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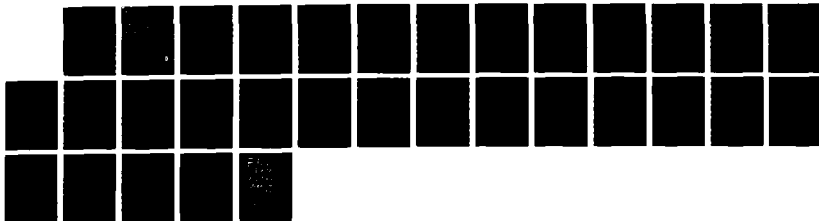
AVSCOM'S MODIFICATIONS TO TELEDYNE SYSTEMS COMPANY'S
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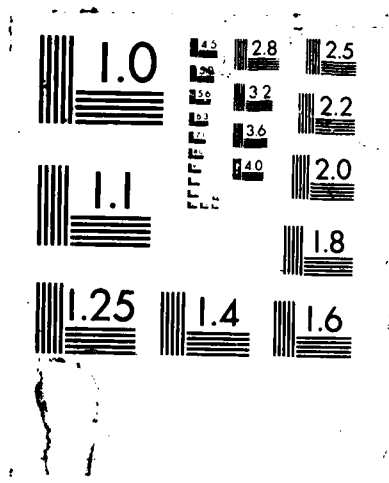
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USAAVSCOM

Technical Memorandum

TM 87-F-3

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**AVSCOM'S MODIFICATIONS
TO TELEDYNE SYSTEMS COMPANY'S
AIR-TO-AIR FIRE CONTROL SYSTEM
SIMULATION MODEL**

D.J. BREYER

Operations Research Analyst

NOVEMBER 1987

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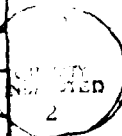


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INTRODUCTION

This report has been written to document the changes made to Teledyne Systems Company's (TSC) Attack Helicopter Air-to-Air (ATA) Fire Control System Simulation model (AIRTOAIR). The model was acquired by the Developmental Systems Analysis Division of the U.S. Army Aviation Systems Command (USAAVSCOM) in April of 1986 under the direction of the Directorate for Engineering. The original model was developed under contract from the USAAVSCOM's Aviation Applied Technology Directorate (AATD) in Fort Eustis, Virginia, and the U.S. Army Armament Research, Development and Engineering Center (ARDEC) in Dover, New Jersey.

II. BACKGROUND TO THE MODEL

The AIRTOAIR Simulation was used as a tool by TSC to assess the effectiveness of several mechanizations of fire control equations. These equations were being formulated with the intent of becoming a product improvement to the existing attack helicopters, the AH-1S COBRA and the AH-64 APACHE. The model simulates a one-on-one, non-dueling, close-in combat scenario using the automatic cannon. Since it is a fire control system representation, all of the sensors that feed information to the fire control computer (FCC) are

modelled. These include:

1. Laser rangefinder.
2. Sight-line measurement via gimbals.
3. Sight-line rates via gyroscopes.
4. Air data sensors.
5. Doppler radar.
6. Heading attitude reference system (APACHE).
7. Vertical gyro/magnetic compass (COBRA).

Error models consisting of instrument biases, scale factors and random noise are used to simulate these sensors. They are modularized so that additions or alterations can easily be made if desired. This allows the analyst to not only study the APACHE or COBRA with ATA equations, but to simulate futuristic aircraft with new sensors, such as a millimeter wave radar or muzzle velocity sensor.

The fire control equations consist of three interrelated modules, a filtering algorithm used to estimate the target states, a prediction algorithm to extrapolate these target states one bullet time of flight into the future, and an airborne ballistics algorithm to determine the gun-laying vectors to put the bullets on the predicted future target position. Two filters were in the original model--a seven-state, rotating frame Kalman filter and a variable coefficient alpha-beta-gamma filter. A quadratic prediction algorithm was employed, and the airborne ballistics were those developed by Mr. Harold Breanx of the USA Ballistics Research Laboratory (BRL).¹

The model then implements a modified 4-degree-of-freedom (DOF) real world

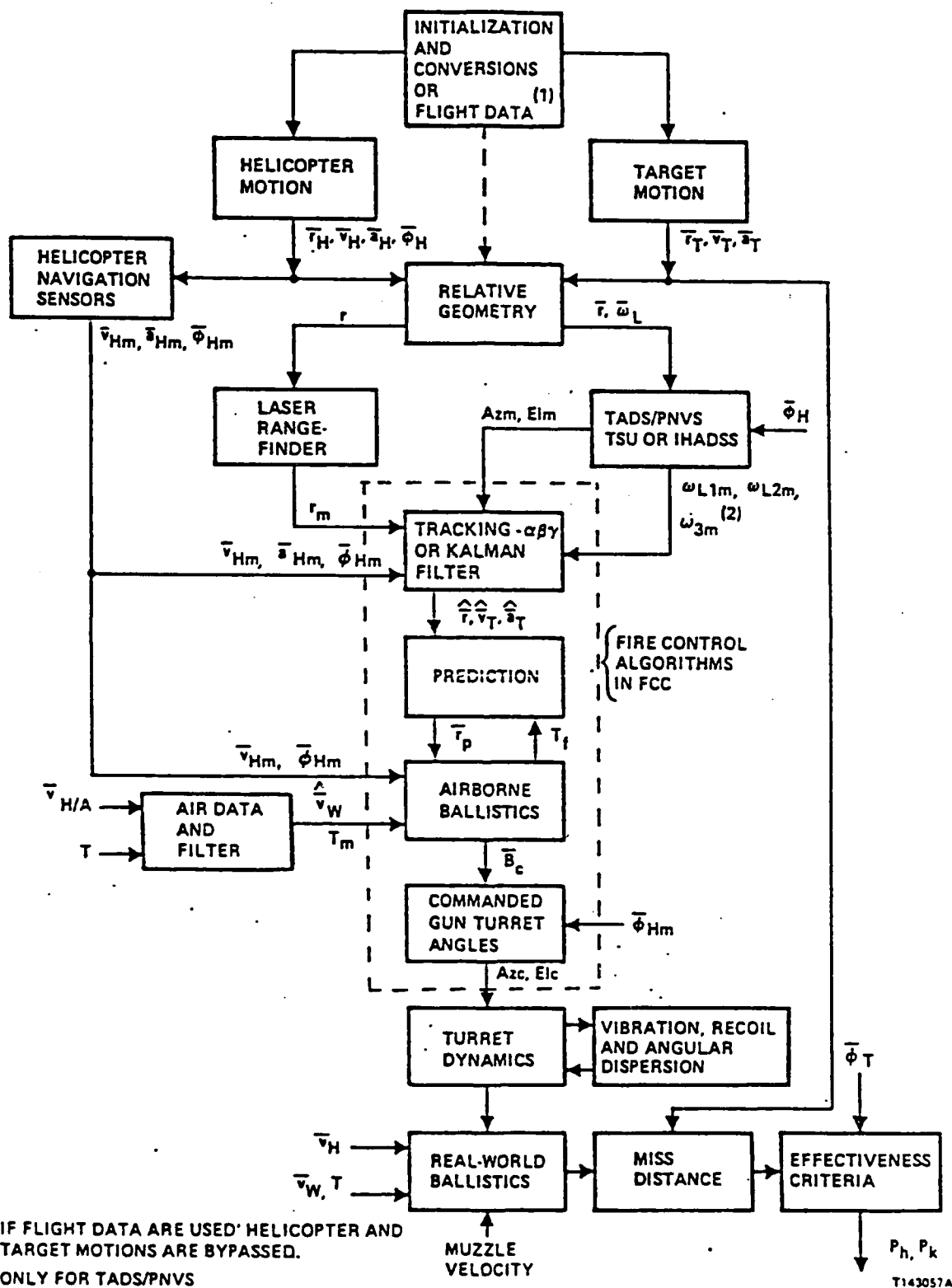
ballistic algorithm (developed by Mr. Tom Hutchings of ARDEC) to simulate bullet flyout to the target and computes miss distances and burst probability of kill. All of this background information is explained in much greater detail within the final report that TSC delivered to ARDEC under contract specifications.² An overall flowchart of the model, taken from reference 2, is shown on the following page (Figure 1). The model is programmed in FORTRAN 77 and is currently running on a DEC VAX (at TSC), a CDC (at ARDEC) and an IBM 3781 (at AVSCOM).

