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GENERIC SURFACE-TO-AIR MISSILE MODEL.(U)

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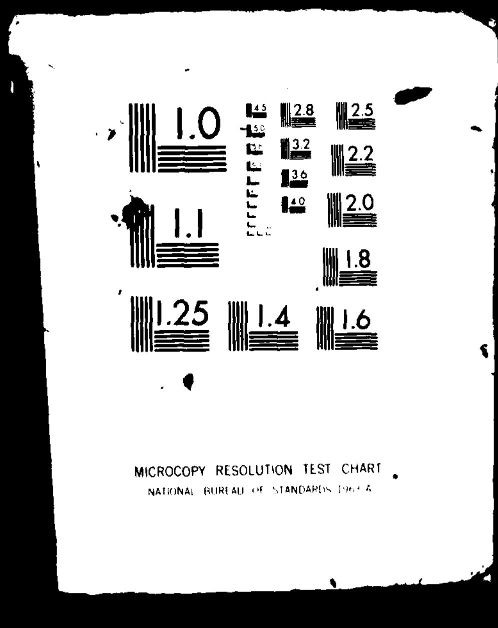

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A. T. KEARNEY, INC.
CAYWOOD-SCHILLER DIVISION
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CHICAGO, ILLINOIS 60606

GENERIC SURFACE-TO-AIR MISSILE MODEL

OCTOBER 1979

FINAL TECHNICAL REPORT
N62269-78-C-0235

PREPARED FOR:

NAVAL AIR DEVELOPMENT CENTER
WARMINSTER, PENNSYLVANIA 18974

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

This report describes the Generic Surface-to-Air Missile Model (GENSAM) which evaluates the outcome of an engagement between a surface-to-air missile system and an attacking aircraft. The model treats a large variety of SAMs from the initial encounter through target intercept. The attacker flies a pre-set flight path but may deviate from this in order to execute an evasive maneuver. It may also employ several types of electronic counter-measures.

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1. INTRODUCTION

1.1 Introduction and Background

The Generic Surface-to-Air Missile Model (GENSAM) is a computer-based model developed to help evaluate air-to-surface systems by simulating performance of aircraft systems and surface-to-air weapons in combat. This volume presents the model structure, assumptions, and details so that the interested analyst can understand and assess the model results. GENSAM is the result of the continuing study of surface-to-air combat by the Caywood-Schiller Division, A. T. Kearney, Inc., and the JTCG/AS. The study included a review of requirements and existing capability. A summary of that portion of the study is included in the JTCG publication ______________________________.

1.2 Model Characteristics

The GENSAM model provides a basis for the evaluation of surface-to-air missile launching opportunities, subsequent missile fly-out performance and missile intercept conditions under realistic encounter conditions. In order to accomplish this, it is necessary to simulate aircraft-missile system encounters in the most realistic manner that is consistent with the requirements for simple inputs and short running time.

1.2.1 Model Structure

The model simulates the entire engagement of an aircraft by a surface-to-air missile system. Aircraft inputs include performance capabilities and limitations for propulsion, aerodynamic, pilot and electronic systems as well as certain passive characteristics such as signature data. Missile system inputs include radar, missile, launch, propulsion, aerodynamic, guidance and lethality data.

An incoming attacker initially flies a pre-planned flight path. At some point it may detect SAM systems emission and commence avoidance and evasive measures (ECM, maneuver, decoy launch). The SAM system detects, tracks, launches missiles and attempts to intercept the target aircraft. If the aircraft deviates from its flight plan, it will attempt to return to it.

The output lists significant events in the engagement sequence such as enter radar coverage, detection, initiation of countermeasures, track, launch, intercept, etc.

1.2.2 Multi-Aircraft

Realistic evaluation of surface-to-air combat requires consideration of an environment in which more than one aircraft are engaged. The GENSAM simulation model has provisions for multi-aircraft combat.

1.2.3 Dynamic Tactics

The philosophy underlying the tactical routines of GENSAM is that of instantaneous decision, based upon current posture vis-a-vis the SAM. At any time, the posture of each attacker is determined with respect to each SAM, and this information, plus knowledge of his partner's (if any) posture, determines his action.

No "canned" maneuvers are used; action consists of a desired velocity vector rate of change (or equivalent control deflection). Subsequently, the same or a new action may be directed.

2. ORGANIZATION OF GENSAM MODEL

The purpose of this section is to indicate how major submodels of GENSAM are related to each other and to indicate major inputs and outputs of each submodel. Figure 2-1 displays the overall structure. Starting with initial conditions, consisting of the initial ranges, relative headings and altitudes of the attackers, the model treats the ensuing engagement by considering the dynamics of the aircraft and missile systems.

The major submodels are discussed in the subsections below.

2.1 Read Inputs and Initialize Runsets

The subroutines in this logical block are concerned primarily with loading the aircraft performance tables, signature data, flight plan, tactical decision tables and other control variables; and SAM system radar, launching missile and warhead/fuze performance data necessary for a computer run.

Aircraft and missile thrust, fuel consumption and drag coefficients as a function of altitude, mach number and lift coefficient are required. Target signature data for either radar or infrared systems is needed. Likewise, aircraft system emitter and sensor data is needed. This is in the form of azimuth and elevation limits in aircraft body coordinates and average gain factors.

Target flight plan data is in the form of checkpoints,

FIGURE 2-1

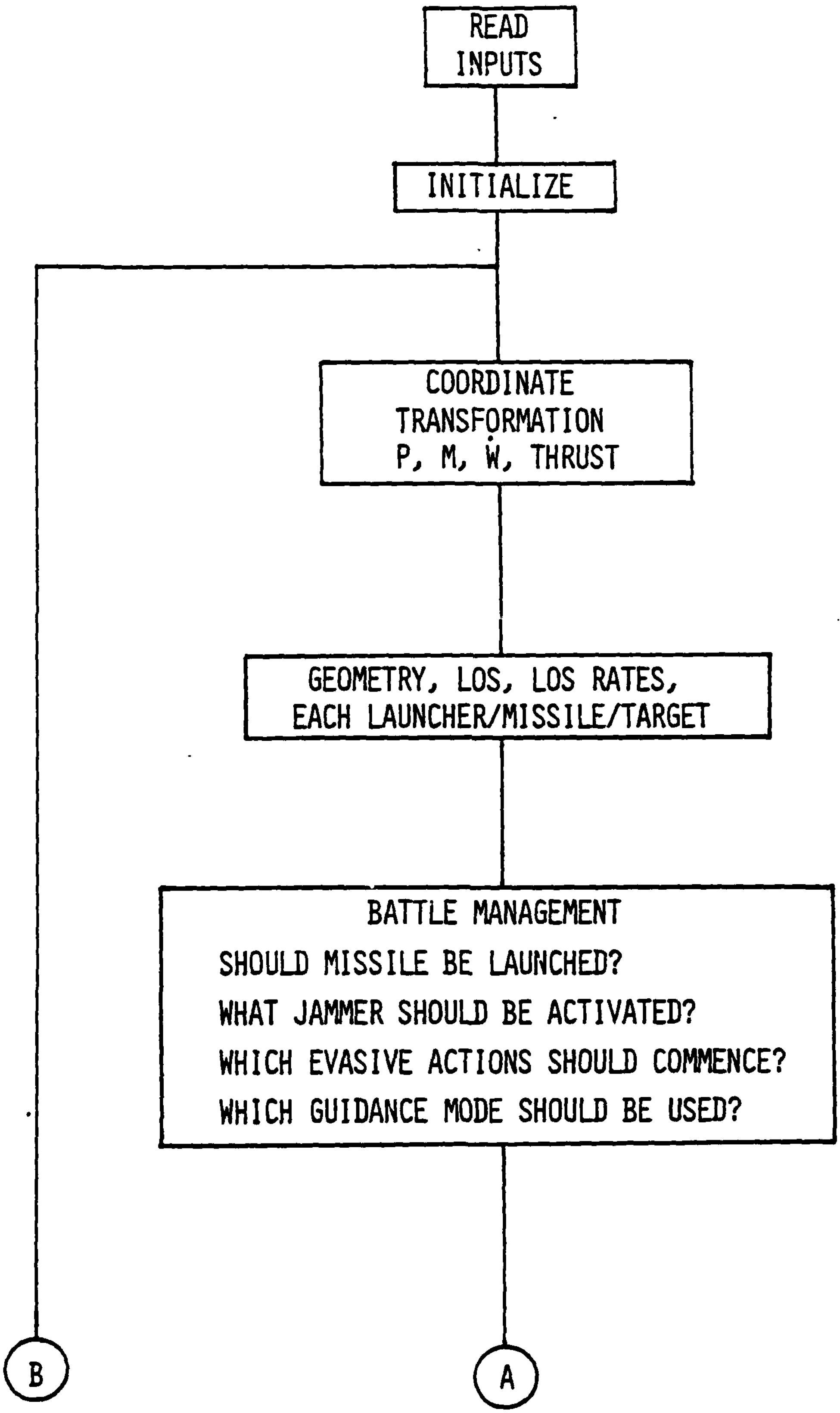
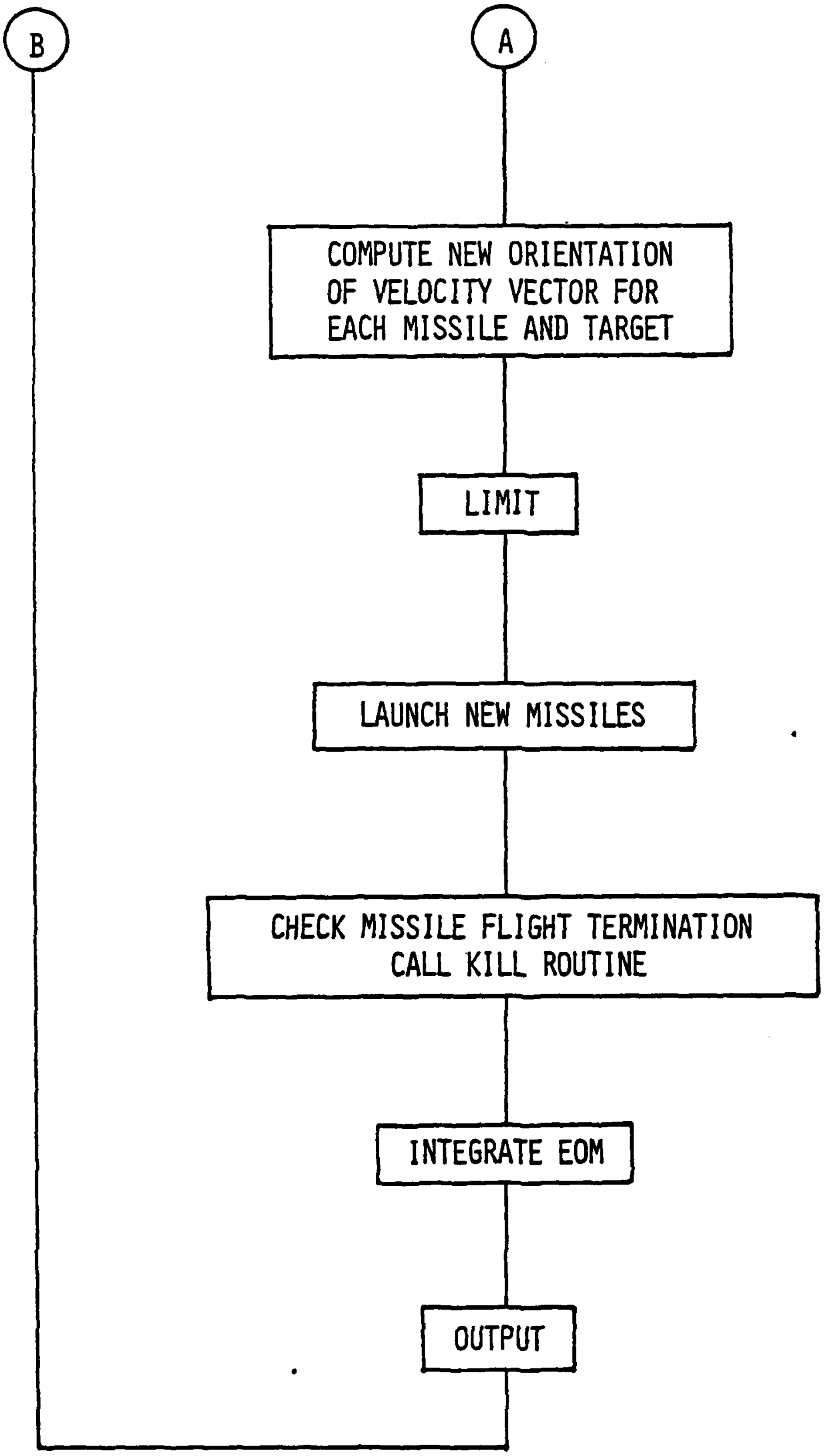

READ INPUTS
INITIALIZE
COORDINATE TRANSFORMATION P, M, Ẇ, THRUST
GEOMETRY, LOS, LOS RATES, EACH LAUNCHER/MISSILE/TARGET
BATTLE MANAGEMENT
SHOULD MISSILE BE LAUNCHED?
WHAT JAMMER SHOULD BE ACTIVATED?
WHICH EVASIVE ACTIONS SHOULD COMMENCE?
WHICH GUIDANCE MODE SHOULD BE USED?
B
A

FIGURE 2-1 (CONT'D)



headings and speeds. The program pieces together the overall flight profile taking into account performance limits.

SAM system sensor performance boundaries and capabilities are also required for search, tracking and missile borne systems.

These inputs include maximum azimuth, elevation, range and ceiling limits in ground or body coordinate systems and average gain factors. Other systems limitations must also be specified. These include delay times (detect, search to track, launch), minimum times (track, flyout), launch limitations (LOS rates, slewing rates), maximum range, maximum and minimum elevation angles, maximum and minimum range rates.

Similar missile seeker data must be provided: seeker angular limits, maximum range, maximum and minimum range rates, and LOS limits.

Likewise, the conditions for executing and the types of evasive maneuvers must be specified. Activating conditions include track initiation, missile launch detection and missile detection. Appropriate reactive measures include maneuver, activation of ECM and dispensing expendables.

Other parameters specified in Initialize Runset are the ranges and increments of the mask angle (minimum system elevation) and acquisition delay time. These two parameters can be systematically varied in a runset in order to test the sensitivity. An average value over runs using these parameters is also obtained.

A set of initial aircraft conditions (e.g., offset and heading) may also be specified.

2.2 Initialize Run

The purpose of this logical element is to initialize aircraft heading, speed, weight and altitude, and SAM system time delay and masking conditions. As many runs may be combined in a runset as desired provided they differ only with respect to the aforementioned variables.

2.3 Information and Relative Geometry

The routines in this logical block perform three principal functions; coordinate transformation, line-of-sight computations and information assessment. There are three necessary (or at least convenient) coordinate systems used in GENSAM, i.e., an inertial system, a relative wind system, and a body axis system. At any time, and for each aircraft and missile, several sets of direction cosines are computed permitting parameter values to be conveniently transformed from one coordinate systems to another. Range and range rates, line-of-sight angles and angular rates are computed for each radar/missile/aircraft pair, and in several coordinate systems, for use in the routines concerned with information states and tactical maneuvers.

2.3.1 Information States

These subroutines are concerned primarily with matching the line-of-sight data developed above with the limitating geometric sensor patterns (inputs) to determine the information states of each radar, missile and aircraft with respect to all others. Active and passive sensors are considered.

Additionally, the time for which this information state has been uninterrupted is stored for later use.

2.3.2 Other Information

Other information is needed to carry out the simulation. This includes such data as air pressure and density as a function of altitude, aircraft and missile weight changes as a function of time and aircraft and missile thrust profiles.

The subroutines comprising this block compute, for each missile and aircraft in the duel, all the necessary parameters that are a function of missile or aircraft altitude, velocity and weight, only. These parameters include air density, speed of sound, maximum thrust and fuel consumption. The first two of these are determined from ARDC standard day Model Atmosphere functions; the latter two are arrived at by interpolation from aircraft performance tables.

2.4 Battle Management

This set of subroutines in concerned with threat detection, initiation of measures and countermeasures, missile launch, and the like. On the part of the penetrator, the following items are treated:

- Hostile Surveillance Radar Detection
- Initiation of Surveillance Radar Jamming

- Hostile Track Radar Detection
- Initiation of Track Radar Jamming
- Hostile Missile Launch
- Launch of Expendables
- Initiation of Evasive Maneuvers

On the part of the SAM systems, the following items are considered:

- Detection of Hostile Aircraft
- Assignment of Tracking Radar
- Radar Tracking
- Launcher Assignment
- Launch Limits
- Launch
- Guidance Mode Assignment

2.4.1 Tactics

In this logical block the information which has been computed about performance capability, relative position, and information states is utilized, together with tactical parameters which have been read as data, to determine the desired evasive maneuvers. Each aircraft compares his position and information status with a set of input parameters which determine his posture vis-a-vis the SAM at the present instant. For each posture, there exists a maneuver routine that is performed until the next evaluation is made.

The only purpose of the above mentioned maneuver routine is to determine the rates of change of the desired direction and magnitude of the velocity vector.

2.4.2 Capabilities of Missiles, Aircraft and Pilot (Limit)

Three types of gee limitations are considered in order to determine the maximum gees allowed at the given altitude and velocity. These three are the maximum gees sustainable by the pilot, the maximum gees sustainable by the structure, and the maximum gees sustainable due to aerodynamic limitations.

The parameters computed by these subroutines represent theoretical capabilities of the aircraft. The current maneuver states or attitude is not a factor in their computation. However, they are used in conjunction with tactical routines to contain maneuvers within the performance envelopes available to aircraft and/or pilots.

2.5 Launch New Missiles

When an attacker is assigned a launcher, the following steps may occur:

1. Launch Delay
2. Launch Slewing Rate Check, in Azimuth and Elevation.
3. Launch Acquisition Check (S/N exceeds critical value, or if jamming compute J/S).
4. Select Guidance Mode.
5. Possible Intercept Check.
6. Launch Abort.
7. Missile Abort.

8. Subsequent Launch Delay (Ripple Fire Mode).

9. Subsequent Launch Delay (Shoot-Look-Shoot Mode).

2.6 Terminal Encounter

2.6.1 Termination of Flight

Missile flight will be terminated if any of the following conditions prevail:

1. Missile range exceeds maximum range.
2. Missile altitude falls below a critical value.
3. Missile time-of-flight exceeds maximum time-of-flight.
4. Missile velocity falls below a critical value.

2.6.2 Guidance Termination

Guidance will terminate and the missile will continue along a straight line flight path if:

1. The missile-aircraft range falls below a critical value.
2. Signal Strength (J + S) exceeds a critical value.

2.6.3 Kill Probability

Three options are available for kill probability calculations:

1. On-Line. An estimate of PK will be made based on CEP and lethal radius inputs and J/S ratio at intercept.
2. Sub-routine. A non-Monte Carlo endgame subroutine using CEP, vulnerable area and fuzing inputs will be incorporated into the program.

3. Off-Line. The program will generate inputs for a standard Monte-Carlo simulation of endgame effects.

2.7 Integration

The subroutines in this block perform a number of functions associated with the iteration process of digital simulation. First, the desired velocity vector rate changes are limited to values commensurate with the capacity values discussed in Section 2.4, and compromises performed where necessary. Second, the individual aircraft orientation and engine control setting are determined that will permit the required velocity vector changes. Finally, those positions, velocities and angular measurements whose updated values require determination from rate computations are updated. In general, linear integration is used, with special attention to orientation-free treatment of angles.

3. DETAILS OF THE GENERIC SAM MODEL

This section contains a more detailed treatment of certain aspects of the GENSAM model.

3.1 Coordinate Transformations

3.1.1 Coordinate Systems

As a prerequisite to this discussion, two coordinate systems must be defined. An inertial coordinate system (X_I,Y_I,Z_I) is established with its origin at an arbitrary point on the ground, the positive Z_I axis pointing vertically upwards, and the X_I and Y_I axes in the horizontal plane, positive in such directions as to form a right-handed orthogonal coordinate system as shown in Figure 3-1. A second coordinate system (X_W,Y_W,Z_W) is established moving with the aircraft with its origin at the center of gravity of the aircraft. The positive X_W axis is in the direction of the aircraft velocity vector. The Y_W axis is in the horizontal plane and is positive to the left of the positive X_W axis. The positive Z_W axis is defined so as to form a right-handed orthogonal coordinate system. This coordinate system, based on the aircraft velocity vector, is known as the relative wind system.

