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A WILD WEASEL PENETRATION MODEL

THESIS

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by

Kenneth C. Anderson  
Major USAF

Ronald B. Nenner  
Major USAF

Graduate Strategic and Tactical Sciences

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Abstract

Defense suppression of enemy ground forces is basic to successful counterair objectives. The F-4G Wild Weasel (WW) weapon system provides the teeth in getting the defense suppression job done--identifying, locating, and killing enemy ground based threat radars. The objective of this thesis was to develop a methodology that could examine and evaluate the WW defense suppression mission. The problem was developed for a NATO/Warsaw Pact encounter in Central Europe.

A model of the threat environment was built using the SLAM computer simulation language. Threats in the defense sector can be moved as desired. Friendly aircraft can enter the system at a variety of intervals, altitudes, and airspeeds. Wws hunt for threats to attack by searching, identifying, locating, and then launching their weapons at the threat. WW tactics can be changed as the requirements of the mission dictate or at the desire of the WW crew. Self-protection jamming can be selected by either WW or attack aircraft. Enemy threats will fire at an aircraft when the aircraft comes within the threat's range as long as the threat is not engaged with another aircraft. Early warning radars account for threat radar

command and control functions; their control over the associated radars can be changed as desired.

Changing the WW's altitude from 60 meters to 200 meters did not effect friendly attack aircraft survivability. Leading the attack force into the threat area by 30 seconds as opposed to accompanying the attack force did not influence attack force survivability. Further development of the model to include turn-mode capability for the WW weapon and a tactic for pre-emptive weapons launch in anticipation of threat radar radiation is recommended.

## A WILD WEASEL PENETRATION MODEL

### I. Introduction

#### Background

The requirement for a weapon system that would deal exclusively with the surface-to-air missile (SAM) threat developed from air battles in the Vietnam War. The North Vietnamese used Soviet SA-2 SAMs in concert with AAA and MIG aircraft to counter a numerically superior air force. To counter these tactics, the USAF developed the F-100/F-105 Wild Weasel (WW), a weapon system dedicated to the anti-SAM mission.

The current strategy of the Soviet Union and Warsaw Pact countries emphasizes air doctrine through their ground forces to gain superiority on the battlefield (Ref 6:69). Their extensive, sophisticated mobile air defenses, consisting of mixes of guns and missiles, provides overlapping coverage. The net effect is a wide-ranging, protective umbrella for their ground forces.

NATO's task in a confrontation against the Warsaw Pact will be the ultimate test of its airpower capabilities. Counterair operations must gain air superiority over the battlefield if ground forces are to be effective.

USAF Basic Doctrine, AFM 1-1, recognizes this important requirement and now includes defense suppression, along with offensive and defensive counterair operations, as a primary task within the counterair mission (Ref 1:2-16). Defense suppression is a fundamental objective for an effective air-ground force.

The WW weapon system represents a key element in the defense suppression mission. The F-4G aircraft, the current WW used by the USAF, can accomplish defense suppression objectives against threat radar systems by either physically destroying the radars with anti-radiation missiles (ARMs) or bombs, or by causing the radars to cease operation as a precaution against an attack by the WW.

If the F-4G WW is the ideal airpower instrument for suppressing enemy air defenses then the question remains as how best to use this tool to maximum effectiveness. In light of the fact that both the F-4G and its specialized ARM weapons are very limited resources, WW operations must be effective preventing threat radars from attacking friendly aircraft while at the same time surviving attack from these very same radars. The highly fluid arena of the air-ground battle coupled with the expected heavy concentration of enemy radar threats and the diversity of their employment make WW operations a complex and difficult task.

In planning for a defense suppression mission not only must many different factors be considered but also the

underlying relationships between them clearly understood. Aspects such as ARMs employment, force sizing, ingress/egress routing, threat hierarchy, electronic countermeasures, and command and control must be carefully thought out and planned for. In addition, defense suppression operations must be amenable to last-second changes as a result of the evolving air battle.

Needless to say, choosing the best tactic or best set of tactic options for WW operations is not easy. Nonetheless, if counterair operations are to be successful then neutralizing enemy air defenses must be accomplished by WWs using optimum defense suppression tactics.

An analysis for the most advantageous weapons allocation and tactics that explicitly evaluates the WW as a complete system has yet to be accomplished. Although no single weapon system can be expected to successfully counter every aspect of a highly sophisticated threat environment, the F-4G's WW defense suppression effectiveness is a major factor upon which the USAF's counterair mission rests.

#### Problem Statement

The ability of WWs to perform defense suppression operations in a radar-rich threat environment is basic to successful counterair operations. The objective of this thesis is to develop a methodology, through a simulation

model, for evaluating the WW defense suppression mission. In particular, the methodology should be capable of analyzing force sizing, ARM configurations, and WW tactics. These parameters were selected because they are considered significant areas that impact on the WW mission (Refs 10; 11).

#### Assumptions and Limitations

Conclusions from this thesis can only be applied within the context of the developed system. Thus, because of the complexity of the WW defense suppression operations, not all components and variables of the system are included. It should be noted that only WW defense suppression operations, and not any other WW mission, are analyzed in this research effort.

The following major assumptions and limitations apply to the system.

1. WWs carry only ARMs. For other types of missions WWs may operate in a mixed-mode configuration (ARMS and hard bombs) or with only hard bombs. For the escort-type scenario in this thesis only ARMs are used.
2. Self-protection jamming is used only by attack aircraft. Jamming pods for WWs are available but are not used.
3. Once a WW begins an attack, the attack is continued until the WW launches an ARM at the threat or the WW is killed.

4. WVs have perfect inter-aircraft radio communications. Although this assumption is open to debate, secure voice radio equipment may insure it.

Results of the thesis are only useful for making relative comparisons between alternatives evaluated. When five out of ten aircraft are predicted to survive for a particular simulation run, given one set of conditions, and only one survives for another set of conditions, the important result is the comparison between the alternatives not the number of surviving aircraft.

#### Threat Scenario

A WV-threat environment was developed based on confrontation between NATO and Warsaw Pact in Central Europe. The threat consists of a typical Soviet ground army deployed along the forward edge of the battle area (FEBA). A force of WVs are assigned the task of defense suppression in support of a low-level fighter attack force that will penetrate the FEBA and fly through the enemy defenses to strike a target behind enemy lines. For the scenario the WVs can realize their defense suppression objectives by destroying ground-based threat radars or associated early warning (EW) radars.

The air defense elements of a typical Soviet Army, located within an area 50 kilometers wide by 100 kilometers long, consists of approximately 1000 SAMs and AAA units.

Concentrated close to the FEBA will be hundreds of small arms. However, weapons that require optical information to acquire and track targets are marginally effective against high speed, maneuvering aircraft. In addition, Soviet interceptors are hypothesized not to be a factor for the low altitude attack force as their doctrine prescribes operation along the FEBA at or above 10,000 feet, leaving the ground forces responsibility for the air superiority mission up to this altitude (Ref 6:70).

For these reasons the following defense elements were selected as potential threats to the attack force.

1. AAA
2. SAM-A
3. SAM-B
4. SAM-C
5. SAM-D

Command and control of threat radars is represented by EW radars. For this particular threat environment there are eight of these radars positioned in the defense sector.

#### Structural Model

Figure 1 is the structural model of the air defense developed within the constraints of the scenario. Threats are located in belts that approximate their expected position. Their actual position, however, will depend on battlefield tactics, terrain features, employment

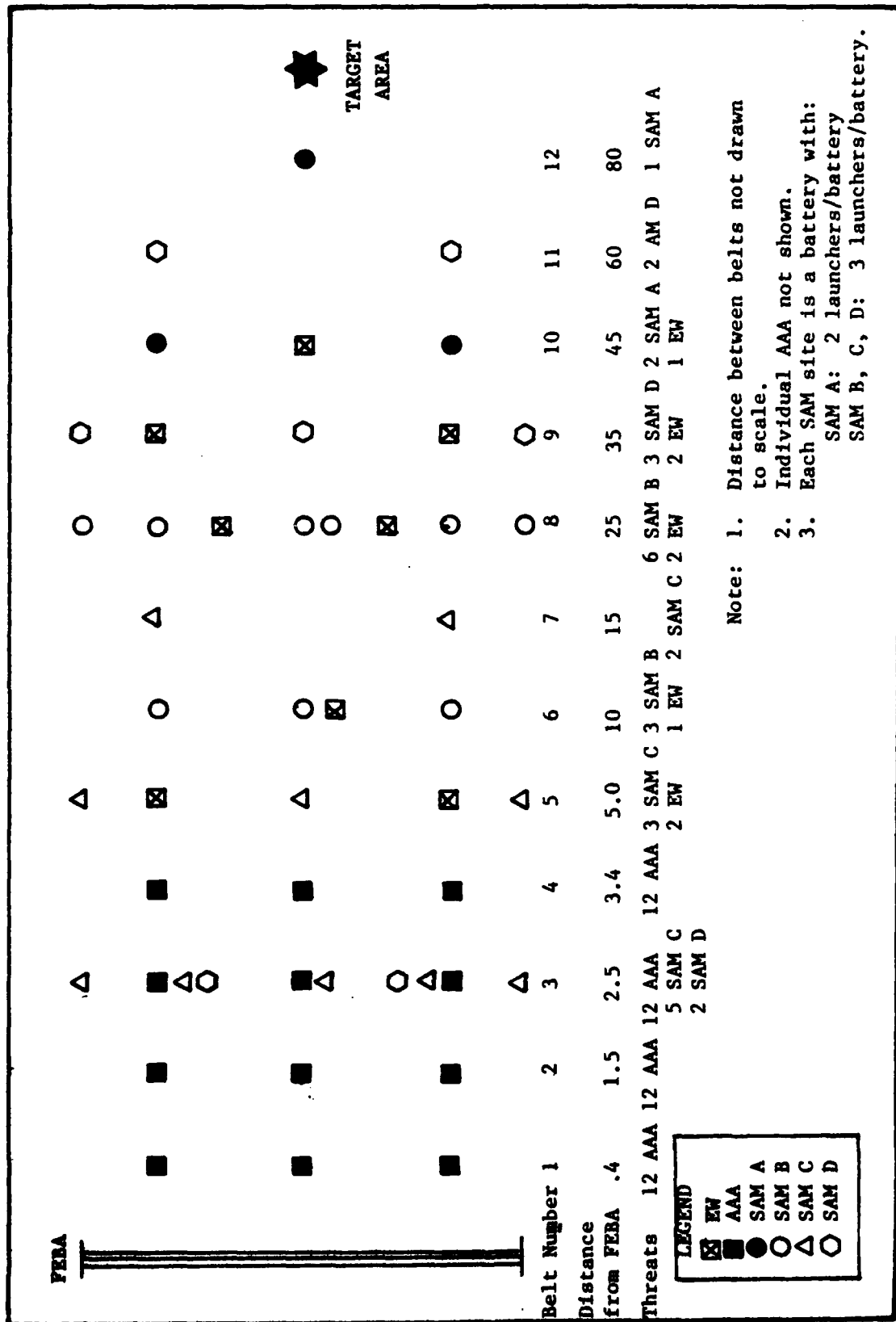


Fig. 1. Structural Model of Defensive Network

doctrine, etc. Note that the number of each threat is specified in Figure 1 but not exact location.

The enemy's area of operation behind the FEBA is modeled by a single line of communication (LOC) road network extending from the target area to the FEBA. The LOC's layout depends on the area's terrain features and the requirements to carry equipment and supplies to the front line. The attack force will avoid any major LOC due to the probable concentration of weapons along it. Accordingly, the LOC for the scenario is hypothesized to lie at the upper portion of the defense area. Figure 2 depicts a typical LOC.

#### Methodology

WW defense suppression operations are considerably complex involving many dynamic component interactions. Sets of threat radars search for, acquire, track, and attack aircraft that fly through their defense sector. Wws search for, identify, locate, and launch their weapons at threat radars while maneuvering in the battle area. Attack aircraft penetrate then fly through the threat scenario enroute to a target far behind enemy lines.

Because of the complexity of the WW system and the need to study the intricate interplays of the system components, a computer simulation model of the WW defense suppression mission was developed. Simulation was chosen

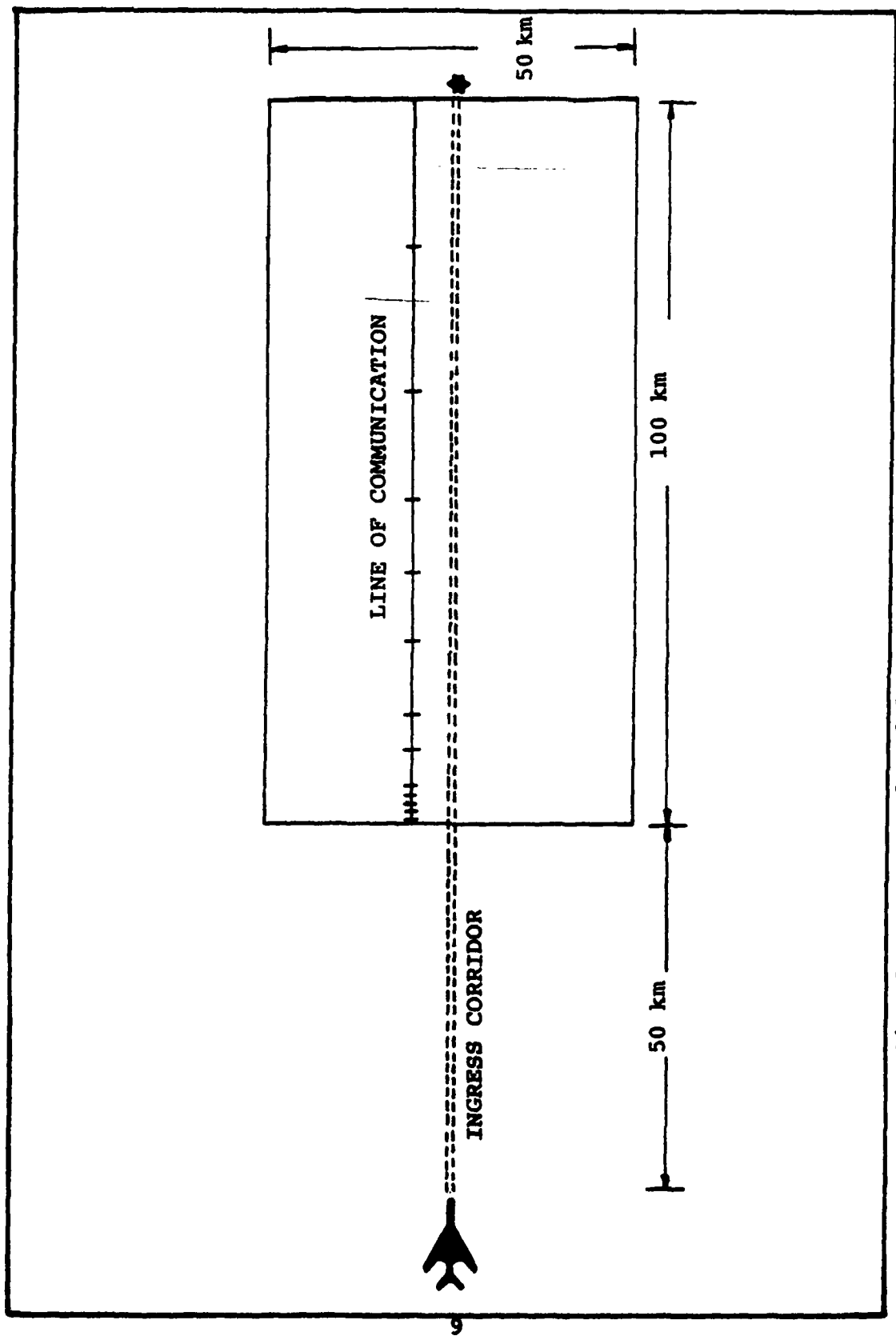


Fig. 2. Structural Model and Lines of Communication

because the problem lends itself to this methodology. Shannon lists several conditions when simulation should be considered for use; two of these cast a strong vote for the defense suppression problem.

1. A complete mathematical formulation of the problem does not exist or analytical methods of solving the mathematical model have not yet been developed.

2. Simulation may be the only possibility because of the difficulty in conducting experiments and observing phenomena in their actual environment (Ref 14:11).

An added and perhaps equally important advantage is that with simulation the complex system under investigation can be expressed in elementary events (Ref 12:3). By formulating the simulation and thus the problem in terms of elementary events complex interactions such as those in the WW defense suppression system can be synthesized.

SLAM was chosen as the simulation language because of the power and flexibility it offered. The dynamic portrayal of the WW attack as well as the threat radar-aircraft interactions were accurately represented through the use of SLAM's language and concept of process orientation. These features will be discussed in detail in Chapter III.

## Overview

The thesis is explained in detail in the following chapters. The system structure of the model and the basic components that make up the system are discussed in Chapter II. The simulation model is explained in a logical, sequential manner in Chapter III. In Chapter IV, data collection, experimental design, the results of the experiment, and the validation of the experiment are all discussed. Finally, the results of the thesis are covered in Chapter V and recommendations for follow-on areas are listed in Chapter VI.

## II. Systems Structure

### Introduction

The purpose of this thesis is to develop a model for investigating the interaction between a friendly aircraft force penetrating the forward edge of the battle area (FEBA) to strike targets in a rear area and the enemy air defense network responsible for preventing this penetration. Two elements comprise the friendly force: a strike force of fighter aircraft and WW aircraft employed in a defense suppression mission. The air defense network is composed of SAM, AAA, and early warning (EW) systems. Possible interaction between the elements include the following:

1. The WW attack and attempt to neutralize any of the air defense systems. Neutralize includes either physically destroying the site or stopping them from radiating.

2. The air defense systems attempt to destroy both strike and WW aircraft penetrating the FEBA.

The model will be used to study specific strike force and WW tactics such as ingress altitude, airspeed, and spacing between aircraft with the ultimate intent of developing procedures designed to increase the overall probability of the strike force successfully penetrating to

the target area. The model must be flexible enough to allow both the size and mix of both friendly and enemy forces to be varied.

Pertinent to the model's development are the major system elements required to describe the system. These elements are the following:

1. The WW aircraft, its associated characteristics and tactics,
2. The strike force, and
3. The enemy defensive network.

This chapter discusses each element separately and in detail. It explains the analytical methodology required by each element to perform its mission.

#### Wild Weasel Mission Scenario

Today's WW platform is a modified F4-G aircraft containing sensitive radar homing and warning (RHAW) equipment. The WW crew's mission is to search the enemy's area of operation, detect and identify enemy radar signals associated with SAMs, AAA, or EW systems, and force these radars to cease operation by either physically destroying the site with bombs or antiradiation missiles (ARMs) or by causing the sites to stop radiating to preclude being attacked by a WW.

Leek and Schmidt investigated the FEBA penetration and the associated enemy defense network by a flight of

strike aircraft and evaluated the loss rates incurred in the penetration. This thesis extends their analysis by including WW aircraft employed in a defense suppression mission and again evaluates the loss rates of both strike and WW aircraft. In this scenario specific threat locations will not be known before the mission by the WW crews although estimates of the number and type of enemy radars will be provided by intelligence briefings. The WW knows the corridor used by the strike force during ingress to the target. This, along with projected capabilities of the enemy radars, allows the WW to estimate an approximate distance either side of the attack corridor a specific SAM or AAA can be located and constitute a threat to the strike force.

Figure 3 depicts the four phases of a typical WW mission profile: search, detection, ranging, and attack. The figure illustrates the dynamic nature of the scenario. For the mission, the WW aircraft assemble 50 km prior to the FEBA and over friendly airspace. In the search phase the WW proceeds toward the enemy defenses, its RHAW equipment sweeping through radar frequencies attempting to detect and identify enemy radar signals. At detection, the RHAW system alerts the crew to the type of threat, the bearing to the site from the aircraft, and an approximate distance to the threat radar. The WW's onboard processor will refine the site's location to within a few meters during the

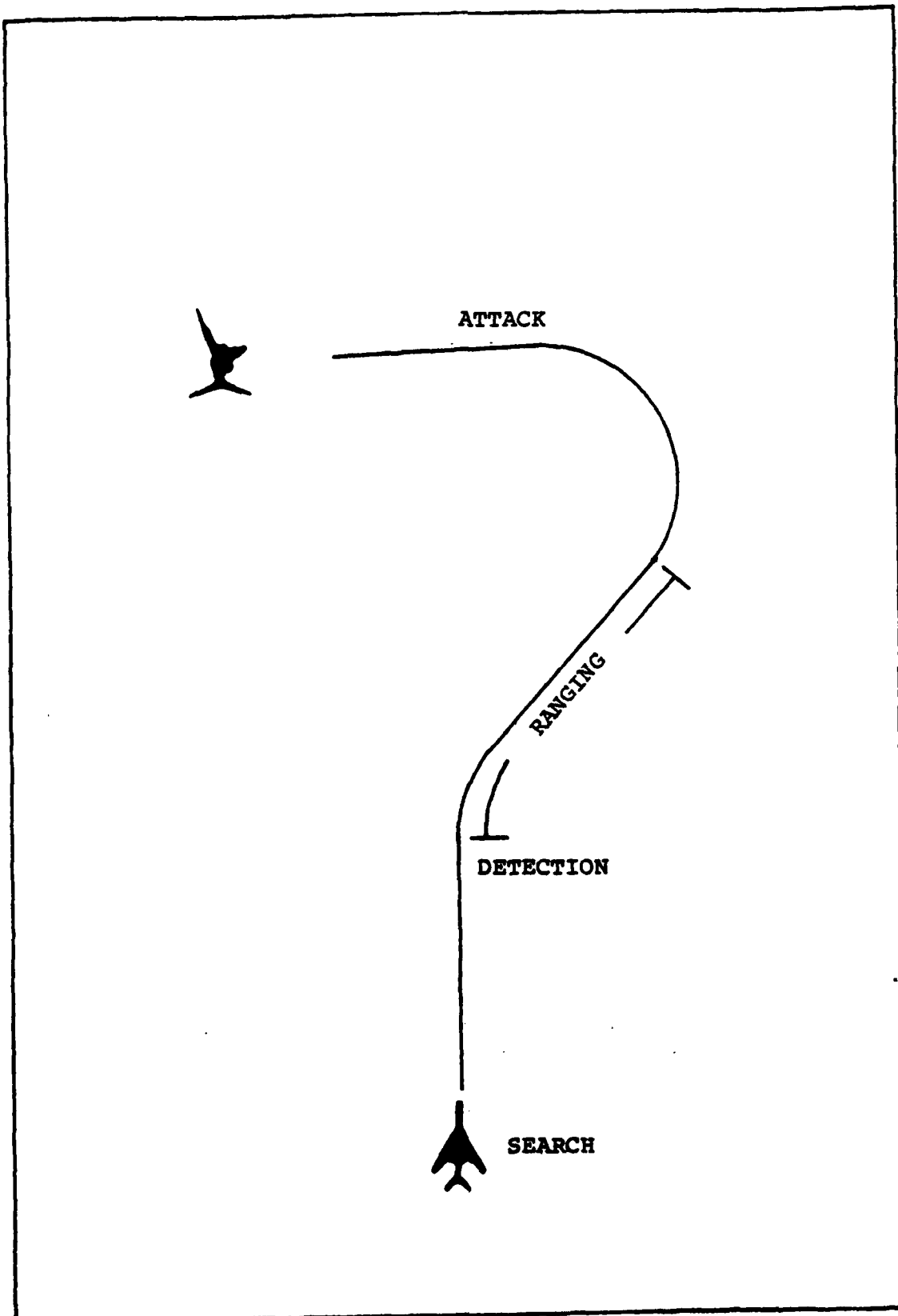


Fig. 3. Wild Weasel Defense Suppression Mission Scenario

ranging phase. Here, the system calculates numerous lines of position (LOP) between the aircraft and the radar site as the aircraft flies through approximately 30 degrees of bearing change. The site's location is estimated to be the intersection of the LOPs. The more LOPs, the more precise the site's location. After completing the ranging routine, the aircraft enters the attack phase by turning toward the site, and for this profile, launching an ARM. After launch the aircraft enters the next search sequence and the process repeats until the WW depletes all its ARMs.

Implicit within the profile description are several areas that must be determined during the mission. Did the search phase start while the threats were beyond the field of view (FOV) of the aircraft or when the sites were inside the FOV? Did the WW maneuver in a direction that allowed it to minimize the amount of time required to complete each profile? What happens if the attack phase occurs inside the minimum launch range of an ARM? These questions and the logic required to evaluate them will be addressed in the following paragraphs.

#### Threat Detection Criteria

The WW search phase begins well before the FEBA. The minimum distance the WW can detect specific ground-based emitters is limited by either the RHAW receiver's sensitivity or the radar horizon (or FOV) of the aircraft.

Receiver sensitivity indicates the minimum power signal at the aircraft's RHAW receiver that can be processed by the equipment. In certain instances either sensitivity or limited FOV dominates the other in determining the maximum detection range. Which one dominates in the WW case will now be determined.

An aircraft's radar horizon depends on its altitude. The earth's curvature limits the radar horizon of either a transmitter or receiver. (See Figure 4.) The horizon can be approximated by the following equation:

$$R = .868 \sqrt{2h} \quad (1)$$

where  $h$  = aircraft's altitude, feet; and

$R$  = radar horizon, NM (Ref 5:36).

Converting both  $R$  and  $h$  to meters, the equation becomes:

$$R = 4117.3 \sqrt{h} \quad (2)$$

where  $h$  = aircraft's altitude, m; and

$R$  = radar horizon, m.

Thus, an emitter at a height of 60 meters could detect objects out to 32,000 meters (disregarding clutter and terrain blockage). Objects at some height above the earth's surface beyond this 32,000 meter range could extend this detection distance. For example, the same emitter at

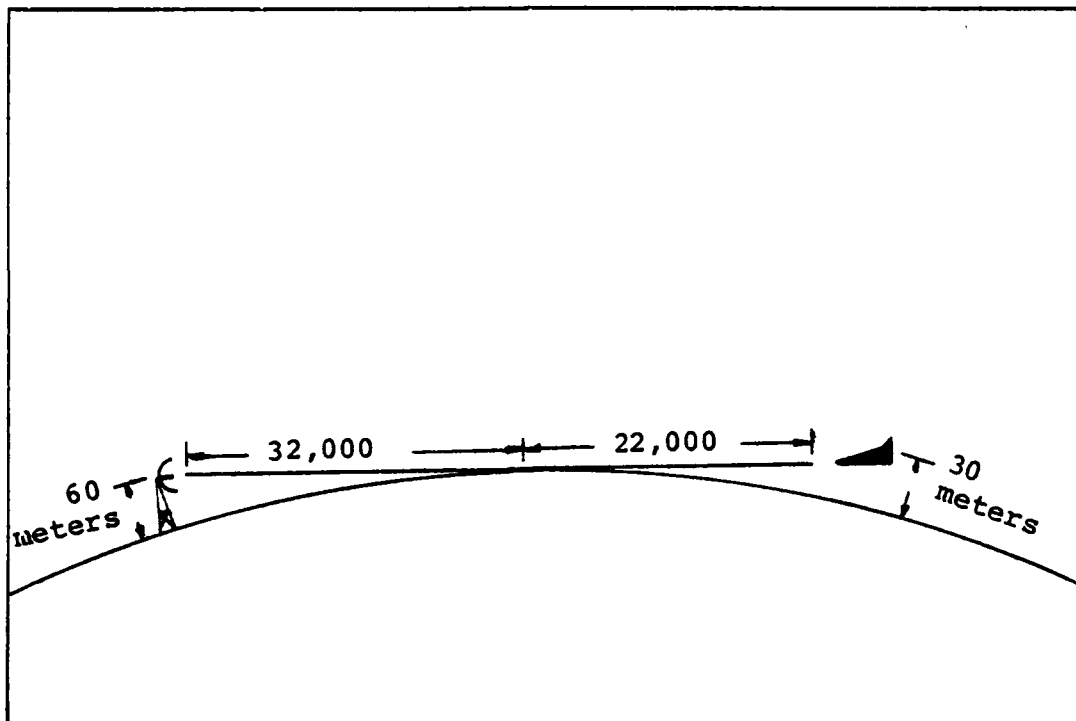


Fig. 4. Radar Horizon

60 meters could detect an object at a height of 30 meters out to 54,000 meters (again disregarding clutter and terrain blockage). For ground based emitters with antenna extending less than 10 meters above the surface, the radar horizon calculations of equation (2) appear sufficient for this model.

Power received at the aircraft,  $P_r$ , is proportional to the radar's effective radiated power reaching the WW aircraft ( $P_t G_t$ ) and the WW effective antenna area,  $A_e$ , where  $P_t$  is the transmitted power in watts and  $G_t$  is the transmitting antenna signal gain in the direction of the WW aircraft.  $A_e$ , in square meters, can be approximated as follows:

$$A_e = \left(\frac{c}{f}\right)^2 \frac{G_r}{4\pi} \quad (3)$$

where  $c$  = speed of light, meters per second (mps);

$f$  = radar transmit frequency, in Hertz (Hz); and

$G_r$  = WW receiver antenna gain (Ref 5:18).

For the case of the WW receiver antenna, the gain will be assumed to be one, or the antenna is omnidirectional. Power received at the aircraft is inversely proportional to the receiver's internal losses,  $L$ , and the square of the distance between the site and the aircraft,  $R$ . Expressed mathematically,  $P_r$  becomes:

$$P_r = \left(\frac{P_t G_t}{4\pi R^2}\right) \left(\frac{c}{f}\right)^2 \left(\frac{G_r}{4\pi L}\right) \quad (4)$$

where all terms are as previously defined (Ref 5:18).

A RHAW receiver is designed to a sensitivity specification determined by the type of signals radiated in the receiver's working environment. Once designed, the minimum sensitivity cannot be changed. If the receiver is too sensitive the processor will be saturated by too many signals; not sensitive enough and many threats will not be detected by the WW until the aircraft is too close to the site. Receiver sensitivity is expressed in decibels (dB) referenced to a specific power level. For this thesis, the reference will be 1 watt and the sensitivity expressed

as dB, watts or dBw. Converting a parameter such as radiated power to dBw is accomplished as follows:

$$P_{t_{dBw}} = 10 \log_{10} (P_{t_{watts}}) \quad (5)$$

Converting all of the terms of the  $P_r$  equation yields:

$$P_{r_{dB}} = P_{t_{dB}} + G_{t_{dB}} + 2(c)_{dB} - 2(4\pi)_{dB} - 2(R)_{dB} - L_{dB} - 2(f)_{dB} \quad (6)$$

For a given aircraft/radar encounter all terms in the  $P_r$  calculations can be assumed to be constant except  $P_r$ ,  $R$ , and  $G_t$ . Table I depicts typical values for  $P_r$ ,  $f$ , and  $L$  in the FEBA. Rearranging equation (6) and solving for  $G_t$  in terms of  $P_t$  and  $R$  yields:

$$G_{t_{dB}} = 2(R)_{dB} - P_{t_{dB}} + 2(4\pi)_{dB} + P_{r_{dB}} + L_{dB} + 2(f)_{dB} - 2(c)_{dB} \quad (7)$$

where all terms are as previously defined.

TABLE I  
AVERAGE SYSTEM PARAMETERS

Parameter	Normal Units	Decibels (dBw)
Transmit Power, $P_r$	50-100 kw	47-50
Radar Frequency, $f$	10-15 GHz	100-102
System Losses, $L$	-	10

Setting  $P_r$  to the receiver sensitivity,  $S$ , at the aircraft, equation (7) becomes an equation for  $G_t$  in terms of  $R$  alone. A receiver sensitivity of -100 dBw is both technologically feasible and operationally effective. Setting  $P_r$  to -100 dBw equation (7) becomes:

$$G_{t_{dB}} = 2(R)_{dB} - 80.6 \text{ dB} \quad (8)$$

As a limit of the  $G_t$  required to process a signal assume  $R$  is the radar horizon of an aircraft flying at an altitude of 100 m ( $R = 41,173$  m or 46.15 dB). Solving equation (8) for  $G_t$  yields:

$$G_{t_{dB}} = 92.3 - 80.6 = 11.7 \text{ dB} \quad (9)$$

Typical values for the main beam  $G_t$  near the FEBA are 40 dB with an average sidelobe gain 20 dB down from this maximum, or the average sidelobe  $G_t$  of 20 dB. Since the receiver requires only 11.7 dB (or 28.3 dB below maximum) at the radar horizon, the system could identify radars when receiving sidelobe level energy signals or, stated another way, the receiver could process radar signals from an emitter where the antenna main beam is randomly oriented with respect to the WW. For this reason, the aircraft's FOV and not the receiver sensitivity limits the WW in detecting threat radars in this model.

### Wild Weasel Heading System

The continuous time model allows the WW aircraft to maneuver in response to a threat. A heading reference system (HRS) similar to an aircraft's horizontal situation indicator or compass was developed to follow an aircraft throughout its mission. By using this HRS the key elements of the WW's low altitude mission could be determined. Four quantities defined by the HRS are listed below and described in the following paragraphs:

1. The WW's heading, H;
2. The magnetic bearing from the aircraft to the site, B;
3. The absolute bearing, AB; and
4. The relative bearing.

The WW's heading, H, is the direction of the aircraft's flight vector referenced to North or 000 degrees and is calculated as follows. (Note: the model assumes a no-wind condition, thus the aircraft's flight vector, velocity vector, and heading are aligned.) An initial heading,  $H_i$ , and a rate of heading change with time,  $\Delta H$ , are initially specified. A left hand turn results in negative  $\Delta H$  and a right hand turn, a positive  $\Delta H$ . The new heading,  $H_n$ ,  $\Delta t$  time units later is determined as follows:

$$H_n = H_i + (\Delta H)(\Delta t) \quad (10)$$

A 360 degree correction factor limits the value of H to 0-360 degrees. For example, if the WW's heading,  $H_i$ , was 010 degrees and a left hand turn of four degrees per second for five seconds is required, equation (10) calculates a new heading,  $H_n$ , of -10 degrees. The correction factor of + 360 degrees is applied to negative headings, and H equals 350 degrees.

