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TECHNICAL REPORT NO. 308

A MONTE CARLO MODEL FOR DETERMINING COPPERHEAD PROBABILITY OF ACQUISITION AND MANEUVER

MICHAEL STARKS

AUGUST 1980

U. S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
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This report documents AMSAA's Probability of Acquisition and Maneuver (PAM) model. The model is used to develop performance estimates for COPPERHEAD and related weapon systems. A mathematical method for modeling the acquisition and maneuver portions of a COPPERHEAD trajectory is presented. In addition, the report contains a FORTRAN implementation of the model, a description of the required inputs, and a sample case with input and output.

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The general method of modeling COPPERHEAD presented in this report was developed by Richard Scungio, who also wrote the first version of the program. The version of the program documented in Reference 1 was written by Julian Chernick and Michael Starks. Richard Sandmeyer wrote the subprogram which controls the interface of PAM with the COPE model.

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A MONTE CARLO MODEL FOR DETERMINING COPPERHEAD PROBABILITY OF ACQUISITION AND MANEUVER

1. INTRODUCTION

AMSAA's Probability of Acquisition and Maneuver (PAM) model has proven to be a useful tool for evaluating the COPPERHEAD weapon system. Different versions of the model have been used in two different ways.

A "stand alone" version of the model was used in the COPPERHEAD analysis documented in Reference 1. This analysis evaluated the sensitivity of COPPERHEAD system performance to a large number of factors, including:

- cloud ceiling
- designator power
- designator range
- target reflectivity
- target location error
- atmospheric transmission
- seeker sensitivity
- gun-target range
- unguided delivery error

An improved version of the stand alone PAM model was later used to evaluate the sensitivity of COPPERHEAD system performance to:

- designator-target-howitzer azimuth angle (ANGLE-T)
- target velocity
- response time
- additional delay time
- target heading angle
- point of target's closest approach to Predicted Intercept Point (PIP)

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[1]Chernick, Julian A., Richard C. Scungio, Michael Starks, Utility of COPPERHEAD With Ground Laser Designation in a European Battlefield Environment (U), Technical Report No. 257, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, December 1978, (CONFIDENTIAL report).

The results of this analysis were published as part of the COPPERHEAD COEA (Reference 2). Other "stand alone" uses to which modified versions of PAM have been applied include data generation for the Advanced Anti-Armor Vehicle Evaluation (ARMVAL) tests, and for a forthcoming Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) publication on COPPERHEAD.

In addition to its use as a stand-alone model, PAM serves as one of the preprocessors for AMSAA's COPPERHEAD Operational Performance Evaluation (COPE) model. For a description of the COPE model, including details of that model's interface with PAM, see Reference 3.

Thus far, the model applications mentioned have concerned the COPPERHEAD system. First-order performance estimates for other weapon systems have also been developed through use of modified versions of the PAM/COPE models. These systems include HELLFIRE and extended range COPPERHEAD (Reference 4).

The purpose of this report is to document the structure of the PAM model so that other activities may more easily use it in related analyses. The report is organized as follows:

- The assumptions made in the course of constructing the model are discussed.
- A general overview of the model structure is presented.
- The way in which the acquisition portion of the COPPERHEAD trajectory is modeled is described in detail.
- The way in which the maneuver portion of the COPPERHEAD trajectory is modeled is described in detail.
- Appendix A lists the inputs required to drive the model, along with the appropriate units.
- Appendix B contains a copy of the FORTRAN SOURCE LIST.
- Appendix C gives a sample case with input and output.

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[2] Cost and Operational Effectiveness Analysis (COPPERHEAD, COEA)(U), ACN 18812, US Army Field Artillery School, FT Sill, OK, October 1979, (SECRET report).

[3] Sandmeyer, Richard S., COPE Computer Program: User and Analyst Manuals, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, Technical Report to be published.

[4] Chernick, Julian A., Preliminary Analysis of Extended Range COPPERHEAD Operational Performance (U), GWD Interim Note No. G-85, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, January 1980, (CONFIDENTIAL report).

2. ASSUMPTIONS AND LIMITATIONS

As the name of the model suggests, the PAM model computes the Probability of a COPPERHEAD projectile being able to both Acquire a target by sensing reflected laser energy, and Maneuver to that target once it has been acquired. The fundamental difference between the probability of acquisition and maneuver (PAM) and probability of hit (P_H), is that estimates of P_H for COPPERHEAD-type systems must include the effect of laser energy overspill and underspill.

Such effects are a complex function of the entire time-history of laser pulses, and simulating those effects requires detailed modeling of the system's seeker logic. The Laser Designator Weapon System Simulation (LDWSS) model (Reference 5) does simulate the seeker logic, so the resulting estimates of P_H include the effects of laser energy overspill and underspill.

The PAM model does not simulate these effects; however, there is reason to believe that this limitation is not too severe. Section 2.3.2 of Reference 6 presents LDWSS estimates of P_H for the COPPERHEAD system under various conditions. Under conditions of high visibility, high cloud ceiling, low errors, and GLLD designator, it is plausible to assume that any degradation in P_H is due to spillover/spillunder. As the data shows, there is little degradation in P_H against a fully exposed moving target out to 3 km. Therefore there is little problem with spillover/spillunder against such a target out to 3 km. However, for a partially exposed target or a target at longer range, the spillover/spilunder problem is more severe. Under these conditions the probability of acquisition and maneuver is a poor estimator of probability of hit.

A second limitation of the PAM model is the use of a lambertian reflectance distribution (cosine law) of energy from the target rather than specific reflectivity maps generated from a three-dimensional target description. While significant differences could exist in terms of the actual shape of the acquisition volume for each reflected laser pulse, the spot jitter and the time-variability of target heading is probably sufficient to smooth out the shape of the acquisition volume in such a way that the cosine law is approximately correct.

Additional limitations arise because the model uses Monte Carlo sampling. The results are somewhat noisy ($\leq$10 percent) when a sample size of 100 is used; trends which intuitively should be monotonic are not always so. Moreover, when larger sample sizes are used, the model becomes fairly time consuming to run. Still, results of good quality can be obtained with greater ease and at lesser expense than by use of LDWSS; the LDWSS model also uses Monte Carlo sampling.

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[5] Lewis, C.L., A.G. Nichols, and A.W. Lee, User's Guide for the Phase I Laser Designator/Weapon System Simulation (LDWSS) of the COPPERHEAD Guided Projectile System, Vol I, Technical Report RG-77-25, US Army Missile Command, Redstone Arsenal, AL, July 1977, (UNCLASSIFIED report).

[6] Independent Evaluation Report for the 155mm XM712 COPPERHEAD (U), IER No. 6-80, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, July 1979, (CONFIDENTIAL report).

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3. GENERAL OVERVIEW

The overall flow of the main PAM model is shown in Figure 1. The most important part of the model is devoted to answering the two questions which appear near the center of Figure 1: "Does the projectile acquire?" and if so, "Can the projectile maneuver to the target?"

