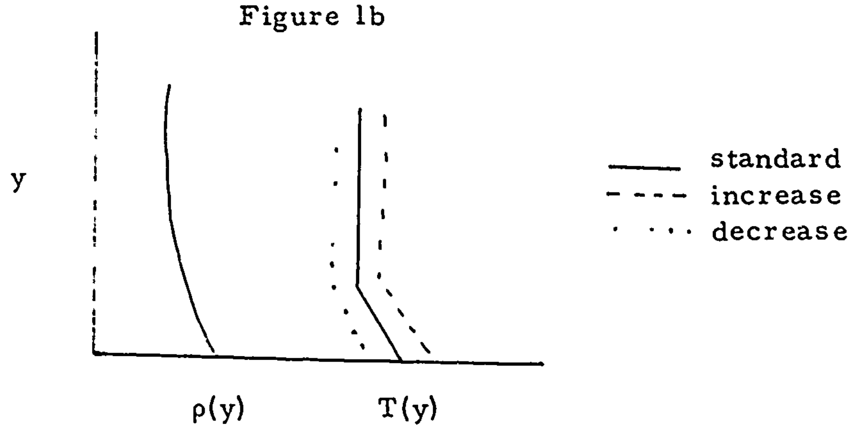

Figure 1c

Figure 1. Atmospheric Profiles for the Density Aloft – Temperature Aloft System

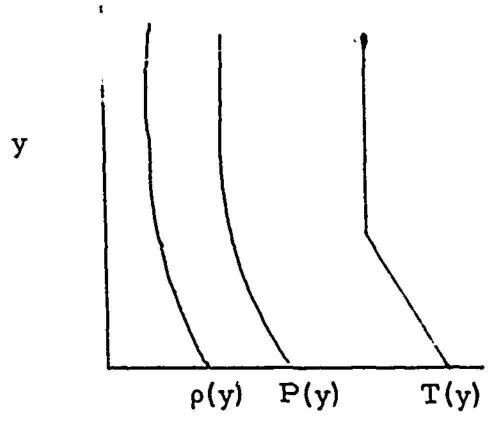

Figure 2a

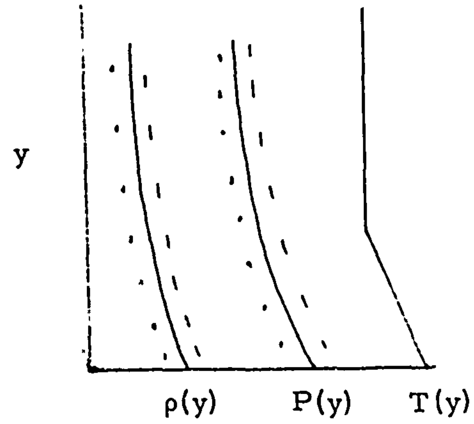

Figure 2b

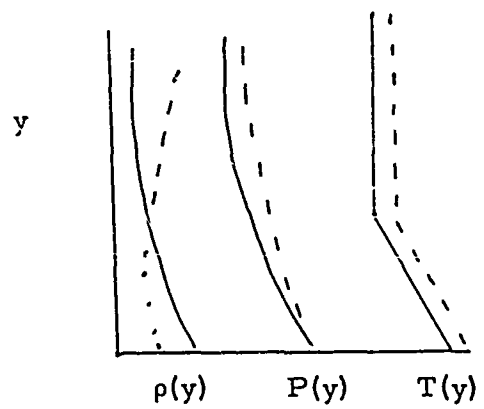

Figure 2c

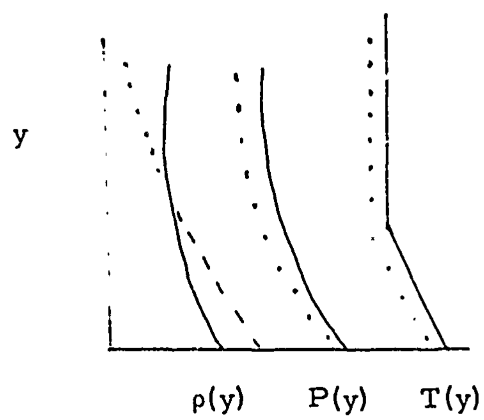

Figure 2d

—— standard
- - - increase
. . . decrease

Figure 2. Atmospheric Profiles for Ground Pressure – Temperature Aloft System

III. FIRING TABLES

For purposes of this study, special firing tables were prepared for the following weapon systems:

Weapon Nomenclature	Projectile Nomenclature	Charge Numbers
M108 (105mm)	HE, M1	1-7
M109 (155mm)	HE, M107	1G-5G, 3W-7W, 8 *
M107 (175mm)	HE, M437	1-3
Honest John Rocket	M50 (Light)	-

The tables contain standard range/elevation relationships and bilinear columns of unit range corrections for density and temperature in the case of System A, and for ground pressure and temperature aloft in the case of System B. It is to be noted that System B requires the addition of two columns of temperature range corrections for each entry having an associated line number above 9. This is because the change in density, resulting from a constant change in temperature, reverses direction at about line 9. To allow for an increase and decrease in density during a single trajectory, obviously requires an extra degree of freedom in the system. In this case, one other temperature correction column was added to the firing tables.