The magnetic bearing, B, locates the threat radar site with respect to the aircraft and as was true with H, is referenced to North or 000 degrees. B depends on the relative position of the aircraft with respect to the radar. Figure 5 depicts the airspace around an emitter, S, divided into four quadrants. For each quadrant the angle  $\theta$  is calculated as follows:

$$\theta = \tan^{-1} \left( \frac{Y_S - Y_A}{X_S - X_A} \right) \quad (11)$$

where  $Y_S$  = y coordinate of the threat radar,  
 $X_S$  = x coordinate of the threat radar,  
 $y_A$  = y coordinate of the aircraft, and  
 $x_A$  = x coordinate of the aircraft.

Knowing the magnitude of the Tan  $\theta$  and the magnitude of the quantity  $(Y_S - Y_A)$  the aircraft, A, is located in a specific quadrant around the threat radar. For example, consider an aircraft located in quadrant II. The quantity  $(Y_S - Y_A)$  is positive, and the quantity

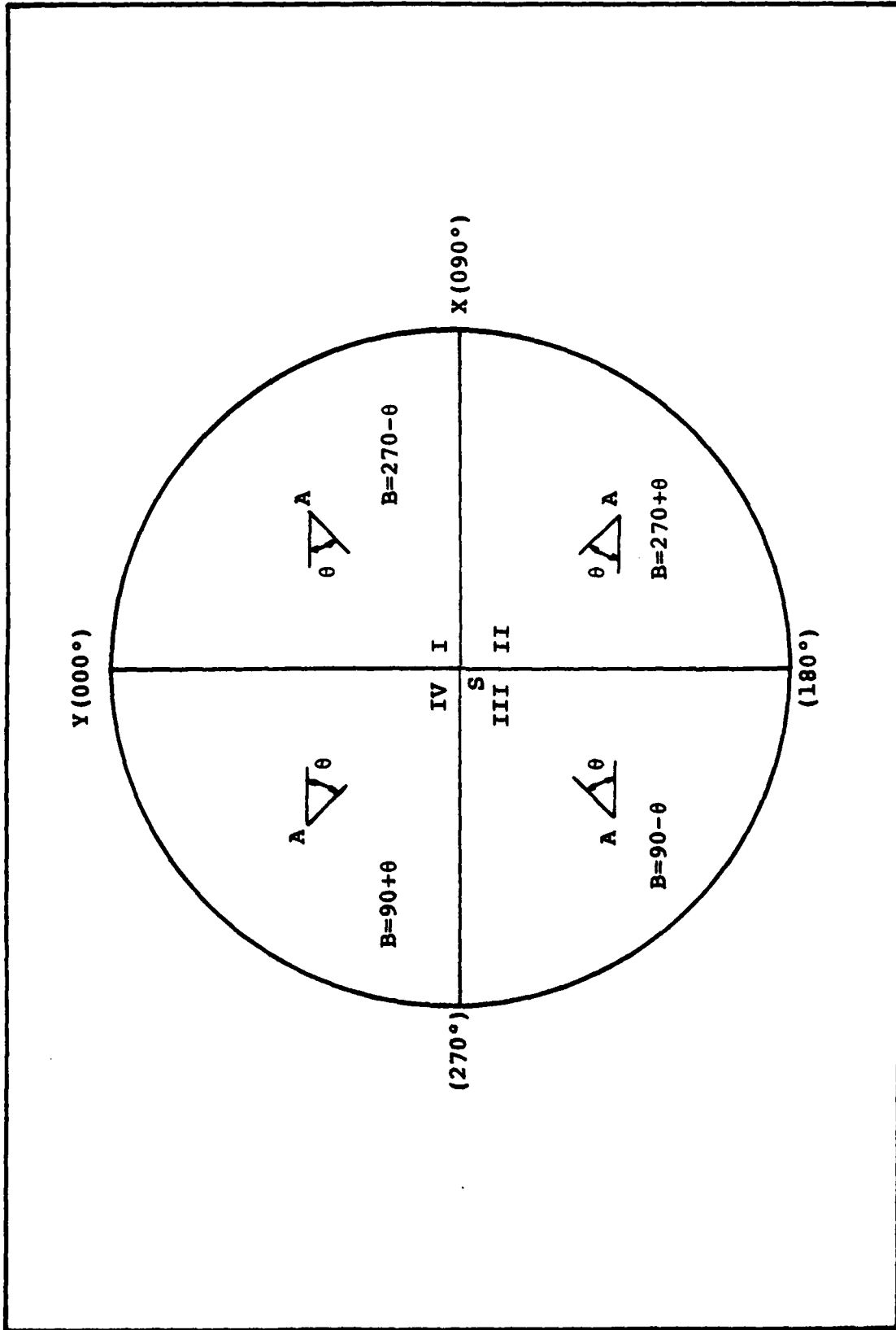


Fig. 5. Magnetic Bearing Determination

$(X_S - x_A)$  is negative.  $\tan \theta$  will be negative. A negative  $\tan \theta$  and a positive  $(Y_S - y_A)$  occurs only in quadrant II. B is then referenced to 000 degrees by either adding  $\theta$  to or subtracting  $\theta$  from one of two cardinal headings-- 090 or 270 degrees. The B calculation for each quadrant around site S is also depicted in Figure 5.

The absolute bearing, AB, is the absolute value of the difference between the heading, H, and the magnetic bearing, B, or:

$$AB = \text{Absolute value } (H-B) \quad (12)$$

All of the WW's low altitude ranging routines are simulated by calculating the value of AB. For instance, after detecting a threat radar and with both H and B known, the WW will start turning until AB reaches 75 degrees, the hypothesized value of AB required to start the WW's LOP calculations. The WW will stop the turn and allow AB to increase to 105 degrees to simulate the entire ranging routine.

As will be shown, AB is used in the relative bearing calculations and is limited to a maximum of 180 degrees. For computed values greater than 180 degrees, a new value is calculated as follows:

$$AB = 360 - AB \quad (13)$$

Knowing H, B, and hence, AB, the WW can accomplish its low altitude attack profile in both a minimum time and air-space. Also, by knowing these terms, a fourth quantity of the HRS is specified--the relative bearing, RB. RB is the bearing of the site from the aircraft referenced to the aircraft's current heading. If (H > B), the site is located AB degrees to the left of the aircraft. If (B > H), the site is located AB degrees to the right of the aircraft. Subsequent turns away from and toward the site will be made in reference to the current RB. Figure 6 depicts an aircraft heading 090 degrees with a RB of 045 degrees to the site, S. Since (H > B), the site is located (90 - 45) or 45 degrees to the left of the aircraft.

#### Slant Range to Site Calculations

After developing a HRS, the analytical model continued by calculating the slant range, SR, between the radar site and the WW aircraft for each time increment during the simulation run. Solving for SR by triangulation:

$$SR = \sqrt{(Y_S - Y_A)^2 + (X_S - X_A)^2 + ALT^2} \quad (14)$$

where ALT = the aircraft's altitude, meters (m), and other terms as previously defined.

As the aircraft proceeds toward the FEBA, its x and y position change continuously, and the SR to a specific

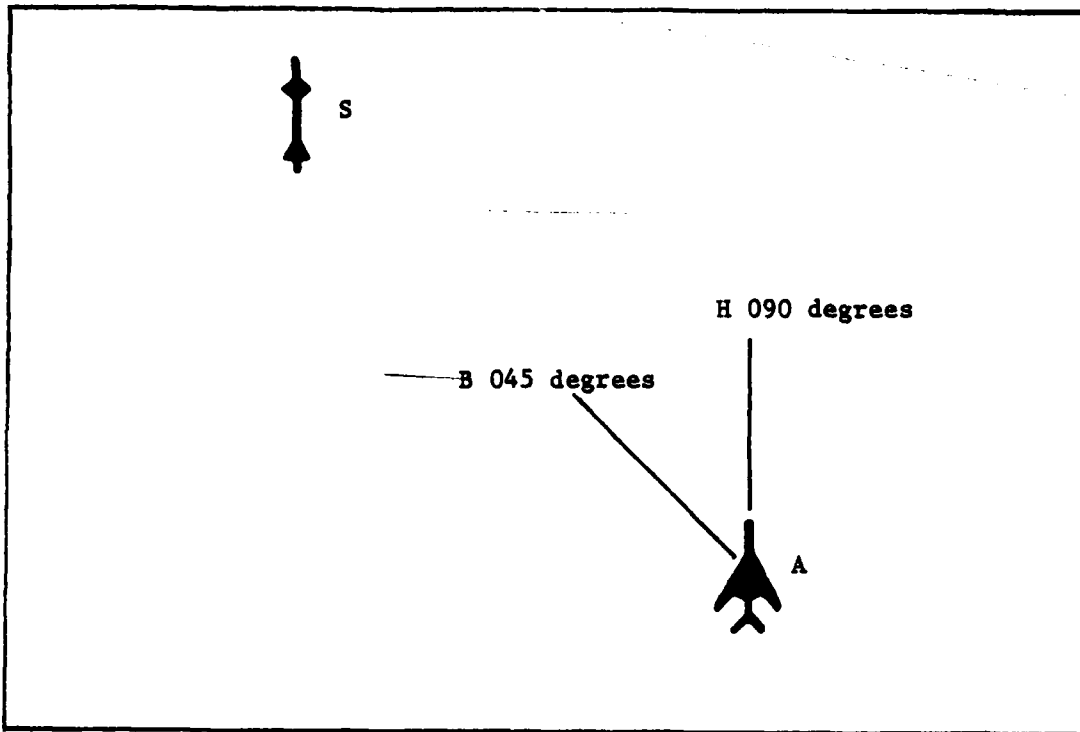


Fig. 6. Aircraft/Site Relationship

site also changes. When the SR to a site decreases to less than the WW's FOV the model assumes the site has been detected. In the model detection includes both determining the type of radar and its RB from the aircraft's current position. After detecting the threat, the WW maneuvers to a position from which the ranging phase of the profile can be accomplished. For this thesis, the aircraft will turn in the shortest direction to achieve a 75 degree AB. For an operational WW system the entire ranging routine requires continuous LOP calculations for a 30 degree change in AB. Thus, the ranging requires AB to increase from 75 to 105 degrees. Figure 7 depicts the reason 75

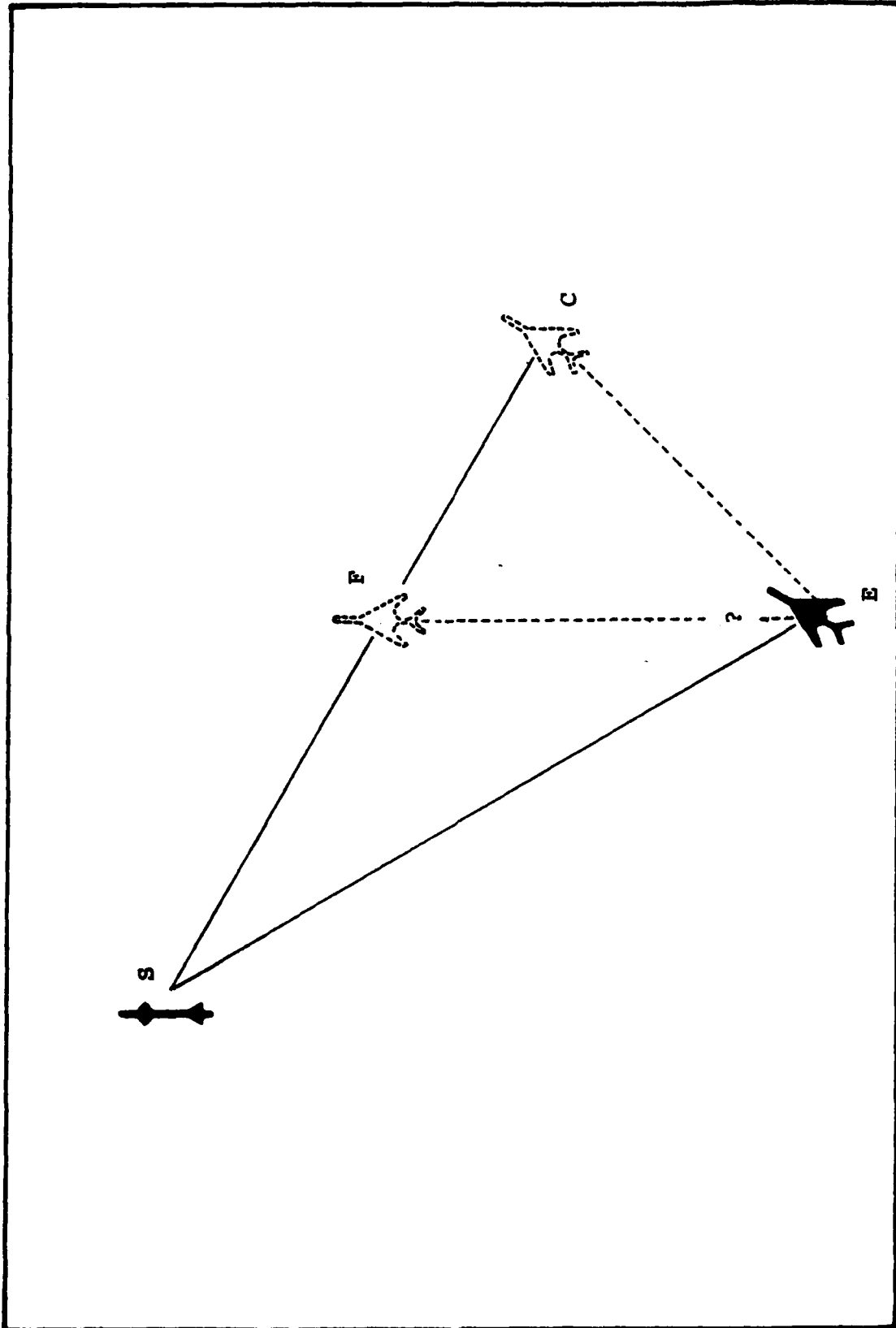


Fig. 7. Wild Weasel Ranging Problem

degrees AB was chosen as the initial rollout bearing. An aircraft would need to fly the distance EF to achieve a 30 degree AB change if the initial AB was 30 degrees, but a shorter length leg (EC) for an initial AB of 90 degrees. By making the required AB change symmetrical about the 90 degree AB, a minimum ranging time duration can be achieved. This technique is similar to an aircraft flying an arc about a TACAN station. Thus, the initial and final AB were chosen to be 75 and 105 degrees ( $90 \pm 15$ ).

#### Wild Weasel Turn Direction Algorithm

The first pilot input to the WW flight scenario is to determine the initial turn direction required to achieve the desired AB of 75 degrees. As was mentioned earlier, time is critical during the ranging routine. The WW's self-protection and evasive tactics are limited during this time period, so, the turn to 75 degrees should be in the direction which takes the shortest time. In the aircraft, the decision is simple. The pilot looks at his RHAW display and determines the RB to the site. He turns either left or right depending on the value of RB. If the site is at the pilot's 10 O'clock position (as in Figure 6), the turn will be to the right.

Converting from the pilot "seeing" the RB to the model computing the direction can be accomplished once the B and AB have been calculated. The initial decision is to

compare the site's x coordinate,  $X_S$ , with the aircraft's x coordinate,  $x_A$ . If ( $X_S > x_A$ ) the bearing to the site (in degrees) will fall in the range ( $000 < B < 180$ ). Next, the model analyzes which side of the site the aircraft will pass or has passed, if the aircraft maintains a constant H. From Figure 6, the aircraft will pass to the right of the site if it continues on its present heading. Converting to the model's logic, if [ $B < H < (B + 180)$ ], the aircraft will pass to the right of the site. Again, from Figure 6, the aircraft's H is 090 degrees, the B to the site is 45 degrees. The heading falls in the range of ( $45 < 90 < 225$ ) and satisfies the requirement for passing to the right of the site.

After determining the site's position in relation to the aircraft and whether the aircraft will pass or has passed to either the right or left of the site, the final comparison checks the magnitude of AB. If ( $AB < 75$ ) degrees the turn will be made to increase AB to 75 degrees. If ( $AB > 75$  degrees) the turn will be in a direction to decrease AB to 75 degrees. This completes the logic required to turn the aircraft in the shortest direction to initiate the ranging phase.

At the completion of ranging, the aircraft turns again, this time toward the site and prepares for the attack phase. This second turn direction is dependent only on the site's position in relation to the aircraft

prior to the initial ranging turn. Table II summarizes all positions and relative bearing combinations prior to the initial turn with the decision blocks indicating the direction of the initial turn to start the ranging phase and the second turn to initiate the attack phase. For example, for the aircraft in Figure 6, it is to the right of the site and  $AB < 75$  degrees. To start the ranging, the aircraft would turn right and to start the attack phase the second turn would be to the left.

TABLE II  
WILD WEASEL TURN LOGIC

Side of Closest Approach to Site	$\leq 75$		$> 75$	
	Ranging Turn	Attack Turn	Ranging Turn	Attack Turn
Left	Left	Right	Right	Right
Right	Right	Left	Left	Left

Addressing the requirement for turning in the shortest direction, a question arises as to how much time is saved in a WW mission scenario by turning in the shortest direction. Figure 8 depicts to scale the situation where a WW detects a threat at a point, turns in the shortest direction to initiate ranging, then turns in the shortest direction to attack the site. Figure 9 shows the aircraft under the same initial AB and H conditions,

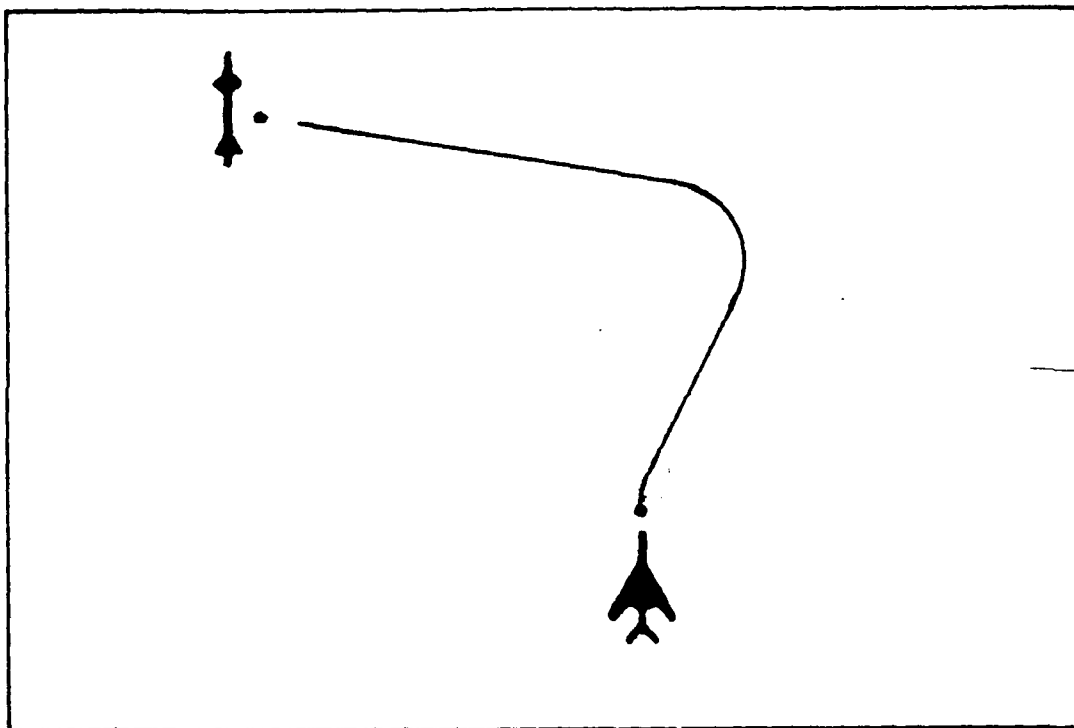


Fig. 8. Correct Turn Maneuvering

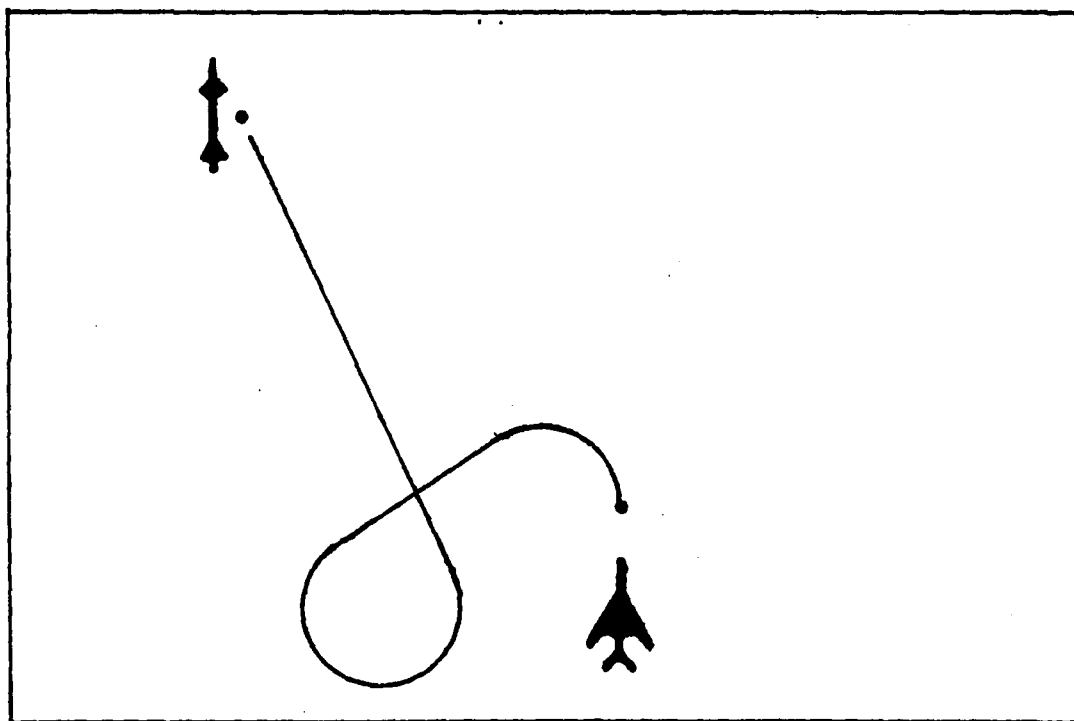


Fig. 9. Incorrect Turn Maneuvering

but which maneuvers in the incorrect direction for both turns. The increased time required by the "wrong turn" aircraft in completing the profile can be translated into fewer sites attacked during a mission or increased exposure to the enemy threats. This increased exposure translates into an increased probability of either being detected by the enemy sites or by being destroyed after being detected. Thus maneuvering in the shortest direction to achieve the required AB increases the number of sites attacked per mission and may decrease and probability of the WW being destroyed.

#### Attack Phase of WW Profile

The final and most important phase of the WW's mission profile is the actual attack of the site. After completing the ranging phase and with an accurate estimate of the site's location the WW turns back toward the threat. In this thesis the aircraft stops turning when its flight vector aligns with the site's location and the WW is boresighted on the threat (AB = 0 degrees). Although not required by all types of ARMs, boresighting on the threat increases the ARM's delivery accuracy. Any launch azimuth off of boresight results in a decreased delivery accuracy.

The WW carries two types of ARMs: a type B designated for a long range launch and an older, shorter range missile designated type A. For a given launch speed and

altitude each ARM has an associated envelope that denotes the minimum and maximum firing distances, representative flyout velocities, and an associated  $P_k$ . For the WW altitude used in this model, these hypothesized parameters are shown in Table III. Given the increased  $P_k$  for ARM type B, the decision logic for selecting a weapon will be as follows. If any type Bs are left, the WW crew selects a type B weapon.

TABLE III  
ANTI-RADIATION MISSILE (ARM) CHARACTERISTICS

	Type	
	A	B
Average Velocity (m/sec)	350	450
Probability of Kill ( $P_k$ )	.8	.85
Range (m) (Min/Max)	8000/15,000	8000/25,000

This thesis assumes weapons delivery accuracy is independent of launch range when launch occurs in the launch window. After boresighting on the threat the WW's next action depends on the slant range to the site. Three possible conditions exist:

1. The SR falls in the launch envelope,
2. The SR is greater than the maximum launch range ( $R_{max}$ ), or

3. The SR is less than the minimum launch range ( $R_{\min}$ ).

If the SR satisfies the first case, the launch point will occur somewhere between the current SR and the  $R_{\min}$ . The model assumes that any point between SR and  $R_{\min}$  is equally likely and determines a launch range,  $R_{\text{lau}}$ , based on a uniform probability distribution between SR and  $R_{\min}$ .

For case 2, the aircraft must delay launch until it enters the launch envelope. Here, the launch point is assumed to be uniform between  $R_{\max}$  and  $R_{\min}$ . For both cases 1 and 2 the WW proceeds toward the site until its SR reaches  $R_{\text{lau}}$ , launches the ARM, allows the weapon to clear the aircraft (assumed to be launch time plus five seconds), and begins searching for the next threat.

Case 3 requires the WW to maneuver away from the site. Using the turn algorithm, the WW aircraft turns away from the site until AB = 180 degrees, rolls out of the turn, and proceeds outbound until the SR to the site increases to 18,000 meters, reverses its turn and bore-sights on the site. This insures the second attack will fall in case 2 and a launch will culminate the attack. The case 3 profile typifies action required by the WW in a threat-rich environment given the launch envelope of the ARMs.

WW Defense Suppression  
Mission Summary

In summary, three key elements comprise the WW's defense suppression system structure:

1. The heading reference system (HRS) and its associated logic,
2. The aircraft maneuvering logic, and
3. The Defense Suppression Mission Phases.

The HRS can be compared to an aircraft's horizontal situation indicator. It allows the model to describe a threat radar's position in relation to an aircraft's current position and heading. The first two outputs calculated by the HRS are the aircraft's heading and the magnetic bearing to a threat radar site. These two elements, in turn, define a third quantity, the relative bearing of the threat radar to the aircraft's current heading. Knowing these three elements allows the model to solve the maneuvering logic to accomplish the mission scenario.

Four key phases of the defense suppression mission scenario are the following:

1. Search,
2. Detection,
3. Ranging, and
4. Attack.

The search phase occurs when the WW has weapons remaining and is attempting to locate a target to destroy. At detection, the aircraft's RHAW system alerts the crew to a potential target. During ranging, the WW's onboard processor refines the site's location estimate to within a tolerance required by the aircraft's weapons. The attack phase culminates the mission scenario. The aircraft selects an ARM and launches it against the site. The mission scenario continues until the WW exhausts its ARMs.

Although important to the overall success of the mission, the WW egress from the target area was not addressed in this chapter. The model will handle egress by assigning the x and y coordinates of (0, 25000 m) as the site coordinates of the next target when all ARMs are depleted. The WW turns toward this point, boresights on it and departs the enemy portion of the FEBA.

#### Strike Aircraft System Structure

The strike aircraft flight forms with the WW over friendly territory well before the FEBA. The planned ingress corridor keeps the strike force as far away as possible from the enemy's main lines of communication (LOC) (Ref 9:83). The enemy uses these LOCs to transfer troops and equipment forward to and away from the FEBA, and thus, concentrates his defenses near them. The mission's target is located in an area 95 km behind the FEBA. The aircraft

penetrate the FEBA near the target's latitude at an altitude of 200 m. The speed to the target is a constant 480 kts (247 m/sec). No aircraft turning in response to threats is modeled and the ingress heading is kept constant at 090 degrees.

### Defensive System Structure

The final system element is the defensive array the WW and strike aircraft will attempt to penetrate. The major areas addressed in this section are the following:

1. Radar system characteristics and limitations,
2. SAM probability of kill calculations,
3. Intercept geometry calculations,
4. Specific differences with previous modeling efforts,
5. AAA probability of kill calculations, and
6. Command and control.

### Radar System Characteristics and Limitations

The radar systems composing the defensive network can be characterized by certain system parameters listed in Table IV (Ref 9:18). The  $P_t$ ,  $G_t$ , and RF are the same parameters defined in the receiver sensitivity section of this thesis. The maximum range and minimum altitude represent restrictions on either the radar itself or the missile associated with the radar. The acquisition and

TABLE IV  
DEFENSIVE SYSTEM PARAMETERS

System	Transmit Power, $P_T$ (kw)	Antenna Gain, $G_t$	Maximum Detection Range (m)	Minimum Engagement Altitude (m)	Lethal Radius (m)	Acquisition Time (sec)		Average Missile Velocity (mps)	Confounding Delay (sec)
						Minimum	Maximum		
AAA	123	40	2,990	0	-	6	25	-	30
SMA	600	31.7	50,050	91.0	56.4	18	51	592	13
SMB	100	42	74,150	305.0	43.6	12	26	759	15
SAMC	200	41	22,250	15.0	26.2	17	38	599	30
SAMD	100	43	10,200	45.0	22.0	10	23	525	30

tracking time is the time required by the system operators after detecting an aircraft to evaluate the flight path and to determine if the probability of destroying the target warrants further tracking by the site. At its minimum limit, it represents the minimum time after detecting a threat for a site to schedule a missile launch. The missile velocity is the average velocity of the missile from launch to detonation. In this thesis missile acceleration will not be modeled. The confounding delay is the minimum time required by the site to prepare the system for the next engagement. Typical examples of confounding delays could be the time after missile detonation required by the site before searching for a new target or the time for a site to access a target disappearing from its radar scope (an aircraft going out of range or being destroyed by another site).

For this thesis' model, the defensive radar site must be capable of analyzing aircraft engagements from any attack azimuth and heading. Additionally, the aircraft can employ either jamming (wet) or nonjamming (dry) tactics (WW aircraft do not operate ECM equipment during a defense suppression mission profile).

The methodology required for determining the probability of destroying the attacking aircraft will be developed in the following paragraphs.

Radar system parameters such as the pulse repetition interval (PRI) determine the maximum range most radars can detect and track a target. The accuracy achieved by these radars and their associated missiles has led the attacking aircraft force to employ low altitude penetration as one means of increasing its probability of reaching the target area. The low altitude penetration complicates the radar tracking problem because it introduces the multipath signal problem. Below a certain altitude, the reflected radar return from a target interacts with a mirror image signal reflected off the earth's surface at the radar processor (Ref 15:172). Because the target return interferes with and cannot be distinguished from the mirror image, accurate tracking cannot be accomplished. The signal can induce wild fluctuations in the radar's range gate and causes the return to "break lock." At some elevation angle, referred to as the multipath angle, the difference in the arrival time between the signal and its mirror image is great enough that the two signals can be distinguished and accurate tracking of the actual return becomes possible. For the radars in this thesis, an average multipath angle of .25 degrees will be used. This represents an average of the values used by Leek and Schmidt (Ref 9:15). Thus, in addition to being inside the maximum detection range of a radar, the aircraft

must be at an elevation angle,  $\alpha$ , above the horizon such that  $\alpha > .25$  degrees, where  $\alpha$  is defined as follows:

$$\alpha = \sin^{-1} \left( \frac{ALT}{SR} \right) \quad (15)$$

where ALT = altitude of the aircraft, and

SR = slant range from the radar to the aircraft.

After detecting the aircraft, the radar site attempts to track the target and launch its missile in such a manner as to achieve the highest probability of kill ( $P_k$ ). In a similar manner to Leek and Schmidt, this thesis evaluates the  $P_k$  in terms of the missile's lethal radius (LR) and the circular error probable (CEP) (Ref 9:19-22). LR is the distance from the SAM's detonation point where as many aircraft survive as are killed by the detonation beyond it. CEP is the error associated with the distance measured between the desired and actual point of impact (Ref 2:44). More precisely, CEP or spherical error probable, is a sphere around the target aircraft within which 50 percent of the missiles fired under a given set of conditions will detonate (Ref 9:19). Thus,  $P_k$ , evaluated in terms of CEP and LR reduces to the following equation:

$$P_k = 1 - (.5) \left( \frac{LR}{CEP} \right)^2 \quad (\text{Ref 9:22}) \quad (16)$$

For a specific SAM system, LR is a constant. By decreasing CEP, the missile's  $P_k$  increases; for the highest  $P_k$ , the missile must deliver its missiles with the smallest CEP.

CEP calculations depend on whether the target aircraft is either wet or dry--either jamming or not jamming. Leek and Schmidt evaluated the wet case where CEP is determined as follows:

$$CEP = \sqrt{A(J/S)R_i^2 + B(J/S) + C} \quad (17)$$

where A, B, and C = constants dependent on the type of SAM,

$R_i$  = range from the launch point to the target, and

J/S = the jamming to signal ratio.

The range to intercept,  $R_i$ , will be evaluated later in this section for all intercept cases. (J/S) is dependent on the range from the radar to the target aircraft, the effective radiated power (ERP) of the aircraft's jammer, the technical parameters of the radar, and  $\sigma_{RCS}$ , the radar cross-section (RCS) of the target aircraft. RCS is dependent on the intercept geometry between the aircraft and radar and represents the amount of reflected signal energy reradiated back toward the radar. It is usually expressed in decibels referenced to square meters of reflected signal strength. Table V lists the RCS in

TABLE V  
 RADAR CROSS-SECTION OF FIGHTER  
 AGAINST DEFENSIVE SYSTEMS

<u>Radar Cross-Section (in dBm<sup>2</sup>)</u>			
Aspect (Degrees)	SAM-A	SAM-B, SAM-C	SAM-D, AAA
0.	10.75	3.60	8.20
5.	4.75	.40	6.70
10.	4.65	2.55	1.90
15.	-2.33	3.03	3.48
20.	4.80	1.70	.85
25.	2.75	2.50	3.95
30.	1.20	10.65	5.20
35.	-1.65	7.95	-1.20
40.	2.15	3.45	1.70
45.	4.70	3.70	6.35
50.	1.75	-.95	3.10
55.	1.10	-.65	1.00
60.	-4.00	-.95	1.90
65.	.43	.05	.25
70.	9.23	8.45	8.19
75.	13.73	14.55	13.43
80.	13.98	16.35	16.70
85.	16.38	16.00	16.08
90.	25.85	24.98	24.38
95.	20.88	19.95	19.23
100.	17.00	15.75	16.58
105.	7.03	9.20	5.83
110.	9.80	8.73	9.50
115.	1.75	3.65	6.20
120.	-.75	2.33	7.85
125.	-.23	3.13	4.28
130.	-2.33	3.03	3.48
135.	.08	-1.08	4.35
140.	-1.28	-2.60	3.90
145.	-1.90	.50	6.00
150.	2.78	.55	5.23
155.	6.55	.43	6.93
160.	.50	.58	2.95
165.	.55	6.38	4.73
170.	4.15	6.53	9.93
175.	4.63	8.85	13.50
180.	.98	9.48	15.05

dB (meters<sup>2</sup>) for the aircraft in this thesis and listed as an intercept angle.

