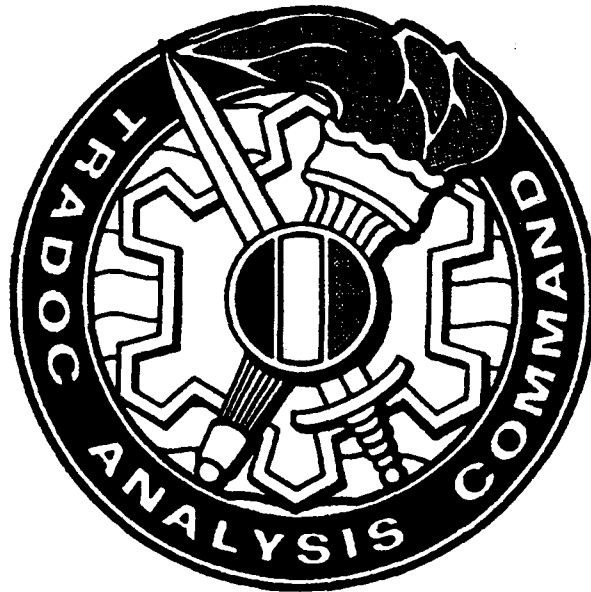


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A BURST FIRE ALGORITHM



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TRADOC ANALYSIS COMMAND

OPERATIONS ANALYSIS CENTER

MODEL DEVELOPMENT & MAINTENANCE DIRECTORATE

FORT LEAVENWORTH, KS 66027-5200

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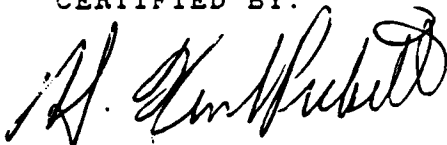
A BURST FIRE ALGORITHM

by

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<p>This report describes a methodology put into a preprocessor for computer wargame models. The preprocessor computes kill rates or probability of kills (Pk) for selected direct fire weapons against selected targets. These are input data used by the wargame models.</p> <p>The methodology replaced a methodology already in the preprocessor. This methodology computes probability of hit (Ph) and probability of kill given a hit (Pk/h) for a particular type of weapon fired against the target. The weapon type fires a designated number of rounds in bursts and is called a burst fire weapon. Ph and Pk/h are intermediate values used in computing the kill rate of Pk.</p> <p>The new methodology was needed to reduce computer time when processing the burst fire type weapons. The old methodology was a Monte Carlo process which takes more time than other methods.</p>			
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ABSTRACT

This report describes a methodology put into a preprocessor for computer wargame models. The preprocessor computes kill rates or probability of kills (Pk) for selected direct fire weapons against selected targets. These are input data used by the wargame models.

The methodology replaced a methodology already in the preprocessor. This methodology computes probability of hit (Ph) and probability of kill given a hit (Pk/h) for a particular type of weapon fired against the target. The weapon type fires a designated number of rounds in bursts and is called a burst fire weapon. Ph and Pk/h are intermediate values used in computing the kill rate or Pk.

The new methodology was needed to reduce computer time when processing the burst fire type weapons. The old methodology was a Monte Carlo process which takes more time than other methods.

1. Introduction. TRADOC Analysis Command at White Sands Missile Range (TRAC-WSMR) has developed a program called Direct Fire Weapon Preprocessor (DFWP) which computes kill rates for Vector In Commander (VIC) and other computer wargame models. The kill rate data are for selected direct fire weapons against selected targets. TRAC at Fort Leavenworth (TRAC-FLVN) uses DFWP with modifications. F-DFWP shall refer to FLVN's DFWP and W-DFWP shall refer to WSMR's DFWP. Because of long computer time used for burst fire type weapons, a methodology for these weapons in W-DFWP was not adequate for F-DFWP. This report discusses the problem and defines the solution.

2. Problem. The methodologies for probability of hit (P_h) and probability of kill given a hit (P_k/h) needed to be changed.

a. Overview of P_h computation.

(1) DFWP uses two kinds of data.

(a) One is the target dimensions. This is available from the Ballistic Research Laboratory (BRL).

(b) The other is the probability data for round impacts of the weapon. This is available from the Army Materiel Systems Analysis Activity (AMSAA).

(2) DFWP computes the P_h from the target dimensions and weapon probability data.

b. Overview of P_k/h computation.

(1) BRL provides the P_k/h data for a round.

(2) DFWP uses the P_k/h data "as is" for non burst fire weapons. DFWP recomputes the P_k/h data for burst fire weapons.

c. P_h computation for burst fire weapons.

(1) Probability data. Burst fire weapons have a probability density function (pdf) $p_b(X,Y)$ for bursts centered at (X,Y) in addition to a pdf $p_r(x,y)$ for the round impacts. Pdf $p_r(x,y)$ is actually a conditional pdf for round impact at (x,y) given that the burst is centered at (X,Y) . Pdf $p_r(x,y)$ may be written $p_r(x,y | X,Y)$.

(2) Description. P_h for burst fire weapons is the probability that a burst will have at least one round hitting the target.

(3) Formulas.

$$Ph = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} pb(X,Y) * Phb(X,Y) dY dX$$

$Phb(X,Y)$ is the Ph for a burst centered at (X,Y). $Phb(X,Y)$ may be found by the power-up formula:

$$Phb(X,Y) = 1 - (1 - Phr(X,Y)) ** Rnds$$

Rnds is the number of rounds in a burst. $Phr(X,Y)$ is the Ph for a round in a burst centered at (X,Y). $Phr(X,Y)$ is found by integrating $pr(x,y)$ over the target area.

$$Phr(X,Y) = \int_{\text{Target area}} pr(x,y | X,Y) dy dx$$

d. Pk/h computation for burst fire weapons.

(1) Description. Pk/h for burst fire weapons is the probability of kill (Pk) if there is at least one hit in a burst.

(2) Formulas.

$$Pk/h = Pk / Ph$$

$$Pk = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} pb(X,Y) * Pkb(X,Y) dY dX$$

$Pkb(X,Y)$ is the Pk for a burst centered at (X,Y). $Pkb(X,Y)$ may be found by the power-up formula.

$$Pkb(X,Y) = 1 - (1 - Pkhr * Phr(X,Y)) ** Rnds$$

$Pkhr$ is the Pk/h data supplied by BRL.

e. Problem. DFWP computes Ph and Pk/h for about 1,000 combinations of range, aspect angle, posture, and movement condition. W-DFWP used a Monte Carlo process to compute Ph and Pk/h. It uses a significant amount of computer time. F-DFWP needed a more efficient methodology to compute Ph and Pk/h.

3. Assumptions.

a. The DFWP assumes the targets to be a box or two boxes, one on top of the other. If two boxes are assumed, then the bottom box is called the hull, and the top box is called the turret. The turret is assumed to be exactly on the center of the hull. (See figure 1.) (This might change in the future.)

b. The DFWP assumes $p_b(X,Y)$ to be normal and independent in the horizontal and vertical directions. Therefore, $p_b(X,Y)$ is an uncorrelated binormal pdf. The DFWP also assumes $p_r(x,y)$ to be normal and independent in the horizontal and vertical with mean given by the burst center (X,Y) .

c. The DFWP assumes the flight path to be parallel to the ground.

d. The DFWP assumes the aimpoint to be the center of target.