Quadrant elevations are determined from the tables, using corrected entry ranges. These are computed for the two systems as follows: for System A,

$$CER = ER + \frac{\Delta x}{\Delta \rho} \left| B_{\rho} - 100 \right| + \frac{\Delta x}{\Delta T} \left| B_{T} - 100 \right|$$

*In Tables V and VI, charges 1G - 5G are designated as 1-5; 3W - 7W as 6-10; and charge 8 as 11.

and for System B,

$$CER = ER + \frac{\Delta x}{\Delta P_o} |P_o - 100| + \left(\frac{\Delta x}{\Delta T}\right)_L |B_{TL} - 100| + \left(\frac{\Delta x}{\Delta T}\right)_U |B_{TU} - 100|$$

where

CER	=	corrected entry range in meters,
ER	=	entry range in meters,
$\frac{\Delta x}{\Delta \rho}$	=	unit range correction for density in meters per percent,
$\frac{\Delta x}{\Delta P_o}$	=	unit range correction for ground pressure in meters per percent,
$\frac{\Delta x}{\Delta T}$	=	unit range correction for temperature in meters per percent,
$\left(\frac{\Delta x}{\Delta T}\right)_L$	=	unit range correction for temperature for the lower line numbers in meters per percent,
$\left(\frac{\Delta x}{\Delta T}\right)_U$	=	unit range correction for temperature for the upper line numbers in meters per percent,
B_ρ	=	ballistic density in percent of standard,
P_o	=	ground pressure in percent of standard,
B_T	=	ballistic temperature in percent of standard,
B_{TL}	=	ballistic temperature for the lower line numbers per percent of standard
B_{TU}	=	ballistic temperature for the upper line numbers per percent of standard.

IV. COMPUTATION OF WEIGHTING FACTORS

A. System A, Density Aloft - Temperature Aloft Weighting Factors.

Both density and temperature weighting factors are required by System A. The ones for density are those previously agreed upon among the NATO nations, whereas those for temperature were computed. (Tables I and II).

In order to obtain the optimum temperature weighting factors for this system, it was necessary to compute individual weighting factors and functions. This was done using temperature perturbations of -10%, -5%, +5% and +10% and the following weapon system/line number combinations:

Weapon Nomenclature	Projectile Nomenclature	Charge Numbers	Line Numbers
M108 (105mm)	HE, M1	1-7	1-8
M109 (155mm)	HE, M107	1G-5G, 3W-7W, 8	1-10
M107 (175mm)	HE, M437	1-3	1-15
Honest John Rocket	M50 (Light)	-	1-15

For purposes of the computation, the atmosphere was divided into layers (zones) as determined by NATO line numbers - each line number, n, contains n layers. Then the procedure followed in finding the temperature weighting factors was that indicated below.

- The quadrant elevation to achieve the top of a line, under standard conditions, was determined.
- This quadrant elevation was used in the computation of a trajectory to determine a range effect, E_i, due to the introduction of the temperature perturbation in each layer.

Table I. Density Weighting Factors

Line No.	Zone No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.00														
2	.43	.57													
3	.22	.31	.47												
4	.15	21	.32	.32											
5	.11	.17	.25	.22	.25										
6	.08	.11	.17	.17	.15	.32									
7	.06	.08	.14	.13	.12	.22	.25								
8	.05	.06	.11	.11	.10	.19	.17	.21							
9	.04	.06	.09	.09	.08	.17	.15	.14	.18						
10	.03	.04	.07	.07	.07	.13	.12	.11	.11	.25					
11	.01	.03	.05	.05	.06	.12	.11	.09	.09	.16	.23				
12	.02	.03	.05	.05	.05	.11	.10	.09	.08	.14	.12	.16			
13	.02	.02	.04	.05	.05	.11	.09	.09	.08	.14	.10	.09	.12		
14	.02	.03	.05	.05	.05	.10	.09	.08	.07	.13	.11	.08	.06	.08	
15	.02	.04	.05	.05	.05	.10	.09	.08	.07	.12	.09	.08	.05	.05	.06

Table II. Temperature Weighting Factors

Line No.	Zone No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.00														
2	.30	.70													
3	.09	.24	.67												
4	.05	.12	.33	.50											
5	-.02	.02	.17	.33	.50										
6	-.01	.01	.07	.14	.20	.59									
7	.04	.07	.12	.12	.12	.26	.27								
8	.04	.06	.10	.10	.10	.20	.20	.20							
9	.04	.05	.09	.09	.09	.17	.16	.16	.15						
10	.03	.05	.08	.08	.07	.14	.13	.12	.11	.19					
11	.03	.04	.07	.07	.07	.12	.11	.10	.10	.16	.13				
12	.03	.04	.07	.06	.06	.11	.11	.10	.09	.15	.11	.07			
13	.03	.05	.07	.07	.07	.13	.11	.10	.09	.14	.09	.05	.00		
14	.05	.07	.12	.11	.11	.20	.17	.15	.12	.17	.08	-.02	-.12	-.21	
15	.04	.05	.08	.08	.08	.15	.13	.11	.10	.17	.11	.06	.00	-.05	-.11

- A weighting factor, W_i, was computed for each layer,

$$W_i = E_i / \sum_{i=1}^{n} E_i , \qquad i = 1, 2, \ldots, n.$$

- A weighting function was then determined by

$$\Lambda(h_j) = 1 - \sum_{i=1}^{j} W_i , \qquad j = 1, 2, \ldots, n,$$

where $\Lambda(h_j)$ = weighting function,

and h_j = (height, top of zone)/(height, top of layer).

Several approaches were tried in an effort to determine the optimum temperature weighting function for a given line number that could be utilized with all equipment. Because of the scatter produced in these data by the nonlinearity of the Mach number effect, this task was found to be nearly impossible. However, the weighting function was forced to fit a parabola, with the sum of the residual errors equal to zero. Weighting factors were determined from these curves and are those appearing in Table II.