III. THE CHANGES

Since acquiring the model, many modifications have been made. Some have been as easy as adding several lines of coding, while others have required new input data files or subroutines. The changes in coding will be provided, along with a description of the methodology. It should be noted here that the model continues to be modified, and future alterations will need to be explained under another cover, although several planned ones will be touched upon here.

The modifications to be discussed include the following:

1. 20MM M70 Pyrotechnically-initiated explosive (PIE) round added.
2. End-game methodology improved.
3. Existing APACHE and COBRA target tracking Kalman filters added.
4. Linear prediction algorithm added.
5. Change from deterministic to Monte Carlo with appropriate statistics computed.



"AIRTOAIR" PROGRAM FLOWCHART

Figure 1

6. Graphic program accessed to study Kalman filter performance.

7. More engagement files created and run.

Since the purpose of this report is to explain the modifications, applications of these to specific projects will be discussed only briefly whenever applicable.

A. Addition of the 20MM PIE round included both "real world" data and airborne ballistic coefficients. The data needed by the 4-DOF algorithm is produced by BRL from actual firings of the rounds (Table 1). The airborne ballistics algorithm in the fire control computer uses 24 different coefficients, which are derived from fitted approximations to the raw data, to closely predict bullet time-of-flight to the estimated target position (Table 2). Lethality data from the round against various red air and ground targets also needed to be obtained from BRL for the end game calculations.

The 20MM PIE has been a leading candidate for the LHX cannon, primarily due to its aerodynamic qualities, resulting in decreased time-of-flight, and its excellent destructive capabilities on thin-skinned airborne targets. Numerous trade-off studies between the 20MM PIE and 30MM HEDP (high explosive/dual purpose) have been conducted for LHX purposes to examine the time-of-flight versus lethality issue. The studies show that the burst probability of kill is highly engagement-dependent, and that normally more 20MM rounds will strike the target than 30MM, but sometimes probability of kill is greater for the 30MM due to its exceptional destructive ability.

B. The most important and time-consuming change was the reprogramming of the end game methodology. In the original model, target vulnerable area

20MM PGU-28/B "REAL WORLD" COEFFICIENTS

LIFT FACTOR	1.0
YAW DRAG FACTOR	1.0
DOWN RANGE YAW LIMIT CYCLE (DEGREES)	6.0
PROJECTILE DIAMETER (METERS)	.0199
PROJECTILE MASS (KG)	.1015
MUZZLE VELOCITY (M/SEC)	1051.56
INITIAL SPIN (RAD/SEC)	13071.55
CENTER OF GRAVITY (CALIBER)	2.8846
LONGITUDINAL MOMENT OF INERTIA (KG*M**2)	.00000547
TRANSVERSE MOMENT OF INERTIA (KG*M**2)	.00003498
MAGNUS FORCE POSITION (CALIBER)	0.0
DRAG FUNCTION FORM FACTOR	1.0
FIN CANT ANGLE (DEGREES)	0.0

Table 1

20MM PGU-28/B "REAL WORLD" COEFFICIENTS

<u>MACH NUMBER</u>	<u>DRAG</u>	<u>YAW DRAG</u>	<u>LIFT FORCE</u>	<u>SPIN DAMPING MOMENT</u>	<u>OVERTURNING MOMENT</u>	<u>MAGNUS MOMENT</u>
0.0	.160	3.05	1.40	-.021	3.54	.135
0.2					3.60	
0.3	.160	3.05		-.021		
0.4				-.0209		
0.5	.161	3.20		-.0206		
0.6				-.0204	3.79	
0.7	.165	3.70				
0.75				-.0195		
0.8	.170	4.20			3.94	
0.85	.175	4.50			3.97	
0.9	.190	5.20		-.0186	4.04	
0.95	.251		1.40		4.10	
1.0	.363	7.10		-.0180	3.99	
1.05	.423	7.55				
1.1	.430	7.80	1.57	-.0174	3.78	
1.15	.432					
1.2	.428	8.10				
1.25		8.20				
1.3	.417	8.10	1.78		3.52	
1.4		7.90		-.0160		
1.45					3.39	
1.5	.393	7.65	1.90			
1.6				-.0152		
1.7			2.10			
1.8	.365		2.16	-.0144	3.21	
2.0			2.26	-.0137	3.14	
2.2			2.34	-.0131		
2.4			2.38	-.0126	3.00	
2.5	.302					
2.6			2.42	-.0120		
2.8		3.10	2.43			
2.85					2.87	
2.9	.278					
3.0		2.40	2.42	-.0110	2.85	
3.2	.261	1.90		-.0106		
3.25					2.79	
3.3		1.70				
3.5	.245	1.50	2.42	-.0100	2.75	.135

Table 1
(Continued)

