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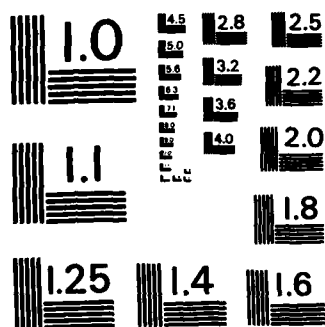UNCLASSIFIED   F/G 12/1   NL

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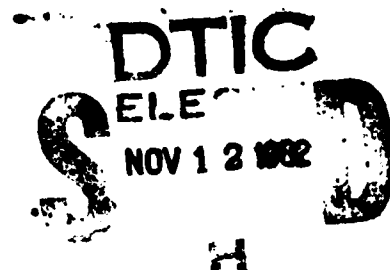
Technical Document 503

TRAM: TARGET REACTION AND MANEUVER — A MONTE CARLO SIMULATION

DH Lackowski

April 1982

Final Report: October-December 1981
Prepared for Naval Sea Systems Command

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CONVERSION TO METRIC

1 ft	$\approx$	0.3 m
1 yard	$\approx$	0.9 m
1 knot	$\approx$	1.8 km/h

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a computer program which provides a Monte Carlo simulation to determine cumulative hit probability for an ASW weapon delivery system with an evasive submarine as target.

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1.0 INTRODUCTION

The TRAM program provides a Monte Carlo simulation to determine a cumulative hit probability for an ASW weapon delivery system with an evasive submarine as target. The target evasive maneuver is a course change with a simultaneous speed change order (new thrust level). By user choice, the maneuver parameters may be fixed or may be random within prescribed statistical limits. The program also takes into account random errors of the weapon delivery system. These include errors in target localization, target motion analysis (TMA), and the delivery error of the system.

Hit probability for a given weapon delivery point is determined by a user-provided rectangular grid of hit probabilities. The grid structure provides rectangular areas distributed about the target with a prescribed hit probability associated with weapon delivery in each area.

The program is written in Sperry Univac 1100 Series FORTRAN (ASCII) — Level 9R1. See reference 1. A complete source program listing is contained in Appendix A.

Logical simplicity of the source code was emphasized to make the program and its logical flow more easily understood by the user. In some instances, this resulted in deliberately redundant or inefficient source code.

2.0 MATHEMATICAL DESCRIPTION

Figure 1 presents a representative illustration of target motion and weapon delivery system geometry. The geometry is two-dimensional; target depth is assumed constant.

At time $t = 0$ the target is located at position $T(0)$, located at the origin of the xy coordinate frame, with an initial velocity v_o along the positive x-axis. At some subsequent time $t = T_1$, the target initiates a

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[1] Sperry Rand Corporation. Sperry Univac Series 1100 FORTRAN (ASCII) - Level 9R1, Programmer Reference. 1979.
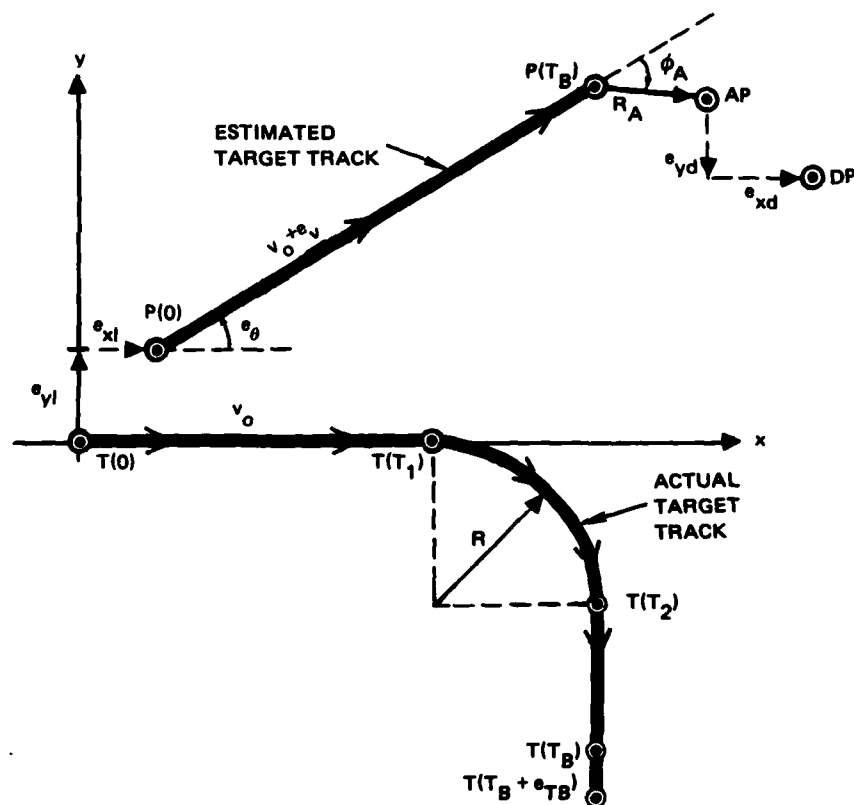
Figure 1. Illustrative run geometry.

maneuver which consists of a course change, or an instantaneous change in thrust level (change in ordered speed), or both, or neither.

The time $t = T_1$ may be prescribed by the user or, otherwise, will be chosen by the program from a random distribution of times uniformly distributed over the interval from $t = 0$ to $t = T_B + e_{TB}$, where T_B is the estimated blind time of the weapon delivery system, ie, the time between last observed target position and weapon delivery, and e_{TB} is the error in the estimate of T_B. e_{TB} is a random variable chosen by the program from a normal distribution, with zero mean and a user-specified standard deviation.

The thrust level change at $t = T_1$ is specified by the user. The course change magnitude may also be specified by the user or, otherwise, is chosen by the program from a uniform distribution between limits provided by the user. The direction of the course change is randomly chosen by the program, with either direction equally probable.

The maneuver event itself may be treated as a random variable by the program. That is, while the user may prescribe that a maneuver does occur, he may, alternatively, provide only a probability that a maneuver occurs. In the latter case, the program will determine the occurrence of the maneuver by comparing a random number, drawn from a uniform distribution over the interval zero to one, with the prescribed probability.

The time $t = T_2$ is the time at which the course change, if any, is completed. Thereafter, the target will proceed on a steady course with constant thrust level until the end of the run at time $t = T_B + e_{TB}$.

Target dynamics during the maneuver are determined from the two-degree-of-freedom equations described in Appendix B.

At time $t = 0$, the weapon delivery system assumes the target to be at position $P(0)$. e_{x1} and e_{y1} are the x and y target localization errors. These errors are chosen by the program from a zero mean normal distribution with a user-specified standard deviation.

The weapon delivery system assumes that the target maintains a steady course e_θ and steady speed $v_o + e_v$ from time $t = 0$ until $t = T_B$. The target course estimate error e_θ is chosen by the program from a zero mean normal distribution with a standard deviation specified by the user. The target speed estimate error e_v is chosen from another zero mean normal distribution with a user specified standard deviation.

At time $t = T_B$, the weapon delivery system's estimated (predicted) target position is at position $P(T_B)$. The aimpoint AP is specified by the user in

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terms of range (R_A) and bearing (ϕ_A) offsets relative to the predicted target position at $t = T_B$.

The weapon delivery point is at DP. The delivery point is offset from the aimpoint AP by the weapon delivery errors e_{xd} and e_{yd}. Both are chosen by the program from a zero mean normal distribution with a user-specified standard deviation.

The probability of hit for a given weapon delivery is determined by the location of the weapon delivery point in a user-defined hit probability grid. The rectangular grid is formed by a series of straight lines parallel to the target's course at weapon delivery and by another series of straight lines perpendicular to the target course. An illustrative example is shown on Figure 2.

The target is located at the origin ($x = 0$, $y = 0$) and the target course is along the positive x-axis. The grid lines are specified by the user and may be located anywhere relative to the target. There is no requirement for symmetry about any axis.

The user provides a probability of hit for each rectangle formed by the grid. The left-hand and lower boundaries of each rectangle are assumed to belong to that rectangle. Thus, for example, if the weapon delivery point was located anywhere in the rectangle defined by $500 \leq x < 1000$ yards and $-900 \leq y < -500$ yards, the hit probability for that weapon delivery would be 0.8.

An overall, cumulative hit probability is computed from a set of hit probabilities from individual "runs", where a run is defined as one target trajectory and associated weapon deliveries. A "set" of runs is defined as a collection of runs made under conditions that differ, one run from another, only in a stochastic sense. This structure comprises a Monte Carlo simulation.