B. System B, Ground Pressure - Temperature Aloft Weighting Factors

Ground pressure weighting factors are, of course, not required. The difference between the measured ground pressure and the standard value is computed merely as a percent of standard in order to determine the necessary range correction.

The temperature weighting factors for System B are, for line numbers one through nine, the same as those given in FM 6-16; and for numbers ten through fifteen, the ones that w re computed by Denmark and the United Kingdom. The complete set, ines one through fifteen, are given in Table III.

V. ATMOSPHERIC PROFILES

A. Raw Met Data

Nineteen nonstandard tempera re profiles were furnished the BRL by the United Kingdom. These temperature structures, when used with the standard ground pressure, provided the pressure and density profiles utilized throughout this study.

B. Ballistic Met Data

The raw met data were zoned and weighted in order to prepare ballistic met messages for both meteorological correction systems from the nineteen nonstandard profiles. *

VI. DETERMINATION OF RANGE ERRORS

In order to prove which met correction system was more accurate, the errors introduced by each system had to be theoretically determined. This was done as follows:

. Five target ranges were chosen for each tube artillery weapon, and twenty-four for the Honest John Rocket.

* Refer to FM 6-15.

Table III. Temperature Weighting Factors

Line No.	Zone No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.00														
2	.27	.73													
3	.13	.20	.67												
4	.08	.12	.25	.55											
5	.05	.10	.20	.21	.44										
6	.04	.04	.09	.11	.13	.59									
7	.02	.04	.07	.09	.11	.26	.41								
8	.01	.03	.05	.04	.10	.19	.23	.35							
9	.01	.01	.02	.03	.03	.09	.13	.24	.44						
10	.00	.00	.00	.00	.00	-.03	.02	.07	.13	.81					
11	.00	.00	.00	.00	.00	.00	.00	-.03	.02	.17	.84				
12	.00	.00	.00	.00	.00	.00	.00	.00	.00	-.02	.16	.86			
13	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-.02	.14	.88		
14	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-.01	.14	.87	
15	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.10	.29	.61

- Using the specially prepared firing tables, an adjusted elevation was computed at each target range by making range corrections for each of the 19 nonstandard atmospheric profiles.
- With each of the adjusted elevations, a trajectory was computed using the associated nonstandard met.
- The difference between these trajectory ranges and the target ranges gave the range errors due to the particular met correction system, since all other conditions remained standard.

All trajectories were computed with the following mathematical model:

$$\dot{\vec{u}} = \left\{ \left[-\rho(y) \cdot v \cdot K_D(M) \cdot \vec{v} \right] / C \right\} - \vec{g},$$

$$\vec{v} = \vec{u} - \vec{w},$$

where

$\dot{\vec{u}}$ = acceleration of the projectile w. r. t. ground,

$\vec{u}$ = velocity of the projectile w. r. t. ground,

$\vec{w}$ = velocity of the air w. r. t. ground,

$\vec{v}$ = velocity of the projectile w. r. t. air,

$\vec{g}$ = acceleration due to gravity,

$\rho(y)$ = air density given as a function of height,

$K_D(M)$ = drag coefficient given as a function of Mach number,

M = Mach number,

and C = ballistic coefficient.

There were 2451 range errors computed for each met correction system. The mean and standard deviation of these range errors for a given weapon, charge, and range are listed in Table IV.

VII. TECHNIQUES OF ANALYSIS AND SUMMARY OF RESULTS

In making an analysis of the range errors introduced by each of the met correction systems, it was decided that they should be compared on the basis of common criteria.

Range impacts were assumed to be normally distributed about each target range. For the tube artillery systems, two approximations were made of dispersion; first, that it had a probable error equal to .3% of range; secondly, that it had a probable error equal to .6% of range. With the Honest John Rocket, for ranges less than 17,500 meters, the range probable error was defined by the following expression:

$$PE = \left[.01 + .006217\,(.001\ RN - 17.5)^2 \right] RN.$$

For ranges greater than 17,500 meters, the probable error was said to be 1% of range.

If no errors were introduced by the unit corrections and ballistic met messages, 50% of all rounds fired on a single occasion would be expected to fall within plus and minus one probable error of the target range, and 82.3% of these rounds would be expected to fall within plus and minus two probable errors. However, when errors due to imprecise met corrections are introduced, it would be expected that fewer rounds would fall within the above limits. The theoretical met range error distribution was statistically combined with the assumed normal distribution of ranges in order to estimate the probability of rounds falling within one probable error and within two probable errors

Table IV. Range Errors

Wpn	Chg	Line No.	Range Meters	Mean Range Errors In Meters For Met System A	Mean Range Errors In Meters For Met System B	Standard Deviations In Meters For Met System A	Standard Deviations In Meters For Met System B
		0	900	- 0.3	- 0.4	0.02	0.11
		1	1800	- 0.7	- 0.5	0.29	0.38
105MM	1	1	2800	1.1	0.8	0.94	0.83
		4	3400	0.2	- 0.6	0.49	0.86
		4	2700	0.9	- 0.1	0.88	0.62
		0	1100	- 0.5	- 0.2	0.41	0.21
		1	2200	0.4	0.5	0.25	0.33
	2	1	3200	1.7	1.7	1.45	1.24
		4	3900	1.5	0.3	1.58	0.85
		5	3300	0.2	- 0.8	0.65	0.95
		0	1300	0.0	- 0.2	0.29	0.09
		1	2600	0.4	0.3	0.30	0.74
	3	2	3900	0.4	- 0.1	0.49	1.17
		5	4700	1.1	- 0.5	1.20	1.42
		5	3900	1.7	0.0	2.35	1.04
		0	1600	0.1	0.3	0.58	0.68
		1	3200	0.0	0.5	1.22	1.70
	4	2	4700	0.8	0.6	1.46	2.58
		5	5700	2.6	0.1	3.32	2.75
		6	4800	- 1.6	- 4.3	2.56	5.16
		0	2000	1.2	3.3	3.50	2.48
		1	4100	4.1	7.9	7.99	7.19
	5	2	6100	3.2	5.7	11.97	13.00
		6	7300	-36.3	-35.1	39.69	42.25
		7	6000	-31.1	-34.8	34.49	39.81
		0	2400	- 2.1	1.5	2.74	1.3
		1	4800	5.7	12.8	12.17	12.32
	6	3	7200	-10.1	- 3.8	9.43	11.63
		7	8000	-30.2	-35.8	30.99	42.89
		8	6800	-35.8	-41.5	36.28	47.61
		0	2900	1.4	1.9	1.28	1.48
		2	5800	- 6.9	2.6	7.49	3.64
	7	3	8600	12.4	19.6	15.12	13.05
		8	10400	-17.4	-22.1	29.02	39.07
		9	8200	-19.5	-32.8	30.62	49.73