The X_W axis is made to coincide with the aircraft velocity vector by rotating a vector parallel to X_I through angle (β) necessary to align it with the ground trace of the velocity vector, and then up through the angle (γ) to the velocity vector (Figure 3-2). These rotations (sometimes called course and climb) leave the Y_W axis in the horizontal plane, where it is

FIGURE 3-1

THE INERTIAL COORDINATE SYSTEM

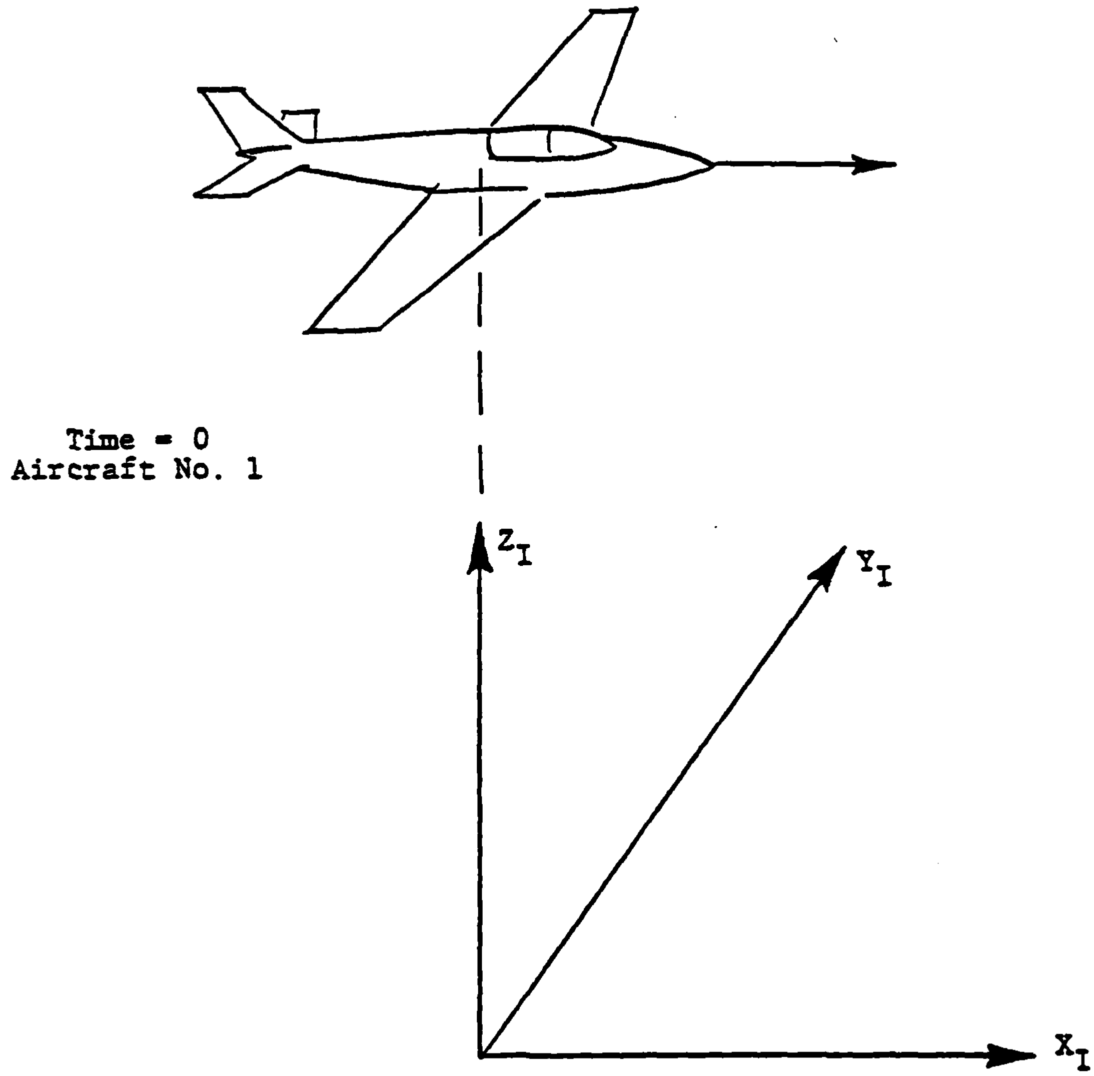
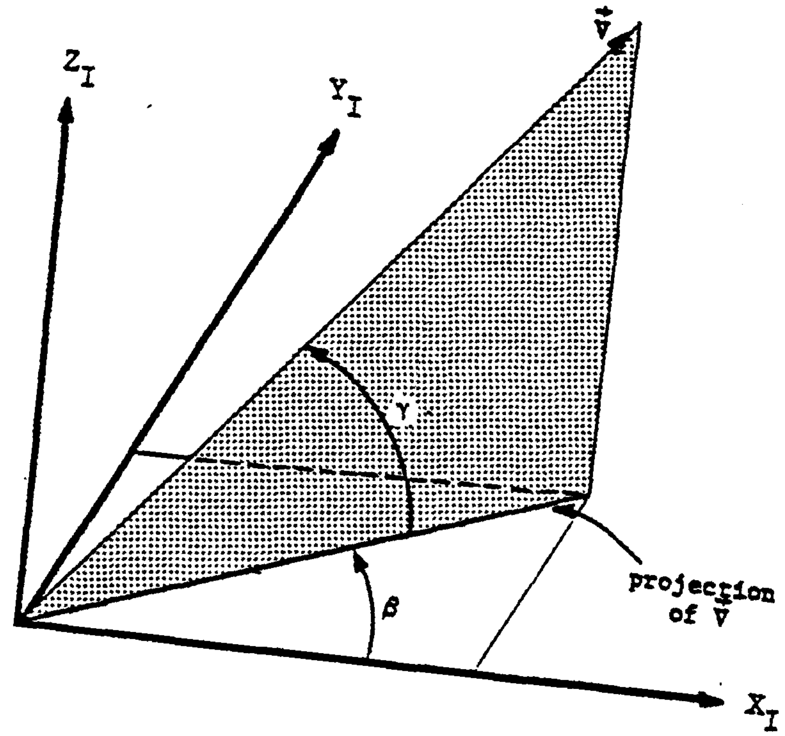


FIGURE 3-2

AZIMUTH AND ELEVATION OF THE VELOCITY VECTOR



referred to as the local axis.

Certain measurement will be referred to an aircraft or missile body axis without respect to its orientation. Therefore, a body system (X_B, Y_B, Z_B) is established by rolling an aircraft about the velocity vector by an angle (μ) and then pitching about the wing line by an angle (α). μ and α meet the classic definition of bank angle and attack angle (Figure 3-3) and are set to values of zero in INITA.

3.1.2 Coordinate Transformations

Measurement of various forces and other vectors are conventionally associated with each type of coordinate system. A convenient way of describing the orientation of one coordinate system with respect to another is to tabulate the direction cosines of the angles between unit vectors on each axis with all 3 axes of the other system. This 3 by 3 table is called a transformation matrix.

The relation between Inertial and Wind axes is achieved by rotation through Beta and Gamma. In matrix notation:

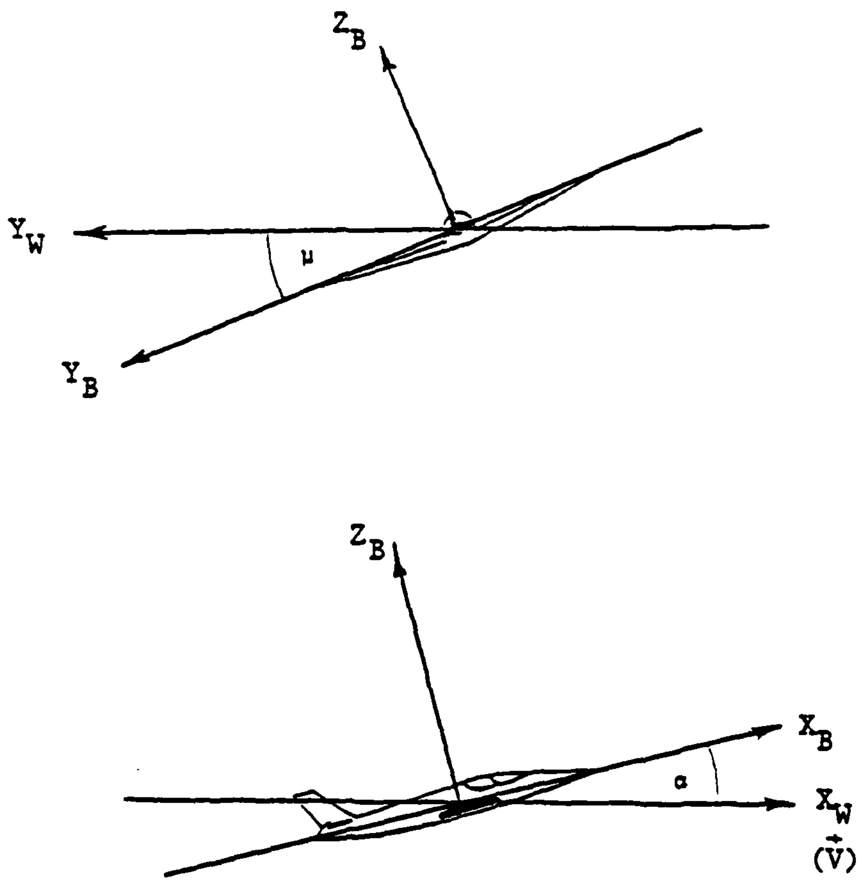
$$\begin{pmatrix} X_I \\ Y_I \\ Z_I \end{pmatrix} = \begin{pmatrix} TBG \end{pmatrix} \begin{pmatrix} X_W \\ Y_W \\ Z_W \end{pmatrix},$$

where,

$$\begin{pmatrix} TBG \end{pmatrix} = \begin{pmatrix} TBG_1 & TBG_2 & TBG_3 \\ TBG_4 & TBG_5 & TBG_6 \\ TBG_7 & TBG_8 & TBG_9 \end{pmatrix} = \begin{pmatrix} \cos\beta\cdot\cos\gamma & -\sin\beta & -\cos\beta\cdot\sin\gamma \\ \sin\beta\cdot\cos\gamma & \cos\beta & -\sin\beta\cdot\sin\gamma \\ \sin\gamma & 0 & \cos\gamma \end{pmatrix}$$

FIGURE 3-3

THE BODY COORDINATE SYSTEM



Transformation between Body and Wind axes requires rotation through attack angle, Alpha and roll angle, Mu.

$$\begin{pmatrix} X_W \\ Y_W \\ Z_W \end{pmatrix} = \begin{pmatrix} TMA \end{pmatrix} \begin{pmatrix} X_B \\ Y_B \\ Z_B \end{pmatrix},$$

where,

$$\begin{pmatrix} TMA \end{pmatrix} = \begin{pmatrix} TMA_1 & TMA_2 & TMA_3 \\ TMA_4 & TMA_5 & TMA_6 \\ TMA_7 & TMA_8 & TMA_9 \end{pmatrix} = \begin{pmatrix} \cos\alpha & 0 & -\sin\alpha \\ \sin\alpha \cdot \sin\mu & \cos\mu & \cos\alpha \cdot \sin\mu \\ \sin\alpha \cdot \cos\mu & -\sin\mu & \cos\alpha \cdot \cos\mu \end{pmatrix}$$

And finally, transformation from inertial to body coordinates requires

$$\begin{pmatrix} X_I \\ Y_I \\ Z_I \end{pmatrix} = \begin{pmatrix} TMX \end{pmatrix} \begin{pmatrix} X_B \\ Y_B \\ Z_B \end{pmatrix}$$

where,

$$\begin{pmatrix} TMX \end{pmatrix} = \begin{pmatrix} TMX_1 & TMX_2 & TMX_3 \\ TMX_4 & TMX_5 & TMX_6 \\ TMX_7 & TMX_8 & TMX_9 \end{pmatrix} = \begin{pmatrix} TBG \end{pmatrix} \begin{pmatrix} TMA \end{pmatrix}$$

All of the 27 matrix elements are computed for each aircraft at the start of every iteration, and are used in several subsequent routines.

3.1.3 Functions of Altitude, Velocity and Weight

This subroutine computes all necessary parameters and performance capabilities that are a function of altitude (Z), velocity (V) and weight only.

First, atmospheric parameters are computed based upon an ARDC atmosphere model, yielding:

air density $$\rho(Z) = \begin{cases} A\cdot(1-B\cdot Z)^C, & Z<\bar{Z} \\ D\, e^{-E\cdot(Z-\bar{Z})}, & Z\geq\bar{Z} \end{cases}$$

speed of sound $$a(Z) = \begin{cases} F\sqrt{G-H\cdot Z}\,, & Z<\bar{Z} \\ 968.4652\,, & Z\geq\bar{Z} \end{cases}$$

A = .0023769199
B = .000006875347
C = 4.256155
D = .00070612811
E = .0000480634
F = 49.040772
G = 518.688
H = .00356616
$\bar{Z}$ = 36089.

The following parameters are then determined for each aircraft:

mach number $M = V/a$

dynamic pressure $Q = \frac{\rho}{2}\cdot V^2$

$$U = \frac{\rho}{2}\cdot a^2\cdot \text{Area/Weight}$$

The maximum lateral acceleration characteristics of each combatant aircraft are now determined from the computed mach number, air density and the maximum lift coefficient which was read in as a function of mach number in tabular form. By means of the subroutine VSOLVE, values for stall velocity (V_{st}), and corner velocity (V_{cn}) are determined, as illustrated graphically in Figure 3 - 4 Provision is made in the subroutine for the case where the maximum structural gee line (η_{str}) is higher than the aerodynamically limited gee curve (η_{max}), which may occur at very high altitude.

The potential engine capacity is next obtained by double entry look-up (velocity, altitude) into the engine performance tables, utilizing the utility subroutine, VALUE1, and obtaining the following parameters:

TH_{AB} = Thrust, maximum afterburner

TH_{MP} = Thrust, military power

FC_{AB} = Fuel consumption, maximum afterburner

$TH_{AB,CV}$ = Thrust, maximum afterburner, at corner velocity.

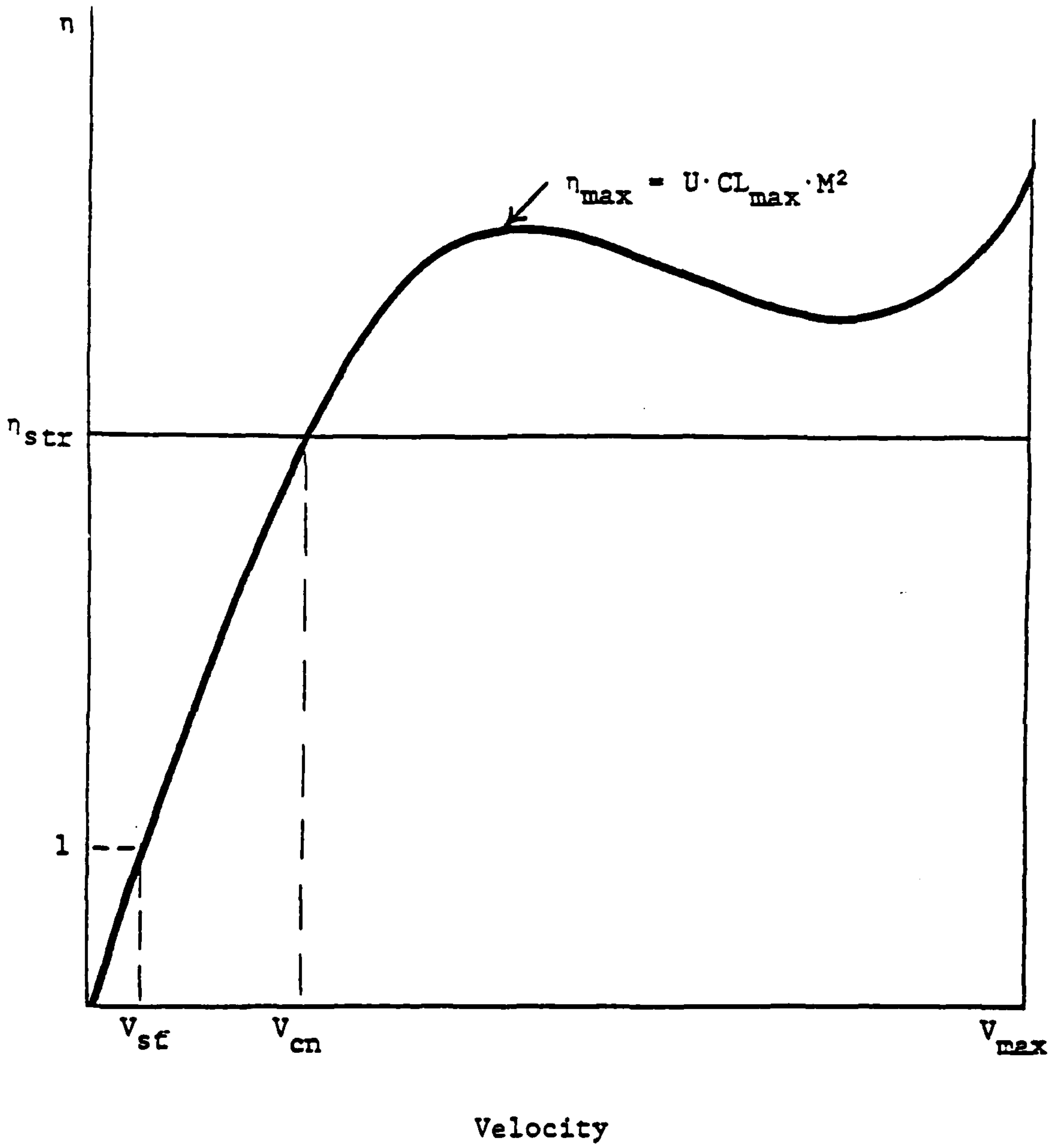
CL_{max} is then determined by single entry look-up. Finally, the subroutine PERFORM computes a radius of turn (RT) by the formula:

$$RT = V^2/(g \cdot \eta_{max})$$

and so uses this to enter limit climb (γ_{HI}) and dive (γ_{LO}) angles so as to keep the aircraft above the ground and below the combat ceiling (H_{max}).

FIGURE 3-4

LOAD FACTOR CURVE



3.1.4 Thrust

Values of full afterburner thrust and military power thrust along with cooresponding fuel consumption values, as a function of missile or aircraft mach number and altitude are updated.

This subroutine also returns values of corner velocity and stall velocity as a function of aircraft altitude, weight and structural gee limit. This subroutine requires the sources of subroutine VSOLVE in performing this function.

Double Interpolation Technicue. Given a variable (thrust, fuel consumption, etc.) that is tabulated as a function of two arguments (e.g., altitude, velocity), a value for this variable at any set of entries within the limits of the table is determined by double interpolation. This is shown pictorially below (see Figure 3-5) and the procedure is as follows. (Thrust, altitude and mach numbers are used as an example.)

1) Determine the tabular argument above and below (HARG(KN) and HARG(KH+1)) the desired altitude (Z).

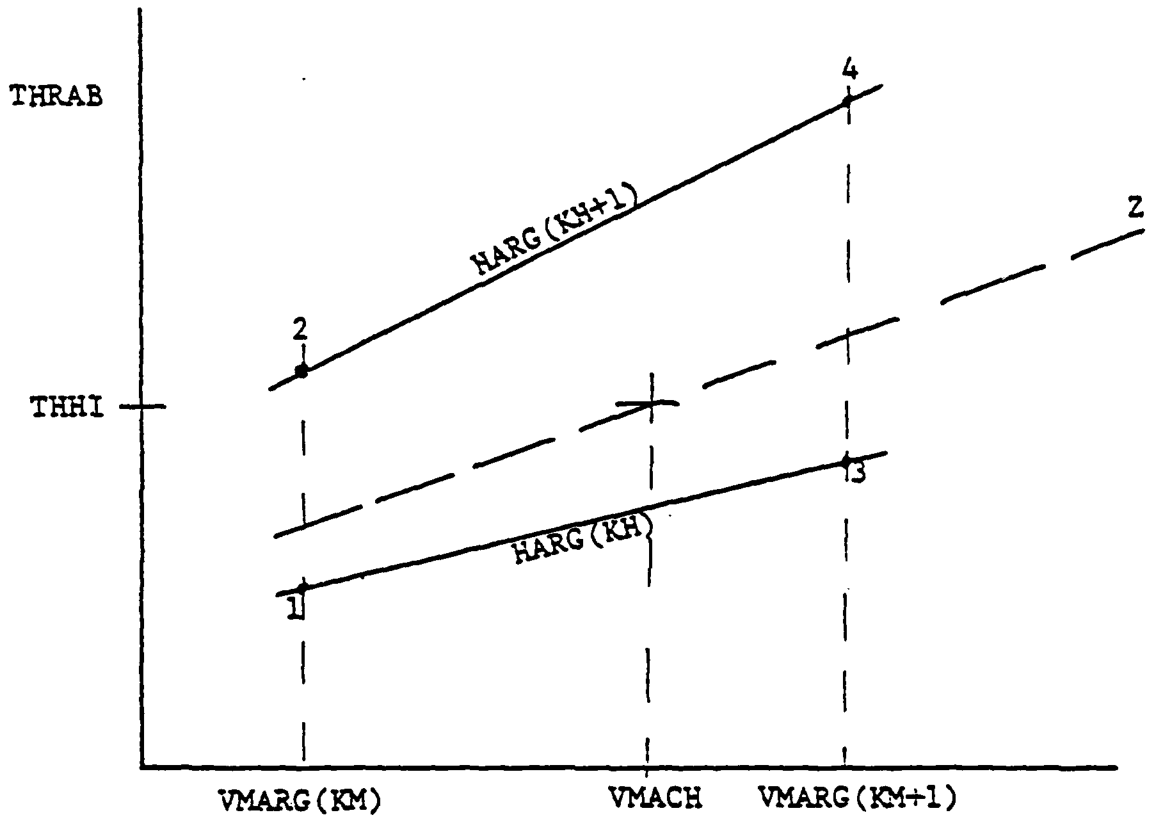
2) Determine the tabular arguments above and below (VMARG(KM) and VMARG(KM+1)) the desired mach number (VMACH).

3) Read out the four tabular entries bracketing the desired value, i.e.,

THRAB(KH,KM)	at Point 1
THRAB(KH+1,KM)	2
THRAB(KH,KM+1)	3
THRAB(KH+1,KM+1)	4

FIGURE 3-5

DIAGRAM - VALUE1



DOUBLE LINEAR INTERPOLATION

4) Then SS = (VMACH=VMARG(KM)/VMARG(KM+1)-VMARG(KM))
TT = (Z-HARG(KH)/(HARG(KH+1)-HARG(KH))
UU = 1-TT
E1 = UU x THRAB(KH,KM)+TT x THRAB(KH+1,KM)
F1 = UU x THRAB(KH,KM+1)+TT x THRAB(KH+1,KM+1)
THHI = E1 + SS x (F1-E1)

5) Since SS, TT, UU are functions of the arguments only, they can be used again with new values of E and F to find fuel consumption, military power thrust, etc. Note that in the program, additional indices to identify aircraft (i) and aircraft type (KT) are used, but they are omitted here for clarity.