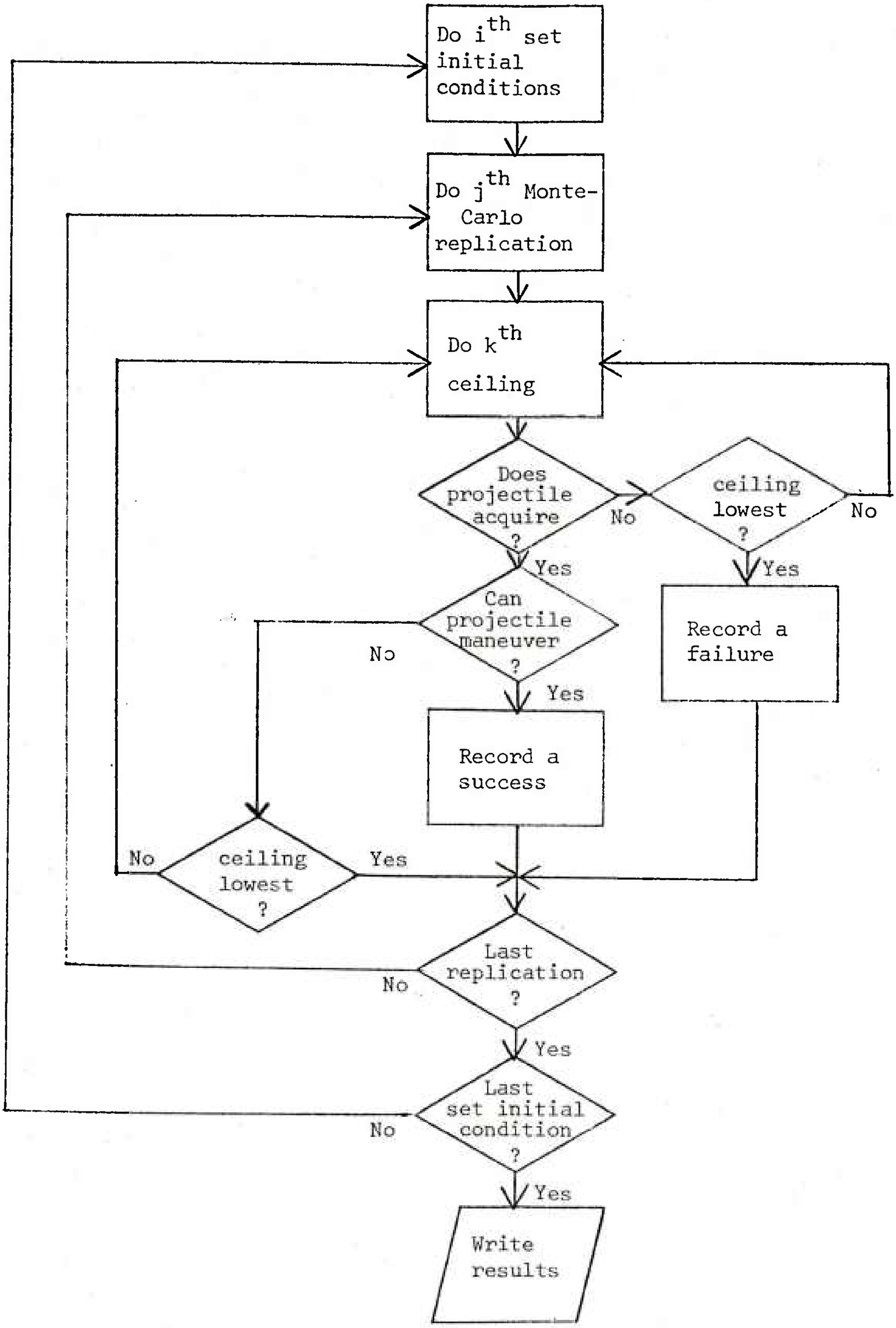
Figure 2 shows the general situation of a ground-based laser designating a target. The acquisition volume is the volume within which there is sufficient reflected laser energy for the COPPERHEAD projectile to acquire the target. The optical properties of the atmosphere determine the extent of laser energy attenuation along both the laser-target path and the target projectile path. The cloud ceiling acts as an energy cutoff level, prohibiting acquisition until the projectile descends below the cloud layer. Cloud cover is treated as opaque; beneath a cloud layer the visibility is assumed uniform.

Once the COPPERHEAD projectile breaks through a cloud ceiling, it acquires a target only if reflected laser energy reaches the seeker in sufficient quantity. This process is illustrated in Figure 3.

Since there is a ceiling at altitude A, acquisition is impossible above this ceiling. At altitude B, acquisition is possible but does not take place because insufficient energy reaches the seeker. At altitude C, sufficient energy reaches the seeker for acquisition to take place.

The (x,y) coordinates of intersection with the acquisition volume at a given altitude plane is a function of unguided delivery error. Given (x,y,z) coordinates of acquisition, the limits of projectile maneuver in the ground plane are fixed. For the case illustrated in Figure 3, the target is within the limits of projectile maneuver, so the engagement is a success.

FIGURE 1 CONCEPTUAL FLOWCHART OF PAM MODEL



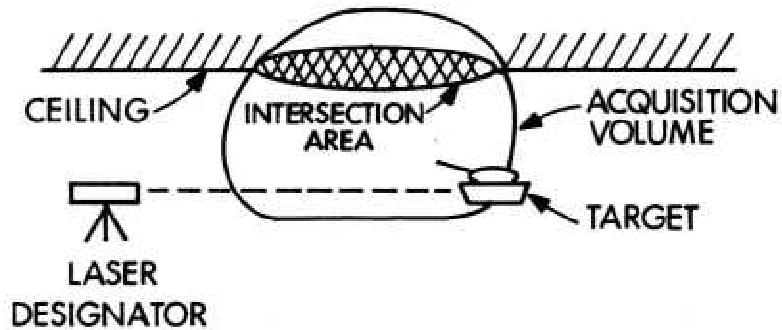
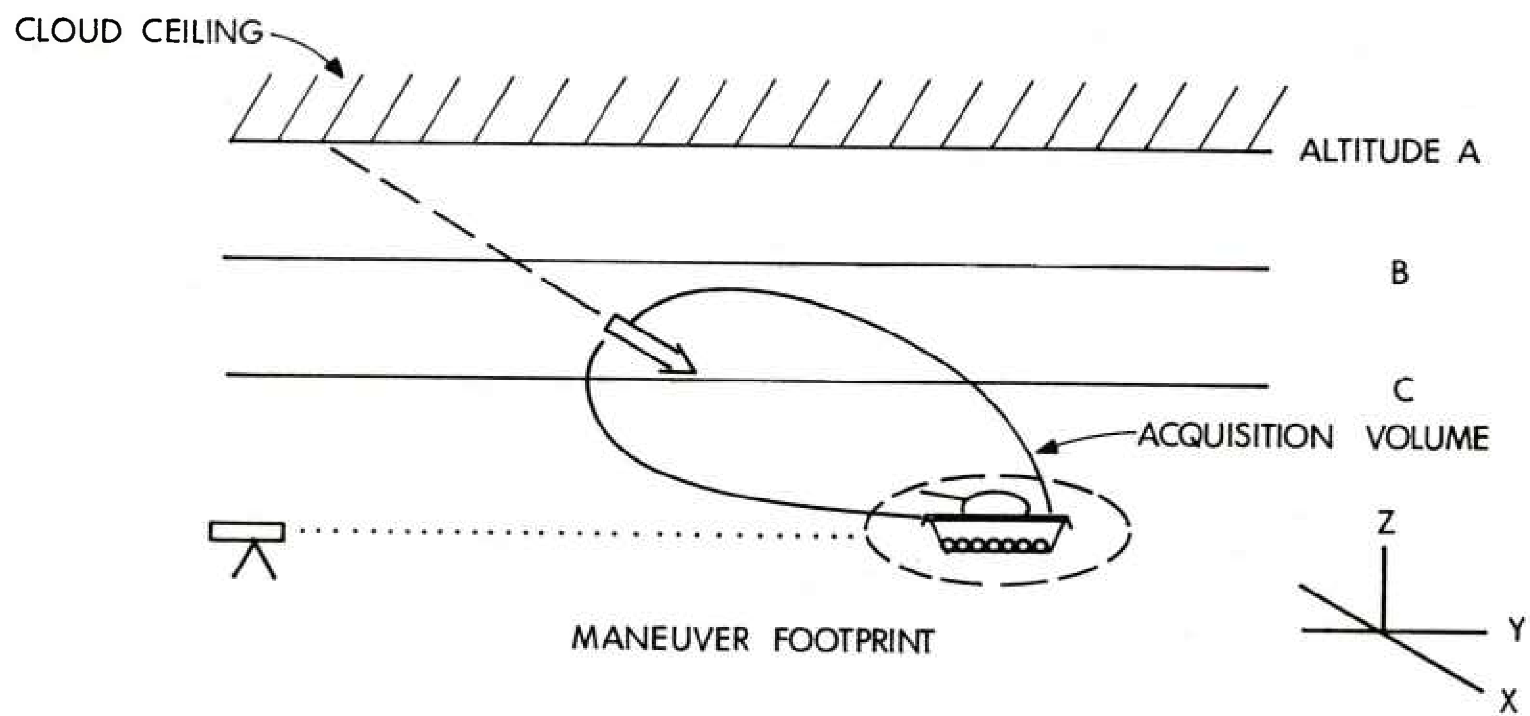