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Y

y (YARDS) ——

0	0	0	.1	.1	.1	0
0	0	.3	.3	.2	.2	.1
0	.1	.4	.5	.5	.2	.1
.1	.3	.5	.6	.8	.4	.2
.2	.5	.6	.8	.9	.7	.3
.4	.6	.5	.6	.8	.6	.2
.2	.5	.6	.8	.9	.7	.3
.1	.3	.5	.6	.8	.4	.2
0	.1	.4	.5	.5	.2	.1
0	0	.3	.3	.2	.2	.1
0	0	0	.1	.1	.1	0

TARGET

X

2000, 1500, 1200, 900, 500, 200, 0, -200, -500, -900, -1200, -1500, -2000

-1000   -500   -100 0   300   500   1000   1500   2000

x (YARDS) ——
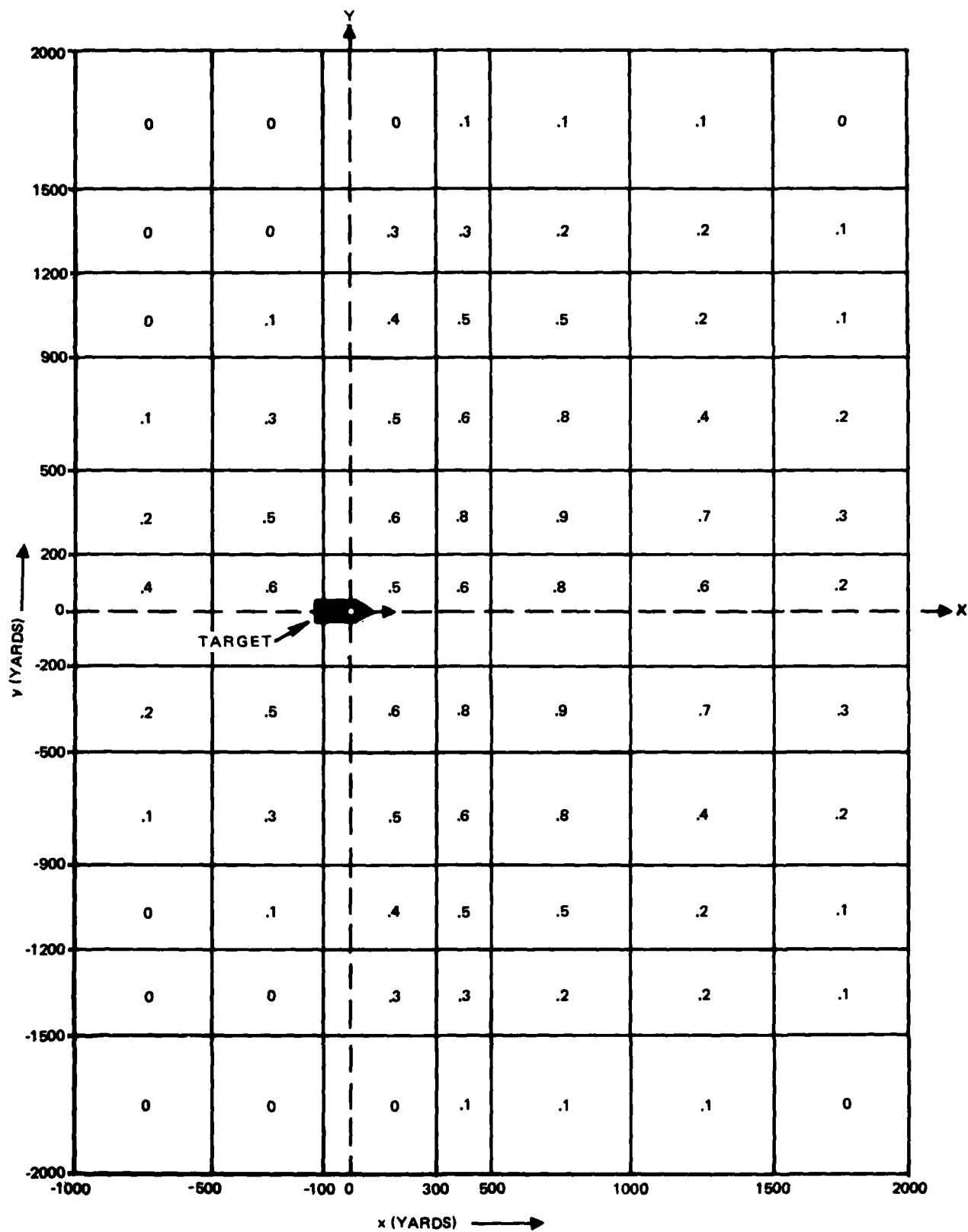
Figure 2. Illustrative hit probability grid.

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The user specifies the number of runs in a set and may also specify more than one set of runs for a given program execution. He may also specify any number of weapon deliveries for each run (salvo launch).

For a run with salvo launch of N weapons, the hit probability for the run is computed according to the equation:

$$P_n = P_n' + P_{n-1}' - P_n' P_{n-1}' \qquad n = 1, 2, \ldots N \tag{1}$$

where P_n is the probability that at least one of the first n weapons will hit and P_n' is the hit probability for the nth weapon.

The cumulative hit probability (Monte Carlo probability) for a set of N runs is computed according to the equation:

$$P = \frac{1}{N} \sum_{k=1}^{N} P_k \tag{2}$$

where P_k is the hit probability for the kth run in the set.

The random variables for each run are provided by two random number generator subroutines: UNFRM and GAUSS. Both generators run continuously (without reset) through a set of runs, so generally different sequences of numbers are provided for different runs in a set. A seed number for the generators is provided by the user at the beginning of each set of runs.

UNFRM generates a sequence of real numbers uniformly distributed over the interval [0,1]. The algorithm used is a multiplicative type of the form:

$$x_{n+1} = (185363) \; x_n \qquad (\mod 2^{35}) \tag{3}$$

The interval of the distribution is changed to [0,1] by discarding all $x_k > 2^{27}$ and multiplying the others by 2^{-27}. The 2^{27} factor is a consequence of the integer-to-real conversion process used with the Sperry Univac 1100

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Series FORTRAN (ASCII) compiler. See references 1 and 2 for additional details.

The subroutine GAUSS generates a sequence of normally distributed random numbers. The algorithm is based upon the Central Limit theorem and is of the form:

$$x = \left(\sum_{k=1}^{12} y_k - 6 \right) \sigma_x + \bar{x}$$

where x is the normally distributed random variable, the y_k are random numbers uniformly distributed over the interval [0,1] (provided by subroutine UNFRM), σ_x is the standard deviation of the distribution, and $\bar{x}$ is the mean. $\bar{x}$ and σ_x are specified in the program call for the subroutine. See reference 2 for additional details.

Source code listings of UNFRM and GAUSS are included in Appendix A.

3.0 INPUT DATA REQUIREMENTS

For the convenience of the user in formatting input data, all input data variable names are defined with a NAMELIST statement. See reference 1 for details of NAMELIST input.

The program defines three NAMELIST names: NL1, NL2, and NL3. Every input data variable is assigned to one of the three. Upon initiation of program execution, the program searches for and reads-in NL1 data. Upon initiation of each set of runs, the program searches for and reads-in NL2 and NL3 data. For the first set of runs, all NL2 and NL3 data variables must be explicitly defined on an input record (card). For subsequent sets, only those input variables whose values change from the preceding set need to be redefined. If none of the variables in NL2 or NL3 change value from the preceding set, an input card with a blank data field must nevertheless be provided for that

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[2] Hamming, R. W. Numerical Methods for Scientists and Engineers. McGraw-Hill, 1973.

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NAMELIST name, since the program will search for both NL2 and NL3 input cards before executing a set of runs.

Appendix C contains a listing of all input data variable names and a description of the datum each represents. Appendix D contains an example of input data cards to illustrate input data requirements and format.

4.0 SUBROUTINE REQUIREMENTS

The main program calls two subroutines: UNFRM and GAUSS. Subroutine UNFRM (N0, N1, X) returns to the calling program a real number X, which represents one pseudorandom sample from a uniform distribution over the interval [0,1], and an integer number N1, which represents one pseudo-random sample from a set of integers uniformly distributed over the interval $[0,2^{27}]$. Subroutine GAUSS (N0, XMEAN, XSIGMA, N1, X) returns to the calling program a real number X, which represents one pseudorandom sample from a normal distribution with mean XMEAN and standard deviation XSIGMA, and an integer number N1, which represents a pseudorandom sample from a set of integers uniformly distributed over the interval $[0,2^{27}]$.

For both UNFRM and GAUSS, the integer N0 is provided by the calling program. For the first call for either UNFRM or GAUSS, N0 may be any odd integer. If either UNFRM or GAUSS has been called prior to a current call for either subroutine, then N0 should be the value of N1 returned from that call, for either subroutine, which immediately precedes the current call.

Source code listings of UNFRM and GAUSS are included in Appendix A. A mathematical description was provided in Section 2.0. Note that subroutine GAUSS calls the subroutine UNFRM.

5.0 OUTPUT DATA

Appendix E contains the printout for program execution with the input data illustrated in Appendix D.

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6.0 TOP LEVEL FLOWCHART

The top-level program flowchart is shown in Figure 3. At the level shown, program execution is essentially controlled by three nested do-loops.

The outermost loop (I=1, NSET) cycles once for each set of runs, while the second loop (J=1, NRUN) cycles once for each run within a set. The innermost loop (K=1, NSHOT) cycles once for each weapon shot of a run. With one exception, lower level flowcharts are not necessary, since program logic is obvious. A second-level flowchart for the one exception, Target Course and Position at Weapon Delivery, is presented in the next section.

7.0 TARGET COURSE AND POSITION AT WEAPON DELIVERY - LEVEL II FLOWCHART

Figure 4 is a level II flowchart for target course and position at weapon delivery. The logical flow of program execution can be discerned from the flowchart and the comments included in the source code listing (Appendix A).

8.0 INTERNAL VARIABLE AND FUNCTION NAMES

Appendix F contains a listing of all internal variable and function names used in the program along with a definition of each.

9.0 REFERENCES

[1] Sperry Rand Corporation. Sperry Univac Series 1100 FORTRAN (ASCII) - Level 9R1, Programmer Reference. 1979.

[2] Hamming, R. W. Numerical Methods for Scientists and Engineers. McGraw-Hill, 1973.

Figure 3. Top-level flow chart

START

TARGET MANEUVER?

NO → TARGET POSITION AT WEAPON DELIVERY → D

YES → 001 TIME MANEUVER STARTS

POSITION AT START OF MANEUVER

COURSE CHANGE?

YES → 003 SET COEFFICIENTS

NO → SET COEFFICIENTS

$\nu_0 > 1?$

NO → POSITION AT WEAPON DELIVERY

YES → 004 POSITION AT WEAPON DELIVERY

→ C

COURSE CHANGE MAGNITUDE

TERMINAL SPEED

ARC LENGTH TO COMPLETE TURN

$\nu_0 > 1?$

NO → $\nu_0 = 1?$

YES → 005 TIME TO COMPLETE TURN

NO → TIME TO COMPLETE TURN

YES → 006 TIME TO COMPLETE TURN

TURN COMPLETED BEFORE WEAPON DELIVERY?