The same value of SS and TT can be used for interpolation of the single argument tables (Max Lift Coefficient as a function of Mach number, and Max Mach number as a function of Weight) as

CLMAX = CLTOP(KM) + SS x (CLTOP(KM+1) - CLTOP(KM))
VMAX = VMTOP(KH) + TT x (VMTOP(KH+1) - VMTOP(KH))

3.2 Information

3.2.1 LOS

The line-of-sight between a sensor and a target, or receiver and source may be defined as the vector connecting their centers of gravity, with a length denoted by R(range). In inertial coordinates, two angles representing bearing and inclination of this line are definable as azimuth (AZ) and elevation (EL). Bearing and inclination measured in body coordinates (where pilots and sensors measure quantities) are denoted as ALF and EPS.

Considering a sensor (i) and aircraft (j), components of the range in inertial coordinates may be written, with their time derivatives as

$$DX = X(j)-X(i) \qquad \dot{DX} = \dot{X}(j)-\dot{X}(i)$$
$$DY = Y(j)-Y(i) \qquad \dot{DY} = \dot{Y}(j)-\dot{Y}(i)$$
$$DZ = Z(j)-Z(i) \qquad \dot{DZ} = \dot{Z}(j)-\dot{Z}(i)$$

where the velocity vector in inertial coordinates is given by

$$\begin{pmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{pmatrix} = \begin{pmatrix} TBG \end{pmatrix} \begin{pmatrix} V \\ 0 \\ 0 \end{pmatrix} = V \begin{pmatrix} TBG_1 \\ TBG_4 \\ TBG_7 \end{pmatrix} = \begin{pmatrix} V\cdot\cos\beta\cdot\cos\gamma \\ V\cdot\sin\beta\cdot\cos\gamma \\ V\cdot\sin\gamma \end{pmatrix}$$

Thus, it can readily be seen that the vector (TBG_1, TBG_4, TBG_7) in inertial coordinates is the unit vector in the direction of the velocity vector.

With these definitions, the LCS subroutine computes the following values. Coordinate system is indicated, where applicable.

<u>Ground Range</u> $RG^2 = DX^2 + DY^2$

<u>Range</u> $R^2 = DX^2 + DY^2 + DZ^2$

<u>Ground Range Rate</u> $\dot{RG} = (DX\cdot\dot{DX} + DY\cdot\dot{DY})/RG$

<u>Range Rate</u> $\dot{R} = (DX\cdot\dot{DX} + DY\cdot\dot{DY} + DZ\cdot\dot{DZ})/R$

<u>Azimuth (inertial)</u> $\sin(AZ) = DY/RG$
$\cos(AZ) = DX/RG$

<u>Elevation (inertial)</u> $\sin(EL) = DZ/R$
$\cos(EL) = RG/R$

<u>Azimuth Rate</u> $\dot{AZ} = (DX \cdot \dot{DY} - DY \cdot \dot{DX})/RG^2$

<u>Elevation Rate</u> $\dot{EL} = (RG \cdot \dot{DZ} - \dot{RG} \cdot DZ)/R^2$

Direction cosines of the line-of-sight in inertial coordinates may be written as

$$Q_1 = \cos(AZ) \cdot \cos(EL), \text{ or } DX/R$$

$$Q_2 = \sin(AZ) \cdot \cos(EL), \text{ or } DY/R$$

$$Q_3 = \sin(EL) \quad , \text{ or } DZ/R$$

Then, the direction cosines of the LOS in body coordinates are obtained by multiplying the direction cosines in the inertial system by the transpose of the matrix (TMX). Thus

$$\begin{pmatrix} P_1 \\ P_2 \\ P_3 \end{pmatrix} = \begin{pmatrix} TMX_1 & TMX_4 & TMX_7 \\ TMX_2 & TMX_5 & TMX_8 \\ TMX_3 & TMX_6 & TMX_9 \end{pmatrix} \begin{pmatrix} Q_1 \\ Q_2 \\ Q_3 \end{pmatrix}$$

and the missile line-of-sight angles are

<u>Sensor Elevation (body)</u> $\sin(EPS) = P_3$
$\cos(EPS) = \sqrt{1-P_3^2}$

<u>Sensor Azimuth (body)</u> , $\sin(ALF) = P_2/\cos(EPS)$
$\cos(ALF) = P_1/\cos(EPS)$

Finally, the total angle between an aircraft's velocity vector and the line-of-sight vector, termed the off angle (OFF), can be computed from the scalar product of these two vectors.

<u>OFF Angle</u> $\cos(OFF) = Q_1 \cdot TBG_1 + Q_2 \cdot TBG_4 + Q_3 \cdot TBG_7$

The LOS subroutine takes proper cognizance of singularities in the trigonometric functions computed. All items above are computed for each aircraft pair in the combat, at each time pulse.

3.2.2 The Details of Information States

A single subroutine is used here to determine the state of information that exists for each SAM system concerning every enemy aircraft in the engagement.

Subroutine INFORM determines the information states that exists between SAMs and aircraft by comparing the range and the line-of-sight coordinates in the body system to the various sensor volumes which have been read in to represent the particular aircraft types concerned. Nominally, four kinds of ground sensors are considered (optical, radar search, radar tracker, IR), which are defined by one or more geometric limits.

Three types of aircraft sensors are considered: radar, launch and missile approach detectors. Their limits are also defined by geometric shapes within the limits, performance may be limited by other parameters. These sensors provide warning to the attacker so that suitable avoidance and evasion measures may be initiated.

The aircraft also have ECM transmitters, either noise ECM

(NECM) or deception ECM (DECM) which may be used against surveillance or track radars and missiles. The transmission pattern is also a function of geometric limits.

A set of codes for information state has been established as shown in Tables 3-1, 3-2 and 3-3.

3.3 Battle Management

3.3.1 Overview

The purpose of the BATTLE MANAGEMENT (BATMAN) routine is to assess the informational action status of the various participants in the engagement.

The ground participants are the surveillance radar, the track radar, the IR tracker, and the launcher. In BATMAN, initial awareness or detection times are calculated. After appropriate delays, track radars are assigned, or in the case of IR systems, tracking IR devices. After acquisition, and the passage of minimum tracking times, a launcher may be assigned, provided tracking azimuth, elevation and range rate limitations are not exceeded. A minimum launch delay is required after which launch occurs, provided seeker lock-on is established and launcher slewing rates are acceptable.

The attacker may employ radar, missile launch and missile approach sensors. When certain range, azimuth, elevation or S/N conditions apply, the attacker becomes aware of these phenomenon. Several options are available: maneuver, initiate ECM or launch expendables. These measures will affect ground or missile participants provided they fall within the assigned fields-of-view.

Missile participants may employ passive, semi-active or command guidance. Prior to launch, missiles in the passive and semi-active mode must acquire and lock-on to targets.

In the command mode, the tracking system must acquire the target. Pursuit, proportional or beam rider navigation may be employed depending on guidance type and degree of ECM being employed.

Missile fly-out and aircraft movement are treated by a separate subroutine. The endgame is also treated in a separate routine.

An overall flow chart for the BATMAN routine is shown in Figure 3-6.

Details of BATMAN are described in the following sections.

3.3.2 Ground Battle

The ground battle is concerned with the sequence of events leading from target detection through missile launch. In the GENSAM model certain events are pegged by system performance limitations, such as detection ranges under jamming conditions and the process is further limited by minimal time delays. The process may be altered when certain geometric constraints are violated such as an aircraft leaving the volumetric coverage of a radar, or an aircraft jammer gain pattern being directed away from a ground radar as the result of a maneuver.

3.3.2.1 Information/Action States

The allowable information states used in the ground battle are listed in Table 3-1.

FIGURE 3-6

BATTLE MANAGEMENT

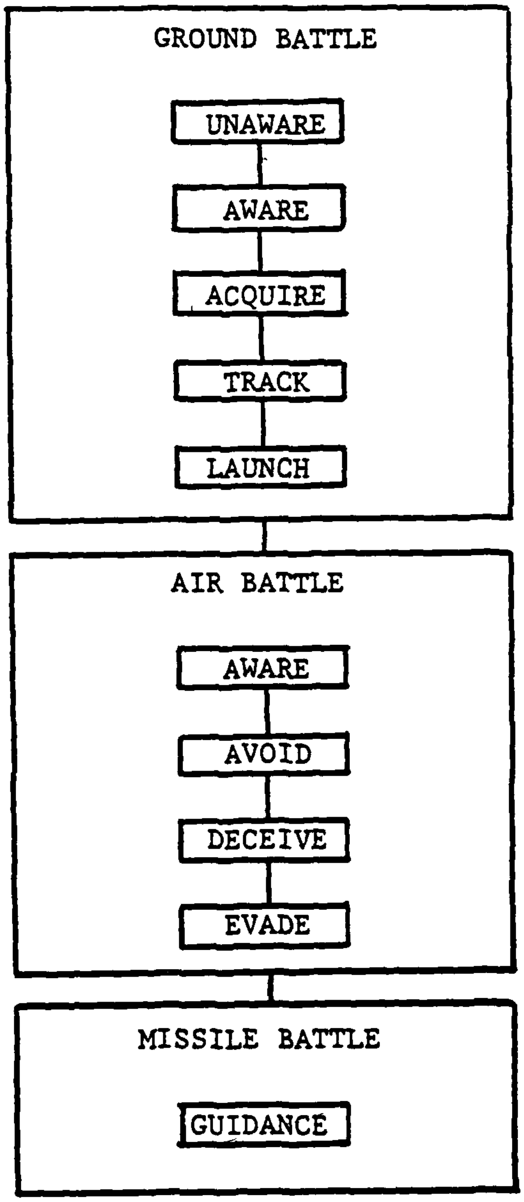


TABLE 3-1

GROUND BATTLE INFORMATION STATES

	SITUATION				
PHASE	NO ECM	NECM	DECM	IR	OPTICAL
UNAWARE	111			114	115
AWARE	121	122	123	124	125
ACQUIRE	131	132	133	134	135
TRACK	141	142	143	144	145
LAUNCH	151	152	153	154	155
LOSE	161			164	165

Unaware refers to a case where the attacker is within the volumetric coverage of a ground sensor, but beyond the performance limits against a target of its size.

Acquire refers to a target within the volumetric and performance limits and which meets certain J/S requirements.

Track refers to a situation where the target is within the volumetric, performance, S/J and range and angular rate limits of tracking systems.

Launch refers to a situation where the attacker is within specified range limits and the launcher slewing limits are not violated. Launch restriction due to seeker lock-on limits are considered later.

Lose refers to a situation where the attacker exits the performance or volumetric limits of the acquisition system.

3.3.2.2 Subroutine UNAWARE

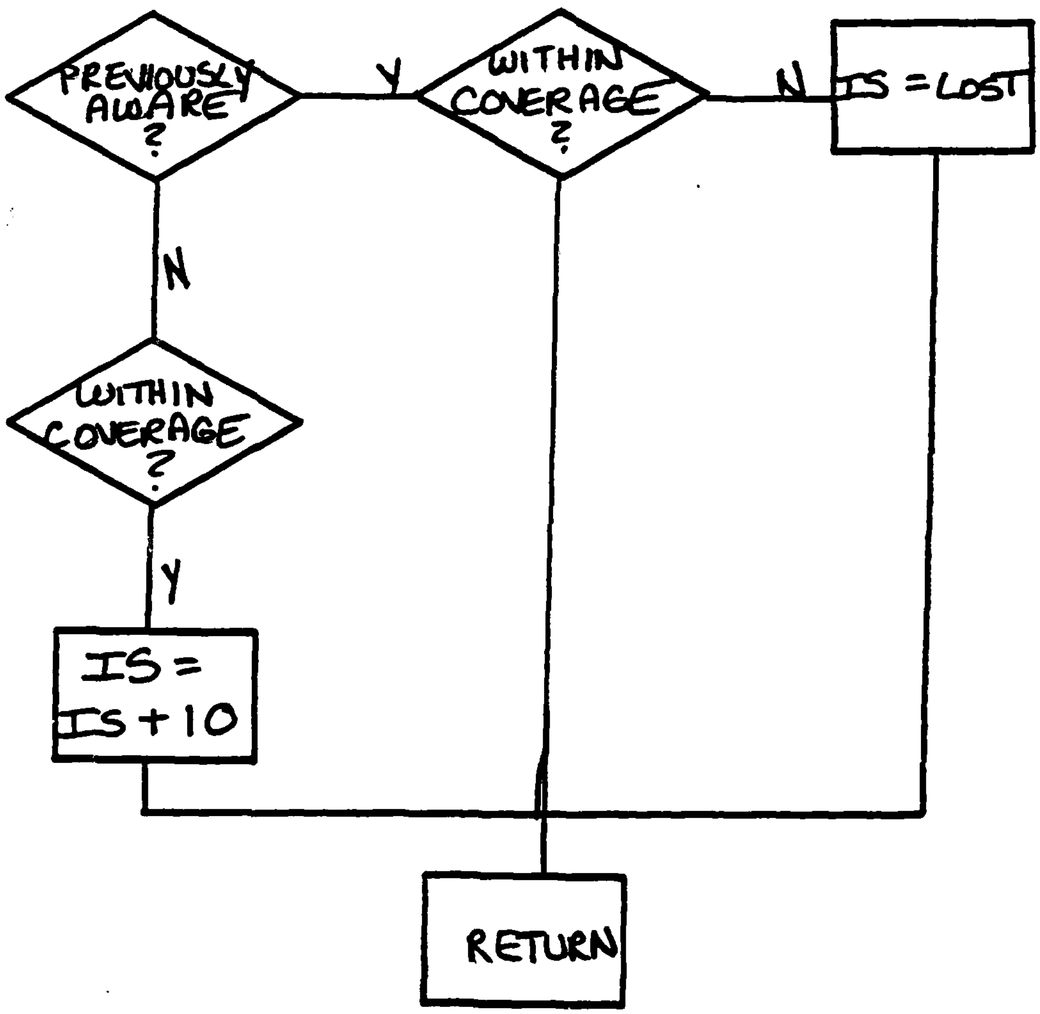
This routine determines for each attacker the change of information state resulting from entering or exiting the volumetric survellance coverage. (Figure 3-7)

3.3.2.3 Subroutine AWARE

This routine ascertains the change of information state where an attacker enters the surveillance radar performance limits, or IR surveillance system performance limit. Different sealing laws are used for the differing systems. In the case of radar RDET, the detection range is:

FIGURE 3-7

UNAWARE



$$RDET \sim R_0 \sqrt[4]{\sigma}$$

where

R_0 = Radar performance input

σ = Target radar mass section, a function of azimuth and elevation in the aircraft body coordinate system.

In the case of IR systems:

$$RDET = R_0 \sqrt[2]{S} \; f(R,T)$$

where

R_0 = IR surveillance performance parameters,

S = IR signature, a function of azimuth and elevation in target aircraft body coordinate system, and

T = Atmospheric transmisivity.

The information states change to AWARE.

The information states may also chane due to the activation of target DECM or NECM, provided the ground radar is within the defined coverage pattern of the jammers. (Figure 3-8)

3.3.2.4 Subroutine ACQUIRE

This routine assigns an acquisition delay time depending on prior acquisition status and state of ECM. (Figure 3-9)

DECM1

If DECM is employed, the delay is a ramp function depending on the J/S ratio. (Figure 3-10)

NECM1

If NECM is employed, acquisition does not occur until after radar burnthrough. (Figure 3-11)