4. The old methodology. The W-DFWP methodology computes P_h and P_k (the integrals in paragraphs 2c(3) and 2d(2)) by a two stage simulation.

a. First stage. 2,000 bursts are simulated. A table of normal random numbers supplies an X and a Y value for each burst center.

b. $P_{hr}(X,Y)$ computation. A burst center, (X,Y) , is the mean of $p_r(x,y)$. This mean and the round standard deviation data determine $p_r(x,y)$. W-DFWP computes P_{hr} by integrating $p_r(x,y)$ over the hull and turret areas. (See figure 1.)

$$P_{hr} = \begin{matrix} & & \text{Ph on hull} & + & \text{Ph on turret} \\ & X_4 & Y_2 & & X_3 & Y_3 \\ & | & | & & | & | \\ P_{hr} = & | & | & p_r(x,y) dy dx & + & | & | & p_r(x,y) dy dx \\ & | & | & & & | & | & \\ & X_1 & Y_1 & & & X_2 & Y_2 \end{matrix}$$

Pdf $p_r(x,y)$ equals the product of normal pdfs in X and Y directions.

$$p_r(x,y) = f(x) * f(y)$$

(The X measurements are in units of round X standard deviation, and the Y measurements are in units of round Y standard deviation.) Each double integral can be changed into a product of two single integrals, thus:

$$Phr = \int_{X1}^{X4} f(x) dx * \int_{Y1}^{Y2} f(y) dy + \int_{X2}^{X3} f(x) dx * \int_{Y2}^{Y3} f(y) dy$$

Each integral can be evaluated from two lookups in the normal distribution table.

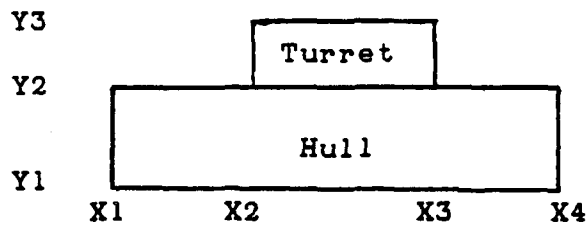


Figure 1. Target area

c. Second stage. $Ph_b(X,Y)$ and $Pk_b(X,Y)$ are not computed by the power-up formulas (paragraphs 2c(3) and 2d(2)). Instead, a simulation is done which returns a value of one or zero, indicating whether a hit is made in the burst, and a value of one or zero, indicating whether a kill is made. The simulation is such that the probability of returning a one for a hit is $Ph_b(X,Y)$ and the probability of returning a one for a kill is $Pk_b(X,Y)$. The generator generates two random numbers in [0,1] for each round in the burst. It compares the first number to Phr to determine if a hit is made. If a hit is made, it compares the second number to $Pkhr$ to determine if a kill is made.

d. Ph and Pk computation. W-DFWP computes Ph as the number of burst hits divided by 2,000 and Pk as the number of burst kills divided by 2,000.

e. Mathematical description. Pdf $pb(X,Y)$ equals the product of normal pdfs in X and Y directions.

$$pb(X,Y) = f(X) * f(Y)$$

(The X measurements are in units of burst X standard deviation, and the Y measurements are in units of burst Y standard deviation.) The formulas in paragraphs 2c(3) and 2d(2) may be written:

$$Ph = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(X) * f(Y) * Ph_b(X,Y) dY dX$$

$$P_k = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(X) * f(Y) * P_{kb}(X,Y) dY dX$$

Make the following substitutions:

$$U = F(X) = \int_{-\infty}^X f(T) dT, \quad V = F(Y) = \int_{-\infty}^Y f(T) dT$$

$$dU = f(X) dX, \quad dV = f(Y) dY.$$

This changes the formulas to:

$$P_h = \int_0^1 \int_0^1 P_{hb}(X,Y) dV dU, \quad P_k = \int_0^1 \int_0^1 P_{kb}(X,Y) dV dU$$

The inverse normal table must compute X and Y from U and V.

$$X = F^{-1}(U), \quad Y = F^{-1}(V)$$

The Monte Carlo process would use random numbers in [0,1] for U and V. Then the inverse normal table would compute X and Y from U and V. X and Y would be normal random numbers.

5. The new methodology. The F-DFWP methodology replaces the two stage simulation in the W-DFWP methodology by direct methods.

a. First stage. Two direct methods were tried to replace the first stage simulation in the W-DFWP methodology. The methods use deterministic Us and Vs, instead of random Us and Vs. The inverse normal table then computes the Xs and Ys (as in paragraph 4e).

$$X = F^{-1}(U), \quad Y = F^{-1}(V)$$

(1) Equally spaced method. The first direct method tried divides [0,1] into equal intervals. The Us and Vs are the midpoints of these intervals. Combinations of the Us and Vs are the midpoints of square intervals. These square intervals divide up the area of integration which is the unit square. If [0,1] is divided into 10 intervals, then values of U and V would be .05, .15, . . . , .95, and there would be 100 combinations of Us and Vs or burst simulations.

(2) Gauss method. The second direct method tried divides [0,1] into unequal intervals. A Gauss algorithm determines beforehand the U_s and V_s . F-DFWP implements this method. (Numerical analysis books describe the Gauss method for numerical integration. See for example Schaum's Outline of Numerical Analysis.)

b. $Ph_r(X,Y)$ computation. The F-DFWP methodology computes Ph_r the same way as the W-DFWP methodology (paragraph 4b).

c. Second stage. The F-DFWP methodology replaces the second stage simulation in W-DFWP by using the power-up formulas in paragraphs 2c(3) and 2d(2) to compute Ph_b and Pk_b . The integrals for Ph and Pk in paragraph 4e may, therefore, be written as:

$$Ph = \int_0^1 \int_0^1 (1 - (1 - Ph_r(X,Y))^{Rnds}) dV dU$$

$$Pk = \int_0^1 \int_0^1 (1 - (1 - Pk_{hr} * Ph_r(X,Y))^{Rnds}) dV dU$$

d. Ph and Pk computation. Ph_b and Pk_b (integrand of the integrals in paragraph 5c) are computed for all combinations of X and Y (paragraph 5a).

(1) Equally spaced method. Ph is computed as the average of the Ph_b s and Pk is computed as the average of the Pk_b s.

(2) Gauss method. The Ph_b s and Pk_b s are not averaged as in the equally spaced method but are weighted and summed. The weights are determined beforehand at the same time as the U_s and V_s by the Gauss algorithm.

6. Computer program Burst Ph.

a. Description. Program Burst_Ph compares the methodologies. Inputs to the program are the target dimensions. The program sets the X & Y burst dispersions to two. It computes for combinations of different burst bias, round dispersion, range, number of rounds in burst, and Pk_{hr} . Output is labeled Monte Carlo, Summate, and Gauss. Monte Carlo is the old methodology, Summate is the equally spaced methodology, and Gauss is the Gauss methodology.

Appendix A contains output from the program. Hull length and height inputs are five and two and turret length and height inputs are two and one.

b. Conclusions. The difference between the Gauss values for the different number of iterations in the program outputs is usually much less than the difference between the Summate values for the different iterations. Also, as the iterations increase, in which case the accuracy increases, the Summate values appear to converge to the Gauss values. These observations indicate that the Gauss method is much more accurate than the Summate method.

The accuracy of the Monte_Carlo method varies. Usually it looks less accurate than the Summate method for 400 and 1,600 repetitions. It appears less accurate for PROB. of KILL/HIT than for PROB. of HIT.