J/S can be determined by the following formula:

$$(J/S) = \frac{R^2 (4\pi) (ERP)}{P_t G_t \sigma_{RCS}} \quad (18)$$

where all terms are as previously defined (Ref 9:101-102). Converting all terms in equation (18) to dB equivalents yields:

$$(J/S)_{dB} = 2(R)_{dB} + (4\pi)_{dB} + ERP_{dB} - P_{t_{dB}} - G_{t_{dB}} - \sigma_{RCS_{dB}} \quad (19)$$

For a particular aircraft/SAM engagement, the terms  $4\pi$ , ERP,  $P_t$ , and  $G_t$  are constant and the J/S ratio becomes:

$$(J/S)_{dB} = 2(R)_{dB} - \sigma_{RCS_{dB}} + K \quad (20)$$

where  $K = 4\pi + ERP - P_t - T_t$ .

The J/S required for equation (17) is obtained by converting the dB equivalent back to the actual value, or:

$$(J/S) = 10^{(J/S)_{dB}/10} \quad (21)$$

From equation (17), a smaller value of (J/S) results in a smaller CEP. The radar attempts to control (J/S) by insuring the missile impact occurs at the minimum

possible range from the site and the largest value of RCS. Both values can be achieved simultaneously when the missile impacts near the aircraft as the aircraft nears its closest approach point,  $R_c$ , to the site or the aircraft comes abeam the site. Here, the intercept angle is 90 degrees and from the values of RCS in Table V, RCS is a maximum. The launch rule for the radar sites in this thesis will be to attempt a launch when the intercept with the target occurs at the closest approach point to the site. This firing methodology is similar to the constant bearing intercept discussed by Breuer (Ref 3:166-173). A constant bearing intercept provides the shortest duration trajectory for a constant velocity target.

For a dry aircraft, CEP can be evaluated as follows:

$$CEP = \sqrt{D \frac{R^6}{\sigma_{RCS}^2} + E \frac{R^4}{\sigma_{RCS}^2} + F} \quad (22)$$

where  $D$ ,  $E$ , and  $F$  are constants dependent on the type of SAM and all other terms as previously defined.

The  $\sigma_{RCS}$  required in equation (22) is the one obtained by converting the dB equivalent to the actual values, or:

$$\sigma = 10^{\sigma_{dB}/10} \quad (23)$$

Again, the lowest CEP and the highest  $P_k$  result when the intercept range is a minimum and the RCS is a maximum. For both wet and dry aircraft, the same launch decision rule will be applied: attempt to launch so that intercept occurs at 90 degrees angle between the aircraft's flight vector and the site's bearing to the aircraft (point C in Figure 11).

### Intercept Geometry

At the completion of acquisition and tracking the model evaluates the specific encounter conditions between the threat radar and an aircraft. During acquisition and tracking the site determines the aircraft's heading,  $H$ , velocity,  $V_a$ , and both its slant range,  $SR$ , and bearing from the site. For each encounter two major areas dictate the intercept computations. Figures 10 and 12 depict these conditions. Based on its position, velocity, and heading the aircraft is located either prior to or past the closest approach point to the site,  $C$ . Within the first case (prior to the closest approach point) two possible conditions exist: the missile if fired immediately at the end of acquisition and tracking will intercept the aircraft at or prior to the closest approach point, or the missile will intercept the aircraft past the closest approach point. Referring to Figure 10, an aircraft at point A is headed in a direction such that its closest

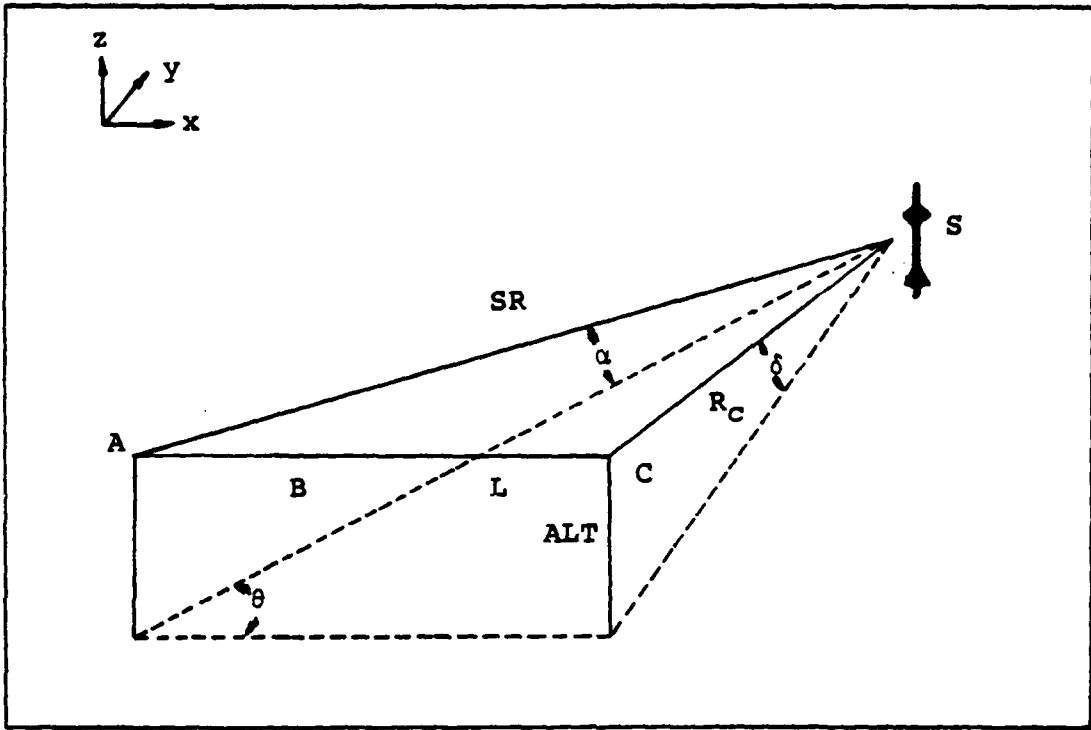


Fig. 10. Aircraft Prior to Closest Approach Point (3-Dimension)

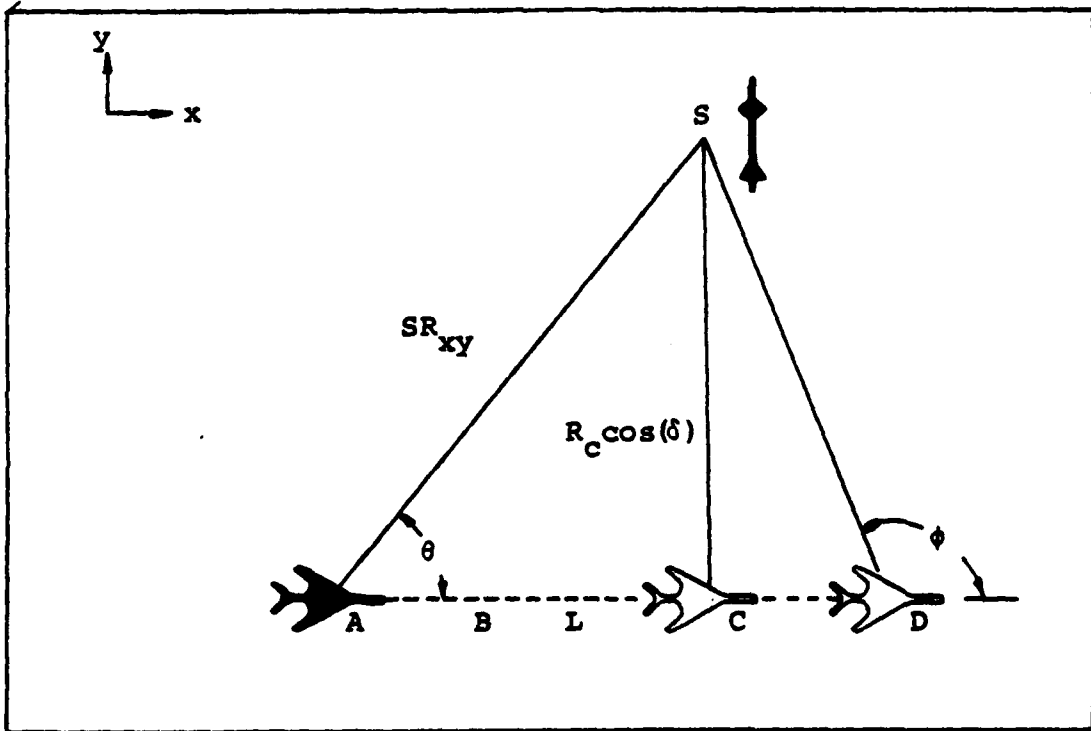


Fig. 11. Aircraft Prior to Closest Approach Point (2-Dimension)

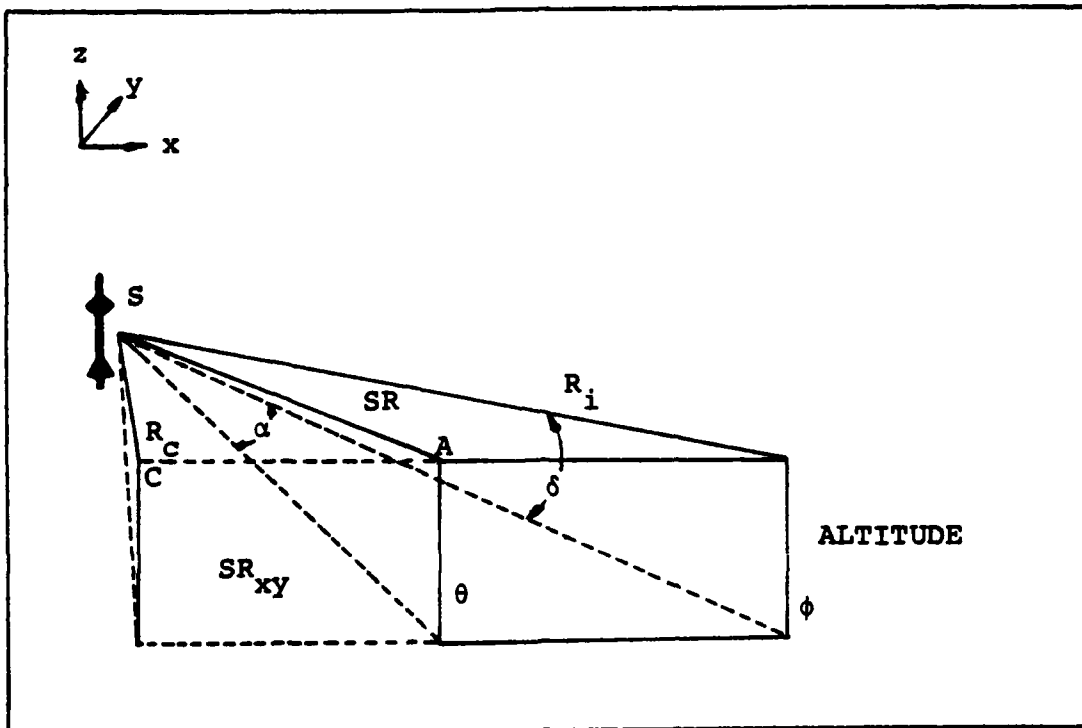


Fig. 12. Aircraft Past Closest Approach Point (3-Dimension)

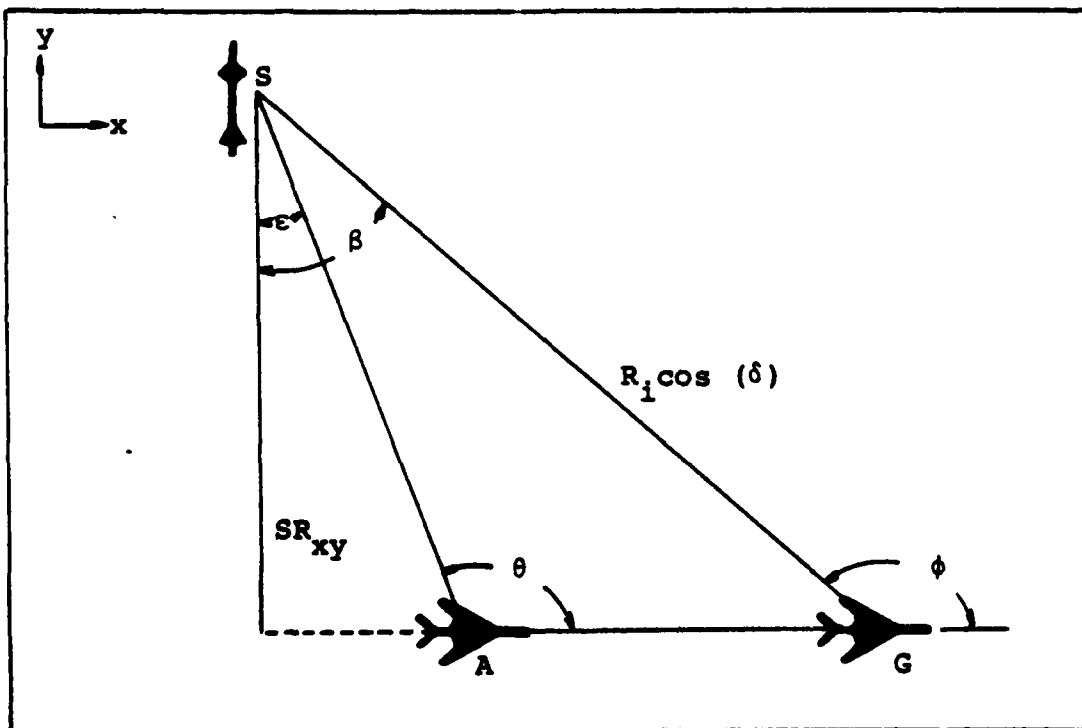


Fig. 13. Aircraft Past Closest Approach Point (2-Dimension)

approach to the site S occurs at point C. The slant range from the site to the aircraft, SR, is known (see equation (14)). The SR is projected down to the x-y plane as follows (see Figure 11):

$$SR_{xy} = SR \cos \alpha \quad (24)$$

where  $SR_{xy}$  = the projection of SR in the x-y plane, and all other terms as previously defined.

Using the bearing from the site to the aircraft and the aircraft's H, the angle  $\theta$  is calculated. The time for the aircraft to reach point C,  $t_{AC}$ , is calculated as follows:

$$t_{AC} = \frac{AC}{V_a} = \frac{SR_{xy} \cos \theta}{V_a} \quad (25)$$

where  $AC = \frac{SR_{xy} \cos \theta}{\cos \theta}$ ,  
 $AC =$  the length of the leg from A to C or  $SR \cos \theta$ ,

$V_a =$  the aircraft's velocity, and all other terms as previously defined.

The time required for the missile to get from S to C,  $t_{MC}$ , is also known:

$$t_{MC} = \frac{SC}{V_m} = \frac{\sqrt{(SR_{xy} \sin \theta)^2 + ALT^2}}{V_m} \quad (26)$$

where  $SC =$  distance from point S to point C,

$V_m =$  average missile flyout velocity, and all other terms as previously defined.

Note: For a strike aircraft with a constant H, the  $R_i$  depends only on the difference between the site's and the aircraft's y coordinates,  $\Delta y$ , and the aircraft's altitude, ALT:

$$SC = \sqrt{ALT^2 + (\Delta y)^2} \quad (27)$$

where all terms are as previously defined.

The model now compares  $t_{AC}$  and  $t_{MC}$ . If ( $t_{AC} > t_{MC}$ ) the missile, if fired now, would arrive at point C before the aircraft. Since the intercept must occur at C to achieve the lowest CEP, and highest  $P_k$ , a delay of ( $t_{AC} - t_{MC}$ ) time units is programmed into the missile's firing schedule, resulting in both missile and aircraft arriving at point C simultaneously.

If ( $t_{MC} > t_{AC}$ ) the missile, if fired now, would arrive at C after the aircraft. In this case, the intercept will occur past the optimum 90 degree intercept point. The new intercept point, D, can be calculated as follows:

$$CD = (t_{MC} - t_{AC})V_a \quad (28)$$

where CD = the distance past point C the intercept will occur, and

all other terms as previously defined.

The actual range to intercept,  $R_i$  can be calculated as follows:

$$R_i = \sqrt{CD^2 + (SR_{xy} \sin \theta)^2 + ALT^2} \quad (29)$$

$$t_{MD} = \frac{R_i}{V_m} \quad (30)$$

where  $t_{MD}$  = time of the missile to flyout to point D, and all the terms are as previously defined.

Instead of the RCS angle being an optimum 90 degrees, it will be a new angle,  $\phi$ , where  $\phi$  can be calculated as follows (see Figure 10 and 11):

$$\delta = \sin^{-1} \left( \frac{ALT}{R_i} \right) \quad (31)$$

$$\gamma = \cos^{-1} \left( \frac{CD}{R_i \cos \delta} \right) \quad (32)$$

$$\phi = 180 - \gamma \quad (33)$$

where all terms as previously defined.

Thus, the  $P_k$  can be calculated with CEP determined by the RCS for an aspect angle  $\phi$  and the intercept range,  $R_i$ .

At this time the site, knowing the expected  $P_k$ , would evaluate its decision to fire. If the  $P_k$  is above some threshold value, the decision would be made to fire; if below, the site would be released from this threat and resume searching for another target aircraft. The

threshold value depends on other criteria such as the number of missiles available for firing and the priority placed on destroying the strike force/WW aircraft. For FEBA engagements early in a conflict with high stockpile levels of missiles, this threshold value will be low. For this thesis,  $P_k$  values above .05 will be considered adequate to warrant the site firing at the aircraft. Leek and Schmidt used an even lower threshold value of .02 in the firing logic of their thesis (Ref 9:50). If the  $P_k$  is above the threshold value, the missile is launched immediately with intercept occurring  $t_{MD}$  time units later.

The second major category of target is one already past the closest approach point at the completion of tracking and acquisition. Again, the site has determined the SR and bearing from the site plus the aircraft's H and  $V_a$ . (See Figure 12 and 13, page 49.) The range to missile intercept can be calculated as follows. The intercept will occur at a point, B. The time for the aircraft to get from its present position, A, to the intercept point,  $t_{AB}$ , will be the same as the time required for the missile to go from S to B,  $t_{MB}$ , or:

$$t_{AB} = \frac{AB}{V_a} \quad (34)$$

$$t_{MB} = \frac{R_i}{V_m} \quad (35)$$

and 
$$AB = \left(\frac{V_a}{V_m}\right)R_i = V_r R_i \quad (36)$$

where  $V_r$  = the velocity ratio,  $V_a/V_m$ , and all other terms are as previously defined.

For small angles,  $\delta$ ,  $R_i = R_{i_{xy}}$ , where  $\delta$  is defined as follows (see Figure 12):

$$\delta = \sin^{-1} \left( \frac{ALT}{R_i} \right) \quad (37)$$

$$R_{i_{xy}} = R_i \cos \delta \quad (38)$$

where all terms are as previously defined.

The distance,  $R_i$ , can be determined using the Law of Cosines:

$$R_i^2 = (SR \cos \alpha)^2 + (AB)^2 - 2(SR \cos \alpha)(AB) \cos \theta \quad (39)$$

where all terms are as previously defined.

The angle  $\theta$  is determined because the aircraft's heading and its bearing from the site are both known. Substituting from equation (36) for AB, equation (39) becomes:

$$R_i^2 = (SR \cos \alpha)^2 + (V_r R_i)^2 - 2(SR \cos \alpha)(V_r R_i) \cos \theta \quad (40)$$

where all terms are as previously defined.

Rearranging terms, the equation becomes a quadratic in  $R_i^2$ . Equation (40) is solved by the quadratic formula with:

$$a = 1 - V_r^2$$

$$b = 2(SR \cos \alpha) (V_r) \cos \theta$$

$$c = -(SR \cos \alpha)^2$$

$$R_i = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (41)$$

The negative of the term under the radical is neglected since  $R_i$  is a positive number. The RCS angle at intercept can be determined since the bearing to the target,  $\beta$ , and the target's heading is known at intercept.

$$R_c = SR_{xy} \cos \epsilon \quad (42)$$

$$\beta = \cos^{-1} \left( \frac{R_i}{R_c} \right) \quad (43)$$

$$\gamma + \beta = 90^\circ \quad (44)$$

$$\phi_{RCS} = 180 - \gamma \quad (45)$$

$$\phi_{RCS} = 90 + \beta \quad (46)$$

Again, knowing  $R_i$  and the RCS aspect angle  $\phi$ , the CEP and  $P_k$  can be evaluated at intercept. Similar to the cases prior to the closest approach point  $P_k$  is above the .05

threshold value, the missile is fired. Because the intercept is beyond the closest approach point, the missile is fired immediately and intercept occurs  $t_{MB}$  time units later.

An additional consideration necessary before leaving the SAM attack geometry calculations is the necessity of the calculations to handle a maneuvering aircraft. The initial  $P_k$  evaluation at the end of acquisition and tracking was made considering the aircraft's heading to be constant. Since the WW aircraft can maneuver, this may not be true. To account for a turning possibility this thesis incorporates the following modification. At the scheduled missile firing time, a new  $R_i$  is calculated (see equation (29) or (41)). If the  $R_{i_{new}}$  is the same as the initial  $R_i$  calculated at the end of acquisition and tracking, the aircraft has not turned and the intercept will be the same. To preclude small variations in the  $R_i$  calculations, a .1 tolerance is allowed, or, intercept will be considered the same if:

$$(.9 R_i \leq R_{i_{new}} \leq 1.1 R_i) \quad (47)$$

If ( $R_{i_{new}} < R_i$ ), the aircraft must have turned toward the site. A new  $\phi$  and  $P_k$  are calculated and a new launch time computed based on the  $R_{i_{new}}$ . A new launch time is computed using the above calculations (equations (25)-(26))

and a new launch time is schedule. If ( $R_{i_{new}} > R_i$ ), the new  $P_k$  is evaluated. If the  $P_k$  is above the .05 threshold value, the site immediately fires the missile and computes a scheduled impact time.

At the scheduled impact time the  $R_i$  is again compared to the value computed at the missile launch time. If both the  $R_i$  values are the same, the  $P_k$  can be evaluated. If the new  $R_i$  is less than the launch  $R_i$ , the aircraft has turned towards the site. The  $P_k$  and  $\phi$  are evaluated at the new  $R_i$ . If the new  $R_i$  is greater than the launch  $R_i$  a new impact time is scheduled. This new impact time is

$$t_i = \left( \frac{R_{i_{now}}}{R_{i_{launch}}} \right) \left( \frac{R_{i_{launch}}}{V_m} \right) \quad (48)$$

or

$$t_i = \frac{R_{i_{new}}}{V_m} \quad (49)$$

where all terms are as previously defined.

At the new impact time, the same calculations are made and the  $P_k$  reevaluated. In this manner, the flight time of the missile can be approximated without requiring a separate missile flyout time routine as part of the thesis.

### Differences with Previous Modeling Efforts

The SAM engagement portion of this thesis differs from the approach used by Leek and Schmidt. In their model, Leek and Schmidt assumed that if the attack aircraft maintained a 20 dB J/S ratio at the radar the site was denied the ability to track in both range and azimuth. Using this criteria, kill zones in which the J/S dropped below 20 dB for the particular SAM were established. If the aircraft passed through this kill zone at the scheduled impact time the  $P_k$  was calculated. If the aircraft intercept occurred outside the zone, the  $P_k$  was set equal to zero. To this end the Leek and Schmidt model attempted to control the SAM launches such that, if possible, launches were delayed so that intercept occurred when the aircraft entered a kill zone. The kill zone criteria resulted in a narrow azimuth window near the 90 degree relative bearing to the site (Ref 9:24-31).

The main criticism is that this approach does not consider even the most rudimentary electronic counter countermeasures (ECCM) techniques. Most modern SAMs employ some type of ECCM such as frequency discrimination, side-lobe blanking, or polarization mismatch to defeat ECM techniques. Although not explicitly stated, attack aircraft in the Leek and Schmidt model used noise jamming. This type of jamming normally denies range information to a site

although angle information can be obtained since the output from the noise jammer results in a strobe on the radar scope of the site emanating from the azimuth of the target aircraft. In this case, a network of sites such as the model employs could triangulate and to determine the aircraft's approximate location (Ref 15:547-550). For this reason kill zones are not defined. Instead, a necessary assumption in the analytical portion of the model is that the sites use some type of ECCM techniques and the aircraft's  $P_k$  is based on the calculated value of CEP,  $R_i$ , and  $\sigma_{RCS}$  determined in the above equations, not whether the aircraft at missile impact falls in a kill zone. For large values of  $R_i$  and high CEPs an appropriate decrease in  $P_k$  will be calculated as per equations (17) and (22).

#### AAA Probability of Kill

The AAA  $P_k$  calculations follow closely the work of Leek and Schmidt (Ref 9:35-40). The short maximum engagement range of the AAA (2990 m, see Table IV) means the aircraft must pass near the site before being attacked. The  $P_k$  calculations are based on the vulnerable surface area of the aircraft as a percentage of total surface area as viewed from a specific aspect angle, the dispersion of the AAA rounds around the actual aim point, the time of flight (TOF) of each round from the gun to target, and the number of rounds fired in each engagement.

The projectile's TOF is a function of the initial and final velocity of the projectile. The velocity of the round at impact,  $V_f$ , can be determined as follows:

$$V_f = V_i \exp[-\rho C_d A R_i / 2m] \quad (50)$$

where  $V_i$  = the initial muzzle velocity of the round, m/sec (930);

$\rho$  = density of the air, kg/m<sup>3</sup> (1.2247);

$C_d$  = dimensionless coefficient of drag (.38);

$A$  = cross-sectional area of the round, m<sup>2</sup> (4.16 x 10<sup>-4</sup>);

$R$  = intercept range, km; and

$m$  = mass of the round, kg (.195) (Ref 3:48).

Substituting the average values used in the calculations (in parenthesis, above) the equation reduces to the following in terms of  $R$  kilometers to intercept:

$$V_f = 930 \exp[-.4965 R_i] \quad (51)$$

From the velocity calculation, the TOF, in seconds, can be determined:

$$TOF = \frac{2m}{\rho C_d A} \left[ \frac{1}{V_f} - \frac{1}{V_i} \right] \quad (52)$$

where the terms are as previously defined (Ref 3:48).

Substituting the average values from the above equation this becomes:

$$\text{TOF} = \frac{2014.46}{V_f} - 2.166 \quad (53)$$

Leek and Schmidt use an average vulnerable area ( $A_v$ ) of 55.65 ft<sup>2</sup> (5.17 m<sup>2</sup>) (Ref 9:39). This was based on an average viewing aspect of a total projected area of 265 ft<sup>2</sup> and a 21 percent vulnerable area.

The dispersion of the rounds about the aim point in a combat situation was assumed to be 20 mils (Ref 9:39). This angular dispersion represented a one sigma standard deviation. Figure 14 depicts the angular deviation  $\sigma$  in terms of R. Converted to range at intercept, the  $\sigma$  becomes:

$$\sigma_m = \sigma R \quad (54)$$

where R = intercept range, km;

$\sigma$  = angular deviation, in mils;

$$\text{or} \quad \sigma_m = 20R \quad (55)$$

The single shot probability of kill ( $P_{k_{ss}}$ ) becomes:

$$P_{k_{ss}} = \frac{A_v}{2\pi\sigma^2 + A_v} \exp\left\{-\frac{1}{2} \left[ \frac{[9.8 g \text{ TOF}^2]^2}{2\pi\sigma^2 + A_v} \right]\right\} \quad (56)$$

where g = the number of "g's" the aircraft is undergoing for its current position in the battle area (Ref 13:98).

Sustituting the constant terms the equation becomes:

$$P_{k_{ss}} = \frac{5.17}{2\pi\sigma^2 + 5.17} \exp\left\{-\frac{1}{2} \left[ \frac{[9.8 g \text{ TOF}^2]^2}{2\pi\sigma^2 + 5.17} \right]\right\} \quad (57)$$

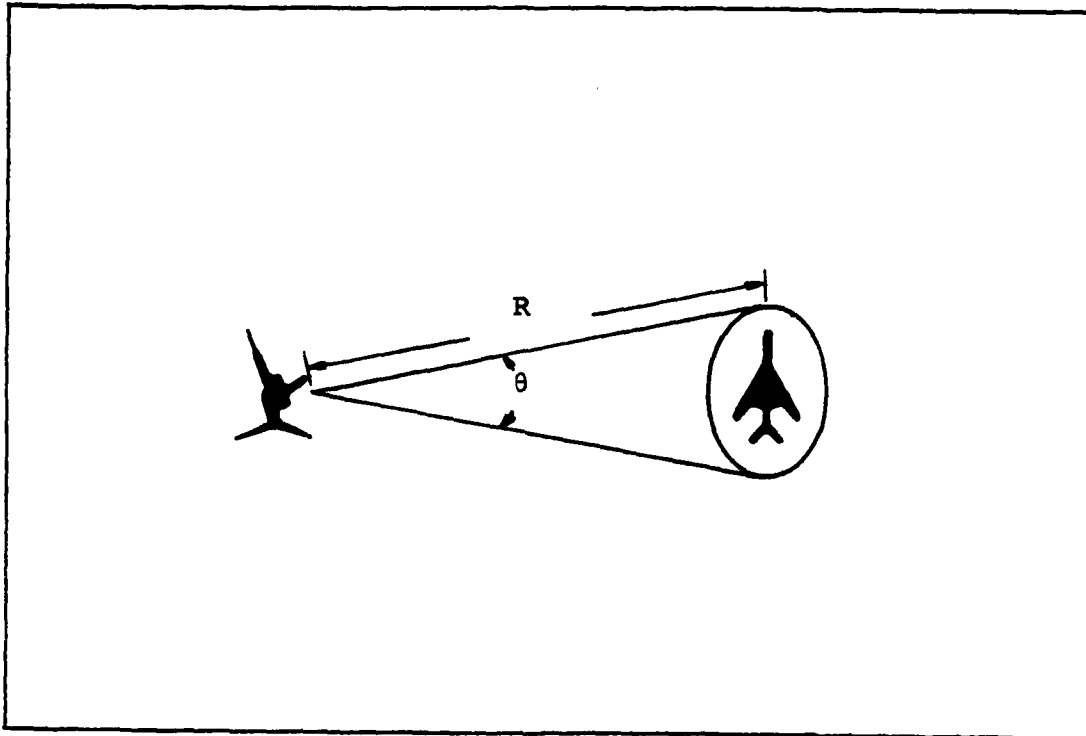


Fig. 14. AAA Dispersion Pattern

The overall  $P_k$  is dependent on the  $P_{k_{ss}}$  and the number of rounds,  $n$ , fired by the AAA. Fifty rounds would be typical for the combat arena: adequate to cover the target, yet not enough to overheat and damage the gun barrels. For the AAA weapons of the model, this represents a 2/3 second burst. Finally, the  $P_k$  calculation becomes:

$$P_k = 1.0 - (1 - P_{k_{ss}})^{50} \quad (58)$$

or the probability of AAA kill,  $P_k$ , is 1 minus the probability of the aircraft surviving 50 single round shots (Ref 9:39).

### Command and Control

The Soviets employ numerous EW radars to augment the command and control of the air defense behind the FEBA. This thesis portrays command and control of threat radars by associating EW radars with randomly selected weapon system radars. The EW sectors are defined in terms of threat belts and the LOC. The EW radars and their assigned coverage sectors are shown in Figure 15. EW radars depicted in the figure as an  $\overline{X}^{Nn}$  are used for area control of radars located in sector "n" and control all systems types within that sector. An EW radar depicted as  $\overline{X}^w$  is associated with a specific weapon system battery.

Area 1 extends from the FEBA to belt 5 (five kilometers behind the FEBA) and north of the LOC (see Figure 1). Area 2 covers the same east-west distance south of the LOC. Area 3 extends from belt 5 to belt 9 (35 kilometers behind the FEBA) and north of the LOC. Area 4 covers south of the LOC and below area 3. Area 5 extends east from belt 9 to the target area, covering both north and south of the LOC.

Each of the area specific EWs provides early warning information for threat batteries located within its area. By attacking the EW radars the WW can disrupt the normal handoff communication between the EW and its associated threat radars, thus increasing the time required by

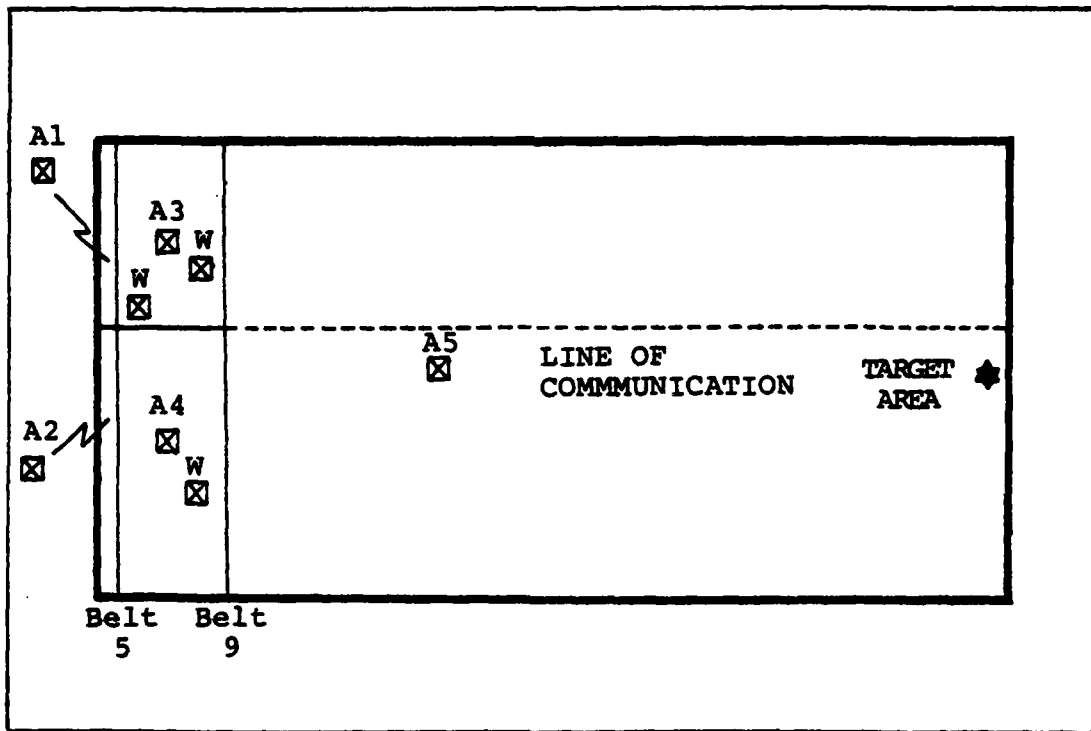


Fig. 15. Early Warning Network

individual sites to acquire, track and fire on an aircraft.