Tabie IV. Range Errors (Continued)

Wpn	Chg	Line No.	Range Meters	Mean Range Errors In Meters For Met System A	B	Standard Deviations In Meters For Met System A	B
		0	1000	0.1	0.5	0.27	0.07
		1	2000	- 0.2	- 0.1	0.18	0.27
155MM	1	1	3100	0.8	1.0	1.17	1.16
		4	3700	0.4	- 0.3	0.59	0.95
		5	2900	- 0.7	- 1.1	0.33	1.18
		0	1300	0.0	0.3	0.07	0.17
		1	2600	- 0.1	0.3	0.21	0.39
	2	2	3800	- 0.3	- 0.2	0.28	0.81
		5	4600	- 0.2	- 1.0	0.33	1.46
		5	3600	0.3	- 0.3	0.91	0.96
		0	1600	- 0.6	- 0.4	0.10	0.14
		1	3200	0.0	0.2	0.48	0.68
	3	2	4800	1.1	0.7	1.26	1.34
		5	5800	2.6	0.7	3.23	1.53
		6	4500	- 0.8	- 2.4	1.00	3.26
		0	2000	0.4	0.9	4.56	4.58
		1	4100	2.5	3.9	9.59	9.93
	4	2	6100	3.8	4.0	11.71	13.12
		6	7300	- 7.5	- 9.4	14.79	17.35
		7	5800	- 8.9	-10.4	13.86	15.39
		0	2500	- 2.5	1.0	2.61	1.77
		1	5000	6.3	12.4	11.79	12.19
	5	3	7500	-11.8	- 6.6	10.67	13.19
		7	9000	-35.4	-40.1	33.59	44.87
		8	7000	-35.5	-41.1	33.59	44.08
		0	1700	- 0.5	- 0.8	0.19	0.33
		1	3400	0.6	1.2	0.58	0.77
	6	2	5000	1.3	0.9	1.44	1.48
		5	6100	3.5	1.7	3.97	1.92
		6	4700	- 0.8	- 2.6	0.67	3.09
		0	2100	1.0	1.9	5.33	5.26
		1	4200	4.6	6.4	11.75	12.00
	7	2	6200	4.4	5.2	14.83	16.20
		6	7500	-13.7	-15.0	22.86	25.44
		7	5800	-13.7	-15.8	19.82	22.50

Table IV. Range Errors (Continued)

Wpn	Chg	Line No.	Range Meters	Mean Range Errors In Meters For Met System A	Mean Range Errors In Meters For Met System B	Standard Deviations In Meters For Met System A	Standard Deviations In Meters For Met System B
		0	2500	- 3.2	0.2	2.85	1.54
		1	5000	5.9	12.5	12.02	12.27
155MM	8	3	7500	-10.7	- 5.5	10.04	12.45
		7	9000	-33.9	-38.8	32.33	43.84
		8	7000	-34.7	-40.2	33.26	43.86
		0	3000	1.6	1.2	1.69	1.00
		2	6000	- 7.0	1.9	7.58	3.13
	9	3	9000	13.8	19.6	16.43	14.32
		8	10800	-15.4	-20.5	25.27	34.71
		9	8400	-19.3	-31.7	28.49	45.99
		0	3600	1.2	0.6	2.15	1.34
		2	7300	- 4.8	3.1	5.62	3.95
	10	4	11000	7.5	11.5	15.84	9.94
		9	13200	2.2	-11.4	21.52	23.79
		10	10200	-12.8	-29.9	38.92	48.75
		0	4500	5.4	4.5	3.36	1.82
		2	9000	5.2	5.9	7.29	5.67
	11	5	13500	3.2	8.7	16.28	8.12
		10	16900	- 5.3	-16.2	48.50	44.30
		10	15400	- 0.6	-11.0	32.67	33.90
		0	3800	0.7	0.1	2.57	1.10
		2	7600	- 2.6	3.2	4.75	3.82
175MM	1	4	11300	5.0	12.0	16.28	11.52
		9	14300	0.6	-10.7	23.15	25.31
		9	12600	4.4	- 8.2	18.34	17.39
		1	5500	0.7	0.4	2.62	2.01
		2	11100	23.1	11.9	18.37	9.16
	2	5	16600	14.1	15.2	31.20	14.00
		11	20900	-27.1	2.4	63.65	32.71
		12	19100	-26.7	-25.7	89.35	102.45
		1	8200	1.0	- 0.8	5.24	4.52
		3	16400	37.8	8.7	33.81	7.61
	3	7	24500	30.7	0.5	37.66	7.33
		15	30200	-41.3	-13.6	84.07	23.24
		15	28500	-36.0	-14.8	91.20	21.45