It appears that the Gauss method using 400 or fewer iterations will give greater accuracy than the 2,000 repetition Monte Carlo method (the old methodology).

APPENDIX A

BURST_PH OUTPUT

HULL LENGTH AND HEIGHT?

5.000 2.000

TURRET LENGTH AND HEIGHT?

2.000 1.000

		X	Y
ROUND DISPERSION	=	1.00	1.00
BURST BIAS	=	0.00	0.00

ROUNDS = 5
RANGE = 200.

PROB. of HIT

		Iterations			
		100	400	1600	2000
MONTE_CARLO					1.00000
SUMMATE	1.00000	1.00000	0.99999		
GAUSS	0.99999	0.99991	0.99986		

PROB. of KILL/HIT

RND PKH = 0.10

		100	400	1600	2000
MONTE_CARLO					0.40000
SUMMATE	0.40912	0.40879	0.40854		
GAUSS	0.40846	0.40829	0.40820		

PROB. of KILL/HIT

RND PKH = 0.50

		100	400	1600	2000
MONTE_CARLO					0.97100
SUMMATE	0.96856	0.96836	0.96816		
GAUSS	0.96810	0.96790	0.96785		

PROB. of KILL/HIT

RND PKH = 0.90

		100	400	1600	2000
MONTE_CARLO					0.99950
SUMMATE	0.99999	0.99999	0.99998		
GAUSS	0.99997	0.99994	0.99994		

ROUND DISPERSION	=	X	Y
		1.00	1.00
BURST BIAS	=	0.00	0.00

ROUNDS = 5
RANGE = 800.

PROB. of HIT

		Iterations			
		100	400	1600	2000
MONTE_CARLO					0.73800
SUMMATE	0.75644		0.74284	0.73937	
GAUSS	0.73802		0.73876	0.73877	

PROB. of KILL/HIT
RND PKH = 0.10

		100	400	1600	2000
MONTE_CARLO					0.23645
SUMMATE	0.24965		0.25194	0.25269	
GAUSS	0.25301		0.25283	0.25282	

PROB. of KILL/HIT
RND PKH = 0.50

		100	400	1600	2000
MONTE_CARLO					0.80623
SUMMATE	0.78946		0.79330	0.79475	
GAUSS	0.79539		0.79502	0.79502	

PROB. of KILL/HIT
RND PKH = 0.90

		100	400	1600	2000
MONTE_CARLO					0.97764
SUMMATE	0.97482		0.97562	0.97599	
GAUSS	0.97616		0.97606	0.97606	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	1.00	1.00
		0.00	0.00

ROUNDS = 5
RANGE = 3000.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.17300
SUMMATE	0.16825	0.16835	0.16836	
GAUSS	0.16835	0.16836	0.16835	

PROB. of KILL/HIT

RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.14162
SUMMATE	0.12014	0.12013	0.12013	
GAUSS	0.12013	0.12013	0.12013	

PROB. of KILL/HIT

RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.53468
SUMMATE	0.55297	0.55293	0.55293	
GAUSS	0.55293	0.55293	0.55293	

PROB. of KILL/HIT

RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				0.91329
SUMMATE	0.91806	0.91805	0.91805	
GAUSS	0.91805	0.91805	0.91805	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	1.00	1.00
		0.00	0.00

ROUNDS = 20
RANGE = 200.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				1.00000
SUMMATE	1.00000	1.00000	1.00000	
GAUSS	1.00000	1.00000	0.99999	

PROB. of KILL/HIT

RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.87000
SUMMATE	0.87809	0.87780	0.87752	
GAUSS	0.87743	0.87714	0.87703	

PROB. of KILL/HIT

RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				1.00000
SUMMATE	1.00000	1.00000	1.00000	
GAUSS	1.00000	0.99999	0.99996	

PROB. of KILL/HIT

RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				1.00000
SUMMATE	1.00000	1.00000	1.00000	
GAUSS	1.00000	1.00000	1.00000	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	1.00	1.00
		0.00	0.00

ROUNDS = 20
RANGE = 800.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.87250
SUMMATE	0.90618	0.88024	0.87243	
GAUSS	0.87083	0.86932	0.86939	

PROB. of KILL/HIT
RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.55989
SUMMATE	0.56163	0.57100	0.57458	
GAUSS	0.57509	0.57637	0.57633	

PROB. of KILL/HIT
RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.93238
SUMMATE	0.92508	0.93135	0.93272	
GAUSS	0.93210	0.93443	0.93438	

PROB. of KILL/HIT
RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				0.99198
SUMMATE	0.99014	0.99147	0.99147	
GAUSS	0.99139	0.99183	0.99181	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	1.00	1.00
		0.00	0.00

ROUNDS = 20
 RANGE = 3000.

PROB. of HIT

		Iterations			
		100	400	1600	2000
MONTE_CARLO					0.38100
SUMMATE	0.38640		0.38683	0.38686	
GAUSS	0.38685		0.38686	0.38686	

PROB. of KILL/HIT
 RND PKH = 0.10

		100	400	1600	2000
MONTE_CARLO					0.19948
SUMMATE	0.19390		0.19379	0.19379	
GAUSS	0.19379		0.19379	0.19378	

PROB. of KILL/HIT
 RND PKH = 0.50

		100	400	1600	2000
MONTE_CARLO					0.68635
SUMMATE	0.69213		0.69190	0.69189	
GAUSS	0.69189		0.69189	0.69188	

PROB. of KILL/HIT
 ROUND PKH = 0.90

		100	400	1600	2000
MONTE_CARLO					0.95538
SUMMATE	0.95372		0.95365	0.95365	
GAUSS	0.95365		0.95365	0.95364	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	1.00	1.00
		1.20	1.50

ROUNDS = 5
 RANGE = 200.

PROB. of HIT

		Iterations			
		100	400	1600	2000
MONTE_CARLO					0.99750
SUMMATE	0.99996		0.99961	0.99901	
GAUSS	0.99882		0.99853	0.99835	

PROB. of KILL/HIT
 RND PKH = 0.10

		100	400	1600	2000
MONTE_CARLO					0.39599
SUMMATE	0.40541		0.40448	0.40409	
GAUSS	0.40396		0.40354	0.40345	

PROB. of KILL/HIT
 RND PKH = 0.50

		100	400	1600	2000
MONTE_CARLO					0.96742
SUMMATE	0.96601		0.96488	0.96450	
GAUSS	0.96434		0.96405	0.96384	

PROB. of KILL/HIT
 RND PKH = 0.90

		100	400	1600	2000
MONTE_CARLO					0.99950
SUMMATE	0.99989		0.99973	0.99967	
GAUSS	0.99963		0.99964	0.99959	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	1.00	1.00
		1.20	1.50

ROUNDS = 5
 RANGE = 800.