The threat environment of this model associates 50 percent of each threat type radars with a specific area EW radar. (Note: The Soviets have many types of EW systems. This thesis models a general system associated with only a percent of the total threat radars.) For example, half of the threat radars in area 1 are assigned to  $\overset{N1}{\boxed{X}}$ . If the WW kills this EW radar or forces it to stop radiating, those radars associated with it must operate autonomously and the corresponding target acquisition and tracking time will be at a maximum value. The remaining threat radars

that do not have an associated EW in the model will be assumed to have acquisition and tracking times uniformly distributed between a minimum and maximum value.

#### Summary of the Defensive System Structure

The WW and strike aircraft attempt to penetrate an enemy defensive structure comprised of four types of SAMs, one AAA weapon system, and an EW radar network. The enemy weapon systems attempt to engage the aircraft as soon as possible and evaluate the probability of destroying the target. System characteristics such as maximum detection range and minimum detection altitude limit the distance at which an aircraft can be detected. After detection the radars track the targets for a specified time. The duration of this acquisition and tracking time depends on whether or not the site received track information on the aircraft from an EW site. During this time period the site calculates the aircraft's heading, velocity, and both the slant range and bearing from the site.

The sites attempt to launch a missile or fire on the aircraft so as to maximize the  $P_k$ .  $P_k$  calculations for SAMs depend on the range to intercept,  $R_i$ , the aircraft's RCS at intercept, and the weapon's lethal radius. AAA  $P_k$  depend on the TOF of each round, the dispersion pattern of rounds about the target, the target's vulnerable surface area, and the number of rounds fired at the

aircraft per engagement. If the weapon's estimated  $P_k$  is greater than a 5 percent threshold value the site will launch at or fire on the target.

The model also provides a method for evaluating launch and impact/intercept times for maneuvering targets. At the end of acquisition and tracking the model calculates a range to intercept,  $R_i$ , at the launch time. When the simulation time reaches this scheduled launch time the model recalculates and compares this new  $R_i$  to the one calculated at the end of acquisition and tracking. If the two values compare within 10 percent, the site launches its missile. If the two differ a new launch time is scheduled. In a similar manner, the  $R_i$  at impact/intercept is calculated and compared to the one computed at launch. If the two differ by more than 10 percent, the impact/intercept is rescheduled.

#### Summary

The chapter described each of the three major elements comprising the FEBA penetration air battle and developed the analytical methodology of the interaction between the three elements. In the next chapter this methodology will be translated into a simulation model.

### III. Simulation Model

#### Overview

In the previous chapter the components and characteristics of the WW defense suppression system were described and the system structure defined. Once this has been done the model can be computerized. In this chapter the structural model is translated into the SLAM simulation language. First, simulation models are reviewed with emphasis on the two basic timekeeping orientations. Next, the SLAM language is introduced and the interfaces with the structural model are covered. Finally, the simulation model is presented in a logical, sequential manner.

#### Simulation and Combined Simulation Models

Simulation modeling was chosen as the methodology to analyze the WW defense suppression problem because there were no analytical methods available that could represent the dynamic interactions and extreme complexities of WW operations. In addition, it would be very difficult if not impossible to conduct an experiment with the necessary system components of the WW defense suppression mission. Simulation modeling offers a viable alternative for analyzing the WW system.

Simulation modeling is a technique for studying problems in which a model of the problem is constructed resembling the system under investigation. After the model is developed experiments are conducted over the time period of interest simulating the operation of the system. Data are then gathered to estimate the characteristics of the problem.

Models can be classified as either discrete change or continuous change systems. The basic difference between the two systems is the manner in which system time is modeled. In discrete change simulations system variables change only at specified points in simulation time. These points are commonly called event times. An example of a discrete change system is a bank where the number of customers in the bank changes only when a customer arrives or departs. In continuous change simulations the system variables continuously with time. An example is an airplane in flight. Because the variables change continuously over time differential equations are required to define the relationships between the variables.

Real systems are neither discrete nor continuous but a combination of both. In a combined discrete-continuous simulation there are three types of interactions that can occur:

1. A discrete event may cause a discrete change in the value of a continuous system variable.

2. A discrete event may cause the relationship governing a continuous system variable to change at a particular time.

3. A continuous state variable achieves some predetermined value (threshold value) which may cause a discrete event to occur or be scheduled (Ref 8:47).

The conceptual framework for the combined model is that the system can be described in terms of entities (such as airplanes or radar systems), their attributes (which are characteristics of entities such as velocity and altitude for an airplane or minimum and maximum effective range for a radar system), and state variables (which are the continuous system variables that change with time such as an airplane's position in flight). The behavior of the system is simulated by computing the values of the state variables at small time steps and by computing the values of attributes of entities at event times (Ref 12:72). In combined simulations, events can occur at a scheduled point in time or when the system reaches a certain state. An example of the former is when an aircraft is detected by a radar system. Its exact position can only be determined after a given time interval, representing the radar's tracking and acquisition time. In a simulation, this event would be scheduled to occur. An example of an event occurring when the system reaches a certain state is when a WW searches for a threat radar to attack. As the WW proceeds

across the defense area, its position continuously changes. As its position changes, its line-of-sight distance and the distance to the nearest available radar that the WW can attack are compared. As the line-of-sight distance crosses the distance to the nearest available radar, a state event is defined to have occurred: the radar has been detected by the WW. The possible occurrence of a state-event must be tested at every simulation time advance.

#### SLAM and Structural Model Interfaces

The WW defense suppression system, as described in the structural model presentation in Chapter II, consists of three entities--WW aircraft, attack aircraft, and threat radars. The attributes of the aircraft can be considered the following: call sign, velocity, altitude, ARM configuration (WW only), turn rate (WW only), radar cross-section, and heading. The attributes of the radar are its sequential number, minimum effective altitude, maximum effective range, associated EW radar (if any), power configuration, and position. The state variables for the system are the attack aircraft's position and the WW's position, heading, velocity components, distance to the attacked radar, line-of-sight distance, relative and absolute relative bearing to the attacked radar. Note that the concept of a state variable is dependent on the viewpoint of the modeler.

As previously noted, continuous modeling involves characterizing a system's behavior through a set of time-dependent equations (Ref 12:62). The WW's position and heading are described by a set of such equations. Figures 16 and 17 depict how the model solves for the aircraft's position over each small time increment. In Figure 16, an aircraft is located at point A with an x and y coordinate  $(x_1, y_1)$  and a heading H. The aircraft's velocity vector,  $\bar{v}$ , at point A can be resolved into two components,  $V_x$  and  $V_y$ . An increment of time  $\Delta t$  later, the aircraft is located at point B  $(x_2, y_2)$ . The model solves for the value of the new coordinates as follows:

$$x_2 = x_1 + \bar{v} \Delta t \quad (59)$$

$$x_2 = x_1 + (V \cos \theta) \Delta t \quad (60)$$

Similar evaluations of the y components of heading allows the aircraft to "fly" across the battle area.

The SLAM simulation language was chosen for this problem because of its power and flexibility to incorporate a combined simulation model necessary for the WW defense suppression mission. The many dynamic interactions and inherent complexities of the WW system required a language that was capable of representing model processes in a simple and direct manner.

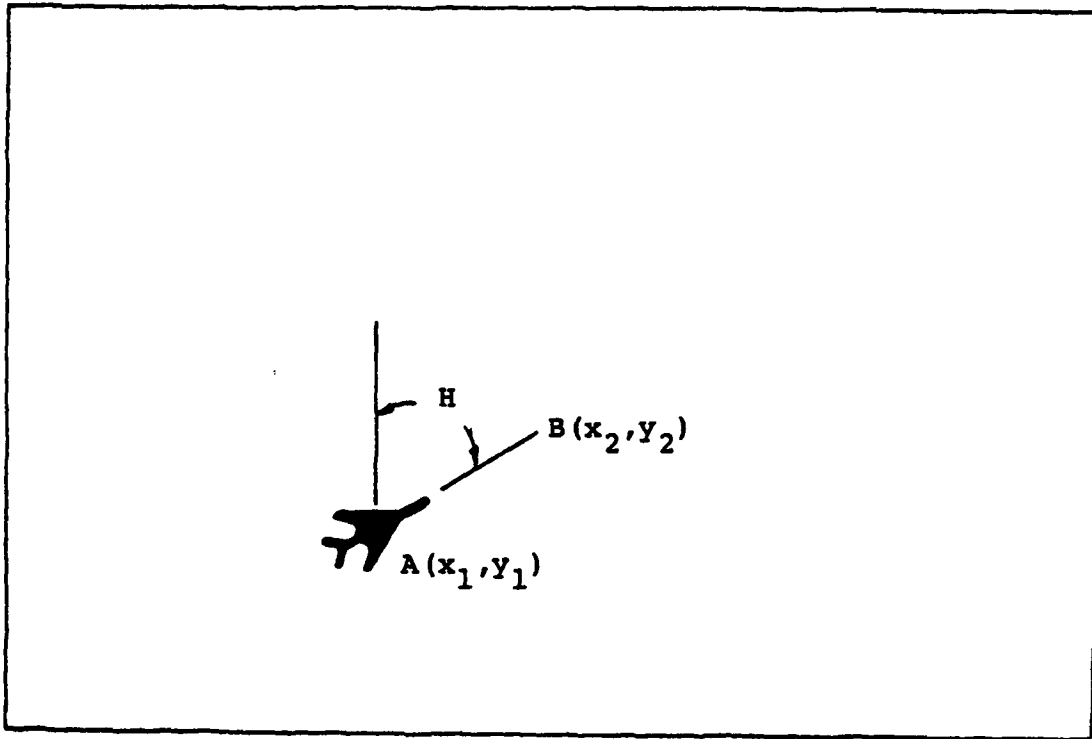


Fig. 16. Continuous Model Diagram

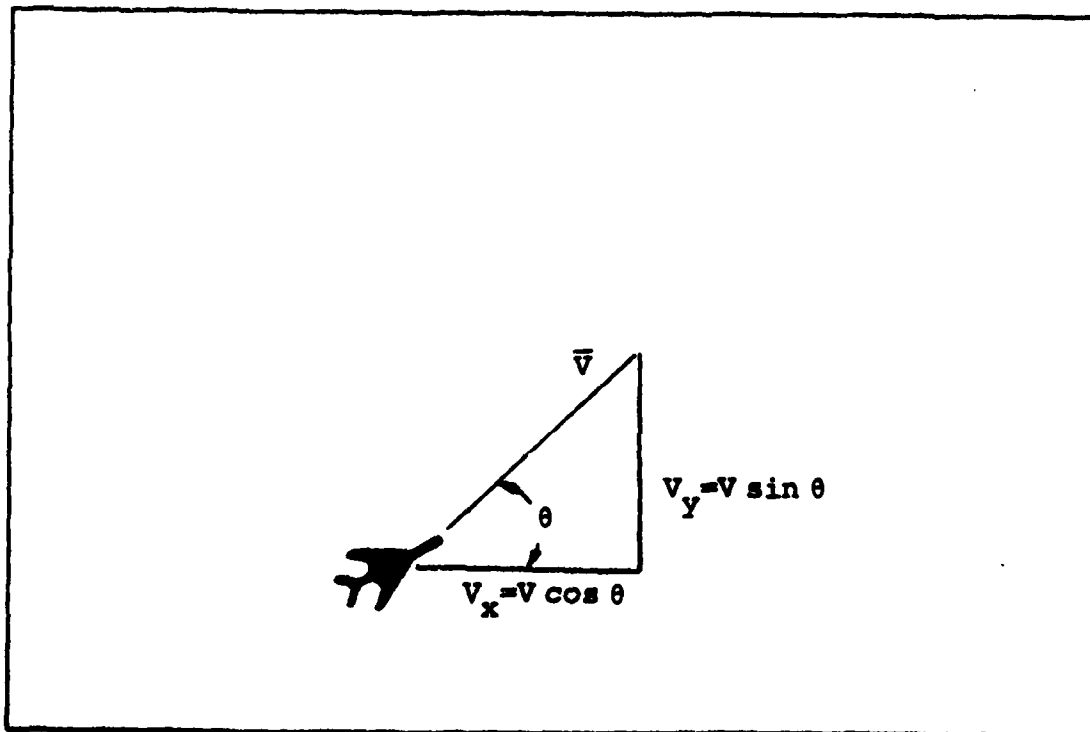


Fig. 17. Continuous Time Velocity Components

In the WW structural model, aircraft fly through the defense area enroute to the target area (attack aircraft) or fly through the area in pursuit of threat radars to attack (WW). SLAM portrays this process of entities flowing in a system by employing the concept of a network structure. The network consists of special symbols called nodes and branches. These symbols model elements in the WW system where an activity (branch) or an event (node) could be realized. The network is essentially a pictorial representation of the system. The use of a network structure to describe the system structure is especially helpful to the modeler in getting the "whole idea" concept of the model.

Aircraft (entities), therefore, are modeled as flying through the defense area where processes occur. The processes that aircraft undergo are attack by threat radars or, in the case of the WW, attack on the WW by threat radars and the WW attack on the threat radars.

SLAM incorporates discrete change simulation by allowing the modeler to define an event and the changes that occur in the system at discrete points in time. The time where the state of the system changes is called an event time and the associated logic for processing the change is called an EVENT in the SLAM notation. The WW attack profile logic is modeled using events, specifically events 1 through 13. See Appendix A.

The interface between the network, discrete event, and continuous models is crucial in modeling discrete-continuous change systems. Continuous change variables interact with discrete change variables through a state-event. This mechanism is nothing more than an event which is triggered by a continuous state variable reaching a predetermined value. The predetermined value is commonly called a threshold value.

The SLAM DETECT node is the primary interface between the network and continuous portions of the combined model and is used extensively in the WW attack profile. The duration that the WW is engaged in certain activities is keyed to the release of the appropriate DETECT node. For example, when the WW initially detects a threat radar a turn direction is computed for the WW as it begins its ranging routine on the threat (EVENT 1 in the simulation model). The duration or time the WW is in that turn is keyed to the release of a detect node (DETECT node W17 for WW1). When the continuous state variable, in this example the absolute relative bearing to the threat radar (state variable SS(49) for WW1), reaches the predetermined value of 75 degrees then the duration of the first ranging routine is completed and the WW reaches the next network node (EVENT 2 for the example). See Appendix A for the SLAM network.

SLAM incorporates numerous modeling mechanisms to assist the modeler in translating the system into the simulation model. These mechanisms are invaluable tools for not only making the computerization of the model straightforward but also for helping crystalize a system's complex interactions into clear and simple programming. The more important mechanisms are presented in the following paragraphs while the remainder are discussed in the simulation model itself.

A simulation model is built for a specific purpose. Once the model is built system variables are changed to test various conditions of the model. The ease in which these variables can be changed is a test of the language's flexibility. SLAM incorporates the concept of a global variable (XX(i) in SLAM notation) to provide this flexibility. System variables such as aircraft altitude or velocity can be defined in the simulation model as global variables. The global variables can be changed to another value by the modeler in subsequent experimental runs of the model. For example, WW altitude is defined in the simulation model equal to global variable XX(3) (see Appendix A). For the first 5 experimental runs WW altitude is to 60 meters (XX(3)=60, see line 172 of the SLAM program in Appendix A). For the following 5 experimental runs, altitude is changed to 200 meters (XX(3)=200, see line 178 of the SLAM program). The ease and efficiency of changing

system variables in this manner demonstrates the power and flexibility of SLAM.

Entities are generated in the model and routed through the network by CREATE nodes. At these nodes, the time of an entity's first creation, the time between entity creations, and the number of entity creations are specified. For the simulation model two CREATE nodes are used, one for generating WVs and the other for attack aircraft.

Entities have unique characteristics associated with them which SLAM denotes as attributes. In the simulation model WV aircraft have two explicit attributes: call sign (211 or 212) and ARM configuration. These attributes flow with their respective entities in the network. SLAM designates attributes at ASSIGN nodes. In the model ASSIGN node WAS prescribes attributes for the WV and ASSIGN node AAS for the attack aircraft.

### Simulation Model

The WV-threat environment system structure was modeled into the SLAM network and is shown in Appendix A. The network can be considered to be in two parts: a WV attack network, where the WV hunts for threats to attack; and a radar attack network, where threat radars attack aircraft flying through the defense area.

Two WVs enter the engagement through the CREATE node with the time between arrivals specified as global

variable XX(8). The WVs enter the conflict area 50 km prior to the FEBA to allow sufficient time to search for threats. The WV's attributes are specified in the ASSIGN node WAS. Attribute one is the WV's tail number (211 or 212) and attribute two is its ARM allocation. The first digit of attribute two indicates the number of AGM-Bs and the second digit the number of AGM-As. Each WV enters the area  $\pm 500$  meters of the centerline that divides the area into equal north and south components.

The attack force aircraft are created at the second CREATE node with time between creations equal to XX(7). A total of ten attack aircraft are created. As with the WVs, the attack force enters the area 50 km prior to the FEBA. Attribute one for the attack force is assigned at node AAS and represents the call sign of the aircraft (1 to 10). The attack force also enters  $\pm 500$  meters of the FEBA centerline.

#### WV-Attack Profile

Continuous modeling concepts are used to simulate the WV-attack profile of the model. This essentially involves characterizing the behavior of the WV to a system of equations. As the status of the WVs change in the system, the equations that describe the WV also change.

After the WVs are created they are separated at node G1 based on their tail number and go to either

GW1 or GW2. (All aircraft are routed to node RATK for the radar-attack phase of the model. This network will be described later in the chapter.) Each WW is then routed through a sequence of events determined by whether certain conditions are detected by key model parameters. These conditions roughly correspond to the phases in the structural model. The network phases are identical for each WW.

At node G1, WW1 begins an activity. The duration of the activity from node G1 to node RN1 is specified as REL(W1S). REL is a release specification and it is used throughout the WW-attack portion of the network. When the node upon which the release specification is realized, in this case node W1S, then the activity is completed. Thus, the time it takes for WW1 to get from G1 to RN1 is keyed to the release of node W1S. W1S is a DETECT node whose condition for release is that the range of WW1(SS(37)) decreases to less than WW1's radar line-of-sight (SS(41)). WW1 is held in the activity between G1 and RN1 until W1S is detected. Continuous state equations describe the WW's position as time advances and are explained in the paragraph on subroutine STATE. At each new iteration of time, the WW's position is changed and ranges to all candidate threat radars are evaluated. Finally, when the WW's range is less than the line-of-sight range, W1S is detected which in turn releases REL(W1S). WW1, along with its attributes proceeds to node RN1.

At RN1 event 1 is called (line 31). Event 1 turns the WW in the shortest direction to begin its triangulation routine on the radar. Turn rate for the WW is specified as RATE and is set to four degrees per second (simulating a 60° bank, level turn). The WW's working designator, SS(I+12), is set to 1 to key subroutine STATE from computing new threat parameters when the WW has just started to engage a radar. The radar the WW is attacking has its 14th attribute reset to the WW's call sign, replaced in File 2, and then copied into the WW's attack file.

WW1 now starts the activity from RN1 to RE1. The release specification for this activity is W17. W17 detects an absolute relative bearing (SS(49)) of 75 (degrees) and sends WW1 to event 2. Event 2 rolls the WW out of its turn (RATE=0). The next activity is begun and is keyed to detect node W10 which is realized when the WW's absolute relative bearing increases to 105. Upon detection, WW1 is sent to event 3 (lines 447-454) which now turns the WW back into the threat (RATE=±4 depending on turn direction). WW1 now waits until detect node W1T is realized which occurs when the aircraft is within 10 degrees relative bearing to the threat. When W1T is released event 4 is called (lines 455-464) which reduces the WW's turn rate to 2 degrees per second. Following event 4, WW1 begins an activity until detect node W1B is realized. This occurs when WW1's

heading (SS(29)) and relative bearing to the threat (SS(45)) are identical (aircraft boresighted on the radar).

Event 5 (lines 466-529) begins by selecting which ARM to fire. If the WW is too close to fire an ARM (range to threat is less than minimum range of the ARM) then the WW is sent back into the network for a "repositioning routine" (events 10 and 11). Otherwise, ARM firing range is determined based on minimum and maximum ranges of the ARM and the distance from the WW to the threat. Flight time of the ARM is computed based on ARM firing range and velocity.  $P_k$  is determined from a random sample draw. The time for the WW to get to the ARM release point is calculated (RLWW) and is loaded into XX(15) (XX(IR)). XX(16) is set equal to the ARM's flight time (TOF). The WW's turn rate is set to zero. The WW now re-enters the network.

Back in the network, WW1 can take one of two paths. If the WW is too close to fire an ARM (range to threat less than the minimum ARM range, SS(38) less than 800) then it begins a repositioning routine to place it in firing range and takes the branch to node WR2 with a release specification of WR2. (Repositioning routine network will be discussed later in the chapter.) Otherwise the WW takes the branch to event 6 with a duration specified as XX(15), the time to get WW1 to ARM release point.

At event 6 the WW launches an ARM. Each of the WW's four ARMs has its own TOF designator. For WW1, ARM

number one's TOF is set to XX(85), number two's to XX(86), number three's to XX(87), and number four's to XX(88).

Thus the capability exists in the model to have a WW launch all four ARMS simultaneously. The TOF for each ARM is used to evaluate its respective  $P_k$  at impact time. This is accomplished by calling the appropriate ENTER node. For WW1 ENTER node 1 is called with the attributes of the radar being passed along to the ENTER node. After the WW is sent back to the network, a check is made to see if there are any ARMS remaining. If the WW is out of ARMS, then its working designator is set to nine to key subroutine STATE.

WW1 goes back to the network and can branch in one of two directions. If it no longer has any ARMS then the WW is sent to node WGH to begin a "go home routine." Otherwise, after a five-second delay to simulate release of the ARM, the WW goes to event 7. Here its working designator is set to zero to key subroutine STATE to select a new radar to attack. After a 0.1 second delay in the network, which allows STATE to select a new threat, event 8 is reached.

Event 8 enters the WW back into the network depending on its distance to the new radar. If the distance to the threat is less than line-of-sight range (for WW1, SS(37) less than SS(41)), then the triangulation routine is started, the WW's working designator set to one, a turn direction is computed, and the network is re-entered. If

the distance to the threat is beyond the WW's line-of-sight range then no activities are performed by the WW in event 8. When the WW returns to the network from event 8 it can take one of two branches. If the distance to the threat was less than its line-of-sight distance, then the WW branches to node RE1, with a release specification of W1C, absolute relative bearing passing 75. (Node RE1 is event 2 where the remainder of the triangulation routine is performed.) If the WW does not detect the new threat, which was selected by subroutine STATE as the closest threat to the WW, then the WW branches to node GW1, where it essentially begins the process of searching for threats to attack once more.

As described previously in the paragraph on event 6, when the WW launches an ARM, the appropriate ENTER node is called. The network for ENTER nodes one and two simulate the flight path of the ARM. At ENTER node one, the ARM can take one of four paths to node WRK depending on whether it is the first, second, third, or fourth ARM launched by WW1 (XX(17)=1,2,3, or 4). The duration of the activity for the ARM to get from the ENTER node to WRK is equal to the TOF of the ARM which was calculated in event 5 and set equal to the appropriate global variable (XX(85,86,87, or 88)).

At node WRK event 9 occurs which evaluates the  $P_k$  of the ARM. If the WW kills the radar, then the following

sequence of events takes place. First, if the radar was an EW radar (ATTRIB(1)=1) then all threat radars associated with it have their 5th attribute set to 10 to key tracking and acquisition time computations, which are described in the radar-attack portion of the model. Next, the destroyed radar is removed from both the current radar file (File 1) and the WW available file (File 2). All events associated with this radar are removed from the event calendar. Finally, XX(49) is set to attribute one, the radar's sequential number in the model.

If the radar is not killed, then its 14th attribute is reset to zero to indicate that the radar is once again available for engagement by a WW.

From event 9 the ARM/WW will go to node WKL if the radar was killed. It then enters an assign node where XX(50) counts the number of radars killed by the WW.

If after the WW completes the triangulation routine and finds itself too close to fire an ARM due to the minimum range of the ARM (event 5) then a repositioning routine is started. This routine begins in event 5 which initially turns the WW away from the site after the range to the radar was determined to be too small to fire the ARM. From event 5 the network is entered and WW1 is sent to node WWR after waiting until node WLR is released, which occurs when the absolute relative bearing to the site is 179. This position places the radar at the WW's 6 O'clock

position as the WW attempts to get sufficient distance to fire its ARM. Node WWR is event 10 which rolls the WW out of its turn. From event 10, WW1 enters the network with an activity duration whose release specification is WLD. Node WLD is realized when WW1's range to the radar passes 18,000 meters. WW1 proceeds to event 11 where it is turned back into the site to re-attack. When WW1 is boresighted on the site (WLE), event 5 is reached once again where an evaluation for an ARM launch is made.

When the WW fires its last ARM it is sent back across the FEBA via node WGH, event 13, and node WHM. Global variable XX(48) counts the WWs as they reach the home point.

The network logic for WW1 and WW2 is identical. Each WW, however, has its own separate network where only activities that pertain to it can occur. The logic for the events that describe the WW-attack scenario are the same no matter if the aircraft is WW1 or WW2.

#### Radar-Attack Profile

In the radar-attack portion of the network threat radars engage both attack force and WW aircraft. As each aircraft enters the network the range to the closest radar that isn't tracking an aircraft is calculated. If the range is less than the maximum effective range of the threat radar, then a sequence of events is started that

simulates the profile for a threat system to launch a SAM or shoot a AAA at the target aircraft.

All aircraft, after they are created, proceed to node RATK, where event 14 is called. This event simulates the radar search phase of the system. If the aircraft has reached the target area then global variable XX(55) is set to the call sign of the aircraft to key the network and the event is terminated. Similarly, if there are five threats already engaged with the aircraft, then radars are not allowed to search for this particular aircraft and the event is terminated. If these two conditions are not encountered then subroutine SEARCH is called.

#### Subroutine SEARCH

Subroutine SEARCH simulates the actual threat radars searching for aircraft as they fly through the threat environment. When an aircraft enters SEARCH every radar is evaluated to determine if it can engage the aircraft. Four checks are first made to determine if the radar can engage the aircraft. If the radar is an EW radar or if the aircraft's altitude is below the radar's minimum altitude or if the radar is already engaged or if the radar is not operating; if any of these conditions are met, then the radar cannot engage the aircraft. If the radar passes these four checks, then the distance is greater than the multi-path range then the radar will be unable

to track the aircraft. Finally, if the distance from aircraft to radar is greater than the maximum effective range of the radar, then this too excludes the radar from tracking the aircraft. If the radar passes all of these checks then the model allows the radar to start the engagement sequence. The radar's 8th attribute is set to the aircraft's call sign, the radar, along with its attributes, are filed in the radar aircraft file (LF), the radar, with its new 8th attribute, is copied back into File 1, and an acquisition and tracking time is computed. This time, TRC, is computed from a uniform distribution based on the threat radar's minimum and maximum acquisition time unless the threat radar's associated EW radar was killed previously by a WW. In this case, TRC is set to the radar's maximum acquisition time. Discrete event 15 is scheduled at the end of the tracking and acquisition time which will make the initial calculations of the weapon  $P_k$ .

#### Radar-Attack Profile--continued

Subroutine SEARCH returns to event 14 where the network is entered. From event 14 the aircraft takes one of three paths. If the aircraft reached the target area then it will go to node TGT. If the aircraft was killed by a threat weapon system in discrete event 17, which will be described later in the chapter, then the aircraft will take the path to node AKL. If the above two conditions

are not met, then the aircraft will proceed back to node RATK after a one-second activity duration. Thus radars will discretely search for the aircraft as they fly through the threat system in one-second intervals. If the aircraft either reaches the target area or is killed then the screening process stops for that aircraft.

Discrete events 15, 16, 17, 18, and 19 apply to the radar-attack portion of the system. These events are FORTRAN code using SLAM subroutines that evaluate the radar's attack profile on the engaged aircraft.

Event 15, which is scheduled from subroutine SEARCH, occurs at the end of the tracking and acquisition time, TRC. Here, the radar first determines if it has a chance of getting a shot at the aircraft. Subroutine PROB is called which computes the  $P_k$  of the weapon, the estimated range to intercept (RI), time of weapons launch (TL), and time of impact (TI). If the  $P_k$  is below 5 percent, then the radar is disengaged from the profile and event 19 is scheduled, which releases the radar from the aircraft. Otherwise, the radar-attack profile is continued. If TL is equal to the current simulation time, TNOW, then the threat radar "fires" its associated weapon and event 17 is scheduled to occur at impact time. If TL is greater than TNOW, then event 16 is scheduled at estimated launch time.

Event 16 occurs at launch time, TL. Subroutine PROB passes new estimates of  $P_k$ , RI, TL, and TI back to the event. Once again, if the  $P_k$  is below 5 percent then event 19 is scheduled to disengage the radar and aircraft. If the  $P_k$  is acceptable event 17 is scheduled to occur at the new time of impact.

Event 17 is realized at weapon's impact time. Subroutine PROB is called one last time for the final evaluation of  $P_k$  and RI. If the aircraft turned away from the site when the weapon was airborne then RATIO is computed to determine how much its position has changed. If RATIO is greater than 1.1 then event 17 is rescheduled with time of occurrence set how long it takes the weapon to get to the new intercept range. If the aircraft did not turn or did turn but the turn was not appreciable, then a kill determination is made by using a random sample draw. If the aircraft is killed, then XX(54) is set to the call sign of the aircraft to key the network. Global variable XX(59) or XX(57) is incremented as appropriate and all events associated with the destroyed aircraft are removed from the event calendar. In any case, event 18 is scheduled to occur in 30 seconds, representing the delay time of disengaging the radar from the aircraft.

Event 18 frees the appropriate radars to re-engage new targets. If the aircraft was not killed, ATRIB(6) not equal to 1, then only that radar that fired at the



aircraft is released. If the aircraft was killed, then all radars associated with it are disengaged.

#### Subroutine PROB

This subroutine calculates the probability of kill for the threat weapon system, the range to intercept the target aircraft (RI), the time of weapons launch (TL), and the time of weapons impact (TI). First the attributes of the aircraft are decoded (lines 979-992), the multi-path range calculated, and the appropriate radar-attack file obtained. The distance from radar to aircraft is compared to the multi-path range and the maximum effective weapon range. If the radar-aircraft distance is greater than either of the above then  $P_k$  is set to zero and the subroutine terminated.

For the SAM threats the following is accomplished. The relative bearing between the radar and the aircraft is computed (ANG, lines 1014-1025). Based upon whether the aircraft is ahead or behind the threat the appropriate values of TL, TI, and RI are calculated. Aircraft radar cross-section is obtained from File 19 based on the aspect angle between the threat and the aircraft (lines 1056-1061). Next,  $P_k$  is calculated. First, if RI is greater than the maximum effective radius of the weapon,  $P_k$  is set to zero. Otherwise, CEP is computed based on whether the aircraft

is ECM (attack force) or non-jamming (WW). Using CEP,  $P_k$  is calculated.

For the AAA threats the following applies. "G" forces are determined based on whether the aircraft is a WW (turning or straight and level) or an attack force (in or outside the expected area of AAA concentration).  $P_k$  calculations are given in lines 1092-1100.

#### Subroutine INTLC

Subroutine INTLC initializes variables to their starting values. In addition the radar file, File 1, and the WW-attack file, File 2, are built. Radar cross-section data is built and stored in File 19.

#### Subroutine STATE

Subroutine STATE contains the equations that define the continuous set of variables for the model. These equations explicitly characterize the model as it changes over time. This time-dependent, event-dependent portrayal is fundamental to the concept of the system as a combined simulation model.

Rate equations for the attack force aircraft consist of just one differential equation. Because the attack aircraft never change heading and their heading is 090 degrees in the model's coordinate system, the velocity of the attack aircraft, DD(I), is defined to be a constant, XX(14).

Rate equations for the WW are only slightly more complicated. The WW will have velocity components in both the x and y direction. In addition, because the WW changes heading (direction) as it works its way through the threat environment, its heading rate of change is expressed as a differential equation. Line 39 gives the differential equation for this heading rate change as equal to RATE. The next two equations correct the WW's heading to the limits of 0° to 360°. Lines 45-46 define the velocity of the WW in the x- and y-direction. Next, the WW working designator is evaluated. If the WW is engaged in an attack profile, working designator between one and eight, then the WW does not enter the radar selection phase of STATE (lines 62-75) but instead proceeds to "101" to calculate the remaining STATE variables. If, on the other hand, the working designator is equal to nine, indicating that the WW is out of ARMs, then a designated go home point is chosen (lines 53-57). If the WW's working designator is zero, signifying that the WW is searching for threats to attack, then the radar selection routine is performed (lines 62-75). In this routine the closest radar that the WW can attack from File 2, the WW-attack file, is selected, its sequential number placed in "L" and its coordinates set to XX(I+11) and XX(I+12). Line 76 calculates the distance from the designated radar to the WW. Line 78 is the line-of-sight range to the WW. The relative bearing is

calculated in lines 79-88 based on the position and heading of the WW with respect to the radar. The absolute relative bearing is calculated in lines 89-90 and corrected for the limits of 0° to 180°.