Figure 2 Laser Designating a Target.



CLOUD CEILING AT ALTITUDE A

NO ACQUISITION AT ALTITUDE B

ACQUISITION AT ALTITUDE C

Figure 3 Copperhead Acquisition and Maneuver.

4. ACQUISITION METHODOLOGY

The equations used in PAM to describe the laser energy transmission are the same as those used in the LDWSS model (Reference 5). The laser beam energy signal-to-threshold (S/T) ratio is:

$$S/T = \frac{E_d T_d T_s \rho \cos\theta}{\pi R_s^2 E_t}$$

where

E_t = threshold energy density at the seeker aperature (J/km^2)

E_d = laser designator energy (J)

T_d = designator-to-target transmission coefficient

T_s = target-to-seeker transmission coefficient

ρ = target reflectivity

θ = lambertian angle (angle from seeker LOS to designator beam)

R_s = slant range from target to seeker (km)

The transmission coefficients of the laser equation are complex functions of altitude, general atmospheric condition, and wavelength. These coefficients are calculated as functions of visibility, altitude (H_s), projectile range to the target (R_s) and designator range to the target (R_d) in km:*

$$T_d = e^{-R_d}$$

$$T_s = \begin{cases} e^{-\gamma \frac{1 - e^{-.00025H_s}}{.00025H_s} R_s}, & \text{for } H_s > 0 \text{ (Ft)} \\ e^{-\gamma R_s}, & \text{for } H_s \leq 0 \text{ (Ft)} \end{cases}$$

*It can be seen from examination of these two expressions that PAM and LDWSS both assume that electro-optical transmissivity improves as a function of increasing altitude. Recent work done at the Atmospheric Sciences Laboratory indicates that this assumption is not always true (Reference 7). During certain conditions of fog and haze, transmissivity may be as much as two orders of magnitude worse at 150m above the ground than at ground level.

[7]Pinnick, R.G., et.al., Vertical Structure in Atmospheric Fog and Haze and Its Effects on IR Extinction, Atmospheric Sciences Laboratory, White Sands Missile Range, NM, ECOM-TR-0010, July 1978.

The atmospheric attenuation coefficient (γ) is a function of visibility (VIS):

$$\gamma = \frac{.0019(.519)^{Q}}{VIS}$$

with Q determined as a function of visibility in kilometers:

$$\left(\frac{VIS}{5}\right)^{1/3}, \quad 0<VIS<6$$

$$0.86 + \frac{VIS}{30}, \quad 6\leq VIS<9$$

$$0.98 + \frac{VIS}{50}, \quad \leq VIS<12$$

$$1.15 + \frac{VIS}{200}, \quad VIS\geq 12$$

The resultant visibility volume around the target has its maximum length along the direction of the designator and is of negligible extent for angles greater than 90 degrees from the designator-target line.

The model uses a nominal input value for angle T (FO-Target-Howitzer azimuth angle). However, the cosine law of reflectance is not applied directly to that angle, but to the input angle adjusted for the actual target location present in a particular Monte Carlo replication after unguided errors and target location errors are sampled.

5. MANEUVER METHODOLOGY

If, for a given Monte Carlo replication, the model determines that a COPPERHEAD projectile acquires a target, then computations are made to determine whether the projectile can maneuver to that target. This is accomplished by means of maneuverability footprints.*

For a given gun-target range, mode of fire, angle of fall, and altitude at which initial acquisition takes place, the footprints circumscribe an area in the ground plane within which a reliable projectile can successfully maneuver. This area is the intersection of the seeker field-of-view projected into the ground plane and the extreme limits of projectile maneuver capability. Because the footprints lack radial symmetry, they are input as a series of distances as a function of angle from the predicted target intercept point (PIP).

The model considers three kinds of error source: unguided delivery errors, random target location errors, and bias target location errors. Given values for these three error terms, the model determines whether the target is in the footprint at the time of round arrival.

Unguided delivery errors are associated with the part of the COPPERHEAD trajectory between launch and acquisition. Such errors have the effect of shifting the location of the footprint in the ground plane; they are monte carlo sampled for each simulated trajectory.

Standard deviations for these errors in range and deflection are shown in Figure 4. The information shown was supplied by Martin Marietta Corporation, and was generated by use of six-degree-of-freedom simulation techniques. Range errors are larger than deflection errors primarily because of COPPERHEAD's relatively shallow angle of fall. Although the range and deflection errors are not too different in the plane normal to the velocity vector, when they are projected into the ground plane, the range error becomes elongated.

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*Both ARRADCOM and Martin Marietta Corporation have supplied AMSAA with these footprints. For details on the ARRADCOM model which generates footprints see Reference 8.

[8]Amoruso, Michael, J., Tice F. DeYoung, Dennis D. Ladd, and Roger D. Schulz, <u>A Comprehensive Digital Flight Simulation of the Cannon Launched Guided Projectile</u>, Rodman Laboratory, Rock Island, IL, January 1977, R-TR-77-007 (UNCLASSIFIED report).