PROB. of HIT

		Iterations			
		100	400	1600	2000
MONTE_CARLO					0.58200
SUMMATE	0.58851		0.57904	0.57348	
GAUSS	0.57139		0.57099	0.57102	

PROB. of KILL/HIT
 RND PKH = 0.10

		100	400	1600	2000
MONTE_CARLO					0.22079
SUMMATE	0.23464		0.23366	0.23444	
GAUSS	0.23476		0.23496	0.23495	

PROB. of KILL/HIT
 RND PKH = 0.50

		100	400	1600	2000
MONTE_CARLO					0.77406
SUMMATE	0.76656		0.76336	0.76449	
GAUSS	0.76494		0.76546	0.76545	

PROB. of KILL/HIT
 RND PKH = 0.90

		100	400	1600	2000
MONTE_CARLO					0.97509
SUMMATE	0.97040		0.96932	0.96949	
GAUSS	0.96954		0.96973	0.96973	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	1.00	1.00
		1.20	1.50

ROUNDS = 5
RANGE = 3000.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.11250
SUMMATE	0.11640	0.11570	0.11569	
GAUSS	0.11570	0.11569	0.11569	

PROB. of KILL/HIT
ROUND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.13778
SUMMATE	0.11884	0.11907	0.11908	
GAUSS	0.11907	0.11908	0.11908	

PROB. of KILL/HIT
RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.57333
SUMMATE	0.54958	0.55021	0.55023	
GAUSS	0.55021	0.55022	0.55023	

PROB. of KILL/HIT
RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				0.93778
SUMMATE	0.91691	0.91714	0.91714	
GAUSS	0.91714	0.91714	0.91714	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	1.00	1.00
		1.20	1.50

ROUNDS = 20
RANGE = 200.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.99900
SUMMATE	1.00000	1.00000	0.99999	
GAUSS	0.99999	0.99975	0.99974	

PROB. of KILL/HIT
RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.86737
SUMMATE	0.87441	0.87285	0.87187	
GAUSS	0.87154	0.87107	0.87074	

PROB. of KILL/HIT
RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				1.00000
SUMMATE	1.00000	0.99996	0.99978	
GAUSS	0.99973	0.99958	0.99958	

PROB. of KILL/HIT
RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				1.00000
SUMMATE	1.00000	1.00000	0.99999	
GAUSS	0.99999	0.99996	0.99996	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	1.00	1.00
		1.20	1.50

ROUNDS = 20
 RANGE = 800.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.72800
SUMMATE	0.73875	0.73209	0.72901	
GAUSS	0.72843	0.72392	0.72401	

PROB. of KILL/HIT
RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.49657
SUMMATE	0.51729	0.51151	0.50967	
GAUSS	0.50860	0.51175	0.51172	

PROB. of KILL/HIT
RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.90934
SUMMATE	0.90412	0.90357	0.90007	
GAUSS	0.89859	0.90100	0.90096	

PROB. of KILL/HIT
RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				0.98970
SUMMATE	0.98686	0.98724	0.98666	
GAUSS	0.98649	0.98671	0.98670	

ROUND DISPERSION	=	X	Y
		1.00	1.00
BURST BIAS	=	1.20	1.50

ROUNDS = 20
RANGE = 3000.

PROB. of HIT

		Iterations			
		100	400	1600	2000
MONTE_CARLO					0.27800
SUMMATE	0.27822		0.27363	0.27351	
GAUSS	0.27366		0.27353	0.27353	

PROB. of KILL/HIT
RND PKH = 0.10

		100	400	1600	2000
MONTE_CARLO					0.18345
SUMMATE	0.18509		0.18729	0.18736	
GAUSS	0.18727		0.18735	0.18736	

PROB. of KILL/HIT
RND PKH = 0.50

		100	400	1600	2000
MONTE_CARLO					0.68885
SUMMATE	0.67520		0.67997	0.68016	
GAUSS	0.67998		0.68014	0.68015	

PROB. of KILL/HIT
RND PKH = 0.90

		100	400	1600	2000
MONTE_CARLO					0.95683
SUMMATE	0.94929		0.95064	0.95070	
GAUSS	0.95067		0.95070	0.95070	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	4.00	5.00
		0.00	0.00

ROUNDS = 5
RANGE = 200.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.99850
SUMMATE	0.99921	0.99910	0.99901	
GAUSS	0.99899	0.99891	0.99888	

PROB. of KILL/HIT
RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.32098
SUMMATE	0.33202	0.33116	0.33073	
GAUSS	0.33058	0.33038	0.33034	

PROB. of KILL/HIT
RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.91838
SUMMATE	0.91362	0.91263	0.91211	
GAUSS	0.91193	0.91166	0.91159	

PROB. of KILL/HIT
RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				0.99700
SUMMATE	0.99787	0.99776	0.99770	
GAUSS	0.99768	0.99764	0.99762	

ROUND DISPERSION = X Y
 BURST BIAS = 4.00 5.00
 = 0.00 0.00

ROUNDS = 5
 RANGE = 800.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.45350
SUMMATE	0.45708	0.45387	0.45234	
GAUSS	0.45182	0.45118	0.45103	

PROB. of KILL/HIT
 RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.11466
SUMMATE	0.12337	0.12326	0.12323	
GAUSS	0.12322	0.12322	0.12322	

PROB. of KILL/HIT
 RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.57552
SUMMATE	0.56173	0.56145	0.56136	
GAUSS	0.56133	0.56133	0.56133	

PROB. of KILL/HIT
 RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				0.93826
SUMMATE	0.92113	0.92104	0.92101	
GAUSS	0.92100	0.92100	0.92100	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	4.00	5.00
		0.00	0.00

ROUNDS = 5
 RANGE = 3000.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.04300
SUMMATE	0.04367	0.04330	0.04314	
GAUSS	0.04308	0.04302	0.04300	

PROB. of KILL/HIT
 RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.10465
SUMMATE	0.10164	0.10164	0.10164	
GAUSS	0.10164	0.10164	0.10164	

PROB. of KILL/HIT
 RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.46512
SUMMATE	0.50455	0.50453	0.50453	
GAUSS	0.50453	0.50453	0.50453	

PROB. of KILL/HIT
 RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				0.91860
SUMMATE	0.90163	0.90163	0.90162	
GAUSS	0.90162	0.90162	0.90162	

ROUND DISPERSION	=	X	Y
		4.00	5.00
BURST BIAS	=	0.00	0.00

ROUNDS = 20
 RANGE = 200.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				1.00000
SUMMATE	1.00000	1.00000	1.00000	
GAUSS	1.00000	1.00000	1.00000	

PROB. of KILL/HIT
RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.79650
SUMMATE	0.80008	0.79885	0.79820	
GAUSS	0.79798	0.79763	0.79753	

PROB. of KILL/HIT
RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.99950
SUMMATE	0.99993	0.99992	0.99992	
GAUSS	0.99991	0.99991	0.99990	

PROB. of KILL/HIT
RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				1.00000
SUMMATE	1.00000	1.00000	1.00000	
GAUSS	1.00000	1.00000	1.00000	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	4.00	5.00
		0.00	0.00

ROUNDS = 20
 RANGE = 800.