NO → H   YES → G J

TURN COMPLETED BEFORE WEAPON DELIVERY?

NO → (G) (J)   YES → I F

TURN COMPLETED BEFORE WEAPON DELIVERY?

NO → I F   YES → E
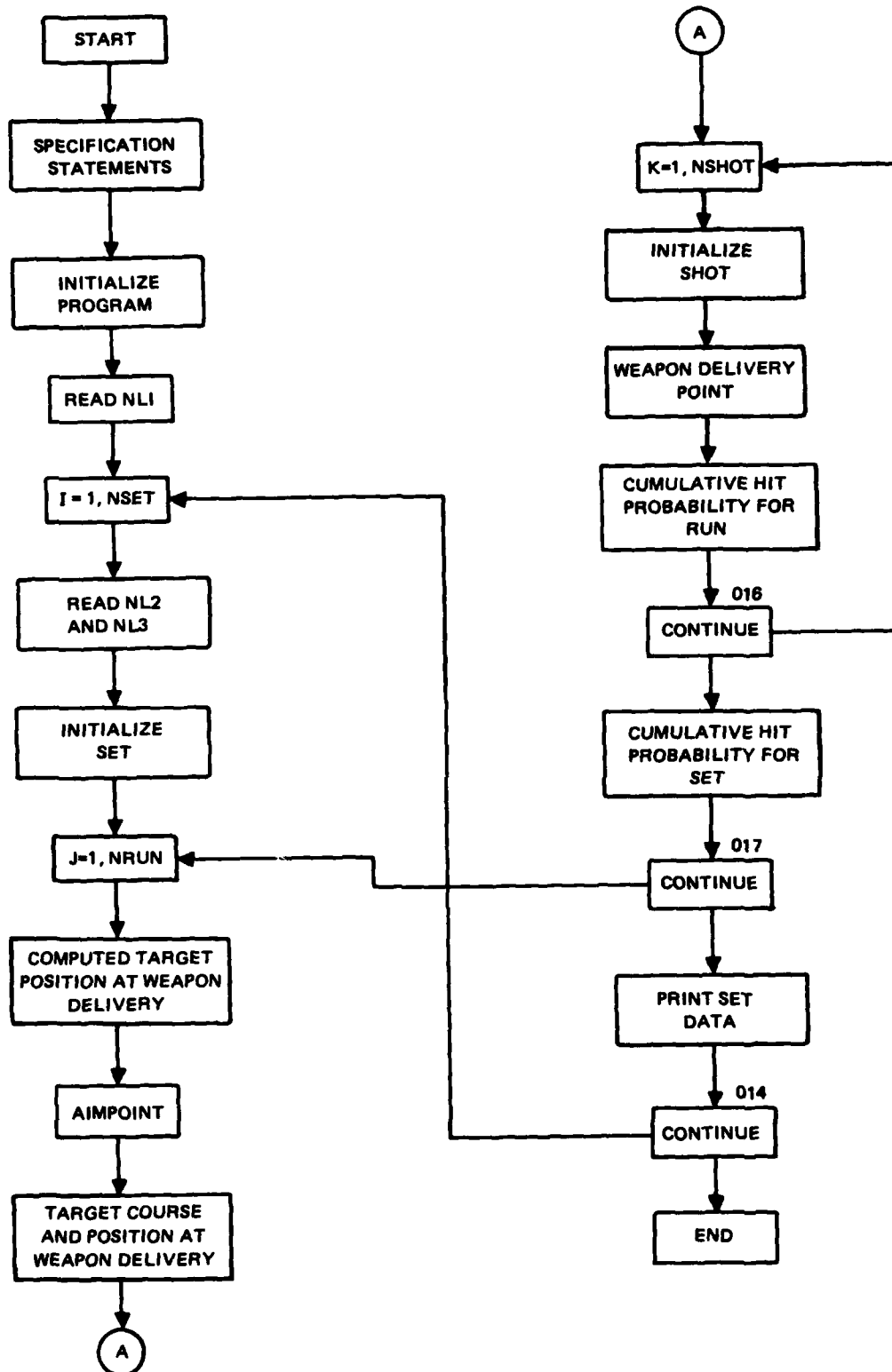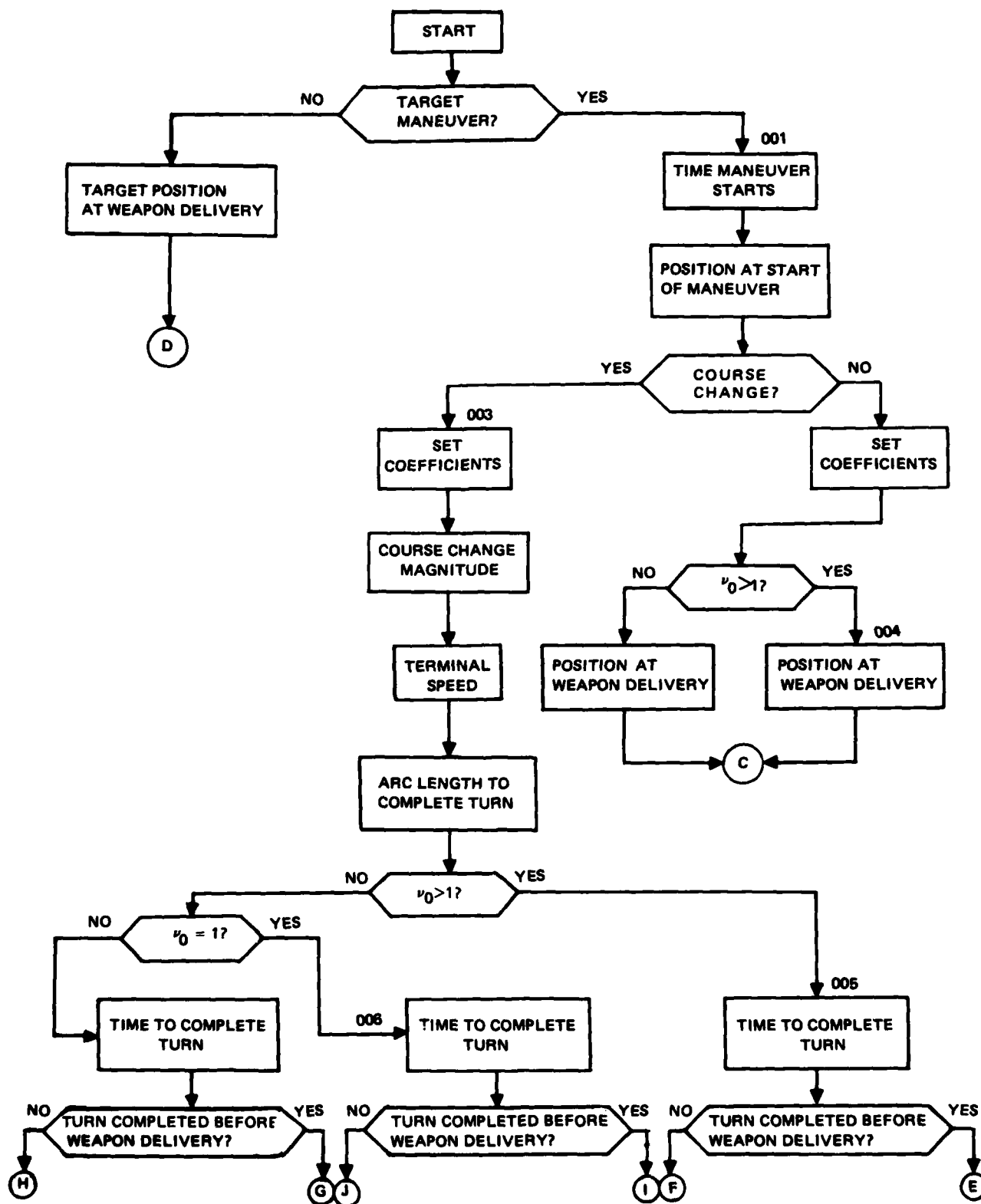
Figure 4. Target course and position at weapon delivery – Level II Flow chart
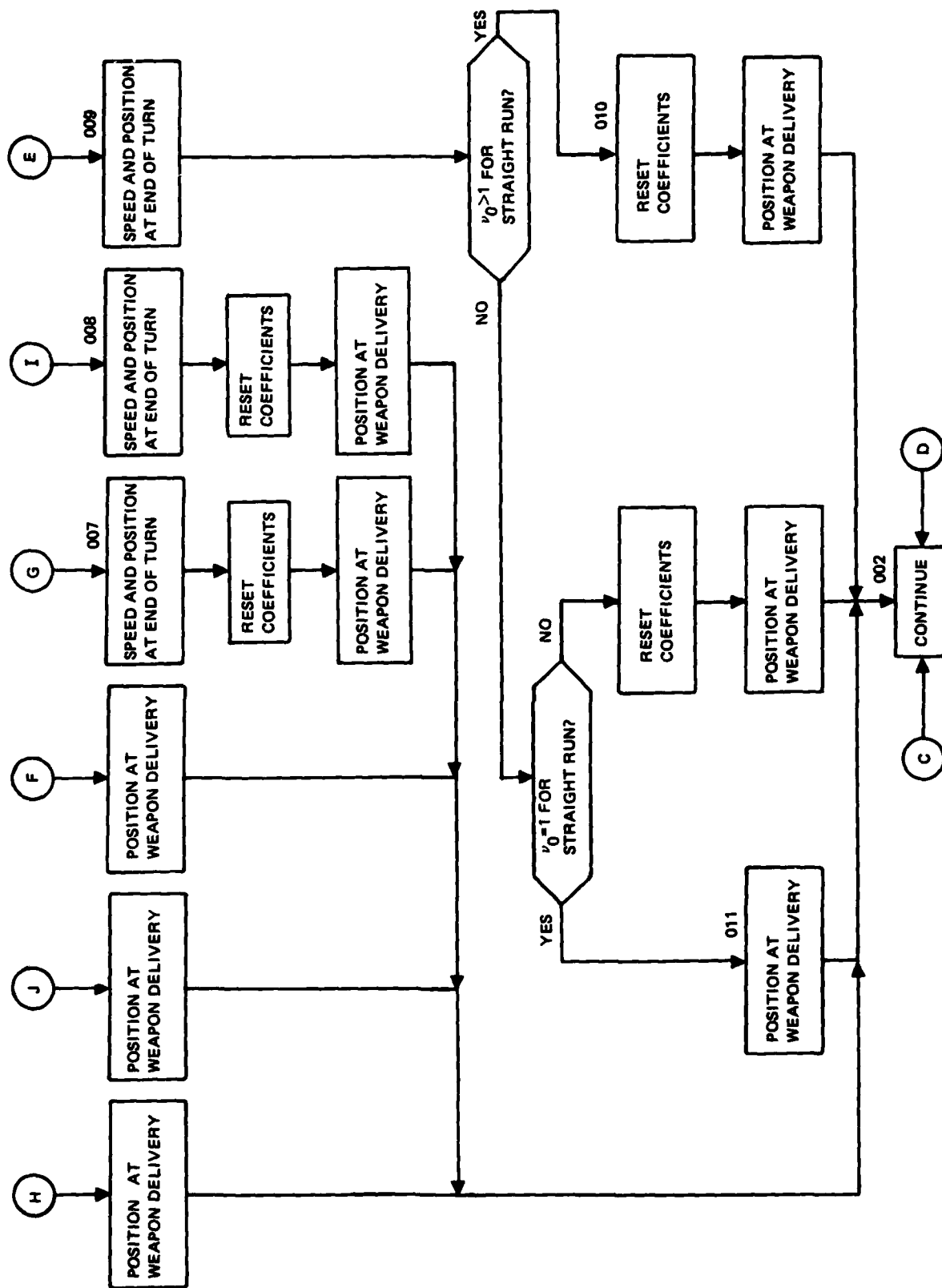
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Figure 4. Continued.