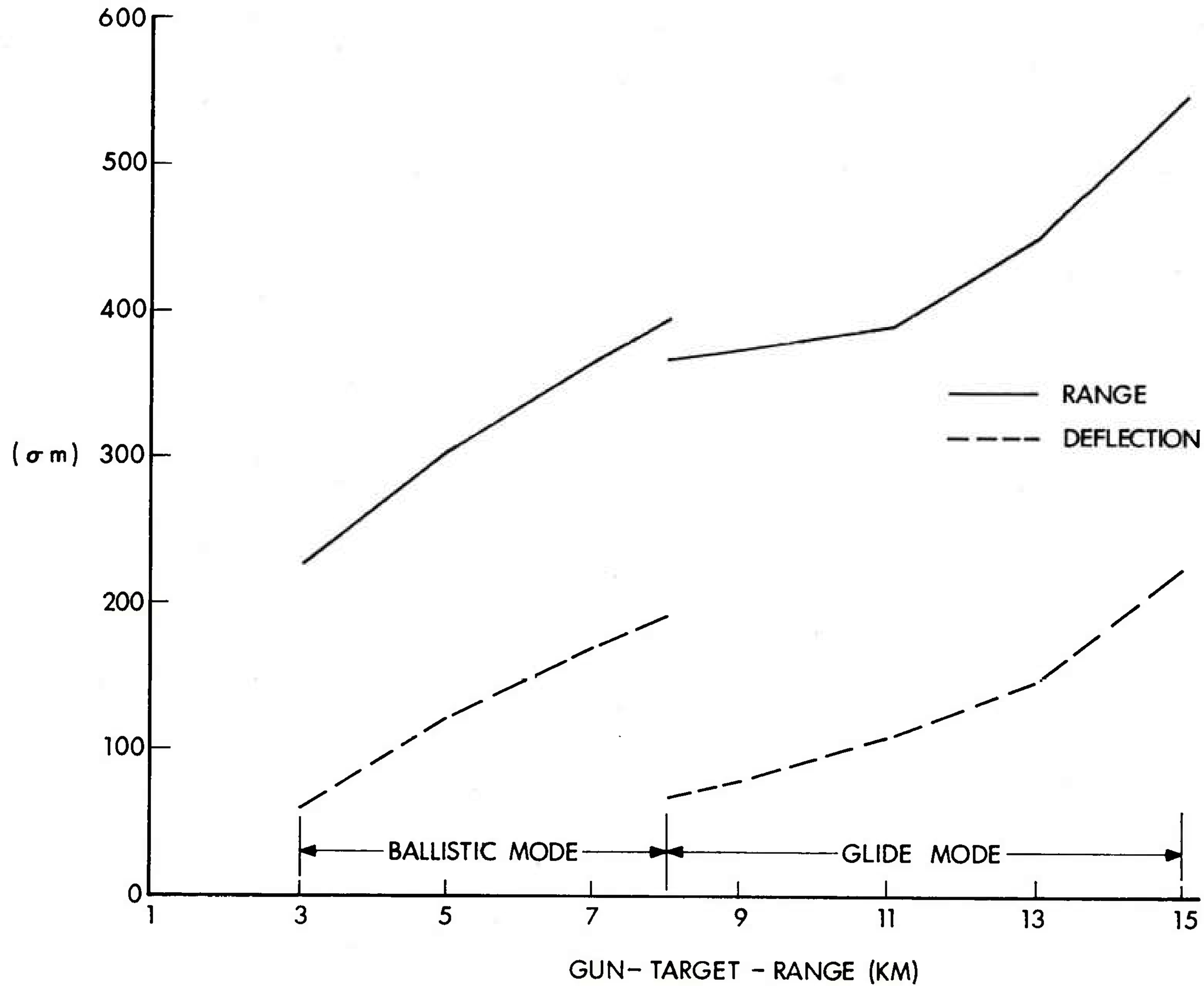

Figure 4. Unguided Delivery Errors

The random component of target location error (σ) can be input to PAM directly or computed internally according to the following algorithm derived from unpublished work of Julian Chernick.* The algorithm contains two error terms and a parameter:

$$\sigma^2 TLE = \sigma^2 FO + (\sigma^2 S \times T^2)$$

where

$\sigma^2 TLE$ = variance of target location error

$\sigma^2 FO$ = variance of FO/FDC error in locating FO position

$\sigma^2 S$ = variance of FO error in estimating target speed

T = total system response time

The time term in the algorithm is the sum of the expected response time and the unanticipated delay time. Expected response time is the average time between the beginning of the FO's call for fire and the time of round arrival on target; it is an input to the model. Unanticipated delays are played parametrically in the model with values of 0, 30, 90, 150 and 300 seconds.

The random TLE algorithm above allows σTLE to be computed about a single target vehicle, for either a preplanned target or a target of opportunity. Since the PAM model was designed to evaluate COPPERHEAD against groups of target vehicles as well as against a single target vehicle, a method was derived to generate σTLE to the nearest target vehicle when more than one vehicle is present in a target.

Based on work reported in Reference 9, the following relationship is used for computing σTLE when the PIP is bracketed by target vehicles:

$$\sigma TLE \text{ (multiple)} = .68 \ \sigma TLE \text{ (single)}$$

---

*A more general account of this type of error has recently been developed by Chernick (Reference 10). The numerical results, however, are similar to those resulting from the present algorithm.

[9]Weaver, Jonathan M., and Lawrence Bowman, Multiple Target Simulation (MUTSI) - A Discrete Monte Carlo Technique That Evaluates the Availability of Multiple Enemy Ground Targets in a GLLD/COPPERHEAD Target of Opportunity Situation, GWD Interim Note No. G-61, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, July 1979 (UNCLASSIFIED report).

[10]Chernick, Julian A., Moving Target Location Errors for Ground Targets, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, September 1980, to be published.

The final error source considered in the PAM model is a bias TLE. The random TLE discussed above is computed on the assumption that the mean target position at round impact is the PIP. This assumption will seldom be satisfied in combat, hence the resulting offsets from the PIP are treated as bias TLEs.

One important source of bias error is unanticipated delays in the time required to get a COPPERHEAD round on target. If the FO estimates it will take 100 seconds to get a round on target, but it actually takes 200 seconds, then the target may overrun the footprint before the round arrives.

In addition to the contribution of time delays to bias TLE, there are factors which could cause the target's point of closest approach (PCA) to the PIP to differ, on the average, from zero. If the footprint (aimpoint) is preplanned, it would be unreasonable to expect that potential targets would be headed directly towards the PIP. And for a target-of-opportunity, there is a possibility of large changes of direction after the command to fire is given.

Bias error is played in PAM as follows: If a COPPERHEAD projectile approaches the target from the direction of negative y, the x and y components of bias TLE are given by

$$XBIAS = PCA_x + \mathrm{Sin}(H)V\tau$$

$$YBIAS = PCA_y - \mathrm{Cos}(H)V\tau$$

where

PCA - point of closest approach

H - target heading angle

V - target velocity

τ - unanticipated delay

After these computations are made, the random and bias TLEs are summed to yield the target's location on the ground. The distance from that location to the PIP is computed, and is compared to the distance from the PIP to the edge of the maneuverability footprint for an equivalent angle. If the target is within the footprint, then the replication counts as a success; otherwise it does not.

6. SUMMARY

This report presents the general structure of the PAM model, and describes the modeling of the acquisition and maneuver positions of the COPPERHEAD trajectory in detail. In addition, a description of the input variables, a FORTRAN source listing, and a sample case are presented.

REFERENCES

1. Chernick, Julian A., Richard C. Scungio, Michael Starks, Utility of COPPERHEAD With Ground Laser Designation in a European Battlefield Environment (U), Technical Report No. 257, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, December 1978, (CONFIDENTIAL report).

2. Cost and Operational Effectiveness Analysis (COPPERHEAD, COEA) (U), US Army Field Artillery School, ACN 18812, FT. Sill, OK, October 1979, (SECRET report).

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4. Chernick, Julian A., Preliminary Analysis of Extended Range COPPERHEAD Operational Performance (U), GWD Interim Note G-85, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, January 1980, (CONFIDENTIAL report).

5. Lewis, C. L., A. G. Nichols, and A. W. Lee, User's Guide for the Phase I Laser Designator/Weapon System Simulation (LDWSS) of the COPPERHEAD Guided Projectile System, Vol I, Technical Report RG-77-25. US Army Missile Command, Redstone Arsenal, AL, July 1977, (UNCLASSIFIED report).

6. Independent Evaluation Report for the 155mm XM712 COPPERHEAD (U), IER 6-80, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, July 1979, (CONFIDENTIAL report).

7. Pinnick, R.G., et.al., Vertical Structure in Atmospheric Fog and Haze and Its Effects on IR Extinction, Atmospheric Sciences Laboratory, White Sands Missile Range, NM, ECOM-TR-0010, July 1978.