20MM PGU-28/B AIRBORNE BALLISTIC COEFFICIENTS

<u>ARRAY ELEMENT</u>	<u>DEFINITION</u>	<u>COEFFICIENT</u>
CA(1,J)	Drag at Standard Density	.00050617
CA(2,J)	Initial Mach Number	3.09
CA(3,J)	Component of Drag Coefficient	8.1648
CA(4,J)	Muzzle Velocity	1051.6
CA(5,J)	Time of Flight	.99313
CA(6,J)	Time of Flight	-2.9300
CA(7,J)	Time of Flight	.42296
CA(8,J)	Time of Flight	5.2728
CA(9,J)	Time of Flight	-.22338
CA(10,J)	Time of Flight	-.14626
CA(11,J)	Time of Flight	.55981
CA(12,J)	Time of Flight	0.0
CA(13,J)	Direction Cosines	-.33719
CA(14,J)	Direction Cosines	-1.0
CA(15,J)	Direction Cosines	-.41969
CA(16,J)	Direction Cosines	-.24146
CA(17,J)	Direction Cosines	.32397
CA(18,J)	Burnout Velocity	0.0
CA(19,J)	Burnout Velocity	0.0
CC(1,J)	Lift Moment Coefficient	2.42
CC(2,J)	Overturning Moment Coefficient	2.83
CC(3,J)	Lift Constant (Dimensionless)	0.0
CC(4,J)	Overturning Constant (Dimensionless)	0.0
CC(5,J)	Aerodynamic Jump Constant (Dimensionless)	.033378

Table 2

was input in square meters and then reduced to a circle. The area was capable of being changed during the engagement, but TSC only slightly varied it based on severity of the maneuvers being modelled. After a miss distance was calculated to the actual target position for each bullet, it was compared to the radius of the effective area circle to decide whether the bullet hit or missed. If scored a hit, the burst probability of kill was increased using a constant single shot probability of kill given hit for each type of round modelled (20MM or 30MM).

The new methodology is based upon the typical end game used by the U.S. Army Materiel Systems Analysis Activity (AMSAA) within their simulation models. Vulnerable and presented areas are input, in square meters, using front, rear, bottom, top and two sides. The vulnerable areas are dependent upon striking velocity of the projectile and are further delineated by damage conditions, i.e., mission abort, forced landing and attrition kill. Logic has been programmed in to use either the shoebox or Armitage ellipsoid representation for the target, and the kill definition can also be chosen based on the above damage conditions.

The second part of the new end game is used when the bullet reaches its closest approach to the actual target position. A target coordinate system had to be defined so that target and projectile velocities could be computed. The three faces of the target that are exposed to the incoming round are determined and the relative projectile striking velocity, as well as vulnerable areas based on that striking velocity, are computed. These vulnerable areas, along with the presented area, are combined into one area for each damage

condition using either target representation mentioned above (shoebox or ellipsoid). A presented area radius is computed in the same fashion as the TSC methodology and compared to the miss distance. If that bullet is scored a hit, a probability of kill given hit (ratio of vulnerable area to presented area) is calculated dependent upon kill criteria used and the burst probability of kill is augmented appropriately. The main difference between the two methodologies is that the new one allows for the vulnerable and presented areas, as well as the single shot probability of kill given hit, to vary based upon engagement geometry and each individual bullet's flight path. The subroutines integrated into the model that handle the new end game methodology are TRGATD (determination of exposed areas) and TRGINP (inputs the new vulnerability data), which are shown in Figure 2. Additions were made to subroutines MISDIS and PROBK for the new methodology.

C. The next most important modification was the addition of the existing APACHE and COBRA Kalman tracking filters to the model. The first step involved requesting the algorithms directly from McDonnell Douglas Helicopter Company (APACHE) and Bell Helicopter (COBRA). After clarifying questions on variables and sources of data for the filters, the two algorithms were integrated into the model.

The APACHE currently utilizes a 3-state Kalman filter which estimates target range, range rate and acceleration along the line-of-sight. Additional measurements needed by this filter, beyond the ones used by the TSC-developed 7-state Kalman filter, are provided to the FCC by the APACHE's Heading Attitude

```

C *****
C NO. 60
C THE CALL TO THIS SUBROUTINE FROM 'MISDIS' IS WHEN THE BULLET HAS
C REACHED ITS CLOSEST APPROACH TO THE TARGET. THE STRIKING
C VELOCITY (VS), VULNERABLE AREA DEPENDANT UPON THAT STRIKING
C VELOCITY, AND TARGET AND PROJECTILE VELOCITIES IN THE TARGET COORD-
C INATE SYSTEM ARE COMPUTED AT THIS TIME (POSITIONS ARE NO LONGER
C REQUIRED). THE PRIMED COMPONENTS OF THE PROJECTILE VELOCITY ARE
C USED TO DETERMINE THE THREE FACES OF THE TARGET EXPOSED TO THE IN-
C COMING ROUND, AS IT IS IN RELATION TO THE TARGET.
C CINTRG - TRANSFORMS ANY VECTOR IN INERTIAL SYSTEM TO TARGET SYSTEM
C VTT - VELOCITY VECTOR OF TARGET IN INERTIAL FRAME (VTX,VTY,VTZ)
C VB - VELOCITY VECTOR OF BULLET IN INERTIAL FRAME (VBX,VBY,VBZ)
C SIGN CONVENTION : AZIMUTH - POSITIVE TO THE TARGET'S RIGHT SIDE
C ELEVATION - POSITIVE UP
C TARGET COORDINATE SYSTEM - X-AXIS POSITIVE THROUGH THE NOSE
C Y-AXIS POSITIVE THROUGH THE RIGHT WING
C Z-AXIS POSITIVE THROUGH THE ROTOR SHAFT
C FACE CONVENTION : 1 = FRONT, 2 = RIGHT SIDE, 3 = REAR, 4 = LEFT
C SIDE, 5 = TOP, 6 = BOTTOM
C *****
C SUBROUTINE TRGATD(VTT,VB,VS)
C DIMENSION CINTRG(3,3),VTTPRM(3),VBPRIM(3),FACE(6),VTT(3),VB(3)
C COMMON /TRGVA/ VAREA(6,7,4),VV(7),NARMT,IKILL,VA(4),PARAD,PKHX
C COMMON /TARGET/ XT,YT,ZT,VTH,SIST,GANT,ALT,RHOT,PSIT,THETAT,
C PHIT,ALFT
C COMMON /CNVRSN/ RTD,DTR,GEE,KNTMPS
C
C C1 = COS(PSIT)
C S1 = SIN(PSIT)
C C2 = COS(THETAT)
C S2 = SIN(THETAT)
C C3 = COS(PHIT)
C S3 = SIN(PHIT)
C CINTRG(1,1) = C1*C2
C CINTRG(1,2) = S1*C2
C CINTRG(1,3) = -S2
C CINTRG(2,1) = C1*S2*S3-S1*C3
C CINTRG(2,2) = S1*S2*S3+C1*C3
C CINTRG(2,3) = C2*S3
C CINTRG(3,1) = C1*S2*C3+S1*S3
C CINTRG(3,2) = -C1*S3+S1*S2*C3
C CINTRG(3,3) = C2*C3
C CALL MXMULT(CINTRG,VTT,VTTPRM,3,3,1)
C CALL MXMULT(CINTRG,VB,VBPRIM,3,3,1)
C DO 180 ICOMP=1,4
C IF (VS .GT. VV(1)) GO TO 110
C DO 100 I=1,6
C FACE(I) = VAREA(I,1,ICOMP)*VS/VV(1)
100 CONTINUE
C GO TO 170
110 K=2
120 IF (VS .GT. VV(K)) GO TO 140
C DO 130 I=1,6
C FACE(I) = VAREA(I,K-1,ICOMP) + (VS-VV(K-1))*(VAREA(I,K,ICOMP)-
C VAREA(I,K-1,ICOMP))/(VV(K)-VV(K-1))
130 CONTINUE
C GO TO 170
140 IF (K .EQ. 7) GO TO 150
C K = K+1
C GO TO 120
150 DO 160 I=1,6
C FACE(I) = VAREA(I,7,ICOMP)
160 CONTINUE
170 CONTINUE
C AZB = 90.
C IF (ABS(VBPRIM(1)) .LT. .00001) GO TO 777
C AZB = ATAN(ABS(VBPRIM(2)/VBPRIM(1)))*RTD
777 ELB = 90.
C IF (VBPRIM(3) .LT. 0.) ELB = -90.
C A = SQRT(VBPRIM(1)**2 + VBPRIM(2)**2)
C IF (A .LT. .00001) GO TO 778
C ELB = ATAN(VBPRIM(3)/A)*RTD