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APPENDIX A: TRAM SOURCE

CODE LISTING

```
1.    C      THIS PROGRAM COMPUTES A CUMULATIVE HIT PROBABILITY FOR EACH SET OF
2.    C      MONTE-CARLO RUNS FOR AN ASW WEAPON DELIVERY SYSTEM WITH A TARGET
3.    C      THAT MAY EXECUTE A RANDOM MANEUVER DURING THE BLIND TIME INTERVAL
4.    C      BETWEEN TIME OF LAST OBSERVED TARGET POSITION AND TIME OF WEAPON
5.    C      DELIVERY. THE PROGRAM CALLS SUBROUTINES UNFRM AND GAUSS. INPUT
6.    C      DATA ARE THE FOLLOWING:
7.
8.    C         SYMBOL    UNITS    DESCRIPTION
9.
10.   C         NSET      ----     NUMBER OF SETS OF MONTE-CARLO RUNS
11.   C         NRUM      ----     NUMBER OF RUNS IN EACH SET
12.   C         NSHOT     ----     NUMBER OF INDEPENDENT WEAPON DELIVERIES FOR
13.   C                            EACH RUN
14.   C         PTM       ----     PROBABILITY THAT TARGET WILL MANEUVER DURING
15.   C                            BLIND TIME INTERVAL. IF PTM .LT. 0.0 AND PTM
16.   C                            .GT. -1.0, THEN TARGET WILL MANEUVER STARTING
17.   C                            AT -100.0*PTM PERCENT OF BLIND TIME.
18.   C         TS1       KTS      TARGET SPEED BEFORE START OF MANEUVER
19.   C         TS2       KTS      TARGET SPEED ORDERED AT TIME MANEUVER STARTS
20.   C         CMAX      DEG      MAXIMUM MAGNITUDE OF COURSE CHANGE
21.   C         CMIN      DEG      MINIMUM MAGNITUDE OF COURSE CHANGE
22.   C         TR        YDS      TARGET TURN RADIUS
23.   C         TCL       FT       TARGET CHARACTERISTIC LENGTH
24.   C         TR2       YDS**2   TARGET CHARACTERISTIC DRAG RADIUS SQUARED
25.   C         TB        SEC      BLIND TIME
26.   C         APR       YDS      AIMPOINT OFFSET RADIUS
27.   C         APA       DEG      RELATIVE BEARING OF AIMPOINT FROM TARGET
28.   C                            (AIMPOINT OFFSET ANGLE)
29.   C         SIGTB     SEC      STANDARD DEVIATION OF NORMAL ERROR IN ESTIMATE
30.   C                            OF TB
31.   C         SIGTC     DEG      STANDARD DEVIATION OF NORMAL ERROR IN ESTIMATE
32.   C                            OF TARGET INITIAL COURSE
33.   C         SIGTS     KTS      STANDARD DEVIATION OF NORMAL ERROR IN ESTIMATE
34.   C                            OF TARGET INITIAL SPEED
35.   C         SIGL      YDS      STANDARD DEVIATION OF CIRCULAR NORMAL ERROR
36.   C                            IN ESTIMATE OF TARGET INITIAL POSITION
37.   C         SIGD      YDS      STANDARD DEVIATION OF CIRCULAR NORMAL ERROR
38.   C                            OF WEAPON DELIVERY
39.   C         NX        ----     NUMBER OF HIT PROBABILITY GRID LINES
40.   C                            PERPENDICULAR TO TARGET CENTERLINE (25 MAX)
41.   C         NY        ----     NUMBER OF HIT PROBABILITY GRID LINES PARALLEL
42.   C                            TO TARGET CENTERLINE (25 MAX)
43.   C         NRAN      ----     ARBITRARY INTEGER SEED FOR RANDOM NUMBER
44.   C                            GENERATOR
45.   C         GRIDX(I)  YDS      ARRAY (25 MAX) OF X COORDINATES OF HIT
46.   C                            PROBABILITY GRID LINES. POSITIVE AHEAD,
47.   C                            NEGATIVE ASTERN. ARRAY IS STRUCTURED IN
48.   C                            ASCENDING ORDER - GRIDX(I) .LT. GRIDX(I+1).
49.   C         GRIDY(I)  YDS      ARRAY (25 MAX) OF Y COORDINATES OF HIT
50.   C                            PROBABILITY GRID LINES. POSITIVE TO PORT,
51.   C                            NEGATIVE TO STBD. ARRAY IS STRUCTURED IN
52.   C                            ASCENDING ORDER - GRIDY(I) .LT. GRIDY(I+1).
53.   C         PH(I,J)   ----     ARRAY (24 BY 24 MAX) OF HIT PROBABILITIES.
54.   C                            PH(I,J) IS THE PROBABILITY ASSOCIATED WITH THE
55.   C                            HIT PROBABILITY GRID RECTANGLE DEFINED BY
```

```
56.     C                                  ((GRIDX(I) .LE. X) .AND. (GRIDX(I+1) .GT. X))
57.     C                                          .AND.
58.     C                                  ((GRIDY(J) .LE. Y) .AND. (GRIDY(J+1) .GT. Y))
59.
60.     C       FOR THE FIRST SET, ALL INPUT DATA MUST BE PROVIDED. FOR SUBSEQUENT
61.     C       SETS, ONLY DATA MODIFICATIONS ARE REQUIRED. NSET IS READ ONLY ONCE
62.     C       AT THE START OF THE PROGRAM. ALL OTHER DATA ARE READ AT START OF
63.     C       EACH SET. NAMELIST INPUT IS USED.
64.
65.     C       SPECIFICATION STATEMENTS
66.             DIMENSION GRIDX(25),GRIDY(25),PH(24,24)
67.             NAMELIST /NL1/NSET
68.           X             /NL2/NRUN,NSHOT,PTM,TS1,TS2,CMAX,CMIN,TR,TCL,TR2,TB,APR,
69.           X                  APA,SIGTB,SIGTC,SIGTS,SIGL,SIGD,NX,NY,NRAN
70.           X             /NL3/GRIDX,GRIDY,PH
71.       022 FORMAT(1H1,49HCUMULATIVE HIT PROBABILITY FOR ALL RUNS THIS SET:,
72.           X        2X,6HPCH = ,F7.4//1X,30HINPUT DATA FOR THE SET FOLLOW:)
73.       026 FORMAT(1H ,14HGRIDX(I) (I=1,,I2,2H):/10(F8.1:2X))
74.       027 FORMAT(1H ,14HGRIDY(J) (J=1,,I2,2H):/10(F8.1:2X))
75.       028 FORMAT(1H ,13HPH(I,J) (I=1,,I2,7H),(J=1,,I2,2H):/10(F8.4:2X))
76.
77.     C       DEFINE INVERSE HYPERBOLIC FUNCTIONS
78.             ASINH(X)=ALOG(X+SQRT(X*X+1.0))
79.             ACOSH(X)=ALOG(X+SQRT(X*X-1.0))
80.             ATANH(X)=0.5*ALOG((1.0+X)/(1.0-X))
81.             ACOTH(X)=0.5*ALOG((X+1.0)/(X-1.0))
82.
83.     C       INITIATE LOOP FOR SETS OF RUNS
84.             READ(5,NL1)
85.             DO 014 I=1,NSET
86.
87.     C       READ INPUT DATA FOR SET
88.             READ(5,NL2)
89.             READ(5,NL3)
90.
91.     C       INITIALIZE DATA FOR THIS SET
92.             DUM1=0.562962963
93.             TS11=DUM1*TS1
94.             TS21=DUM1*TS2
95.             SIGTS1=DUM1*SIGTS
96.             TCL1=TCL/3.0
97.             DUM1=0.01745329
98.             APA1=DUM1*APA
99.             SIGTC1=DUM1*SIGTC
100.            NRAN1=2*NRAN+1
101.            PCH=0.0
102.            FNRUN=FLOAT(NRUN)
103.
104.    C       INITIATE LOOP FOR RUNS IN THIS SET
105.            DO 017 J=1,NRUN
106.
107.    C       TIME TO WEAPON DELIVERY FOR THIS RUN
108.            CALL GAUSS(NRAN1,0.0,SIGTB,NRAN1,TI)
109.            TI=TB+TI
110.
111.    C       COMPUTED TARGET POSITION AT WEAPON DELIVERY
112.            CALL GAUSS(NRAN1,0.0,SIGL,NRAN1,XTC)
```

```
113.            CALL GAUSS(NPAN1,0.0,SIGL,NRAN1,YTC)
114.            CALL GAUSS(NRAN1,0.0,SIGTS1,NPAN1,DUM1)
115.            DUM1=(TS11+DUM1)*TB
116.            CALL GAUSS(NRAN1,0.0,SIGTC1,NRAN1,DUM2)
117.            XTC=XTC+DUM1*COS(DUM2)
118.            YTC=YTC-DUM1*SIN(DUM2)
119.
120.    C       AIMPOINT
121.            DUM2=DUM2+APA1
122.            XAP=XTC+APR*COS(DUM2)
123.            YAP=YTC-APR*SIN(DUM2)
124.
125.    C       TARGET COURSE AND POSITION AT WEAPON DELIVERY
126.
127.    C       IS THERE A TARGET MANEUVER
128.            CALL UNFRM(NRAN1,NRAN1,RN)
129.            IF((((PTM.LT.0.0).OR.(RN.LT.PTM)).AND.((CMAX.NE.0.0).OR.
130.        X   (TS2.NE.TS1))) GO TO 001
131.
132.    C       TARGET COURSE AND POSITION AT WEAPON DELIVERY. NO MANEUVER.
133.            TCWD=0.0
134.            XT=TS11*T1
135.            YT=0.0
136.            GO TO 002
137.
138.    C       TARGET MANEUVER. TIME MANEUVER STARTS.
139.      001   IF(PTM.LT.0.0) GO TO 012
140.            CALL UNFRM(NRAN1,NRAN1,RN)
141.            TM=RN*T1
142.            GO TO 013
143.      012   TM=-1.0*PTM*T1
144.      013   CONTINUE
145.
146.    C       TARGET POSITION AT START OF MANEUVER
147.            XT=TS11*TM
148.            YT=0.0
149.
150.    C       DOES MANEUVER INCLUDE COURSE CHANGE
151.            CALL UNFRM(NRAN1,NRAN1,RN)
152.            CCM=CMIN+RN*(CMAX-CMIN)
153.            IF(CCM.NE.0.0) GO TO 003
154.
155.    C       TARGET COURSE AND POSITION AT WEAPON DELIVERY. SPEED CHANGE ONLY.
156.            TCWD=0.0
157.            FNU0=TS1/TS2
158.            TAU=TS21*(T1-TM)/TCL1
159.            IF(FNU0.GT.1.0) GO TO 004
160.
161.    C       TARGET ACCELERATES
162.            DUM1=ATANH(FNU0)
163.            XT=XT+TCL1*ALOG(COSH(TAU+DUM1)/COSH(DUM1))
164.            GO TO 002
165.
166.    C       TARGET DECELERATES
167.      004   DUM1=ACOTH(FNU0)
168.            XT=XT+TCL1*ALOG(SINH(TAU+DUM1)/SINH(DUM1))
169.            GO TO 002
```

```
170.
171.    C       TARGET COURSE AND POSITION AT WEAPON DELIVERY. COURSE CHANGE.
172.      003 DUM1=1.0+TR2/(TR*TR)
173.          CR=TCLI/DUM1
174.