8. Amoruso, Michael, J., Tice F. DeYoung, Dennis D. Ladd, and Roger D. Schulz, A Comprehensive Digital Flight Simulation of the Cannon Launched Guided Projectile, Rodman Laboratory, Rock Island, IL January 1977, R-TR-77-007, (UNCLASSIFIED report).

9. Chernick, Julian A., Moving Target Location Errors for Ground Targets, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, September 1980, (to be published).

10. Weaver, Jonathan M., and Lawrence Bowman, Multiple Target Simulation (MUTSI) - A Discrete Monte Carlo Technique that Evaluates the Availability of Multiple Enemy Ground Targets in a GLLD/COPPERHEAD Target of Opportunity Situation, GWD Interim Note No. G-61, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, July 1979, (UNCLASSIFIED report).

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APPENDIX A

PAM INPUTS

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APPENDIX A

PAM INPUTS

Table A-1 provides a list of the inputs required for the PAM model. These are read in with list-directed read statements as indicated in the FORTRAN listing in Appendix B.

In addition to the input variables which are read in, three arrays are filled in the program and the values could be changed at the discretion of the program user. These arrays are:

GAMARY (11)

H (6)

DTS (5)

The GAMARY array contains the laser energy attenuation coefficients, as a function of atmospheric visibility in km, from 1 to 11 km.

The H array defines the heights at which the check for acquisition is made, from highest to lowest, in meters.

The DTS array holds the values of unanticipated delay times played in seconds, as discussed in the Maneuver Methodology section of this report.

TABLE A-1 PAM INPUT VARIABLES

VARIABLE NAME	MEANING	UNITS
IMF	Mode of fire	1 = preplanned 2 = target of opportunity
ETH	Seeker Energy Threshold	Joules/SQKM
AOF	Fly under Fly out (FUFO) Angle of Fall	Degrees
TH	Target Heading Angle	Degrees
PCA	Point of Closest Approach	Meters
AZDT	Nominal Angle T	Degrees
V	Target Velocity	M/S
RHO	Target Reflectivity	N/A
ED	Designator Energy	Joules
TR	Nominal Response Time Including TOF	Seconds
NK	Number of Monte Carlo Cases	N/A
RNG	Gun Target Range	Meters
ACCX	Ballistic Error x (σ)	Meters
ACCY	Ballistic Error y (σ)	Meters
IDRMN	Minimum Designation Rng	Km
IDRMX	Maximum Designation Rng	Km
IVMX	Maximum Visibility Rng	Km
NI(J)	# of Pts in which Jth Footprint is input	N/A
THEMN(I,J)	Ith Angle from PIP in Jth footprint	Degrees
DISMH(I,J)	Ith Distance from PIP to edge of Jth Footprint	Meters

APPENDIX B

FORTRAN SOURCE LIST

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APPENDIX B

FORTRAN SOURCE LIST

This Appendix contains a FORTRAN listing of the PAM model as configured for a CDC 7600 computer. The version of the program given here is for interface with the COPE model; comment cards at the beginning of the listing indicate necessary deletions for use as a stand-alone model.