FIGURE 3-8

AWARE

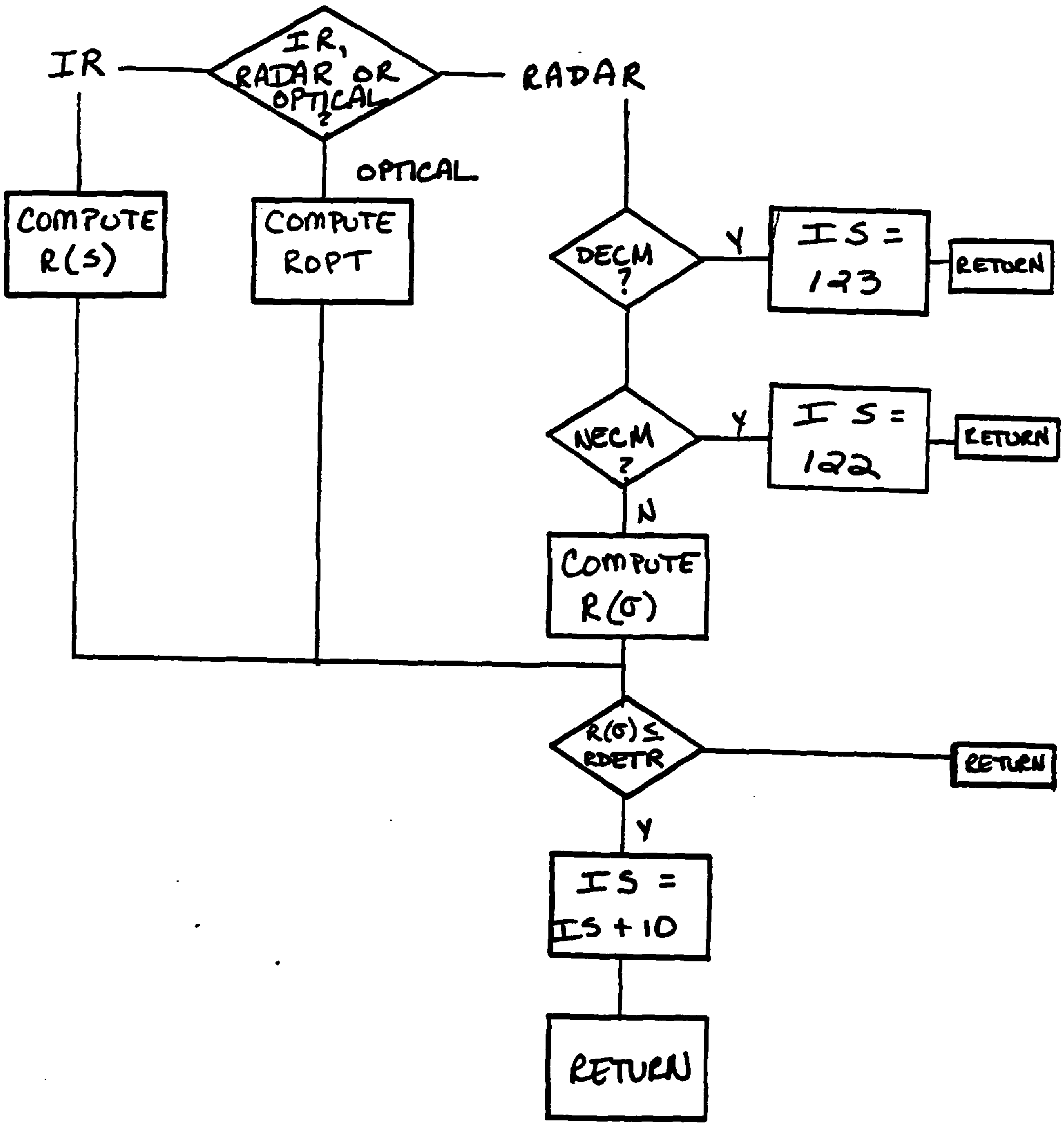


FIGURE 3-9

ACQUIRE

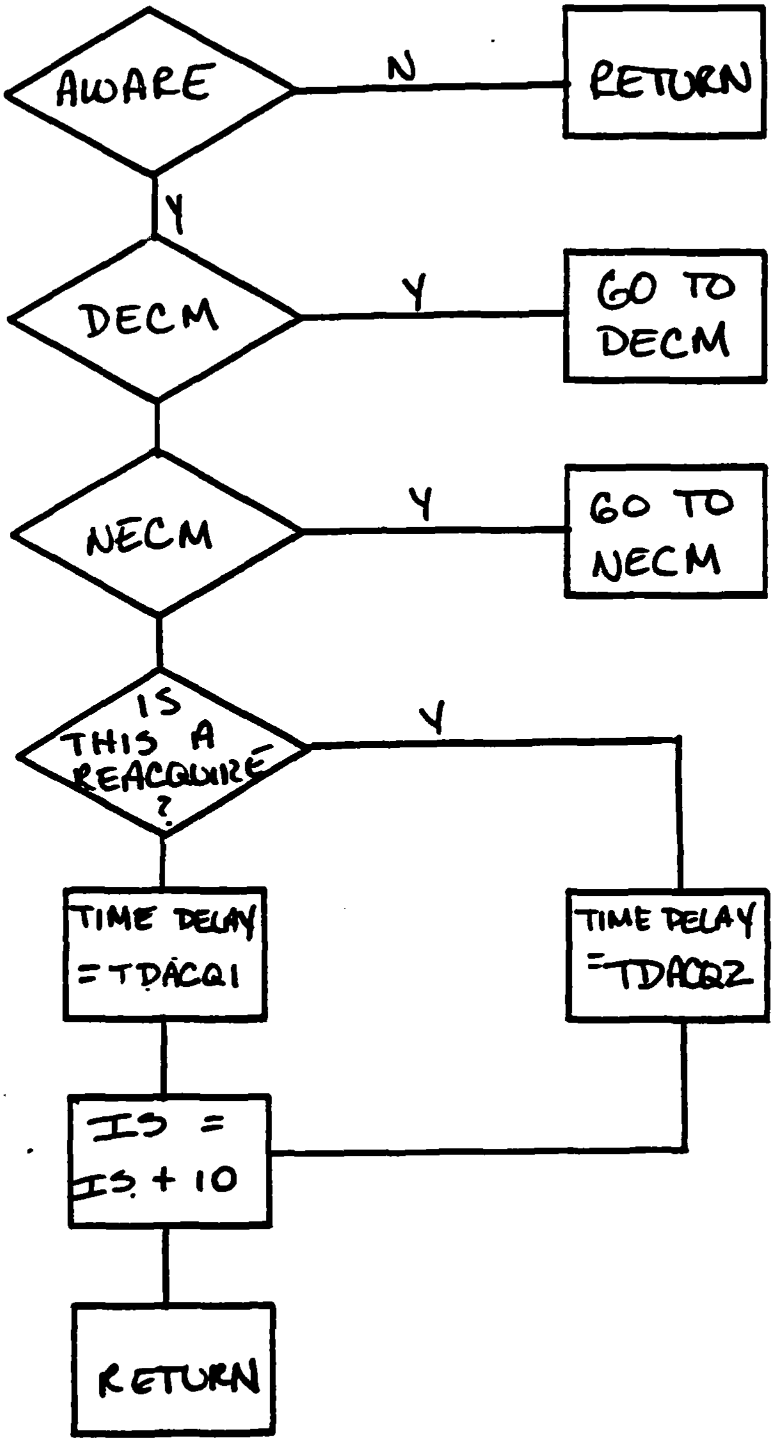


FIGURE 3-10

DECM 1

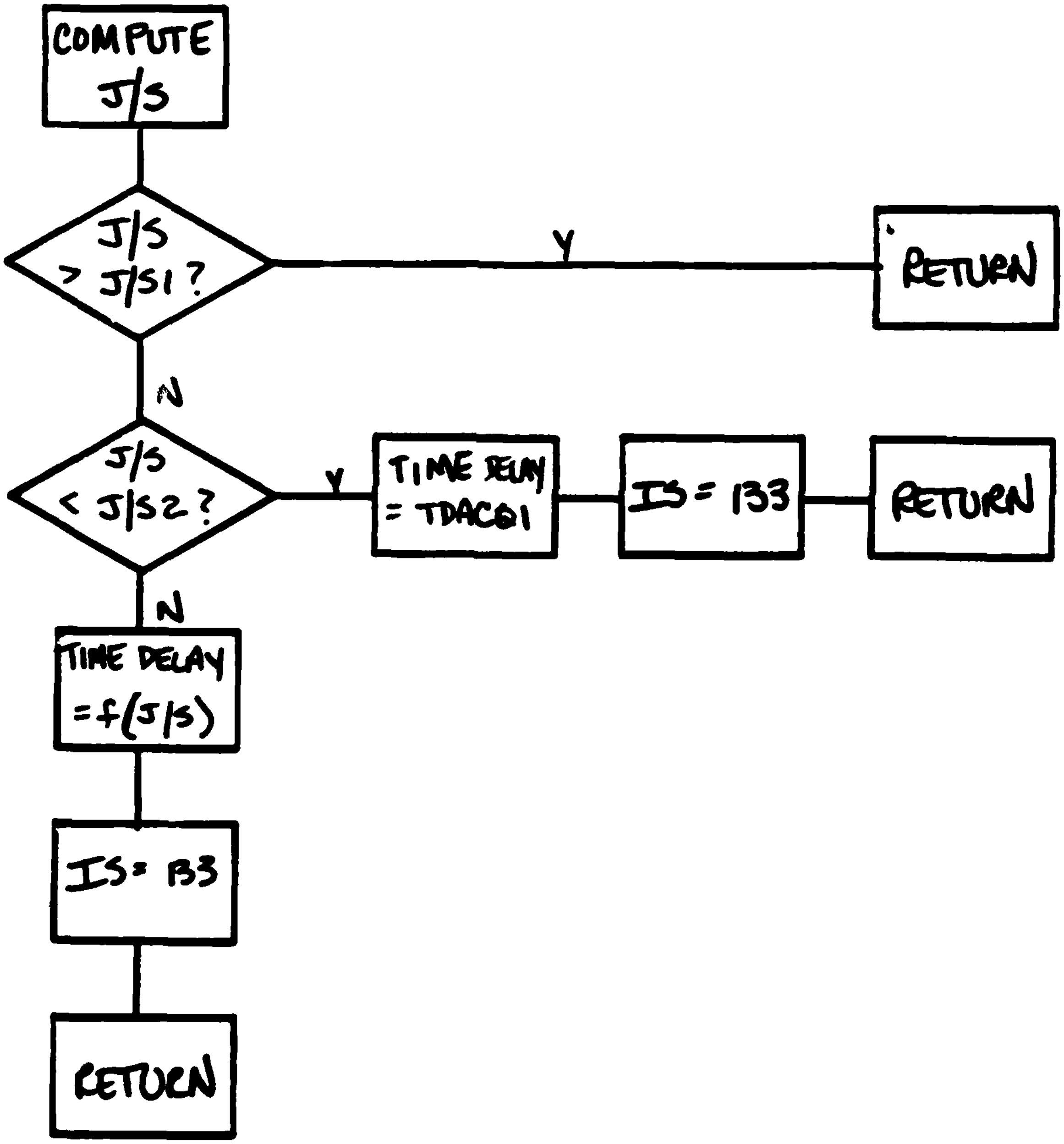
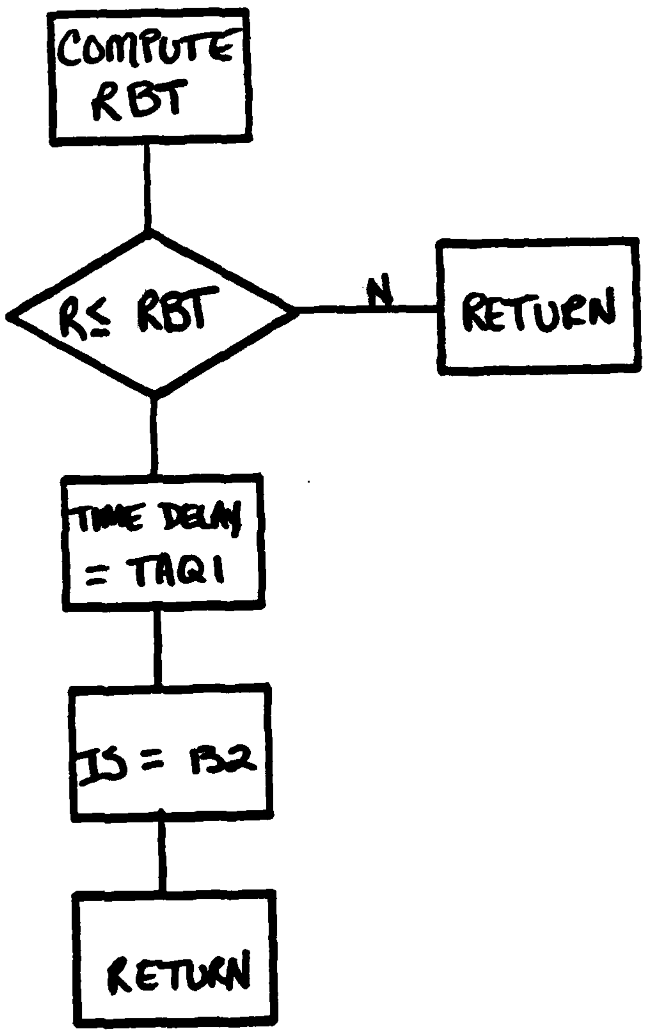


FIGURE 3-11

NECM1



3.3.2.5 Subroutine TRACK

In order for tracking to commence the attacker must be in the track radar or IR volumetric coverage and performance limits (range, range rate, angular rates). A track radar acquisition time delay is assigned. (Figure 3-12)

DECM2

If DECM is employed, track radar acquisition delays are a ramp function of the J/S ratio. (Figure 3-13)

NECM2

In the case of noise jamming of track radars, if burnthrough has occurred the time delay is the same as in a non-ECM situation.. If strobe information is the only available, a "strobe" tracking time delay may be assigned. (Figure 3-14)

3.3.2.6 Subroutine LAUNCH

Launch may occur if launcher slewing rates permit and if target range restricutions are not violated. Before launch occurs, seeker restrictions, dealt with later, must also be met. (See Figure 3-15.)

FIGURE 3-12

TRACK

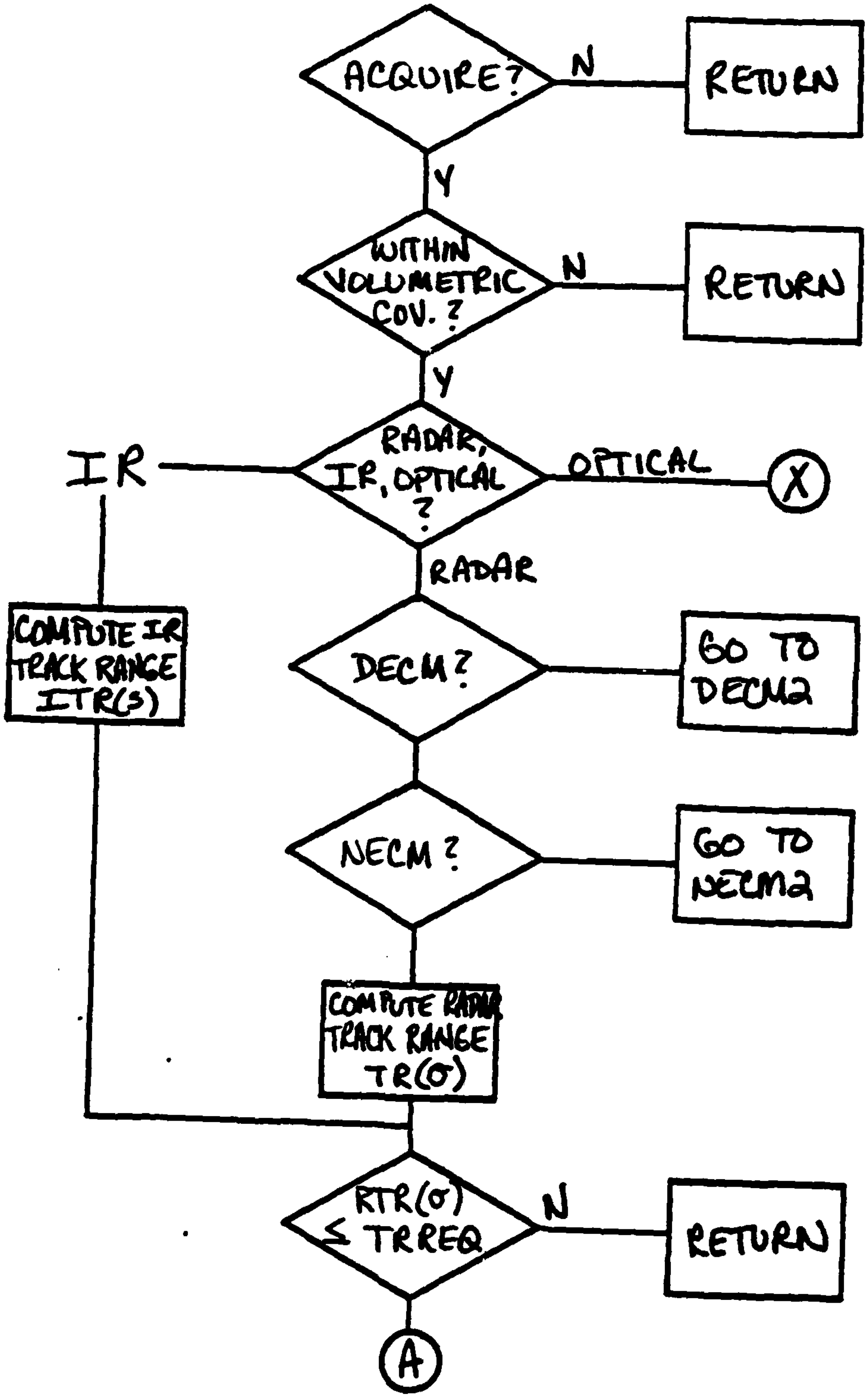


FIGURE 3-12 (CONT'D)

TRACK (CONT)

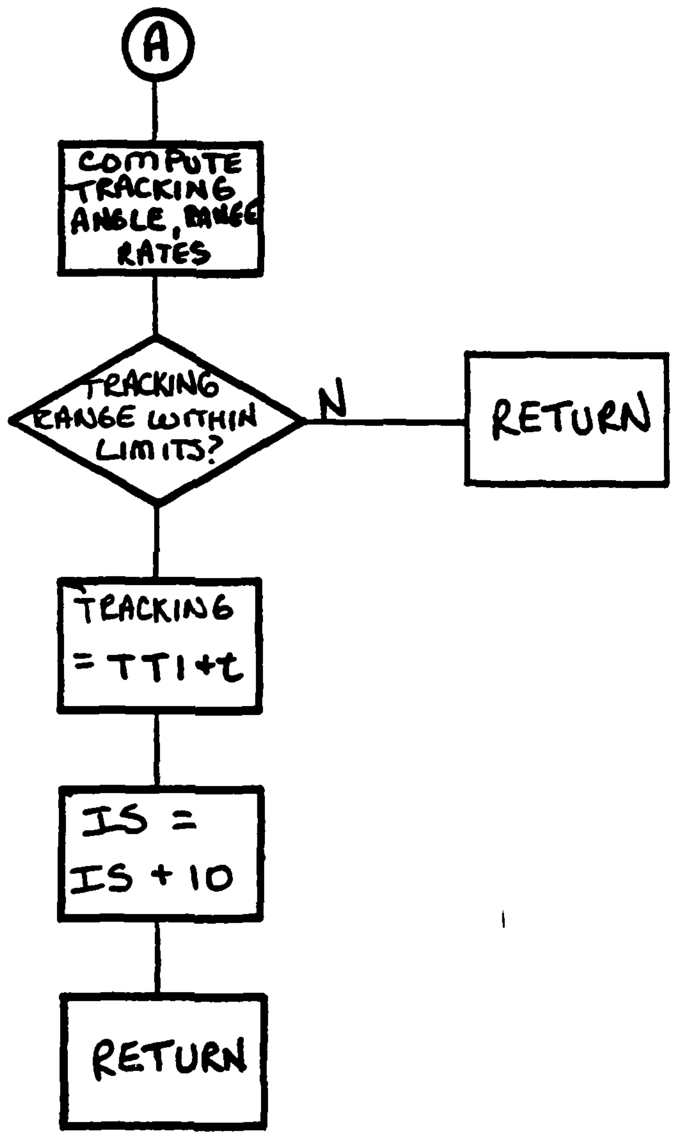


FIGURE 3-13

DECM2

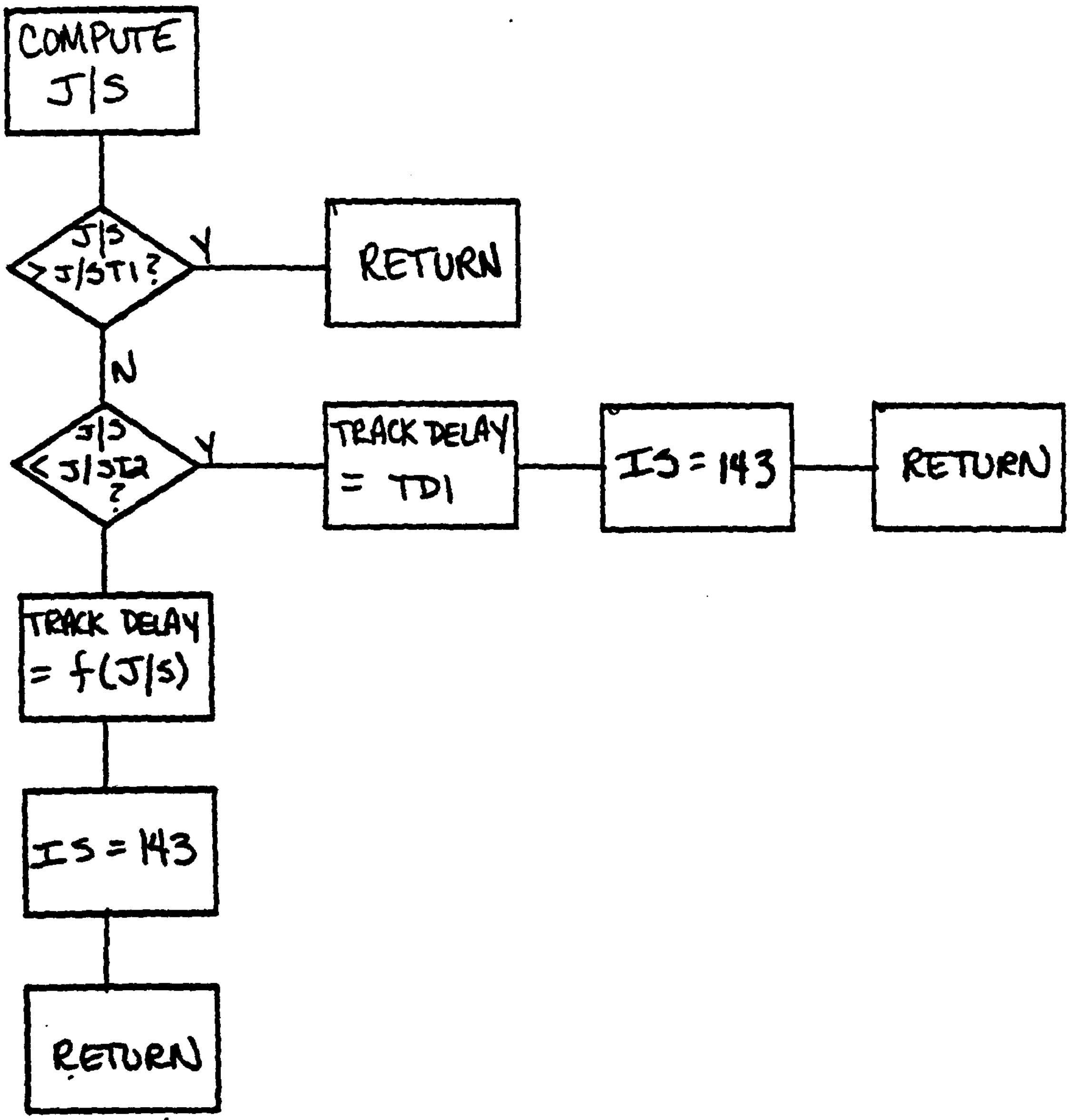


FIGURE 3-14

NECM2

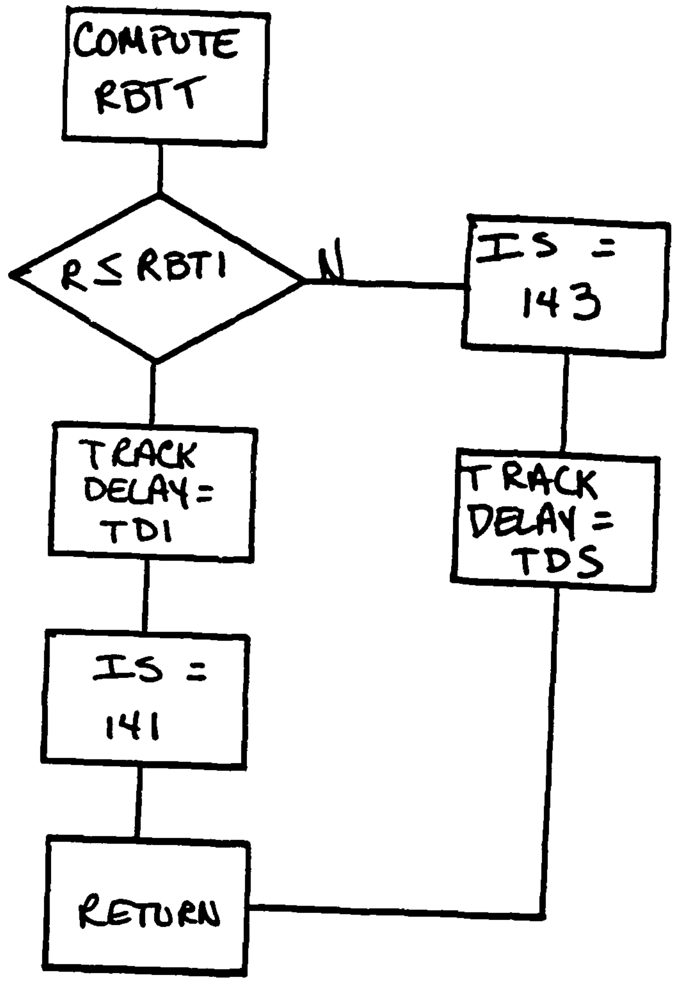
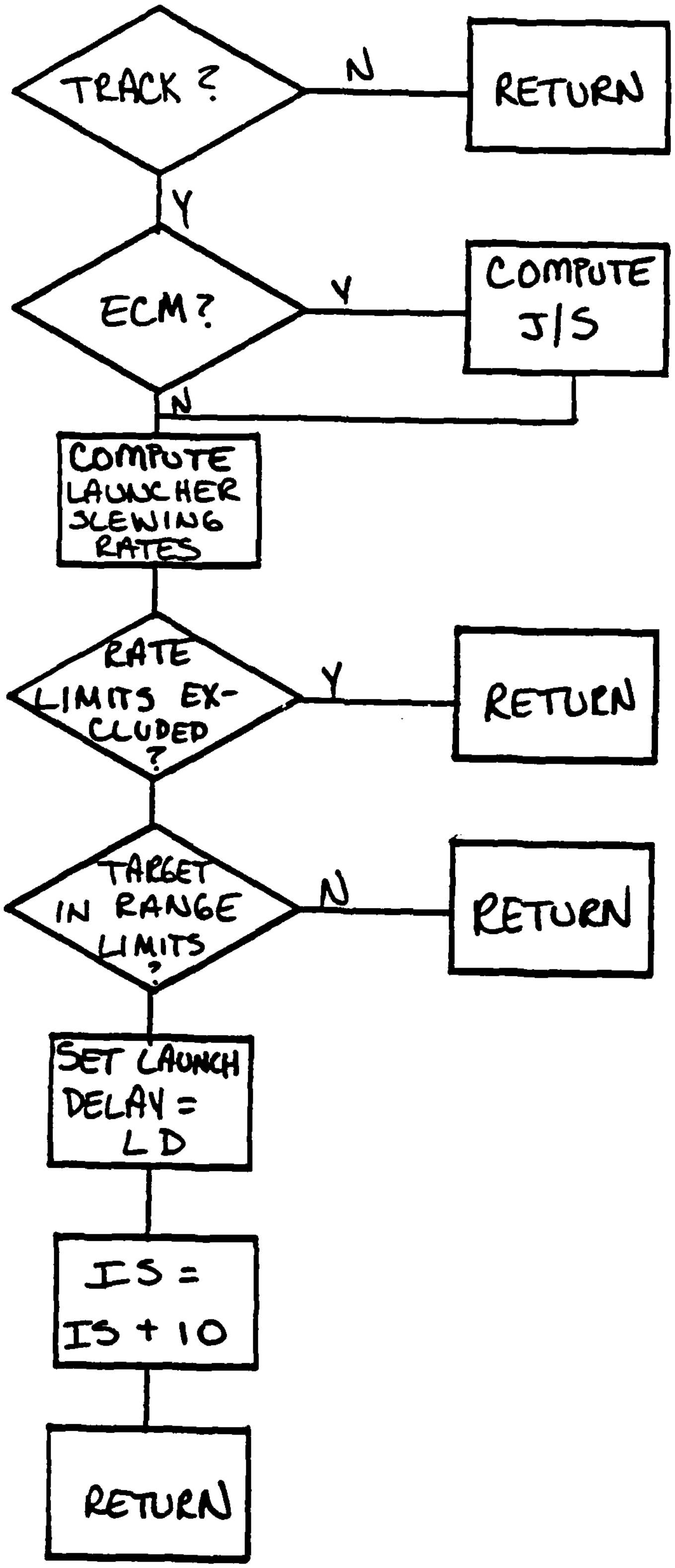


FIGURE 3-15

LAUNCH



3.3.3 Air Battle

The Air Battle routines determine the attacker's information and action states. The attacker may be provided with a number of sensors:

- surveillance radar detector
- track radar detector
- missile launch detector
- missile approach detector

Each of these sensors must be defined by coverage limits in the aircraft body coordinate system. When a radar or missile is within a coverage limit, it is detected by the aircraft.