175.    C       MAGNITUDE AND DIRECTION OF COURSE CHANGE
176.          CCM=0.01745329*CCM
177.          CALL UNFRN(NRAN1,NRAN1,RN)
178.          CCS=1.0
179.          IF(RN.GT.0.5) CCS=-1.0
180.
181.    C       TERMINAL SPEED FOR INFINITE TURN
182.          TST=TS2I/SQRT(DUM1)
183.
184.    C       ARC LENGTH OF FULL TURN
185.          S=TR*CCM
186.
187.    C       DOES TARGET ACCELERATE OR DECELERATE DURING TURN
188.          FNUO=TS1I/TST
189.          IF(FNUO.GT.1.0) GO TO 005
190.          IF(FNUO.EQ.1.0) GO TO 006
191.
192.    C       TIME TO COMPLETE TURN. TARGET ACCELERATES.
193.          DUM1=ATANH(FNUO)
194.          T2=(CR/TST)*(ACOSH(EXF(S/CR)*COSH(DUM1))-DUM1)
195.
196.    C       CAN TURN BE COMPLETED BEFORE WEAPON DELIVERY
197.          IF((TM+T2).LE.T1) GO TO 007
198.
199.    C       COURSE AND POSITION DURING TURN AT WEAPON DELIVERY
200.          TAU=(TST/CR)*(T1-TM)
201.          S=CR*ALOG(COSH(TAU+DUM1)/COSH(DUM1))
202.          DUM2=S/TR
203.          TCWD=DUM2*CCS
204.          XT=XT+TR*SIN(DUM2)
205.          YT=TR*(1.0-COS(DUM2))*CCS
206.          GO TO 002
207.
208.    C       SPEED AND POSITION AT END OF TURN
209.      007 XT=XT+TR*SIN(CCM)
210.          YT=TR*(1.0-COS(CCM))*CCS
211.          TAU=(TST/CR)*T2
212.          TSE=TST*TANH(TAU+DUM1)
213.
214.    C       RESET COEFFICIENTS FOR STRAIGHT RUN AFTER TURN
215.          FNUO=TSE/TS2I
216.          TAU=(TS2I/CR)*(T1-TM-T2)
217.          DUM1=ATANH(FNUO)
218.
219.    C       COURSE AND POSITION AT WEAPON DELIVERY
220.          TCWD=CCM*CCS
221.          DUM2=TCLI*ALOG(COSH(TAU+DUM1)/COSH(DUM1))
222.          XT=XT+DUM2*COS(CCM)
223.          YT=YT+DUM2*SIN(CCM)*CCS
224.          GO TO 002
225.
226.    C       TIME TO COMPLETE TURN. TARGET SPEED CONSTANT.
```

```
227.      006 T2=TR*CCM/TS11
228.
229.  C     CAN TURN BE COMPLETED BEFORE WEAPON DELIVERY
230.        IF((TM+T2).LE.T1) GO TO 008
231.
232.  C     COURSE AND POSITION DURING TURN AT WEAPON DELIVERY
233.        DUM2=CCM*(T1-TM)/T2
234.        TCWD=DUM2*CCS
235.        XT=XT+TR*SIN(DUM2)
236.        YT=TR*(1.0-COS(DUM2))*CCS
237.        GO TO 002
238.
239.  C     POSITION AT END OF TURN
240.      008 XT=XT+TR*SIN(CCM)
241.        YT=TR*(1.0-COS(CCM))*CCS
242.
243.  C     RESET COEFFICIENTS FOR STRAIGHT RUN AFTER TURN
244.        FNUO=TS11/TS21
245.        TAU=(TS21/CR)*(T1-TM-T2)
246.        DUM1=ATANH(FNUO)
247.
248.  C     COURSE AND POSITION AT WEAPON DELIVERY
249.        TCWD=CCM*CCS
250.        DUM2=TCL1*ALOG(COSH(TAU+DUM1)/COSH(DUM1))
251.        XT=XT+DUM2*COS(CCM)
252.        YT=YT+DUM2*SIN(CCM)*CCS
253.        GO TO 002
254.
255.  C     TIME TO COMPLETE TURN, TARGET DECELERATES
256.      005 DUM1=ACOTH(FNUO)
257.        T2=(CR/TST)*(ASINH(EXP(S/CR)*SINH(DUM1))-DUM1)
258.
259.  C     CAN TURN BE COMPLETED BEFORE WEAPON DELIVERY
260.        IF((TM+T2).LE.T1) GO TO 009
261.
262.  C     COURSE AND POSITION DURING TURN AT WEAPON DELIVERY
263.        TAU=(TST/CR)*(T1-TM)
264.        S=CR*ALOG(SINH(TAU+DUM1)/SINH(DUM1))
265.        DUM2=S/TR
266.        TCWD=DUM2*CCS
267.        XT=XT+TR*SIN(DUM2)
268.        YT=TR*(1.0-COS(DUM2))*CCS
269.        GO TO 002
270.
271.  C     SPEED AND POSITION AT END OF TURN
272.      009 XT=XT+TR*SIN(CCM)
273.        YT=TR*(1.0-COS(CCM))*CCS
274.        TAU=(TST/CR)*T2
275.        TSE=TST/TANH(TAU+DUM1)
276.
277.  C     DOES TARGET ACCELERATE OR DECELERATE AFTER TURN
278.        FNUO=TSE/TS21
279.        IF(FNUO.GT.1.0) GO TO 010
280.        IF(FNUO.EQ.1.0) GO TO 011
281.
282.  C     TARGET ACCELERATES AFTER TURN, RESET COEFFICIENTS FOR STRAIGHT
283.  C     RUN.
```

```
284.          TAU=(TS2I/CR)*(TI-TM-T2)
285.          DUM1=ATANH(FNUO)
286.
287.    C     COURSE AND POSITION AT WEAPON DELIVERY
288.          TCWD=CCM*CCS
289.          DUM2=TCLI*ALOG(COSH(TAU+DUM1)/COSH(DUM1))
290.          XT=XT+DUM2*COS(CCM)
291.          YT=YT+DUM2*SIN(CCM)*CCS
292.          GO TO 002
293.
294.    C     TARGET SPEED CONSTANT AFTER TURN. COURSE AND POSITION AT WEAPON
295.    C     DELIVERY.
296.      011 TCWD=CCM*CCS
297.          DUM2=TSE*(TI-TM-T2)
298.          XT=XT+DUM2*COS(CCM)
299.          YT=YT+DUM2*SIN(CCM)*CCS
300.          GO TO 002
301.
302.    C     TARGET DECELERATES AFTER TURN. RESET COEFFICIENTS FOR STRAIGHT
303.    C     RUN.
304.      010 TAU=(TS2I/CR)*(TI-TM-T2)
305.          DUM1=ACOTH(FNUO)
306.
307.    C     COURSE AND POSITION AT WEAPON DELIVERY
308.          TCWD=CCM*CCS
309.          DUM2=TCLI*ALOG(SINH(TAU+DUM1)/SINH(DUM1))
310.          XT=XT+DUM2*COS(CCM)
311.          YT=YT+DUM2*SIN(CCM)*CCS
312.
313.    C     TERMINAL FOR TARGET COURSE AND POSITION
314.      002 CONTINUE
315.
316.    C     INITIALIZE LOOP FOR NUMBER OF SHOTS ON RUN
317.          PCHS=0.0
318.          DO 016 K=1,NSHOT
319.
320.    C     WEAPON DELIVERY POINT
321.          CALL GAUSS(NRAN1,0.0,SIGD,NRAN1,XWD)
322.          CALL GAUSS(NRAN1,0.0,SIGD,NRAN1,YWD)
323.          XWD=XWD+XAP
324.          YWD=YWD+YAP
325.
326.    C     CONVERT WEAPON DELIVERY POINT TO HIT PROBABILITY GRID COORDINATES
327.          DUM1=SIN(TCWD)
328.          DUM2=COS(TCWD)
329.          DUM3=XWD-XT
330.          DUM4=YWD-YT
331.          XWDG=DUM4*DUM1+DUM3*DUM2
332.          YWDG=DUM4*DUM2-DUM3*DUM1
333.
334.    C     IS THE WEAPON DELIVERY POINT OUTSIDE THE HIT PROBABILITY GRID
335.          IF((XWDG.LT.GRIDX(1)).OR.(XWDG.GE.GRIDX(NX)).OR.
336.        X    (YWDG.LT.GRIDY(1)).OR.(YWDG.GE.GRIDY(NY))) GO TO 016
337.
338.    C     CUMULATIVE HIT PROBABILITY FOR RUN
339.          II=1
340.      020 IF((GRIDX(II).LE.XWDG).AND.(GRIDX(II+1).GT.XWDG)) GO TO 019
```

```
341.          II=II+1
342.          GO TO 020
343.    019 JJ=1
344.    018 IF((GRIDY(JJ).LE.YWDG).AND.(GRIDY(JJ+1).GT.YWDG)) GO TO 021
345.          JJ=JJ+1
346.          GO TO 018
347.    021 PCHS=PCHS+PH(II,JJ)-PCHS*PH(II,JJ)
348.
349.  C       LOOP TERMINAL FOR NUMBER OF SHOTS ON THIS RUN
350.    016 CONTINUE
351.
352.  C       CUMULATIVE HIT PROBABILITY FOR SET
353.          PCH=PCH+PCHS/FNRUN
354.
355.  C       LOOP TERMINAL FOR RUNS IN THIS SET
356.    017 CONTINUE
357.
358.  C       PRINT RESULTS FOR SET
359.          WRITE(6,22) PCH
360.          WRITE(6,NL2)
361.          WRITE(6,26) NX,(GRIDX(II),II=1,NX)
362.          WRITE(6,27) NY,(GRIDY(II),II=1,NY)
363.          NXI=NX-1
364.          NYI=NY-1
365.          WRITE(6,28) NXI,NYI,((PH(II,JJ),II=1,NXI),JJ=1,NYI)
366.
367.  C       LOOP TERMINAL FOR SETS OF RUNS
368.    014 CONTINUE
369.
370.          END
```

```
 1.   C      SUBROUTINE UNFRM(NO,N1,X) COMPUTES A REAL PSEUDO-RANDOM VARIABLE X
 2.   C      UNIFORMLY DISTRIBUTED OVER THE INTERVAL 0.0 TO 1.0 AND AN INTEGER
 3.   C      PSEUDO-RANDOM VARIABLE N1 UNIFORMLY DISTRIBUTED OVER THE INTERVAL
 4.   C      0 TO (2**35-1)-(2**8-1). IF A CALL FOR UNFRM HAS NOT BEEN
 5.   C      PRECEEDED BY ANOTHER CALL FOR UNFRM OR A CALL FOR GAUSS, THE SEED
 6.   C      VARIABLE NO MUST BE AN ODD INTEGER. OTHERWISE NO SHOULD BE THE
 7.   C      VALUE OF N1 RETURNED BY THE PRECEEDING CALL FOR UNFRM OR GAUSS.
 8.   C      THIS SUBROUTINE IS INTENDED FOR USE WITH A COMPUTER HAVING AN
 9.   C      INTEGER WORD LENGTH OF 35 BITS PLUS SIGN AND AN INTEGER-TO-REAL
10.   C      CONVERSION FUNCTION FLOAT(I) WHICH RETAINS ONLY THE 27 MS BITS
11.   C      OF THE INTEGER. THE PERIOD OF THE PSEUDO RANDOM NUMBERS IS
12.   C      APPROXIMATELY 2**33.
13.          SUBROUTINE UNFRM(NO,N1,X)
14.      002 N1=185363*NO
15.          IF(N1.GE.0) GO TO 001
16.          N1=-1*N1
17.      001 IF(N1.GT.34359738112) GO TO 002
18.          X=FLOAT(N1)/34359738112.0
19.          RETURN
20.          END
```

```
1.    C         SUBROUTINE GAUSS(NO,XM,XS,NI,X) COMPUTES A REAL, NORMALLY
2.    C         DISTRIBUTED, PSEUDO-RANDOM VARIABLE X WITH MEAN XM AND STANDARD
3.    C         DEVIATION XS. IF A CALL FOR GAUSS HAS NOT BEEN PRECEEDED BY
4.    C         ANOTHER CALL FOR GAUSS OR A CALL FOR UNFRM,THE SEED VARIABLE NO
5.    C         MUST BE AN ODD INTEGER. OTHERWISE NO SHOULD BE THE VALUE OF NI
6.    C         RETURNED BY THE PRECEEDING CALL FOR GAUSS OR UNFRM. SUBROUTINE
7.    C         GAUSS CALLS THE SUBROUTINE UNFRM.
8.              SUBROUTINE GAUSS(NO,XM,XS,NI,X)
9.              X=0.0
10.             DO 001 I=1,12
11.             CALL UNFRM(NO,NO,DX)
12.             X=X+DX
13.       001 CONTINUE
14.             NI=NO
15.             X=(X-6.0)*XS+XM
16.             RETURN
17.             END
```