```

Figure 2 SUBROUTINES "TRGATD" & "TRGINP"

```

778 IF (VBPRIM(1) .LT. 0. .AND. VBPRIM(2) .LT. 0.) AZB = 180. + AZB
IF (VBPRIM(1) .LT. 0. .AND. VBPRIM(2) .GE. 0.) AZB = 180. - AZB
IF (VBPRIM(1) .GE. 0. .AND. VBPRIM(2) .LT. 0.) AZB = 360. - AZB
IF (AZB .GE. 0. .AND. AZB .LE. 90.) THEN
    S1 = FACE(3)*COS(AZB*DTR)
    S2 = FACE(4)*SIN(AZB*DTR)
ELSEIF (AZB .GE. 90. .AND. AZB .LE. 180.) THEN
    S1 = FACE(4)*COS((AZB-90.)*DTR)
    S2 = FACE(1)*SIN((AZB-90.)*DTR)
ELSEIF (AZB .GE. 180. .AND. AZB .LE. 270.) THEN
    S1 = FACE(1)*COS((AZB-180.)*DTR)
    S2 = FACE(2)*SIN((AZB-180.)*DTR)
ELSEIF (AZB .GE. 270. .AND. AZB .LE. 360.) THEN
    S1 = FACE(2)*COS((AZB-270.)*DTR)
    S2 = FACE(3)*SIN((AZB-270.)*DTR)
ENDIF
IF (ELB .GE. 0. .AND. ELB .LE. 90.) THEN
    S3 = FACE(6)*SIN(ABS(ELB*DTR))
ELSEIF (ELB .GE. -90. .AND. ELB .LE. 0.) THEN
    S3 = FACE(5)*SIN(ABS(ELB*DTR))
ENDIF
S1 = S1*COS(ELB*DTR)
S2 = S2*COS(ELB*DTR)
IF (NARMT .EQ. 0) VA(ICOMP) = S1 + S2 + S3
IF (NARMT .EQ. 1) VA(ICOMP) = SQRT( S1**2 + S2**2 + S3**2)
180 CONTINUE
RETURN
END

```

NO. 62

THIS SUBROUTINE INPUTS VULNERABILITY TABLES IN THE EVADE II
 FORMAT — I=1,6 CARDINAL FACES, J=1,7 STRIKING VELOCITIES, K=1,4
 DAMAGE CONDITIONS WITH PRESENTED AREA OF THE TARGET BEING THE
 FIRST GROUP INPUT. PRESENTED AREAS AND VULNERABLE AREAS ARE INPUT
 IN METERS**2, STRIKING VELOCITIES IN METERS/SEC, AND 'NARMT' IS
 ZERO FOR THE SHOEBOX REPRESENTATION OF THE TARGET, AND ONE FOR
 THE ARMITAGE ELLIPSOID REPRESENTATION. 'IKILL' DETERMINES THE
 DEFINITION OF A KILL — WHEN 'IKILL' EQUALS ONE, ATTRITION VULNER-
 ABLE AREA ONLY IS USED, WHEN IT EQUALS TWO, ATTRITION AND FORCED
 LANDING, AND WHEN IT EQUALS THREE, ATTRITION, FORCED LANDING, AND
 MISSION ABORT. THIS FLAG IS USED IN SUBROUTINE PROBLK.

SUBROUTINE TRGINP
 COMMON /TRGVA/ VAREA(6,7,4),VV(7),NARMT,IKILL,VA(4),PARAD,PKHX
 PKHX=0.0
 DO 50 K=1,4
 DO 40 J=1,7
 READ(9,190) (VAREA(I,J,K),I=1,6)
 40 CONTINUE
 50 CONTINUE
 READ(9,200) (VV(I),I=1,7)
 READ(9,210) NARMT,IKILL
 190 FORMAT(6F10.2)
 200 FORMAT(7F10.1)
 210 FORMAT(2I10)
 RETURN
 END

Figure 2 (Continued)

Reference System (HARS). These additional measurements included ownship roll, pitch and yaw rates, pitch and yaw accelerations, and body accelerations with respect to the earth in the aircraft coordinate system. As with the existing error models, the actual values, based on orientation of the attacker, are corrupted by instrument biases and accuracies taken from the procurement specifications for the HARS. The linear prediction algorithm was included immediately following execution of the filter (instead of using two separate subroutines) with the estimated, predicted target position passed directly to the airborne ballistics algorithm.