Appendix F lists a summary of the events and subroutines.

In this chapter the structural model was translated into the simulation model using the SLAM language. Basic concepts of simulation modeling were presented and the interfaces of SLAM and the structural model discussed. Once the simulation model has been developed tests are ready to begin. The next chapter demonstrates the capability of the model to analyze WW operations through experimentation.

## IV. Experimentation

### Overview

The purpose of the research effort was to develop a methodology that could be used to analyze WW defense suppression operations. Once the structural model has been translated into the simulation model then the simulation model can be executed and an experiment conducted to demonstrate the capability of the model to analyze WW operations. In this chapter experimentation of the simulation model is performed. First, the data collection phase is presented: WW variables that may be analyzed in the model are discussed and two are selected for the experiment; experimental design is set forth; sample size for the experiment is determined. In the next phase the experiment is conducted and the results are discussed. In the final phase, the model is validated in a three-step process.

### Phase One: Data Collection

The simulation model was constructed with the capability to analyze the WW defense suppression mission firmly in mind. To that end, SLAM global variables were used so that various system variables could be changed quickly and effortlessly to analyze different aspects of the WW mission. Table VI lists these variables and their associated global

TABLE VI  
 VARIABLES THAT CAN BE CHANGED/EVALUATED

Variable	Global Variable
<u>WW</u>	
Altitude	XX (3)
Velocity	XX (5)
Interval/Spacing	XX (8)
Number in System	XX (6)
ARM Configuration	XX (81-82)
ARM Launch Range	XX (4)
Entry Position	SS (25,29) *
<u>Attack Aircraft</u>	
Altitude	XX (13)
Velocity	XX (14)
Interval/Spacing	XX (7)
Number in System	XX (9)
Entry Position	XX (61-70)
<u>Radar Systems</u>	
Dispersion on LOC	XX (52)

\*State Variable--see text.

variable. (The entry positions of WW1 and WW2 are changed with state variables SS(25) and SS(29), respectively.) Through the use of global variables any of the system variables listed in the table can be changed and experiment conducted to analyze their effect on the output data.

To demonstrate the capability of the simulation model two variables were selected for the experiment: WW altitude and WW tactic. These two variables were suggested by WW experts at George AFB (Refs 10; 11) as having significant impact on WW defense suppression operations. The two altitudes chosen for the experiment were 60 meters and 200 meters. At a relatively higher altitude the WW can "see" farther with its radar homing and warning equipment and will be able to begin an attack on threat radars sooner than if it was at a lower altitude. But at the same time, because the WW is at a higher altitude, threat radars will be able to detect the WW sooner and begin their attack on the WW earlier. The two tactics chosen for the experiment were the WW leading the attack force into the threat area by 30 seconds and accompanying the attack force into the threat area. If the WW leads the attack force into the area, it may be possible to attrite enough radars so that more attack aircraft can get to the target area. But the WWs will have increased their exposure time to the threats in this tactic.

In the SLAM program WW altitude is specified at line 172 (XX(3) = 60) and line 178 (XX(3) = 200). Tactic 1, WVs leading the attack force by 30 seconds is specified in the SLAM program in Appendix A. This is denoted by the "30" in the attack aircraft CREATE node entry at line 18 signifying that the time of the first attack aircraft generated in the system is at 30 seconds simulation time. Tactic 2 is not shown in Appendix A but is identical to the Appendix A program except that the attack aircraft CREATE node entry in line 18 is changed from "30" to "5" signifying that the first attack aircraft follows the first WW in the simulation by 5 seconds.

Experimental Design. Experimental design provides a way of deciding which system variables to experiment so that the results can be obtained in the most efficient manner, efficiency equated to least time and money.

(In the terminology of the experimental design the input variables (for the WW model--altitude and tactic) are called factors and the different conditions of the factors (WW altitude of 60 m and 200 m) are called levels.)

The design chosen for the experiment was a full factorial design (Ref 8:372). The full factorial design is one in which all levels of a given factor are combined with all levels of every other factor in the experiment. The advantages of the factorial design are as follows:

1. Maximum efficiency in the estimation of the effects of the variables.
2. Correct identification and interpretation of factor interactions if they exist.
3. The effect of a factor is estimated at several levels of other factors, and thus the conclusions reached hold over a wide range of conditions.
4. Ease of use and interpretation (Ref 14:165).

The main disadvantage of a full factorial experiment is that the number of runs required to test all levels of all factors may become prohibitively excessive. The number of runs required for this experiment did not preclude the use of the full factorial design. This will be discussed in Sample Size Determination.

Measure of Merit. The measure of merit chosen to evaluate the experiment was the number of aircraft surviving each run and reaching the target area. This permitted an analysis of WW defense suppression effectiveness within the context of the model's threat environments.

Sample Size Determination. A simulation model is an abstraction of a real system. Experiments are conducted on the model in order to draw inferences on the real system. Because the model is an abstraction or approximation of the real world, the model must be executed a number of times

before valid inferences can be made on the output data. Determining the number of runs for the experiment is called sample size determination. Determining how large a sample to use in an experiment depends on the size of the risk you're willing to take on the inferences and variability that is present in the model.

The sample size that was chosen for the experiment was determined by Stein's method (Ref 7:482). A trial experiment of five simulations was conducted. Each factor in the trial was set at its lowest level: WW altitude at 60 and WW tactic leading the attack force. The objective of the trial experiment was to be 95 percent confident that the sample mean would be within one aircraft of the true mean. The following equation gives the required number of runs.

$$M = \frac{t_{n-1}^{\alpha/2}}{c} s^2$$

where  $M$  = required number of runs,

$c$  = maximum units wrong,

$s^2$  = sample variance in trial, and

$t_{n-1}^{\alpha/2}$  = t-statistic for  $(1-\alpha)$  confidence level with  $(n-1)$  degrees of freedom.

The trial experiment produced the following results.

<u>Run</u>	<u>Number of Aircraft Surviving (out of 10)</u>
Run 1	3
Run 2	1
Run 3	1
Run 4	5
Run 5	4

Thus,

$$M = \frac{t_4^{.025}}{c} s^2 = \frac{2.76 \times 3.36}{1} = 9.2$$

The results of the experiment indicated that the minimum number of runs would be 10. This resulted in a total of five replications per cell for the experimental design. See Table VII.

TABLE VII  
EXPERIMENTAL DESIGN

	WW ALT--60	WW ALT--200
Tactic 1--WW Leading	XXXXX	XXXXX
Tactic 2--WW Accompanying	XXXXX	XXXXX

x = replication.

## Data Analysis

Once the factors and levels for the experiment were chosen, the number of runs determined, and the experimental design set, the experiment was performed. The results of the experiment are analyzed in this phase of the experimentation.

To determine if WW altitude or tactics effected attack force survivability a two-way analysis of variance (ANOVA) statistical procedure was conducted. The output of the statistical analysis along with the results from each experimental run are listed in Appendix G.

The null hypothesis for the experiment is the following.

$H_0$ : Neither altitude nor tactic effected aircraft survivability.

The test statistic for the experiment is the F-statistic. The null hypothesis is rejected with the F-statistic is greater than the following.

$$F_{.05,1,16} = 4.49$$

The ANOVA shows:

$$F = 1.14$$

Thus the null hypothesis cannot be rejected at the .95 confidence level.

Although the results of the experiment show an inconsequential relationship between the two WW factors and attack force survivability, the experiment must be viewed within the broad perspective of the developed model. The following factors, viewed separately or in combination with one another may have contributed to the experimental results.

1. Threat environment density. The number of threat radars (78) in the threat area was too great for a force of only 2 WW to suppress. The threat radars were not modeled to stop radiating in anticipation of an ARM impact, real or imagined. Whether radars would stop radiating in response to a WW attack in an all-out encounter between NATO and Warsaw Pact is open to conjecture. The simulation model allows for this concept by defining the threat radar's ninth attribute as the radiation attribute. See Appendix E.

2. WW tactic. The WW tactic required the WW to boresight on the threat before an ARM could be launched. In addition, the WW attacked every threat regardless of the attack positioned the WW.

3. Ranging routine. Threats were required to be accurately located before an ARM was launched. This meant that the WW had to complete the entire ranging routine before ARM launch. Another tactic that a WW might use in a radar-rich threat environment is to pre-emptively launch ARMs in anticipation of threat radar emissions. Although

this would decrease the WW's exposure time in the threat area it is not certain to what extent, if any, it would decrease the WW's effectiveness.

4. Self-protection jamming. The WW did not use self-protection jamming either before or after attack by a threat radar. If the WW did use jamming its survivability might be increased.

Needless to say there are many factors that influence and are critical to WW defense suppression operations. A thorough and comprehensive investigation of these many factors is easily realized with this WW simulation model. Manipulations of various parameters such as altitude, air-speed, timing tactics, radar shutdown, and jamming can be accomplished with minor adjustments of the defining simulation variables.

#### Validation

Law and Kelton (Ref 8:338) elaborate on a three-step approach to validation that was first presented by Naylor and Finger.

1. Develop the model with high face validity.
2. Test assumptions of the model empirically.
3. Determine how representative the simulation data are.

This three-step approach will be used for the WW simulation model in order to establish its validity.

Model Face Validity. A model that has high face validity is one which seems reasonable to people who are knowledgeable about the system. To establish the model's face validity the following was accomplished.

1. Before the WW model was developed, experts on WW employment from the 37th Tactical Fighter Wing at George AFB were interviewed. Crew members and instructors who are familiar with the WW and its varying missions were consulted. In addition, as the model was being built, these experts were asked to confirm various aspects on possible WW tactics and current operational concepts to make sure that the model's assumptions were realistic (Ref 11).

2. In order that the model's threat environment be representative of a typical enemy threat array, defensive systems experts were consulted (Ref 4). The threat scenario that resulted developed from these consultations.

Empirical Tests. In order to ensure that the model behaved as it was intended to behave, quantitative tests were run. These tests consisted of the following.

1. WW Profile. To determine the validity of the WW attack portion of the model, a WW was followed as it proceeded through the threat array hunting for radars to attack. The logic and action points, as well as the probability of kill routine for the WW, were hand-calculated and then compared to model output. The results are listed

in Appendix I. The model's output compares favorably with the hand-calculated figures.

2. Radar-Attack Profile. As with the WW portion of the model, the logic and subroutines of the radar-attack profile are validated by following an attack force aircraft as it flies through the threat array. The results are listed in Appendix I and these too compare favorably.

3. Extreme Values. The model was tested at extreme values of various system parameters to determine if the model behaved as it should. When attack aircraft velocity was decreased to 50 m/sec, all aircraft were killed. Similarly, when attack aircraft altitude was set at zero, all but one aircraft survived, the lone kill being recorded by AAA. Additionally, WW altitude was decreased to zero and WVs were able to launch a total of seven ARMs before being killed by AAA.

Simulation Output Data. The best test for a simulation model would be to establish that the model's output data closely follows the output data one would expect from the real system being modeled. Because the developed WW simulation model had no equivalent system with which to test it, a modified Turing test (Ref 8:341) was conducted. The object of the Turing test was to compare the model's output data against a hypothetical system by experts who are knowledgeable with the system. To that end three WW

experts were asked to predict the outcome of the model's threat scenario given the same input data as the model's. The WW experts consisted of two crew members and a WW systems project officer, all of whom are familiar with the capabilities and concept of operation of the F-4G WW. The predictions of the panel of experts agreed consistently with the model output data.

In this chapter experimentation of the simulation model was presented. This included selecting the data and methodology for the experiment, performing the experiment, and analyzing the results. In addition, the three-step process of model validation was discussed. In the next chapter, conclusions and recommendations are presented.

## V. Conclusions and Recommendations

The objective of this thesis, as stated in Chapter I, was to develop a methodology, through a simulation model, for evaluating the WW defense suppression mission. Conclusions resulting from this objective break down into two categories:

1. Primary--those based on the SLAM modeling of the FEBA air battle, and
2. Secondary--those based on the model's experimental results.

### Primary Conclusions

This thesis developed a model for evaluating combined air operations and tactics near the FEBA. The model expanded on Leek and Schmidt's initial work by including WW defense suppression support for an ingressing fighter strike force. The model required the flexibility to allow an experimenter the latitude for evaluating alternative procedures and tactics yet retain the accuracy required to portray the actual combat area. The SLAM model does capture the dynamic nature of the FEBA air battle. The combined modeling approach allows the experimenter to view the interactions between the aircraft and threats on a moment-by-moment basis. SLAM's flexibility offers an experimenter

the opportunity of varying the state and global variables to design meaningful experiments and evaluate effects on WW tactics and procedures. Appendix C lists these variables and gives an idea to the type of experimental design that can be undertaken.

#### Experiment Conclusions

The model's present structure was developed with the objective of obtaining the highest  $P_k$  per engagement for both the WW and enemy threat systems independent of other action. It represents the most restrictive case for both the major system elements (WWs and threats) and required the most computer logic and subroutines. At the other end of the scenario spectrum lies the area of maximum self-protection for both elements. It requires little logic (stay low for the WW and do not radiate for the threat radars). In between these two extremes lies the area of actual operations and an area where experimentation can be done: achieve a desired level of  $P_k$  on a threat while achieving some desired level of self-protection.

Consider the WW. Its stated objective for a defense suppression mission is to eliminate the enemy's radar controlled weapon threat. The existing model simulates a methodology which attempts to maximize this probability of destroying the threat. The WW's ranging routine duration (30 degree of relative bearing change) represents

the method of most accurately determining the threat's location given the WW must operate in the low altitude arena. The attack phase requirement for boresighting on the threat again represents the method required for achieving the highest  $P_k$ .

The same can be said of the threat's portion of the model. The logic attempted to maximize the single engagement  $P_k$ . For both the SAM and AAA systems, the shot was delayed, if possible, until the aircraft came abeam the site, thus increasing the maximum radar cross-section while launching at the minimum range (resulting in the minimum CEP and maximum  $P_k$ ).

To get from the restrictive case of the existing model to a likely operational area requires small deletions from and changes to the existing model whereas going from the total self-protection end of the spectrum to the operational area requires major additions to the program. For this reason the restrictive case is easier for an experimenter to use and modify. The experimental conclusions and recommendations are made with this in mind and represent areas where operators in the field indicate a need exists for additional study and the analyst can readily adapt the model.

The model's experiment of varying WW tactics (timing with the strike force) and altitude did not affect strike force survivability. It must be emphasized that this

conclusion is drawn based on the constraints and limitations imposed in the model. In addition, the experiment's measure of merit was strike force aircraft reaching the target and not WW survivability. The results appear consistent for an area where the ground threats enjoy a 7:1 numerical advantage over the aircraft.

Specific limitations and constraints imposed by the model on the WW and affecting its performance are explained below. In general, the WW tactics employed in the model increased the WW exposure time in the threat environment.

1. The WW continued to attack threats until it depleted all weapons. In the dense threat environment this longer exposure time to the threats increased the site's  $P_k$  against the WW. (Restrictive case discussed above.)

2. The WW did not employ an ARM turn launch option (off the boresight axis). The increased time required to turn and boresight on the threat again increased the WW's exposure time. (Again, restrictive case discussed above.)

3. The WW did not immediately abort the mission scenario if the slant range to the site was less than the minimum ARM range. (Restrictive case.)

4. The WW ARM's  $P_k$  against a site did not vary for launch altitude, although degradation for lower launch

altitude does exist. (Restrictive case.)

Model limitations imposed on the threat radars and affecting the experiment's outcome are listed below:

1. The SAMs did not have a minimum launch range. Actual SAMs have both a minimum and maximum launch range. By excluding the minimum range, the site could allow the aircraft to fly over the site before launching a missile and thus the model calculated an inflated  $P_k$  based on this lower launch range to impact.

2. The sites neither jammed the WW's RHAW receivers nor stopped radiating if detecting a possible WW attack.

3. The threat radars were modeled as totally concentrating on the attacking aircraft. Combined arms operations near the FEBA may hinder the site's operation when other ground threats in the area attack near the SAM sites.

4. The threat network included neither infrared (IR) and visual detection means nor small arms fire.

#### Recommendations

Based on the experimental conclusions, the following recommendations are made (here, the model moves from the restrictive to operational):

1. When possible, ARM launch should occur at the maximum launch range.

2. If the WW finds itself in a position inside the minimum launch range, the aircraft should immediately

abort the attack and not attempt to maneuver to achieve a permissible launch condition.

3. An effort should be made to decrease the time required to complete the ranging phase of the mission.

4. WW crews should always operate at the lowest possible altitude.

5. An analysis should be continued in developing a longer range ARM.

## VI. Recommended Follow-on Study

This thesis concentrated on developing a model for experimenting with combined air operations near the FEBA and did not concentrate on the actual experimentation. The model achieved an operational status and is now ready to be used for experimentation. The following indicate possible follow-on study areas:

1. The WW preemptive ARM launch option should be investigated. Preemptive launch requires no mission ranging phase. Based on intelligence estimates the crew launches its ARM into a concentrated area of weapons from a maximum range.

2. The use of WW self-protective ECM and its effect on WW survivability must be analyzed. This may be limited by the WW's onboard RHAW equipment and the possible interference.

3. The number of ARM launches the WW attempts per mission may affect its survivability. For example, continuous attacks in a dense threat radar environment resulted in the WW being destroyed on all experiment runs. By limiting the attacks to a smaller number per mission, followed by the WW withdrawing to safe airspace may increase the number of surviving WW.

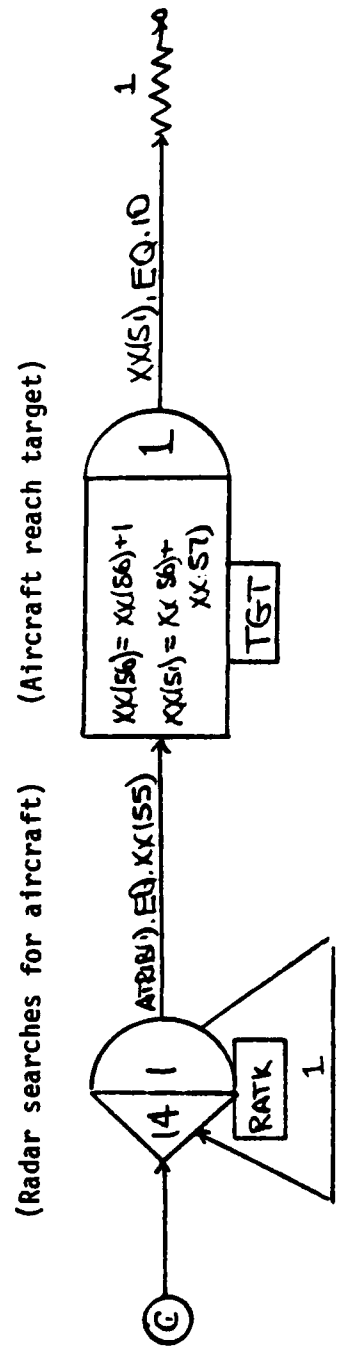
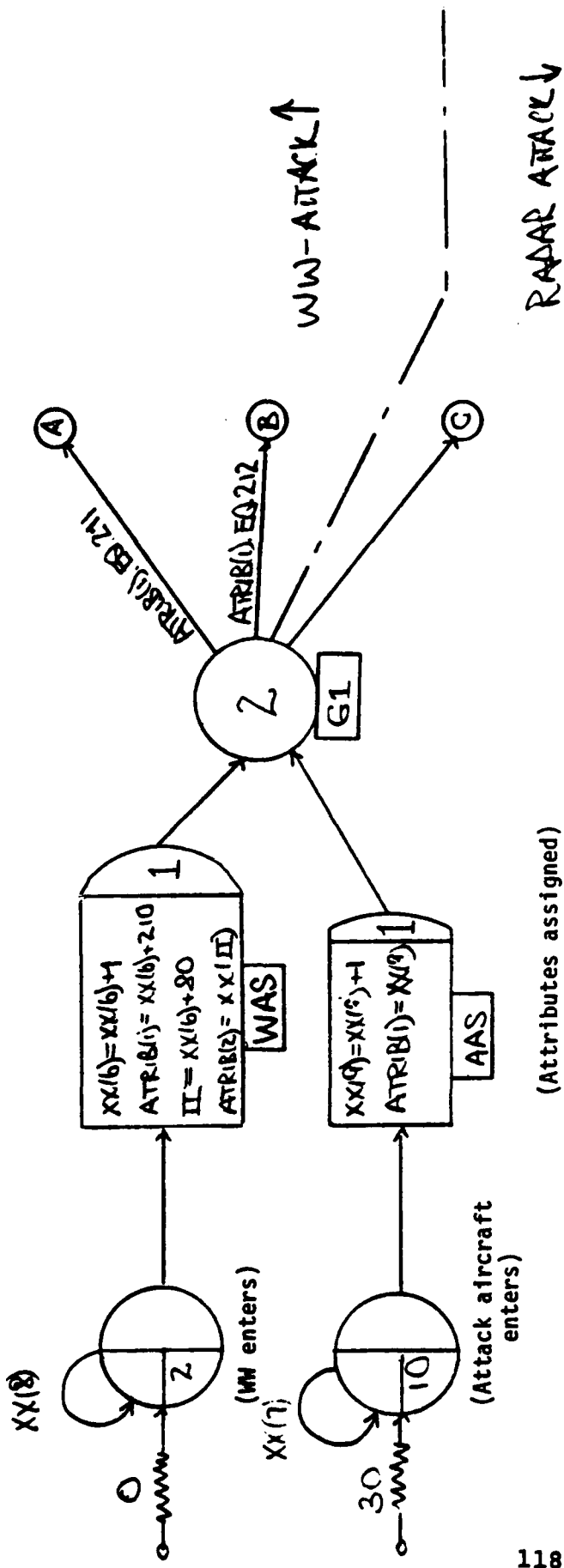
4. A modification of the model would allow the WW to employ the ARM launches from its turn mode, thus decreasing the time required to perform each mission scenario.

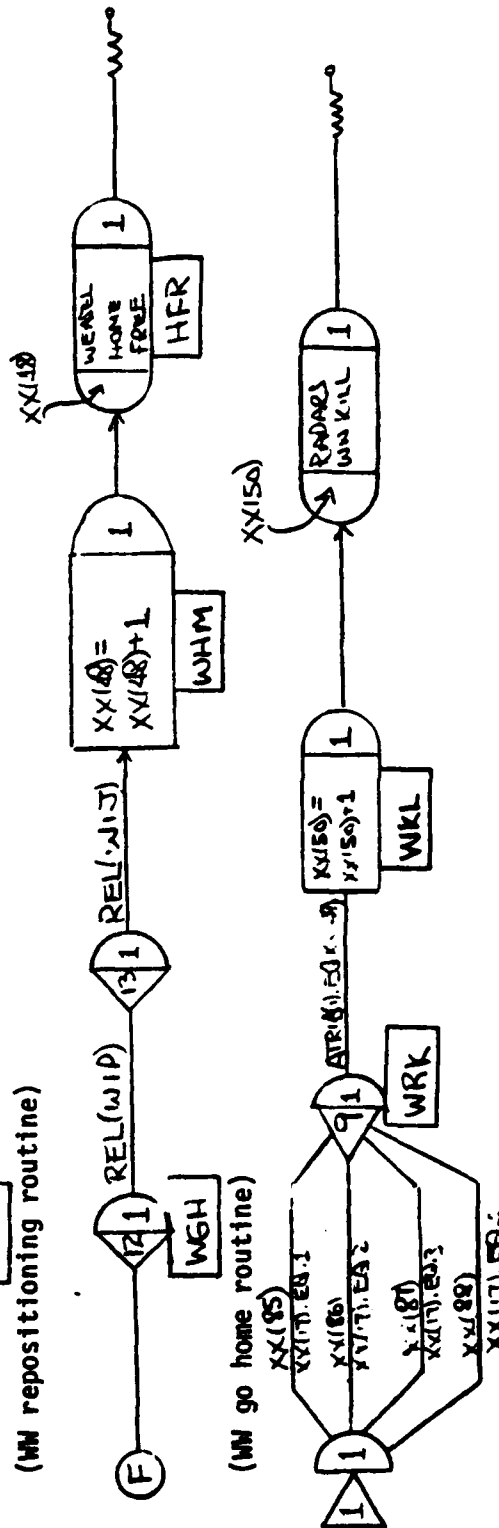
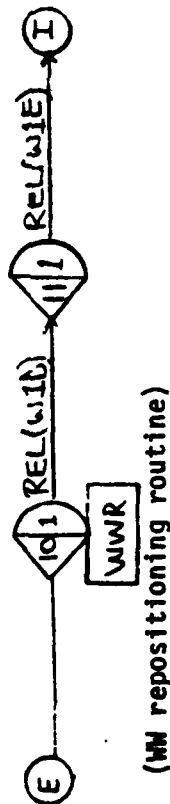
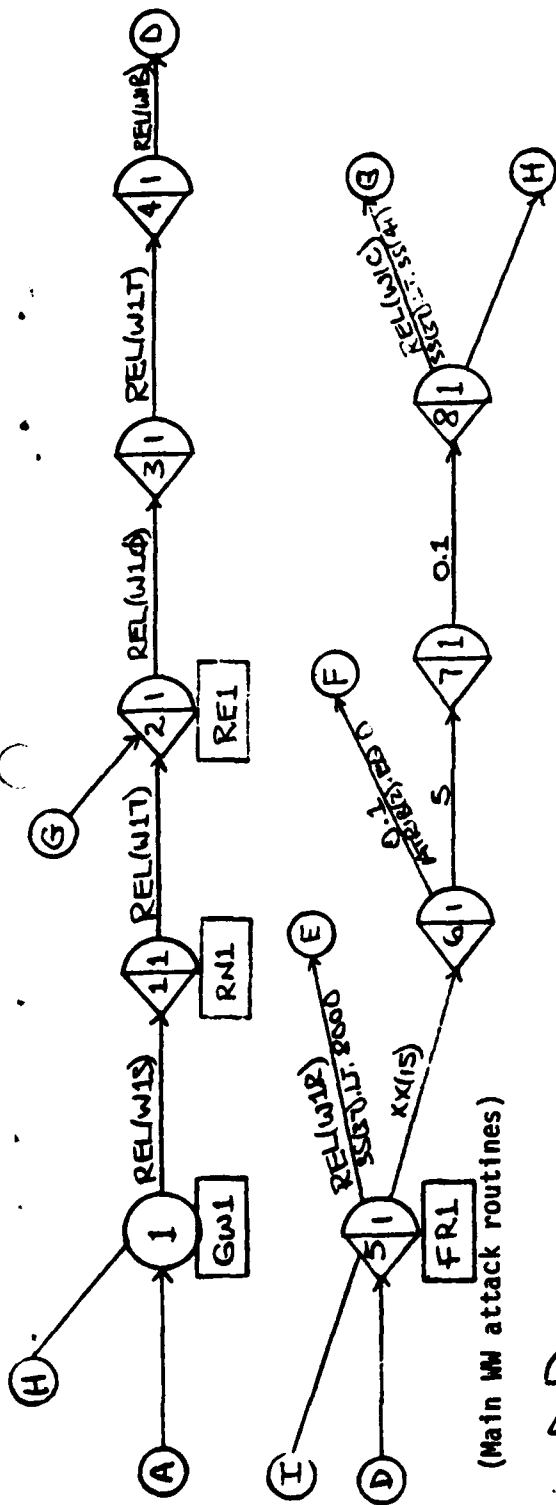
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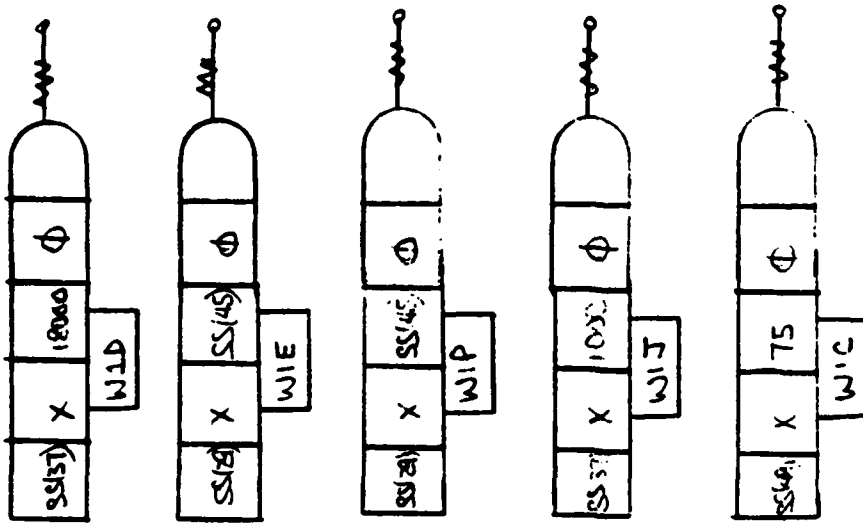
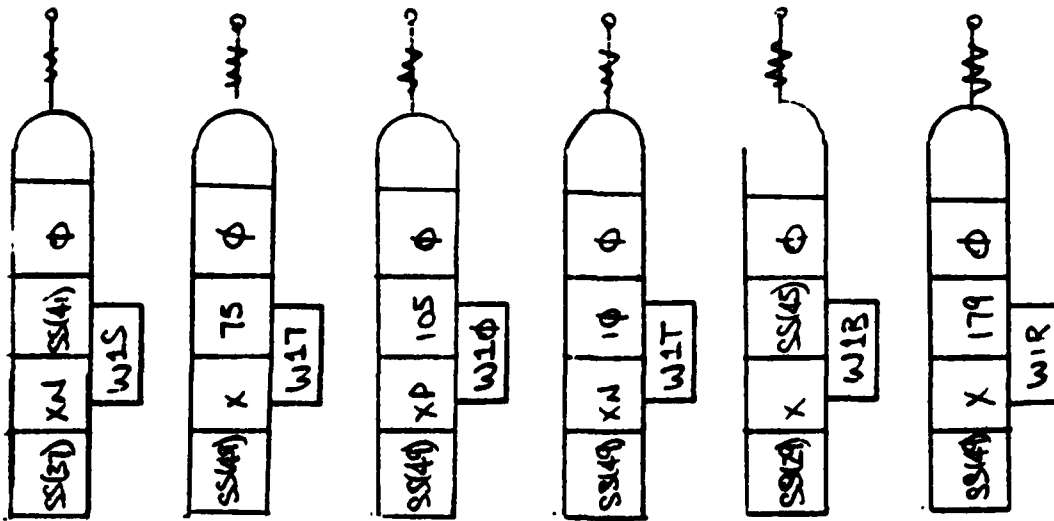
Appendix A  
SLAM Network

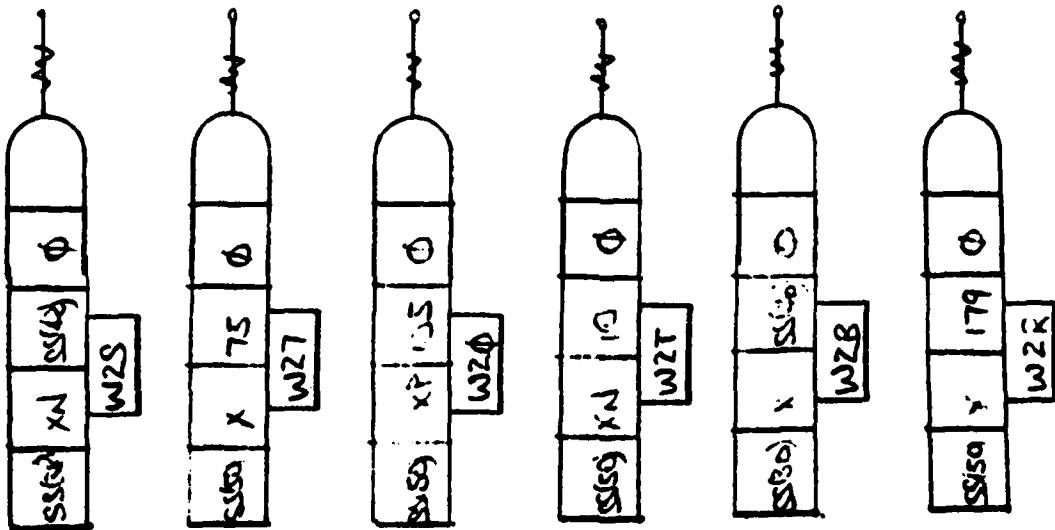
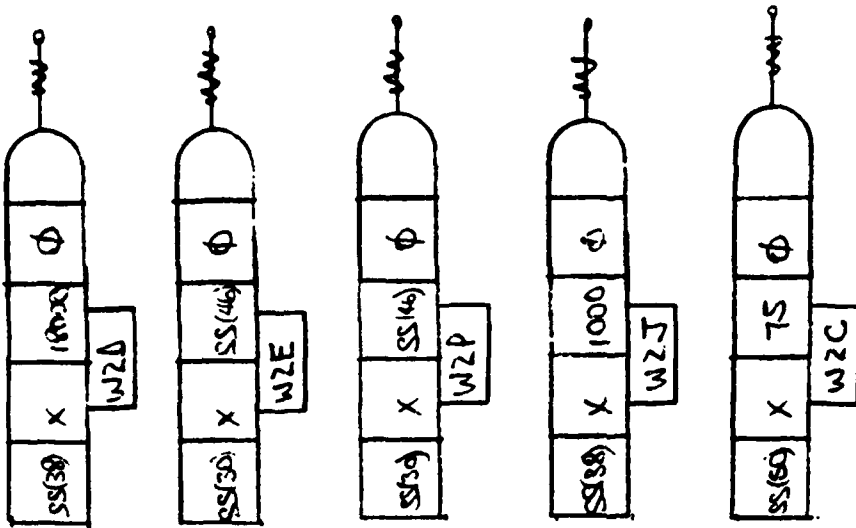