A-10

APPENDIX B: TWO-DEGREE-OF-FREEDOM

EQUATIONS OF MOTION FOR A MANEUVERING TARGET

TERMINAL SPEED FOR A GIVEN THRUST LEVEL

The terminal (steady-state) speed v of a submerged body with constant thrust level T is given by:

$$v = \sqrt{\frac{2T}{\rho C_D S}} \tag{B-1}$$

where:

ρ = density of the medium

C_D = drag coefficient

S = characteristic area

Now let C_{D1} denote the drag coefficient of the body for motion along a straight path and C_{D2} the drag coefficient of the body in a turn. Let v_1 denote the terminal speed of the body for a straight run with constant thrust T and v_2 the terminal speed in an infinite turn with the same thrust level T. Then, it follows from equation (B-.):

$$v_2 = v_1 \sqrt{\frac{C_{D1}}{C_{D2}}} \tag{B-2}$$

Assume C_{D2} is of the form:

$$C_{D2} = C_{D1} + K C_L^2 \tag{B-3}$$

where K is some constant and C_L is the lift coefficient due to turning. Then:

$$\frac{C_{D1}}{C_{D2}} = \left(1 + \frac{K C_L^2}{C_{D1}}\right)^{-1} \tag{B-4}$$

The lift L for a body at speed v during a turn of constant radius R is given by:

$$L = \frac{1}{2} \rho v^2 C_L S = \frac{2mv^2}{R} \qquad \text{(B-5)}$$

where m is the body mass and is equal to the mass of the water displaced by the body (we assume trim for neutral buoyancy).

Then, solving for C_L:

$$C_L = \frac{4m}{\rho SR} \qquad \text{(B-6)}$$

Substituting (B-6) into (B-4):

$$\frac{C_{D1}}{C_{D2}} = \left(1 + \frac{16 \ Km^2}{\rho^2 S^2 R^2 C_{D1}} \right)^{-1} \qquad \text{(B-7)}$$

Or

$$\frac{C_{D1}}{C_{D2}} = \left(1 + \frac{R_c^2}{R^2} \right)^{-1} \qquad \text{(B-8)}$$

where

$$R_c^2 = \frac{16 \ Km^2}{\rho^2 S^2 \ C_{D1}} \qquad \text{(B-9)}$$

R_c^2 is defined as the characteristic drag radius squared of the body. Then, from equations (B-2) and (B-8):

$$v_2 = v_1 \left(1 + \frac{R_c^2}{R^2} \right)^{-\frac{1}{2}} \qquad \text{(B-10)}$$

B-3

Equation (B-10) is used to compute the terminal speed v_2 for a target in a circular turn of constant radius R, at a constant thrust level which would produce a terminal speed v_1 if the target were on a straight run $(R = \infty)$. This formulation is a consequence of the fact that thrust levels for a ship or submarine are ordered in terms of the corresponding straight-run terminal speed.