Table IV. Range Errors (Continued)

Wpn	Line No.	Range Meters	Mean Range Errors In Meters For Met System A	Mean Range Errors In Meters For Met System B	Standard Deviations In Meters For Met System A	Standard Deviations In Meters For Met System B
M50	0	6000	- 0.5	- 2.6	3.1	0.3
	1	8000	4.5	1.8	5.5	0.6
	1	10000	8.0	2.4	12.7	4.6
	1	12000	20.5	10.8	22.9	11.9
	2	14000	27.5	10.6	24.5	7.1
	2	16000	59.3	30.7	49.3	24.0
	3	18000	66.5	23.5	59.3	18.7
	4	19000	58.7	12.2	51.2	8.3
	4	20000	78.3	23.0	71.3	20.1
	5	21000	83.6	20.3	75.8	17.9
	5	22000	109.6	35.6	104.0	33.0
	6	23000	82.2	11.1	76.2	14.1
	6	24000	110.9	28.3	108.6	27.7
	6	25000	140.6	43.6	146.5	46.3
	7	26000	82.5	34.6	95.3	41.2
	7	27000	111.1	47.7	135.7	58.1
	8	28000	89.5	40.9	109.7	52.8
	9	29000	81.2	29.7	92.0	44.8
	9	30000	113.6	42.8	152.3	59.9
	10	31000	63.8	38.9	60.1	100.4
	10	32000	74.3	-36.8	110.2	33.1
	10	33000	87.6	-53.7	192.4	58.5
	11	34000	12.2	-21.3	38.3	17.3
	11	35000	-144.3	-23.2	189.7	52.7

of the target range. These probabilities, expressed in percent, for the criteria of .3% and .6% of range are listed in Tables V, VI, VII, and VIII for the three tube artillery weapons. In tables V and VI, they appear as a function of weapon, charge, and line number and in Tables VII and VIII, as a function of line number alone. Table IX presents the probabilities that were found for the Honest John Rocket.

VIII. CONCLUSIONS

Prior to this study, it was thought that in the area of lines 10-15, System B, utilizing ground pressure and temperature aloft, should be superior to System A, which uses density and temperature aloft, since it requires an extra range correction for these upper line numbers. The study did indeed show such a superiority for lines 11 and 15, but in the case of lines 10 and 12, this was not found to be true.

Examination of the overall averages, as summarized in Table X, led to the conclusion that the two meteorological correction systems were equivalent from the standpoint of accuracy, since both gave practically the same results in the majority of cases. It was also found that the effectiveness of an individual system was closely related to a particular combination of weapon, line number, and nonstandard met profile.

Table V. The Percent of Rounds Falling Within Plus and Minus One and Two Probable Errors of Target Range, as a Function of Weapon, Charge, and Line No. (Probable Error Equals .3% of Range)

Wpn	Chg	Line No.	Range Meters	One Prob. Error Met System A	One Prob. Error Met System B	Two Prob. Errors Met System A	Two Prob. Errors Met System B
		0	900	49.9	49.8	82.2	82.1
		1	1800	49.8	49.9	82.1	82.1
105MM	1	1	2800	49.7	49.8	82.0	82.1
		4	3400	50.0	49.9	82.2	82.2
		4	2700	49.8	49.9	82.0	82.2
		0	1100	49.6	49.9	81.8	82.2
		1	2200	49.9	49.9	82.2	82.2
	2	1	3200	49.5	49.5	81.7	81.8
		4	3900	49.7	49.9	81.9	82.2
		5	3300	50.0	49.9	82.2	82.1
		0	1300	49.9	50.0	82.2	82.2
		1	2600	50.0	49.9	82.2	82.2
	3	2	3900	50.0	49.9	82.2	82.2
		5	4700	49.9	49.9	82.1	82.2
		5	3900	49.4	49.9	81.7	82.2
		0	1600	49.9	49.8	82.1	82.0
		1	3200	49.8	49.7	82.1	81.9
	4	2	4700	49.9	49.7	82.1	81.9
		5	5700	49.4	49.8	81.7	82.0
		6	4800	49.6	48.0	81.8	80.2
		0	2000	46.6	45.9	78.7	77.9
		1	4100	45.5	43.8	77.3	75.5
	5	2	6100	46.0	45.0	78.0	76.8
		6	7300	26.1	26.0	49.9	49.6
		7	6000	25.2	22.8	48.3	44.0
		0	2400	47.9	49.3	80.1	81.5
		1	4800	43.2	39.1	74.6	69.6
	6	3	7200	46.3	47.1	78.4	79.2
		7	8000	32.2	27.5	59.8	52.0
		8	6800	25.5	21.0	49.0	42.3
		0	2900	49.5	49.2	81.8	81.5
		2	5800	46.9	49.4	79.0	81.6
	7	3	8600	45.1	43.0	77.0	74.7
		8	10400	41.3	37.0	72.3	66.6
		9	8200	36.5	27.1	65.9	51.3

Table V. The Percent of Rounds Falling Within Plus and Minus One and Two Probable Errors of Target Range, as a Function of Weapon, Charge, and Line No. (Continued)
(Probable Error Equals .3% of Range)