(ARM launch and impact, PK determined)  
 WILD WEASEL 1 - ATTACK PROFILE NETWORK







WILD WEASEL 2 - DETECT NODES

Appendix B  
SLAM State Variables

<u>SS</u>	<u>Use</u>	<u>Corres- ponding DD</u>	<u>Definition of DD</u>
1-10	Attack aircraft (1-10) x-position	1-10	Velocity
21	WW1 x-position	21	WW1 velocity in x-direction
22	WW2 x-position	22	WW2 velocity in x-direction
25	WW1 y-position	25	WW1 velocity in y-direction
26	WW2 y-position	26	WW2 velocity in y-direction
29	WW1 heading	29	WW1 heading rate change
30	WW2 heading	30	WW2 heading rate change
33	WW1 working designator	--	
34	WW2 working designator	--	
37	Distance from WW1 to attacked threat	--	
38	Distance from WW2 to attacked threat	--	
41	WW1 line-of-sight distance	--	
42	WW2 line-of-sight distance	--	
45	WW1 relative bearing to threat	--	
46	WW2 relative bearing to threat	--	
49	WW1 absolute relative bearing to threat	--	
50	WW2 absolute relative bearing to threat	--	

Appendix C  
SLAM Global Variables

<u>XX</u>	<u>Use</u>
1-2	Not used
3	WW altitude
4	Actual firing range of ARM
5	WW velocity
6	Counter for number of WWs created
7	Time between creations for attack force aircraft
8	Time between creations for WW
9	Counter for number of attack aircraft created
11-12	Not used
13	Attack force altitude
14	Attack force velocity
15	Time for WW1 to get to ARM release point after completion of triangulation route
16	ARM time of flight for WW1
17	ARM counter for WW1 (number of ARMs launched)
18	Not used
19	Time for WW2 to get to ARM release point
20	ARM time of flight for WW2
21	ARM counter for WW2
22-31	Not used
32	x-position of threat being attacked by WW1
33	x-position of threat being attacked by WW2
34-35	Not used
36	y-position of threat being attacked by WW1
37	y-position of threat being attacked by WW2
38-47	Not used
48	Counter for WWs reaching "home"
49	Flag for threat killed by a WW
50	Counter for threats killed by a WW
51	Not used
52	Standard deviation for road network

<u>XX</u>	<u>Use</u>
53	Not used
54	Flag for WW1 killed by a threat
55	Flag for attack aircraft reaching target
56	Counter for attack aircraft reaching target
57	Counter for attack aircraft killed by threats
58	Flag for WW2 killed by threat
59	Counter for WWS killed by aircraft
60	Not used
61-70	y-position of attack aircraft 1-10
81	ARM load of WW1
82	ARM load of WW2
83-84	Not used
85	Flight time ARM #1 WW1
86	Flight time ARM #2 WW1
87	Flight time ARM #3 WW1
88	Flight time ARM #4 WW1
89-92	Flight time ARM #1 through #4 for WW2

Appendix D  
SLAM File Structure

<u>File</u>	<u>Use</u>
1	All radars in threat scenario
2	Radars that WVs can attack
3	WW1 working threat file
4	WW1 kill file--radars that WW1 has killed
5	WW2 working threat file
6	WW2 kill file--radars that WW2 has killed
7-16	Radar aircraft files; file 7 contains those radars engaged with aircraft 1, file 8 with aircraft 2, etc.
17	Radar--WW1 file
18	Radar--WW2 file
19	Data for radar cross-section

Appendix E  
Attribute Listing

### Aircraft Entity

<u>Attribute</u>	<u>Use</u>
1	Call sign WW--211, 212 Attack--1 to 10
2	ARM Load (WW only)

### Radar Entity

<u>Attribute</u>	<u>Use</u>
1	Sequential number (1-85)
2	Type 1--AAA 2--SAM-A 3--SAM-B 4--SAM-C 5--SAM-D 6--EW
3	x-position
4	y-position
5	Associated EW 0--None 10--Associated EW killed by WW
6	Threat maximum effect range (meters)
7	Threat minimum effective altitude (m)
8	Call sign of aircraft being attacked by threat
9	Radiating 0--No 1--Yes
14	Call sign of WW attacking threat

Appendix F  
Subroutine and Event Summary

<u>Event/ Subroutine</u>	<u>Type</u>	<u>Function and Comments</u>
1	WW only	Starts WW ranging routine; realized from DETECT nodes W1S or W2S
2	WW only	Rolls WW out of turn; realized from DETECT nodes W17 or W27
3	WW only	Starts WW back into threat it is attacking; realized from DETECT nodes W10 or W20
4	WW only	Reduces WW heading rate as it starts to line up for ARM launch; realized from DETECT nodes W1T or W2T
5	WW only	Determines ARM firing parameters or if too close to threat starts repositioning routine; event realized from DETECT nodes W1B or W2B
6	WW only	ARM fired at this event; ENTER nodes 1 or 2 are called to determine ARM PK; event realized at the end of ARM release time—XX(15/19)
7	WW only	Gets the WW back into the hunting stage 5 seconds after ARM release
8	WW only	Enters WW back into network based on position and threat it's to attack
9	WW only	Realized from WW ENTER node 1/2; determines PK of the ARM; removes radar from appropriate file (as necessary)
10	WW only	Repositioning routine event; realized from event 5 after time duration of DETECT node W1R or W2R

<u>Event/ Subroutine</u>	<u>Type</u>	<u>Function and Comments</u>
11	WW only	Repositioning routine; realized from DETECT node W1D or W2D
12	WW only	Starts WW home after it fires its last ARM; previous event—event 6 (ARM launch event)
13	WW only	Rolls WW out after its initial turn home; from DETECT node W1P or W2P
14	All acft	Radar search event; occurs every 1 second as long as the aircraft is in the FEBA area and not killed; calls subroutine SEARCH; evaluates if aircraft has reached target area; allows only a maximum of 5 threats to work aircraft; this is a network event
15	All acft	Discrete event; called at the end of tracking and acquisition time by function SCHDL in subroutine SEARCH; based on evaluation of PK for the threat, events 16, 17, or 19 are scheduled
16	All acft	Discrete event; called at time of launch (TL) from event 15 by SCHDL func- tion; based on PK, event 17 or 19 is scheduled
17	All acft	Discrete event; call at time of weapons impact (TI) from event 15 or 16 by SCHDL function; event 18 is scheduled 30 seconds from this event's time

<u>Event/ Subroutine</u>	<u>Type</u>	<u>Function and Comments</u>
18	All acft	Discrete event; called from event 17; releases appropriate radars if aircraft was killed/not killed, removes aircraft from network if killed
19	All acft	Discrete event; called from event 15 or 16 when PK is below certain value; frees radars to search for new aircraft to attack
SEARCH	All acft	Discrete event; called by event 14; radars are paired up with aircraft based on correct values of radar/aircraft; event 15 is scheduled based on calculation of tracking and acquisition time for radar
PROB	All acft	Discrete event; called from event 15, 16, and/or 17; evaluates four factors-- time of launch (TL), time of impact (TI), range to intercept (RI), and PK of weapon (PKR)

Appendix G  
SLAM Computer Model

```

1      RBN,CH170000,T1000,I0100. T820024,NENNER,4567
2      ATTACH,PROCFIL,ID=A810171,SN=ASDAD.
3      BEGIN,NOSFILE.
4      GET,BBWE,ID=MAGGIE.
5      ATTACH,PROCFIL,SLAMPROC,ID=AFIT.
6      BEGIN,SLAM,,N=BBWE,PL=16000.
7      GEN,ANDERSON AND NENNER,THESIS,2/9/82,10,YES;
8      LIMITS,19,14,500;
9      INITIALIZE,0,900;
10     CONTINUOUS,32,20,1,5,10;
11     NETWORK;
12         CREATE,XX(8),0,,2,1;
13         ACT/1;
14     ;WEASEL ASSIGN NODE
15     WAS ASSIGN,XX(6)=XX(6)+1,ATRIB(1)=XX(6)+210;
16         ASSIGN,II=XX(6)+80,ATRIB(2)=XX(II);
17         ACT/2,,,G1;
18         CREATE,XX(7),30,,10,1;
19         ACT/3;
20     ;ATTACK FORCE ASSIGN NODE
21     AAS ASSIGN,XX(9)=XX(9)+1,ATRIB(1)=XX(9);
22         ACT/4;
23     G1 COON,2;
24         ACT,,ATRIB(1).EQ.211,GW1;
25         ACT,,ATRIB(1).EQ.212,GW2;
26         ACT,,RATK;
27     ;NETWORK FOR MW1
28     GW1 COON,1;
29         ACT,,SS(37).LT.SS(41),RN1;
30         ACT,REL(W15);
31     RN1 EVENT,1,1;
32         ACT,REL(W17);
33     REL EVENT,2,1;
34         ACT,REL(W10);
35         EVENT,3,1;
36         ACT,REL(W17);
37         EVENT,4,1;
38         ACT,REL(W18);
39     FR1 EVENT,5,1;
40         ACT,REL(W1R),SS(37).LT.8000.0,WNR;
41         ACT,XX(15);
42         EVENT,6,1;
43         ACT,,1,ATRIB(2).EQ.0,WCH;
44         ACT,5;
45         EVENT,7,1;
46         ACT,,1;
47         EVENT,8,1;
48         ACT,REL(W1C),SS(37).LT.SS(41),RE1;
49         ACT,,GW1;
50     ENTER,1,1;

```

```

51      ACT,XX(85),XX(17).EQ.1,WRK;
52      ACT,XX(86),XX(17).EQ.2,WRK;
53      ACT,XX(87),XX(17).EQ.3,WRK;
54      ACT,XX(88),XX(17).EQ.4,WRK;
55      WRK  EVENT,9,1;
56      ACT,,ATRI(1).EQ.XX(49);
57      WKL  ASSIGN,XX(50)=XX(50)+1;
58      ACT;
59      COLCT,XX(50),RADARS WW KILL;
60      ACT;
61      TERM;
62      WWR  EVENT,10,1;
63      ACT,REL(W1D);
64      EVENT,11,1;
65      ACT,REL(W1E),,FR1;
66      WCH  EVENT,12,1;
67      ACT,REL(W1P);
68      EVENT,13,1;
69      ACT,REL(W1J);
70      WWM  ASSIGN,XX(48)=XX(48)+1;
71      ACT;
72      HFR  COLCT,XX(48),WEASEL HOME FREE;
73      ACT;
74      TERM;
75      ;NETWORK FOR WM2
76      CM2  COON,1;
77      ACT,,SS(38).LT.SS(42),RN2;
78      ACT,REL(W2S);
79      RN2  EVENT,1,1;
80      ACT,REL(W27);
81      RE2  EVENT,2,1;
82      ACT,REL(W20);
83      EVENT,3,1;
84      ACT,REL(W2T);
85      EVENT,4,1;
86      ACT,REL(W2B);
87      FR2  EVENT,5,1;
88      ACT,REL(W2R),SS(38).LT.3000.0,WR2;
89      ACT,XX(19);
90      EVENT,6,1;
91      ACT,,ATRI(2).EQ.0,WC2;
92      ACT,5;
93      EVENT,7,1;
94      ACT,.1;
95      EVENT,8,1;
96      ACT,REL(W2C),SS(38).LT.SS(42),RE2;
97      ACT,,,CM2;
98      WR2  EVENT,10,1;
99      ACT,REL(W20);
100     EVENT,11,1;

```

```

101          ACT,REL(WZE),,FR2;
102      WG2  EVENT,12,1;
103          ACT,REL(W2P);
104          EVENT,13,1;
105          ACT,REL(W2J),,WHM;
106          ENTER,2,1;
107          ACT,XX(89),XX(21).EQ.1,WK2;
108          ACT,XX(90),XX(21).EQ.2,WK2;
109          ACT,XX(91),XX(21).EQ.3,WK2;
110          ACT,XX(92),XX(21).EQ.4,WK2;
111      WK2  EVENT,9,1;
112          ACT,,ATRIB(1).EQ.XX(49),WKL;
113          ENTER,3,1;
114          TERM;
115      ;DETECT NODES FOR WW'S
116      ;DETECT FOR WW1
117      W1S  DETECT,SS(37),XN,SS(41);
118          TERM;
119      W17  DETECT,SS(49),X,75,0;
120          TERM;
121      W10  DETECT,SS(49),XP,105,0;
122          TERM;
123      W1T  DETECT,SS(49),XN,10,0;
124          TERM;
125      W1B  DETECT,SS(29),X,SS(45),0;
126          TERM;
127      W1R  DETECT,SS(49),X,179,0;
128          TERM;
129      W1D  DETECT,SS(37),X,1000,0;
130          TERM;
131      W1E  DETECT,SS(29),X,SS(45),0;
132          TERM;
133      W1P  DETECT,SS(29),X,SS(45),0;
134          TERM;
135      W1J  DETECT,SS(37),X,1000,0;
136          TERM;
137      W1C  DETECT,SS(49),X,75,0;
138          TERM;
139      ;DETECT NODES FOR WW2
140      W2S  DETECT,SS(38),XN,SS(42),0;
141          TERM;
142      W27  DETECT,SS(50),X,75,0;
143          TERM;
144      W20  DETECT,SS(50),XP,105,0;
145          TERM;
146      W2T  DETECT,SS(50),XN,10,0;
147          TERM;
148      W2B  DETECT,SS(30),X,SS(46),0;
149          TERM;
150      W2R  DETECT,SS(50),X,179,0;

```

```

151          TERM;
152      W2D  DETECT,SS(38),X,18000,0;
153          TERM;
154      W2E  DETECT,SS(30),X,SS(46),0;
155          TERM;
156      W2P  DETECT,SS(30),X,SS(46),0;
157          TERM;
158      W2J  DETECT,SS(38),X,1000,0;
159          TERM;
160      W2C  DETECT,SS(50),X,75,0;
161          TERM;
162          ;
163      ;NETWORK FOR ALL AIRCRAFT
164          ;
165      RATK  EVENT,14,1;
166          ACT,,ATRIB(1).EQ.XX(55),TGT;
167          ACT,1,,RATK;
168      TGT  ASSIGN,XX(56)=XX(56)+1,XX(51)=XX(56)+XX(57);
169          ACT,,XX(51).EQ.10;
170          TERM,1;
171          ENDNETWORK;
172      INTLC,XX(7)=5,XX(8)=30,XX(3)=60;
173      SIMULATE;
174      SIMULATE;
175      SIMULATE;
176      SIMULATE;
177      SIMULATE;
178      INTLC,XX(3)=200;
179      SIMULATE;
180      SIMULATE;
181      SIMULATE;
182      SIMULATE;
183      SIMULATE;
184      FIN;

```

```

1          PROGRAM MAIN(INPUT,OUTPUT,TAPES=INPUT,TAPE6=OUTPUT,TAPE7)
2          DIMENSION NSET(25000)
3          COMMON QSET(25000)
4          COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLN
5          &,MCRDR,NPRNT,NMRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
6          &TNOW,XX(100)
7          EQUIVALENCE(NSET(1),QSET(1))
8          MCRDR=5
9          NPRNT=6
10         NTAPE=7
11         NNSET=25000
12         CALL SLAM
13         STOP
14         END
15         SUBROUTINE STATE
16         COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLN
17         &,MCRDR,NPRNT,NMRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
18         &TNOW,XX(100)
19         COMMON/UCOM1/RATE(2),L(2)
20         DIMENSION A(16)
21         C
22         C          RATE EQUATIONS FOR STRIKE AIRCRAFT
23         C
24         JJ=XX(9)
25         IF(JJ.EQ.0)GO TO 15
26         DO 10 I=1,JJ
27         DD(I)=XX(14)
28         10  CONTINUE
29         C
30         C          RATE EQUATIONS FOR WW AIRCRAFT
31         C
32         15  KK=XX(6)+20
33         IF(KK.EQ.20)RETURN
34         DO 20 I=21,KK
35         J=I-20
36         C
37         C          HEADING RATE CHANGE IS EQUAL TO RATE
38         C
39         DD(I+8)=RATE(J)
40         IF(SS(I+8).LT.0)SS(I+8)=SS(I+8)+360
41         IF(SS(I+8).GT.360)SS(I+8)=SS(I+8)-360
42         C
43         C          VELOCITY OF WW IN X-DIRECTION AND Y-DIRECTION
44         C
45         DD(I)=XX(5)*COSD(90-SS(I+8))
46         DD(I+4)=XX(5)*SIND(90-SS(I+8))
47         C
48         C          BASED ON THE VALUE OF THE WW WORKING DESIGNATOR,
49         C          EITHER COMPUTE A "LOOK AHEAD" RADAR TO ATTACK
50         C          OR PROCEED WITH OTHER STATE VARIABLE COMPUTATIONS.

```

```

51      C
52      IF(SS(I+12).GT.0.AND.SS(I+12).LT.9)GO TO 101
53      IF(SS(I+12).EQ.9)THEN
54          XX(I+11)=0.0
55          XX(I+15)=-10000.0
56          GO TO 101
57      ENDIF
58      C
59      C     PRE-SELECT RADAR FOR WW TO ATTACK BASED ON THE
60      C     CLOSEST RADAR TO THE WW.
61      C
62      SR2=999999999.9
63      DO 22 I0=1,NNQ(2)
64          CALL COPY(I0,2,A)
65          IF(A(14).GT.0)GO TO 22
66          X=A(3)
67          Y=A(4)
68          SR1=SQRT((SS(I)-X)**2+(SS(I+4)-Y)**2+XX(3)**2)
69          IF(SR1.LT.SR2)THEN
70              SR2=SR1
71              L(J)=A(1)
72              XX(I+11)=X
73              XX(I+15)=Y
74          ENDIF
75      22  CONTINUE
76      101  SS(I+16)=SQRT((SS(I)-XX(I+11))**2+(SS(I+4)-XX(I+15))
77          &**2+XX(3)**2)
78          SS(I+20)=4117.2*SQRT(XX(3))
79          D=(XX(I+15)-SS(I+4))/(XX(I+11)-SS(I))
80          IF(D.GE.0.AND.(XX(I+15)-SS(I+4)).GE.0)THEN
81              SS(I+24)=57.3*ATAN(1/D)
82          ELSEIF(D.LT.0.AND.(XX(I+15)-SS(I+4)).GE.0)THEN
83              SS(I+24)=270+57.3*ABS(ATAN(D))
84          ELSEIF(D.LT.0.AND.(XX(I+15)-SS(I+4)).LT.0)THEN
85              SS(I+24)=90+57.3*ABS(ATAN(D))
86          ELSE
87              SS(I+24)=270-57.3*ATAN(D)
88          ENDIF
89          SS(I+28)=ABS(SS(I+8)-SS(I+24))
90          IF(SS(I+28).GT.100)SS(I+28)=360-SS(I+28)
91      20  CONTINUE
92      RETURN
93      END

```

```

94      SUBROUTINE INTLC()
95      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLN
96      &NCRDR,NPRNT,NMRUN,NMSET,NTAPE,SS(100),SSL(100),TNEXT,
97      &TNOW,XX(100)
98      DIMENSION RNG(12),A(16),ARY(37,6)
99      COMMON/UCOM1/RATE(2),L(2)
100     DATA A/16*0.0/
101     DATA RNG/12*30000.0/
102
103     C
104     C      DATA IN "ARY" IS USED TO CALCULATE THE RADAR CROSS
105     C      SECTION OF THE AIRCRAFT BASED ON THE ASPECT THE RADAR
106     C      VIEWS THE AIRCRAFT. "ARY" IS PLACED IN FILE 19.
107     C
108     DATA(ARY(IA,JA),JA=1,6),IA=1,37)/0,-21.8,-19.3,-26.4,-26.4,-21.
109     &5,-23.3,-25.3,-29.6,-29.6,-23.3,10,-28.1,-25.4,-27.5,-27.5,-28.1
110     &15,-26.5,-32.3,-27.1,-27.1,-26.5,20,-19.2,-25.2,-28.3,-28.3,-19.2,
111     &25,-26.1,-27.3,-27.5,-27.5,-26.1,30,-24.8,-28.8,-19.4,-19.4,-25.
112     &35,-31.2,-31.7,-22.1,-22.1,-31.2,40,-28.3,-27.9,-26.6,-26.6,-28.
113     &45,-23.7,-25.3,-26.3,-26.3,-23.7,50,-27.1,-28.3,-31.1,-31.1,-26.9,
114     &55,-29.1,-28.9,-30.7,-30.7,-29.1,60,-28.1,-34.1,-31.1,-31.1,-28.1,
115     &65,-29.8,-29.6,-30.1,-30.1,-29.8,70,-21.8,-20.8,-21.6,-21.6,-21.8,
116     &75,-16.6,-16.3,-15.5,-15.5,-16.6,80,-13.3,-16.1,-13.7,-13.7,-13.3
117     &85,-13.9,-16.6,-14.0,-14.0,-13.9,90,-5.6,-4.2,-5.1,-5.1,-5.6,
118     &95,-10.8,-5.1,-10.1,-10.1,-10.8,100,-13.4,-13.1,-14.3,-14.3,-13.4,
119     &105,-24.2,-23.1,-20.8,-20.8,-24.2,110,-20.5,-20.2,-21.3,-21.3,-21
120     &115,-23.8,-28.3,-26.4,-26.4,-23.8,120,-22.1,-30.8,-27.7,-27.7,-22
121     &125,-25.7,-30.2,-27.1,-27.1,-25.7,130,-26.5,-32.3,-27.1,-27.1,-26.5,
122     &135,-25.7,-29.9,-31.1,-31.1,-25.7,140,-26.1,-31.3,-32.6,-32.6,-26.
123     &145,-24,-31.9,-29.5,-29.5,-24,150,-24.8,-27.2,-29.5,-29.5,-24.1
124     &155,-23.1,-23.5,-29.6,-29.6,-23.1,160,-27.1,-30.1,-29.4,-29.4,-27.
125     &165,-25.3,-29.5,-24.1,-24.1,-25.3,170,-20.1,-25.9,-23.5,-23.5,-20.
126     &175,-16.5,-25.4,-21.1,-21.1,-16.5,180,-15.1,-29.1,-21.1,-21.1,-15.1/
127     DO 47 IN=1,37
128     A(1)=ARY(IN,1)
129     A(2)=ARY(IN,2)+30.0
130     A(3)=ARY(IN,3)+30.0
131     A(4)=ARY(IN,4)+30.0
132     A(5)=ARY(IN,5)+30.0
133     A(6)=ARY(IN,6)+30.0
134     CALL FILEH(19,A)
135     CONTINUE
136
137     C
138     C      INITIAL VALUES FOR ATTACK AIRCRAFT
139     C
140     DO 21 I=1,70
141     XX(I)=UNFRN(24500.0,25500.0,1)
142     JJ=I-60
143     SS(JJ)=0.0
144     CONTINUE
145
146     C
147     C
148     C
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144      C      INITIAL VALUES FOR WW
145      C
146      DO 22 I=21,22
147      SS(I)=0.0
148      SS(I+4)=UNFRM(24500.0,25500.0,1)
149      SS(I+8)=90.0
150      SS(I+12)=0.0
151      SS(I+16)=0.0
152      SS(I+20)=0.0
153      SS(I+24)=0.0
154      SS(I+28)=0.0
155      DD(I+4)=0.0
156      DD(I+8)=0.0
157      22    CONTINUE
158      C
159      C      SET VALUES FOR OTHER VARIABLES
160      C
161      XX(52)=6000.0
162      XX(5)=247.0
163      XX(13)=310.0
164      XX(14)=247.0
165      XX(81)=22.0
166      XX(82)=22.0
167      XX(83)=22.0
168      XX(84)=22.0
169      RATE(1)=0.
170      RATE(2)=0.
171      C
172      C      CONSTRUCTION OF RADARS
173      C
174      DO 55 I=1,85
175      A(I)=I
176      IF(A(1).GE.49.AND.A(1).LE.51)GO TO 57
177      IF(A(1).GE.52.AND.A(1).LE.60)GO TO 58
178      IF(A(1).GE.61.AND.A(1).LE.70)GO TO 59
179      IF(A(1).GE.71.AND.A(1).LE.77)GO TO 60
180      IF(A(1).GE.78)GO TO 62
181      C
182      C      TYPE AAA RADARS
183      C
184      A(2)=1.0
185      A(6)=2990.0
186      A(7)=0.0
187      A(9)=1.0
188      IF(A(1).LE.12)THEN
189      A(3)=400.0
190      A(4)=RNORM(RNG(1),XX(52),1)
191      ELSEIF(A(1).LE.24)THEN
192      A(3)=1500.0
193      A(4)=RNORM(RNG(2),XX(52),1)

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194      ELSEIF(A(1).LE.36)THEN
195      A(3)=2500.0
196      A(4)=RNORM(RNG(3),XX(52),1)
197      ELSE
198      A(3)=3400.0
199      A(4)=RNORM(RNG(4),XX(52),1)
200      ENDIF
201      GO TO 63
202      C
203      C      TYPE SAM-A RADARS
204      C
205      57  A(2)=2.0
206      A(6)=50050.0
207      A(7)=91.0
208      A(9)=1.0
209      IF(A(1).LE.50)THEN
210      A(3)=45000.0
211      A(4)=RNORM(RNG(10),XX(52),1)
212      ELSE
213      A(3)=80000.0
214      A(4)=RNORM(RNG(12),XX(52),1)
215      ENDIF
216      GO TO 63
217      C
218      C      TYPE SAM-B RADARS
219      C
220      58  A(2)=3.0
221      A(6)=74150.0
222      A(7)=305.0
223      A(9)=1.0
224      IF(A(1).LE.54)THEN
225      A(3)=10000.0
226      A(4)=RNORM(RNG(6),XX(52),1)
227      ELSE
228      A(3)=25000.0
229      A(4)=RNORM(RNG(8),XX(52),1)
230      ENDIF
231      GO TO 63
232      C
233      C      TYPE SAM-C RADARS
234      C
235      59  A(2)=4.0
236      A(6)=22250.0
237      A(7)=15.0
238      A(9)=1.0
239      IF(A(1).LE.65)THEN
240      A(3)=2500.0
241      A(4)=RNORM(RNG(3),XX(52),1)
242      ELSEIF(A(1).LE.68)THEN
243      A(3)=5000.0

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244      A(4)=RNORM(RNG(5),XX(52),1)
245      ELSE
246      A(3)=15000.0
247      A(4)=RNORM(RNG(7),XX(52),1)
248      ENDFIF
249      GO TO 63
250      C
251      C      TYPE SAM-D RADARS
252      C
253      60 A(2)=5.0
254      A(6)=10200.0
255      A(7)=45.0
256      A(9)=1.0
257      IF(A(1).LE.72)THEN
258      A(3)=25000.0
259      A(4)=RNORM(RNG(3),XX(52),1)
260      ELSEIF(A(1).LE.75)THEN
261      A(3)=35000.0
262      A(4)=RNORM(RNG(9),XX(52),1)
263      ELSE
264      A(3)=60000.0
265      A(4)=RNORM(RNG(11),XX(52),1)
266      ENDFIF
267      GO TO 63
268      C
269      C      EW/GCI RADARS
270      C
271      62 A(2)=6.0
272      A(9)=1.0
273      IF(A(1).LE.79)THEN
274      A(3)=50000.0
275      A(4)=RNORM(RNG(5),XX(52),1)+1000.0
276      A(5)=1.0
277      IF(A(1).EQ.79)THEN
278      A(4)=A(4)-10000.0
279      A(5)=2.0
280      ENDFIF
281      ELSEIF(A(1).LE.80)THEN
282      A(3)=10000.0
283      A(4)=RNORM(RNG(6),XX(52),1)
284      A(5)=3.0
285      ELSEIF(A(1).LE.82)THEN
286      A(3)=25000.0
287      A(4)=RNORM(RNG(8),XX(52),1)+1000.0
288      A(5)=4.0
289      IF(A(1).EQ.82)THEN
290      A(4)=A(4)-10000.0
291      A(5)=5.0
292      ENDFIF
293      ELSEIF(A(1).LE.84)THEN

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294          A(3)=35000.0
295          A(4)=RNORM(RNG(8),XX(52),1)+1000.0
296          A(5)=6.0
297          IF(A(1).EQ.84)THEN
298              A(4)=A(4)-10000.0
299              A(5)=7.0
300          ENDIF
301          ELSE
302              A(3)=45000.0
303              A(4)=RNORM(RNG(10),XX(52),1)
304              A(5)=8.0
305          ENDIF
306          A(3)=A(3)+50000.0
307          GO TO 64
63          A(3)=A(3)+50000.0
309          A(5)=0.0
310          IF(A(3).LE.55000)THEN
311              IF(A(4).GT.RNG(5))THEN
312                  IF(DRAND(2).GT.5)A(5)=1.0
313              ELSEIF(A(4).LE.RNG(5))THEN
314                  IF(DRAND(2).GT.5)A(5)=2.0
315              ENDIF
316              ELSEIF(DRAND(2).GT.5)THEN
317                  A(5)=8.0
318              ENDIF
319              IF(A(2).EQ.3)THEN
320                  IF(A(3).EQ.60000.0)THEN
321                      A(5)=3.0
322                  ELSEIF(A(4).GT.RNG(8))THEN
323                      A(5)=4.0
324                  ELSE
325                      A(5)=5.0
326                  ENDIF
327              ENDIF
328          CONTINUE
329          CALL FILEN(1,A)
330          CONTINUE
331          C
332          C      WW RADAR FILE "2" - ONLY THOSE RADARS MEETING CERTAIN
333          C      SPECIFICATIONS ARE PLACED IN THIS FILE. WW CAN ONLY
334          C      ATTACK RADARS FROM THIS FILE.
335          C
336          NEXT=MMFE(1)
337          IF(NEXT.EQ.0)GO TO 20
338          CALL COPY(-NEXT,1,A)
339          IF((A(2).EQ.4.OR.A(2).EQ.5.OR.A(2).EQ.6).AND.A(4).LT.50000)THEN
340              CALL FILEN(2,A)
341          ENDIF
342          NEXT=NSUCR(NEXT)
343          GO TO 10

```

344  
345  
346  
347  
348

28 CONTINUE  
CALL PRNPF(1)  
CALL PRNPF(2)  
RETURN  
END

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349          SUBROUTINE EVENT(IX)
350          COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLN
351          &NCRDR,NPRNT,NMRUN,NMSET,NTAPE,SS(100),SSL(100),TNEXT,
352          &TNOW,XX(100)
353          DIMENSION REV(4),TOF(4),PK(4)
354          COMMON/UCOM2/TL,TI,PKR,RI,SRR
355          COMMON/UCOM1/RATE(2),L(2)
356          DIMENSION A(16),C(16),F(16),G(16),EA(16),EB(16)
357          I=ATRIB(1)
358          IF(I.GT.200)THEN
359              I=I-190
360              J=I-20
361              JW=(2*J)+1
362              IR=(4*J)+11
363              LF=I-4
364          ENDIF
365          IF(I.LE.10)LF=I+6
366          C
367          C           IF A RADAR OR AN AIRCRAFT IS KILLED IN THE
368          C           IMMEDIATE PRIOR EVENT, EVENT NODE "3" IS CALLED
369          C           TO ENSURE THE ENTITY IS REMOVED FROM THE PROGRAM.
370          C
371          IF(IX.LT.14)THEN
372              IF(ATRIB(1).EQ.XX(54).OR.ATRIB(1).EQ.XX(58))THEN
373                  CALL ENTER(3,ATRIB)
374                  RETURN
375              ENDIF
376          ENDIF
377          GO TO(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,
378          &16,17,18,19),IX
379          *****
380          C
381          C           EVENT 1(WM NODE ONLY) - REALIZED WHEN A WM'S RANGE TO
382          C           RADAR DECREASED TO WM FIELD-OF-VIEW.
383          C
384          I      PRINT*,'EV 1 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
385          C      BASED ON POSITION AND HEADING OF WM TURN THE WM TO
386          C      START RANGING ROUTINE.
387          C
388          IF(SS(I+24).GT.0.AND.SS(I+24).LT.100)THEN
389              IF(SS(I+8).GT.SS(I+24).AND.SS(I+8).LT.(SS(I+24)+
390              &100))THEN
391                  REV(J)=1.0
392                  IF(SS(I+20).LT.75.0)THEN
393                      RATE(J)=4.0
394                  ELSE
395                      RATE(J)=-4.0
396                  ENDIF
397              ELSE
398                  REV(J)=2.0

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399          IF(SS(I+28).LT.75.0)THEN
400             RATE(J)=-4.0
401          ELSE
402             RATE(J)=4.0
403          ENDIF
404          ENDIF
405          ELSE
406             IF(SS(I+8).GT.(SS(I+24)-100).AND.SS(I+8).LT.
407             &SS(I+24))THEN
408                REV(J)=2.0
409                IF(SS(I+28).LT.75)THEN
410                   RATE(J)=-4.0
411                ELSE
412                   RATE(J)=4.0
413                ENDIF
414            ELSE
415                REV(J)=1.0
416                IF(SS(I+28).LT.75.0)THEN
417                   RATE(J)=4.0
418                ELSE
419                   RATE(J)=-4.0
420                ENDIF
421            ENDIF
422          ENDIF
423          C          SET WW WORKING DESIGNATOR TO 1
424          SS(I+12)=1.0
425          C
426          C          FOR THE RADAR THAT THE WW IS ATTACKING, SET ITS
427          C          14TH ATTRIBUTE EQUAL TO THE CALL SIGN OF THE WW.
428          C
429          AL=L(J)
430          NGET=NFIND(1,2,1,0,AL,0.0)
431          CALL REMOVE(NGET,2,A)
432          A(14)=ATRIB(1)
433          CALL FILEN(2,A)
434          CALL FILEN(JW,A)
435          RETURN
436          *****
437          C
438          C          EVENT 2(WW NODE ONLY) - REALIZED WHEN WW DETECTS 70 DEGREES
439          C          RELATIVE BEARING ON THE RADAR SITE IT IS ATTACKING. THIS
440          C          EVENT ROLLS THE WW OUT OF ITS TURN.
441          C
442          Z          PRINT*,'EV 2 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
443          RATE(J)=0.0
444          RETURN
445          *****
446          C
447          C          EVENT 3(WW NODE ONLY) - REALIZED WHEN WW DETECTS 105
448          C          DEGREES RELATIVE BEARING ON THE RADAR IT IS WORKING.