Two subprograms, generally available as system routines (for example, on the Ballistic Research Laboratory computer at APG) are included to facilitate program portability. These are subroutines NRAN31 which generates pairs of normally distributed random numbers, and subroutine DVDINT, which does divided difference interpolation.

```
      PROGRAM PAM (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7,TAPE11)  000160
C                                                                       000170
C     **  THIS VERSION OF PAM IS CONFIGURED FOR USE AS A PREPROCESSOR   000180
C     **  FOR COPE.  MAKE THESE CHANGES FOR STAND-ALONE RUNS:           000190
C     **      1.  DELETE CALL TO OPENMS (FIRST EXECUTABLE STATEMENT)    000200
C     **      2.  DELETE CALL TO PENAM2                                 000210
C     **      3.  DELETE CALLS TO WRITMS AND CLOSMS                     000220
C     **      4.  DELETE SUBROUTINE PENAM2                              000230
C                                                                       000240
      DIMENSION ACQ(6,6), H(6), TDT(6), INDEX(6,5,2), PE(60,10,7),      000250
     1 AMTX(4260), INDX11(2001), THEMHI(11), TDT2(6,10), DISMH(11,6),   000260
     2 DISMHI(11), THEMH(11,6), NI(6), LKUP(7,5,2), PENG(70,10,6),      000270
     3 GAMARY(11), DTS(5)                                               000280
C                                                                       000290
      EQUIVALENCE (AMTX(1),INDEX(1)), (AMTX(61),PE(1))                  000300
C                                                                       000310
      REAL MDIS                                                         000320
C                                                                       000330
C     GAMARY HOLDS THE ATTENUATION COEFFICIENTS AS A FUNCTION OF RANGE  000340
      DATA GAMARY /2.6644, 1.2058, .7496, .5317, .4059, .3252, .2727, .2000350
     1334, .2030, .1803, .1618/                                         000360
      PI=3.1416                                                         000370
C                                                                       000380
C     H ARRAY HOLDS ALTITUDES FOR WHICH ACQUISITION IS CHECKED          000390
      DATA H /1372.0, 914.0, 762.0, 610.0, 457.0, 304.0/                000400
C                                                                       000410
C      DTS ARRAY HOLDS DELAY TIMES PLAYED                               000420
      DATA DTS /0.0, 30., 90., 150., 300./                              000430
      DATA IRN1 /1234567/                                               000440
      DATA IRN2 /7654321/                                               000450
      CALL OPENMS (11,INDX11,2001,1)                                    000460
      READ (5,*) IMF                                                    000470
      IF (IMF.EQ.1) WRITE (6,300)                                       000480
      IF (IMF.EQ.2) WRITE (6,310)                                       000490
      READ (5,320) ETH                                                  000500
      WRITE (6,330) ETH                                                 000510
      SKSEN=ETH*1000000.                                                000520
      READ (5,*) ADF                                                    000530
      ADF=ADF*.01745329252                                              000540
      READ (5,*) TH,PCA                                                 000550
      READ (5,*) AZDT,V,RHO,DP,TR                                       000560
      WRITE (6,350) AZDT,V,RHO,DP,TR,ADF                                000570
      WRITE (6,340) TH,PCA                                              000580
      IF (DP.EQ..10) IDSG=1                                             000590
      IF (DP.EQ..07) IDSG=2                                             000600
      READ (5,*) MK,RNG,ACCX,ACCY                                       000610
      CTR=RNG/1000.                                                     000620
      WRITE (6,360) MK,RNG,ACCX,ACCY                                    000630
      READ (5,*) IDRMN,IDRMX,IVMX                                       000640
      WRITE (6,370) IDRMN,IDRMX,IVMX                                    000650
      DO 110 J=1,6                                                      000660
      READ (5,*) NI(J)                                                  000670
      NIJ=NI(J)                                                         000680
      WRITE (6,390) J,NI(J)                                             000690
      READ (5,*) (THEMH(I,J),I=1,NIJ)                                   000700
      READ (5,*) (DISMH(I,J),I=1,NIJ)                                   000710
      WRITE (6,380) (THEMH(I,J),I=1,NIJ)                                000720
```

```
      WRITE (6,400) (DISMH(I,J),I=1,NIJ)                                000730
      DO 100 I=1,NIJ                                                    000740
      THENH(I,J)=THENH(I,J)*0.01745329252                               000750
  100 CONTINUE                                                          000760
  110 CONTINUE                                                          000770
      CALL PENAM2 (TR,IDSG,V,GTR,RHO,AZDT,PCA,TH,SKSEN,IDCODE)          000780
      WRITE (6,410) IDCODE,IDCODE                                       000790
      WRITE (6,420) V,TR,DP,RHO                                         000800
C                                                                       000810
C                                                                       000820
      TH=TH*.01745329252                                                000830
      DO 240 IDR=IDRMN,IDRMX                                            000840
      RD=FLOAT(IDR)                                                     000850
      DO 230 IV=1,IVMX                                                  000860
      DO 220 IDELT=1,5                                                  000870
      DT=DTS(IDELT)                                                     000880
C                                                                       000890
      DO 210 IMTS=1,2                                                   000900
C         COMPUTE SIGMA OF RANDOM TLE                                   000910
      TLOC=SQRT(2500.+(TR+DT)**2)                                       000920
      IF (IMF.EQ.1) TLOC=SQRT((2500.+1.5*((TR+DT)**2.)))                000930
      IF (IMTS.EQ.2.AND.IDELT.EQ.1) TLOC=.68*TLOC                       000940
C                                                                       000950
C         COMPUTE COORDINATES OF POINT OF CLOSEST APPROACH              000960
      PCAX=PCA*COS(TH)                                                  000970
      PCAY=PCA*SIN(TH)                                                  000980
C         COMPUTE TARGET COORDINATES FOR GIVEN DELAY/VELOCITY           000990
      BIASX=PCAX+(SIN(TH)*V*DT)                                         001000
      BIASY=PCAY-(COS(TH)*V*DT)                                         001010
C                                                                       001020
C         BEGIN MONTE CARLO LOOP BY SAMPLING TLE                        001030
      DO 150 K=1,NK                                                     001040
      CALL NRAN31 (SX1,SX2,IRN1)                                        001050
      TLOCY=SX1*TLOC                                                    001060
      TLOCX=SX2*TLOC                                                    001070
C         SUM RANDOM ERROR TO BIAS ERROR                                001080
      TLEX=TLOCX+BIASX                                                  001090
      TLEY=TLOCY+BIASY                                                  001100
C         SAMPLE BALLISTIC ACCURACY                                     001110
      CALL NRAN31 (SX1,SX2,IRN2)                                        001120
      BIPY=SX1*ACCY                                                     001130
      BIPX=SX2*ACCX                                                     001140
C                                                                       001150
C         AQUISITION VOLUME ENERGY COMPAPISON                           001160
C                                                                       001170
      DO 140 IC=1,6                                                     001180
      DO 130 IA=IC,6                                                    001190
      YINT=-H(IA)*COT(ADF)+BIPY                                         001200
      XINT=BIPX                                                         001210
      X=(TLEX-XINT)                                                     001220
      Y=(TLEY-YINT)                                                     001230
      ALPHA=ATAN2(X,Y)                                                  001240
      ANGSUM=(AZDT*.01745329252)+ALPHA                                  001250
      GAM=GAMARY(IV)                                                    001260
      TD=EXP(-GAM*RD)                                                   001270
      HS=(H(IA)*3.28)                                                   001280
      RS=SQRT((XINT-TLEX)**2.+(YINT-TLEY)**2.+H(IA)**2.)                001290
```

```
              RS=RS/1000.0
              TS=EXP((-GAM*RS)*(1.-EXP(-.00025*HS))/(.00025*HS))
              TFACT=COS(ANGSUM)
              ES=(DP*TO*TS*RHO*TFACT)/(PI*RS*RS)
              IF (ETH.GT.ES) GO TO 130
        C
        C          MANUEVERABILITY FOOTPRINT DISTANCE COMPARISON
        C
              TANG=ABS((TLEY-BIPY)/(TLEX-BIPX))
              BETA=ATAN(TANG)
              BETA=1.5708-BETA
              IF (TLEY.LT.BIPY) BETA=3.1416-BETA
              DIST=SQRT((TLEX-BIPX)**2.+(TLEY-BIPY)**2.)
              NIJ=NI(IA)
              DO 120 J=1,NIJ
              THEMHI(J)=THEMH(J,IA)
              DISMHI(J)=DISMH(J,IA)
          120 CONTINUE
              CALL OVOINT (BETA,MDIS,THEMHI,DISMHI,NIJ,2)
              IF (DIST.GT.MDIS) GO TO 130
              ACQ(IC,IA)=ACQ(IC,IA)+1.0
              GO TO 140
          130 CONTINUE
          140 CONTINUE
          150 CONTINUE
        C
        C          ACCUMULATE RESULTS OVER CEILING AND ALTITUDE
              DO 160 IC=1,6
              DO 160 IA=1,6
              ACQ(IC,IA)=ACQ(IC,IA)/FLOAT(NK)
          160 TOT(IC)=TOT(IC)+ACQ(IC,IA)
        C     WRITE(6,102)(H(IC),IC=1,6),(H(IA),(ACQ(IC,IA),IC=1,6),IA=1,6)
        C     WRITE(6,100) (TOT(IC),IC=1,6)
        C
        C          INDEX RESULTS FOR COPE INTERFACE AND FOR TAPE6 OUTPUT
        C
              DO 170 II=1,6
              JPE=10*(II-1)+2*(IDELT-1)+IMTS
              INDEX(II,IDELT,IMTS)=JPE
          170 PE(JPE,IV,IDR)=TOT(II)
              DO 180 II=1,6
              IPE=10*(IDR-1)+2*(IDELT-1)+IMTS
              LKUP(IDR,IDELT,IMTS)=IPE
          180 PENG(IPE,IV,II)=TOT(II)
              DO 190 IC=1,6
              TOT2(IC,IV)=TOT(IC)
          190 CONTINUE
              DO 200 IC=1,6
              DO 200 IA=1,6
              ACQ(IC,IA)=0.
              TOT(IC)=0.
          200 CONTINUE
          210 CONTINUE
          220 CONTINUE
          230 CONTINUE
          240 CONTINUE
              DO 250 I=1,7
```

```
      DO 250 J=1,5
      DO 250 K=1,2
      IF ((K.EQ.2).AND.(J.GT.1)) GO TO 250
      DT=DTS(J)
      WRITE (6,430) I,DT,K
      IQ=10*(I-1)+2*(J-1)+K
      WRITE (6,440) ((PENG(IQ,JQ,KQ),KQ=1,6),JQ=1,10)
  250 CONTINUE
      IUNIT=7
  260 DO 270 I=1,6
      WRITE (IUNIT,450) ((INDEX(I,J,K),K=1,2),J=1,5)
  270 CONTINUE
      DO 280 I=1,60
      WRITE (IUNIT,460) ((PE(I,J,K),K=1,7),J=1,10)
  280 CONTINUE
      IF (IUNIT.EQ.7) GO TO 290
      IUNIT=7
      GO TO 260
  290 CALL WRITMS (11,ANTX,4260,IDCODE,-1,0)
      CALL CLOSMS (11)
      STOP ' IN PAM: NORMAL PROGRAM TERMINATION '
C
C
C  * * *   F O R M A T   S T A T E M E N T S   * * *
C
  300 FORMAT (1H ,17HPREPLANNED TARGET)
  310 FORMAT (1H ,21HTARGET OF OPPORTUNITY)
  320 FORMAT (F12.8)
  330 FORMAT (1H ,4HETH=,F12.8)
  340 FORMAT (1H ,24H TARGET HEADING ANGLE = ,F5.2,13H PT CLS APP= ,F7.2
     1)
  350 FORMAT (1H ,6H AZDT=,F5.2,3H V=,F5.2,6H RHO= ,F5.2,5H OP= ,F4.2,5H
     1 TP= ,F7.2,6H ADF= ,F5.2)
  360 FORMAT (1H ,5H NK= ,I6,6H RNG= ,F10.1,6H ACCX=,F6.2,8H ACCY = ,F6.
     11,)
  370 FORMAT (1H ,6HIDRMN=,I4,8H  IDRMX=,I4,7H  IVMX=,I4)
  380 FORMAT (1H ,12HTHEMH(I,J)= /(12F10.1))
  390 FORMAT (1H0,5H  J= ,I4,9H  NI(J)= ,I4)
  400 FORMAT (1H ,12H DISMH(I,J)=/(11F10.1))
  410 FORMAT (1H ,10H IDCODE = ,A10,9H IDCODE= ,O20)
  420 FORMAT (1H ,10H VELOCITY=,F4.2,16H MEAN RESP TIME=,F7.2,18H DESIGN
     1ATOR POWER=,F4.2,15H REFLECTIVITY= ,F4.2)
  430 FORMAT (1H ,/,1H ,18HDESIGNATION RANGE=,I4,13H  DELTA TIME=,F8.4,2
     15H ONE OR SEVERAL TARGETS =,I4)
  440 FORMAT (6F10.5)
  450 FORMAT (2I10)
  460 FORMAT (7F10.5)
      END
```