TARGET MANEUVERS

The program provides for a target maneuver which consists of an instantaneous thrust change and/or a circular turn maneuver with the start of the turn at the time of thrust change.

We define the following:

v = instantaneous target speed

v_o = initial target speed at time maneuver starts $(t=0)$

T_o = thrust level before start of maneuver

T_T = thrust level after start of maneuver

v_T = terminal speed for the maneuver at thrust level T_T

During the maneuver, the force acting on the target is:

$$F = T_T - \frac{1}{2} \rho v^2 C_{D2} S \qquad \text{(B-11)}$$

$$= \frac{1}{2} \rho C_{D2} S \left(v_T^2 - v^2 \right)$$

Then the target acceleration is:

$$a = c \left(v_T^2 - v^2 \right) \qquad \text{(B-12)}$$

where:

$$c = \frac{\rho C_{D2} S}{2m} \qquad \text{(B-13)}$$

From equation (B-8):

$$c = \frac{\rho C_{D1} S}{2m} \left(1 + \frac{R_c^2}{R^2} \right) \qquad \text{(B-14)}$$

$$= \frac{1}{\ell_c} \left(1 + \frac{R_c^2}{R^2} \right)$$

The term ℓ_c is called the characteristic length of the target:

$$\ell_c = \frac{2m}{\rho C_{D1} S} \qquad \text{(B-15)}$$

From equation (B-12) we obtain the differential equation:

$$\frac{dv}{1-v^2} = c v_T dt = K dt \qquad \text{(B-16)}$$

where

$$v = \frac{v}{v_T} \qquad \text{(B-17)}$$

and

$$K = c v_T \qquad \text{(B-18)}$$

The solution of the differential equation (B-16) by integration depends upon the value of v. We identify three cases:

    Case I: Target accelerates during maneuver ($v < 1$)

Case II: Target decelerates during maneuver ($\nu > 1$)

Case III: Target speed constant during maneuver ($\nu = 1$)

Case I: Target Accelerates during Maneuver ($\nu < 1$)

For $\nu < 1$, the solution of the differential equation (B-16) is:

$$\tanh^{-1} \nu - \tanh^{-1} \nu_o = Kt \tag{B-19}$$

where:

$$\nu_o = \frac{v_o}{v_T} \tag{B-20}$$

Or:

$$\nu = \tanh\left(Kt + \tanh^{-1} \nu_o\right) \tag{B-21}$$

From equations (B-17) and (B-18) we see that

$$\nu = \frac{cv}{K} \tag{B-22}$$

Or

$$\nu = \left(\frac{c}{K}\right) \frac{ds}{dt} \tag{B-23}$$

where s is the path length variable during the maneuver.

Then equation (B-21) may be rewritten:

$$c \, ds = K \tanh\left(Kt + \tanh^{-1} \nu_o\right) dt \tag{B-24}$$

Integration of equation (B-24) yields:

$$s = \frac{1}{c} \ln\left[\frac{\cosh\left(Kt + \tanh^{-1} \nu_o\right)}{\cosh\left(\tanh^{-1} \nu_o\right)}\right] \tag{B-25}$$

Equation (B-25) defines the path length traveled as a function of time. In the case of a turn maneuver, this is equivalent to the angle of turn (course change), since the turn is assumed to be circular (constant radius).

To compute the time required to travel a given path length, or, in the case of a turn, to complete a given course change, we solve equation (B-25) for t:

$$t = \frac{1}{K} \left\{ \cosh^{-1}\left[e^{cs}\cosh(\tanh^{-1}v_o) \right] - \tanh^{-1}v_o \right\} \quad\quad (B-26)$$

Target speed at any time during the maneuver is computed with equation (B-21).

Case II: Target Accelerates during Maneuver ($v > 1$)

For $v > 1$, the differential equation (B-16) has a solution:

$$\coth^{-1}v - \coth^{-1}v_o = Kt \quad\quad (B-27)$$

If we proceed from equation (B-27) in the same manner as we did from equation (B-19) for Case I ($v < 1$), we obtain:

$$v = \coth\left(Kt + \coth^{-1}v_o \right) \qu\quad (B-28)$$

$$s = \frac{1}{c} \ln\left[\frac{\sinh\left(Kt + \coth^{-1}v_o\right)}{\sinh\left(\coth^{-1}v_o\right)} \right] \quad\quad (B-29)$$

$$t = \frac{1}{K} \left\{ \sinh^{-1}\left[e^{cs}\sinh\left(\coth^{-1}v_o\right) \right] - \coth^{-1}v_o \right\} \qu\quad (B-30)$$

Equation (B-28) provides target speed at any time during the maneuver, while (B-29) provides distance traveled (or course change) since start of the maneuver. Equation (B-30) provides the time required to travel a given distance, or, in the case of a turn, the time required to complete a given course change.

Case III: Target Speed Constant During Maneuver ($\nu = 1$)

For the case of constant speed during the maneuver ($\nu = 1$), the equations of motion are trivial, since we have linear motion at constant speed or motion along a circular arc at constant speed.

APPENDIX C: INPUT DATA VARIABLES

NAMELIST NL1

NSET: Number of sets of runs

NAMELIST NL2

NRUN: Number of runs in the set

NSHOT: Number of weapons simultaneously launched for each
                        run.

PTM: Probability that the target will initiate a maneuver
                        (course and/or thrust change) at some time during the
                        blind time interval. If $-1.0 < PTM < 0.0$, then the
                        target will initiate a maneuver at $-100.0 * PTM$ per-
                        cent of the blind time.

TS1:   Initial target speed (knots).

TS2:   New target speed ordered at time maneuver is initiated
                        (knots).

CMAX: Maximum magnitude of target course change (degrees).

CMIN: Minimum magnitude of target course change (degrees).

TR: Target turn radius for course change (yards)

TCL: Target characteristic length (feet)

TR2:   Target characteristic drag radius squared (yards
                        squared)

TB: Estimated blind time (seconds)

APR: Aimpoint offset radius. Distance of aimpoint from estimated target position at estimated time of weapon delivery (yards).

APA: Aimpoint offset angle. Relative bearing of aimpoint from estimated target position and course at estimated time of weapon delivery. (degrees)

SIGTB: Standard deviation of normal error in estimate of blind time. (seconds)

SIGTC: Standard deviation of normal error in estimate of target course (degrees)

SIGTS: Standard deviation of normal error in estimate of target speed (knots)

SIGL: Standard deviation of normal target localization errors (yards).

SIGD: Standard deviation of normal weapon delivery errors (yards).

NX: Number of hit probability grid lines perpendicular to target centerline (program limit: 25 maximum)

NY: Number of hit probability grid lines parallel to target centerline (program limit: 25 maximum)

NRAN: Seed for random number generators. May be any integer less than 2^{35} in magnitude.

NAMELIST NL3

GRIDX(I), (I=1, NX):   Distance from target, along target centerline, to I^{th} hit probability grid line perpendicular to centerline. Positive ahead, negative astern. Array must be ordered such that GRIDX(I) < GRIDX(I+1).

GRIDY(I), (I=1, NY):   Distance from target centerline to Ith hit probability grid line parallel to centerline. Positive to port, negative to starboard. Array must be ordered such that GRIDY(I) < GRIDY(I+1).

PH(I,J), (I=1, NX-1), (J=1, NY-1):   Probability of hit for hit probability grid rectangle defined by GRIDX(I) $\leq$ x < GRIDX(I+1) and GRIDY(J) $\leq$ y < GRIDY (J+1)

APPENDIX D: INPUT DATA CARDS

The following key punch work sheets represent a typical set of input data cards for program execution, with each line of each work sheet representing one card. The numbers shown in columns 79-80 are not part of the input data and would not be included in the actual input cards. The numbers are included only for reference purposes in the text of this appendix.

Card 01 specifies that program execution will consist of four sets of runs. Parameters for the initial set of runs are contained in cards 02-21. The hit probability grid parameters, contained on cards 07-21, correspond to the hit probability grid shown on Figure (2).

Input parameters for the second set of runs are provided by cards 22-23. These specify that input parameters for the second set of runs will be identical to these of the first, except for a different seed (NRAN) for the random number generators. Thus sets one and two can test for stochastic convergence by comparing results for generally different sequences of random variables from the same statistical distributions. Note that, even though there are no changes to NL3 namelist data for the second set, a blank NL3 card (#23) is provided, as required, for proper program execution.

Card 24 changes the magnitude of target turn maneuvers and the random number generator seed for the third set. Card 25 provides the required card for NL3, even though there are no NL3 data changes.

Cards 26-27 specify that the input parameters for the fourth set will be identical to those of the third, except for the random number generator seed.