PROB. of HIT

		Iterations			
	100	400	1600	2000	
MONTE_CARLO					0.90200
SUMMATE	0.90946	0.90612	0.90427		
GAUSS	0.90365	0.90259	0.90230		

PROB. of KILL/HIT
 RND PKH = 0.10

	100	400	1600	2000	
MONTE_CARLO					0.22118
SUMMATE	0.22754	0.22666	0.22632		
GAUSS	0.22620	0.22614	0.22614		

PROB. of KILL/HIT
 ROUND PKH = 0.50

	100	400	1600	2000	
MONTE_CARLO					0.77661
SUMMATE	0.76103	0.75943	0.75877		
GAUSS	0.75855	0.75840	0.75839		

PROB. of KILL/HIT
 RND PKH = 0.90

	100	400	1600	2000	
MONTE_CARLO					0.97506
SUMMATE	0.97194	0.97156	0.97140		
GAUSS	0.97134	0.97129	0.97129		

ROUND DISPERSION	=	X	Y
BURST BIAS	=	4.00	5.00
		0.00	0.00

ROUNDS = 20
RANGE = 3000.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.15350
SUMMATE	0.16339	0.16204	0.16143	
GAUSS	0.16122	0.16099	0.16094	

PROB. of KILL/HIT
RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.09121
SUMMATE	0.10794	0.10791	0.10790	
GAUSS	0.10790	0.10790	0.10790	

PROB. of KILL/HIT
RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.51792
SUMMATE	0.52157	0.52149	0.52147	
GAUSS	0.52146	0.52146	0.52147	

PROB. of KILL/HIT
RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				0.91531
SUMMATE	0.90760	0.90757	0.90756	
GAUSS	0.90756	0.90756	0.90756	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	4.00	5.00
		1.20	1.50

ROUNDS = 5
 RANGE = 200.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.99650
SUMMATE	0.99759	0.99728	0.99709	
GAUSS	0.99703	0.99688	0.99683	

PROB. of KILL/HIT
 RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.30858
SUMMATE	0.31903	0.31823	0.31785	
GAUSS	0.31772	0.31755	0.31751	

PROB. of KILL/HIT
 RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.90567
SUMMATE	0.89923	0.89820	0.89768	
GAUSS	0.89750	0.89726	0.89720	

PROB. of KILL/HIT
 RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				0.99649
SUMMATE	0.99635	0.99620	0.99612	
GAUSS	0.99610	0.99605	0.99604	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	4.00	5.00
		1.20	1.50

ROUNDS = 5
 RANGE = 800.

PROB. of HIT

		Iterations			
		100	400	1600	2000
MONTE_CARLO					0.42500
SUMMATE	0.42602		0.42319	0.42184	
GAUSS	0.42138		0.42081	0.42069	

PROB. of KILL/HIT
 RND PKH = 0.10

		100	400	1600	2000
MONTE_CARLO					0.10941
SUMMATE	0.12178		0.12169	0.12166	
GAUSS	0.12165		0.12165	0.12165	

PROB. of KILL/HIT
 RND PKH = 0.50

		100	400	1600	2000
MONTE_CARLO					0.56353
SUMMATE	0.55766		0.55744	0.55736	
GAUSS	0.55733		0.55732	0.55732	

PROB. of KILL/HIT
 RND PKH = 0.90

		100	400	1600	2000
MONTE_CARLO					0.93647
SUMMATE	0.91979		0.91971	0.91969	
GAUSS	0.91968		0.91967	0.91967	

ROUND DISPERSION	=	X	Y
		4.00	5.00
BURST BIAS	=	1.20	1.50

ROUNDS = 5
 RANGE = 3000.

PROB. of HIT

		Iterations			
	100	400	1600	2000	
MONTE_CARLO					0.04000
SUMMATE	0.04038	0.04006	0.03991		
GAUSS	0.03986	0.03980	0.03979		

PROB. of KILL/HIT
 RND PKH = 0.10

	100	400	1600	2000	
MONTE_CARLO					0.10000
SUMMATE	0.10155	0.10155	0.10155		
GAUSS	0.10155	0.10155	0.10155		

PROB. of KILL/HIT
 RND PKH = 0.50

	100	400	1600	2000	
MONTE_CARLO					0.46250
SUMMATE	0.50430	0.50428	0.50428		
GAUSS	0.50428	0.50428	0.50428		

PROB. of KILL/HIT
 RND PKH = 0.90

	100	400	1600	2000	
MONTE_CARLO					0.90000
SUMMATE	0.90154	0.90154	0.90154		
GAUSS	0.90153	0.90153	0.90153		

ROUND DISPERSION	=	X	Y
BURST BIAS	=	4.00	5.00
		1.20	1.50

ROUNDS = 20
RANGE = 200.

PROB. of HIT

		Iterations			
		100	400	1600	2000
MONTE_CARLO					1.00000
SUMMATE	1.00000		1.00000	1.00000	
GAUSS	1.00000		1.00000	1.00000	

PROB. of KILL/HIT
RND PKH = 0.10

		100	400	1600	2000
MONTE_CARLO					0.77850
SUMMATE	0.78209		0.78073	0.78002	
GAUSS	0.77978		0.77942	0.77932	

PROB. of KILL/HIT
ROUND PKH = 0.50

		100	400	1600	2000
MONTE_CARLO					1.00000
SUMMATE	0.99980		0.99977	0.99974	
GAUSS	0.99973		0.99971	0.99970	

PROB. of KILL/HIT
RND PKH = 0.90

		100	400	1600	2000
MONTE_CARLO					1.00000
SUMMATE	1.00000		1.00000	1.00000	
GAUSS	1.00000		1.00000	1.00000	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	4.00	5.00
		1.20	1.50

ROUNDS = 20
RANGE = 800.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.87850
SUMMATE	0.88154	0.87795	0.87605	
GAUSS	0.87540	0.87441	0.87416	

PROB. of KILL/HIT
RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.20888
SUMMATE	0.21710	0.21644	0.21619	
GAUSS	0.21610	0.21605	0.21605	

PROB. of KILL/HIT
RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.76039
SUMMATE	0.74378	0.74258	0.74209	
GAUSS	0.74192	0.74181	0.74180	

PROB. of KILL/HIT
RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				0.97382
SUMMATE	0.96815	0.96786	0.96774	
GAUSS	0.96770	0.96766	0.96766	

ROUND DISPERSION	=	X	Y
BURST BIAS	=	4.00	5.00
		1.20	1.50

ROUNDS = 20
RANGE = 3000.

PROB. of HIT

		Iterations		
	100	400	1600	2000
MONTE_CARLO				0.14450
SUMMATE	0.15161	0.15044	0.14990	
GAUSS	0.14971	0.14950	0.14946	

PROB. of KILL/HIT
RND PKH = 0.10

	100	400	1600	2000
MONTE_CARLO				0.08304
SUMMATE	0.10749	0.10746	0.10746	
GAUSS	0.10745	0.10745	0.10745	

PROB. of KILL/HIT
RND PKH = 0.50

	100	400	1600	2000
MONTE_CARLO				0.50865
SUMMATE	0.52037	0.52030	0.52027	
GAUSS	0.52026	0.52026	0.52026	

PROB. of KILL/HIT
RND PKH = 0.90

	100	400	1600	2000
MONTE_CARLO				0.92042
SUMMATE	0.90718	0.90715	0.90715	
GAUSS	0.90714	0.90714	0.90714	

APPENDIX B

BURST_PH CODE

PROGRAM BURST_PH

CHARACTER ANS

REAL PKH_CARLO(3)
 REAL PH_SUMMATE(3), PKH_SUMMATE(3,3)
 REAL PH_GAUSS(3), PKH_GAUSS(3,3)
 REAL X_BURST_DISPERSION /2./, Y_BURST_DISPERSION /2./
 REAL XDISP (2) /1., 4./, YDISP (2) /1., 5./
 REAL XBIAS (2) /0., 1.2/, YBIAS (2) /0., 1.5/
 INTEGER RNDS (2) /5, 20/, ROUNDS
 REAL PKH_RND(3) /.1, .5, .9/
 REAL RANGE (3) /200., 800., 3000./
 COMMON X_BURST_BIAS, X_BURST_DISPERSION,
 1Y_BURST_BIAS, Y_BURST_DISPERSION,
 2X_DISPERSION, Y_DISPERSION,
 3X_HULL, Y_HULL, X_TURR, Y_TURR, ROUNDS, PKH_RND