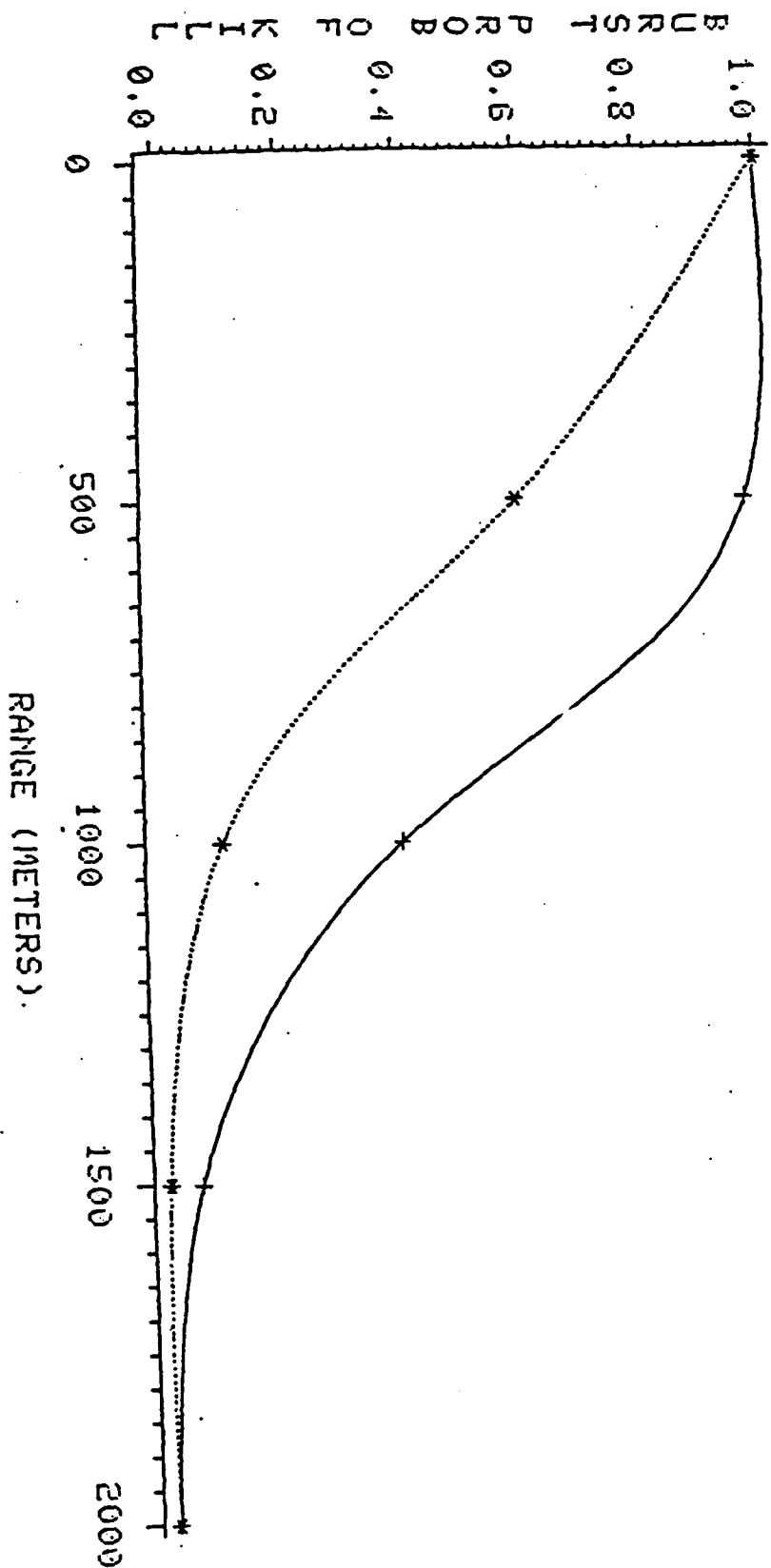
The COBRA's FCC utilizes a 4-state Kalman filter which estimates target range and three components of target velocity in the sight-line coordinate system. No information, beyond that provided by the sensors already modelled, needed to be derived, so the algorithm was programmed directly into the model. Again, the linear prediction algorithm was connected to the filter with its output passed to the airborne ballistics routine.

The reason for programming the existing filters was to provide insight into the increase in effectiveness of the ATA equations over the current equations, developed primarily for air-to-ground, area suppression operations. The ATA equations have been proposed to be one of the product improvements to the APACHE and COBRA to provide a near-term counter-air capability. Figures 3 and 4 show results of several computer runs completed for this study. Coding for the filters cannot be shown due to company proprietary information contained in the mathematical formulations.

D. As described above, the original model used a quadratic prediction algorithm to estimate the future target position. This position is derived using the seven state estimates from the Kalman filter (relative range and

EFFECT OF FIRE CONTROL ON PROBABILITY OF KILL AH-64 APACHE

- + - ATA FIRE CONTROL (7-STATE TRACKER, QUADRATIC PREDICTOR)
 - * - EXISTING FIRE CONTROL (3-STATE TRACKER, LINEAR PREDICTOR)
- BURST SIZE IS 20 ROUNDS