SYMBOLIC REFERENCE MAP (R=1)

```
          SUBROUTINE DVDINT (X,FX,XT,FT,NP,ND)                              002350
          DIMENSION XT(NP), FT(NP), T(16)                                   002360
          N=ND                                                              002370
          N1=(N-1)/2                                                        002380
          N2=N/2                                                            002390
          N3=NP-N2+1                                                        002400
          IF (NP-N) 250,100,100                                             002410
      100 N4=N1+2                                                           002420
          IF (XT(1)-XT(2)) 110,330,260                                      002430
      110 CONTINUE                                                          002440
          IF (X-2.*XT(1)+XT(2)) 240,240,120                                 002450
      120 IF (X-2.*XT(NP)+XT(NP-1)) 130,130,240                             002460
      130 IF (NP.LT.10) GO TO 150                                           002470
          N5=NP-N                                                           002480
      140 N5=N5/2                                                           002490
          N6=N4+N5                                                          002500
          IF (XT(N6).LT.X) N4=N6                                            002510
          IF (N5.GT.1) GO TO 140                                            002520
      150 IF (X-XT(N4)) 180,160,160                                         002530
      160 IF (N4-N3) 170,180,170                                            002540
      170 N4=N4+1                                                           002550
          GO TO 150                                                         002560
      180 N4=N4-1                                                           002570
          N5=N4-N1                                                          002580
          DO 190 I=1,N                                                      002590
          T(I)=FT(N5)                                                       002600
      190 N5=N5+1                                                           002610
          L=(N+1)/2                                                         002620
          TR=T(L)                                                           002630
          N6=N4                                                             002640
          N7=N4+1                                                           002650
          JU=1                                                              002660
          N2=N-1                                                            002670
          UN=1.0                                                            002680
          DO 230 J=1,N2                                                     002690
          N5=N4-N1                                                          002700
          N3=N-J                                                            002710
          DO 200 I=1,N3                                                     002720
          N8=N5+J                                                           002730
          T(I)=(T(I+1)-T(I))/(XT(N8)-XT(N5))                                002740
      200 N5=N5+1                                                           002750
          GO TO (210,220), JU                                               002760
      210 UN=UN*(X-XT(N6))                                                  002770
          JU=2                                                              002780
          N6=N6-1                                                           002790
          GO TO 230                                                         002800
      220 UN=UN*(X-XT(N7))                                                  002810
          JU=1                                                              002820
          N7=N7+1                                                           002830
          L=L-1                                                             002840
      230 TR=TR+UN*T(L)                                                     002850
          FX=TR                                                             002860
          RETURN                                                            002870
      240 WRITE (6,340) X,XT(1),XT(NP)                                      002880
          STOP                                                              002890
      250 WRITE (6,350) NP,ND                                               002900
          STOP                                                              002910
```

```
      260 IF (X-2.*XT(1)+XT(2)) 270,240,240                                     002920
      270 IF (X-2.*XT(NP)+XT(NP-1)) 240,280,280                                 002930
      280 IF (NP.LT.10) GO TO 300                                               002940
          N5=NP-N                                                               002950
      290 N5=N5/2                                                               002960
          N6=N4+N5                                                              002970
          IF (XT(N6).GT.X) N4=N6                                                002980
          IF (N5.GT.1) GO TO 290                                                002990
      300 IF (X-XT(N4)) 310,310,180                                             003000
      310 IF (N4-N3) 320,180,320                                                003010
      320 N4=N4+1                                                               003020
          GO TO 300                                                             003030
      330 WRITE (6,360) XT(1)                                                   003040
          STOP                                                                  003050
C                                                                               003060
C   * * *  F O R M A T   S T A T E M E N T S  * * *                             003070
C                                                                               003080
      340 FORMAT (23H ARG. NOT IN TABLE  X= ,E14.7,9H  XT(1)= ,E14.7,10H  XT003090
     1(NP)= ,E14.7,2X,6HDVDINT)                                                 003100
      350 FORMAT (22H TABLE TOO SMALL  NP= ,I5,6H  ND= ,I5,2X,6HDVDINT)         003110
      360 FORMAT (23H CONSTANT TABLE XT(1)= ,E14.7,2X,6HDVDINT)                 003120
          END                                                                   003130
```

CARD NR. SEVERITY DETAILS   DIAGNOSIS OF PROBLEM

```
   42     I              AN IF STATEMENT MAY BE MORE EFFICIENT THAN A 2 OR 3 BRANCH COMPUTED GO TO STATEMENT.
```

SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS
3 DVDINT

VARIABLES		SN TYPE		RELOCATION			TYPE		
0	FT	REAL	ARRAY	F.P.	0	FX	REAL		F.P.
265	I	INTEGER			273	J	INTEGER		
271	JU	INTEGER			266	L	INTEGER		
256	N	INTEGER			0	ND	INTEGER		F.P.
0	NP	INTEGER		F.P.	257	N1	INTEGER		
260	N2	INTEGER			261	N3	INTEGER		
262	N4	INTEGER			263	N5	INTEGER		
264	N6	INTEGER			270	N7	INTEGER		
274	NB	INTEGER			275	T	REAL	ARRAY	
267	TR	REAL			272	UN	REAL		
0	X	REAL		F.P.	0	XT	REAL	ARRAY	F.P.