Each aircraft has a set of options it may employ against ground radars and missiles. These include:

- NECM vs. surveillance radar
- DECM vs. surveilland radar
- NECM vs. track radar
- DECM vs. track radar
- Flares vs. IR missiles
- Maneuvers

In order for an ECM response or flares to be effective, the radiation pattern must cover the field of view of the radar or seeker.

3.3.3.1 Information/Action States

The information and action states of the attacker are shown in Table 3-2.

TABLE 3-2

AIR BATTLE INFORMATION STATES

	THREAT				
PHASE	ACQ RAD	TRK RAD	IR	MISSILE LAUNCH	MISSILE APPROACH
UNAWARE	211	212	213	214	215
AWARE	221	222	223	224	225
AVOID	231	232	233	234	235
DECEIVE	241	242	243	244	245
EVADE	251	252	253	254	255

UNAWARE refers to a situation where the defenders radars or missiles do not fall within the attacker's sensor patterns.

AWARE refers to a situation where the sensors have detected radars or missiles. If an attacker is once AWARE, it is always AWARE of a given system type.

AVOID refers to a situtión where the attacker maneuvers to minimize exposure to surveillance radar.

DECEIVE is a state where the attacker attempts to jam surveillance radars.

EVADE refers to a state where ECM and/or maneuvers may be used to evade track radar systems or flares may be used to evade IR missiles.

3.3.3.2 <u>Subroutine AIR UNAWARE</u>

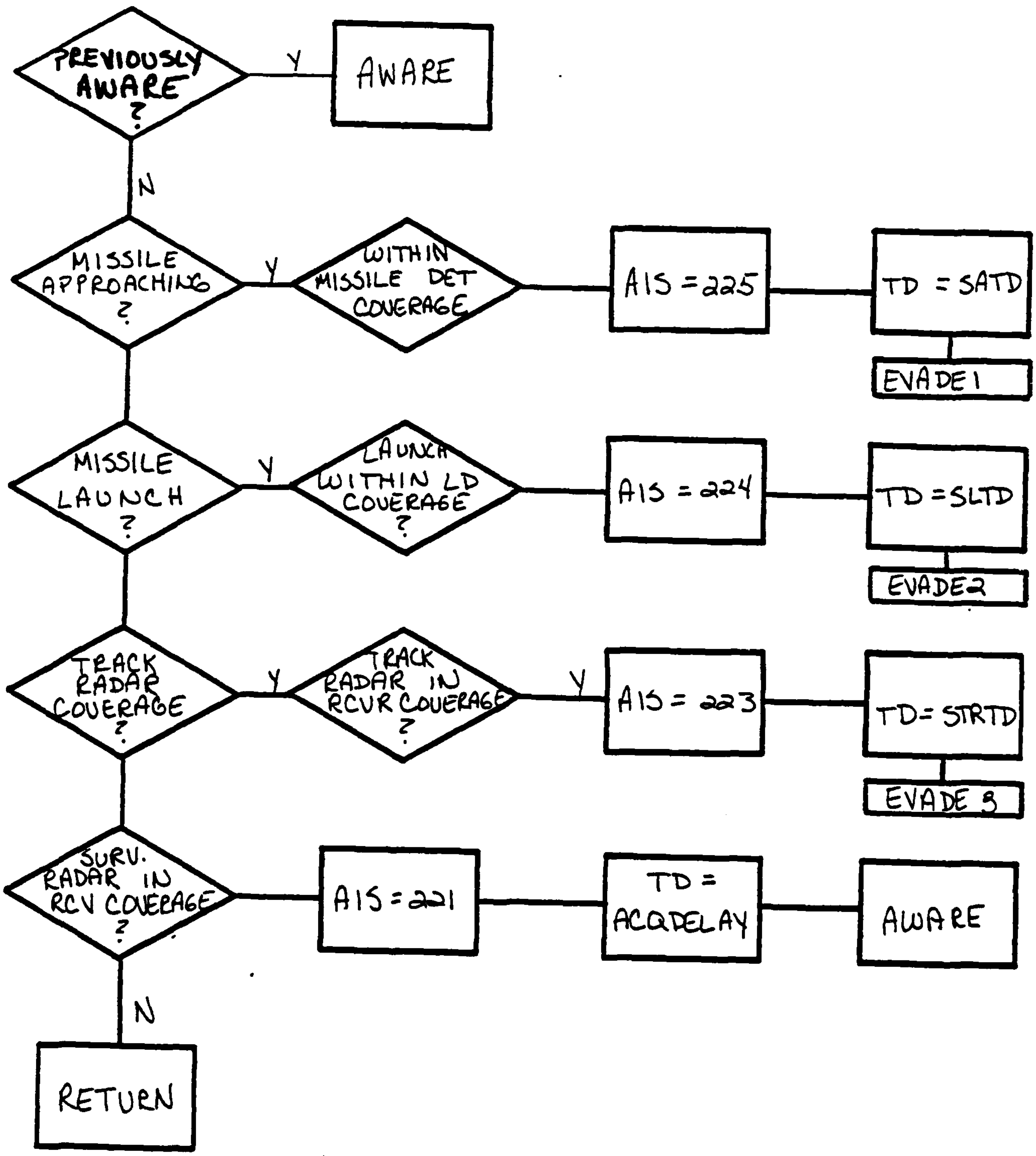
This subroutine provides for the transition from unware to aware states. This may occur in one of several ways: encounter with a surveillance radar, track radar, missile launch or approaching missile. Since in this case these are all initial system encounter situations, provision is made to assign, if desired, a delay time. (Figure 3-16)

3.3.3.3 <u>Subroutine AIR AWARE</u>

The object of this subroutine is to prioritize certain threat encounter conditions so that attacker options relating to more critical encounter conditions will be exercised. The

FIGURE 3-16

AIR UNAWARE



prioritization of threats is as follows:

- Missile approach
- Missile launch
- Track radar
- Surveillance radar (See Figure 3-17)

3.3.3.4 Subroutine AVOID

The object of this routine is to postpone the initiation of ECM until the completion of an avoidance maneuver, if such is desired. If one is desired, an avoidance maneuver initiation delay time is assigned. (Figure 3-18)

3.3.3.5 Subroutine DECEIVE

This routine activates NECM or DECM against surveillance radars after an input delay time has elapsed, provided that awareness of the following events has not already occurred: track radar lock-on, missile launch, or missile approach. (Fig. 3-19)

3.3.3.6 Subroutine EVADE3

This routine controls the initiation of track breaking maneuvers and track radar ECM. Maneuvers may be postponed until after ordnance release. An input minimum track radar lock-on time is required. (Figure 3-20)

3.3.3.7 Subroutine EVADE 2

In this routine a decision is made based on prior engagement history regarding the nature of a missile launch that is detected. If no prior radar involvement has occurred, the program assumes that the missile involved has IR guidance. Restrictions may be

FIGURE 3-17

AIR AWARE

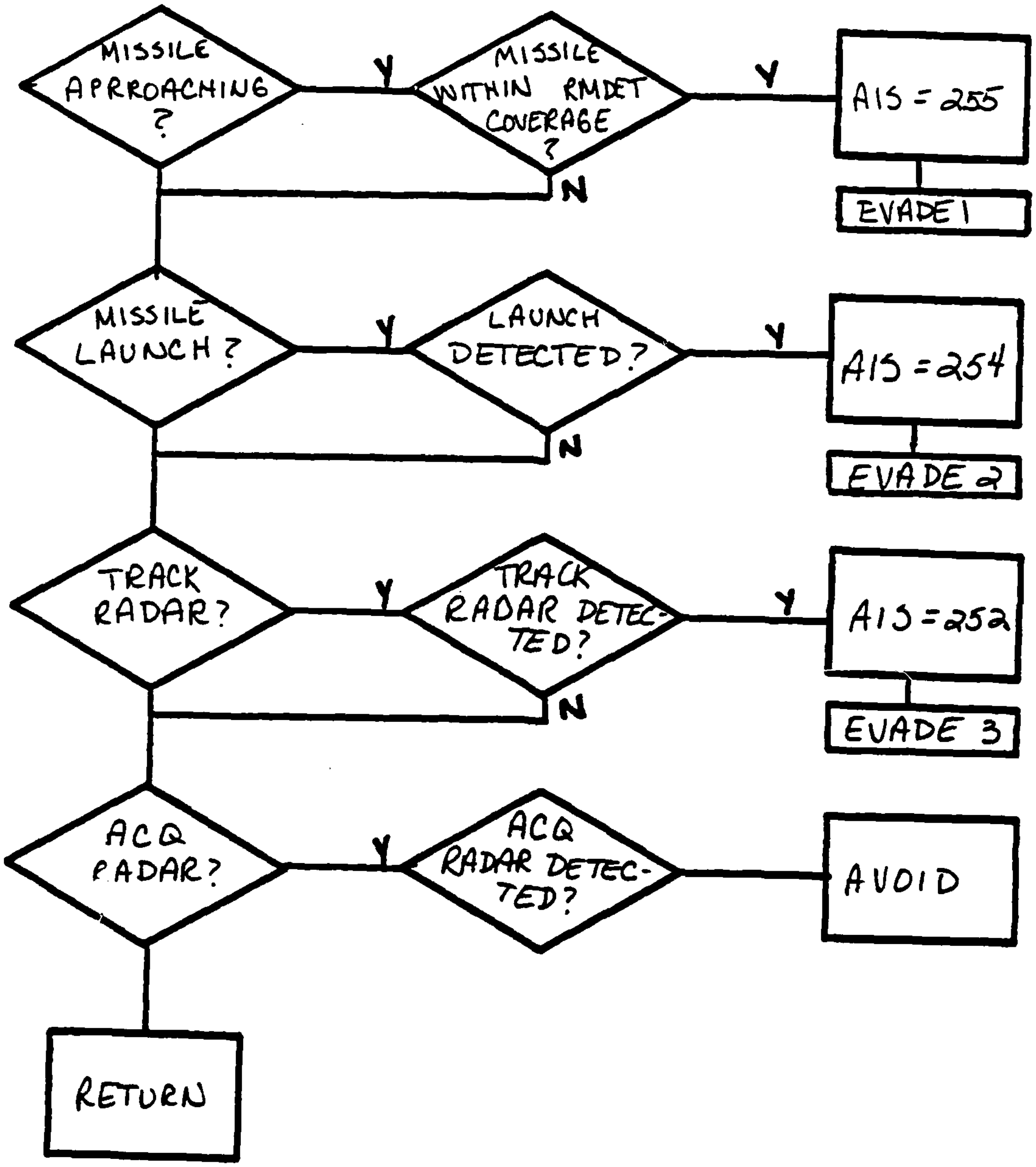


FIGURE 3-18

AVOID

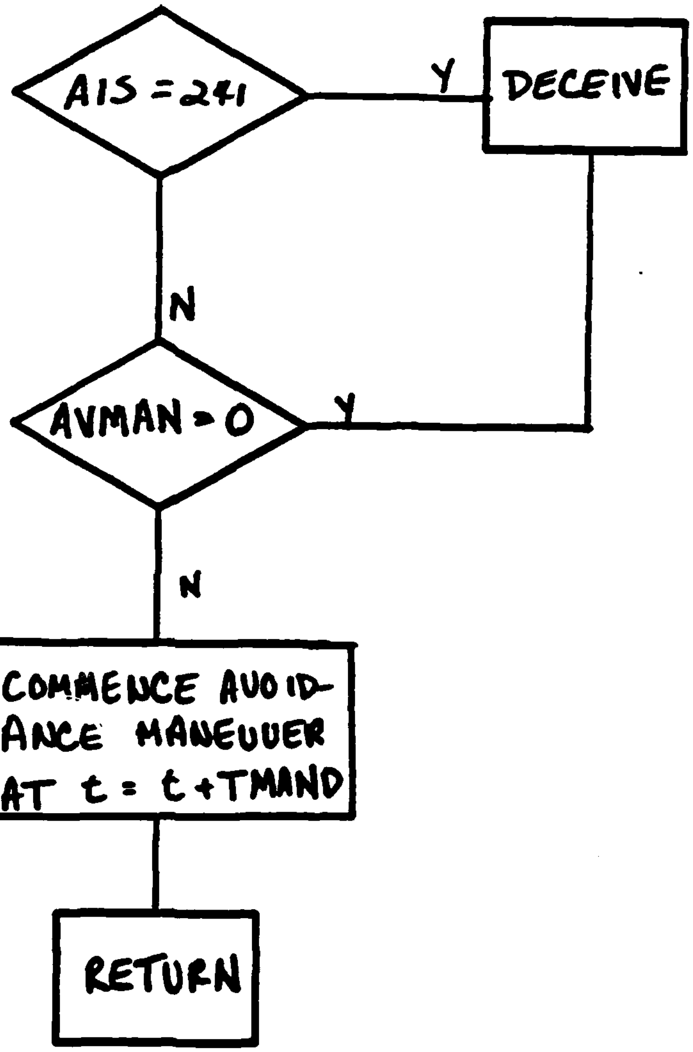


FIGURE 3-19

DECEIVE

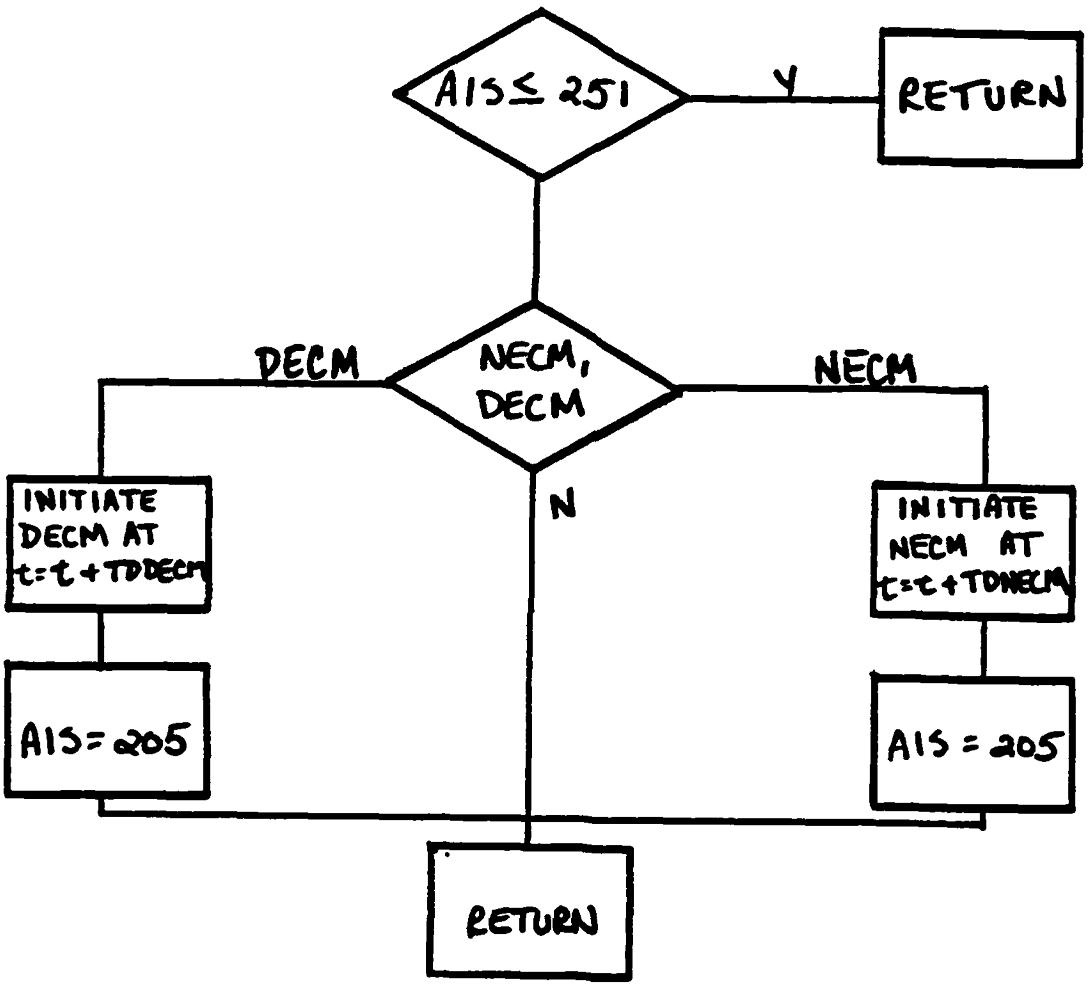


FIGURE 3-20

EVADE3

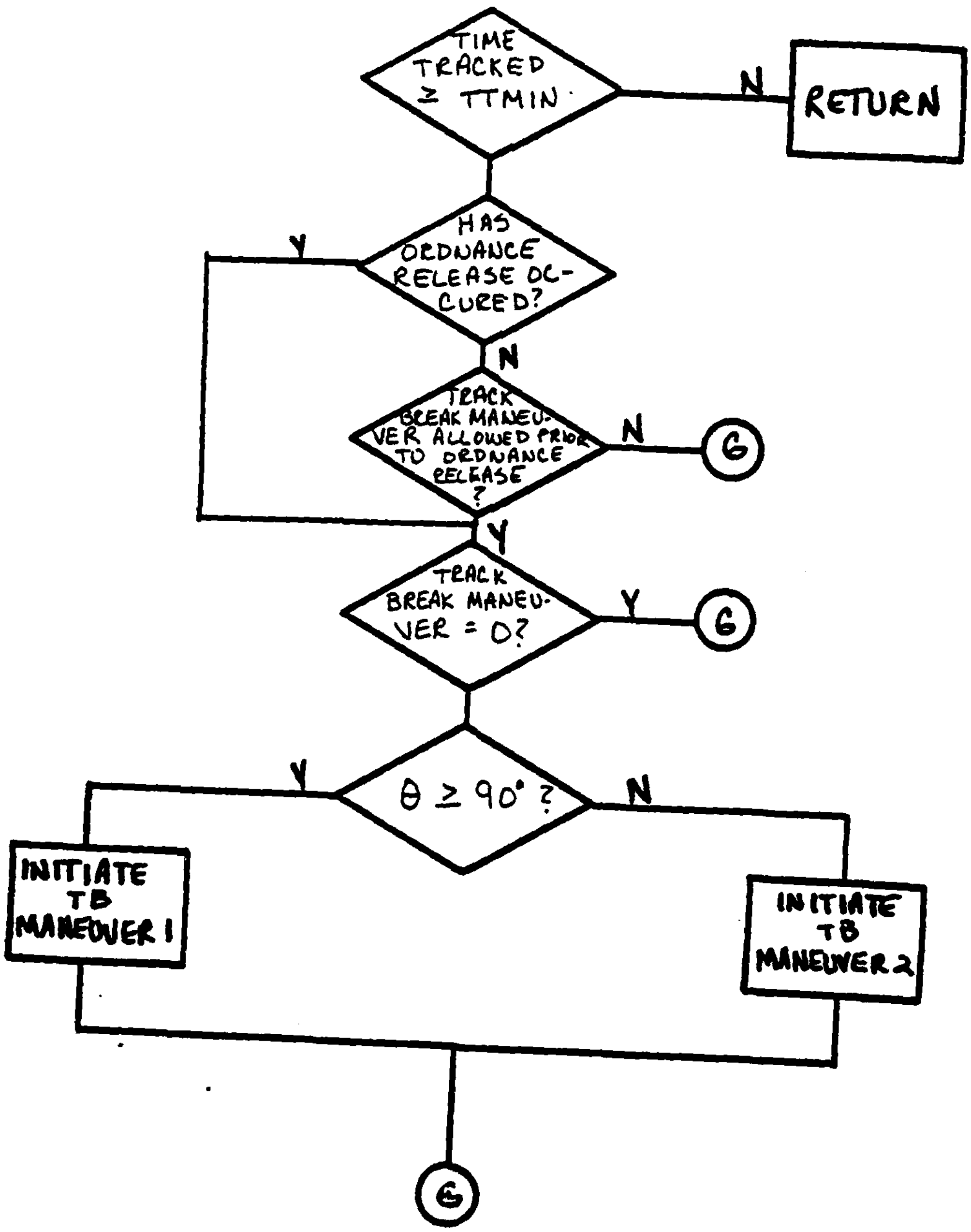
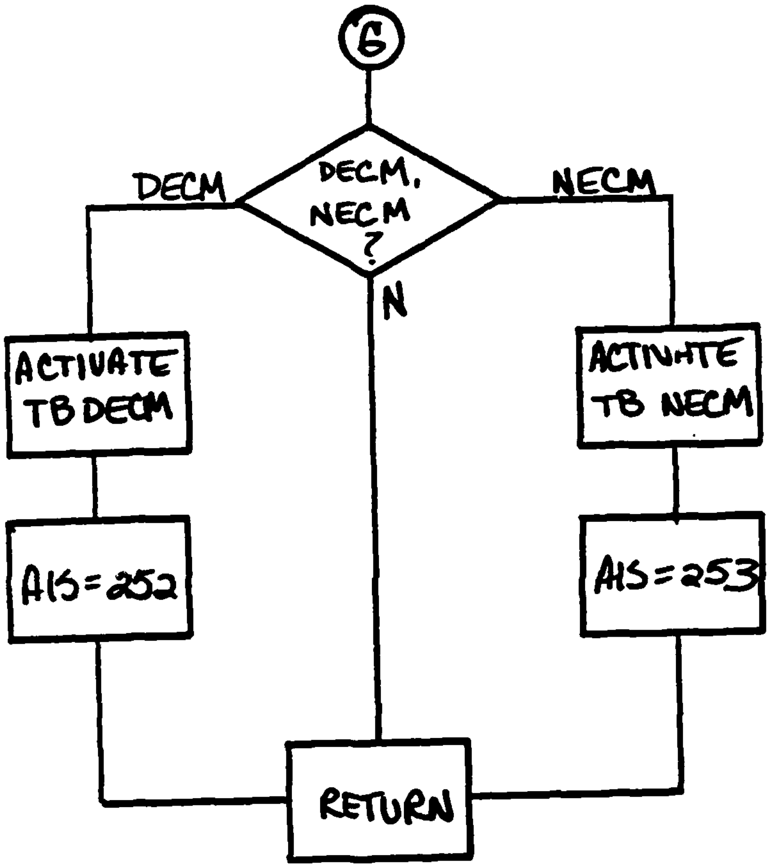