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449      C      THIS EVENT ROLLS THE WM BACK INTO THE SITE.
450      C
451      3      PRINT*, 'EV 3 TNOW= ', TNOW, ' ATRIB(1)= ', ATRIB(1)
452      IF (REV(J).EQ.1) RATE(J)=-4.#
453      IF (REV(J).EQ.2) RATE(J)=4.#
454      RETURN
455      *****
456      C
457      C      EVENT 4(WM MODE ONLY) - REALIZED WHEN WM DETECTS 10 DEGREES
458      C      RELATIVE BEARING ON THE SITE IT IS ATTACKING. THIS EVENT
459      C      REDUCES THE TURN RATE OF THE WM.
460      C
461      4      PRINT*, 'EV 4 TNOW= ', TNOW, ' ATRIB(1)= ', ATRIB(1)
462      IF (REV(J).EQ.1) RATE(J)=-2.#
463      IF (REV(J).EQ.2) RATE(J)=2.#
464      RETURN
465      *****
466      C
467      C      EVENT 5(WM MODE ONLY) - REALIZED WHEN WM IS BORESIGHTED ON
468      C      THE RADAR IT IS ATTACKING. BASED ON THE POSITION OF THE
469      C      WM, A DECISION IS MADE OF WHETHER TO FIRE AN ARM. IF
470      C      THE WM DECIDES IT WILL FIRE AN ARM, THEN THE PK OF THE
471      C      ARM IS DETERMINED AND THE FIRING RANGE OF THE ARM CAL-
472      C      CULATED.
473      C
474      5      PRINT*, 'EV 5 TNOW= ', TNOW, ' ATRIB(1)= ', ATRIB(1)
475      C      IF WM HAS AGM-78S, THEN SELECT THAT TYPE ARM TO
476      C      FIRE(ATRIB(2) GREATER THAN 10). OTHERWISE SELECT
477      C      AN AGM-45.
478      C      IF (ATRIB(2).GE.10) GO TO 40
479      C      RM45=MINIMUM LAUNCH RANGE OF AGM-45
480      C      RM45=8000.#
481      C      XX(10)=MAXIMUM LAUNCH RANGE. IF RANGE TO TARGET IS
482      C      GREATER THAN 15000#, THEN USE 15000# AS MAXIMUM RANGE
483      C      FOR THE MISSILE. IF THE ACTUAL RANGE TO THE TARGET
484      C      IS LESS THAN THE MINIMUM RANGE OF THE ARM, THEN DO
485      C      NOT COMPUTE PK; GO TO "REPOSITIONING ROUTINE."
486      C      XX(10)=SS(I+16)
487      C      IF (XX(10).GT.15000.#) XX(10)=15000.#
488      C      IF (SS(I+16).LT.RM45) GO TO 42
489      C      XX(4)=ACTUAL FIRING RANGE OF ARM. TOF IS FLIGHT TIME OF
490      C      THE MISSILE FROM THE LAUNCH POINT TO IMPACT POINT.
491      C      XX(4)=UNFRN(8000.#, XX(10), 1)
492      C      [OF(J)=XX(4)/350.#
493      C      ATRIB(2)=ATRIB(2)-1
494      C      DETERMINE PK OF ARM
495      C      SAMPLE=BRAND(1)
496      C      IF (SAMPLE.LT..8) THEN
497      C      PK(J)=1.#
498      C      ELSE

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499          PK(J)=0.0
500      ENDIF
501      GO TO 41
502      C      CALCULATIONS FOR AGM-78
503      40      RM78=8000.0
504          XX(10)=SS(I+16)
505          IF(XX(10).GT.25000.0)XX(10)=25000.0
506          IF(SS(I+16).LT.RM78)GO TO 42
507          XX(4)=UNFRM(8000.0,XX(10),1)
508          TOF(J)=XX(4)/450.0
509          ATRIB(2)=ATRIB(2)-10.0
510          SAMPLE=DRAND(1)
511          IF(SAMPLE.LT..85)THEN
512              PK(J)=1.0
513          ELSE
514              PK(J)=0.0
515          ENDIF
516      41      CONTINUE
517      C      RLMW=TIME FOR THE MW TO GET FROM ITS PRESENT POSITION
518      C      TO ITS ARM FIRING RANGE.
519          RLMW=((SS(I+16)*COS(ASIN(XX(3)/SS(I+16)))-XX(4))/XX(5))
520          XX(IR)=RLMW
521          XX(IR+1)=TOF(J)
522          RATE(J)=0.0
523          REV(J)=0.0
524          RETURN
525      C      IF THE MW WAS TOO CLOSE TO FIRE THE ARM THEN START MW
526      C      TURNING FOR "REPOSITIONING ROUTINE."
527      42      RATE(J)=-4.0
528          IF(REV(J).EQ.1)RATE(J)=4.0
529          RETURN
530      *****
531      C
532      C      EVENT 6(MW NODE ONLY) - REALIZED WHEN THE MW GETS TO ARM
533      C      FIRING RANGE. "ENTER NODE 1/2" CALLED FROM THIS EVENT IN
534      C      ORDER TO EVALUATE THE PK OF THE ARM AT IMPACT TIME.
535      C
536      6      PRINT*,'EV 6 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
537          IF(J.EQ.1)THEN
538              XX(17)=XX(17)+1.0
539              P=XX(17)+84
540              XX(P)=XX(IR+1)
541          ELSEIF(J.EQ.2)THEN
542              XX(21)=XX(21)+1.0
543              P=XX(21)+89
544              XX(P)=XX(IR+1)
545          ENDIF
546      C      FIND THE RADAR IN FILE 2 THAT THE MW IS ATTACKING.
547      C      CALL ENTER NODE 1/2 WITH THE ATTRIBUTES OF THE RADAR
548      C      LOADED INTO THE ATRIB ARRY.

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549      AL=L(J)
550      NCT=NFIND(1,2,1,0,AL,0)
551      IF(J.EQ.1)THEN
552          CALL COPY(NCT,2,EA)
553          CALL ENTER(1,EA)
554      ELSEIF(J.EQ.2)THEN
555          CALL COPY(NCT,2,EB)
556          CALL ENTER(2,EB)
557      ENDIF
558      C      CHECK TO SEE IF WW OUT OF ARMS. IF IT IS THEN SET
559      C      WW WORKING DESIGNATOR EQUAL TO 9.
560      IF(ATRIB(2).EQ.0)SS(I+12)=9.0
561      RETURN
562      *****
563      C
564      C      EVENT 7(WW MODE ONLY) - THIS EVENT OCCURS 5 SECONDS AFTER
565      C      THE WW LAUNCHES ARM. WW WORKING DESIGNATOR IS SET TO 0
566      C      TO ALLOW THE WW TO BEGIN SEARCHING FOR A NEW RADAR TO
567      C      ATTACK.
568      C
569      7      PRINT*, 'EV 7 TNOW= ',TNOW, ' ATRIB(1)= ',ATRIB(1)
570      SS(I+12)=0.0
571      RETURN
572      *****
573      C
574      C      EVENT 8(WW MODE ONLY) - THIS EVENT ENTERS THE WW BACK INTO
575      C      THE NETWORK BASED ON ITS POSITION RELATIVE TO THE RADAR
576      C      SITE IT IS ATTACKING.
577      C
578      8      PRINT*, 'EV 8 TNOW= ',TNOW, ' ATRIB(1)= ',ATRIB(1)
579      IF(SS(I+16).LT.SS(I+20))THEN
580          AL=L(J)
581          NCET=NFIND(1,2,1,0,AL,0)
582          CALL RMOVE(NCET,2,A)
583          A(14)=ATRIB(1)
584          CALL FILEN(2,A)
585          CALL FILEN(JW,A)
586          SS(I+12)=1.0
587          IF(SS(I+24).GT.0.AND.SS(I+24).LT.100)THEN
588              IF(SS(I+8).GT.SS(I+24).AND.SS(I+8).LT.(SS(I+24)+
589      8100))THEN
590                  REV(J)=1.0
591                  IF(SS(I+28).LT.75)THEN
592                      RATE(J)=4.0
593                  ELSE
594                      RATE(J)=-4.0
595                  ENDIF
596              ELSE
597                  REV(J)=2.0
598                  IF(SS(I+28).LT.75)THEN

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599         RATE(J)=-4.0
600     ELSE
601         RATE(J)=4.0
602     ENDIF
603     ENDIF
604     ENDIF
605     ELSE
606     IF(SS(I+8).GT.(SS(I+24)-180).AND.SS(I+8).LT.SS(I+24))THEN
607         REV(J)=2.0
608         IF(SS(I+28).LT.75)THEN
609             RATE(J)=-4.0
610         ELSE
611             RATE(J)=4.0
612         ENDIF
613     ELSE
614         REV(J)=1.0
615         IF(SS(I+28).LT.75)THEN
616             RATE(J)=4.0
617         ELSE
618             RATE(J)=-4.0
619         ENDIF
620     ENDIF
621     ENDIF
622     RETURN
623 *****
624     C
625     C     EVENT 9(WM NODE ONLY) - EVENT REALIZED FROM WM ENTER
626     C     NODE. DETERMINES PK OF ARM AT THE END OF ARM'S FLIGHT
627     C     TIME.
628     C
629     9     PRINT+,'EV 9 TNOW= ',TNOW,' ATRIB(1)= ',ATTRIB(1)
630     LF=ATTRIB(14)-194
631     J=ATTRIB(14)-210
632     JM=(2*J)+1
633     PRINT+,'AT(14)= ',ATTRIB(14),'LF= ',LF,'J= ',J
634     NF2=NFIND(1,2,1,0,ATTRIB(1),0)
635     IF(NF2.EQ.0)RETURN
636     NF=NFIND(1,JM,1,0,ATTRIB(1),0)
637     IF(NF.EQ.0)RETURN
638     NF1=NFIND(1,1,1,0,ATTRIB(1),0)
639     PRINT+,'NF1= ',NF1
640     IF(NF1.EQ.0)RETURN
641     C     IF THE WM KILLS THE RADAR, THEN THE RADAR IS CHECKED
642     C     TO SEE IF IT WAS A EM/CCI RADAR. IF IT WAS, THEN ALL
643     C     ASSOCIATED RADARS THAT USE THIS EM/CCI FOR ACQUISITION
644     C     AND TRACKING HAVE THEIR 5TH ATTRIBUTE SET TO 10.
645     C     THE "DEAD" RADAR IS REMOVED FROM FILE 1,FILE 2 AND THE
646     C     WEASEL'S WORKING FILE. XX(49) IS SET EQUAL TO THE
647     C     RADAR'S SEQUENTIAL NUMBER(ATRIB(1) FOR THIS EVENT).
648     C     THE RADAR IS REMOVED FROM THE EVENT CALENDAR.

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649      IF(PK(J).EQ.1)THEN
650      PRINT*,'RADAR ',ATRI(1),' KILLED BY WW ',ATRI(14)
651      CALL RMOVE(NF1,1,A)
652      PRINT*,'A(1)= ',A(1)
653      CALL RMOVE(NF,JW,A)
654      IF(A(2).EQ.6)THEN
655          DO 66 IT=1,NM(1)
656          CALL COPY(IT,1,G)
657          IF(A(5).EQ.G(5))THEN
658              CALL RMOVE(IT,1,G)
659              G(5)=10.0
660              CALL FILEM(1,G)
661          ENDIF
662      66      CONTINUE
663      ENDIF
664      CALL FILEM(JW+1,A)
665      CALL RMOVE(NF2,2,A)
666      XX(49)=ATRI(1)
667      91  NREN=NFIND(1,NCLNR,3,0,ATRI(1),0)
668      IF(NREN.GT.0)THEN
669          CALL ULINK(NREN,NCLNR)
670          GO TO 91
671      ENDIF
672      C      IF THE RADAR IS NOT KILLED, IT IS REMOVED FROM THE WW'S
673      C      WORKING FILE AND ITS 14TH ATTRIBUTE IS RESET TO 0 IN
674      C      FILE 2.
675      ELSEIF(PK(J).EQ.0)THEN
676      CALL RMOVE(NF,JW,A)
677      CALL RMOVE(NF2,2,A)
678      A(14)=0.0
679      CALL FILEM(2,A)
680      ENDIF
681      RETURN
682      *****
683      C
684      C      EVENT 10(WW NODE ONLY) - REPOSITIONING ROUTINE.
685      C      EVENT REALIZED WHEN WW TURNS 179 DEGREES ABSOLUTE
686      C      RELATIVE BEARING FROM SITE IT IS ATTACKING.
687      C      EVENT ROLLS WW OUT OF TURN.
688      C
689      10  PRINT*,'EV 10 TNOW= ',TNOW,' ATRI(1)= ',ATRI(1)
690      RATE(J)=0.0
691      RETURN
692      *****
693      C
694      C      EVENT 11(WW NODE ONLY) - REPOSITIONING ROUTINE.
695      C      EVENT REALIZED WHEN WW DETECTS REQUIRED RANGE FROM
696      C      SITE IT IS ATTACKING. EVENT ROLLS WW BACK INTO TURN.
697      C
698      11  PRINT*,'EV 11 TNOW= ',TNOW,' ATRI(1)= ',ATRI(1)

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699          RATE(J)=-4.#
700          IF(REV(J).EQ.1)RATE(J)=4.#
701          RETURN
702          *****
703          C
704          C      EVENT 12(WW NODE ONLY) - WW SENT HOME.
705          C      THIS EVENT SENDS THE WW HOME AFTER IT FIRES ALL
706          C      OF ITS ARMS.
707          C
708          12  PRINT*,'EV 12 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
709          RATE(J)=4.#
710          REV(J)=1.#
711          RETURN
712          *****
713          C
714          C      EVENT 13(WW NODE ONLY) - WW SENT HOME.
715          C      THIS EVENT ROLLS WW OUT AFTER ITS INITIAL TURN HOME.
716          C
717          13  PRINT*,'EV 13 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
718          RATE(J)=0.#
719          RETURN
720          *****
721          C
722          C      EVENT 14(ALL AIRCRAFT) - THIS EVENT APPLIES FOR ALL
723          C      AIRCRAFT. IT SIMULATES RADARS SEARCHING FOR AIRCRAFT.
724          C      A CHECK IS FIRST MADE TO ENSURE THAT NO MORE THAN
725          C      5 RADARS ARE ENGAGED WITH THE AIRCRAFT. IF THERE ARE
726          C      5 RADARS ALREADY WORKING THE AIRCRAFT THEN THE EVENT
727          C      IS BY-PASSED. OTHERWISE SUBROUTINE SEARCH IS CALLED.
728          C
729          14  IF(SS(1).GT.145000.AND.ATRIB(1).LT.200)THEN
730          XX(55)=ATRIB(1)
731          RETURN
732          ENDIF
733          IF(NNQ(LF).EQ.5)RETURN
734          CALL SEARCH
735          RETURN
736          *****
737          C
738          C      EVENT 15(ALL AIRCRAFT) - EVENT REALIZED AT THE END OF
739          C      TRACKING AND ACQUISITION TIME. SUBROUTINE PROB IS CALL-
740          C      ED TO DETERMINE PK, TI(TIME OF INTERCEPT), TL(TIME OF
741          C      LAUNCH). BASED ON THESE VALUE THE FOLLOWING CAN OCCUR.
742          C      1) EVENT 16 IS SCHEDULED AT ESTIMATED LAUNCH TIME.
743          C      2) EVENT 17 IS SCHEDULED AT ESTIMATED IMPACT TIME.
744          C      3) EVENT 19 IS SCHEDULED TO OCCUR IN 30 SECONDS BAS-
745          C      ED ON A LOW VALUE OF PK.
746          C
747          15  PRINT*,'EV 15 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
748          CALL PROB

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749         IF(PKR.LT..05)THEN
750             CALL SCHDL(19,30.0,ATRIB)
751             RETURN
752         ENDIF
753         NP1=NFIND(1,1,1,0,ATRIB(3),0)
754         PRINT*, 'NP1= ',NP1
755         IF(NP1.EQ.0)THEN
756             CALL SCHDL(19,30.0,ATRIB)
757             RETURN
758         ENDIF
759         CALL COPY(NP1,1,A)
760         ATRIB(4)=TL
761         ATRIB(5)=TI
762         ATRIB(6)=PKR
763         ATRIB(7)=A(6)
764         ATRIB(8)=A(3)
765         ATRIB(9)=A(4)
766         IF(TNOW.EQ.TL)THEN
767             ATRIB(10)=RI
768             T=TI-TNOW
769             CALL SCHDL(17,T,ATRIB)
770         ELSE
771             T=TL-TNOW
772             CALL SCHDL(16,T,ATRIB)
773         ENDIF
774         RETURN
775         *****
776         C
777         C     EVENT 16(ALL AIRCRAFT) - EVENT REALIZED AT ESTIMATED
778         C     MISSILE LAUNCH TIME. SUBROUTINE PROB IS CALLED TO DE-
779         C     TERMINE NEW PK AND TI. BASED ON THESE VALUES EITHER
780         C     EVENT 19 IS SCHEDULED(PK TOO LOW) OR EVENT 17 IS
781         C     SCHEDULED AT MISSILE IMPACT TIME.
782         C
783         16  PRINT*, 'EV 16 TNOW= ',TNOW, ' ATRIB(1)= ',ATRIB(1)
784         CALL PROB
785         IF(PKR.LT..05)THEN
786             CALL SCHDL(19,30.0,ATRIB)
787             RETURN
788         ENDIF
789         ATRIB(6)=PKR
790         ATRIB(5)=TI
791         ATRIB(10)=RI
792         TT=TI-TNOW
793         CALL SCHDL(17,TT,ATRIB)
794         RETURN
795         *****
796         C
797         C     EVENT 17(ALL AIRCRAFT) - EVENT REALIZED AT MISSILE IMPACT
798         C     TIME. SUBROUTINE PROB IS CALLED TO DETERMINE PK AND NEW

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799          C      TI. IF THE AIRCRAFT HAS TURNED AWAY FROM THE RADAR
800          C      SITE("RATIO" GREATER THAN 1.1) THEN ANOTHER ITERATION
801          C      IS MADE AND EVENT 17 IS SCHEDULED AT THE TIME IT TAKES
802          C      FOR THE AIRCRAFT TO MOVE TO THE NEW TI. OTHERWISE, THE
803          C      KILL/NOT KILL IS EVALUATED BASED ON MONTE CARLO DRAW.
804          C
805          17     PRINT*, 'EV 17 TNOW= ', TNOW, ' ATRIB(1)= ', ATRIB(1)
806          PRINT*, 'ATRIB(3)= ', ATRIB(3)
807          CALL PROB
808          T=((ATRIB(5)-ATRIB(4))*SRR)/ATRIB(10)
809          RATIO=SRR/ATRIB(10)
810          IF(RATIO.GT.1.1)THEN
811            ATRIB(6)=PKR
812            CALL SCHDL(17,T,ATRIB)
813            RETURN
814          ENDIF
815          SAMPLE=DRAND(1)
816          IF(SAMPLE.LE.ATRIB(6))THEN
817            PRINT*, 'AIRCRAFT ', ATRIB(1), ' KILLED BY RADAR ', ATRIB(3)
818            IF(ATRIB(1).GT.200)THEN
819              XX(59)=XX(59)+1.0
820              IF(ATRIB(1).EQ.211)XX(54)=ATRIB(1)
821              IF(ATRIB(1).EQ.212)XX(58)=ATRIB(1)
822            ENDIF
823            IF(ATRIB(1).LT.200)XX(57)=XX(57)+1.0
824          55     NREM=NFIN(1,NCLNR,1,0,ATRIB(1),0)
825            IF(NREM.GT.0)THEN
826              CALL ULINK(NREM,NCLNR)
827              GO TO 55
828            ENDIF
829            ATRIB(6)=1.0
830          ENDIF
831            CALL SCHDL(18,30.0,ATRIB)
832            RETURN
833          *****
834          C
835          C      EVENT 18(ALL AIRCRAFT) - EVENT OCCURS 30 SECONDS AFTER
836          C      MISSILE IMPACT. BASED ON WHETHER THE AIRCRAFT WAS KILLED/
837          C      NOT KILLED RADAR(S) ARE FREED TO BEGIN NEW SEARCH.
838          C
839          18     PRINT*, 'EV 18 TNOW= ', TNOW, ' ATRIB(1)= ', ATRIB(1)
840          IF(ATRIB(6).NE.1)THEN
841            C      IF THE AIRCRAFT WAS NOT KILLED THEN ONLY FREE THAT RADAR
842            C      THAT WAS SHOOTING.
843            NC=NFIN(1,LF,1,0,ATRIB(3),0)
844            IF(NC.EQ.0)GO TO 200
845            CALL RMOVE(NC,LF,A)
846            NC1=NFIN(1,1,1,0,ATRIB(3),0)
847            PRINT*, 'NC1= ', NC1
848            IF(NC1.EQ.0)GO TO 200

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849          CALL RMOVE(NC1,1,A)
850          A(8)=0.0
851          CALL FILEN(1,A)
852      200  RETURN
853          ELSE
854      C      IF THE AIRCRAFT WAS KILLED THEN FREE ALL RADARS TRACK-
855      C      ING IT.
856      102  NR=NFIND(1,LF,8,0,ATRIB(1),0)
857          IF(NR.GT.0)THEN
858              CALL RMOVE(NR,LF,A)
859              GO TO 102
860          ENDF
861      103  NR1=NFIND(1,1,8,0,ATRIB(1),0)
862          IF(NR1.GT.0)THEN
863              CALL RMOVE(NR1,1,A)
864              A(8)=0.0
865              CALL FILEN(1,A)
866              GO TO 103
867          ENDF
868          ENDF
869          RETURN
870 *****
871      C
872      C      EVENT 19(ALL AIRCRAFT) - EVENT IS SCHEDULED FROM EVENTS
873      C      15 OR 16 WHEN THE CALCULATED PK IS DETERMINED TOO LOW
874      C      FOR THE RADAR TO CONTINUE TRACKING.
875      C
876      19  PRINT*,'EV 19 TNOW=',TNOW,'AT(1)=' ,ATRIB(1),'AT(3)=' ,ATRIB(3)
877          NP=NFIND(1,LF,1,0,ATRIB(3),0)
878          PRINT*,'NP= ',NP
879          CALL RMOVE(NP,LF,A)
880          NP=NFIND(1,1,1,0,ATRIB(3),0)
881          PRINT*,'NP= ',NP
882          CALL RMOVE(NP,1,A)
883          A(8)=0.
884          CALL FILEN(1,A)
885          RETURN
886          END
887 *****
888 *****
889      C
890      C      SUBROUTINE SEARCH IS CALLED BY EVENT 14. THIS SUBROUTINE
891      C      SIMULATES THE SEARCHING BY RADARS FOR AIRCRAFT. BASED ON
892      C      VARIOUS PARANTERS THE RADAR WILL DETECT THE AIRCRAFT AND
893      C      SCHEDULE TRACKING AND ACQUISITION TIME.
894      C
895      C      SUBROUTINE SEARCH
896      C      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
897      C      &NCRDR,NPRINT,NR1UN,NR1SET,NTAPE,SS(100),SSL(100),TNEXT,
898      C      &TNOW,XX(100)

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899          COMMON/UCOM1/RATE(2),L(2)
900          COMMON/UCOM3/SAM(5,12)
901          DIMENSION A(16),B(16),BA(16)
902          I=ATRIB(1)
903          IF(I.LT.200)THEN
904              ALT=XX(13)
905              YPOS=XX(60+I)
906              LF=I+6
907          ELSE
908              I=I-190
909              J=I-20
910              YPOS=SS(I+4)
911              ALT=XX(3)
912              LF=I-4
913          ENDIF
914          SRMP=ALT/SIND(0.25)
915          LL=MMFE(1)
916          25 CALL COPY(-LL,1,BA)
917          C      IF THE RADAR IS AN EW/CCI
918              IF(BA(2).EQ.6)GO TO 27
919          C      OR IF THE AIRCRAFT'S ALTITUDE IS BELOW RADAR COVERAGE
920              IF(ALT.LT.BA(7))GO TO 27
921          C      OR IF THE RADAR IS ALREADY ENGAGED
922              IF(BA(8).CT.#)GO TO 27
923          C      OR IF THE RADAR IS SHUTDOWN >>>> GO TO THE NEXT RADAR
924              IF(BA(9).EQ.#)GO TO 27
925              X=BA(3)
926              Y=BA(4)
927              SR=SQRT((X-SS(I))**2+(Y-YPOS)**2+ALT**2)
928          C      IF THE RANGE TO THE AIRCRAFT IS LESS THAN MULTI-PATH
929              IF(SR.CT.SRMP)GO TO 27
930          C      OTHERWISE, IF THE RANGE IS LESS THAN THE MAXIMUM RANGE
931              IF(SR.LT.BA(6))THEN
932                  BA(8)=ATRIB(1)
933                  CALL FILEN(LF,BA)
934                  CALL RMOVE(-LL,1,A)
935                  CALL FILEN(1,BA)
936                  PRINT*, 'A(1)= ',A(1), ' BA(1)= ',BA(1)
937                  IT=BA(2)
938          C      DETERMINE ACQUISITION AND TRACKING TIME BASED ON UNIFORM
939          C      DISTRIBUTION UNLESS THE RADAR'S ASSOCIATED EW/CCI WAS
940          C      KILLED(BA(5)=10) - IN THAT CASE USE ONLY THE HIGH TIME.
941              TL=SAN(IT,7)
942              TH=SAN(IT,8)
943              TRC=UNFRN(TL,TH,1)
944              IF(BA(5).EQ.10)TRC=TH
945              B(1)=ATRIB(1)
946              B(3)=BA(1)
947              CALL SCHDL(15,TRC,B)
948          ENDIF

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949      IF(NNG(LF).EQ.5)GO TO 26
950      27  LL=NSUCR(LL)
951      IF(LL.NE.0)GO TO 25
952      26  CONTINUE
953      RETURN
954      END
955      *****
956      *****
957      C
958      C      SUBROUTINE PROB - THIS SUBROUTINE CALCULATES THE PK'S
959      C      FOR THE APPROPRIATE SYSTEM, AS WELL AS THE TIME OF LAUNCH
960      C      (TL) AND TIME OF IMPACT(TI).
961      C
962      SUBROUTINE PROB
963      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
964      &NCRDR,NPRNT,NNRUN,NMSET,NTAPE,SS(100),SSL(100),TNEXT,
965      &TNOW,XX(100)
966      COMMON/UCOM2/TL,TI,PKR,RI,SRR
967      COMMON/UCOM1/RATE(2),L(2)
968      DIMENSION A(16),B(16),BA(16)
969      COMMON/UCOM3/SAM(5,12)
970      DATA((SAM(IA,JA),JA=1,12),IA=1,5)/
971      &0.0,0.0,0.0,0.0,6.25,0,-47.6,0,30,
972      &2.52E-5,9610,671,7.3E-27,6.36E-17,671,18,51,592,-46.2,56.4,
973      &13,
974      &5.62E-6,2500,232,7.3E-27,6.36E-17,232,12,26,759,-51.4,43.6,
975      &15,
976      &7.1E-7,2200,58,4.03E-27,1.02E-16,58,17,38,599,-53.4,26.2,
977      &30,
978      &3.25E-7,1890,25,8.09E-27,4.84E-16,25,10,23,525,-52.4,22,30/
979      I=ATRIB(1)
980      IF(I.LT.200)THEN
981          YPOS=XX(60+I)
982          ALT=XX(13)
983          VEL=XX(14)
984          HDC=90.0
985      ELSE
986          I=I-190
987          J=I-190
988          HDC=SS(I+8)
989          YPOS=SS(I+4)
990          ALT=XX(3)
991          VEL=XX(5)
992      ENDIF
993      SRMP=ALT/SIND(0.25)
994      IF(I.LE.10)LF=I+6
995      IF(I.GT.10)LF=I-4
996      C      GET THE FILE OF THE AIRCRAFT BEING ATTACKED.
997      NC=NFIND(1,LF,1,0,ATRIB(3),0)
998      CALL COPY(NC,LF,A)

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999      X=A(3)
1000     Y=A(4)
1001     SR=SQRT((X-SS(I))**2+(Y-YPOS)**2+ALT**2)
1002     ANCN=57.3*ASIN(ALT/SR)
1003     SRN=SR*COSD(ANCN)
1004     C      IF THE RANGE IS GREATER THAN MULTI-PATH OR GREATER THAN
1005     C      MAXIMUM RANGE OF THE THREAT SET PK EQUAL TO 0.
1006     IF(SR.GT.SRMP.OR.SR.GT.A(6))THEN
1007         PKR=0.0
1008         RETURN
1009     ENDIF
1010     SRR=SR
1011     C      IF THE THREAT IS A AAA GO TO AAA ROUTINE(99)
1012     IF(A(2).EQ.1)GO TO 99
1013     C      DETERMINE ASPECT ANGLE OF THREAT/AIRCRAFT.
1014     D=(Y-YPOS)/(X-SS(I))
1015     YT=Y-YPOS
1016     IF(D.GE.0.AND.YT.GE.0)THEN
1017         FANG=57.3*ATAN(1/D)
1018     ELSEIF(D.LT.0.AND.YT.GE.0)THEN
1019         FANG=270+57.3*ABS(ATAN(D))
1020     ELSEIF(D.LT.0.AND.YT.LT.0)THEN
1021         FANG=90+57.3*ABS(ATAN(D))
1022     ELSEIF(D.GE.0.AND.YT.LT.0)THEN
1023         FANG=270-57.3*ATAN(D)
1024     ENDIF
1025     ANG=ABS(FANG-HDC)
1026     IF(ANG.GT.180)ANG=360-ANG
1027     C      IF THE ANGLE(ANG) IS LESS THAN 90 DEGREES THEN THE
1028     C      AIRCRAFT IS IN FRONT OF THE THREAT. CALCULATE PARA-
1029     C      METERS TO OBTAIN TI AND TL.
1030     IF(ANG.LT.90)THEN
1031         RC=SR*SIND(ANG)
1032         AB=SR*COSD(ANG)
1033         TINAC=AB/VEL
1034         TMFO=RC/SAN(A(2),9)
1035         IF(TINAC.GE.TMFO)THEN
1036             TL=TMFO+TINAC-TMFO
1037             TI=TMFO+TL
1038             RI=RC
1039         ELSE
1040             RI=SQRT(((TMFO-TINAC)*VEL)**2+RC**2)
1041             TL=TMFO
1042             TI=TL+(RI/SAN(A(2),9))
1043         ENDIF
1044     ELSE
1045         ANG2=180-ANG
1046         RC=SQRT((SRN*SIND(ANG))**2+ALT**2)
1047         VR=VEL/(SAN(A(2),9))
1048         E=1.0-(VR**2)

```

```

1049      F=- (2*SRN*VR*COSD(ANG))
1050      G=SQRT((F**2)+(4*E*(SRN**2)))
1051      RI=(G-F)/(2*E)
1052      RI=SQRT(RI**2+ALT**2)
1053      TL=TNOW
1054      TI=TL+(RI/SAM(A(2),9))
1055      ENDIF
1056      TRCS=180-57.3*(ASIN(RC/RI))
1057      IJ=A(2)
1058      ICET=NFIND(1,19,1,0,TRCS,2.51)
1059      CALL COPY(ICET,19,8)
1060      JR=IJ+1
1061      SIGMA=B(JR)
1062      IF(RI.GE.A(6))THEN
1063         PKR=0.0
1064      ELSE
1065         IF(ATRIB(1).LT.200)THEN
1066            AJSBDM=SAM(A(2),10)+20*ALOG10(RI)-SIGMA
1067            AJS=10*(AJSBDM/10)
1068            CEP=SQRT((((SAM(A(2),1)+AJS*(RI**2))+SAM(A(2),2)+AJS)+
1069                &SAM(A(2),3)))
1070            ELSE
1071            SIGM2=10*(SIGMA/10)
1072            CEP=SQRT(((SAM(A(2),4)*(RI**6)/SIGM2)+(SAM(A(2),5)*
1073                &(RI**4)/SIGM2)+SAM(A(2),6)))
1074            ENDIF
1075            PKR=1.0-(.5*((SAM(A(2),11)/CEP)**2))
1076            IF(PKR.LT..02)PKR=0.0
1077        ENDIF
1078        RETURN
1079    99 IF(ATRIB(1).GT.200)THEN
1080        IF(RATE(J).NE.0)THEN
1081            C=2.0
1082        ELSE
1083            C=1.3
1084        ENDIF
1085        ELSE
1086        IF(SS(I).GT.45000.0.AND.SS(I).LT.65000.0)THEN
1087            C=2.0
1088        ELSE
1089            C=1.3
1090        ENDIF
1091        ENDIF
1092        SRK=SR/1000.0
1093        SIGMA2=(20*SRK)**2.0
1094        VF=930.0*EXP(-.4965*SRK)
1095        TOFL=(2014.46/VF)-2.166
1096        TI=TNOW+TOFL
1097        DA=(2.*3.14159*SIGMA2)+5.1727
1098        PKSS=(5.1727/DA)*EXP((-5*(9.0+C*(TOFL**2.1))**2.0)/DA)

```