TARGET IN 1 G TURN AND DIVE AT 100 KNOTS
ATTACKER IN CONSTANT 100 KNOT TAIL CHASE

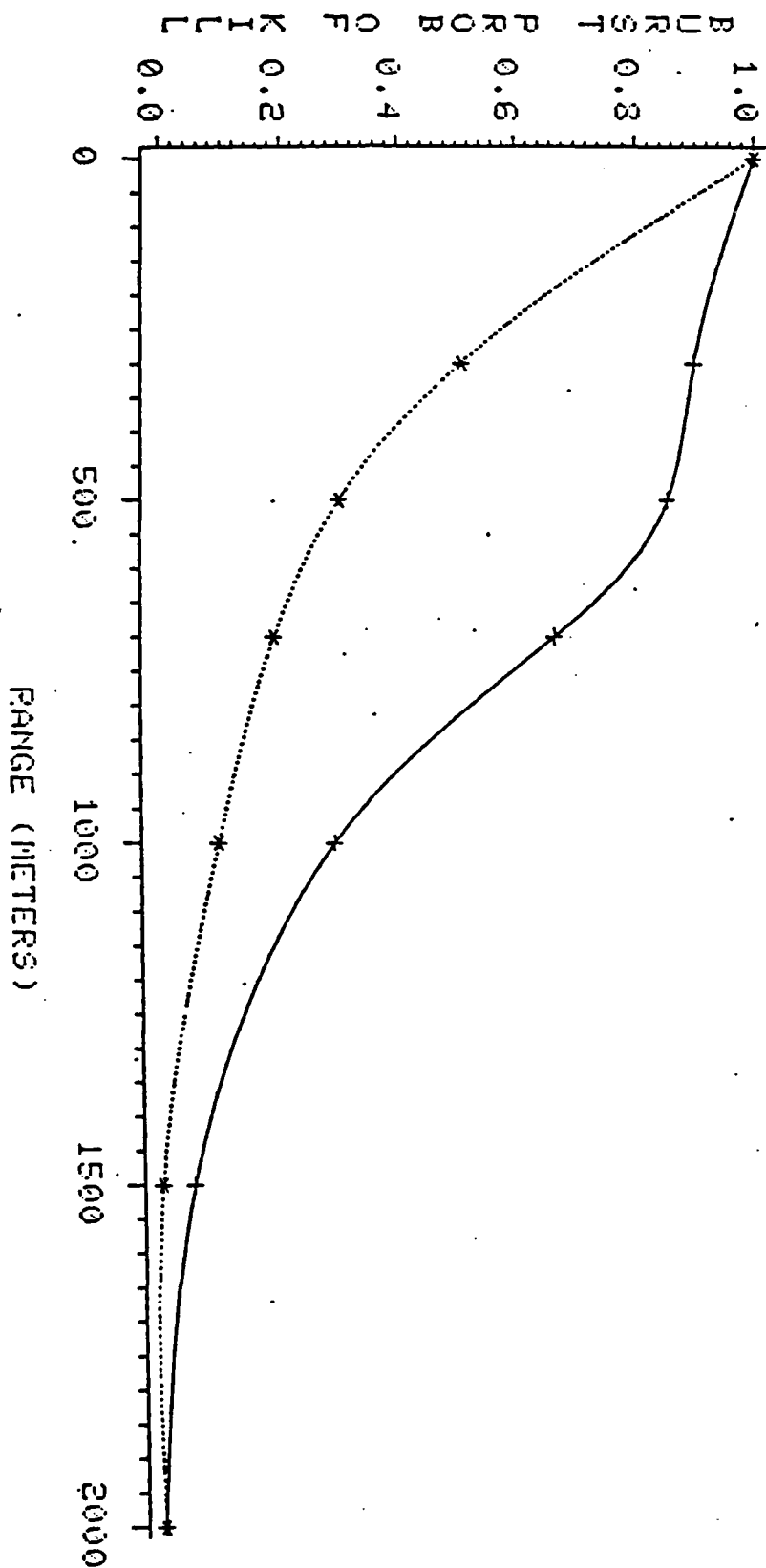
APACHE FIRE CONTROL EQUATIONS COMPARISON

Figure 3

EFFECT OF FIRE CONTROL ON PROBABILITY OF KILL AH-1S COBRA

- + - ATTA FIRE CONTROL (7-STATE TRACKER, QUADRATIC PREDICTOR)
- * - EXISTING FIRE CONTROL (4-STATE TRACKER, LINEAR PREDICTOR)

BURST SIZE IS 20 ROUNDS



TARGET IN 1 G TURN AND DIVE AT 100 KNOTS
ATTACKER IN CONSTANT 100 KNOT TAIL CHASE

COBRA FIRE CONTROL EQUATIONS COMPARISON

Figure 4

three components of both velocity and acceleration in the sight-line coordinate system) together with the time-of-flight (TOF) of the bullet in the following format:

$$\text{PREDICTED TARGET RANGE} = \text{RANGE} + (\text{TOF})(\text{VELOCITY}) + (\text{TOF})^2 (\text{ACCELERATION})$$

A linear model was programmed, similar to those used in the current filters described above, to study the effect of the prediction method on probability of hit using the ATA equations. The algorithm uses the same format as the quadratic model, but leaves off the acceleration term, as follows:

$$\text{PREDICTED TARGET RANGE} = \text{RANGE} + (\text{TOF})(\text{VELOCITY})$$

As can be expected, the quadratic predictor does much better in the high "g" turning and jinking maneuvers, while in the more benign scenarios, where there are little accelerations, the linear algorithm provides an almost equal estimate because the acceleration term has been dropped.

E. Another deficiency in the original version centered on running the model through one iteration instead of several. This was an unreasonable approach given the amount of randomness in the model. Several runs were made using different random number generator seeds, resulting in wide variations in number of hits per burst and associated kill probability. Therefore, coding was added so that any number of runs could be made at one time with appropriate statistics computed, such as average hits and probability of kill per burst, as well as standard deviations. The model now runs 20 iterations, since standard deviations for most scenarios tend to settle in this time frame, but it can easily be changed. Minor modifications were made to the main program at the beginning of the simulation loop to rewind files for output purposes and to

run to 20 iterations with a new random number generator seed. Subroutine AVG, called at the end of the main program after the appropriate data had been accumulated, computes and outputs the statistics (Figure 5).

F. The model now has the ability to access a Tektronix, Inc. graphics package called PLOT-10, resident on AVSOCM's IBM mainframe computer. The user has the option to run the graphics program, which plots several charts that display Kalman filter performance. The three graphs (also done by TSC for their final report) show magnitude of range, velocity and acceleration errors and standard deviations over the 12 second engagement. They can be used to study how accurate the filter's estimates are, settling time of those estimates and effects of sensor input rates and accuracies on the estimates. The FORTRAN PLOT-10 program, PLOT FORTRAN, is called by the master executive file after the main program is done and has output the variables to be plotted to a separate data file (Figure 6).