FILE NAMES   MODE
TAPE6   FMT

```
SUBROUTINE NRAN31      76/76    UO ROUND=+-*/              FTN 4.8+508        07/10/80  10.11.52       PAGE     10

          C                                                                      003140
                SUBROUTINE NRAN31 (X1,X2,I)                                      003150
                X3=SQRT(-2.0*ALOG(URAN31(I)))                                    003160
                X4=6.2831853072*URAN31(I)                                        003170
                X2=X3*SIN(X4)                                                    003180
                X1=X3*COS(X4)                                                    003190
                RETURN                                                           003200
                END                                                              003210


     SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS
    3  NRAN31

VARIABLES       SN  TYPE           RELOCATION
    0  I            INTEGER             F.P.        0  X1        REAL              F.P.
    0  X2           REAL                F.P.       31  X3        REAL
   32  X4           REAL

EXTERNALS           TYPE     ARGS
       ALOG         REAL       1 LIBRARY               COS       REAL      1 LIBRARY
       SIN          REAL       - LIBRARY               SQRT      REAL      1 LIBRARY
       URAN31       REAL       -

STATISTICS
  PROGRAM LENGTH                   33B      27
         55000B SCM USED
```

```
      SUBROUTINE PENAN2 (TR,IOT,VEL,GTR,REFL,ANGLET,DEFB,TGTHD,SKSEN,
     1  IOCODE)
C
      COMMON /XVALUE/ XVALUE(8,9,2)
      DIMENSION AVALUE(9), NP(9)
C
C
C     * * * * *   FILL IN XVALUE COMMON BLOCK   * * * * *
C
      DATA (((XVALUE(I,J,K),I=1,8),K=1,2),J=1,9) /
C          DUMMY SLOTS FOR NOMINAL RESPONSE TIMES
     1      8*0.,
     2      8*8.,
C          DESIGNATOR TYPES
     1      1.,     2.,     3.,     5*0.,
     2      0.,     1.,     1.,     5*8.,
C          TARGET VELOCITIES
     1      2.,     3.,     5.,     8.,     9.,     3*0.,
     2      0.,     0.,     1.,     2.,     2.,     3*8.,
C          GUN-TARGET RANGES
     1      8.,     12.,    20.,    30.,    40.,    10.,    16.,    0.,
     2      0.,     1.,     2.,     3.,     4.,     5.,     6.,     8.,
C          REFLECTIVITIES
     1      .05,    .10,    .20,    .30,    4*0.,
     2      0.,     1.,     2.,     3.,     4*8.,
C          ANGLES T
     1      0.,     25.,    30.,    60.,    90.,    120.,   2*0.,
     2      0.,     1.,     2.,     3.,     4.,     5.,     2*8.,
C          DEFLECTION BIASES
     1      -200., -100., 0.,       100.,   200.,   3*0.,
     2      0.,     1.,     2.,     3.,     4.,     3*8.,
C          TARGET HEADINGS
     1      -60.,   -30.,   0.,     30.,    60.,    3*0.,
     2      0.,     1.,     2.,     3.,     4.,     3*8.,
C          SEEKER SENSITIVITIES
     1      12.,    18.,    24.,    30.,    36.,    3*0.,
     2      0.,     1.,     2.,     3.,     4.,     3*8./
C
C
      AVALUE(1)=TR
      AVALUE(2)=IOT
      AVALUE(3)=VEL
      AVALUE(4)=GTR
      AVALUE(5)=REFL
      AVALUE(6)=ANGLET
      AVALUE(7)=DEFB
      AVALUE(8)=TGTHD
      AVALUE(9)=SKSEN
C
      DO 110 J=2,9
      DO 100 I=1,8
      IF (ABS(AVALUE(J)-XVALUE(I,J,1)).GT..0001) GO TO 100
      NP(J)=XVALUE(I,J,2)+.5
      GO TO 110
  100 CONTINUE
      STOP ' IN PENAN2: ERROR NUMBER 1'
  110 CONTINUE
```

```
C
      DO 120 J=2,9
      IF (NP(J).GE.8) STOP ' IN PENAM2: ERROR NUMBER 2 '
  120 CONTINUE
C
      IF (TR.LE.0.0.OR.TR.GE.999.5) STOP ' IN PENAM2: ERROR NUMBER 3 '
      NCODE=TR+.50
C
      DO 130 J=2,9
  130 NCODE=8*NCODE+NP(J)
C
      ENCODE (10,170,IDCODE) NCODE
C
      RETURN
C
C   *     *     *     *     *     *     *     *     *     *     *     *
C
      ENTRY PEIDNT
C
      DECODE (10,180,IDCODE) NCODE
C
      DO 140 J=2,9
      NP(11-J)=MOD(NCODE,8)
      NCODE=NCODE/8
  140 CONTINUE
C
      NP(1)=NCODE
C
      DO 160 J=2,9
      DO 150 I=1,8
      IF (ABS(FLOAT(NP(J))-XVALUE(I,J,2)).GT..0001) GO TO 150
      AVALUE(J)=XVALUE(I,J,1)
      GO TO 160
  150 CONTINUE
      STOP ' IN PENAM2 (PEIDNT): ERROR NUMBER 4'
  160 CONTINUE
C
      AVALUE(1)=NCODE
C
      TR=AVALUE(1)
      IDT=AVALUE(2)
      VEL=AVALUE(3)
      GTR=AVALUE(4)
      REFL=AVALUE(5)
      ANGLET=AVALUE(6)
      DEFB=AVALUE(7)
      TGTHD=AVALUE(8)
      SKSEN=AVALUE(9)
C
      RETURN
C
C
C   * * *   F O R M A T   S T A T E M E N T S   * * *
C
  170 FORMAT (4HPE00,R6)
  180 FORMAT (4X,R6)
      END
```

APPENDIX C

SAMPLE CASE

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APPENDIX C

SAMPLE CASE

A list of input values as used in a sample PAM run is shown in Table C-1. These values are for the purpose of illustration only. The values are read into the input variables in the order that those variables are listed in Table A-1. For example, the first card indicates that the program run is for a preplanned footprint situation; the second card indicates that the seeker sensitivity being played is .00003 Joules/Km^2.

Part of the output which resulted from running the program with the sample input stream is shown in Figure C-2. For each combination of designation range and unanticipated delay time there is a 6 x 10 output matrix. In addition, for the case where there is no unanticipated delay, probabilities are printed for both single and multiple target TLEs.

Output values are configured in each matrix as follows:

Highest ceiling ..... Lowest Ceiling

Visibility = 1 Km

'

'

'

Visibility = 10 Km

Variable (See Table A1)	Sample Values(s)
IMF	1
ETH	.000030
AOF	20.0
TH,PCA	0.0.0.0
A2DT,V,RHO,ED,TR	25.0.5.,.10,.1,106.
NK,RNG,ACCX,ACCY	100,8000.,73.,366.
IDRMN,IDRMX,IVMX	1,7,10
NI(1)	8
THEMN(1,8)	0.0.20.,30.,45.,60.,90.,135.,180.
DISMH(1,8)	1200.,1100.,1200.,1000.,600.,500.,400.,700.
NI(2)	8
THEMN(2,8)	0.,20.,30.,45.,60.,90.,135.,180.
DISMH(2,8)	1200.,1100.,1200.,1000.,600.,500.,400.,700.
NI(3)	8
THEMN(3,8)	0.,20.,30.,45.,60.,90.,135.,180.
DISMH(2,8)	1100.,1000.,1100.,900.,500.,400.,300.,700.
NI(4)	8
THEMN(4,8)	0.,20.,30.,45.,60.,90.,135.,180.
DISMH(4,8)	1000.,900.,10C0.,800.,500.,300.,300.,500.
NI(5)	8
THEMN(5,8)	0.,20.,30.,45.,60.,90.,135.,180.
DISMH(5,8)	600.,500.,600.,400.,500.,400.,400.,600.
NI(6)	8
THEMN(6,8)	0.,20.,30.,45.,60.,90.,135.,180.
DISMN(6,8)	400.,300.,400.,300.,400.,300.,300.,400.

FIGURE C2 SAMPLE PAM INPUTS

PROBABILITIES OF ACQUISITION AND MANEUVER

Visibility Range (km)	Designation Range 1 km Time Delay 30s Cloud Ceiling (Ft)					
	4500	3000	2500	2000	1500	1000
1	.20	.20	.20	.20	.20	.16
2	.48	.48	.46	.44	.44	.24
3	.46	.46	.40	.34	.31	.22
4	.54	.54	.51	.49	.47	.30
5	.54	.54	.49	.47	.45	.28
6	.54	.54	.49	.44	.39	.25
7	.51	.51	.47	.44	.42	.29
8	.54	.54	.50	.48	.48	.28
9	.45	.45	.40	.36	.33	.21
10	.55	.55	.48	.45	.42	.25

FIGURE C2 SAMPLE PAM OUTPUT

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