Wpn	Chg	Line No.	Range Meters	One Prob. Error Met System A	One Prob. Error Met System B	Two Prob. Errors Met System A	Two Prob. Errors Met System B
		0	1000	49.9	49.7	82.2	82.0
		1	2000	50.0	50.0	82.2	82.2
155MM	1	1	3100	49.8	49.7	82.0	82.0
		4	3700	50.0	49.9	82.2	82.2
		5	2900	49.9	49.7	82.2	81.9
		0	1300	50.0	49.9	82.3	82.2
		1	2600	50.0	50.0	82.3	82.2
	2	2	3800	50.0	49.9	82.3	82.2
		5	4600	50.0	49.8	82.3	82.1
		5	3600	49.9	49.9	82.2	82.2
		0	1600	49.8	49.9	82.1	82.2
		1	3200	50.0	49.9	82.2	82.2
	3	2	4800	49.9	49.9	82.1	82.2
		5	5800	49.5	49.9	81.7	82.2
		6	4500	49.9	49.1	82.2	81.4
		0	2000	45.1	45.0	77.0	76.8
		1	4100	44.7	43.9	76.4	75.5
	4	2	6100	46.1	45.3	78.1	77.1
		6	7300	45.2	43.5	77.0	75.1
		7	5800	42.9	41.5	74.4	72.6
		0	2500	47.9	49.3	80.1	81.6
		1	5000	43.7	40.1	75.2	70.9
	5	3	7500	45.7	46.3	77.6	78.3
		7	9000	32.0	28.2	59.5	53.3
		8	7000	26.7	23.0	51.1	44.5
		0	1700	49.9	49.7	82.1	82.0
		1	3400	49.9	49.8	82.2	82.1
	6	2	5000	49.8	49.9	82.1	82.1
		5	6100	49.2	49.8	81.5	82.1
		6	4700	49.9	49.2	82.2	81.5
		0	2100	44.0	43.7	75.7	75.3
		1	4200	42.4	41.4	73.6	72.4
	7	2	6200	44.4	43.4	76.0	74.9
		6	7500	40.1	38.5	70.7	68.7
		7	5900	37.6	35.2	67.4	64.1

Table V. The Percent of Rounds Falling Within Plus and Minus One and Two Probable Errors of Target Range, as a Function of Weapon, Charge, and Line No. (Continued)
(Probable Error Equals .3% of Range)

Wpn	Chg	Line No.	Range Meters	One Prob. Error Met System A	One Prob. Error Met System B	Two Prob. Errors Met System A	Two Prob. Errors Met System B
		0	2500	47.0	49.6	79.2	81.8
		1	5000	43.6	40.0	75.2	70.7
155MM	8	3	7500	46.2	46.8	78.3	78.6
		7	9000	32.8	28.7	60.8	54.2
		8	7000	27.1	23.3	51.8	45.0
		0	3000	49.4	49.7	81.6	82.0
		2	6000	47.1	49.6	79.2	81.9
	9	3	9000	44.7	43.2	76.5	74.9
		8	10800	43.4	39.4	74.9	69.8
		9	8400	37.8	28.8	67.7	54.1
		0	3600	49.5	49.8	81.8	82.1
		2	7300	48.9	49.5	81.1	81.8
	10	4	11000	47.5	48.0	79.6	80.2
		9	13200	47.3	46.1	79.4	78.1
		10	10200	38.3	32.2	68.3	59.5
		0	4500	47.9	48.8	80.1	81.0
		2	9000	49.0	49.1	81.2	81.4
	11	5	13500	48.4	49.2	80.6	81.4
		10	16900	42.8	43.2	74.2	74.7
		10	15400	45.7	45.0	77.7	76.9
		0	3800	49.5	49.9	81.7	82.2
		2	7600	49.5	49.5	81.7	81.8
175MM	1	4	11300	47.7	47.8	79.9	80.0
		9	14300	47.4	46.4	79.5	78.4
		9	12600	47.7	47.7	79.9	79.8
		1	5500	49.7	49.8	82.0	82.1
		2	11100	43.5	48.1	75.1	80.3
	2	5	16600	45.9	48.4	77.9	80.6
		11	20900	41.1	47.5	72.1	79.7
		12	19100	35.0	32.7	63.6	60.2
		1	8200	49.5	49.7	81.8	81.9
		3	16400	41.7	49.5	72.9	81.7
	3	7	24500	46.2	49.9	78.2	82.2
		15	30200	42.0	49.2	73.1	81.4
		15	28500	40.6	49.1	71.4	81.4

Table VI. The Percent of Rounds Falling Within Plus and Minus One and Two Probable Errors of Target Range, as a Function of Weapon, Charge, and Line No.
(Probable Error Equals .6% of Range)

Wpn	Chg	Line No.	Range Meters	One Prob. Error Met System A	One Prob. Error Met System B	Two Prob. Errors Met System A	Two Prob. Errors Met System B
		0	900	50.0	50.0	82.2	82.2
		1	1800	50.0	50.0	82.2	82.2
105MM	1	1	2800	49.9	50.0	82.2	82.2
		4	3400	50.0	50.0	82.3	82.2
		4	2700	49.9	50.0	82.2	82.3
		0	1100	49.9	50.0	82.2	82.2
		1	2200	50.0	50.0	82.3	82.2
	2	1	3200	49.9	49.9	82.1	82.2
		4	3900	49.9	50.0	82.2	82.3
		5	3300	50.0	50.0	82.3	82.2
		0	1300	50.0	50.0	82.3	82.3
		1	2600	50.0	50.0	82.3	82.2
	3	2	3900	50.0	50.0	82.3	82.2
		5	4700	50.0	50.0	82.2	82.2
		5	3900	49.9	50.0	82.1	82.2
		0	1600	50.0	49.9	82.2	82.2
		1	3200	50.0	49.9	82.2	82.2
	4	2	4700	50.0	49.9	82.2	82.2
		5	5700	49.9	49.9	82.1	82.2
		6	4800	49.9	49.5	82.2	81.7
		0	2000	49.1	48.9	81.3	81.1
		1	4100	40.7	48.2	81.0	80.5
	5	2	6100	48.9	48.6	81.2	80.8
		6	7300	39.3	39.1	69.8	69.4
		7	6000	38.5	36.3	68.8	65.7
		0	2400	49.4	49.8	81.7	82.1
		1	4800	48.0	46.6	80.2	78.7
	6	3	7200	49.0	49.2	81.3	81.5
		7	8000	43.4	40.2	75.0	70.9
		8	6800	38.9	35.4	69.4	64.4
		0	2900	49.9	49.8	82.1	82.1
		2	5800	49.2	49.8	81.4	82.1
	7	3	8600	48.7	48.1	80.9	80.3
		8	10400	47.3	45.6	79.5	77.5
		9	8200	45.4	39.7	77.3	70.3