G. Finally, many more engagement input files have been created to study key fire control system parameters. These engagements include everything from both ownship and target hovering (to baseline the new filters programmed into the model), to both aircraft maneuvering. Most of the engagements were developed for LHX purposes to examine the requirements of hit and kill stated in the LHX airframe request for proposals (RFP) for the turreted gun system. Also, runs were made to study the trade-offs between using 20MM or 30MM cannons in ATA combat, the main trade being between aerodynamic qualities of the round (which translates into time-of-flight) and lethality of it on the target. Several of the engagements are now contained in LHX specifications for modelling by the two contractor teams to validate their fire control system performance abilities.

```

C *****
C
C NO. 14
C
C THIS SUBROUTINE COMPUTES THE AVERAGE, STANDARD DEVIATION AND
C UPPER AND LOWER BOUNDS OF THE NUMBER OF HITS AND CUMULATIVE
C PROBABILITY OF KILL FOR THE TWO BURSTS AFTER 20 REPLICATIONS.
C *****
      SUBROUTINE AVG(NENGAG,KBUL30)
      REAL KILL1(20),KILL2(20),LOWER(4)
      COMMON /MONCAR/ HITS1(20),KILL1,HITS2(20),KILL2
      DIMENSION SUMM(4),SUMSQ(4),XBAR(4),SQSUM(4),VAR(4),SDEV(4),
      +         UPPER(4)
      TEE = 2.093
      SAMPLE = 20.
      DO 10 K = 1,4
      SUMM(K) = 0.0
      SUMSQ(K) = 0.0
      XBAR(K) = 0.0
      SQSUM(K) = 0.0
      VAR(K) = 0.0
      SDEV(K) = 0.0
      UPPER(K) = 0.0
      LOWER(K) = 0.0
10  CONTINUE
      DO 20 I=1,20
      SUMM(1) = SUMM(1) + HITS1(I)
      SUMM(2) = SUMM(2) + KILL1(I)
      SUMM(3) = SUMM(3) + HITS2(I)
      SUMM(4) = SUMM(4) + KILL2(I)
      SUMSQ(1) = SUMSQ(1) + HITS1(I)*HITS1(I)
      SUMSQ(2) = SUMSQ(2) + KILL1(I)*KILL1(I)
      SUMSQ(3) = SUMSQ(3) + HITS2(I)*HITS2(I)
      SUMSQ(4) = SUMSQ(4) + KILL2(I)*KILL2(I)
20  CONTINUE
      DO 30 J=1,4
      XBAR(J) = SUMM(J)/SAMPLE
      SQSUM(J) = SUMM(J)*SUMM(J)
      VAR(J) = (1./(SAMPLE*(SAMPLE-1)))*(SAMPLE*SUMSQ(J)-SQSUM(J))
      SDEV(J) = SQRT(VAR(J))
      UPPER(J) = XBAR(J) + (TEE*SDEV(J)/SQRT(SAMPLE))
      LOWER(J) = XBAR(J) - (TEE*SDEV(J)/SQRT(SAMPLE))
30  CONTINUE
      WRITE(8,100) NENGAG
100 FORMAT(/3X,'ENGAGEMENT NUMBER',I4,/)
      IF (KBUL30.EQ. 0) THEN
        WRITE(8,200)
200  FORMAT(3X,'BULLET USED IS 20MM HEI'//)
      ELSEIF (KBUL30.EQ. 2) THEN
        WRITE(8,300)
300  FORMAT(3X,'BULLET USED IS 20MM PIE'//)
      ELSEIF (KBUL30.EQ. 1) THEN
        WRITE(8,400)
400  FORMAT(3X,'BULLET USED IS 30MM HEDP'//)
      ENDIF
      WRITE(8,500)
500  FORMAT(/3X,'STATISTICS AFTER 20 REPLICATIONS :'/
      + 15X,'AVERAGE',10X,'BOUNDS FOR 95 %',23X,'BOUNDS FOR 95 %'/
      + 17X,'HITS',9X,'CONFIDENCE INTERVAL',4X,'PROBABILITY',4X,
      + 'CONFIDENCE INTERVAL'/
      + 13X,'(STAND. DEV.)',6X,'LOWER',5X,'UPPER',8X,'OF KILL',8X,
      + 'LOWER',5X,'UPPER'/
      + 13X,'_____',6X,'_____',5X,'_____',8X,'_____',8X,
      + '_____',5X,'_____'//)
      WRITE(8,600) XBAR(1),LOWER(1),UPPER(1),XBAR(2),LOWER(2),UPPER(2),
      + SDEV(1),XBAR(3),LOWER(3),UPPER(3),XBAR(4),LOWER(4),UPPER(4),
      + SDEV(3)
600  FORMAT(1X,'BURST 1',9X,F5.2,10X,F5.2,5X,F5.2,9X,F4.3,10X,F4.3,6X,
      + F4.3,/16X,'(,F5.2,)',//
      + 1X,'BURST 2',9X,F5.2,10X,F5.2,5X,F5.2,9X,F4.3,10X,F4.3,6X,F4.3,/
      + 16X,'(,F5.2,)'//)
      RETURN
      END