OPEN (1, FILE='BURST_PH', STATUS='NEW',
 1 CARRIAGECONTROL='LIST')
 100 WRITE (*,'(A)') ' HULL LENGTH AND HEIGHT?'
 WRITE (1,'(A)') ' HULL LENGTH AND HEIGHT?'
 READ (*,'(2F6.0)') XHULL, YHULL
 WRITE (1,'(2F7.3)') XHULL, YHULL
 WRITE (*,'(A)') ' TURRET LENGTH AND HEIGHT?'
 WRITE (1,'(A)') ' TURRET LENGTH AND HEIGHT?'
 READ (*,'(2F6.0)') XTURR, YTURR
 WRITE (1,'(2F7.3)') XTURR, YTURR

DO IDISP = 1, 2
 X_DISPERSION = XDISP(IDISP)
 Y_DISPERSION = YDISP(IDISP)
 DO IBIAS = 1, 2
 X_BURST_BIAS = XBIAS(IBIAS)
 Y_BURST_BIAS = YBIAS(IBIAS)
 DO IRNDS = 1, 2
 ROUNDS = RNDS(IRNDS)
 DO IRNG = 1, 3
 X_HULL = XHULL * 1000. / RANGE(IRNG)
 Y_HULL = YHULL * 1000. / RANGE(IRNG)
 X_TURR = XTURR * 1000. / RANGE(IRNG)
 Y_TURR = YTURR * 1000. / RANGE(IRNG)
 CALL MONTE_CARLO (PH_CARLO, PKH_CARLO)
 CALL SUMMATE (PH_SUMMATE, PKH_SUMMATE)
 CALL GAUSS (PH_GAUSS, PKH_GAUSS)
 3 FORMAT (A, 2F7.2)
 4 FORMAT (/A, I5)
 5 FORMAT (A, F6.0)
 1 FORMAT (A, F5.2)

```

2          FORMAT (/18X, A)
11         FORMAT (A, F40.5)
12         FORMAT (A, 4X, 3F10.5)
          WRITE (1, '(//A)') '          X          Y'
          WRITE (1,3) ' ROUND DISPERSION =',
1 XDISP(IDISP), YDISP(IDISP)
          WRITE (1,3) ' BURST BIAS =',
1 XBIAS(IBIAS), YBIAS(IBIAS)
          WRITE (1,4) ' ROUNDS =', ROUNDS
          WRITE (1,5) ' RANGE =', RANGE(IRNG)
C *** PH output
          WRITE (1,*)
          WRITE (1,*)
          WRITE (1,1) ' PROB. of HIT'
          WRITE (1,1) ' Iterations'
          WRITE (1,2) '100          400          1600          2000'
          WRITE (1,11) ' MONTE_CARLO', PH_CARLO
          WRITE (1,12) ' SUMMATE', (PH_SUMMATE(K), K = 1, 3)
          WRITE (1,12) ' GAUSS', (PH_GAUSS(K), K = 1, 3)
C *** PKH output
          DO J = 1, 3
          WRITE (1,*)
          WRITE (1,*)
          WRITE (1,1) ' PROB. of KILL/HIT'
          WRITE (1,1) ' RND PKH =', PKH_RND(J)
          WRITE (1,2) '100          400          1600          2000'
          WRITE (1,11) ' MONTE_CARLO', PKH_CARLO(J)
          WRITE (1,12) ' SUMMATE', (PKH_SUMMATE(K,J), K = 1, 3)
          WRITE (1,12) ' GAUSS', (PKH_GAUSS(K,J), K = 1, 3)
          END DO ! J
          END DO ! IRNG
          END DO ! IRNDS
          END DO ! IBIAS
          END DO ! IDISP
          WRITE (*, '(A)') ' CONTINUE?'
          READ (*, '(A1)') ANS
          IF (ANS .NE. 'Y') STOP
          WRITE (*, '(///)')
          WRITE (1, '(///)')
          GO TO 100
          END

```

```

FUNCTION DFN (X)

```

```

FROM HASTINGS APPROXIMATIONS FOR DIGITAL COMPUTERS

```

```

F = 0.

```

```

AX = ABS (X)

```

```

IF (AX .GE. 5.) GO TO 1

```

```

F = ((((((.5383E-5 * AX + .488906E-4) * AX

```

```

1 + .380036E-4) * AX 1 + .0032776263) * AX

```

```

1      + .0211410061) * AX + .0498673469) * AX + 1.
F = .5 / ((F**8)**2)
1 IF (X .GE. 0.) F = 1. - F
DFN = F
END

```

```

SUBROUTINE MONTE_CARLO (PH, PKH)

```

```

PARAMETER REPS = 2000
REAL PKH(3), KILL(3), KILLS(3)
REAL XXP(50), XPK(50)
INTEGER REP, RND, RNDS
COMMON X_BURST_BIAS, X_BURST_DISPERSION,
1Y_BURST_BIAS, Y_BURST_DISPERSION,
2X_DISPERSION, Y_DISPERSION,
3X_HULL, Y_HULL, X_TURR, Y_TURR, RNDS, PKH_RND(3)

```

```

INCLUDE 'RANDOM_NUMBERS'! Data for
! NRANDOM(2000), DEVIATE(2000,2)

```

```

C *** Initialize

```

```

HITS = 0.
KILLS(1) = 0.
KILLS(2) = 0.
KILLS(3) = 0.

```

```

C *** Calculate target boundaries.

```

```

X2TURR = X_TURR / 2.
X1TURR = -X2TURR
X2HULL = X_HULL / 2.
X1HULL = -X2HULL
Y2TURR = (Y_HULL + Y_TURR) / 2.
Y1TURR = Y2TURR - Y_TURR
Y2HULL = Y1TURR
Y1HULL = -Y2TURR

```

```

DO REP = 1, REPS
ISEED = NRANDOM (REP)

```

```

C *** Draw random numbers for PH, PK for each round in burst.

```

```

DO RND = 1, RNDS
XXP(RND) = BARN(ISEED)
XPK(RND) = BARN(ISEED)

```

```

END DO

```

```

X_BIAS = X_BURST_BIAS + X_BURST_DISPERSION *
1 DEVIATE(REP,1)
Y_BIAS = Y_BURST_BIAS + Y_BURST_DISPERSION *
1 DEVIATE(REP,2)

```

```

C *** Prob. of hit on hull in X-direction

```

```

T2 = (X2HULL - X_BIAS) / X_DISPERSION
T1 = (X1HULL - X_BIAS) / X_DISPERSION
X_PH_HULL = DFN(T2) - DFN(T1)