Table VI. The Percent of Rounds Falling Within Plus and Minus One and Two Probable Errors of Target Range, as a Function of Weapon, Charge, and Line No. (Continued)
(Probable Error Equals .6% of Range)

Wpn	Chg	Line No.	Range Meters	One Prob. Error Met System A	One Prob. Error Met System B	Two Prob. Errors Met System A	Two Prob. Errors Met System B
		0	1000	50.0	49.9	82.2	82.2
		1	2000	50.0	50.0	82.3	82.3
155MM	1	1	3100	50.0	49.9	82.2	82.2
		4	3700	50.0	50.0	82.3	82.2
		5	2900	50.0	49.9	82.2	82.2
		0	1300	50.0	50.0	82.3	82.2
		1	2600	50.0	50.0	82.3	82.3
	2	2	3800	50.0	50.0	82.3	82.3
		5	4600	50.0	50.0	82.3	82.2
		5	3600	50.0	50.0	82.2	82.2
		0	1600	50.0	50.0	82.2	82.2
		1	3200	50.0	50.0	82.3	82.3
	3	2	4800	50.0	50.0	82.2	82.2
		5	5800	49.9	50.0	82.1	82.2
		6	4500	50.0	49.8	82.2	82.0
		0	2000	48.6	48.6	80.9	80.8
		1	4100	48.5	48.3	80.7	80.5
	4	2	6100	48.9	48.7	81.2	80.9
		6	7300	48.7	48.1	80.9	80.3
		7	5800	47.9	47.4	80.1	79.6
		0	2500	49.4	49.8	81.7	82.1
		1	5000	48.2	47.0	80.4	79.1
	5	3	7500	48.8	49.0	81.1	81.2
		7	9000	43.3	40.8	74.9	71.7
		8	7000	40.0	36.7	70.8	66.2
		0	1700	50.0	49.9	82.2	82.2
		1	3400	50.0	50.0	82.2	82.2
	6	2	5000	50.0	50.0	82.2	82.2
		5	6100	49.8	50.0	82.1	82.2
		6	4700	50.0	49.8	82.3	82.1
		0	2100	48.3	48.2	80.5	80.4
		1	4200	47.7	47.4	79.9	79.5
	7	2	6200	48.4	48.1	80.6	80.3
		6	7500	46.9	46.3	79.0	78.3
		7	5800	45.9	44.8	77.8	76.6

Table VI. The Percent of Rounds Falling Within Plus and Minus One and Two Probable Errors of Target Range, as a Function of Weapon, Charge, and Line No. (Continued)
(Probable Error Equals .6% of Range)

Wpn	Chg	Line No.	Range Meters	One Prob. Error Met System A	One Prob. Error Met System B	Two Prob. Errors Met System A	Two Prob. Errors Met System B
		0	2500	49.2	49.9	81.5	82.2
		1	5000	48.2	46.9	80.4	79.0
155MM	8	3	7500	49.0	49.1	81.2	81.4
		7	9000	43.8	41.1	75.4	72.2
		8	7000	40.3	36.9	71.1	66.6
		0	3000	49.8	49.9	82.1	82.2
		2	6000	49.2	49.9	81.5	82.2
	9	3	9000	48.5	48.1	80.7	80.3
		8	10800	48.1	46.6	80.3	78.6
		9	8400	46.0	41.0	77.9	71.9
		0	3600	49.9	50.0	82.1	82.2
		2	7300	49.7	49.9	82.0	82.1
	10	4	11000	49.3	49.5	81.6	81.7
		9	13200	49.3	49.0	81.5	81.2
		10	10200	46.1	43.1	78.1	74.6
		0	4500	49.5	49.7	81.7	82.0
		2	9000	49.7	49.8	82.0	82.0
	11	5	13500	49.6	49.8	81.9	82.1
		10	16900	47.9	48.0	80.1	80.2
		10	15400	48.8	48.6	81.1	80.8
		0	3800	49.9	50.0	82.1	82.2
		2	7600	49.9	49.9	82.1	82.1
175MM	1	4	11300	49.4	49.4	81.7	81.7
		9	14300	49.3	49.0	81.6	81.3
		9	12600	49.4	49.4	81.7	81.6
		1	5500	49.9	50.0	82.2	82.2
		2	11100	48.2	49.5	80.4	81.8
	2	5	16600	48.9	49.6	81.1	81.8
		11	20900	47.3	49.3	79.4	81.6
		12	19100	44.6	43.3	76.3	74.8
		1	8200	49.9	49.9	82.2	82.2
		3	16400	47.6	49.9	79.7	82.1
	3	7	24500	49.0	50.0	81.2	82.2
		15	30200	47.6	49.8	79.7	82.0
		15	28500	47.1	49.8	79.2	82.0