```

```

TEM14610
TEM14620
TEM14630
TEM14640
TEM14650
TEM14660
TEM14670
TEM14680
TEM14690
TEM14700
TEM14710
TEM14720
TEM14730
TEM14740
TEM14750
TEM14760
TEM14770
TEM14780
TEM14790
TEM14800
TEM14810
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TEM15150
TEM15160
TEM15170
TEM15180
TEM15190
TEM15200
TEM15210
TEM15220
TEM15230
TEM15240
TEM15250
TEM15260
TEM15270
TEM15280
TEM15290
TEM15300
TEM15310
TEM15320
TEM15330
TEM15340
TEM15350

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SUBROUTINE "AVG"
Figure 5

DIMENSION RNGERR(50), RNGSD(50), VELERR(50), VELSD(50), ACCERR(50),	PL000010
+ ACCSD(50), XDATA(14)	PL000020
DATA XDATA/13.,0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12./	PL000030
RNGERR(1)=13.	PL000040
RNGSD(1)=13.	PL000050
VELERR(1)=13.	PL000060
VELSD(1)=13.	PL000070
ACCERR(1)=13.	PL000080
ACCSD(1)=13.	PL000090
REWIND 10	PL000100
DO 2 I=2,14	PL000110
READ (10,1) RNGERR(I), RNGSD(I)	PL000120
READ (10,1) VELERR(I), VELSD(I)	PL000130
READ (10,1) ACCERR(I), ACCSD(I)	PL000140
1 FORMAT (2F10.5)	PL000150
2 CONTINUE	PL000160
CALL INITT(120)	PL000170
BMIN=-6.000000	PL000180
BMAX=6.000000	PL000190
CALL BINITT	PL000200
CALL DLIMY(BMIN,BMAX)	PL000210
CALL LINE(0)	PL000220
CALL CHECK(XDATA,RNGERR)	PL000230
CALL DISPLAY(XDATA,RNGERR)	PL000240
CALL LINE(1)	PL000250
CALL CPLOT(XDATA,RNGSD)	PL000260
CALL MOVABS(400,750)	PL000270
CALL AOUTST(29,'KALMAN FILTER CHARACTERISTICS')	PL000280
CALL MOVABS(400,735)	PL000290
CALL AOUTST(29,' RANGE ')	PL000300
CALL MOVABS(400,720)	PL000310
CALL AOUTST(29,' ENGAGEMENT NUMBER ')	PL000320
CALL MOVABS(485,35)	PL000330
CALL AOUTST(10,'TIME (SEC)')	PL000340
CALL MOVABS(20,410)	PL000350
CALL AOUTST(6,'METERS')	PL000360
CALL MOVABS(650,65)	PL000370
CALL AOUTST(15,' MAGNITUDE OF')	PL000380
CALL MOVABS(650,52)	PL000390
CALL AOUTST(15,' RANGE ERROR')	PL000400
CALL DSHABS(800,52,0)	PL000410
CALL MOVABS(650,26)	PL000420
CALL AOUTST(15,' MAGNITUDE OF')	PL000430
CALL MOVABS(650,13)	PL000440
CALL AOUTST(15,'RANGE STD. DEV.')	PL000450
CALL DSHABS(800,13,1)	PL000460
CALL TINPUT(ICHAR)	PL000470
BMIN=0.000000	PL000480
BMAX=50.000000	PL000490
CALL BINITT	PL000500
CALL NEWPAG	PL000510
CALL DLIMY(BMIN,BMAX)	PL000520
CALL LINE(0)	PL000530
CALL CHECK(XDATA,VELERR)	PL000540
CALL DISPLAY(XDATA,VELERR)	PL000550

PLOT FORTRAN PROGRAM

Figure 6

CALL LINE(1)	PL000560
CALL CPLOT(XDATA,VELSD)	PL000570
CALL MOVABS(400,750)	PL000580
CALL AOUTST(29,'KALMAN FILTER CHARACTERISTICS')	PL000590
CALL MOVABS(400,735)	PL000600
CALL AOUTST(29,' VELOCITY ')	PL000610
CALL MOVABS(400,720)	PL000620
CALL AOUTST(29,' ENGAGEMENT NUMBER ')	PL000630
CALL MOVABS(485,35)	PL000640
CALL AOUTST(10,'TIME (SEC)')	PL000650
CALL MOVABS(1,410)	PL000660
CALL AOUTST(12,'METERS / SEC')	PL000670
CALL MOVABS(650,65)	PL000680
CALL AOUTST(18,' MAGNITUDE OF')	PL000690
CALL MOVABS(650,52)	PL000700
CALL AOUTST(18,' VELOCITY ERROR')	PL000710
CALL DSHABS(800,52,0)	PL000720
CALL MOVABS(650,26)	PL000730
CALL AOUTST(18,' MAGNITUDE OF')	PL000740
CALL MOVABS(650,13)	PL000750
CALL AOUTST(18,'VELOCITY STD. DEV.')	PL000760
CALL DSHABS(800,13,1)	PL000770
CALL TINPUT(ICHAR)	PL000780
BMIN=0.00000	PL000790
BMAX=40.00000	PL000800
CALL BINITT	PL000810
CALL NEWPAG	PL000820
CALL DLIMY(BMIN,BMAX)	PL000830
CALL LINE(0)	PL000840
CALL CHECK(XDATA,ACCERR)	PL000850
CALL DSHABS(XDATA,ACCERR)	PL000860
CALL LINE(1)	PL000870
CALL CPLOT(XDATA,ACCSO)	PL000880
CALL MOVABS(400,750)	PL000890
CALL AOUTST(29,'KALMAN FILTER CHARACTERISTICS')	PL000900
CALL MOVABS(400,735)	PL000910
CALL AOUTST(29,' ACCELERATION ')	PL000920
CALL MOVABS(400,720)	PL000930
CALL AOUTST(29,' ENGAGEMENT NUMBER ')	PL000940
CALL MOVABS(485,35)	PL000950
CALL AOUTST(10,'TIME (SEC)')	PL000960
CALL MOVABS(1,410)	PL000970
CALL AOUTST(10,'METERS/SEC')	PL000980
CALL MOVABS(80,415)	PL000990
CALL AOUTST(1,'2')	PL001000
CALL MOVABS(650,65)	PL001010
CALL AOUTST(22,' MAGNITUDE OF')	PL001020
CALL MOVABS(650,52)	PL001030
CALL AOUTST(22,' ACCELERATION ERROR')	PL001040
CALL DSHABS(850,52,0)	PL001050
CALL MOVABS(650,26)	PL001060
CALL AOUTST(22,' MAGNITUDE OF')	PL001070
CALL MOVABS(650,13)	PL001080
CALL AOUTST(22,'ACCELERATION STD. DEV.')	PL001090
CALL DSHABS(850,13,1)	PL001100
CALL TINPUT(ICHAR)	PL001110
CALL FINITT(0,700)	PL001120
STOP	PL001130
END	PL001140

Figure 6 (Continued)

IV. FUTURE MODIFICATIONS

A. Several changes are still planned to be made to the model. TSC has completed the addition of 2.75 inch Hydra 70 flechette warhead rockets to the simulation. Due to the size and run time of the flyout model for the rockets, the number of iterations used currently will have to be reduced to save computer time. Also, not all necessary lethality data from field testing has been generated by BRL and AMSAA at this writing, which limits the end-game analysis.

B. The addition of a dueling module, so that the target aircraft can return fire at the attacker, has been discussed as another modification. Methodology similar to AMSAA's Helicopter Air-to-Air Combat Simulation (HATACS) could be adopted for usage in TSC's model.

C. The ability for the model to access actual flight test data has already been discussed and is being looked at by both ARDEC and AVSCOM. This capability would be helpful during flight testing of the ATA equations in the COBRA testbed to exploit as a potential debugging tool, while concurrently validating the model. Also, flight paths from the Air-to-Air Combat Tests I-IV (AACT) at Paxtuxent River sponsored by AATD could be modelled.

D. Several minor modifications have also been planned. These include adding other filters to study in ATA combat. Error budgets are currently being performed for the COBRA and APACHE gun systems, allowing for validation of the numbers used to represent sensor measurement errors in the model. The turret module needs to be upgraded to increase accuracy of actual turret movement and firing. Finally, addition of new sensors, such as a millimeter-wave

radar, closed-loop fire control system radar or muzzle velocity sensor can be accomplished with appropriate error inputs.

CONCLUSIONS

The TSC AIRTOAIR model is beginning to become a widely accepted tool, by both contractor and government analysts, for studying cannon/rocket effectiveness in ATA combat. It is hoped that this report will allow all users of the model to make any of these upgrades they feel as necessary. Also, maintaining a constant version of the model would be favorable, with all users providing documentation of changes made for the widest dissemination as possible.

REFERENCES

1. Breaux, Harold J., A Methodology for the Development of Fire Control Equations for Guns and Rockets Fired from Aircraft, USA BRL Interim Memorandum Report No. 827, October 1984.
2. TSC, Attack Helicopter Air-to-Air Fire Control System Simulation, Final Report (Part 1 - Technical) submitted to the USA ARDEC under contract No. DAAK10-82-C-0055, August 1983.

LIST OF ABBREVIATIONS, ACRONYMS & SYMBOLS

PIE	Pyrotechnically initiated explosive
ATA	Air-to-air
TSC	Teledyne Systems Company
USAAVSCOM	U.S. Army Aviation Systems Command
AATD	Aviation Applied Technology Directorate
ARDEC	Armament Research, Development and Engineering Center
FCC	Fire Control Computer
BRL	Ballistics Research Laboratory
DOF	Degree-of-freedom
LHX	Light Helicopter Family
HEDP	High explosive, dual purpose
AMSAA	Army Materiel Systems Analysis Activity
HARS	Heading Attitude Reference System
TOF	Time-of-flight
RFP	Request for proposals
HATACS	Helicopter Air-to-Air Combat Simulation
AACT	Air-to-Air Combat Tests

END

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