FIGURE 3-20 (CONT'D)



input to force delay of maneuvers until after ordnance release. Maneuver selected may depend on launch-attacker relative orientation. (Figure 3-21)

3.3.3.8 Subroutine EVADE1

In this routine, a missile approach evasive maneuver is selected based on prior radar involvement. (Figure 3-22)

3.3.4 Missile Battle

The missile battle involves the events and information states from missile lock-on to intercept. It is concerned primarily with launch acceptability and fly-out guidance mode. Determination that intercept occurs is made in a separate routine, and the evaluation of intercept in another.

3.3.4.1 Guidance Status

The following phases and guidance modes are employed:

LAUNCH/ACQUIRE. The missile is unlaunched and must acquire the target.

FLY-OUT. The missile is in the fly-out phase.

Proportional Navigation (PN). Conditions are such that proportional navigation may be employed.

Pursuit Course Navigation (PCN). Conditions in system limitations dictate the use of Pursuit Course Navigation.

Beam Rider Navigation (BRN). Conditions are such that Beam Rider Navigation must be employed.

FIGURE 3-21

EVADE 2

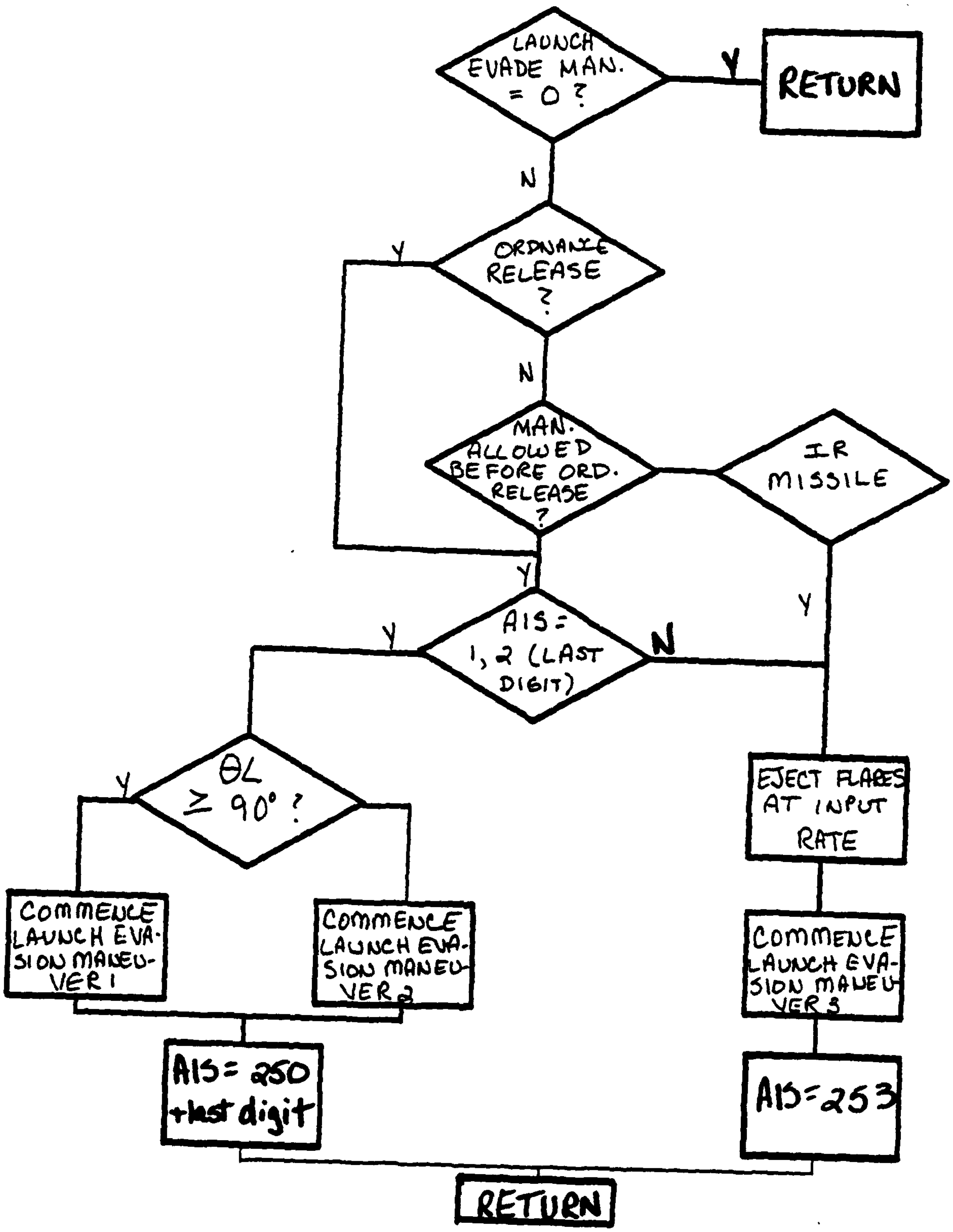
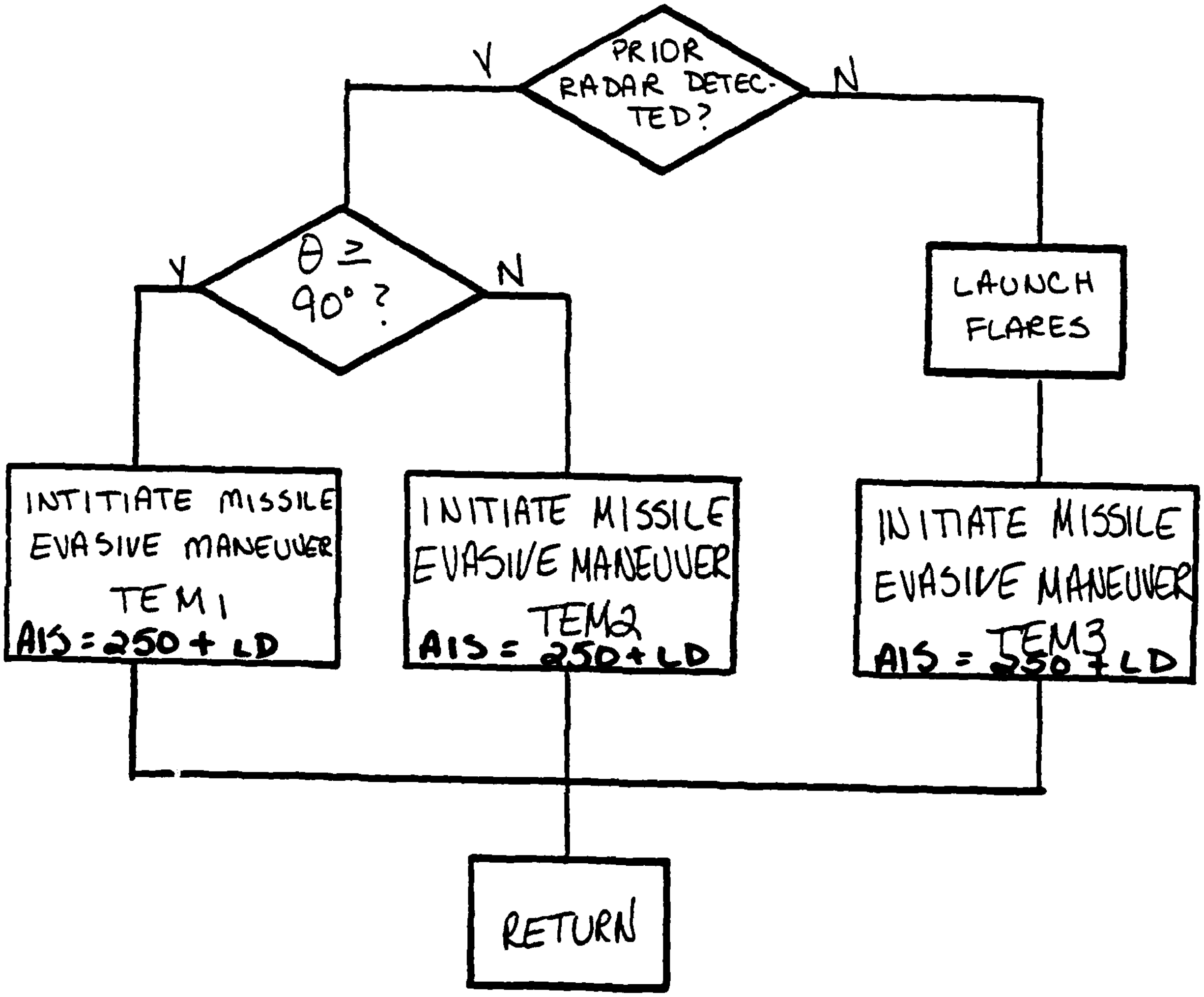


FIGURE 3-22

EVADE 1



3.3.4.2 Subroutine GUIDANCE

The object of this routine is to ascertain the guidance mode at launch and during fly-out and to determine if certain seeker requirements are satisfied (if any) prior to launch. For command guided systems, missile launch is determined by tracker and launcher conditions. For semi-active systems target or strobe lock-on are required. For IR systems, lock-on is required. (See Fig. 3-23 & Table 3-3)

3.3.5 Sensor Maximum Performance

Maximum coverage of sensors simulated in the model is defined as the sensor volume. This volume is defined by a set of spheres, cylinders, cones, planes and azimuth sectors. For ground based sensors, these volumes are defined in the inertial coordinate system. For airborne sensors, they are defined as the missile or aircraft body system.

If a target is outside the sensor volume, it will not be detected by the sensor. Thus, for instance, an aircraft below the coverage zone of a radar will not be seen; or an IR flare outside a missile seeker coverage volume will not affect the missile. Likewise, the jammer on an aircraft may not affect an enemy radar if its coverage turns away from the radar during a maneuver.

3.3.6 Surveillance Radar Performance

Within its sensor coverage volume, the range of a radar (ground based or airborne) is limited by its own characteristics

FIGURE 3-23

MISSILE GUIDANCE

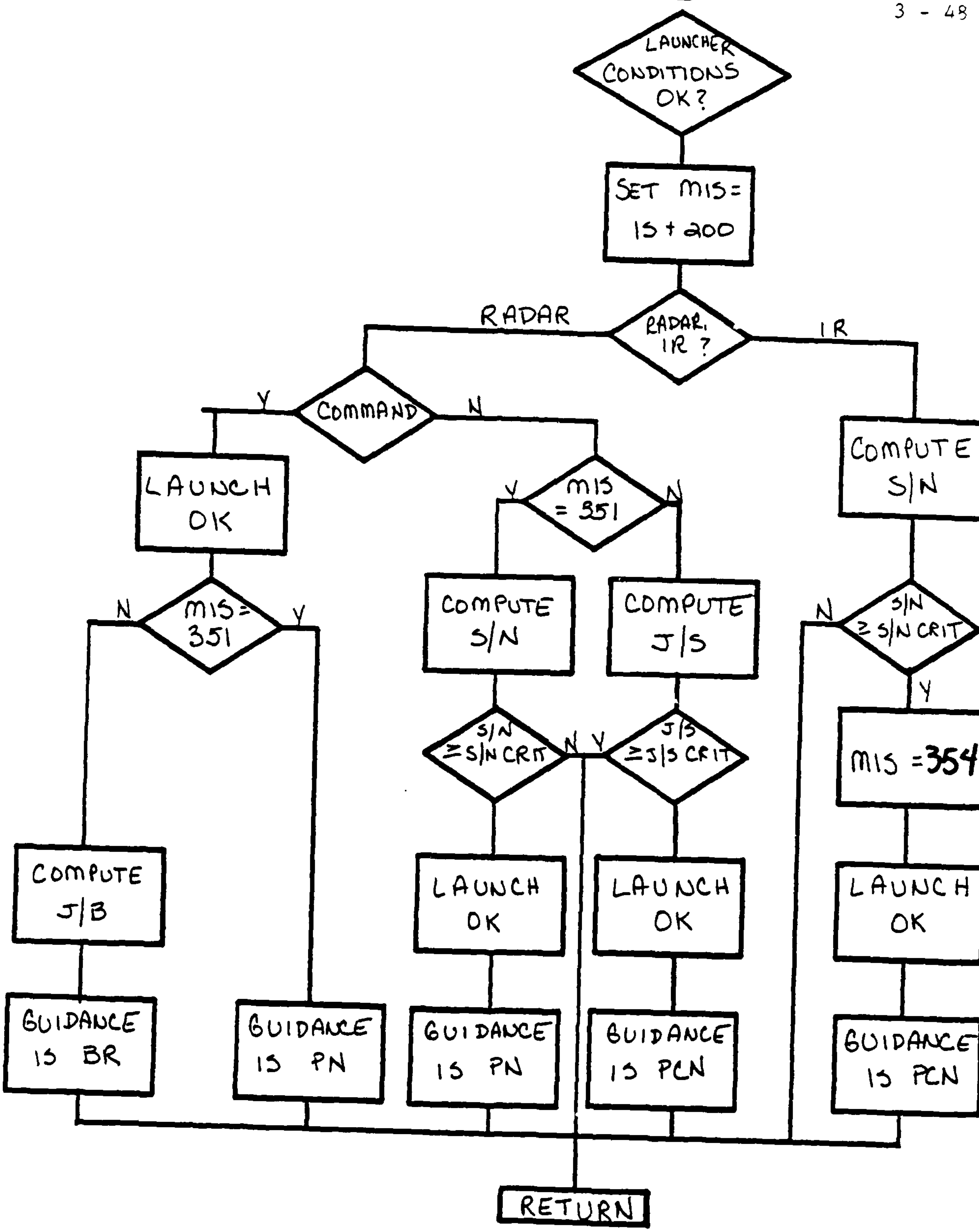


TABLE 3-3

MISSILE BATTLE INFORMATION
GUIDANCE STATES

PHASE	NO. ECM	NECM	DECM	IR
GUIDANCE	351	352	353	354

and the size of the target. A scaling ratio can be derived relating these parameters: (See Figure 3-24)

$$R = R_o \sqrt[4]{\sigma}, \text{ where}$$

R = The detection range of a given radar against a target having radar cross section = σ_T.

R_o = Radar detection range of a given radar against a target having radar cross section of 1 m^2.

R_o incorporates the properties characteristics of the radar, while σ_T is radar cross section (an input). R_o may be determined using the radar range equation, or it may be determined empirically. σ_T must be specified in aircraft body coordinates in both azimuth and elevation.

3.3.7 Surveillance Radar Noise Jamming

Noise jamming degrades the detection range of a radar. The range at which the radar "burns through" the jamming noise is known as the self screening range, R_{ss}. An expression for this is shown in Figure 3-25. It is the product of three items. One involves radar parameters, R_o; thermal noise, KT; the effective antenna aperture A_e and a jammer/radar overlap factor L. The second involves aircraft parameters: σ_T, the cross section; P_j, jammer power; G_j, the gain of the jamming antenna; B_j the bandwidth of the jammer; and L, an overlap factor depending on jammer type - spot, barrage or swept. The third factor is a jamming noise

FIGURE 3-24

RADAR RANGE EQUATION

$$R^4 = \frac{P_T G_T A_T L \sigma_T}{(4\ )^2 KTB_N (S/N)}$$

where

P_T = Transmitted power

G_T = Transmitter power gain

A_T = Effective antenna aperture

L = Losses between transmitter and receiver

σ_T = Target radar cross-section

K = Boltzman's constant

T = System noise temperature

B = Noise bandwidth of receiver

S/N = Minimum signal-to-noise ratio required for detection

Let R_0 = R for $\sigma_T = 1m^2$,

Than $R(\sigma) = R_0 \sqrt[4]{\sigma}$

FIGURE 3-25

NOISE JAMMING

- SPOT
- BARRAGE
- SWEEP

$$R_{ss} = \left(\frac{R_0^4 \; KT}{A_e \; L_R} \right)^{\frac{1}{2}} \left(\frac{\sigma \; T}{\frac{P_j \; G_j \; L}{B_j}} \right)^{\frac{1}{2}} \left[\frac{S/N}{S/J} \right]^{\frac{1}{2}}$$

L = OVERLAP FACTOR

$$\left[\frac{S/N}{S/J} \right]^{\frac{1}{2}} = \text{NOISE QUALITY FACTOR}$$

S/J = NOISE SUSCEPTIBILITY FACTOR

$$R_{ss} = K \left[\frac{R_0 \times \sigma_T}{G_j} \right]^{\frac{1}{2}}$$

spot, barrage or swept. The third factor is a jamming noise quality factor relative to thermal noise. This factor depends on the type of jamming noise and ECCM capabilities of the radar. Estimates of this factor exist for a number of jammer noise type/ ECCM type combinations.

In any case, R_{ss} can be rewritten:

$$R_{ss} = K_D \left[\frac{R_o \ \sigma_T}{G_j} \right]^{\frac{1}{2}} .$$

σ_T and G_j may vary dynamically during the course of an engagement.

3.3.8 Surveillance Radar Deception Jamming

Deception jammers can be used to generate false targets which appear on an oscilloscope display of position thus confusing operators. The result is that detection time delays prior to designation of tracking radars or, perhaps, IR launchers are increased. The length of delay depends on the efficacy of the deception jammer. In GENSAM it is assumed that this delay depends on the J/S ratio:

$$J/S > K_1, \ t_{D1} = T_1$$

$$J/S < K_3, \ t_{D1} = T_3$$

$$K_1 \geq J/S \geq K_3, \ t_{D1} = T_3 + \frac{(T_1 - T_3)(J/S - K_1)}{K_1 - K_3}$$

The jamming to signal ratio J/S is given by

$$J/S = \frac{4\pi \; P_j G_j / R^2}{\sigma_T P_T G_T T L / R^4} \left(\frac{B_N}{B_j} \right),$$

where

P_j = Jammer Power

G_j = Jammer Antenna Gain

B_j = Jammer Bandwidth

and the other terms are as previously defined. Once detection occurs, it assumed that it is maintained.

After detection occurs, an additional time delay, t_{D2} is entailed in designating a track radar.

3.3.9 Tracking Radar Performance

Tracking radars are also limited by coverage volumes and target cross section. The same considerations apply as was the case with search radars: The target must be within the coverage limits and, within those limits, $R = R_o \sqrt[4]{\sigma_T}$. A time delay, t_{D3}, is required to acquire the target prior to track initiation. In addition, tracking will not commence, nor continue, if angular tracking rate limits $\dot{\theta}_{AZ1}$ and $\dot{\theta}_{EL1}$ are exceeded. A minimum tracking time, t_{D4}, is also imposed.