```

```

C *** Prob. of hit on hull in Y-direction

```

```

      T2 = (Y2HULL - Y_BIAS) / Y_DISPERSION
      T1 = (Y1HULL - Y_BIAS) / Y_DISPERSION
      Y_PH_HULL = DFN(T2) - DFN(T1)
C *** Prob. of hit on turret in X-direction
      T2 = (X2TURR - X_BIAS) / X_DISPERSION
      T1 = (X1TURR - X_BIAS) / X_DISPERSION
      X_PH_TURR = DFN(T2) - DFN(T1)
C *** Prob. of hit on turret in Y-direction
      T2 = (Y2TURR - Y_BIAS) / Y_DISPERSION
      T1 = (Y1TURR - Y_BIAS) / Y_DISPERSION
      Y_PH_TURR = DFN(T2) - DFN(T1)
C *** Prob. of hit on target
      PH_TGT = X_PH_HULL * Y_PH_HULL + X_PH_TURR * Y_PH_TURR

C *** Simulate
      HIT = 0.
      KILL(1) = 0.
      KILL(2) = 0.
      KILL(3) = 0.
      DO RND = 1, RNDS
      IF (XXPH(RND) .LE. PH_TGT) THEN
          HIT = 1.
          IF (XXPK(RND) .LE. PKH_RND(1)) KILL(1) = 1.
          IF (XXPK(RND) .LE. PKH_RND(2)) KILL(2) = 1.
          IF (XXPK(RND) .LE. PKH_RND(3)) KILL(3) = 1.
      ENDIF
      END DO
      HITS = HITS + HIT
      KILLS(1) = KILLS(1) + KILL(1)
      KILLS(2) = KILLS(2) + KILL(2)
      KILLS(3) = KILLS(3) + KILL(3)
      END DO ! REP

      PH = HITS / REPS
      IF (HITS .GT. 0.) THEN
          PKH(1) = KILLS(1) / HITS
          PKH(2) = KILLS(2) / HITS
          PKH(3) = KILLS(3) / HITS
      ELSE
          PKH(1) = PKH_RND(1)
          PKH(2) = PKH_RND(2)
          PKH(3) = PKH_RND(3)
      ENDIF
      END

FUNCTION BARN (ISEED)

INTEGER ABARN ,
1      B15 ,
2      B16 ,
3      FHI .

```



```

4      LEFTLO,
5      PBARN ,
6      XALO  ,
7      XHI
      DATA  ABARN /      16807/,
1      B15   /      32768/,
2      B16   /      65536/,
3      PBARN / 2147483647/

```

C

```

C*****THIS RANDOM NUMBER GENERATOR WAS DEVELOPED BY THE
C*****ASSOCIATION OF COMPUTING MACHINERY,INC., COPYRIGHT 1979.
C*****AND PRESENTED IN THE TEXT BOOK "SIMULATION MODELING AND
C*****ANALYSIS" BY AVERILL M. LAW AND W. DAVID KELTON, COPYRIGHT
C*****1982, CHAPTER 6, PAGE 227.

```

C

```

XHI      = ISEED/B16
XALO     = (ISEED-XHI*B16)*ABARN
LEFTLO   = XALO/B16
FHI      = XHI*ABARN + LEFTLO
K        = FHI/B15
ISEED    = (((XALO-LEFTLO*B16)-PBARN)+(FHI-K*B15)*B16)+K
IF (ISEED .LT. 0) ISEED=ISEED+PBARN
BARN     = FLOAT(ISEED)*4.656612875E-10

```

```

C*****PRINT IF RANDOM NO. IS ZERO

```

```

C*****ERROR

```

```

IF (BARN.LT.0.0 .OR. BARN.GT.1.0) THEN
  PRINT *, ' **** INVALID RANDOM NUMBER: ',BARN
  STOP
ENDIF
RETURN
END

```

```

SUBROUTINE SUMMATE (PH, PKH)

```

```

REAL PH(3), PKH(3,3)
INTEGER XREP, YREP, RNDS
INTEGER REPS(3) /10, 20, 40/
REAL XPK(3), YPK(3)
REAL DEVIATE(40,3)
DATA (DEVIATE(J,1), J = 1, 10) /
* -1.64486, -1.03643, -0.67449, -0.38532, -0.12566,
* 0.12566, 0.38532, 0.67449, 1.03643, 1.64486 /
DATA (DEVIATE(J,2), J = 1, 20) /
* -1.95997, -1.43954, -1.15035, -0.93459, -0.75541,
* -0.59776, -0.45376, -0.31864, -0.18913, -0.06271,
* 0.06271, 0.18913, 0.31864, 0.45376, 0.59776,
* 0.75541, 0.93459, 1.15035, 1.43954, 1.95997 /
DATA (DEVIATE(J,3), J = 1, 40) /
* -2.24140, -1.78046, -1.53413, -1.35632, -1.21334,
* -1.09162, -0.98423, -0.88715, -0.79778, -0.71436,
* -0.63566, -0.56071, -0.48878, -0.41929, -0.35178,

```

```

* -0.28584, -0.22112, -0.15731, -0.09414, -0.03133,
* 0.03133, 0.09414, 0.15731, 0.22112, 0.28584,
* 0.35178, 0.41929, 0.48878, 0.56071, 0.63566,
* 0.71436, 0.79778, 0.88715, 0.98423, 1.09162,
* 1.21334, 1.35632, 1.53413, 1.78046, 2.24140 /

```

```

COMMON X_BURST_BIAS, X_BURST_DISPERSION,
1Y_BURST_BIAS, Y_BURST_DISPERSION,
2X_DISPERSION, Y_DISPERSION,
3X_HULL, Y_HULL, X_TURR, Y_TURR, RNDS, PKH_RND(3)

```

```

C *** Calculate target boundaries.

```

```

X2TURR = X_TURR / 2.
X1TURR = -X2TURR
X2HULL = X_HULL / 2.
X1HULL = -X2HULL
Y2TURR = (Y_HULL + Y_TURR) / 2.
Y1TURR = Y2TURR - Y_TURR
Y2HULL = Y1TURR
Y1HULL = -Y2TURR

```

```

DO K = 1, 3

```

```

XPH = 0.

```

```

XPK(1) = 0.

```

```

XPK(2) = 0.

```

```

XPK(3) = 0.

```

```

DO XREP = 1, REPS(K)

```

```

X_BIAS = X_BURST_BIAS + X_BURST_DISPERSION *

```

```

1 DEVIATE(XREP,K)

```

```

C *** Prob. of hit on hull in X-direction

```

```

T2 = (X2HULL - X_BIAS) / X_DISPERSION

```

```

T1 = (X1HULL - X_BIAS) / X_DISPERSION

```

```

X_PH_HULL = DFN(T2) - DFN(T1)

```

```

C *** Prob. of hit on turret in X-direction

```

```

T2 = (X2TURR - X_BIAS) / X_DISPERSION

```

```

T1 = (X1TURR - X_BIAS) / X_DISPERSION

```

```

X_PH_TURR = DFN(T2) - DFN(T1)

```

```

YPH = 0.

```

```

YPK(1) = 0.

```

```

YPK(2) = 0.

```

```

YPK(3) = 0.