Table VII. The Percent of Rounds Falling Within Plus and Minus One and Two Probable Errors of Target Range, as a Function of Line Number
(Probable Error Equal .3% of Range)

Line Number	No. of Ranges	One Probable Error Met System A	One Probable Error Met System B	Two Probable Errors Met System A	Two Probable Errors Met System B
0	19	48.6	48.9	80.8	81.1
1	19	47.9	47.2	80.0	79.0
2	14	47.9	48.4	80.0	80.6
3	6	45.0	46.0	76.8	77.9
4	6	49.1	49.2	81.3	81.5
5	11	49.2	49.7	81.5	81.9
6	6	43.5	42.4	74.0	72.8
7	7	35.6	33.4	64.1	60.3
8	5	32.8	28.9	59.8	53.6
9	5	43.3	39.2	74.5	68.3
10	3	42.3	40.1	73.4	70.4
11	1	41.1	47.5	72.1	79.7
12	1	35.0	32.7	63.6	60.2
15	2	41.3	49.2	72.3	81.4
	105	45.6	45.2	77.0	76.3

Table VIII. The Percent of Rounds Falling Within Plus and Minus One and Two Probable Errors of Target Range, as a Function of Line Number
(Probable Error Equal .6% of Range)

Line Number	No. of Ranges	One Probable Error Met System A	One Probable Error Met System B	Two Probable Errors Met System A	Two Probable Errors Met System B
0	20	49.6	49.7	81.9	82.0
1	22	49.5	49.3	81.8	81.5
2	16	49.4	49.6	81.6	81.8
3	7	48.5	49.0	80.7	81.2
4	8	49.3	49.8	81.6	82.1
5	13	49.3	49.9	81.6	82.2
6	9	47.1	48.0	79.0	80.0
7	9	45.1	44.3	76.9	75.8
8	6	43.7	41.8	75.1	72.5
9	7	47.8	46.7	79.9	78.6
10	6	47.8	48.0	80.0	80.0
11	3	47.7	49.6	79.8	81.9
12	1	44.6	43.3	76.3	74.8
15	2	47.4	49.8	79.5	82.0
	129	47.6	47.8	79.7	79.7

NOTE: No U.S. equipment achieved lines 13 and 14 in such a way that fire problems could be solved for all 19 met structures. Therefore no data were presented for those lines.

Table IX. The Percent of Honest John Rocket Rounds Falling Within Plus and Minus One and Two Probable Errors of Target Range, as a Function of Line Number

Wpn	Line No.	Range Meters	One Probable Error Met System A	One Probable Error Met System B	Two Probable Errors Met System A	Two Probable Errors Met System B
M50	0	6000	50.0	50.0	82.3	82.3
	1	8000	50.0	50.0	82.3	82.3
	1	10000	50.0	50.0	82.3	82.3
	1	12000	49.9	50.0	82.2	82.2
	2	14000	49.8	50.0	82.0	82.2
	2	16000	48.3	49.6	80.5	81.8
	3	18000	47.7	49.7	79.9	82.0
	4	19000	48.4	49.9	80.6	82.2
	4	20000	47.4	49.8	79.6	82.0
	5	21000	47.4	49.9	79.5	82.1
	5	22000	45.9	49.5	77.9	81.8
	6	23000	47.8	49.9	80.0	82.2
	6	24000	46.3	49.7	78.3	82.0
	6	25000	44.5	49.4	76.2	81.6
	7	26000	47.8	49.6	80.0	81.8
	7	27000	46.3	49.3	78.3	81.5
	8	28000	47.7	49.8	79.8	81.7
	9	29000	48.3	49.7	80.5	81.9
	9	30000	46.5	49.4	78.5	81.7
	10	31000	49.2	48.9	81.5	81.1
	10	32000	48.4	49.8	80.6	82.0
	10	33000	46.4	49.4	78.4	81.7
	11	34000	49.9	49.9	82.1	82.2
	11	35000	46.0	49.7	77.9	82.0

Table X. Summary of Statistical Results

		Percent of Rounds Falling within Plus or Minus			
		One Probable Error		Two Probable Errors	
Weapon	Number of	Met System		Met System	
	Ranges	A	B	A	B
		For a Probable Error Equal to .3% of Range			
105mm	35	45.7	44.8	76.9	75.6
155mm	55	45.6	44.8	77.1	75.9
175mm	15	45.1	47.7	76.7	79.6
		For a Probable Error Equal to .6% of Range			
105mm	35	48.4	47.8	80.4	79.7
155mm	55	48.6	48.1	80.7	80.1
175mm	15	48.5	49.3	80.7	81.4
M50	24	47.9	49.7	80.1	81.9
		Combined Results for Tube Artillery and M50*			
		48.4	48.7	80.5	80.8

*These results were obtained by combining the data for .6% of range for the tube artillery systems with those for the Honest John Rocket.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* U. S. Army Aberdeen Research and Development Center Ballistic Research Laboratories Aberdeen Proving Ground, Maryland 21005	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

A COMPARATIVE STUDY OF BALLISTIC METEOROLOGICAL SYSTEMS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*

James A. Matts and Donald "'. McCoy

6. REPORT DATE February 1970	7a. TOTAL NO. OF PAGES 39	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO. b. PROJECT NO. 1T562603A287 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) BRL Memorandum Report No. 2027 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*	

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U. S. Army Materiel Command Washington, D. C.

13. ABSTRACT

Two proposed ballistic meteorological correction systems are presented and discussed. A statistical treatment of theoretical data is given to indicate which system is less degrading to the accuracy of the artillery fire problem solution.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Meteorology						
Effects						
Corrections						
Accuracy						
Artillery						

Unclassified
Security Classification