3.3.10 Noise Jamming and Tracking Radars

Noise jamming may be used to reduce the range of a tracking radar. The self-screening range is then

$$R_{ss} = K_T \left[\frac{R_o \; \sigma_T}{Gj}\right]^{\frac{1}{2}}$$

In the case of noise jamming, missiles may be launched using beam rider guidance after a delay t_{D5}. Otherwise tracking does not commence until burn through occurs.

SAM systems may also employ missile trackers that utilize beacons which transmit energy to the tracking radar to assist in the missile tracking function. These "downlinks" may also be jammed in addition to the radar to attacker "uplink." The effectiveness of jamming is jointly dependent on J/S and J/B, the track radar jamming to signal ratio and the jamming to beacon ratio, J/B.

An expression for the jamming to beacon ratio is

$$J/B = \frac{P_j G_j}{P_B G_B}$$

where

P_B = Beacon transmitted power, and

G_B = Beacon antenna gain.

3.3.11 Deception Jamming and Tracking Radars

There are many types of deception jamming that may be employed against tracking radars. The principal effect is to cause missile intercept miss distances to be biased. The magnitude of this bias depends on J/S:

$$\frac{\text{MISS DISTANCE}}{\text{INTERCEPT RANGE}} = f\,(J/S)$$

$$= MD1,\ J/S < K_1\ ;$$

$$= MD2,\ J/S > K_3\ ;$$

$$= M_D + \frac{(M_2-M_1)(J/S-K_1)}{K_3-K_1}\ ,\ \text{otherwise}$$

In the case of semi-active systems, miss distance is not a function of intercept range.

The expression for J/S for surveillance radars will also be used here. Different input parameters will, of course, apply.

3.3.12 Jamming and Track Radar Downlinks

Command guided systems may employ a missile to track radar beacon. This system may also be jammed. In this case, the parameters in the preceding equations will be a function of J/B. That is, K_1, K_3, MD_1 and MD3 will depend on J/B.

3.3.13 Infrared Surveillance Systems

As was the case with radar systems, we require that the target aircraft be within the IR sensor volume. Within this volume, range is limited by a scaling relationship:

$$R = R_1\sqrt{S}\ f(R,T) \qquad \text{(See Figure 3-26)}$$

where R_1 is the range of the system against a one watt/steradian source under a specified set of atmospheric conditions and S is the target aircraft infrared emission strength (watts per steradian). There is a delay time, t_7, incurred in assigning a missile to a given target.

FIGURE 3- 26

INFRARED RANGE

The infrared range equation may be written:

$$R = K_3\sqrt{S}$$

where

S = Target radient density (watts/steradian)

From this,

$$R(S) = R(1)\sqrt{S/1}$$
$$= R_1\sqrt{S}$$

Strictly speaking, atmospheric losses, a function of weather, visibility and system wavelength, will also be a factor.

A corrected range, or effective range is given by

$$REFF = R(S)*f(\text{atmospheric tranmisivity and range})$$
$$= R(S)f(T,R)$$

The correction term becomes important at certain wavelengths since $T = T(\lambda)$. A table relating REFF to R and T is incorporated in the program.

3.3.14 Infrared Trackers and Infrared Guidance

Infrared trackers and guidance systems are generally the same units. They are differentiated in the model by their sensor coverage. Prior to launch, the guidance unit serves as a tracker. Its coverage volume is limited in range by seeker performance limit, but in azimuth and elevation it is limited only by slewing limitations. As a seeker, the unit is limited by azimuth and elevation angular limitations. Angular limits for each mode as well as range limits for both are user inputs. Within coverage limits, range is limited by the IR scaling law

$$R \sim R_1 \sqrt{S}\, f(T,R).$$

All IR seekers utilize employ the same guidance law, pursuit course navigation.

3.3.15 RF Warning Receivers

Aircraft may employ RF warning receivers. The coverage volume, in aircraft body coordinates, is a user input, as well as R_5, the range at which a signal of one watt/steradian of effective radiated power can be detected. The detection range within the coverage volume will then vary as

$$R = R_5 \sqrt{G_R} \quad ,$$

where G_R is the antenna gain in the direction of the threat radar, which will vary in the course of the simulation.

3.3.16 RF Jammer Power Management

The current one-on-one version of the model does not dynamically vary radiated power characteristics. The only input requirement is L, the overlapping coverage which depends on the jamming model (deception, noise, spot, barrage or swept) and the threat density. Following RF signal detection, jamming may commence with delay to t_{10} (search) or t_{11} (track). In addition, an evasive maneuver may be allowed (delay t_{12}).

3.3.17 Missile Launch Detection

Aircraft may also employ missile launch detectors. Here again a coverage volume must be defined, and range as this volume is limited by

$$R = R_G\sqrt{G_M}$$

where R_6 is the detection range against a unit source of radiation and G_M is an optical gain factor. Typically, this is 1 within the coverage limits and 0 outside. Subsequent to missile launch, an evasive maneuver may be employed after a delay t_{13}.

3.3.18 Missile Approach Detection

A missile approach detector may be employed. Again, a coverage zone must be defined. A maximum range is given by

$$R = R_7\sqrt[4]{G_D}$$

where R_7 is the detection range against the missile, and G_D = the gain of the detector within the coverage volume and equals zero outside.

3.3.19 IR Flares

IR Flares may be launched following RF signal detection, missile launch or missile approach detection. The flares have a burn time of t_B. If R_{TM} is the range of a missile to a target, and R_{FM} the range of a flare to a missile, then the opponent source strengths to the missile seeker are

$$S_T' = \frac{R_{10}S_T}{R^2_{TM}}$$

and

$$S_F' = \frac{K_{10}S_F}{R^2_{MF}} ,$$

where S_T is the source strength (watts/steradian) of the target (an input function of azimuth and elevation in target body coordinates) and S_F is the source strength of the flare (assumed to be isotropic). The missile aim point lies along the relative position vector of flare and missile (provided the flare is in the field of view of the missile):

$$\vec{R}_{TF} = \vec{R}_T - \vec{R}_F ,$$

and is given by

$$AP = \vec{R}_T + \frac{(\vec{R}_F - \vec{R}_T)S'_F}{S'_F + S'_T}$$

3.4 Maneuver (New Orientations of Velocity Vector)

3.4.1 Missile Systems

The future orientation of missile system veolicy vectors is determined by the guidance equations. Three types are allowed: pur-uit, beam-rider and proportional.

Pursuit

If R_{MT} is the target missile separation, ψ is the angle between the line-of-sight and the target velocity vector ζ the angle between the line-of-sight and the missile velocity vector, then the pursuit course equations of motion are

$$\dot{R} = V_T \cos\psi - V_M \cos\zeta$$

$$R\dot{\psi} = V_T \sin\psi + V_M \sin\zeta$$

Beam Rider

If R_{GM} is the range from control center to the missile and θ_{GM} is the angle between the slant range and the ground range as a plane formed by the target velocity vector and the control/unit, then

$$\left(\frac{dR_{GM}}{d\theta_{GM}}\right)^2 + R^2_{GM} = K^2 \csc^4 \theta_{GM}$$

where

$$K = \frac{V_M}{V_T} Z_T, \text{ where}$$

Z_T is the target altitude.

Proportional Navigation

If ψ_M is the bearing angle between the aircraft and missile and A is the navigation constant

$$\dot{R} = V_T \cos\psi - V_M \cos(\psi - \psi_M)$$

$$R\dot{\psi} = -V_T \sin\psi + V_M \sin(\psi - \psi_M)$$

$$\dot{\psi}_M = A\dot{\psi}$$

3.4.2 Aircraft Maneuvers

3.4.2.1 Jinking

The aircraft will fly a jinking maneuver, randomly selecting full or idle throttle, with maximum-gee turn in random direction. Period of selection is three seconds, and provision is made in the program to avoid smooth maneuvers. A feature of the program in the requirement that the same jink is not made successively so as to present an easy target to the foe.

3.4.2.2 Maximum "G" Turn

The aircraft may fly a maximum-gee turn, limited by the most restrictive of structure, aerodynamics and oxygen debt. Full throttle is used and the pilot utilizes a climb (or dive angle) to attempt to reach corner velocity, for maximum turning rate.

3.4.2.3 Steep Dive

Here the aircraft applied full throttle, unloads gees, and dives for the deck at a maximum angle of 30°. At the user's option, the aircraft may make a series of 30° turns after it has reached the deck.

3.4.2.4 Evasive Climb

If the aircraft chooses he may unload gees, apply full throttle, and climb to escape altitude at a designated velocity. If above escape altitude, he will dive down to it at maximum velocity. Upon reaching escape altitude he will fly full throttle, straight and level.

3.4.2.5 Chandelle

The chandelle maneuver is only attempted if the aircraft is initially flying at a speed above corner velocity. The maneuver consists of a 3 gee climbing turn calculated to result in the aircraft's velocity being reduced to corner velocity at the same time that the aircraft has turned to point at it's opponent.

In general, the chandelle is utilized in the program as an alternative to a split-S when the aircraft is too low to perform the latter maneuver.

3.5 Equations of Motion - Limits and Integration

3.5.1 Equation of Motion

"Maneuverability can be defined as the ability to change the direction and/or the magnitude of the velocity vector".

The equations of motion of an aircraft or missile center of gravity can be written in a number of ways. For our purpose, in view of the above definition, it is most useful to express them is the relative wind coordinate system, which is based on the aircraft velocity vector.

The direction of the velocity vector can be expressed in terms of the azimuth angle (ξ) which it forms with the positive X_I axis and the elevation angle (γ) which it forms with the horizontal plane.

Since the quantities V, β, and γ specify the magnitude and direction of the velocity vector $\vec{V}$, the acceleration $d\vec{V}/dt$ is determined by V, β, and γ through the relationship:

$$\frac{d\vec{V}}{dt} = \frac{\partial \vec{V}}{\partial V} \cdot \dot{V} + \frac{\partial \vec{V}}{\partial \beta} \cdot \dot{\beta} + \frac{\partial \vec{V}}{\partial \gamma} \cdot \dot{\gamma}$$

In the relative wind system these partial derivatives can be evaluated in terms of the unit vectors $\vec{X}_W$, $\vec{Y}_W$ and $\vec{Z}_W$ parallel to the axes. This results in:

$$\frac{d\vec{V}}{dt} = \dot{V} \cdot \vec{X}_W + V \cdot \dot{\beta} \cdot \cos\gamma \cdot \vec{Y}_W + V \cdot \dot{\gamma} \cdot \vec{Z}_W$$

The forces acting on the aircraft - namely thrust (T), drag (D), lift (L) and weight (W) can also be resolved into components in the wind system. Applying Newton's Second Law to the components of the force and the acceleration along the three axes results in the following equations of motion.

$$(W/g) \cdot \dot{V} = T \cdot \cos\alpha - D - W \cdot \sin\gamma$$

$$(W/g) \cdot V \cdot \dot{\beta} \cdot \cos\gamma = (T \cdot \sin\alpha + L) \cdot \sin\mu$$

$$(W/g) \cdot V \cdot \dot{\gamma} = (T \cdot \sin\alpha + L) \cdot \cos\mu - W \cdot \cos\gamma$$

Here μ represents the angle between the wingline of the aircraft and the horizontal plane and α is the angle between the velocity vector and the body axis.

Computational Algorithm

In general, the maneuvering goal of an aircraft can be expressed as a desired orientation and magnitude of the velocity vector. In these terms the desired velocity component time derivatives can be written as

$$\dot{V}_{des} = (V_{des} - V)/\Delta t$$

$$\dot{\gamma}_{des} = (\gamma_{des} - \gamma)/\Delta t$$

$$\dot{\beta}_{des} = (\beta_{des} - \beta)/\Delta t$$

where the subscript "des" indicates "desired" and Δt is the period of time which comprises one time pulse.

The computational algorithm is to:

1) Determine the appropriate action for each aircraft.

2) Translate this action into the desired maneuvering goals.

3) Compute the forces and body orientation necessary to achieve them.

4) Compare these forces and orientation with the limits imposed by the structure, engine, pilot, wing, etc.

5) Determine the best compromise between the various goals, limited by performance capability, and the resultant $\dot{V}$, $\dot{\beta}$, $\dot{\gamma}$ and

6) Using $\dot{V}$, $\dot{\beta}$ and $\dot{\gamma}$, update the position, altitude and speed of the aircraft for the next time pulse.

The remainder of this discussion is concerned with the implementation of the last four steps. The following aerodynamic equations will be needed and are defined now.

$$L = \frac{\rho}{2} \cdot S \cdot V^2 \cdot C_L$$

$$D = \frac{\rho}{2} \cdot S \cdot V^2 \cdot C_D$$

$$\eta = L/W$$

where L = Lift

D = Drag

S = Wing Area

ρ = Air Density

V = Velocity

η = Gee Loading

and C_L and C_D are the lift and drag coefficients which are functions of mach number and attack angle (α) for each aircraft type. For a given mach number, C_L is nearly a linear function of attack angle below stall attitude, permitting the approximations:

$$L \simeq \frac{\rho}{2}\cdot S\cdot V^2\cdot\frac{dC_L}{d\alpha}\cdot\alpha \simeq K\cdot\alpha$$

$$\frac{T\cdot\sin\alpha + L}{W} \simeq \frac{T}{W}\cdot\sin\alpha + \frac{K}{W}\cdot\alpha \simeq \alpha\cdot\left(\frac{T}{W} + \frac{K}{W}\right)$$

The second and third equations of motion above can be manipulated to yield

(1) $$\mu = \arctan\left(\frac{\dot{\beta}\cdot\cos\gamma}{\dot{\gamma} - Y_o}\right)$$

(2) $$\alpha = \frac{W}{T+K}\cdot\frac{V}{g}\cdot\sqrt{(\dot{\beta}\cdot\cos\gamma)^2 + (\dot{\gamma}-Y_o)^2}$$

where $Y_o = -\frac{g}{V}\cdot\cos\gamma$ and assuming $\sin\alpha \simeq \alpha$. Thus, there is a unique relation between the angular velocity rate $(\dot{\beta}, \dot{\gamma})$ and the body orientation angles (α, μ). Alternatively, the second equation above can be written in terms of gee-loading as

(3) $$\eta = V/g \cdot \sqrt{(\dot{\beta} \cdot \cos\gamma)^2 + (\dot{\gamma} - \dot{\gamma}_o)^2}$$

with the assumption that the term $T\alpha/W$ is negligible.

Solving equations (1) and (2) simultaneously produces the following relationships which express $\dot{\beta}$ and $\dot{\gamma}$ as functions of μ and η.

(4) $$\dot{\beta} = \frac{g\eta \sin\mu}{V\cos\gamma}$$

(5) $$\dot{\gamma} = \frac{g\eta \cos\mu}{V} + \dot{\gamma}_o$$

3.5.2 Limits

The computational procedure that is used to determine the best compromise between the various goals, limited by performance capability, can now be stated as follows:

1) Check the desired climb rate ($\dot{\gamma}_{des}$) and adjust it if necessary, to keep the aircraft from contacting either the ground or the absolute ceiling.

2) Determine upper and lower limits on the gees that can be pulled by the aircraft, based on the maximum pitch rate of the aircraft and also on the capabilities of the pilot (oxygen debt and stress gees).

3) From equation (3) find the desired gees (η_{des}), resulting from $\dot{\beta}_{des}$ and $\dot{\gamma}_{des}$. Adjust η_{des} if necessary to stay within the

limits determined in step 2.

4) From equation (4) and (5) find the desired roll angle (μ_{des}), corresponding to n_{des}, $\dot{\beta}_{des}$, and $\dot{\gamma}_{des}$. Three options exist for this procedure. These are:

(a) Equal scaling for both rate components,

(b) Horizontal ($\dot{\beta}$) component satisfied first,

(c) Vertical ($\dot{\gamma}$) component satisfied first.

Adjust μ_{des} if necessary to stay within the maximum roll rate of the aircraft.

(5) From equations (4) and (5) determine $\dot{\beta}$ and $\dot{\gamma}$ from μ_{des} and n_{des}.

6) Restrict the acceleration ($\dot{V}$) to keep the aircraft above stall speed, and/or within the limits imposed by drag and thrust, and by throttle rates.

3.5.3 Integration

The straightforward method of linear integration

$$\beta + \dot{\beta}\Delta t \rightarrow \beta$$
$$\gamma + \dot{\gamma}\Delta t \rightarrow \gamma$$

is obviously unsatisfactory for values of γ near $\pm 90^\circ$ (see equation (4)). Therefore an alternative method of integration has been developed based on the total angle through which the velocity vector turns.

After this, linear integration produces

$$V + \dot{V} \cdot \Delta t \rightarrow V$$

$$\dot{x} = V \cdot \cos\gamma \cdot \cos\beta$$

$$\dot{y} = V \cdot \cos\gamma \cdot \sin\beta$$

$$\dot{z} = V \cdot \sin\gamma$$

$$x + \dot{x} \cdot \Delta t \rightarrow x$$

$$y + \dot{y} \cdot \Delta t \rightarrow y$$

$$z + \dot{z} \cdot \Delta t \rightarrow z$$

$$w + \dot{w} \cdot \Delta t \rightarrow w \quad .$$

3.6 Terminal Conditions

3.6.1 Termination of Encounter

The engagement is terminated if certain conditions are met viz:

$V_M < VMIN$

$R > RMAX$

$Z < ZMIN$

$TOF > TOFMAX$

Range = Range of Closest Approach

Guidance is terminated if the following conditions prevail:

$R_{MT} < RCRVT$

$J/S > J/S\ CRIT$.

3.6.2 On-Line Kill Probability Determination

The equations for this subroutine are based on a coordinate system centered on the nose of the missile, having positive X-axis pointing forward along the longitudinal axis of the missile; positive Y-axis in the direction in which the left wing of the missile would lie if the missile had wings, and Z-axis positive so as to form a right-handed Cartesian coordinate system.

The radar fuze pattern is assumed to be a right circular cone of half-angle θ_F, centered at the origin and having its axis coincident with the X-axis. The equation of this cone is

$$X^2 \cdot \tan^2 \theta_F = Y^2 + Z^2 \quad (1)$$

The fuze is activated whenever this cone intersects a glitter point on the target within the range, R_F, of the fuze.

GENSAM updates the positions of the aircraft and the missile at intervals of Δt. The fuze subroutine is called at each time pulse. The location of the glitter point at the time the subroutine is called is $G_{NEW} = (X_{NEW}, Y_{NEW}, Z_{NEW})$. The location of the glitter point at the previous time pulse, $G_{OLD} = (X_{OLD}, Y_{OLD}, Z_{OLD})$ is also known. It is assumed that the glitter point has travelled in a straight line over the period Δt. The equations for this straight line are

$$(X - X_{NEW})/DX = (Y - Y_{NEW})/DY = (Z - Z_{NEW})/DZ, \quad (2)$$

where $DX = X_{OLD} - X_{NEW}$, $DY = Y_{OLD} - Y_{NEW}$ and $DZ = Z_{OLD} - Z_{NEW}$.

Substituting for Y and Z from equations (2) into equation (1) yields the following quadratic equation in X:

$$X^2 \cdot \tan^2\theta_F = \left[(X - X_{NEW}) \cdot DY/DX + Y_{NEW}\right]^2 + \left[(X - X_{NEW}) \cdot DZ/DX + Z_{NEW}\right]^2 \quad (3)$$

This equation, of course does not hold for $DX = 0$ or $\theta_F = \frac{\pi}{2}$. The special cases which arise from those conditions, however, are also treated by the subroutine.

In general, equation (3) has two real roots which, when substituted back into equations (2), give rise to the two points of intersection of the straight line path of the glitter point with the fuzing cone, (X_1, Y_1, Z_1) and (X_2, Y_2, Z_2). These two points must be tested to determine which, if either, represents a valid fuzing point. This testing procedure is as follows:

1) Calculate $\delta_1 = (X_{OLD} - X_1)/DX$ and $\delta_2 = (X_{OLD} - X_2)/DX$. These quantities represent the fractions of the distance between G_{OLD} and G_{NEW} that the intersection points lie. If either fraction is negative or greater than 1, then the corresponding point of intersection does not lie between G_{OLD} and G_{NEW} and must be discarded.

2) The point or points which remain are not tested to see if they are within the range of the fuze. This range depends upon the aspect of the target seen by the fuze, and is determined for each potential point by interpolation in a table based on the azimuth of the line-of-sight vector from the target to the point.

3) If both potential points satisfy criteria 1) and 2), then the point with the smaller   is picked, as this represents the earlier of the two points.

If a valid fuzing point is found, the coordinates of the corresponding burst point (X_B, Y_B, Z_B) are now calculated:

$$X_B = X_{OLD} + (-DX/\Delta t)\cdot(\delta\cdot\Delta t + \tau_D),$$

$$Y_B = Y_{OLD} + (-DY/\Delta t)\cdot(\delta\cdot\Delta t + \tau_D), \text{ and}$$

$$Z_B = Z_{OLD} + (-DZ/\Delta t)\cdot(\delta\cdot\Delta t + \tau_D),$$

where τ_D is the delay time of the fuze.

This burst point is now tested to see whether or not the fragment spray pattern of the warhead intersects the target (considered to be a single point). If the target lies within this pattern, then the kill probability is computed.

The calculation of kill probability is based on the assumptions that the missile trajectory resulting from the GENSAM simulation actually represents the center of a circular normal distribution of trajectories, and that there exists a radius, R, about the target such that a kill will occur if a trajectory approaches within that radius.

The approach distance of the trajectory to the target is given by

$$d = \sqrt{Y_B^2 + Z_B^2 + MD^2}$$

where

$$MD = f(J/S_j J/B) \text{ in a jamming environment.}$$

For computational purposes, the Bennett approximation to the circular normal distribution is used, resulting in the following expression for the kill probability:

$$P_K = \frac{R^2}{C^2} \cdot e^{-\frac{d^2}{C^2}}$$

where

$$C^2 = R^2/2 + 2 \cdot ln \cdot \rho^2$$

Here ρ is the CEP of the missile.