```

```

DO YREP = 1, REPS(K)

```

```

Y_BIAS = Y_BURST_BIAS + Y_BURST_DISPERSION *

```

```

1 DEVIATE(YREP,K)

```

```

C *** Prob. of hit on hull in Y-direction

```

```

T2 = (Y2HULL - Y_BIAS) / Y_DISPERSION

```

```

T1 = (Y1HULL - Y_BIAS) / Y_DISPERSION

```

```

Y_PH_HULL = DFN(T2) - DFN(T1)

```

```

C *** Prob. of hit on turret in Y-direction

```

```

T2 = (Y2TURR - Y_BIAS) / Y_DISPERSION

```

```

T1 = (Y1TURR - Y_BIAS) / Y_DISPERSION

```

```

      Y_PH_TURR = DFN(T2) - DFN(T1)
C *** Prob. of hit for a round
      PH_RND = X_PH_HULL * Y_PH_HULL + X_PH_TURR * Y_PH_TURR
C ** Prob. of hit for the burst
      YPH = 1. - (1. - PH_RND) **RNDS + YPH
C ** Prob. of kill for the burst
      YPK(1) = 1. - (1. - PH_RND * PKH_RND(1)) **RNDS + YPK(1)
      YPK(2) = 1. - (1. - PH_RND * PKH_RND(2)) **RNDS + YPK(2)
      YPK(3) = 1. - (1. - PH_RND * PKH_RND(3)) **RNDS + YPK(3)
      END DO ! YREP

      XPH = YPH + XPH
      XPK(1) = YPK(1) + XPK(1)
      XPK(2) = YPK(2) + XPK(2)
      XPK(3) = YPK(3) + XPK(3)
      END DO ! XREP

      PH(K) = XPH / REPS(K)**2
      PKH(K,1) = XPK(1) / XPH
      PKH(K,2) = XPK(2) / XPH
      PKH(K,3) = XPK(3) / XPH
      END DO ! K
      END

```

SUBROUTINE GAUSS (PH, PKH)

```

      REAL PH(3), PKH(3,3)
      INTEGER XREP, YREP, RNDS
      INTEGER REPS(3) /10, 20, 40/
      REAL XPK(3), YPK(3)
      REAL DEVIATE(40,3), WT(40,3)

      DATA (DEVIATE(J,1), J = 1, 10) /
* -2.22482, -1.49490, -0.99326, -0.57309, -0.18765,
* 0.18765, 0.57309, 0.99326, 1.49490, 2.22482 /
      DATA (WT(J,1), J = 1, 10) /
* .0333357, .0747257, .1095432, .1346334, .1477621,
* .1477621, .1346334, .1095432, .0747257, .0333357 /

      DATA (DEVIATE(J,2), J = 1, 20) /
* -2.70303, -2.09659, -1.70731, -1.40213, -1.14151,
* -0.90787, -0.69168, -0.48697, -0.28946, -0.09604,
* 0.09604, 0.28946, 0.48697, 0.69168, 0.90787,
* 1.14151, 1.40213, 1.70731, 2.09659, 2.70303 /
      DATA (WT(J,2), J = 1, 20) /
* .0088070, .0203007, .0313360, .0416384, .0509651,
* .0590973, .0658443, .0710481, .0745865, .0763767,
* .0763767, .0745865, .0710481, .0658443, .0590973,
* .0509651, .0416384, .0313360, .0203007, .0088070 /

      DATA (DEVIATE(J,3), J = 1, 40) /

```

```

* -3.12759, -2.60178, -2.27780, -2.03268, -1.83041,
* -1.65512, -1.49838, -1.35507, -1.22202, -1.09689,
* -0.97806, -0.86429, -0.75455, -0.64810, -0.54434,
* -0.44266, -0.34268, -0.24393, -0.14603, -0.04861,
* 0.04861, 0.14603, 0.24393, 0.34268, 0.44266,
* 0.54434, 0.64810, 0.75455, 0.86429, 0.97806,
* 1.09689, 1.22202, 1.35507, 1.49838, 1.65512,
* 1.83041, 2.03268, 2.27780, 2.60178, 3.12759 /
DATA (WT(J,3), J = 1, 40) /
* .0022606, .0052491, .0082105, .0111229, .0139685,
* .0167301, .0193911, .0219355, .0243479, .0266139,
* .0287199, .0306531, .0324020, .0339560, .0353058,
* .0364433, .0373616, .0380552, .0385199, .0387530,
* .0387530, .0385199, .0380552, .0373616, .0364433,
* .0353058, .0339560, .0324020, .0306531, .0287199,
* .0266139, .0243479, .0219355, .0193911, .0167301,
* .0139685, .0111229, .0082105, .0052491, .0022606 /

```

```

COMMON X_BURST_BIAS, X_BURST_DISPERSION,
1Y_BURST_BIAS, Y_BURST_DISPERSION,
2X_DISPERSION, Y_DISPERSION,
3X_HULL, Y_HULL, X_TURR, Y_TURR, RNDS, PKH_RND(3)

```

```

C *** Calculate target boundaries.

```

```

X2TURR = X_TURR / 2.
X1TURR = -X2TURR
X2HULL = X_HULL / 2.
X1HULL = -X2HULL
Y2TURR = (Y_HULL + Y_TURR) / 2.
Y1TURR = Y2TURR - Y_TURR
Y2HULL = Y1TURR
Y1HULL = -Y2TURR

```

```

DO K = 1, 3
XPH = 0.
XPK(1) = 0.
XPK(2) = 0.
XPK(3) = 0.
DO XREP = 1, REPS(K)
X_BIAS = X_BURST_BIAS + X_BURST_DISPERSION *
1 DEVIATE(XREP,K)

```

```

C *** Prob. of hit on hull in X-direction
T2 = (X2HULL - X_BIAS) / X_DISPERSION
T1 = (X1HULL - X_BIAS) / X_DISPERSION
X_PH_HULL = DFN(T2) - DFN(T1)

```

```

C *** Prob. of hit on turret in X-direction
T2 = (X2TURR - X_BIAS) / X_DISPERSION
T1 = (X1TURR - X_BIAS) / X_DISPERSION
X_PH_TURR = DFN(T2) - DFN(T1)

```

```

YPH = 0.
YPK(1) = 0.

```

```

      YPK(2) = 0.
      YPK(3) = 0.
      DO YREP = 1, REPS(K)
      Y_BIAS = Y_BURST_BIAS + Y_BURST_DISPERSION *
      1   DEVIATE(YREP,K)
C *** Prob. of hit on hull in Y-direction
      T2 = (Y2HULL - Y_BIAS) / Y_DISPERSION
      T1 = (Y1HULL - Y_BIAS) / Y_DISPERSION
      Y_PH_HULL = DFN(T2) - DFN(T1)
C *** Prob. of hit on turret in Y-direction
      T2 = (Y2TURR - Y_BIAS) / Y_DISPERSION
      T1 = (Y1TURR - Y_BIAS) / Y_DISPERSION
      Y_PH_TURR = DFN(T2) - DFN(T1)
C *** Prob. of hit for a round
      PH_RND = X_PH_HULL * Y_PH_HULL + X_PH_TURR * Y_PH_TURR
C ** Prob. of hit for the burst
      YPH = (1. - (1. - PH_RND) **RNDS) * WT(YREP,K) + YPH
C ** Prob. of kill for the burst
      DO J = 1, 3
      YPK(J) = (1. - (1. - PH_RND * PKH_RND(J)) **RNDS)
      1   * WT(YREP,K) + YPK(J)
      END DO
      END DO ! YREP

      XPH = YPH * WT(XREP,K) + XPH
      XPK(1) = YPK(1) * WT(XREP,K) + XPK(1)
      XPK(2) = YPK(2) * WT(XREP,K) + XPK(2)
      XPK(3) = YPK(3) * WT(XREP,K) + XPK(3)
      END DO ! XREP

      PH(K) = XPH
      PKH(K,1) = XPK(1) / XPH
      PKH(K,2) = XPK(2) / XPH
      PKH(K,3) = XPK(3) / XPH
      END DO ! K
      END

```

APPENDIX C

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