```

1099      PKR=1.0-((1.0-PKSS)**50.)
1100      TL=TNOW
1101      RETURN
1102      END
1103      *****
1104      *****
1105      SUBROUTINE OPUT
1106      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,NFA,NSTOP,NCLNR,
1107      &NCRDR,NPRINT,NBRUN,NMSET,NTAPE,SS(100),SSL(100),TNEXT,
1108      &TNOW,XX(100)
1109      PRINT*
1110      PRINT*
1111      PRINT*, 'ATTACK AIRCRAFT SURVIVING= ',XX(56)
1112      PRINT*, 'ATTACK AIRCRAFT KILLED   = ',XX(57)
1113      PRINT*, 'RADARS KILLED BY WW     = ',XX(58)
1114      PRINT*, 'WW KILLED                = ',XX(59)
1115      RETURN
1116      END

```

Appendix H  
Two-Way ANOVA

The SPSS program for the two-way ANOVA was run with the data contained on the following page. The first column is the number of aircraft surviving and reaching the target area for the run, the next column the level for the factor of altitude (1=60m, 2=200m), and the last column the level for the factor of tactic (1=ahead of the attack force, 2=with the attack force). The overall results for the ANOVA are listed on the page following the data. There were no significant main effects or interactions.

1	3 1 1
2	1 1 1
3	1 1 1
4	5 1 1
5	4 1 1
6	4 2 1
7	4 2 1
8	3 2 1
9	3 2 1
10	2 2 1
11	3 1 2
12	1 1 2
13	0 1 2
14	2 1 2
15	3 1 2
16	5 2 2
17	1 2 2
18	4 2 2
19	1 2 2
20	3 2 2

SPSS Input Data

VOGELBACK COMPUTING CENTER  
 NORTHWESTERN UNIVERSITY

S P S S - - STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

\*\*\*\*\* ANALYSIS OF VARIANCE \*\*\*\*\*

SURVIVE

BY ALT 1=60M,2=200M

TACTIC 1=AHEAD,2=WITH

\*\*\*\*\*

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
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17  
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24  
25  
26  
27  
28  
29  
30

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	4.900	2	2.450	1.114	.353
ALT	2.450	1	2.450	1.114	.307
TACTIC	2.450	1	2.450	1.114	.307
2-WAY INTERACTIONS	.450	1	.450	.205	.657
ALT TACTIC	.450	1	.450	.205	.657
EXPLAINED	5.350	3	1.783	.811	.506
RESIDUAL	35.200	16	2.200		
TOTAL	40.550	19	2.134		

20 CASES WERE PROCESSED.

Appendix I  
Validation

### WW Attack Profile Validation

This appendix contains the validation of the WW attack profile. As the WW proceeds through the threat environment hunting for radars to attack, the logic associated with its profile and the necessary computations that change the WW's behavior in the attack are hand-calculated and compared to computer output data. A typical WW attack is followed as the WW moves from one logic event to the next.

To hand-calculate the required parameters an encounter geometry is defined in the encounter diagram. Position 1 ( $x_1, y_1$ ) depicts the WW in the FEBA geometry as it begins a turn and Position 2 ( $x_2, y_2$ ) when it rolls out. The WW's flight distance from Position 1 to 2 is given by the following formula:

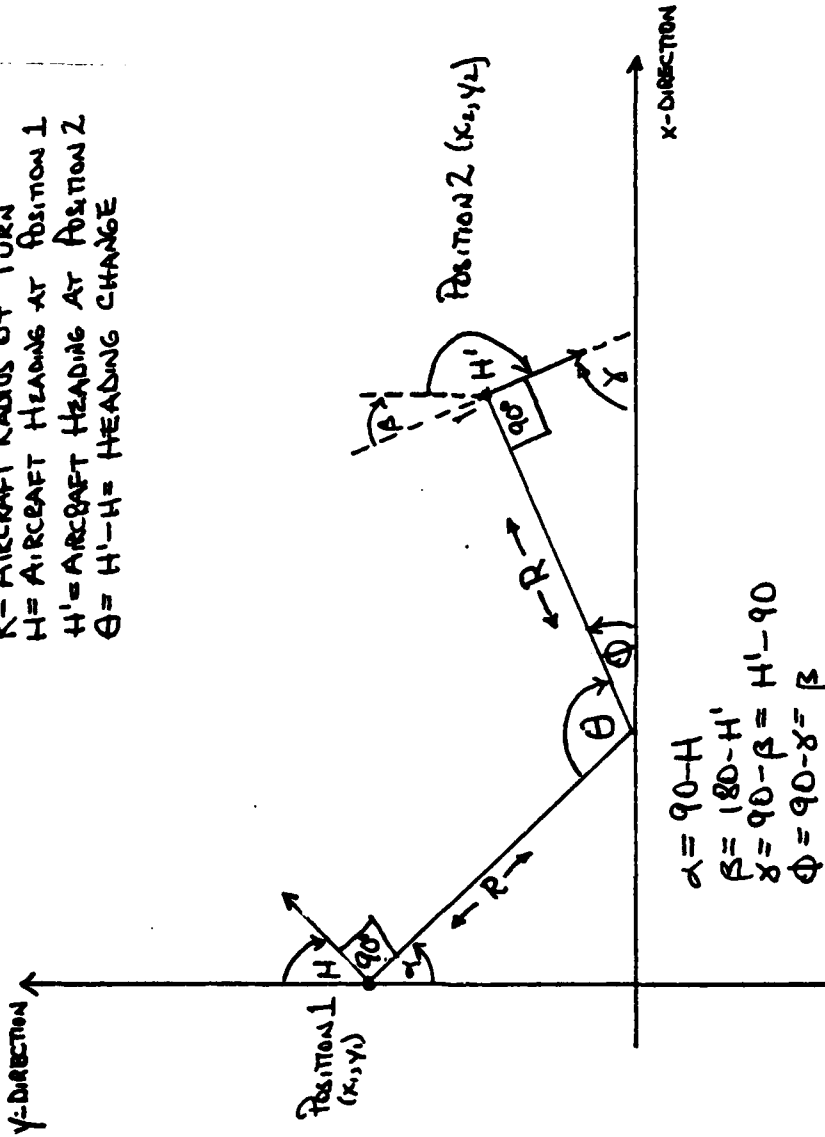
$$S = R\theta$$

where  $s$  = distance WW flies from 1 to 2,

$R$  = WW's radius of turn, and

$\theta$  = number of degrees WW turns from 1 to 2  
(in radians).

$R$  = AIRCRAFT RADIUS OF TURN  
 $H$  = AIRCRAFT HEADING AT POSITION 1  
 $H'$  = AIRCRAFT HEADING AT POSITION 2  
 $\theta$  =  $H' - H$  = HEADING CHANGE



$$\begin{aligned}
 \alpha &= 90 - H \\
 \beta &= 180 - H' \\
 \gamma &= 90 - \beta = H' - 90 \\
 \phi &= 90 - \gamma = \beta \\
 \therefore X_2 &= X_1 + R \sin \alpha + R \cos \phi \\
 Y_2 &= Y_1 - (R \cos \alpha - R \sin \phi)
 \end{aligned}$$

The radius of turn R for an aircraft is given by:

$$R = \frac{V}{TR}$$

where R = radius of turn,

v = aircraft velocity, and

TR = aircraft turn rate in radians per second.

Thus for the WW with a velocity of 247 m/sec and a turn rate of 4 degrees/sec, R is given by:

$$R = \frac{247}{4 \times \frac{2\pi}{360}} = 3538 \text{ m}$$

For a turn rate of 2 degrees per second, R = 7076 m.

By knowing the WW's position when it starts its turn, the number of degrees of heading change, and the radius of turn R, then Position 2, the rollout point, can be determined.

WW1, call sign 211, is followed on its attack profile as it hunts for threats to attack, detects a threat, performs a ranging routine, launches an ARM, and begins a new engagement sequence. Output data from the computer simulation is listed at the end of this appendix.

WW1 enters the threat scenario at time TNOW = 0, x and y coordinates at (0, 25110), heading 090, altitude

60 m. Its radar horizon or line-of-sight range is given by equation (2):

$$h = 4117.3 \sqrt{60} = 31892$$

The closest radar that WW can attack is radar 64 located at (52500, 25139). (See Appendix J for radar coordinates.) WW1 will proceed across the FEBA until the distance to radar 64 is detected to be less than the radar horizon distance at which time event 1 will be called. From the computer output event 1 is realized as TNOW = 84. WW1's position at that time

$$x = 247 \times 84 = 20748$$

$$y = 25110$$

The distance to radar 64 is given by equation (14):

$$\begin{aligned} SR &= \sqrt{(20748 - 52500)^2 + (25110 - 25139)^2 + 60^2} \\ &= 31752 \end{aligned}$$

Event 1 occurs at the correct time and position.

Event 1 starts the WW ranging routine turning the WW away from radar 64 at a turn rate of 4 degrees/second. At event 1 WW1's relative bearing to radar 64 is given by equation (11):

$$R = \tan^{-1} \left[ \frac{52500 - 20748}{25140 - 25110} \right] = 89.9^\circ$$

Event 2 occurs at TNOW = 102 and the absolute relative bearing to the site should be 75 degrees. The heading change from event 1 to event 2 is given by equation (10):

$$\theta = (102-84) \times 4^\circ/\text{sec} = 72^\circ$$

Its new heading at TNOW = 102 should be:

$$H = 90^\circ + 72^\circ = 162^\circ$$

From the encounter geometry, the position of WW1 at event 2 should be:

$$x = 20748 + 3538 \cos 18^\circ = 24113$$

$$y = 25110 - [3538 + 3538 \sin 18^\circ] = 22665$$

Relative bearing to radar 64 at this point is, by equation (11):

$$R = \tan^{-1} \left[ \frac{52500-24113}{25140-22665} \right] = 85^\circ$$

The absolute relative bearing is given by equation (12):

$$AB = (162 - 85) = 77^\circ$$

These figures all agree with the output data.

Event 3 occurs when the absolute relative bearing is 105 degrees. The output data lists TNOW = 159 for event 3. The position of WW1 at this time is given by equations (35) and (46):

$$x = 24110 = 247 \sin 162 \times (159-102) = 28461$$

$$y = 22670 + 247 \cos 162 \times (159-102) = 9280$$

The relative bearing to radar 64, by equation (11) is:

$$R = \tan^{-1} \left[ \frac{52500-28461}{25140-9280} \right] = 56.6^\circ$$

The absolute relative bearing, given by equation (12), is:

$$AB = (162 - 56.6) = 105.4^\circ$$

Hand-calculations confirm output data.

Event 4 occurs when the absolute relative bearing is 10 degrees. Event 3 should turn the WW back towards the site at 4 degrees/second. Event 4 occurs at TNOW = 186.

The heading change is given by equation (10):

$$\theta = (186 - 159) \times 4^\circ/\text{sec} = 108^\circ$$

WW1's heading at event 4 should be:

$$H = 162 - 108 = 54^\circ$$

From the encounter geometry WW1's position is calculated:

$$x = 28460 + 3538(\cos 18 + \cos 54) = 33908$$

$$y = 9279 + 3538(\sin 54 - \sin 18) = 7510$$

Relative bearing to radar 64 at this point, by equation (11):

$$R = \tan^{-1} \left[ \frac{52500-33908}{25140-7510} \right] = 46.5^\circ$$

Absolute relative bearing is given by equation (12):

$$AB = (54 - 46.5) = 7.5^\circ$$

All calculations agree with the output data.

Event 5 occurs when WW1 is boresighted on radar 64 (absolute relative bearing zero). Event 4 turns the WW into the threat at a rate of 2 degrees/second. When event 5 occurs at TNOW = 190, heading change is given by equation (10):

$$\theta = (190 - 180) \times 2^\circ/\text{sec} = 8^\circ$$

WW1's heading should be:

$$H = 54 - 8 = 46^\circ$$

From the encounter geometry the WW position is:

$$x = 33910 + 7076(\sin 44 - \sin 36) = 34618$$

$$y = 7510 + 7076(\cos 36 - \sin 46) = 8146$$

Relative bearing from equation (11) is:

$$R = \tan^{-1} \left[ \frac{52500-34618}{25140-8146} \right] = 46.4$$

The absolute relative bearing, equation (12), is:

$$AB = (46 - 46.5) = 0.5^\circ$$

These calculations agree with the output data.

Event 5 calculates the ARM release time and position, the time of flight for the ARM (TOF), and draws a random sample to evaluate the probability of kill of the ARM. WW1's distance to radar 64 at event 5 is given by equation (14):

$$\begin{aligned} SR &= \sqrt{(34660 - 52500)^2 + (8144 - 25140)^2 + 62^2} \\ &= 24639 \end{aligned}$$

The ARM release point for the WW is taken from a uniform distribution of low value equal to minimum range for the ARM and high value equal to the maximum ARM range or distance to the threat, whichever smaller (as long as ARM is within range of the threat). Computer output sets the release point, XX(4), equal to 24597. The time for WW1 to reach this point from its present position is:

$$\begin{aligned} \text{Time} &= \text{Distance to Release} / \text{WW Velocity} \\ &= \frac{(24639 - 24597)}{247} = 0.17 \text{ sec} \end{aligned}$$

The TOF for the ARM is:

$$\begin{aligned} \text{TOF} &= \text{ARM Distance} / \text{ARM Velocity} \\ &= 24597 / 450 = 54.67 \end{aligned}$$

WW1 will kill radar 64 if the random sample drawn is less than or equal to 0.85, the ARM PK. Event 5 indicates that the random sample drawn is 0.6045. Calculations in event 5 concur with computer data.

Event 6 occurs when WW1 launches the ARM at radar 64. Hand calculations predict this should happen at event 5 time plus the time for WW1 to get from event 5's position to the ARM release point:

$$\text{TNOW(Event 6)} = 190 + 0.17 = 190.17$$

This agrees with the output data.

Event 9 simulates ARM impact and should occur when the ARM launched by WW1 reaches radar 64. This time should be:

$$\begin{aligned}\text{TNOW(Event 9)} &= \text{TNOW(Event 6)} + \text{TOF} \\ &= 190.15 + 54.67 = 244.82\end{aligned}$$

Since the sample drawn in event 5 was less than 0.85, the threat should be killed, as in fact it is according to the output data.

After WW1 fires the ARM it should be released 5 seconds later to start another engagement. Output data concurs with this.

As evidenced by the above comparisons between computer output data and hand-calculations, the WW attack profile is validated.

1                   \*\*INTERMEDIATE RESULTS\*\*  
 2                   EV 1 TNOW=84 ATRIB(1)=211 RADAR 64 IS ENGAGED  
 3                   EV 2 TNOW=102 ATRIB(1)=211  
 4                   EV 3 TNOW=159 ATRIB(1)=211  
 5                   EV 4 TNOW=186 ATRIB(1)=211  
 6                   EV 5 TNOW=190 ATRIB(1)=211  
 7                   XX(10)=24635 XX(4)=24597  
 8                   TOF=54.67 SAMPLE=.6045  
 9                   PK=1 RLHW=.1545  
 10                   EV 6 TNOW=190.154 ATRIB(1)=211  
 11                   EV 7 TNOW=195.154 ATRIB(1)=211  
 12                   EV 8 TNOW=195.254 ATRIB(1)=211  
 13                   EV 2 TNOW=207 ATRIB(1)=211  
 14                   EV 9 TNOW=244.8 ATRIB(1)=64  
 15                   RADAR 64 KILLED BY MW 211  
 16

17                   \*\*TABLE NUMBER 1\*\*  
 18                   TIME XPOS YPOS HDNC RNCE RLDR ABRLB  
 19                   0    0    25110 90    0    0    0  
 20                   84   20750 25110 90    31750 89.96 .039  
 21                   102   24110 22670 162   28490 85   77.0  
 22                   159   28460 9279 162   28800 56.6 105.4  
 23                   186   33910 7510 54    25620 46.5 7.5  
 24                   190   34660 8144 46    24640 46.4 .4  
 25                   195   35550 9002 46    23400 46.4 .4  
 26                   207   36680 11650 359   18920 75.5 76.5

### SAM and AAA Probability of Kill Validation

Event 15 (at the end of acquisition and tracking), event 16 (scheduled missile launch time), event 17 (scheduled missile impact time), and event 18 (freeing the threat radar 30 seconds after impact) represent the discrete events associated with the defensive network. Validating this portion of the model involves computing the variables required to estimate the  $P_k$  and comparing them with a computer print-out of model derived parameters. A set of calculations for both SAM and AAA systems will be developed.

The calculations list the variable, followed by the computer variable for the quantity when the two are different. For example,

$$t_{AC} \text{ (TIMAC)} = \frac{SR_{xy} \cos \theta}{V_m}$$

where " $t_{AC}$ " is the notation for the time required for the aircraft to reach point "C" in the thesis and "TIMAC" is the computer variable of the same quantity.

#### SAM Calculations

Strike aircraft "1" was in threat "54"'s field of view (FOV) at TNOW = 32. Aircraft "1" was created at TNOW = 30 and Subroutine SEARCH assigned site "54" to it at

SAM Probability of Kill Computer Printout

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permit fully legible reproduction

(a) Subroutine SEARCH detects an aircraft

RADAR 54. START TRACKING ACFT 1.  
AT TIME 32.  
TRC= 23.20546885825

(b) Event 15: At the end of Acquisition and Tracking

EV 15 TNOW= 55.26546885825 ATRIB(1)= 1.  
RADAR NUMBER 54.  
YPOS= 24591.66242727 ALT= 311. VEL= 247.  
HDG= 97. SRMP= 71046.992 3508 LG= 7  
X= 51001. Y= 26561.89873 09 SR= 53796.41352336 D= .03684894388766  
ANG= 2.3241552342 RC= 1994.6423345 TIMAC= 217.614245773  
TMFO= 2.819847198182 TLO 277.239545338 TI= 272.919193835  
RI= 1988.40423345 TRCS= 87.99337 47465 SIGMA= 25.  
PKR= .92821302251 CEP= 21.478 3605966  
EV 15 TNOW= 55.58756158515 ATRIB(1)= 1.

(c) Event 16: Missile Launch Time

EV 15 TNOW= 27.299646333 ATRIB(1)= 1.  
YPOS= 24591.66242727 ALT= 31. VEL= 247.  
HDG= 97. SRMP= 71046.992 3508 LG= 7  
X= 51001. Y= 26561.89873 09 SR= 2096.471155199 D= 3.4994552047  
ANG= 71.84565450915 RC= 1994.447188044 TIMAC= 2.644591102758

TMFO= 2.627730155526 TLO 277.3165072832 TI= 272.942374397  
RI= 1994.447188044 TRCS= 89.99337047465 SIGMA= 25.  
PKR= .942326 42332 CEP= 21.49077932368

(d) Event 17: Missile Impact Time

EV 17 TNOW= 272.9442374387 ATRIB(1)= 1.  
YPOS= 24591.66242727 ALT= 31. VEL= 247.  
HDG= 97. SRMP= 71046.992 3508 LG= 7  
X= 50001. Y= 26561.89873 09 SR= 1994.478355044 D= -272.5335192907  
ANG= 90.20354179149 RC= 1994.465769825 TIMAC= .3512574202117  
TMFO= .8498032803339 TLO 272.9442374387 TI= 275.716411154  
RI= 2104.072147843 TRCS= 178.5697372733 SIGMA= 3.7  
PKR= .1114071311733 CEP= 175.6195318368  
AIRCRAFT 1. KILLED BY RADAR 54.

(e) Event 18: Freeing the radar 30 seconds after impact

EV 18 TNOW= 302.9442374387 ATRIB(1)= 1.

this time. Threat "54" is a type SAM B. Specific data on both the threat and the aircraft are specified below:

Threat 54	SAM B	Aircraft 1	Strike
x coord	60,000 m	initial x coord	0
y coord	26,561 m	y coord	24,592 m
Max FOV	74,150 m	x velocity	247 mps
Min detec rng	305 m	Altitude	310 m
		Heading	090°

Aircraft 1's y coordinate does not change during the mission. Its x coordinate at any time can be determined as follows:

$$x = 247 (TNOW - TCREATE) \quad (59)$$

where

x = the aircraft's current x position,

247 = the aircraft's x velocity,

TNOW = the current simulation time, and

TCREATE = the time the entity was created by the model.

Aircraft 1's x position at TNOW = 32 seconds:

$$x = 247(32-30) = 494 \text{ m}$$

The Slant Range, SR, to the site can be computed by solving equation (14):

$$\begin{aligned} SR &= \sqrt{(26,561-24,592)^2 + (60,000-494)^2 + 310^2} \\ &= 59,540 \text{ m} \end{aligned}$$

Thus, Aircraft 1 is inside site 54's maximum detection range of 74,150 m. To be detected, the aircraft must be above the minimum multipath angle,  $\alpha$ , of .25 degrees. Solving equation (15) for  $\alpha$ , the angle above the horizon becomes:

$$\begin{aligned}\alpha &= \sin^{-1} \left( \frac{310}{59,540} \right) \\ &= .298^\circ\end{aligned}$$

Aircraft 1 is inside the maximum detection range of threat 54, above the minimum tracking altitude of 305 m, and above the .25 degree minimum multipath angle. The model assumes threat 54 has detected aircraft 1. It assigns an acquisition and tracking time of 23.265 seconds. This is between the minimum and maximum times of 12 and 26 seconds. (See Table IV.)

The next event that occurs is event 15 at the end of acquisition and tracking. From the computer printout, event 15 occurs at TNOW = 55.265 seconds or (32 + 23.265). At this time, the site recomputes a SR, and determines numerous quantities including a missile firing time, TLO, a missile impact time, TI, the range from the site to the target at impact, RI, the probability of kill, PKR, the radar cross section at impact, RCS, the aspect angle at impact, TRCS, and the circular error probable, CEP. These

and additional values will now be calculated and compared to the computer printout.

The aircraft's x coordinate at TNOW = 55.265 seconds is calculated:

$$\begin{aligned}x &= 247(55.265 - 30) \\ &= 6240 \text{ m}\end{aligned}$$

Solving for the SR:

$$\begin{aligned}\text{SR} &= \sqrt{(26561 - 24592)^2 + (60,000 - 6240)^2} \\ &= 53796 \text{ m}\end{aligned}$$

Because the ( $x_A < x_S$ ), the aircraft is located prior to the closest approach point (see Figure 11).

Solving equation (11) for  $\theta$  yields:

$$\theta \text{ (ANGLE)} = \tan^{-1} \left[ \frac{26561-24592}{60000-6240} \right] = 2.1^\circ$$

Solving equations (25) and (26) determines the firing conditions:

$$\begin{aligned}t_{AC} \text{ (TIMAC)} &= \frac{\left[ 53796 \cos \left( \sin^{-1} \left( \frac{310}{53796} \right) \right) \right] \cos(2.1)}{247} \\ &= 217.6 \text{ sec}\end{aligned}$$

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A WILD WEASEL PENETRATION MODEL.(U)  
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$$t_{MC} \text{ (TMFO)} = \frac{\left\{ [53796 \cos (\sin^{-1} (\frac{310}{54796}) \sin(2.1))]^2 + 310^2 \right\}^{\frac{1}{2}}}{759}$$

$$= 2.6 \text{ sec}$$

Since  $t_{AC} > t_{MC}$ , the firing will be delayed  
(217.6-2.6) seconds or the missile launch time becomes:

$$\text{(TLO)} = \text{TNOW} + (217.6 - 2.6) = 270.3 \text{ seconds}$$

Missile impact occurs 2.6 seconds later or:

$$\text{(TI)} = 270.3 + 2.6 = 272.9 \text{ seconds}$$

For this encounter, the intercept occurs at 90 degrees (ANG=89.99 degrees). The corresponding  $\sigma_{RCS}$  (SIGMA) for a SAM B at a 90 degree aspect angle is 25 dB (see Table V).

Aircraft 1 is wet (jamming). The terms A, B, and C for the CEP evaluation (equation (17)) are:

$$A = 5.62 * 10^{-6}$$

$$B = 2500$$

$$C = 232$$

The term K for equation (20) is -51.4 dB. Solving equations (20) and (21) for J/S yields:

$$J/S_{dB} = 65.97 - 25 - 51.4 = -10.4$$

$$J/S = 10^{-10.4/10} = .0905$$

From equation (17) CEP can be evaluated:

$$\begin{aligned} \text{CEP} &= \sqrt{(5.62 \times 10^{-6}) (.0905) (1988)^2 + (2500) (.0905) + 232} \\ &= 21.45 \text{ m} \end{aligned}$$

Finally, solving equation (16) for the SAM B's  $P_k$  yields:

$$P_k (\text{PKR}) = 1 - .5 (43.6/21.45)^2 = .942$$

Thus event 15 schedules a missile launch time (event 16) for  $\text{TNOW} = 270.3$  since the  $P_k$  value is greater than the threshold value of .05. The computed  $R_i$  is stored in the model as attribute 10 (ATTRIB 10). The model will evaluate the ATTRIB 10 and a computed value for  $R_i$  in event 16 to determine if the aircraft has maneuvered since event 15.

At  $\text{TNOW} = 270.3$  aircraft 1's x coordinate is determined as follows:

$$x = 247(270.3 - 30)$$

The algorithm goes through the same calculations as event 15 to determine a  $R_i$ . It then compares this  $R_i$  with ATTRIB 10. If the Ratio is less than 1.1, the model assumes the aircraft has not turned, where Ratio is defined below:

$$\text{Ratio} = \frac{R_{i \text{ new}}}{R_i}$$

The algorithm goes through the same calculations as event 15

$$x = 247(270.3 - 30) = 59354 \text{ m}$$

Solving equation (14) for SR gives:

$$\begin{aligned} SR &= \sqrt{(26561-24592)^2 + (60000-59354)^2} \\ &= 20953 \text{ m} \end{aligned}$$

The  $R_i$  can be evaluated as follows:

$$\tan \alpha = \frac{\Delta Y}{\Delta X} = \frac{26961-24592}{60000-59354} \quad \alpha = 8.9^\circ$$

$$R_{i_{\text{new}}} = \frac{\Delta Y}{\cos 8.9} = 1991 \text{ m}$$

The model now calculates Ratio:

$$\text{Ratio} = \frac{1991}{1988} = 1.0015$$

Since the Ratio is less than 1.1, the model assumes the aircraft has not maneuvered since event 15. (Note, since aircraft 1 is a strike aircraft and can not turn, the result is expected and the small difference in  $R_i$  is attributed to roundoff error). The calculated J/S, CEP, and PKR remain the same as those calculated at event 15. (See computer printout.) Thus the missile is launched at

this time and event 17 (missile) impact scheduled for  
TNOW + TMFO, or  $270.3 + 2.6 = 272.9$  seconds.

Event 17 occurs at the impact time. The model  
again checks the value of Ratio at impact. The x coordinate,  
SR, and  $R_i$  calculations are depicted below:

$$\begin{aligned}x &= 247(272.9 - 30) \\ &= 59996 \text{ m}\end{aligned}$$

$$\begin{aligned}SR &= \sqrt{(26561 - 24592)^2 + (60000 - 59996)^2 + 310^2} \\ &= 1994 \text{ m}\end{aligned}$$

$$R_i = SR = 1994 \text{ m}$$

At this time the model selects a random number to  
determine if the aircraft has been destroyed. If the random  
number is less than the PKR the aircraft has been destroyed  
and the computer printout annotated.

Thirty seconds later, event 18 occurs and frees the  
site to search for another target. (See computer printout.)

### AAA Calculations

The AAA geometry calculations are the same as those  
in the SAM portion of the model. The difference between  
the two algorithms is in the manner the  $P_k$  is evaluated.  
The AAA  $P_k$  calculations is determined by solving equations

AAA Probability of Kill Computer Printout

(a) Subroutine SEARCH detects an aircraft

RADAR 2. START TRACKING ACFT F.  
AT TIME 243.  
TRC= 17.26292515784

(b) Event 15: At the end of Acquisition and Tracking

EV 15 TNOW= 257.26292515784 ATRIB(1)= 5.  
RADAR NUMBER 2.  
G= 2. SRK= .713957431273 SIGMA2= 2 3.891 37326  
VF= 552.32833687 TOFL= .9215126483649 TI= 254.1845379932  
PKSS= . 361.801253531 PKR= .1554534842513

(Note: Event 15 calculated an immediate launch. Event 16 is skipped and the Program schedules Event 17.)

(c) Event 17: Scheduled Impact Time of the Round

EV 17 TNOW= 254.1845379932 ATRIB(1)= 5.  
G= 2. SRK= .713957431273 SIGMA2= 2 3.891 37326  
VF= 552.32833687 TOFL= .9215126483649 TI= 255.10615 8475  
PKSS= . 361.801253531 PKR= .1554534842513

(d) Event 18: Freeing the radar 30 seconds after impact

EV 18 TNOW= 284.1845379932 ATRIB(1)= 5.

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permit fully legible reproduction

(50) through (58). These are highlighted below. (See computer printout.)

The  $R_i$  is determined as follows:

$$\begin{aligned} R_i &= \frac{\Delta y}{\cos[\tan^{-1}(\frac{ALT}{\Delta y})]} \\ &= \frac{24752 - 24108}{\cos[\tan^{-1}(\frac{310}{24752-24108})]} \\ &= 715 \text{ m} \end{aligned}$$

Converting to kilometers:

$$(SRK) = \frac{R_i}{1000} = .715 \text{ km}$$

From equation (51) the velocity of the round at impact is calculated as follows:

$$\begin{aligned} V_f(VF) &= 930 \exp[-.4965(.715)] \\ &= 652 \frac{\text{m}}{\text{sec}} \end{aligned}$$

Equation (53) uses the  $V_f$  to determine the round's TOF:

$$\text{TOF(TOFL)} = \frac{2014.46}{652} - 2.166 = .92$$

Each round's dispersion pattern around the target,  $\sigma$ , becomes:

$$\sigma_m = 20R = (20)(.715) = 14.28 \text{ m}$$

and  $\sigma^2(\text{SIGAAA2}) = (14.28)^2 = 203.9 \text{ m}^2$

Evaluating the  $P_{k_{ss}}$  from equation (57) yields:

$$P_{k_{ss}}(\text{PKSS}) = \frac{5.17}{2\pi(203.9)+5.17} \exp \left\{ -\frac{1}{2} \left( \frac{9.8(1.3)(.92)^2}{2\pi(203.9)+5.17} \right)^2 \right\}$$
$$= .004$$

This leads to the evaluation of the overall  $P_k$  for the engagement:

$$P_k(\text{PKR}) = 1 - (1-.004)^{50} = .17$$

Appendix J  
Radar Positions in FEBA

\*\*\*\*RADAR POSITIONS\*\*\*\*

	RADAR NO	XPOS	YPOS
1			
2			
3			
4			
5	AAA RADARS		
6			
7	1	50400	34199
8	2	50400	24100
9	3	50400	32176
10	4	50400	17963
11	5	50400	32657
12	6	50400	32641
13	7	50400	21523
14	8	50400	19700
15	9	50400	29298
16	10	50400	33052
17	11	50400	29662
18	12	50400	22993
19	13	51500	38960
20	14	51500	21746
21	15	51500	33304
22	16	51500	31675
23	17	51500	33404
24	18	51500	29685
25	19	51500	21332
26	20	51500	32896
27	21	51500	29177
28	22	51500	29051
29	23	51500	22353
30	24	51500	33660
31	25	52500	28801
32	26	52500	30996
33	27	52500	22804
34	28	52500	41991
35	29	52500	26124
36	30	52500	36900
37	31	52500	26894
38	32	52500	33800
39	33	52500	26250
40	34	52500	33854
41	35	52500	29342
42	36	52500	33834
43	37	53400	40618
44	38	53400	24048
45	39	53400	19222
46	40	53400	22361
47	41	53400	35624
48	42	53400	34556
49	43	53400	27209
50	44	53400	28209

51	45	53400	35772
52	46	53400	28842
53	47	53400	35726
54	48	53400	36986
55	.		
56	SAM-A RADARS		
57	.		
58	49	95000	29327
59	50	95000	38478
60	51	130000	25236
61	.		
62	SAM-B RADARS		
63	.		
64	52	60000	29323
65	53	60000	24026
66	54	60000	26562
67	55	75000	32949
68	56	75000	30951
69	57	75000	36754
70	48	75000	35640
71	59	75000	27318
72	60	75000	11963
73	.		
74	SAM-C RADARS		
75	.		
76	61	52500	30962
77	62	52500	34333
78	63	52500	37129
79	64	52500	25139
80	65	52500	29843
81	66	55000	32399
82	67	55000	23916
83	68	55000	36832
84	69	65000	30801
85	70	65000	32764
86	.		
87	SAM-D RADARS		
88	.		
89	71	52500	31075
90	72	52500	40629
91	73	85000	31936
92	74	85000	22967
93	75	85000	35572
94	76	110000	35485
95	77	110000	24159
96	.		
97	EW RADARS		
98	.		
99	78	55000	26759
100	79	55000	16385

101	80	60000	41162
102	81	75000	35497
103	82	75000	21494
104	83	85000	36311
105	84	85000	18692
106	85	95000	29836

Vitae

Kenneth C. Anderson

Kenneth C. Anderson was born 7 November 1945 in Warsaw, New York. He graduated from Robstown High School, Robstown, Texas in 1964 and attended Texas A&M University. He graduated in January 1969 with a Bachelor of Science degree in Aerospace Engineering and received his commission. He attended pilot training at Moody AFB, Georgia and became a T-38 instructor pilot. Additional assignments include the Foreign Technology Division as a space systems analyst and Pease AFB, New Hampshire as a FB-111 instructor pilot. He received a Master of Science degree in Management Science from the University of Dayton, Ohio in 1976. Following graduation from AFIT he will be stationed at the Air War College, Maxwell AFB, Alabama.

Permanent Address: P. O. Box 10665  
Corpus Christi, Texas 78410

Ronald B. Nenner

Ronald B. Nenner was born on 17 December 1945 in New York City, New York. He graduated from Bryant High School, Queens, New York, in 1962 and then attended the Polytechnic Institute of Brooklyn. He was awarded a Bachelor of Science degree in Electrical Engineering in 1966. In 1967 he entered Officers Training School and was commissioned in June 1967. He completed navigator training in 1967 and pilot training in 1974. He has flown B-52s and F-105s as a navigator and KC-135s as a pilot.

Permanent Address: 5212 Mornington Court  
Fairfax, Virginia 22032



The problem was developed for a NATO/Warsaw Pact encounter in Central Europe.

A model of the threat environment was built using the SLAM computer simulation language. Threats in the defense sector can be moved as desired. Friendly aircraft can enter the system at a variety of intervals, altitudes, and airspeeds. WVs hunt for threats to attack by searching, identifying, locating, and then launching their weapons at the threat. WV tactics can be changed as the requirements of the mission dictate or at the desire of the WV crew. Self-protection jamming can be selected by either WV or attack aircraft. Enemy threats will fire at an aircraft when the aircraft comes within the threat's range as long as the threat is not engaged with another aircraft. Early warning radars account for threat radar command and control functions; their control over the associated radars can be changed as desired.

Changing the WV's altitude from 60 meters to 200 meters did not effect friendly attack aircraft survivability. Leading the attack force into the threat area by 30 seconds as opposed to accompanying the attack force did not influence attack force survivability. Further development of the model to include turn-mode capability for the WV weapon and a tactic for pre-emptive weapons launch in anticipation of threat radar radiation is recommended.