3.6.3 Off-Line Kill Probability Determination

The terminal encounter conditions - RCAP, approach azimuth and elevation and velocities can be stored for future use in an endgame evaluation routine.

3.6.4 Subroutine CVA

This section describes the Conceptual Vulnerability Assessment (CVA) model, which is incorporated as a subroutine. This model is based on the methodology presented in An Approach for Analytical Vulnerability Assessment, by Millard C. Mitchell and Paul Young (Report No. NADC-77303-20). This model was developed to provide the capability to rapidly calculate the vulnerability of conceptual and preliminary design aircraft to nonnuclear proximity-fuzed guided missile warhead detonations.

The model accounts for aircraft description in terms of singly and multiply vulnerable (redundant) components, and missile description in terms of warhead and fuzing parameters.

3.6.4.1 Vulnerable Component Descriptions

Each of the vulnerable components is described by the coordinates of its centroid and the presented areas of its six aspects. Provision has been made in the CVA model to automatically scale the presented areas of the vulnerable components, based on changes in the total gross weight and wing area of the aircraft. For this purpose, each component must be placed into one of four classes. These classes are:

1. Components which do not change in presented area.
2. Components for which the presented area is directly proportional to the wing loading squared.
3. Components for which the presented area is directly proportional to the gross weight to the 2/3 power.
4. Components for which the presented area is directly proportional to the wing area.

The gross weight and wing area of the actual aircraft, together with the fuselage length of the actual aircraft are also used to calculate the radius of the sphere which determines blast kill.

The tables which give the probability of a component kill given a hit on that component ($P_{K|H}$) are inputs by component, aspect, fragment mass and velocity.

3.6.4.2 Missile Input

The fragment density data for a static explosion is an input. The densities are in fragments per steradian. There are values required for angles of 0°, 10°, 20°, ..., 180° for a total of 19 entries (eight on each of the first two cards and three on the third).

The fraction by number of all fragments belonging to each mass class and the average weight of the fragments in that class are also inputs.

Two fuze options are available. Under the parametric fuze option, the burst points are assumed to occur in a series of planes equally spaced along the relative velocity vector and perpendicular to it. The user assigns to each plane a weighting factor which represents the probability of fuzing occurring at that point along the trajectory. Under the conical fuze option only one burst point occurs along each trajectory. The location of this point is determined by simulating the operation of a conical fuze.

The locations of the planes perpendicular to the relative velocity vector in which the burst points occur are determined on one input card. The planes are referenced to the plane which passes through the center of gravity of the aircraft. A plane with a positive D lies before the reference plane, a negative D means that the plane lies after the reference plane. In this sense, before and after refer to directions along the relative velocity vector of the missile. The required inputs are DMAX, the distance in feet of the first plane from the reference plane; DMIN, the distance in feet of the last plane from the reference plane; and ND, the total number of equally spaced planes to be considered. DMAX and DMIN are real variables; ND is an integer variable.

The user must assign to each plane a weighting factor which represents the probability of the explosion occuring in that plane. The weignting factors are read into the real array FREQD from [ND/8] cards.

The coordinates of the glitter points in the aircraft body system are inputs. The conical fuze option requires three constants. These are HAFANG, the half angle of the fuze in degrees; RFUZE, the maximum range at which the fuze is effective; and TD, the delay time of the fuze. They are read as real variables.

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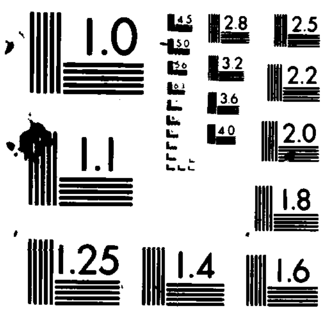


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

GENERIC SAM MODEL
LIST OF INPUTS

Scenario Inputs

TMAX	- Maximum time through which an engagement lasts (seconds).
DELT	- Time increment for integration (seconds).
MC	- Indicator for whether or not initial detection is determined by a Monte-Carlo process (0=NO,1=YES).
PRT	- Indicator for whether or not all input data shall be printed at the start of each set of runs (0=NO,1=YES).
RCT	- Indicator for whether or not a target aircraft reacts to the firing of a missile by opponent (0=NO,1=YES).
NAC	- Number of target aircraft.
NSITES	- Number of SAM sites for which data is to be read in.
NTYPES	- Number of aircraft types for which data is to be read in.
NSAM	- Number of SAM types for which data is to be read in.
DATATP	- Indicator of the format of the aerodynamic data. 1 - indicates that drag coefficient and angle of attack are given as tabular values as a function of Mach number and altitude. 2 - indicates that aerodynamic data is given in linearized form.
AREA	- Wing area (meters).
WTMAX	- Maximum combat weight (kilograms).
WTMIN	- Minimum combat weight (kilograms).
HMAX	- Combat ceiling (meters).
ETASTR	- Normal structural gee limit.
MAX MACH	- Table of maximum Mach number as a function of altitude.

CLMAX - Table of maximum lift coefficient as a function of Mach number.

IRL - Indicator of rate limitations (0=NO,1=YES).

ALDTMX - The maximum rate of change of pitch angle (degrees per second).

EMDTMX - The maximum rate of change of roll angle (degrees per second).

THDTMX - The maximum rate of change of thrust (pounds per second).

THRUSTMP - Table of thrust at military power as a function of Mach number and altitude (kilograms).

THRUSTAB - Table of thrust at full afterburner as a function of Mach number and altitude (kilograms).

FCMP - Table of fuel consumption at military power as a function of Mach number and altitude (kilograms/hour).

FCAB - Table of fuel consumption at full afterburner as a function of Mach number and altitude (kilograms/hour).

CD* - Table of drag coefficient as a function of Mach number and lift coefficient.

ATA* - Table of attack angle as a function of Mach number and lift coefficient.

Missile Inputs

DATATP - Indicator of the format of the aerodynamic data.

1 - indicates that drag coefficient and angle of attack are given as tabular values as a function of Mach number and altitude.

2 - indicates that aerodynamic data is given in linearized form.

*If DATATP is 2, the tables of CD and ATA are replaced by linearized data, as a function of Mach number only.

AREA - Missile cross sectional area (meters).

WEIGHT - Fully fueled weight of missile (kilograms).

ETASTR - Structural gee limit for the missile.

TFMAX - Maximum time of flight before missile flyout is terminated (seconds).

VMIN - Minimum velocity for missile before quitting (meters per second).

RHIT - Nominal lethal radius of the missile (meters).

CEP - Circular probable error of missile's position about simulated mean path (meters).

GUIDANCE TYPE - Represents the guidance law followed by the missile, from the following list:

1 - pursuit course
2 - proportional navigation
3 - beam guidance

SIGNAL TYPE - The type of signal required by the missile.

1 - active
2 - semi-active
3 - passive

The User should make sure that the entries for signal type and guidance type are compatible.

PN1 - Proportional navigation constant for the desired $\dot{\beta}$.

PN2 - Proportional navigation constant for the desired $\dot{\gamma}$.

RSTAR - Range between missile and target at which secondary proportional navigation constants are used (meters).

PN1STAR - Same as PN1, for use when range is less than RSTAR.

PN2STAR - Same as PN2, for use when range is less than RSTAR.

BURNTIM - Time for which missile burns (seconds).

THRUST - Nominal thrust for missile (kilograms).

FC - Nominal fuel consumption for missile (kilograms per hour).

BOOST WT	- The weight of the booster case to be separated (kilograms).
DROPTIM	- The time after launch at which separation occurs (seconds).
TIME	- Time arguments for missile throttle table.
THROTTLE	- Missile throttle setting (between 0 and 1.0) as a function of time of flight.
ALDTMX	- Maximum rate of change of pitch angle for the missile (degrees per second).
EMDTMX	- Maximum rate of change of roll angle for the missile (degrees per second).
CLMAX*	- Table of maximum lift coefficient for the missile as a function of Mach number and altitude.
CD*	- Table of drag coefficient for the missile as a function of Mach number and lift coefficient.
ATA*	- Table of attack angle for the missile as a function of Mach number and lift coefficient.
VLAUNCH	- Initial velocity of the SAM at the point of launcher separation (meters/second). (May be zero.)

Initial Condition Inputs

WEIGHT	- Initial weight of the target aircraft. This must lie between the values of WTMAX and WTMIN for the aircraft type (kilograms).
ALTITUDE	- Initial altitude of the target aircraft. This must be less than the value of HMAX for the aircraft (meters).
VELOCITY	- Initial velocity of the target aircraft. This must not exceed the maximum Mach number at the initial altitude (meters/second).

*If DATATP is 2, the tables of CLMAX, CD and ATA are replaced by linearized data as a function of Mach number only.

Battle Management Inputs

Subroutine UNAWARE

For each ground sensor:

RMAX - The maximum coverage range (meters).

THETAMAX - The maximum azimuth coverage (degrees).

THETAMIN - The minimum azimuth coverage (degrees).

PHIMAX - The maximum elevation coverage (degrees).

PHIMIN - The minimum elevation coverage (degrees).

HMAX - The maximum vertical coverage (meters).

HMIN - The minimum vertical coverage (meters).

Subroutine AWARE

RZERO - Radar system detection performance parameter (meters).

SIGMA - Aircraft radar cross-section, a function of azimuth and elevation in aircraft body coordinate system (m^2 over $1m^2$).

IRZERO - Infrared system detection performance parameter (meters).

IRSIGMA - Aircraft infrared irradiance, a function of azimuth and elevation in target body axis coordinate system (watt/steradian over 1 watt/steradian).

Subroutine ACQUIRE

TACQ1 - A time delay required to establish acquisition.

TACQ2 - A time delay

Subroutine DECM1

PJ - The transmitted jamming power density (watts).

GJ - The jamming antenna gain.

PI - The transmitted radar power (watts).

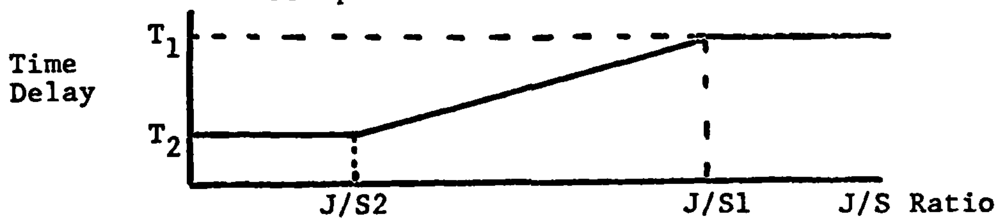
GT - The radar transmitter gain.

L - Totality of radar transmission, atmospheric and reception loss factors.

BJ - Jammer bandwidth (cycles).

BR - Radar bandwidth (cycles).

J/S1,J/S2, T1,T2 - Critical values of J/S in relationship of time delays for acquisition in the presence of deception ECM:



Subroutine NECM1

RBT=RSS - The noise jamming burnthrough or self-screening range.

K - A scaling factor relating jamming and radar parameters to RBT.

Subroutine TRACK

TRMAX - The maximum tracking range of the tracking system.

TRTHMAX - The maximum azimuth tracking angle in a fixed coordinate system (degrees).

TRTHMIN - The minimum azimuth tracking angle in a tracker fixed coordinate system (degrees).

TRPHIMAX - The maximum elevation tracking angle (degrees).

TRPHIMIN - The minimum elevation tracking angle (degrees).

TRHMAX - The maximum vertical tracking coverage (meters).

TRHMIN - The minimum vertical tracking coverage (meters).

TRRZERO - A parameter characterizing track radar lock-on range performance (meters).

TRIRZERO - A parameter characterizing infrared lock-on range performance.

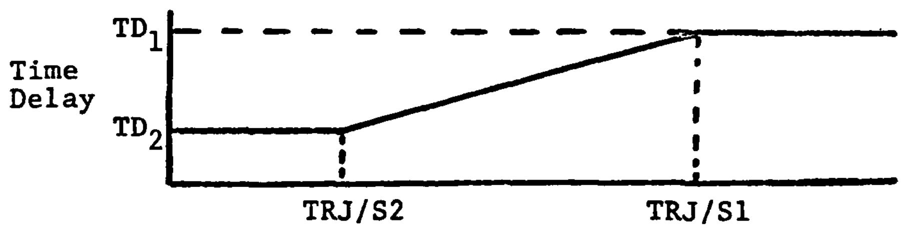
TRTHDOT - Azimuth angular tracking rate limit (degrees/second).

TRPHIDOT - Elevation angular tracking rate limit (degrees/second).

TD1 - A minimum time required to perform the tracking function (seconds).

Subroutine DECM2

TRJ/S1, TRJ/S2, TD1,TD2 - Critical J/S ratios and delay times associated with tracking radars subjected to deception jamming.



Subroutine NECM2

TD2 - A track delay associated with noise jamming situations wherein only strobe information is available (seconds).

Subroutine LAUNCH

LTHDOT - Maximum launcher azimuth angle slewing rate (degrees/sec)

LPHIDOT - Maximum launcher elevation angle slewing rate (degrees/se

LRMAX - Maximum target range at launch (meters).

Subroutine AIR BATTLE

RMDET - The maximum detection range of an airborne missile approach detection device (meters).

THHIMDET - The maximum azimuth coverage angle of a missile approach detection device (degrees).

THLOWMDET - The minimum azimuth coverage angle of a missile approach detection device (degrees).

PHIHIMDET - The maximum elevation coverage angle of a missile approach detection device (degrees).

PHILOWMDET - The minimum elevation coverage angle of a missile approach detection device (degrees).

SMD - A time delay prior to subsequent actions associated with the unanticipated detection of an approaching missile (seconds).

RMLDET	- The maximum range of a missile launch detection device (meters).
THMAXML	- The maximum azimuth coverage angle of a missile launch detector (degrees).
THMINML	- The minimum azimuth coverage angle of a missile launch detector (degrees).
PHIMAXML	- The maximum elevation coverage angle of a missile launch detector (degrees).
PHIMINML	- The minimum elevation coverage angle of a missile launch detector (degrees).
SLTD	- A delay prior to subsequent actions associated with unanticipated detection of a missile launch (seconds).
RTRDMAX	- The maximum range of a track radar detection device(m)
RTRDTH1	- The maximum azimuth coverage angle of a track radar detection receiver (degrees).
RTRDTH2	- The minimum azimuth coverage of a track radar detection receiver (degrees).
RTRDPH1	- The maximum elevation coverage angle of a track radar detection receiver (degrees).
RTRDPH2	- The minimum elevation angle of a track radar detection receiver (degrees).
STRTD	- A delay prior to subsequent actions associated with unanticipated detection of a track radar (seconds).
RSDMAX	- Maximum coverage range of a surveillance radar detector (meters).
RSTAMAX	- The maximum azimuth coverage angle of a surveillance radar detector (degrees).
RSTHMIN	- The minimum azimuth coverage angle of a surveillance radar detector (degrees).
RSPHMAX	- The maximum elevation coverage angle of a surveillance radar detector (degrees).
RSPHMIN	- The minimum elevation coverage angle of a surveillance radar detector (degrees).
ACQDELAY	- A delay time prior to subsequent actions associated with the detection of a surveillance radar (seconds)

Subroutine AIR AWARE

Subroutine AVOID

AVMAN - A designation of avoidance maneuver.

TMAND - A delay time prior to commencement of air avoidance maneuver (seconds).

Subroutine DECEIVE

TDDECM - A time delay prior to initiating DECM (seconds).

TDNECM - A time delay prior to initiating NECM (seconds).

Subroutine EVADE3

TTMIN - A minimum time for the attacker to "track" a track radar, once detected (seconds).

ORDREL - A point on the attacker's trajectory where ordnance release occurs.

TBMAN - An attacker maneuver suitable for track break.

θ - Aspect angle in aircraft body system measured from nose; $90<\theta<270$ implies a rearward threat (degrees).

PJDECM - The total radiated power of a track radar DECM device (watts).

AZHIDECM - Upper azimuth value of a track radar DECM radiation pattern (degrees).

AZLODECM - The lower azimuth value of a track radar DECM radiation pattern (degrees).

ELHIDECM - The upper elevation limit of the track radar DECM radiation pattern (degrees).

ELLODECM - The lower elevation limit of the track radar DECM device (degrees).

PJNECM - The total radiated power of a track radar NECM device (watts).

AZHINECM - The upper azimuth limit of a track radar NECM radiation pattern (degrees).

AZLONECM - The lower azimuth limit of a track radar NECM radiation pattern (degrees).

ELHINECM - The upper elevation limit of the track radar NECM radiation pattern (degrees).

ELLONECM - The lower elevation limit of the track radar NECM device (degrees).

GJNECM - The antenna gain factor for NECM.

GJDECM - The antenna gain factor for DECM.

Subroutine EVADE2

LEVMAXN - The number of evasive maneuvers suitable in missile launch situations.

- X=0 - No maneuver.
- X=1 - Tail chase maneuver.
- X=2 - Frontal approach maneuver.
- X=3 - IR missile maneuver.

MAXFLAR - The maximum number of IR flares carried on aircraft.

EJRATE - The rate at which flares are ejected when flare ejection is warranted (seconds^{-1}).

Subroutine EVADE1

MEVMAXN - A type of missile approach evasive maneuver.

- X=1 - Rearward approaching radar guided missile.
- X=2 - Forward approaching radar guided missile.
- X=3 - Infrared guided missile.

Missile Guidance Inputs

GUIDANCE TYPE - Infrared, command, or semi-active.

PJ - Jammer radiated power (watts).

GJ - Jammer antenna gain factor.

PB - Beacon radiated power (watts).

GB - Beacon antenna gain factor.

PT - Tracking radar transmitted power (watts).

GT - Tracking radar transmitted antenna gain factor.

L - Tracking radar combined loss factors.

BR	-	Bandwidth of tracking radar.
BJ	-	Jammer bandwidth.
σT	-	Aircraft radar cross-section.
ST	-	Aircraft infrared irradiance.
IRZERO	-	IR tracker optics performance factor.
f(R,T)	-	A function of range and optical transmissivity which is correction term in IR range equation.

CVA Inputs

ACTA	- Wing area of actual aircraft (square meters).
ACTW	- Total gross weight of actual aircraft (kilograms).
ACTYPE	- Aircraft name.
AFL	- Aircraft fuselage length (meters).
ALT	- Altitude of aircraft (meters).
AZMAX	- Maximum azimuth which delimits approach sector (degrees, converted to radians internally).
AZMIN	- Minimum azimuth which delimits approach sector (degrees, converted to radians internally).
B	- Air blast factor, comparing the actual explosive energy to that of pentolite.
BASEA	- Wing area of base aircraft (square meters).
BASEW	- Total gross weight of base aircraft (kilograms).
CDR	- Sea level slowdown constant (grams $^{1/3}$/meter).
DMAX	- For parametric fuze, distance of first plane in which burst points occur from reference plane (meters).
DMIN	- For parametric fuze, distance of last plane in which burst points occur from reference plane (meters).
ELMAX	- Maximum elevation which delimits approach sector (degrees, converted to radians internally).
ELMIN	- Minimum elevation which delimits approach sector (degrees, converted to radians internally).
FRACT(IW)	- Fraction by number of all fragments belonging to mass class IW.
FREQD(I)	- For parametric fuze, weighting factor for the Ith plane. Probability that the explosion occurs within DELTAD/2 of that offset.
FREQR(I)	- Weighting factor for the Ith offset. Probability that the miss distance lies within DELTAR/2 of that offset.
HAFANG	- Half-angle of the conical fuze (degrees, converted to radians internally).

MSTYPE	- Missile name.
NC	- Number of vulnerable components.
ND	- For the parametric fuze, the number of planes.
NDUBLY	- The number of pairs of doubly vulnerable components.
NG	- For the conical fuze, the number of glitter points.
NR	- Number of offsets.
NTHETA	- Number of trajectories around the circle at each non-zero offset.
NTRAJ	- Number of missile velocity vectors to be chosen at random from the approach sector.
NW	- Number of fragment mass classes.
PA(I,J)	- Presented area of the Ith aspect of the Jth component (square meters).
PKH(I,J)	- Probability of a component being killed given that it is hit. The index I represents 11 levels of net striking speed. The index J combines aspect, fragment mass class and component.
RFUZE	- Maximum range of the conical fuze (meters).
RMAX	- Maximum miss distance to be considered (meters).
STEAR(I)	- Static fragment density. The index I runs over the 19 angular intervals centered at the angles 0^{o}, 10^{o}, 20^{o}, ..., 180^{o} (fragments/steradian).
TD	- Delay time of the conical fuze (seconds).
VA	- Velocity of the aircraft (meters/second).
VE	- Static emission speed of the fragment (meters/second).
VM	- Velocity of the missile (meters/second).
VNETHI	- Normalizing velocity for $P_{K\|H}$ inputs. Values of $P_{K\|H}$ are read for each of the 11 net striking velocities corresponding to 1, o.1, o.2, . ., 1.0 times VNETHI (meters/second).

WEIGHT(IW)	- Average weight of fragments in mass class IW (grams).
WHE	- Charge weight of the missile warhead (kilograms).
X(I)	- X-coordinate in the aircraft system of the Ith vulnerable component (meters).
XG(I)	- X-coordinate in the aircraft system of the Ith glitter point (meters).
XM	- Metal weight of the missile warhead (kilograms).
Y(I)	- Y-coordinate in the aircraft system of the Ith vulnerable component (meters).
YG(I)	- Y-coordinate in the aircraft system of the Ith glitter point (meters).
Z(I)	- Z-coordinate in the aircraft system of the Ith vulnerable component (meters).
ZG(I)	- Z-coordinate in the aircraft system of the Ith glitter point (meters).

END

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