$NL1   NSET=4, $END

$NL2   NRUN=4000, NSHOT=1.
        PTM=0, .5, TS1=10., TS2=25, CMAX=60, CMIN=30.
        TR=150, TCL=160, TR2=3870,
        TB=120, APR=750, APA=30,

$NL3   SIGTB=2, SIGTC=1, SIGTS=0, SIGL=100, SIGD=500,
        NX=0, NY=12, NRAN=11482, $END
        GRIDX(1)=-100, -50, -100, 50, 100, 150, 200, 50, 950, 1200, 1500,
        GRIDY(1)=-200, -150, -120, -90, -150, -200, -250,
                 2000,

        PH(1, 1)=
        PH(1, 2)=
        PH(1, 3)=
        PH(1, 4)=
        PH(1, 5)=
        PH(1, 6)=
        PH(1, 7)=
        PH(1, 8)=
        PH(1, 9)=
        PH(1,10)=

0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
10
11
12
13
14
15
16
17
18
19
20

APPENDIX E: PROGRAM OUTPUT DATA AND FORMAT

CUMULATIVE HIT PROBABILITY FOR ALL RUNS THIS SET: PCH =   .4075

INPUT DATA FOR THE SET FOLLOW:
$NL2
NRUN =   4CCC,NSHOT =   1,PTM = .50000000+000,TS1 = .10000000+002,TS2 = .25000000+002,CMAX = .60000000+002,
CMIN = .30000000+002,TR = .15000000+003,TCL = .16400000+004,TR2 = .38700000+005,TB = .17000000+003,APR = .75000000+003,
APA = .30000000+002,SIGTR = .20000000+002,SIGTC = .10000000+001,SIGTS = .10000000+001,SIGL = .50000000+000,SIGD = .50000000+003,
NX =   12,NRAN =   11482
B,IY =   12,NRAN =   11482
$END

GRIDX(I) (I=1,8):
-1000.0   -500.0   -100.0   300.0   500.0   1000.0   1500.0   2000.0

GRIDY(J) (J=1,12):
-2000.0 -1500.0 -1200.0   -900.0   -500.0   -200.0   200.0   500.0   900.0   1200.0

PHI(I,J) (I=1,7;J=1,12):										
.0000	.0000	.1000	.1000	.1000	.0000	.0000	.0000	.0000	.3000	
.3000	.2000	.1000	.0000	.1000	.4000	.5000	.5000	.2000		
.1000	.3000	.5000	.6000	.4000	.4000	.2000	.2000	.5000		
.4000	.9000	.7000	.3000	.4000	.6000	.5000	.6000	.8000		
.2000	.2000	.5000	.4000	.2000	.9000	.7000	.3000	.1000		
.5000	.6000	.8000	.4000	.2000	.0000	.1000	.4000	.5000		
.7000	.1000	.0000	.0000	.3000	.3000	.2000	.1000			
.0000	.0000	.1000	.1000	.1000	.0000					

CUMULATIVE HIT PROBABILITY FOR ALL RUNS THIS SET: PCH = .4067

INPUT DATA FOR THE SET FOLLOW:
$NL2
NRUN = 4000,NSHOT = 1,PTM = .5000000+000,TS1 = .1000000+002,TS2 = .2500000+002,CMAX = .6000000+002,
CMIN = .3000000+002,TR = .1500000+003,TCL = .1680000+004,TR2 = .3870000+005,TB = .1200000+003,APR = .7500000+003,
APA = .3000000+002,SIGTB = .2000000+001,SIGTC = .1000000+001,SIGTS = .5000000+000,SIGL = .1000000+003,SIGD = .5000000+003,
NX = 8,NY = 12,NRAN = 3387
$END
GRIDX(I) (I=1,8):
-1000.0   -500.0   -100.0   300.0   500.0   1000.0   1500.0   2000.0
GRIDY(J) (J=1,12):
-2000.0 -1500.0 -1200.0   -900.0   -500.0   -700.0   200.0   500.0   900.0   1200.0
 150.0   2000.0
PHI(I,J) (I=1,7),(J=1,11):
.0000   .0000   .1000   .1000   .1000   .0000   .0000   .3000
.2000   .2000   .4000   .0000   .1000   .5000   .5000   .2000
.1000   .3000   .5000   .6000   .8000   .4000   .2000   .5000
.9000   .7000   .7000   .3000   .4000   .5000   .6000   .8000
.2000   .5000   .5000   .4000   .9000   .9000   .3000   .1000
.5000   .6000   .8000   .4000   .2000   .0000   .1000   .5000
.1000   .1000   .0000   .1000   .3000   .2000   .1000
.0000   .0000   .1000   .1000   .0000   .0000

CUMULATIVE HIT PROBABILITY FOR ALL RUNS THIS SET: PCH =   .3965

INPUT DATA FOR THE SET FOLLOW:
$NL0
NRUN =   4000,NSHOT =   1,PTH = .5000000+003,TS1 = .1000000+002,TS2 = .2500000+002,CMAX = .9000000+002,
CMIN = .6000000+002,TR = .1500000+003,TCL = .1680000+004,YR2 = .3870000+005,TB = .1200000+003,APR = .7500000+003,
APA = .3000000+007,SIGTP = .2000000+001,SIGTC = .1000000+001,SIGTS = .5000000+000,SIGL = .1000000+003,SIGD = .5000000+003,
NX =   8,NY =   12,NRAN =   11482
$END

GPIDX(I) (I=1,8):
  -1000.0   -500.0   -100.0

GRIDY(J) (J=1,12):
  -2000.0 -1500.0 -1200.0   -900.0   -500.0   -200.0   200.0   500.0   900.0   1200.0
   1500.0   2000.0

PHI(I,J) (I=1,7),(J=1,11):

	-900.0	-500.0	-200.0	200.0	500.0	900.0	1200.0
.0000	.1000	.1000	.1000	.0000	.0000	.0000	.3000
.2000	.1000	.0000	.1000	.4000	.5000	.5000	.2000
.3000	.5000	.6000	.8000	.4000	.2000	.2000	.5000
.9000	.7000	.3000	.4000	.6000	.5000	.6000	.8000
.2000	.5000	.6000	.8000	.9000	.7000	.3000	.1000
.6000	.8000	.4000	.2000	.2000	.1000	.4000	.5000
.1000	.3000	.0000	.3000	.3000	.2000	.2000	.1000
.0000	.1000	.1000	.1000	.0000			

CUMULATIVE HIT PROBABILITY FOR ALL RUNS THIS SET: PCH =   .3943

INPUT DATA FOR THE SET FOLLOW:

$NL7

NRUN = 4000,ASHOT = 1,PTM = .5000000+000,TS1 = .1000000+002,TS2 = .2500000+002,CMAX = .9000000+002,

CMIN = .6000000+002,TR = .1500000+003,TCL = .1680000+004,TR2 = .3870000+005,TB = .1200000+003,APR = .7500000+003,

APA = .3000000+002,SIGTP = .2000000+001,SIGTC = .1000000+001,SIGTS = .5000000+000,SIGL = .1000000+003,SIGD = .5000000+003,

NX =   12,NRAN =   3382

$END

R,PY =

GRIDX(I) (I=1, 8):

-1000.0   -500.0   -100.0   300.0   500.0   1000.0   1500.0   2000.0

GRIDY(J) (J=1,12):

-2000.0   -1000.0   -1000.0   -900.0   -500.0   -200.0   200.0   500.0   900.0   1200.0

 1500.0   2000.0

PHI(I,J) (I=1,7),(J=1,11):

.0000	.0000	.1000	.1000	.0000	.0000	.0000	.3000
.2000	.1000	.0000	.1000	.0000	.4000	.5000	.2000
.1000	.3000	.5000	.6000	.4000	.4000	.2000	.5000
.4000	.9000	.7000	.3000	.4000	.6000	.6000	.8000
.6000	.2000	.5000	.6000	.6000	.9000	.7000	.1000
.3000	.5000	.8000	.4000	.2000	.0000	.1000	.5000
.5000	.1000	.0000	.3000	.3000	.3000	.2000	.1000
.0000	.0000	.1000	.1000	.0000	.0000		

$FIN

APPENDIX F: INTERNAL VARIABLE AND FUNCTION NAMES

ACOSH(X):   Statement function which computes the inverse hyper-
                   bolic cosine of X.

ACOTH(X):   Statement function which computes the inverse hyper-
                   bolic cotangent of X.

APAI: Input variable APA converted to radians.

ASINH(X):   Statement function which computes the inverse hyper-
                   bolic sine of X.

ATANH(X):   Statement function which computes the inverse hyper-
                   bolic tangent of X.

CCM: Target course change magnitude (radians)

CCS: Indicates the direction of the target course change.
                   CCM = +1 for a negative change (positive y direction
                   or left turn). CCM = -1 for a positive change (nega-
                   tive y direction or right turn).

CR: Reciprocal of hydrodynamic coefficient c (yards) [see
                   equation (B-14)]

DUM1, DUM2, DUM3, DUM4: Dummy variables for temporary storage of intermediate
                   quantities

FNRUN: Floating point conversion of input variable NRUN

FNU0: ν_o-ratio of initial to terminal speed [see equation
                   (B-20)]

NRAN1:	Running seed integer for random number subroutines UNFRM and GAUSS.
PCH:	Cumulative hit probability for set.
PCHS:	Cumulative hit probability for run.
RN:	Random number from a uniform distribution over the interval [0,1]
S:	arc-length of a turn maneuver (yards)
SIGTCI:	Input variable SIGTC converted to radians
SIGTSI:	Input variable SIGTS converted to yards per second
T1:	Actual time to weapon delivery (seconds)
T2:	Time required to complete a turn maneuver (seconds)
TAU:	Time variable Kt [see equations (B-19) and (B-27)]
TCLI:	Input variable TCL converted to yards
TCWD:	Target course at weapon delivery time (radians)
TM:	Time target maneuver starts (seconds)
TS1I:	Input variable TS1 converted to yards per second
TS2I:	Input variable TS2 converted to yards per second
TSE:	Target speed at end of turn (yards per second)

TST:	Terminal speed for maneuver (yards per second) [see equation (B-10)]
XAP:	x-COORDINATE OF AIMPOINT (YARDS)
XT:	x-coordinate of target (yards)
XTC:	Estimated x-coordinate of target (yards)
XWD:	x-coordinate of weapon delivery point (yards)
XWDG:	x-coordinate of weapon delivery point in hit probability grid coordinates (yards)
YAP:	y-coordinate of aimpoint (yards)
YT:	y-coordinate of target (yards)
YTC:	Estimated y-coordinate of target (yards)
YWD:	y-coordinate of weapon delivery point (yards)
YWDG:	y-coordinate of weapon delivery point in hit probability grid coordinates (yards)